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DIESEL ENGINES IN UNDERGROUND MINING: A Bibliography With Abstracts

by Robert W. Waytulonis and Wanda J. West,
Twin Cities Research Center, Bureau of Mines,
U.S. Department of the Interior,
Minneapolis, Minn.

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This publication contains 1,000 citations of technical and semi-technical literature treating diesel-powered equipment usage underground both generally and specifically. These citations were gathered by U.S. Bureau of Mines personnel over the period of 1978-1983. The citations concern diesel engines as powerplants for underground mining use; their design, emission characteristics and control, maintenance, usage; and health and safety aspects. All citations have been abstracted and arranged in a subject classification system with extensive cross-referencing.

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FOREWARD

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Baumgard, Kirby J., Mechanical Engineer
Dieter, Claudia, Clerk Typist
Leys, Carol, Physical Science Aid
Mejia, Lito C., Mechanical Engineer
Smith, Sean D., Engineering Technician
Yoerger, Michelle, Clerk Typist

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DIESEL ENGINES IN UNDERGROUND MINING:

A Bibliography with Abstracts

by

Robert W. Waytulonis[1]

and Wanda J. West[2]

ABSTRACT

This publication contains 1,000 citations of technical and semi-technical literature treating diesel-powered equipment usage underground both generally and specifically. These citations were gathered by U.S. Bureau of Mines personnel over the period of 1978-1983. The citations concern diesel engines as powerplants for underground mining use; their design, emission characteristics and control, maintenance, usage; and health and safety aspects. All citations have been abstracted and arranged in a subject classification system with extensive cross-referencing.

[1]Supervisory Physical Scientist, Twin Cities Research Center, Bureau of Mines, Minneapolis, Minn.

[2]Program Assistant, Bureau of Mines, Minneapolis, Minn.

INTRODUCTION

Historically, there has been an interest in the use of internal combustion engines for mining applications. Early in the search for suitable power sources, the diesel engine was chosen over the spark ignition engine primarily because carbon monoxide emissions are lower, diesel fuel is much less volatile than gasoline, and the explosion hazards associated with the spark ignition engine are eliminated. Underground mining operations use diesel-powered equipment because it can accommodate the changing conditions of advancing excavations rapidly and safely. In 1982 the United States had approximately 6,200 diesel units in underground non-gassy non-coal mines, 1,400 units in gassy non-coal mines, and 950 units in coal mines.

There is concern for the potential occupational health problems arising from long-term exposure to diesel exhaust. Recent studies (contained in this report) show that certain organic compounds adsorbed to diesel exhaust particulate may cause health problems when inhaled by miners. While the extent and severity of these health problems have not been adequately defined, the Bureau of Mines, under its Health and Safety Technology Research Program, is seeking to reduce potential health threats of diesel use in underground mines by reducing diesel emissions and establishing criteria to ensure safe equipment utilization.

The existing health standards for mines are found in Title 30--Mineral Resources of the Code of Federal Regulations. These regulations incorporate by reference the Threshold Limit Values (TLV's) of the American Conference of Governmental Industrial Hygienists (ACGIH). Regulated contaminants such as particulate matter, nitrogen dioxide (NO_2), nitric oxide (NO), unburned hydrocarbons (UBHC), carbon monoxide (CO), and oxides of sulfur (SO_x) are of special concern because they are found in diesel exhaust. Since air quality in mines is degraded by diesel equipment, it is prudent to identify the quantity and character of particulate and gaseous emissions contributed by diesels and to investigate means to reduce such emissions. The interactions of factors affecting exhaust emission levels are shown schematically in Figure 1.

The purpose of this paper is to provide a starting point toward an understanding of the major aspects of diesel equipment usage in underground mines. It is hoped that the bibliography will be of use to the mine operator who is faced daily with mine safety and productivity and is interested in a better understanding of his equipment operation, and to those in industry and Government involved in research and/or setting the direction of future research. Easily accessible up-to-date information is provided as a basis to control air pollution caused by the operation of diesel-powered equipment. The material which is contained in this report falls into many disciplines. In addition to consultation of technical literature in the disciplines of engineering and chemistry, authoritative sources in the fields of instrumentation, toxicology, and economics are also cited.

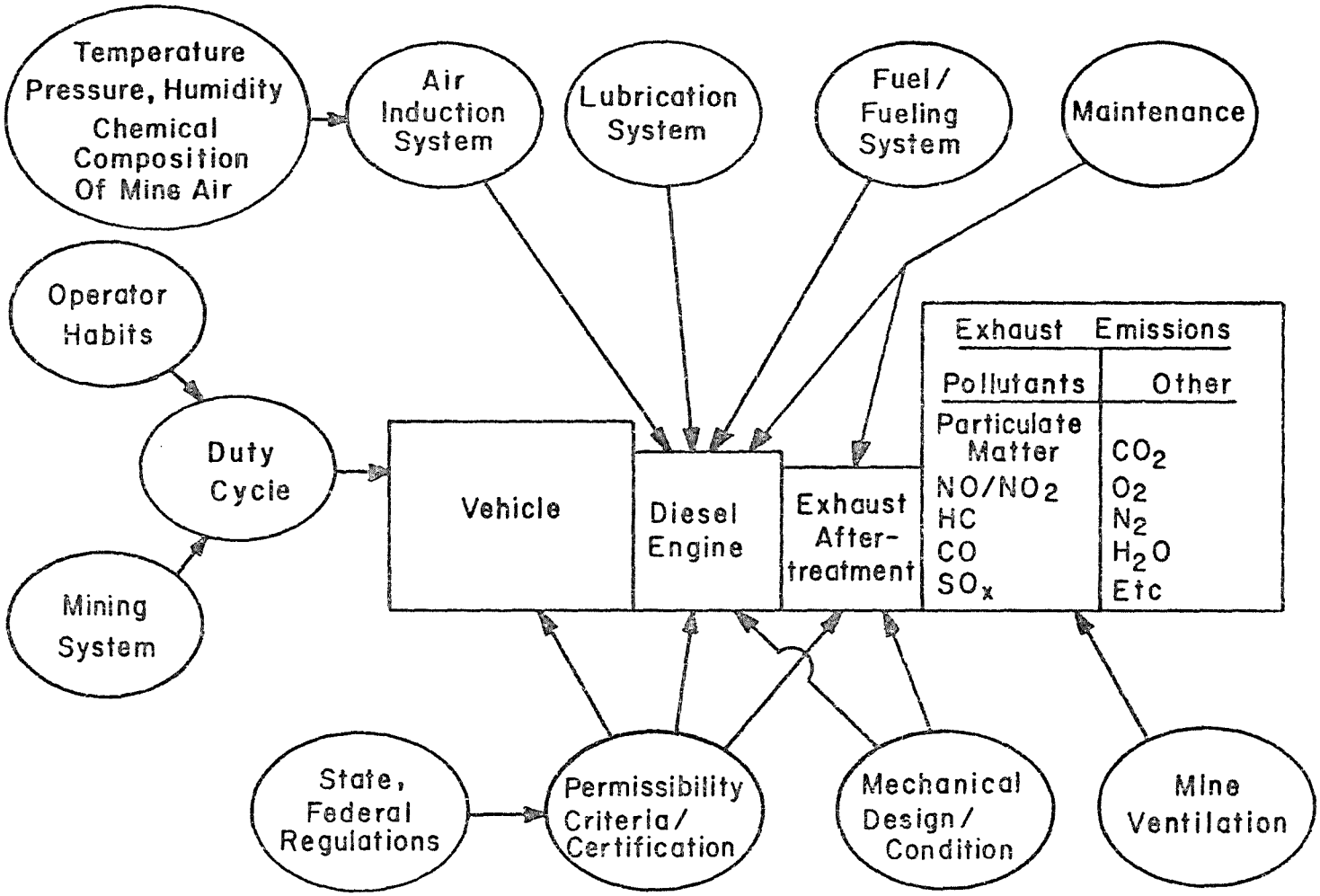

FIGURE 1. - Interaction of factors affecting diesel engine emissions.

Not all the material is directly related to underground diesel usage, but rather shares commonality with other industries, e.g., automotive diesel technology, aerospace and marine control technology and stationary diesel emission controls. Content of the citations varies from highly technically specialized publications to industry experiences and opinions that lack substantive detail. The bibliography is comprehensive but not presumed to be all inclusive.

SUBJECT CLASSIFICATION SYSTEM

The bibliographic material is listed under ten primary subject categories. These in turn are divided into numerous subcategories to minimize search time. The citations have all been scanned by the authors and listed under their appropriate subject categories and subcategories. Abstracts were either taken directly from the original document abstract page or they were composed after reading the document. Because many of the citations are interdisciplinary--that is, their technical content is not limited exclusively to one subject area--extensive cross-reference has been incorporated. Therefore, a citation will be found under every subcategory covered in its text; however, its abstract will be cited only once. When the citation is listed in subsequent subject categories, reference is made to locate the abstract. An outline of the subject classification system is incorporated in the Table of Contents. A close examination of the bibliographic outline is recommended to aid in understanding the scope and interrelationships of the material.

I. DIESEL ENGINE DESIGN

A. Theory of Design

Conta, L. D. Internal-Combustion Engine and the Environment. Presented at the ASME Winter Annual Meeting, Washington, D.C., Nov. 28-Dec. 2, 1971 ASME Preprint 71-WA/DGP-1, 10 pp.

This paper is an attempt to support two major points: (a) Regardless of what is done to develop substitutes for the internal-combustion engine, at least 100 million more engines will be built over the next ten years, and the kind of air we breathe ten years from now will depend more on how these engines are built than on anything else we might do in the vehicle propulsion field; (b) in order to produce engines with satisfactory emission characteristics, a major change in design objective will be necessary. This change in objective should be one of the goals of future versions of the Clean Air Act.

Cummins Engine Co., Inc. Diesel Course Part I. Engine Elements. Columbus, Ind., June 1975, Bulletin No. 3387015-3387024, Workbooks 1-10, 200 pp.

The purpose of this course is to introduce a person to the components of the diesel engine. The course consists of ten (10) workbooks each covering a different topic. The topics include the cylinder block and cylinder head, valve and injector trains, external components and accessories, fuel, air, cooling, exhaust, and lubricating systems.

Cummins Engine Co., Inc. Answers to Questions About Diesels. Columbus, Ind., revised May 1974, Bulletin 3382002, 27 pp.

This pamphlet explains the principles of diesel operation and examines the differences among diesel, gasoline, and other power forms.

Dowdy, M. W. Conventional Engine Technology. v. III: Comparisons and Future Potential. Prepared by Jet Propulsion Laboratory under contract to U.S. Dept. of Energy, NASA-CR-168645, Dec. 15, 1981, 26 pp.

The status of five conventional automobile engine technologies is assessed and the future potential for increasing fuel economy and reducing exhaust emissions is discussed, using the 1980 EPA California emissions standards as a comparitive basis. By 1986, the fuel economy of a uniform charge Otto engine with a three-way catalyst is expected to increase 10%, while vehicles with lean burn (fast burn) engines should show a 20% fuel economy increase. Although vehicles with stratified-charge engines and rotary engines are expected to improve, their fuel economy will remain inferior to the other engine types. When adequate NO_x emissions control methods are implemented to meet the EPA requirements, vehicles with prechamber diesel

engines are expected to yield a fuel economy advantage of about 15%. While successful introduction of direct injection diesel engine technology will provide a fuel savings of 30 to 35%, the planned regulation of exhaust particulates could seriously hinder this technology, because it is expected that only the smallest diesel engine vehicles could meet the proposed particulate requirements.

Ephraim, M., Jr., and H. A. Williams, Jr. A Look at a Modern Two-Cycle Diesel Engine. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Houston, Tex., May 12-18, 1968, ASME Preprint 68-DGP-10, 19 pp.

A new engine series, Model 645, by Electro-Motive Division of General Motors Corp. involves the experience background gained from 28 years of producing the Model 567 series. The Model 645 engine is an increase to 9 1/16 inches from the 8 1/2 inches of the 567 Model. Maximum rated engine speed remains at 900 rpm, but maximum bmep has been increased to 141 psi maximum. A new crankcase design, Model "E," embodies specific structural and manufacturing modifications to assure satisfactory life and performance at the new engine rating. A new 20-cylinder engine replaces the 567 Model's 16 cylinders as the largest size produced by Electro-Motive. Bhp of the 20-cylinder turbocharged engine is 3,900. Reliability and ease of maintenance have been reinforced as essential parameters in the 645 Model and a high degree of interchangeability with existing Model 567 engines has been maintained.

Eriksson, L. J. An Analytical Model for Exhaust System Design. Presented at the Earthmoving Ind. Conf., Central Illinois Section, Peoria, Ill., April 10-12, 1978, SAE Preprint 780472, 11 pp.

An analytical model has been developed that provides a valuable addition to the tools available for practical exhaust system design. Correlation with experimental results has been improved by including the effects of such factors as temperature gradients, complex elements, higher order modes, and source impedance. The model can be used for specific design problems as well as general parameter studies to maximize exhaust system attenuation within a given volume.

Fessler, H., and V. K. Sood. Stress Distributions in Some Diesel Engine Crankshafts. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Toronto, Ontario, Canada, April 18-22, 1971, ASME Preprint 71-DGP-1, 10 pp.

Models of single throws of overlapped crankshafts have been loaded by free and restrained torsion, radial and tangential forces and bending moments, and by axial tension. Stress distributions in the fillets have been obtained by frozen stress photoelasticity. Some peak stresses have been measured with strain gauges. Results, expressed as multiples of convenient nominal stresses, are compared with predictions from published work. The maximum stresses due to any combination of firing force and free torsion were computed and it is shown how the effects of other loading modes may be included.

Givens, L. (ed. by). The Diesel Engine: Today and Tomorrow. Automotive Engineering, v. 84, No. 6, June 1976, pp. 30-34.

This article discusses the recent advances in diesel engine technology. It focuses on increasing fuel economy by de-rating the engine and carefully matching the turbocharger and the transmission to the torque characteristics of the engine. The article also discusses the future of the diesel engine.

Hartley, J. Engine Design Takes to the Right Road for Fuel Economy. v. 16, No. 23, 1976, pp. 30-32.

The stratified charge engine has the possibility of reducing exhaust emissions and conserving energy. Compared to current engines developed to run on low lead fuel, the direct injection SC engine offers an increase in overall economy of 40 pct. The article compares the SC divided chamber and SC open chamber against the gasoline and diesel engine for horsepower, fuel consumption, and engine efficiency in usage of crude oil.

Judge, A. W. Modern Smaller Diesel Engines: In Theory, Construction, Operation and Maintenance. Robert Bentley, Inc., Cambridge, Mass., v. 7, 1965, 336 pp.

This book covers various aspects of the diesel engine. It was written not only for the diesel engineer but also for salesmen, diesel engine operators and servicing maintenance mechanics.

Leonard, T. R., and A. R. Johnson. Architecture of the New GM 4.3 Liter Diesel Engine Designed by Oldsmobile. Presented at the Internat. Cong. & Exposition, Detroit, Mich., Feb. 22-26, 1982, SAE Technical Paper Series 820117, 12 pp.

A detailed discussion of the new 4.3 liter V6 Diesel basic engine hardware is presented. Techniques are used which downsize the engine package and reduce mass while maintaining desired displacement. It includes new technologies in cylinder head, intake manifold and accessory drive.

McIntosh, R. C., and D. E. Larkinson. The New Perkins Mid-Range Diesel Family--Design and Application. Presented at the Internat. Cong. & Exposition, Detroit, Mich., Feb. 22-26, 1982, SAE Technical Paper Series 820034, 10 pp.

A major new family of mid-range diesel engines, designated Q14, which are primarily turbocharged with charge-cooled and naturally aspirated options, has been designed by Perkins Engines Group to meet the needs of on and off-highway applications. The family of 3, 4, 5, and 6 cylinder inline engines will initially be brought to production with a top rating of 170 kW. The ever more stringent and in some cases contradictory requirements of today's market place

have received assiduous attention during the evolution of the engine. Design, development and manufacturing needs have been closely co-ordinated to ensure a product that meets all requirements including all current and proposed controls on gaseous emissions, smoke and noise, even at high volume production but which still has a satisfactory cost structure. In this paper the six cylinder engine concept and design are described together with the subsequent engine application development.

Mackerle, J. Air-Cooled Automotive Engine. Halsted Press Div., John Wiley and Sons, Inc., New York, 2nd ed., 1972, 518 pp.

This new edition has been completely revised and enlarged. It is divided into two parts. The first is on principles and theory of engines. Its chapters cover fundamentals of heat transfer, thermal balance of engines, the characteristics of finned surfaces, etc., and it concludes with text on the utilization of exhaust gas energy. Part two deals with the design of individual components of engines, and with the general concept of engine design. Chapters then follow on the design of fans, ducting, lubrication, and important additions cover the rotary piston engine and the noise aspect of air cooled engines.

Martin, B., and G. Wright. High Output Diesel Engine Design Philosophy. Presented at the Off-Highway Vehicle Meeting & Exhibition, MECCA, Milwaukee, Wis., Sept. 12-15, 1977, SAE Preprint 770755, 6 pp.

A high rate of growth in the power density of diesel engines has been experienced in the past decade. It is anticipated that the trend will continue with the rate of increase being dependent only on the rate of growth in technology. This paper will review the basic reasons for pursuing increased power density and review some of the requirements for increased technology.

Merrion, D. F. Effect of Design Revisions on Two stroke Cycle Diesel Engine Exhaust. Presented at Mid-Year Meeting, Detroit, Mich., May 20-24, 1968, SAE Preprint 680422, 12 pp.

The exhaust emissions of the 6V-71E engines, used in transit coaches, are compared to illustrate that design revisions can affect diesel exhaust. Carbon monoxide and sulfur dioxide are discussed and the effect of design revisions on aldehydes, oxides of nitrogen, and hydrocarbons are illustrated. The effects of the design revisions on exhaust smoke and odor are compared using three different measurement techniques. Smoke is compared using a filtering meter on engine dynamometer tests, a sampling light extinction meter on road tests, and a full flow light extinction meter on chassis dynamometer tests. Odor is compared using a sniff-box technique and a psychological scale, a threshold technique using natural dilution in a large building, and a sniff tube-dilution technique using the Turk bottle rating.

Monaghan, M. L., C. C. J. French, and R. G. Freese. A Study of the Diesel as a Light-Duty Power Plant. Ricardo & Co. Engineers Ltd., Contract No. 68-03-0375, July 1974, EPA Preprint EPA-460/3-74-011, 260 pp.

The purpose of this study was to see if the diesel engine could be used as a viable power plant for the American passenger car. The study was conducted in four phases. The first phase was a literature survey which involved a study of all existing light duty and relevant heavy duty diesel literature. The second phase consisted of a study of all the potentially viable diesel power plants. For the third phase a rating method was derived which allowed numerical comparison to be made of all the different power plants. The final phase involved a consideration of the results of the previous sections in order to make recommendations for further action and effort to achieve the most desirable light duty vehicle.

Obert, E. F. Internal Combustion Engines and Air Pollution. Intext Educational Publishers, Inc., New York, 3rd ed., 1973, 740 pp.

This book presents a fundamental and factual development of the science and engineering underlying the design of combustion engines and turbines, and to synthesize the background of the student in physics, chemistry, fluid flow, heat transfer, and thermodynamics into the art called engineering. Considerable introductory material is included, not only on the foregoing engineering sciences, but also on those aspects of fuels, lubricants, instrumentation, combustion, and kinetics which are related to design, and to air pollution.

Reilly, D. J. The New GM 6.2L V8 Diesel Engine--Designed by Chevrolet Presented at the Internat. Cong. & Exposition, Detroit, Mich., Feb. 22-26, 1982, SAE Technical Paper Series 820115, 11 pp.

The 6.2 liter 90° V8 is a new engine designed to provide diesel power in the General Motors standard size truck line. This paper describes its design features, outlines development and durability testing programs and discusses development problems and their solutions. This engine was designed for compatibility with existing rear wheel drive train components and existing underhood packaging requirements. Materials, combustion chamber and fuel delivery system were selected for their proven performance and durability and have been combined to give excellent fuel economy and responsive performance.

Rogowski, A.R. Elements of Internal-Combustion Engines. McGraw-Hill Book Co., Inc., New York, 1953, 234 pp.

The subject matter of this book has been used successfully in war training programs and in one-term engine courses taken by seniors in mechanical engineering, marine engineering, general engineering and engineering administration. Emphasis has been placed upon the application of the

elementary principles of physics, chemistry, mechanics, etc., to the specific engineering problems connected with estimating and obtaining the maximum power, efficiency, and reliability from the internal-combustion engine.

Schneider, H. W. Conventional Engine Technology. Volume II: Status of Diesel Engine Technology. Prepared by Jet Propulsion Laboratory under contract to U.S. Dept. of Energy, NASA-CR-168644, Dec. 15, 1981, 213 pp.

The engines of diesel cars marketed in the United States are examined. Prominent design features, performance characteristics, fuel economy and emissions data are compared. Specific problems, in particular those of NO_x and smoke emissions, are discussed along with the effects of increasing dieselization on diesel fuel price and availability, current R&D work and advanced diesel concepts. The study generally concludes that diesel cars currently have a fuel economy advantage over gasoline engine powered cars. Many of the inherent diesel drawbacks (noise and odor) have been reduced to a less objectionable level. An equivalent gasoline engine driveability has been obtained with turbocharging. Diesel manufacturers see a growth in the diesel market for the next ten years. Uncertainties regarding future emission regulation may inhibit future diesel production investments. With spark ignition technology advancing in the direction of high compression ratios, the fuel economy advantages of the diesel car is expected to diminish. To retain its fuel economy lead, the diesel's potential for further improvement must be used.

Seale, J. N. Questions and Answers on Diesel Engines. Drake Publishers, Inc., New York, 1972, 128 pp.

This book explains the fundamental aspects of the diesel engine, including principles of operation, engine types, starting methods, fuel-injection pumps, governors, fuel injectors, and fuel filters.

Society of Automotive Engineers, Inc. (New York). Engineering Know-How in Engine Design--Part 18. July 1970, Special Pub. No. 359, 57 pp.

This report contains five (5) lectures on engine design. They include the engine intake system, the turbocharger, the induction and exhaust system, turbocharger aftercooling and muffler selection and design.

Steiger, H. A. Experimental Approach to Question of 2-Stroke or 4-Stroke Cycle, Particularly for Diesel Engines of Extremely High Specific Output. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Kansas City, Mo., April 20-24, 1969, ASME Preprint 69-DGP-6, 17 pp.

The intention of this paper is to present some of the most significant results obtained with each of the two experimental four-cylinder V-engines of 320 mm bore, one operating according to the two-stroke, the other on the four-stroke cycle principle. In all other respects, both of these trunk-piston engines are absoultely similar. This report covers 10 years of intensive testing. It discloses such basic information as the influence of stroke-to-bore ratio, compression ratio, supercharging level of various turbocharging systems, and so forth but deals quite particularly with the relative merits of either two- or four-stroke cycle.

Stinson, K. W. Diesel Engineering Handbook. Business Journals, Inc., Stamford, Conn., 12th ed., 1972, 336 pp.

The 12th edition of the Diesel Engineering Handbook was written with increased emphasis on basic engineering principles accompanied by examples of up-to-date design and construction of engines and their auxiliaries. The Handbook includes the fundamentals on combustion, fuels, lubrication, exhaust systems, supercharging, etc.

Timoney, S. G. A Diesel Design for High Specific Output. Presented at the Winter Annual Meeting and Energy Systems Exposition, New York, Nov. 27-Dec. 1, 1966. ASME Preprint 66-WA/DGP-1, 12 pp.

Increasing specific output and a general improvement in performance of internal-combustion engines have been factors in recent years. This paper suggests the feasibility of retaining good reliability, low maintenance, reduced noise, and equal thermal efficiency while improving the performance parameters.

Underwood, A. F. The Unwritten History of the Light Diesel. Presented at the West Coast Meeting, Town and Country, San Diego, Calif., Aug. 7-10, 1978, SAE Preprint 780713, 8 pp.

The author candidly relates the development of the automobile diesel from his perspective as an active participant of almost fifty years. Anecdotes about people and companies are recorded for the first time. Problems and successes of the past, as well as areas of future concern are detailed. This first of an expected series on automotive diesel engines brings into focus the state-of-the-art of one alternative to the spark ignition engine.

Zinner, K. Power Increase and Reliability of Diesel Engines. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Toronto, Ontario, Canada, April 18-22, 1971, ASME Preprint 71-DGP-11, 16 pp.

The power output of internal combustion engines can be increased by raising mean effective pressure and mean piston speed if number and size of cylinders are given. In this paper the effect of these measures on the engine design is examined. The conclusion is drawn that for heavy duty engines an increase of mean effective pressure is the most simple, cheapest and--after suitable adaption of the engine design--the most reliable solution. This conclusion is verified by examples.

B. Components

1. Filters - a) air

Cummins Engine Co., Diesel Engine Course Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog, v. 43, April 1978, 1626 pp.

The catalog gives the product line of approximately 200 companies along with the general specifications of their products. The directory also gives complete addresses of all the companies participating in the catalog and are presented in their respective section and also in the advertisers index at the back of the catalog.

Maleev, V. L. Diesel Engine Operation and Maintenance. McGraw-Hill Book Co., New York, 1954, 504 pp.

This book was prepared so the student can become thoroughly conversant with the principles behind the operation and maintenance of the diesel engine. The author divides the engine into its main parts, and each part is described in respect to its construction, operation, and maintenance. The troubles which are likely to occur are brought out, and the best methods of adjustment and repair are given and illustrated.

Schulz, E. J. Diesel Mechanics. McGraw-Hill Book Co., New York, 1977 420 pp.

The author wrote this textbook with the diesel mechanic in mind. It is neither too elementary nor too highly engineering oriented. Its basic concept is to pass on the author's many years of experience in maintaining large diesel engine powered fleets of on and off highway vehicles. It is a textbook that shows the operating requirements of the equipment. Design concepts are discussed where necessary. Particular emphasis is placed on the diagnosis, repair, and service of specific malfunctions.

Sopher, B. Air Filtration Using Positive Pressure Aspiration. Diesel & Gas Turbine Progress, September 1976, pp. 24-25.

Twenty years ago the Farr Company developed an effective air filtration aspiration system that used the engine's dust bin. To eliminate the need of the exhaust gas, Farr decided to use a positive pressure aspiration system. They experimented with a Detroit Diesel 8V-71 engine. They used a small amount of air bled from the low positive pressure manifold to aspirate the air cleaner. The new system eliminated the need for the exhaust gas and showed no measurable engine performance degradation.

Treuhaft, M. B., and C. D. Wood. Air Cleaner Development. Southwest Res. Inst., San Antonio, Tex., Feb. 12, 1971, 40 pp.

This report shows the results of an experimental investigation of a method to increase the size and mass of the average dust particle prior to entry into an inertial separator so as to provide increased separator and, therefore, overall system efficiencies. Particle agglomeration is accomplished by first developing a filter cake by dust collection on the surface of an upstream barrier media. When a sufficient quantity of dust is collected to cause a predetermined pressure drop, the dust is suddenly released into the separator. The large increase in separator efficiency so obtained verified the agglomeration principle and demonstrated the availability of a suitable surface collection media. Since the surface collection media is self-cleaning to a high degree, the design of an efficient, long life air filtration system should be possible.

B. Components

1. Filters - b) fuel

Cummins Engine Co., Diesel Course Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a).

Diesel & Gas Turbine Progress. Fuel-Water Separator Improves Fuel Condition. August 1977, p. 43.

This article discusses the Winslow fuel filter which can effectively remove major amounts of water from aviation and diesel fuels. The filter uses a composite media coalescer element in conjunction with a Teflon-coated screen separation stage. The composite media enables the removal of fine water droplets at a low pressure drop. Therefore the unit can be used on either the suction side or the discharge side of the fuel pump.

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Schulz, E. J. Diesel Mechanics. See IB-1a).

B. Components

1. Filters - c) oil

Cummins Engine Co. Diesel Course Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a).

Landis, D. Oil Purification Methods--Their Advantages and Disadvantages. The De Laval Separator Co., October 1968, 2 pp.

Water in the free form in oil can cause serious damage to equipment. This water can be removed by three methods. The methods are: gravity settling; coalescing filters; and centrifugal separation. The article explains the fundamentals and gives the advantages and disadvantages of each method.

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Schulz, E. J. Diesel Mechanics. See IB-1a).

B. Components

2. Turbochargers and Intercoolers

Balint, I., and L. Brinson. Two-Stage Turbocharging and Intercooling. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Houston, Tex., May 12-16, 1968, ASME Preprint 68-DGP-5, 16 pp.

This paper will cover the mechanical and thermodynamic development of a 13-1/2 inch bore, 16-1/2 inch stroke, 4-cycle dual fuel engine for ratings up to 300 bmep. The combined effects of two-stage turbocharging, intercooling, and the Miller system will be discussed. In addition, data will be included to show the load versus speed-response performance of this combined system.

Benson, R. S., and F. V. Svetnicka. Two-Stage Turbocharging of Diesel Engines: A Matching Procedure and an Experimental Investigation. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wis., Sept. 9-12, 1974, SAE Preprint 740740, 18 pp.

A method is described for matching turbines and compressors for two-stage turbocharging of 4-stroke diesel engines. The method is illustrated for a series turbocharged engine. Experimental results are presented which show that the method gives good predictions for the respective pressure ratios in the turbines and compressors and the overall engine performance.

Bly, R. L. Tips on Turbochargers. Coal Age, October 1977, pp. 171, 175, 179, 183, 187; Can. Min. J., July 1977, pp. 41, 43.

This article describes the basic operating principles of the turbocharger. It also describes the routine maintenance that should be performed on the charger.

Cummins Engine Co. Diesel Engine Course, Part 1. See IA.

Diesel & Gas Turbine Progress. New Concept Turbo Wheel Reaches 80% Efficiency. July 1977, p. 32.

The Schwitzer Engineered Components Co. has designed a new backward curved impeller turbocharger compressor wheel that reaches 80 pct efficiency. The article describes the differences and the advantages of the new turbocharger over the conventional turbocharger.

Diesel & Gas Turbine Progress. Turbocharger Lube System. November 1979, p. 56.

The Nycal Co. has come out with a system designed to prevent damage to turbochargers due to lack of lubrication. After an engine is shut down, the oil pressure drops to virtually zero. Because of the lack of lubrication as the turbine wheel is slowing down, bearing damage can result. Nycal's Lube System is designed to maintain a constant oil pressure until the turbine wheel stops. This paper describes the details of the system.

Diesel & Gas Turbine Progress. Diesel & Gas Worldwide Catalog. See I.B.1.a.

Doerfler, P. K. Comprex Supercharging of Vehicle Diesel Engines. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750335, 10 pp.

The purpose of this paper is to demonstrate the superiority of COMPREX® as a supercharging device. Comprex®, a gas-dynamic pressure-wave machine for supercharging vehicle diesel engines in the 100-500 BHP range, uses exhaust gas energy for compressing intake air. Based on a different physical mechanism, it avoids several of the turbocharger's disadvantages. Comprex supercharging gives high torque down to less than 40 pct of rated speed. Almost instantaneous response combines with significant reductions in acceleration smoke. An increase in maximum compression ratio and efficiency and a wider speed range were achieved by recent development work. Endurance tests have been successfully performed and the system has been redesigned for smaller dimensions and adapted to production requirements.

Eisele, E., H. Hiereth, and H. Polz. Experience with Comprex Pressure Wave Supercharger on the High-Speed Passenger Car Diesel Engine. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750334, 12 pp.

After dealing briefly with the mode of operation of the Comprex® pressure wave supercharger, a report is given on its general advantages and drawbacks as well as on experience gained in practical operations on the supercharging system, using a 2.2 dm^3 prechamber passenger car diesel engine. The most important problems which occurred here and the performance and exhaust emission figures resulting from rig and road test measurements are discussed.

Emmenthal, K. D., and W. H. Hucho. Turbocharger Matching for High Torque at Low Engine Speeds. Turbocharging and Turbochargers (A conference sponsored by the Combustion Engines Group of the Institution of Mechanical Engineers, April 18-20, 1978). The Inst. of Mech. Eng., London, England, Conf. Pub. 1978-2, pp. 257-260.

The power output of a 1.6 l SI engine was increased to that of a 2.5 l engine by means of an exhaust gas turbocharger. To get not only the peak power but also the torque characteristic of the bigger displacement engine a special matching of the turbine was necessary. The specifications of the turbine, especially at low total pressure ratios, were evaluated by tests in which the engine was fed with pressurized air and the turbine simulated by a throttle. The data obtained from the tests was used to calculate the turbine efficiencies to reach the required engine performance characteristic.

Gorlich, D. M.A.N. Exhaust Gas Turbochargers to Turbocharge High-Power Diesel Engines. Turbochargers (A conference sponsored by the Combustion Engines Group of the Institution of Mechanical Engineers, April 18-20, 1978). The Inst. of Mech. Eng., London, England. Conf. Pub. 1978-2, pp. 247-257.

The development work in progress at M.A.N. aims at an extension of the range of application of single-stage NA exhaust gas turbochargers to compressor pressure ratios of $V = 4.0$. The compressor and turbine wheels have been matched to suit the higher stresses and an improvement of the compressor and turbine efficiencies at higher pressure ratios have been achieved. For two-stage exhaust gas turbocharging, M.A.N. has the concept of a complete series of two-stage exhaust gas turbochargers. These sets consist of two single-stage types which are flanged together on the turbine side. A prototype has been tested without trouble on the turbocharger combustion chamber testbed and with a test engine. The test results showed the expected improvements.

Hartley, J. Turbocharging and Turbochargers. Inst. Mech. Eng., June/July 1978, pp. 17-20.

This paper briefly describes the topics discussed at the IMechE conference held april 18-20. M. L. Monaghan discussed the importance of turbocharger matching to the reciprocating engine. The Brown Boveri Co. then reported on their comprex method of supercharging. The rest of the paper describes the research and experimentation done by various companies on their turbocharging progress.

Kerklo, P. Development of High-Pressure High-Flow Turbocharger for Tomorrow's High-Output Diesel and Spark-Fired Engines. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Houston, Tex., May 12-16, 1968, ASME Preprint 68-DGP-18, 12 pp.

Modern turbocharged diesel and spark-fired gas engines cover a range of disciplines that challenges many of us. If a fragmentation of this range of technical interest is attempted, at least five very broad categories appear--engine design; turbocharger design; turbocharger application; engine performance; and manifolding and pulse phenomenon--to which many important companies have pledged their financial and technical resources. The author's company has played a very significant role in the development of the modern turbocharged engine, both as a product and as an industry; and, as its area of specialization within this industry, has concentrated on turbochargers as a product although, of necessity, it has participated in all technical areas of the industry. In his paper, the discussion will concentrate on the trends of turbocharger requirements and their influence on its design, and the discussion of the other topics that make up this industry is left to those who have the responsibility in those areas. Specifically, this paper will discuss the "G" turbocharger recently introduced by the author's company, touching on the history that precipitated its development; some of the achievements and difficulties encountered in the development, and, finally, establish where the turbocharger stands in relation to the engines of today.

Khan, M. S., and P. J. Langdon. The Role of the Computer in Turbocharger Design Development and Testing. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790278, 20 pp.

The design process of turbocharger impellers is recursive, involving several iterations in aerodynamics and stress analysis before finalized drawings may be produced. A comprehensive interface to both forms of analysis is discussed which relieves the designer of tedious data preparation, providing graphical interaction throughout. This interaction has been extended to the production of NC tool paths for die making and prototype manufacture and the data base created by the design procedure can be accessed for casting inspection. Finally, use is made of real time data acquisition from test cells to feed the latest empirical data into the design process.

Lang, W. What Can the Turbocharger Do for the Engine? SAE Preprint 660473. Society of Automotive Engineers, Inc. Engineering Know-How in Engine Design, Part 14. 1966, SAE Special Pub. 283, pp. 34-44.

The turbocharged engine, by operating at intake and discharge conditions several times higher than atmospheric pressure, is capable of increasing its specific output to several times that of its naturally aspirated version, and at better fuel economy. Successful integration of the

turbocharger requires recognition of the interrelation and interaction of both reciprocating and turbo machines and changes in their performance characteristics. This paper discusses the relation of intake manifold pressure to engine load and speed as a function of turbocharger performance, and methods of improving performance of the engine at part speed without excessive overboosting at rated speed.

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Mortimer, J. Rotary Blower Developed for Diesel Engines. The Engineer, April 15, 1976, p. 13.

The Wankel Research Institute is developing a rotary supercharger for diesel engines. The supercharger will combine the advantages of both the turbocharger and the positive displacement air pump. The new system consists of two Wankel units on the same shaft, one is an air motor driven by the exhaust gas and the other is an air motor supplying air to the intake manifold. The system is being tested on a diesel passenger car, but no test results are available yet.

Neff, J. J. New Family of Compact Cummins Turbochargers. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Houston, Tex., May 12-16, 1968, ASME Preprint 68-DGP-12, 16 pp.

This paper presents the design philosophy, mechanical design principles, and some of the evolutionary steps completed in the process of developing a new, compact, and simple family of turbochargers, together with a detailed description of their performance characteristics.

Schulz, E. J. Diesel Mechanics. See IB-1a.

Society of Automotive Engineers, Inc. Turbochargers and Turbocharged Engines. Preesented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-Mar. 2, 1979, SAE Special Publications 442, 147 pp.

The proceedings include 19 papers that present a timely description of some of the current activities involving new applications and new technologies related to turbochargers.

von Schnurbeim, E. Constant-Pressure Turbocharging for Medium-Speed Four-Stroke Engines. Turbocharging and Turbochargers (A conference sponsored by the Combustion Engines Group of the Institution of Mechanical Engineers, April 18-20, 1978). The Inst. of Mech. Eng., London, England, Conf. Pub. 1978-2, pp. 21-29.

The transport of exhaust gas energy from cylinder to turbine is examined in detail for pulse-pressure and constant-pressure turbocharging. The conditions for a successful application of the constant pressure turbocharging are stated. Tests have shown that there are no significant differences between the two systems regarding the temperatures of combustion chamber walls. It is demonstrated under which circumstances problems with high temperatures can arise in highly supercharged engines.

Zehnder, G., and E. Meier. Exhaust-Gas Turbochargers and Systems for High-Pressure Charging. Presented at the Energy Technol. Conf. and Exhibit, Houston, Tex., Sept. 18-22, 1977, ASME Preprint 77-DGP-12, 16 pp.; Brown Boveri Review (Baden/Switzerland), v. 64, No. 4, April 1977, pp. 201-214.

The present state and current problems of turbocharging as applied to two- and four-stroke engines are outlined. Reasons are given for the choice of the VTR turbocharger concept and development of this range is explained. After some consideration of future possibilities for increasing the outputs of diesel engines by pressure-charging, the limits for the development of single-stage charging are indicated. For two-stage charging the present turbochargers may be used without major changes. The

pressure-charged diesel engine has by no means reached the ultimate point in its development. Higher m.e.p. demand higher charging pressures which must be produced more efficiently. The part-load behavior of the combination of engine and turbocharger becomes more important and calls for new, simple solutions requiring a minimum of maintenance.

Zinner, K. Supercharging of Internal Combustion Engines. Springer-Verlag Berlin Heidelberg, New York, 1978, 290 pp.

The book is aimed mainly at the engine designer and development engineer who use supercharging as the most important means to increase the engine output, and the interested student who wishes to inform himself about the problems of supercharging. This defines the limits of the contents: the book does not deal with the design and calculation of superchargers or compressors of various types--a subject which is expertly treated in other books--but with the considerations relevant to the interaction between supercharger and engine, and with the effects of supercharging on the operation of the engine.

B. Components

3. Pistons and gaskets

Bertodo, R., T. W. E. Downes, and I. D. Middlemiss. Evolution of a New Combustion System for Diesel Emission Control. Reprinted November 1975, from 1974 SAE Transactions, Section 4, v. 83, 11 pp.

The emission control of small naturally aspirated diesels has posed severe problems and it has been generally thought that their acceptability in pollution sensitive areas would decline. The investigation described attempts to reverse this view. The exhaust quality of engines of this type can be improved by reducing the combustion temperatures and/or reducing the initial heat release rate: a range of methods of achieving this were examined and found commercially unacceptable. A qualitative review of the problem led to the evolution of a modified cycle characterized by high turbulence leading to higher air/fuel mixing rates and faster diffusion burning. This "Squish Lip" combustion system allowed CARB 1977 projected emission levels to be met on development engines without performance deterioration. Bench and field trials are in hand and a second generation system for truck applications is being evaluated.

Bode, D. New U.S. Plant Offers European Piston Technology. Diesel Progress, January 1982, v. XLVIII, No. 1, 2 pp.

The article describes the capabilities of the Karl Schmidt Corp. manufacturing facility in Marinette, Wis., which produces engine components--with primary emphasis on pistons--for U.S. manufacturers of diesel and gasoline engines. The plant is a 50-50 joint venture company of Metallgesellschaft AG, Frankfort, West Germany, and Safeguard Scientific, King of Prussia, Penn.

Cooper, C. L. Fluoroelastomer Seals Meet Diesel Performance Standards. Diesel & Gas Turbine Progress, June 1977, pp. 74-75.

An elastomeric seal must have the properties of withstanding high temperatures, good fluid resistance, able to withstand ozone attach and must be abrasive resistant. Viton fluoroelastomer which is a product of DuPont has these properties. This article describes a number of current sealing applications in the diesel field. The examples compare seals made using Viton fluoroelastomer material to conventional material. The results indicated that the Viton material was superior to conventional material for seal use.

Cummins Engine Co. Diesel Engine Course Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a).

The Engineer. Piston Redesign Cleans Diesels. June 6, 1974, p. 15.

Perkins Engine Co. has designed a new piston which promotes better fuel-air mixing. Combustion efficiency is improved because the pressure rise in the cylinder is better controlled, with gradual burning of the mixture. Therefore it is possible to retard the start of injection which leads to a reduction in the levels of nitrogen oxides and hydrocarbons in the exhaust. This enables the engine to meet the 1977 California and U.S. Federal emission standards.

Hartley, J. Iron Pistons Back in Diesels. The Engineer, June 3, 1976, p. 17.

Rolls-Royce is experimenting with cast iron pistons. They found that cast iron pistons reduce the amount of heat passing from the piston to the cylinder wall, thus increasing thermal efficiency. They also found that a closer piston to bore clearance could be maintained, resulting in reduced noise levels. Finally, with today' s casting techniques the cast iron piston weighs no more than the aluminum piston.

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Newton, D. A., and A. Scholes. Computer Aided Optimal of Diesel Engines Pistons. Presented at the Diesel & Gas Turbine Power Conf. and Exhibit, Dallas, Tex., April 12-16, 1970, ASME Preprint 70-DGP-6, 8 pp.

Digital computers have been used extensively in the strength analysis of diesel engine pistons. This use of computers for analysis led to their application to the quantifiable part of the overall design process. The iterative process of piston design-analysis-redesign has been automated and the computer generates sequentially improved designs which tend to an optimum with respect to a given criterion. This automated design process is discussed in terms of a simplified piston defined by a number of fixed and variable design parameters, and then is shown in its application to the optimization of a production piston. The variable design parameters in the initial investigation are the thicknesses of the piston at various positions and the optimality criterion is that of fatigue strength subject to geometrical constraints on the piston shape and limitations on the piston weight and deflection under load. An initial design is analyzed, evaluated and automatically modified according to a mathematical optimization procedure. Results have been obtained for a piston specified by six variable design parameters using two optimization techniques. An extension to the design optimization of a production piston is then discussed. The final design produced showed a significant improvement in fatigue reserve factor. The current piston design computer program allows the designer to select those parameters which are to be changed during any optimization process. This permits the rapid assessment of the effect on the optimal piston design of individual design parameter variations.

Paris, J. W. Anaerobics--An Answer to the Ideal Gasket Search. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740255, 8 pp.

A new anaerobic material has been developed which overcomes many of the problems associated with preformed, precut, and other formed-in-place gaskets. This new material does not migrate or drip, can be applied by either tracing or stenciling, offers instant sealing capability, and cures upon confinement into a tough, nonrelaxing, gap-filling solid.

Roehrle, M. D. Thermal Effects on Diesel Engine Pistons. Presented at the Off-Highway Vehicle Meeting and Exposition, MECCA, Milwaukee, Wis., Sept. 11-14, 1978, SAE Preprint 780781, 17 pp.

Along with the increase in specific output of internal combustion engines, the determination of piston temperatures in diesel engines and the possibility of influencing these temperatures has attained greater and greater significance. After a survey of the temperature conditions of pistons in non-turbocharged and turbocharged diesel engines and the various temperature measurement techniques used to determine piston temperatures, this paper concentrates on some of the different parameters in pistons for diesel engines in the diameter range of 100 to 140 mm and presents their effects with the aid of comparative investigations.

Rohrle, M. Pistons for High Output Diesel Engines. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, St. Louis, Mo., April 16-20, 1972, ASME Preprint 72-DGP-11, 13 pp.

Along with the increase in specific output of internal combustion engines, the thermal and mechanical loadings on the pistons have grown continually. This paper deals with modern piston designs used on diesel engines for commercial vehicles, railway traction and marine propulsion. A survey on the comprehensive research and development work on pistons and explanations are given by means of practical examples how part of piston trials can be carried out in the laboratory.

Schulz, E. J. Diesel Mechanics. See IB-1a).

Stang, J. H. Designing Adiabatic Engine Components. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-Mar. 3, 1978, SAE Preprint 780069, 12 pp.

A procedure to analyze and design adiabatic diesel engine components is developed. The analytical basis for the procedure is presented. An experimental study of related thermal boundary conditions in the combustion chamber is conducted. Mean effective gas temperatures as high as 2200°F are measured. A new adiabatic diesel piston, using a ceramic top,

is designed and demonstrated using the procedure. Initial engine testing of the piston is encouraging, with full design power being achieved. The piston is considered the critical component in the overall development of an adiabatic diesel engine.

Sunden, H., and R. Schaub. Piston Rings for Slow and Medium Speed Diesel Engines. Tribology Internat., February 1979, pp. 3-14.

The manufacture of piston rings for slow and medium speed diesel engines is a strange mixture of art and science whose final arbiter, the engine, is critical in its judgment of success or failure. Piston ring design is a delicate balance of tribology, practice, and manufacturing techniques, yet the piston ring is the least understood of all the components in a diesel engine, and the one most often found in practice to bear the brunt of the development problems of modern highly rated diesel engines. This paper presents a selection of some of the more practically orientated principles of the successful manufacture of grey cast iron piston rings greater than 175 mm in diameter, and shows that when considered with the sciences of strength of materials and diesel engineering, the subject of piston rings is almost an embodiment of the wider subject of tribology.

B. Components

4. Governors

Barrett, W. J. DYNA--A New Family of Controls: Development of a New Electronic Governor System for Internal Combustion Engines. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Chicago, Ill., April 4-8, 1976, ASME Preprint 76-DGP-7, 12 pp.

The paper describes the development of a new Electronic Governor System. It includes design, development and test data, and a summary of field test experience in a variety of industrial, off-highway, and marine applications. In addition to the electronic package, a series of actuators is also described, and appropriate test and field data are supplied. The paper also describes how multiple actuators can be controlled from one set of electronics, as for multiple engines tied to a single propeller shaft.

Cummins Engine Co. Diesel Course, Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a).

Jaliwala, S. A., E. Day, and W. H. Stahl. Diesel Engine Governing With Load Feedback. Presented at the Energy-Sources Tech. Conf. and Exhibition, January 18-22, 1981, Houston, Texas, ASME Preprint n81-DGP-5, 6 pp.

Stable low droop governing with Cummins automotive or variable speed governors is difficult on generator sets without the use of compensating networks. Also isocronous operation or paralleling with acceptable load sharing is quite impossible with existing hardware. All these considerations dictate the use of proprietary hydraulic or electronic governors with an attendant severe cost penalty. This paper describes a low cost approach to gen-set governing. The basic governing is done with the fly-ball-governor plunger-spring combination. Turbocharger boost pressure, which is proportional to engine load during steady-state operation, is used to continually reset the break point of this governor. The inherent lag in the turbocharger provides a temporary long droop that enables the engine-governor system to be stable. However, during steady-state, this predictor system provides low droop.

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Schulz, E. J. Diesel Mechanics. See IB-1a).

B. Components
5. Fuel systems

Cummins Engine Co. Diesel Engine Course, Part 1. See IA.

DeKeyser, R. A., M. A. Gates, and J. H. Parks. Caterpillar's New Sleeve Metering Fuel Injection Systems. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750079, 16 pp.

Caterpillar's new Sleeve Metering Fuel Injection System comprises a family of lightweight, high speed injection pumps designed to serve the present and future medium horsepower Truck, Industrial, and Captive Vehicle needs. The fuel lubricated pump and governor combines some new innovative design features with proven individual pump durability advantages. The paper discusses the design, development, and test program, and some of the results obtained. Modern manufacturing methods and computerized testing were an integral part of the total system development.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a).

Gaal, S. L., J. P. Perr, G. L. Muntean, and H. L. Wilson. New Injector Concept for Direct-Injection Diesels. Diesel & Gas Turbine Progress, April 1976, pp. 44-46.

The introduction of fuel into the combustion chamber and the fuel-air mixing process has an overwhelming effect on the quality of combustion and the formation of smoke and gaseous emissions. Therefore, a new injector design was looked into. This article discusses the PT-ECON injector. It discusses in detail the design, fuel metering and fuel injection of the injector. The PT-ECON injector was compared to the PT-Type D injector. The results indicated that the PT-ECON injector produced less smoke, less emissions and showed improved BSFC.

Jones, T. O., and M. U. Trenne. Electronic Fuel Injection: Diesels are Next. IEEE Spectrum, v. 18, No. 5, May 1981, pp. 30-34.

Most automobile gasoline engines today are equipped with electronic controls and exhaust aftertreatment to optimize fuel economy and meet emission requirements. Today's automobile diesel engines, on the other hand, use 25 to 50% less fuel than gasoline engines and meet diesel emission standards without electronic controls or exhaust aftertreatment. But as more stringent diesel emission standards evolve in the next several years, electronic controls will be needed to refine diesel performance. The first such application will be for fuel injection control. Diesel

exhaust aftertreatment, now under study, will come later. Diesel engines have been able to meet emission standards thus far with a mechanical diesel fuel pump. It provides precise fuel metering, but not precise enough for the complex advance/speed/load timing requirements of an optimized diesel engine--one that will meet future emission standards. With electronic controls, the diesel pump can be programmed to meet these complex timing needs. This article describes some of the research and possibilities.

Kimberley, J. A., and R. A. DiDomenico. UFIS--A New Diesel Injection System. Presented at the Internat. Autmotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770084, 8 pp.

This diesel fuel injection system provides the capability of universal application to a wide range of existing engines. It also provides the injection quantities, characteristics, and timing variations which may be needed by the new high performance diesel engines with emphasis on gaseous emissions and noise. This is an electro-hydraulic system using unit injectors which are electronically controlled and operate on the common rail principle. It features positive displacement fuel metering, hydraulic pressure amplification and nozzle valve control. The system is highly flexible and can achieve injection characteristics beyond the capability of conventional systems.

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Matsuoka, S., K. Yokota, T. Kamimoto, M. Igoshi. A Study of Fuel Injection Systems in Diesel Engines. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760551, 24 pp.

In this study, the authors show their analytical model of the fuel injection system in a diesel engine, which is constructed to be as accurate but as simple as possible and to have good application in the development of new fuel injection systems. In the first part, the authors initially describe the model assumptions, classification of injection phenomena, and fundamental equations considering the compressibility, inertia and viscosity of hydraulics and the movements of valves and other components to improve the accuracy of the systems. Secondly, regarding the experimental constants and physical properties of the fuel, the authors show the method of selection they used to simplify the analytical model and to get good agreement as a result but without losing physical meanings. Correlations between calculated and experimental results are shown for some areas which have not been carefully investigated before, as follows: (1) sonic velocity in the fuel; (2) pressure loss at pipe connections; (3) effective area of nozzle hole; (4) correction factor of valve area; (5) damping factor of valve motion; (6) coefficient of restitution of valve at valve seat.

Parker, R. F. Future Fuel Injection System Requirements of Diesel Engines for Mobile Power. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760125, 10 pp.

The diesel engine appears destined to play a major role in the mobile power field, through the next decade. In order for this engine to fully realize its superior potential in this field, considerable development work is being conducted throughout the world to optimize each subsystem of the engine. Through this work, the need for a new generation fuel injection system has become apparent. This new system must be based on the latest technology available to provide a cost-effective design with increased capability. It can then provide the flexibility necessary to maximize the thermal efficiency of the engine while minimizing to a socially acceptable level the gaseous emissions, black smoke, noise and odor-irritant emissions of the next generation of diesel engines. Much of the information presented here is based on experience obtained from engines equipped with research type fuel injection systems. It should be considered an interim report, but work to describe an advanced injection system must begin now, to hasten the date of production availability. It is the goal of this paper that these specifications serve as initial guidelines in the development of advanced fuel systems for the next generation diesel engines which are being designed to meet the demanding requirements of mobile power for the future.

Reitz, R. D., and F. B. Bracco. On the Dependence of Spray Angle and Other Spray Parameters on Nozzle Design and Operating Conditions. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790494, 24 pp.

In the atomization regime, liquid jets break up either within the nozzle or immediately upon entering the chamber gas and drops much smaller than the jet diameter are formed. The mechanism of atomization, which is presently unknown, was investigated by the simultaneous use of two photographic techniques. The initial transient was observed with a 10^6 frames/s camera and the steady state by a technique similar to spark photography. The experiment range was: liquid pressure 500 to 2,500 psia; five mixtures of water and glycerol to vary the liquid viscosity; air, nitrogen, helium, and xenon at up to 600 psia as chamber gases to separate gas pressure from gas density effects; and 14 nozzle designs. Not changed were the temperature (room value), the nozzle diemeter (340 μ), and the surface tension (70 dyne/cm). It was found that: jet divergence begins progressively closer to the nozzle exit as the gas density increases until it reaches the exit with no evidence of abrupt change; the divergence angle (spray angle) increases with increasing gas density, and sharpness of nozzle inlet and with decreasing liquid viscosity and nozzle length; divergence angle and jet intact length are quasi-steady with respect to upstream pressure changes which occur on time scales greater than 10 to 30 μs; aerodynamic effects, liquid turbulence, jet velocity profile rearrangments, and liquid pressure oscillations, each could not alone be the mechanism of atomization; cavitation or aerodynamic effects, supplemented by cavitation and/or wall boundary layer relaxation processes, could each be the mechanism of atomization; and the criterion

We > 40.3 for the onset of atomization and a commonly used gas jet expression to predict the spray divergence angle are inadequate. Equations are given for the divergence angle and the onset of atomization which are valid within the tested range.

Schulz, E. J. Diesel Mechanics. See IB-1a).

Trenne, M. U., and A. P. Ives. Closed Loop Design for Electronic Diesel Injection Systems. Presented at the Internat. Cong. and Exposition, Detroit, Mich., Feb. 22-26, 1982, SAE Technical Paper Series 820447, 12 pp.

Consumer expectations of automotive diesel performance combined with stringent emission statutes have accelerated the development of electronically controlled diesel fuel injection systems which provide precise control of the quantity of fuel injected and the timing of injection. A comparison of closed loop and open loop control techniques in this application is presented with closed loop control shown to exhibit superior accuracy, response time and disturbance input rejection characteristics while offering the potential of relaxed actuator specifications.

Wessel W. G., and E. U. Joachim. A Strategy for Optimization of Diesel Fuel Injection System. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich. Feb. 26--March 2, 1979, SAE Technical Paper Series 790036, 20 pp.

The more detailed the performance specifications for diesel engine are defined, the more difficult is the task to find the best possible compromise in applying a fuel injection system. This paper outlines in detail the strategy, how the objectives can be achieved within a reasonable time frame. The application of this strategy is demonstrated using actual results of a study based on optimization of exhaust emissions and fuel economy.

Zias, A. A New Approach to Flowmetering--Simple Mechanical Device Allows Use of Reasonably Specified Pressure Transducer for Flow and for Total Volume Metering. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760019, 12 pp.

The measurement of average velocity or kinetic energy of moving fluid is most often for the purpose of determining the volumetric rate of fluid flow or the mass rate of fluid flow. The determination of fluid flow rate is most often for the purpose of measurement or control of total accumulated fluid volume or fluid mass. Such measurement is called flowmetering. There are many widely differing types of flowmeters available. They can be classified broadly into two groups; one which

presents little or no interference or impedance to the flow stream, and one wherein the mechanism of metering significantly influences the flow stream. The low or zero impedance type are exotic and generally require a great deal of specialized knowledge of specific properties of the fluid flowing. For example, the hot wire anemometer type of flowmeter requires precise knowledge of fluid thermal properties as a function of velocity. For another example, the nuclear magnetic resonance type of obstructionless flowmeter requires precise knowledge of the number of hydrogen atoms present per unit volume or mass of fluid. Most commonly used flowmeters partially obstruct or add impedance to the fluid stream. These also fall into two categories; one utilizing mechanisms dependent upon displacement or position change, and the other dependent upon pressure change. The first type, using such compliant mechanisms as turbine wheels, sliding capacitor plates, sliding potentiometer contacts, oscillating vanes, suffer the usual array of problems associated with precision machines with moving parts. They are delicate, expensive, and require watchmaker caliber labor to build and repair if accuracy is to be achieved. The type of flowmeter dependent upon pressure change, properly conceived, has no moving parts. In this paper, the traditional pressure transducer flowmeters are described. The pressure/flow square law problem and its relation to accuracy is described. A novel solution to the square law accuracy problem is offered. Pressure transducer accuracy is examined. A technique of improving pressure transducer accuracy in flowmetering is offered. In composite, a new flowmeter design is recommended.

Zimmermann, K. D. New Robert Bosch Developments for Diesel Fuel Injection. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760127, 16 pp.

The diesel engine is in a phase of very intensive developments. Therefore the fuel injection system has to be adapted to the growing requirements of the engine. These efforts resulted at ROBERT BOSCH in new higher performance inline and distributor type injection pumps. The company also developed new nozzle versions and improved accessories for the well known proven governor line. In view of diesel injection equipment for the eighties Robert Bosch is involved in basic research and development work; the objectives will be outlined in this paper.

B. Components

6. Exhaust systems

Cummins Engine Co. Diesel Course, Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a).

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Schulz, E. J. Diesel Mechanics. See IB-1a).

B. Components
7. Cooling system

Cummins Engine Co. Diesel Course, Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a).

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a).

Rambie, E. J. An Improved Cooling System for Military and Heavy Duty Vehicles. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770025, 24 pp.

A cooling development program is described for an improved cooling system for the M551 (Armored Reconnaissance/Airborne Assault Vehicle). The M551 specification was to cool at 125°F at 17 tons gross vehicle weight. Requirements for additional ammunition, armor kits and storage increased gross operating weight to 20 tons and increased in-service cooling problems. Field operations have since demonstrated the need to provide for an improved cooling system design for the upweighted vehicle. The original liquid cooled system incorporated water-to-oil engine and transmission oil coolers in series with the engine radiator. The improved design separates engine and transmission heat rejection by incorporation of air-to-oil transmission cooler behind the radiator (cooling air flows in series first through the radiator, then through the transmission air-to-oil cooler). By this means reductions of engine coolant and engine oil temperature of 14°F resulted while the transmission oil temperature was reduced by 39°F. These gains were made over the best previous cooling condition in converter operation without increasing fan speed. The improved cooling system allowed for increased cooling capacity so that the 20 ton upweighted version of the vehicle could be cooled to the limit of track slip without exceeding allowable critical temperature limits. The principle of using a large area low restriction air-to-oil cooler for transmission cooled military heavy duty vehicles to make major gains in vehicle cooling capacity possible. Design considerations for this improved cooling system, laboratory testing at U.S. Army Tank-Automotive Research and Development Command in Warren, Michigan, and field testing at U.S. Army Yuma Proving Ground in Yuma, Arizona, are reported.

Rising, F. G. Engine Cooling System Design for Heavy Duty Trucks. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770023, 12 pp.

A computational model is constructed for an engine cooling system for a heavy duty truck. The required performance data for the key model

elements of engine, fan and radiator is discussed. An example is given for the cooling design engineer to demonstrate the principle use of the model in predicting cooling ATB performance and fan noise dB(A) contribution. The use of the model in analyzing vehicle wind tunnel cooling performance data is discussed.

Schulz, E. J. Diesel Mechanics. See IB-1a).

Walter, J. C., and J. E. Hill. Cooling Higher Horsepower Highway Diesel Engines. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750131, 8 pp.

The increase in power-to-weight ratio that results from the use of higher-horsepower diesel engines in highway service prompted this study of engine cooling. This paper covers the results obtained in testing different power-to-weight ratios on grades from sea level to over 11,000 ft and compares these results with those obtained from chassis and towing dynamometer cooling trials.

B. Components

8. Accessories

Cummins Engine Co. Diesel Course, Part 1. See IA.

Diesel & Gas Turbine Progress. Diesel & Gas Turbine Worldwide Catalog. See IB-1a.

Maleev, V. L. Diesel Engine Operation and Maintenance. See IB-1a.

Schulz, E. J. Diesel Mechanics. See IB-1a.

C. Combustion

Bolt, J. A., and N. A. Henein. The Effect of Some Engine Variables on Ignition Delay and Other Combustion Phenomena in a Diesel Engine. Diesel Engine Combustion. (A Symposium arranged by the Combustion Engines Group of the Institution of Mechanical Engineers, April 7-9, 1970). The Inst. of Mech. Engrs., London, Proceedings 1969-70, v. 184, pt. 3J, pp. 130-137.

Measurements of ignition delay and other combustion phenomena were made on a single cylinder, open-chamber, supercharged research diesel engine. The influence of engine speed, fuel/air ratio, and air-charge pressure are reported. The results show that the elapsed time from the start of injection until illumination occurs is longer than that for pressure rise due to combustion. As expected, the measured ignition delay is decreased with increased speed. However, when a correction was made for cylinder air temperature change due to speed, the ignition delay increased with speed. Increase in the fuel/air ratio decreased the measured ignition delay. However, when corrected, the ignition delay was unaffected by fuel/air ratio. The smoke increased with engine speed and fuel/air ratio.

Boyce, T. R., G. A. Karim, and N. P. W. Moore. The Effects of Some Chemical Factors on Combustion Processes in Diesel Engines. Diesel Engine Combustion. (A Symposium arranged by the Combustion Engines Group of the Institution of Mechanical Engineers, April 7-9, 1970). The Inst. of Mech. Engrs., London, Proceedings 1969-1970, v. 184, pt. 3J, pp. 137-147.

The combustion processes in a direct-injection single-cylinder diesel engine are examined in relation to the findings of an experimental program employing the following chemically biased procedures: (1) direct introduction to the engine air of various concentrations of pure fuel fractions in addition to light distillate diesel fuel vapor; (2) the products of controlled partial oxidation (conducted externally to the engine) of a portion of various fuels in (1); and (3) the aspiration of some of the more active stable intermediate products identified, following analysis by gas chromatography, in the partial oxidation products of (2). It is suggested that the introduction of active intermediates at the right point in the cycle can be effective in producing smoother combustion, coupled with a reduction in exhaust smoke. Moreover, design modifications may be effected to produce the desired results efficiency.

Brisson, B., A. Ecomard, and P. Eyzat. A New Diesel Combustion Chamber--The Variable-Throat Chamber. Presented at the Internat. Autmotive Eng. Cong., Detroit, Mich., Jan. 8-12, 1973, SAE Preprint 730167, 12 pp.

This paper describes a variable-throat combustion chamber developed by I.F.P. and the Societe d'Etude des Machines Thermiques. The chamber seems to offer advantages in overall efficiency with a reduced maximum pressure. It also shows a tendency to emit fewer pollutants than conventional combustion chambers. Design details are discussed, along with combustion speed, heat transfer coefficient, reliability testing, and emissions. The chamber is intended primarily for railroad locomotives.

Dolan, D. F. Experimental and Theoretical Investigation of Diesel Exhaust Particulate Matter. Ph.D. Thesis, Univ. Minn., Minneapolis, Minn., 1977, 174 pp.

This thesis has been done in order to characterize the particulate matter which is emitted in the exhaust of a diesel engine. It includes both an experimental determination of the physical characteristics of the exhaust particles and an analytical formulation of a possible growth mechanism for those particles. A review of the literature pertaining to the formation of solid carbon during hydrocarbon combustion processes is presented along with a review of literature dealing with the dynamics of aerosol growth. Particle size distributions in the exhaust of a single cylinder Onan diesel engine using an Electrical Aerosol Analyzer (EAA) have been measured. These measurements give a volume mean diameter for the exhaust particles of about 0.1 μm. Electron microscope analysis of the particles showed a size range of about 0.05 to 0.6 μm. This analysis showed the existence of both chain and cluster agglomerates. Gravimetric filter analysis showed that the mass collected on the filters was generally higher than that predicted by the EAA at low loads and lower at high loads. Possible reasons for this discrepancy are discussed. A mathematical model for the coagulation of primary smoke particles into the agglomerates seen in the exhaust is presented. This model is based on information presented in the literature along with the experimentally determined exhaust particle size distributions presented in this thesis. It indicates that stratification of the initial particle concentrations within the combustion chamber can explain the observed exhaust particle size distribution.

Hardenberg, H. O., and F. W. Hase. An Empirical Formula for Computing the Pressure Rise Delay of a Fuel From Its Cetane Number and From the Relevant Parameters of Direct-Injection Diesel Engines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790493, 16 pp.

The evaluation of test results from the development of a large number of direct-injection (DI) diesel engines of different design and a great variety of cylinder dimensions enabled an empirical formula to be derived which allows the effect of the fuel, the engine parameters and the ambient conditions on the pressure rise delay to be assessed. Application of the formula indicates the possibilities and limitations of minimizing the pressure rise delay in naturally-aspirated (NA) and turbocharged (TC) diesel engines when operating on diesel fuel as well as on fuels of lower or higher ignition quality.

Henein, N. A., and J. A. Bolt. Kinetic Considerations in the Autoignition and Combustion of Fuel Sprays in Swirling Air. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, St. Louis, Mo., April 16-20, 1972, ASME Preprint 72-DGP-8, 12 pp.

The kinetics of the physical and chemical preignition processes are studied for fuel sprays injected in high speed diesel engines. The chemical reactions are found to be the rate controlling processes. The present and many previous experimental results support this conclusion. The overall preignition reactions follow an Arrhenius-type relationship with temperature. The global activation energy is calculated for three fuels: diesel No. 2, CITE (Compression Ignition Turbine Engine fuel), and gasoline. The global activation energy decreases with increase in the cetane number of the fuel. The rate of heat release reveals two types of reactions for both diesel No. 2, and CITE fuels. A slow reaction starts near the end of the ignition delay and is followed by a fast reaction. These two reactions are also observed when a barium antismoke compound is added to the diesel fuel. The barium additive does not affect the length of the ignition delay, but accelerates the main combustion reactions.

Hoelzer, J. C. Emission Formation Characteristics of the Diesel Combustion Process and Estimated Future Development Trends. SAE Preprint 751002. Society of Automotive Engineers, Inc. August 1975, SAE Special Publications 396, pp. 15-23.

A review of the fuel consumption per capita and population trends is presented which suggests that any significant relaxation in diesel emission goals is undesirable. An analysis is then made of the chemical, thermodynamic and fluid dynamic factors which control the formation of nitric oxide, unburned hydrocarbon, carbon monoxide and exhaust smoke in diesel combustion. Based on this analysis, it is hypothesized that a reduction in the quantity of fuel burned in diffusion flames and increased mixing rates of air and fuel vapor will significantly lower emission levels. It is suggested, therefore, that future trends in direct injection combustion development will need to incorporate increased fuel atomization and toroidal air motion to achieve the required favorable

combustion conditions. A comparison is made of commercially acceptable, state-of-the-art diesel engines developed to meet low emission levels to allow an estimate of the potential improvements from combustion development. The comparison suggests that intense mixing and good fuel atomization, characteristic of the prechamber process, are the keys to lower emissions and can yield up to 40% reductions in HC + CO_2 levels for the direct injection diesel combustion process. A forecast of future engine requirements is made and indicates that hybrid engines combining the diesel and Rankine cycles are feasible for heavy duty engine applications. The combination of the highly efficient diesel cycle and a reciprocating steam engine using diesel engine exhaust energy is a potentially efficient, low emission, socially acceptable prime mover.

Institution of Mechanical Engineers (London). Symposium on Diesel Engines - Breathing and Combustion (A symposium jointly sponsored by the Institution of Mechanical Engineers Automobile Division and the Advanced School of Automobile Engineering, July 5-6, 1966). Proceedings 1965-66, v. 180, pt. 3N, 118 pp.

This book contains 6 papers that were presented July 5-6, 1966, when a symposium was held on Diesel Engines--Breathing and Combustion. Paper one was written by D. Broone, Mech. Eng., who wrote on the breathing requirements of small high speed diesel engines. The second paper was written by B. E. Knight, who wrote on the similarity considerations in assessing diesel engine fuel spray. The third paper written by W. A. Woods and S. R. Khan, did an experimental study of flow through popet valves. The fourth paper discusses the development of an induction system for a high performance direct-injection diesel engine. The fifth paper presented, discussed analytical techniques of studying the turbocharger for the automotive diesel engine. The last paper written by D. W. Tryhorn looks at turbocharging the automotive two-stroke engine.

Khan, I. M., and H. C. Grigg. Progress of Diesel Combustion Research. Presented at the Ninth Internat. Cong. on Combustion Engines, Stockholm, Sweden, 1971, CIMAC Preprint A18, 28 pp.

This paper is a progress report on the diesel combustion research at C.A.V. Limited and is offered as some results of importance have been achieved. It is also hoped to compare notes and invite comments from people involved in similar work. Most of the important aspects of the experimental and theoretical work are covered in this paper. Notable experimental results deal with the emission of smoke, nitric oxide and unburned hydrocarbons from the diesel engine, with air flow measurements by hot wire anemometry and heat release prediction and exhaust smoke prediction models is described.

Lyn, W. T. The Spectrum of Diesel Combustion Research. Diesel Engine Combustion (A symposium arranged by the Combustion Engines Group of the Institution of Mechanical Engineers, April 7-9, 1970). The Inst. of Mech. Engrs., London, Proceedings 1969-1970, v. 184, pt. 3J, pp. 1-17.

This review attempts to thread a unified theme through the whole spectrum of diesel combustion and its related studies--from basic research on a single droplet to the development of a specific combustion chamber--and endeavors to demonstrate how, as a whole, they contribute to provide the quantitative link between design and performance.

McFarland, R. A., and C. D. Wood. An Analog Heat Release Computer for Engine Combustion Evaluation. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760553, 8 pp.

An inexpensive, easy-to-use analog computer has been designed and built that provides real-time analog signals proportional to combustion heat release, rate of heat release, and other related parameters in operating engines. This paper describes the computer and provides examples of engine data obtained with the computer.

Pachernegg, S. J. Efficient and Clean Diesel Combustion. Presented at the 1975 SAE Off-Highway Vehicle Meeting, Milwaukee, Wisc., Sept. 8-11, 1975, SAE Preprint 750787, 20 pp.

Since the available combination of equations describing the kinetic reactions during diesel combustion a) is complicated, and b) falls short in predicting actual NO-emissions, an attempt is made with a simplified model to correlate the squared temperature profile of the cycle over time, integrated above the level of a significant threshold temperature, with NOx formation. This rating permits the evaluation of cycle parameters, like compression ratio, ignition timing, heat release and others, regarding their effect on the compromise between acceptable emission and cycle efficiency. The underlying working theories compare and complement existing analytical models of diesel ignition, combustion and soot emission.

Society of Automotive Engineers, Inc. Diesel Combustion and Emissions. See III.D.

Suziki, T., and T. Shiozaki. A New Combustion System for the Diesel Engine and Its Analysis via High Speed Photography. Presented at the Internat. West Coast Meeting, Vancouver, British Columbia, Aug. 8-11, 1977, SAE Preprint 770674, 16 pp.

Described herein is the tuning of the combustion system of a direct injection type diesel engine to obtain low emission level and better fuel economy. Though the most important method of emission control for a

direct injection system is considered to be timing retardation, it brings a higher level of smoke density and fuel consumption. In order to remove these faults, the authors developed a new combustion system based on a newly designed intake port which provides a favorable local mixing of fuel droplets and air in the combustion chamber for ignition by means of air turbulence. This new combustion system was analyzed with high speed photographs which were taken from the underside of the piston to enable observing the whole combustion chamber. Favorable characteristics of ignition and burning pattern of the new system were recognized by this analysis.

Valdmanis, E., and D. E. Wulfhorst. The Effects of Emulsified Fuels and Water Induction on Diesel Combustion. Presented at the Combined Nat. Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wisc., Sept. 14-17, 1970, SAE Preprint 700736, 12 pp.

Water was inducted with the intake air and injected emulsified with the fuel, in a conventional single cylinder D. I. diesel engine. The major effects of inducted water were an increase in ignition delay, and reduction in the oxides of nitrogen and smoke at a constant fuel/air ratio. When the water was emulsified with the fuel, the ignition delay increased so much that no benefits were obtained except for a reduction in smoke. The results are compared to a similar study on an engine with the "M" combustion system. The major differences between the results obtained with the two combustion systems are attributed to the differences in the ignition delay caused by the water addition.

Vanderpoel, R. E., J. M. Rife, and A. R. Rogowski. More Efficient Combustion in Small Open Chamber Diesel Engines. Presented at the Nat. Combined Farm, Construction and Ind. Machinery and Powerplant Meetings, Milwaukee, Wisc., Sept. 11-14, 1972, SAE Preprint 720775, 12 pp.

Until quite recently, it appeared that there was an effective lower limit on bore size in open-chamber diesel engines. This paper presents a technique for improving combustion in the small open-chamber diesel engine. Recent work at MIT on a 2-1/2 inch bore, short-stroke diesel engine has demonstrated that good efficiency can be obtained through a combination of a large-hole nozzle and the use of air swirl to prevent over penetration. There is some indication that good efficiency can be obtained over a wider operating range than standard diesel practice. A method of design analysis for this type of engine is presented, along with techniques for estimating the swirl and nozzle design parameters.

Williams, T. J., and N. D. Whitehouse. Investigation Into Some Aspects of the Computation of Diesel Engine Combustion. Proc. Inst. Mech. Engrs., v. 190 42/76, 1976, pp. 467-475.

The effect upon computational cost and accuracy of various assumptions in diesel combustion models was investigated by comparing the performance of a range of models and by comparing the results of computation with experimental results.

Witzky, J. E., and J. M. Clark, Jr. Stratification and Combustion in Reciprocating Engines. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Houston, Tex., May 12-16, 1968, ASME Preprint 68-DGP-4, 16 pp.

The major differences in the combustion characteristics of the Otto, diesel, and stratified charge cycles are discussed. For the Otto and diesel cycles, there is a definite fixed fuel requirement for each engine cycle. The Otto cycle utilizes thermally stable gasoline, and the diesel cycle requires a less stable and easily ignitible fuel. In contrast, the stratified charge engine displays a high degree of insensitivity to fuel quality and can be operated on most commonly available hydrocarbon fuels. It is concluded that engine cycles using stratification of fuel with a controlled point ignition source possess certain advantages, such as light weight due to a low maximum combustion pressure; high thermal efficiency that approaches the diesel cycle; a capability of high rotational speed because of lightweight reciprocating components; power output equalling the Otto cycle; compactness of the Otto cycle engine; and relative insensitivity to fuel properties.

D. Performance and Testing

Automotive Engineering. Automating Engine and Emission Testing. v. 81, No. 12, December 1973, pp. 25-33.

Computer control of engine testing is often a must now because of the wide range and large number of tests that are required. In addition to time savings and accuracy benefits, automated control increases testing flexibility, reduces downtime, and saves technical manpower. Here's a summary of five leading systems described at the recent International Symposium on Automation of Engine and Emission Testing held at Queen Mary College, University of London.

Braddock, J. N., and R. L. Bradow. Emissions Patterns of Diesel-Powered Passenger Cars. Presented at the Fuels and Lubricants Meeting, Houston, Tex., Jun 3-5, 1975, SAE Preprint 750682, 20 pp.

The gaseous and particulate emissions from a light-duty diesel powered passenger car were measured by a variety of chemical analysis techniques for three different fuels, typical No. 1 and No. 2 commercial diesel fuels and the Federal Register No. 2-D smoke test fuel. Hydrocarbon emissions were found to be inversely related to fuel molecular weight. The NO_2/NO ratio was found to be much higher than for gasoline engines approaching 0.3 at low load. Particulate emissions were approximately 0.3 grams/mile for all fuels and driving cycles tested. Sulfate emissions were high, approaching that of some catalyst cars. Sulfate emissions decreased with decreasing fuel sulfur and increased by a factor of two in highway driving over urban driving. The potential pollution problems with such cars are worthy of further study.

Braddock, J. N., and P. A. Gabele. Emission Patterns of Diesel-Powered Passenger Cars--Part II. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Feb. 28-March 4, 1977, SAE Preprint 770168, 16 pp.

An experimental program was conducted to characterize the gaseous and particulate emissions from a 1975 Peugeot 504D light duty diesel-powered vehicle. The vehicle was tested over the 1975 Federal Test Procedure, Highway Fuel Economy Test, and Sulfate Emissions Test driving cycles using four different fuels covering a fair range of composition, density, and sulfur content. In addition to fuel economy and regulated gaseous emission measurements of hydrocarbons, carbon monoxide, and oxides of nitrogen, emission measurements were also obtained for non-regulated pollutants including sulfur dioxide, sulfates, aldehydes, benzo[a]pyrene, carbonyl sulfide, hydrogen cyanide, nonreactive hydrocarbons, and particulate matter. The results are discussed in terms of emission trends due to either fuel type or driving cycle influence.

Brandl, F., I. Reverencic, W. Cartellieri, and J. C. Dent. Turbulent Air Flow in the Combustion Bowl of a D.I. Diesel Engine and Its Effect on Engine Performance. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790040, 32 pp.

In developing high speed swirl supported direct injection diesel engines it has been a general experience that different engine results (performance, smoke and emissions) may be obtained when using different intake port designs, although the swirl numbers (stationary flow test rig) of the different ports were identical. Therefore, an in-cylinder flow investigation under motoring conditions using hot wire anemometry was performed for three different inlet port designs having the same swirl number. Special emphasis was drawn on the engine design parameters being as close as possible to reality. Thus, the flow investigation and the engine tests were carried out at a typical compression ratio of 18:1 using a standard combustion bowl in the piston as well as produceable inlet ports. All flow measurements were carried out under motoring conditions covering the speed range from 1,100 to 2,400 rpm. By use of probes located on the piston, a two-dimensional flow field including turbulence parameters could be established throughout the whole cycle. In parallel, engine tests were carried out with the ports in question in order to obtain performance, smoke and gaseous emissions data with these ports. Hence, engine test data could be linked with in-cylinder flow data. As a result certain air motion characteristics within the bowl were found to be essential for the magnitude of smoke in the exhaust and for the efficiency of combustion (fuel economy).

Brands, M. C., J. R. Werner, J. L. Hoehne, and S. Kramer. Vehicle Testing of Cummins Turbocompound Diesel Engine. See IV.J.3.

Diesel & Gas Turbine Progress. Introduction of 9 1/8 inch Bore VHP Diesel Series. June 1976, pp. 28-30.

This paper introduces Waukesha new VHP Diesel Series. The series includes a V16, V12, and a straight six-cylinder engine. The horsepower ranges from 808 for the six to 2156 for the V16. What Waukesha did was to modify their 8 1/2 inch bore engine to a 8 1/4 inch bore turbocharged engine. The new engines showed less smoke and lower emissions along with improved fuel consumption. The article points out the changes made and compares the three engines for torque and fuel consumption.

Ghuman, A. S., M. A. Iwamuro, and H. G. Weber. Turbocharged Diesel Engine Simulation to Predict Steady-State and Transient Performance. Presented at the Energy Technol. Conf. and Exhibit, Houston, Tex., Sept. 18-22, 1977, ASME Preprint 77-DGP-5, 15 pp.

A mathematical model has been developed to predict both the steady-state performance and the transient response of a four-stroke turbocharged diesel engine. Using steady-state experimental data, performance maps for

the engine and the turbocharger were created. Predicted steady-state engine performance is compared to experimental data for free engine acceleration. The model is then used to evaluate the relative merits of various methods of improving engine transient response.

Groenewold, G. M., D. R. Welliver, and R. Kamo. Performance and Sociability of Comprex Supercharged Diesel Engine. Presented at the Energy Technol. Conf. and Exhibit, Houston, Tex., Sept 18-22, 1977, ASME Preprint 77-DGP-4, 13 pp.

Three types of Comprex energy exchangers designed and built by Brown Boveri Company were tested for motor vehicle application; namely, (a) standard unit, (b) low emission unit, and (c) high performance unit. All units were tested on a six-cylinder high-speed truck diesel engine. The effect of exhaust manifold sizes, inlet-exhaust restrictions, Comprex engine speed ratios, exhaust gas recirculation, and silencers were determined on engine performance and sociability.

Joy, R. D. Air Flow Measurement for Engine Control. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760018, 6 pp.

A search for improved sensors to measure and control engine parameters has grown from an effort to improve the fuel economy and to lower emissions output of automobile engines. One necessary requirement is the accurate measure of engine intake air. If this can be achieved, then the control system designer will be able to determine the correct amount of fuel to be injected for accomplishment of a desired operation.

Khan, M. S., and P. J. Langdon. The Role of the Computer in Turbocharger Design Development and Testing. See IB-2.

Marshall, W. F., and R. D. Fleming. Diesel Emissions Reinventoried. BuMines RI 7530, July 1971, 24 pp.

This report describes exhaust-emission data from 10 diesel engines: six 4-cycle, direct-injection, naturally aspirated engines; two 4-cycle, direct-injection turbocharged engines; one 4-cycle, precombustion-chamber, turbocharged engine; and one 2-cycle, direct-injection engine. These engines were tested over a 3-year period (1968-70). Lowest emissions were obtained with a precombustion-chamber engine. Emissions from the 2-cycle, direct-injection engine fell within the range of emission rates for the 4-cycle, naturally aspirated, direct-injection engines. Excluding the precombustion-chamber engine and excepting one of the 4-cycle, naturally aspirated engines, carbon monoxide emission rates were about the same for all engines tested. Test data on smoke, odor, and emissions of hydrocarbons, oxides of nitrogen, carbon monoxide, and aldehydes are given.

Monaghan, M. L., C. C. French, and R. G. Freese. A Study of the Diesel as a Light-Duty Power Plant. See IA.

Pilkington, R., T. Kelly, and H. Wimette. Guidelines for Quality Assurance Programs for Mobile Source Emissions Measurement Systems--Phase II. Heavy Duty Diesel Engines--Test Procedures. Olson Lab., Inc., Contract No. 68-02-1740, June 1975, 185 pp.; NTIS PB-251 333.

Test procedures for Heavy-Duty Diesel Engines Mobile Source Emissions Measurement Systems are presented with the concept of a total quality assurance system. The test procedures are separated into nine distinct sections, covering the topics on quality control, quality assurance, quantitative analysis, gas analysis, exhaust emissions, compliance testing and air pollution. The procedures are presented in document control format and give the detailed test procedures with quality assurance provisions for each part of the total testing system.

Pilkington, R., T. Kelly, and H. Wimette. Guidelines for Quality Assurance Programs for Mobile Source Emissions Measurement Systems: Phase III. Light-Duty-Diesel-Powered Vehicles--Quality Assurance Guidelines. Olson Lab., Inc., Contract No. 68-02-1740, June 1975, 24 pp.; NITS PB-251 562.

Quality Assurance guidelines for Light Duty Diesel-Powered Mobile Source Emissions Measurement Systems are presented with the concept of a total Quality Assurance System. The guidelines apply to Quality Assurance principles and techniques in the areas of procurement, standards and calibration, test quality control, data validation and corrective action. Model Quality Management Procedures are presented to describe the relationships and responsibilities of the various organizational elements in accomplishing the quality functions. This volume is a supplement to EPA-650/4-75-024-a, Guidelines for QA Programs for Mobile Source Emissions Measurement Systems, Phase I, Light Duty Gasoline-Powered Vehicles--QA Guidelines.

Ritchie, P. J. S., and K. C. Barnes-Moss. The Design and Development of a Heavy-Duty, Off-Highway Diesel Engine Family. Part 2--Component Testing and Engine Development. Presented at the Off-Highway Vehicle Meeting & Exhibition, MECCA, Milwaukee, Wisc., Sept. 12-15, 1977, SAE Preprint 770775, pp. 21-38.

A family of 3, 4, and 6-cylinder diesel engines with na and tc options was designed for use in a range of off-highway vehicles. Special requirements included robust construction, maximum reliability, a hydraulic pto up to a maximum equivalent to the power of the 4-cylinder na engine and low noise levels. Reference is made to the engine design,component rig testing and subsequent engine development. The engine concept and design are described in detail in part 1 and the engine performance development together with the use of models, rigs and component tests in part 2.

Society of Automotive Engineers, Inc. Engine Test Code--Spark Ignition and Diesel. SAE Handbook, 1978, SAE J816b, pp. 24.04-24.13.

The purpose of this code is to provide a standard procedure covering laboratory dynamometer test methods for determining performance characteristics of diesel and spark ignition engines. It is applicable to four-stroke and two-stroke cycle diesel engines, naturally aspirated, mechanically supercharged or turbocharged, with or without charge air cooling. It is also applicable to all types of spark ignition engines except turbocharged spark ignition engines on which definitive power correction data are lacking. The code is composed of five sections which include definitions of terminology, test equipment requirements, test procedures, computations, and a section on presentation of results.

Society of Automotive Engineers, Inc. Engine Rating Code-Diesel. SAE Handbook, 1978, SAE J270, pp. 24.18-24.24.

This code specified the conditions of testing and engine configuration which must be satisfied in order to qualify for the designation "SAE net" horsepower or "SAE gross" horsepower or in any way to indicate power capability conforming to SAE standards or requirements. It is applicable to all 4-stroke cycle and 2-stroke cycle diesel engines, naturally aspirated, mechanically supercharged or turbocharged. This code is not intended as a complete laboratory test manual or for the derating of engines for altitude.

Society of Automotive Engineers, Inc. Measurement of Air Flow of Diesel Engines. SAE Handbook, 1978, SAE J244, pp. 25.06-25.16.

The SAE Recommended Practice is presented to provide the necessary information, procedure, and technique for the measurement and calculation of the air and exhaust gas mass flow rates of diesel engines. The recommendations have been limited to three metering systems and the associated equipment required to measure diesel engine gas flows at steady-state operating conditions. Accuracy goals are established, and the procedures and equipment are proposed as required to obtain desired measurement accuracy.

Springer, K. J., and R. C. Stahman. Emissions and Economy of Four Diesel Cars. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750332, 20 pp.

Four diesel-powered passenger cars were subjected to a wide variety of emission and economy evaluations, and the results are presented in this paper. The four production cars included a 1972 Mercedes-Benz 220D, a 1973 Peugeot 504D, an Opel Redord 2100D, and a Nissan diesel-powered Datsun. Tailpipe emissions were measured by the 1975 Light Duty Federal Test Procedure for gaseous emissions, fuel economy (carbon balance and gravimetric) and smoke. Smoke and gaseous emissions were also measured by chassis dynamometer versions of the 1974 Federal heavy-duty procedures.

Odor and related instrumental-chemical measurements were made under seven steady-state and three transient conditions. Odor was measured by a trained panel and the analytical system developed by A. D. Little, Inc., under CRC contract. Noise measurements were taken during SAE driveby and a variety of interior-exterior conditions. The results are compared by category to each other, Federal limits, and to test results obtained by EPA laboratories.

Springer, K. J., and R. C. Stahman. Unregulated Emissions From Diesels Used in Trucks and Buses. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770258, 28 pp.

A wide variety of exhaust emissions is reported for three diesel engines typically used in heavy-duty intercity truck and intracity bus operation. Particulate, odor, sulfate, sulfur dioxide, and selected non-reactive hydrocarbons were measured in addition to the regulated pollutants from Detroit Diesel 6V-71 and 8V-71TA engines and a turbocharged Cummins 855 cubic inch research engines. The 855-TC engine was run in standard and a variable injection timing configuration, while the 6V-71 city bus engine was run with two types of injector designs. Emission rates are summarized in terms of grams per unit of fuel consumed and per unit of power output. The data allow direct comparison between engines and engine configurations, as well as a function of engine speed and load condition.

Tholen, P., and I. Killmann. Investigations on Highly Turbocharged Air-Cooled Diesel Engines. Presented at the Energy Technol. Conf. and Exhibit, Houston, Tex., Sept. 18-22, 1977, ASME Preprint 77-DGP-11, 13 pp.

A higher degree of turbocharging commonly implies higher mechanical and thermal load and disadvantages in starting, low load operation and acceleration response, thus affecting driveability. Possible improvements are discussed with a particular view to air-cooled engines. Making allowance for predetermined load limits, the influence of a decreased compression ratio on power and specific fuel consumption is shown as well as the effects of parameters like air/fuel ratio, charge air pressure and temperature. Methods are explained for heating the combustion air to improve the starting and part load characteristics and to reduce the hydrocarbon emissions. For the purpose of improving driveability, two variations of conventional turbocharging are considered: In the "Register" arrangement of turbocharging the commonly used turbocharger is replaced by two or more smaller units in parallel. In the "Two stage" arrangement the turbochargers are connected in series. The benefits of both systems include a favorable torque curve over a wide speed range and a fast acceleration response.

Wallace, W. B. The Development and Operational Experience of a Range of High Output Medium-Speed Diesel Engines Burning Residual Fuels. Presented at the Diesel & Gas Engine Power Conf. and Exhibit, St. Louis, Mo., April 16-20, 1972, ASME Preprint 72-DGP-5, 16 pp.

This paper describes the devlopment work carried out on a range of high output medium-speed diesel engines to enable them to burn residual fuels. Laboratory tests on exhaust valves are described and the production arrangement utilizing a water cooled seat exhaust valve cage is shown. The methods used to achieve adequate air flow, and hence limit the exhaust gas temperatures are enumerated. Field problems, which were experienced with the first few production engines, are discussed and the solutions which were adopted are given.

Watson, N., and M. Kamel. Thermodynamic Efficiency Evaluation of an Indirect Injection Diesel Engine. Presented at the Cong. and Exposition Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790039, 16 pp.

The lower efficiency of the indirect-injection diesel engine, with respect to the direct injection type, is due to additional heat transfer from the combustion chamber, gas pumping between chambers, later injection timing and a different burning rate schedule. The paper describes a project to isolate and quantify these reasons for low efficiencies, using a mathematical model, supported by experimental verification. The model is based on a two-zone system (main and pre-chamber), with component models for heat transfer, gas flow through the passage, etc. Experimentally derived heat release schedules in main and pre-chamber are used. It is shown that for a 0.1 m bore engine, with a Ricardo Comet Vb pre-chamber, the different burning rate schedule is the major contribution to the difference in efficiency, with injection timing and gas pumping being the least significant.

Winterbone, D. E., R. S. Benson, A. G. Mortimer, P. Kenyon, and A. Stotter. Transient Response of Turbocharged Diesel Engines. Presented at the Internat. Autmotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich. Feb. 28-March 4, 1977, SAE Preprint 770122, 28 pp.

The problem of highly rated turbocharged diesel engines operating under transient load conditions is now well known, and is due to the inability of the turbocharger to supply sufficient air for good combustion. In Part 1, two methods are discussed for reducing turbocharger lag-air injection onto the compressor rotor and oil injection onto a small pelton wheel mounted on the turbocharger shaft. Results are given showing the benefit of fitting these devices to an engine on a test bed. Engine response is improved in all respects particularly smoke and overall response time. In Part 2, a simulation study of a turbocharged diesel engine installed in a 32 ton truck is presented to investigate the engine performance during load and speed changes. It is shown that by injecting compressed air on to the turbocharger compressor rotor tip, smoke emissions from the engine during load changes are reduced. The size of air compressor and receiver required for air injection is the same order as for a conventional truck air braking system. Some preliminary engine tests on a computer-controlled test bed confirm the simulation modelling and results.

E. Comparison With Spark Ignition Engines

Diesel Equipment Superintendent. Gas versus Diesel in Mid-Range Power: The IHC Approach Covers Both Entries. April 1975, pp. 30-32.

This article compares the specifications of International Harvester's new series of gas and diesel engines. The author explains the advantages of the new series in terms of improvements of cooling, lubrication, ignition, and combustion. The author also explains some unique features of the new engines.

Monaghan, M. L., and J. J. McFadden. A Light Duty Diesel for America? Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750330, 11 pp.

This paper describes a study which was carried out to determine the feasibility of the diesel as a light duty power plant for American use. As a result of a literature survey and a specific configuration study, nine 96kW diesel power plants were examined in detail. Further examination of the diesel power plants indicated that only the direct injection four-stroke configurations could meet the primary emission targets using current technology. It was concluded, however, that the diesel engine could provide a viable power plant for light duty vehicles and that considerable improvements in fuel consumption and overall running costs could be obtained.

F. Design and Development

Allsopp, L. E., and D. L. Jones. The Design and Development of Turbocharged 1 Litre per Cylinder 4 and 6 Cylinder Air Cooled Diesel Engines. Presented at the Energy Technol. Conf. and Exhibit, Houston, Tex., Sept. 18-22, 1977, ASME Preprint 77-DGP-9, 9 pp.

This paper discusses the design and development of a range of four- and six-cylinder turbocharged air-cooled diesel engines to complement the already established four- and six-cylinder naturally aspirated air-cooled engines in the Dorman range. It highlights the high thermal efficiency of the engines, combined with the minimum number of alterations from the naturally aspirated engines, thus making for high commonality of components. These new engines will prove ideal for operation in mobile and stationary equipment where maintenance is at a minimum.

Automotive Engineering. Back Pressure Valve Improves Diesel Combustion. v. 83, No. 1, January 1975, p. 27.

This article discusses the effect of regulating the exhaust back pressure on the diesel engine. By increasing the exhaust back pressure and restricting the exhaust flow, the combustion temperature is increased, therefore, improving starting and idling under light load conditions.

Automotive Engineering. Variable Camshaft Boosts Engine Efficiency. v. 81, No. 12, December 1973, pp. 11-13.

A new approach to optimizing inlet and exhaust valve operation under all engine conditions is the Associated Engineering Group Variable Camshaft. The article discusses the advantages of improved torque, power and a reduction of exhaust emissions. The author also discusses the design and operation of the camshaft.

Barnes-Moss, H. W. Engine Design for the Future. See IV.F.

Barnes-Moss, H. W., and A. R. Crouch. The Design and Development of a Heavy-Duty, Off-Highway Diesel Engine Family. Part 1--Engine Concept and Design. Presented at the Off-Highway Vehicle Meeting & Exhibition, MECCA, Milwaukee, Wisc., Sept. 12-15, 1977, SAE Preprint 770775, pp. 1-20.

A family of 3, 4, and 6-cylinder diesel engines with na and tc options was designed for use in a range of off-highway vehicles. Special requirements included robust construction, maximum reliability, a hydraulic pto up to a maximum equivalent to the power of the 4-cylinder na engine and low noise

levels. Reference is made to the engine design, component rig testing and subsequent engine development. The engine concept and design are described in detail in part 1 and the engine performance development together with the use of models, rigs and component tests in part 2.

Bryzik, W. Adiabatic Diesel Engine. Research/Development, January 1978, pp. 34-40.

The Adiabatic Diesel Engine concept is to insulate the diesel combustion chamber with high temperature material to allow "hot" operation near an adiabatic operating condition. With the use of insulating material less heat is lost, therefore, more heat is available to be converted into power. The result is an increase in thermal efficiency. This paper discusses the design and development of the ceramic piston crown. In order to test the piston, a single cylinder engine was used. The ceramic material was studied for cracks and voids using x-ray radiography and ultrasonics. The paper also studies the stresses of different ceramic materials so a correct choice can be made.

Chalpin, E. S., R. E. Anderson, J. J. Shore, J. L. Smith, D. M. Jassowski, and R. A. Hewitt. Research in Advanced Power Systems for Mining Health and Safety. Aerojet Liquid Rocket Co., BuMines Contract No. H0220004, July 20, 1972, Open File Report 40-72; NTIS PB 226 944/AS, 243 pp.

On August 25, 1971, the U.S. Bureau of Mines contracted with the Aerojet Liquid Rocket Company to perform an engineering research program to be completed on May 25, 1972. The program objective was to evaluate the advantages and disadvantages of the underground use of several power sources including but not limited to a closed cycle diesel, electric cable/motor, rechargeable battery/motor and exhausting diesel for mine shuttle cars, with emphasis on health and safety. This report, Research in Advanced Power Systems for Mining Health and Safety consists of four main parts: (1) Hazards and Safety Analysis of Mine Power Systems, (2) Evaluation of Closed Cycle Diesel Power System for Mine Applications, (3) Closed Cycle Diesel Power System Consumables Compatibility, and (4) Concluding Remarks and Recommendations. The hazards introduced to a mine by shuttle car power system failure modes were evaluated and reported. A "fault tree" analysis was generated for each power system and the probability of death or injury during an eight hour shift and for a week of operation (105 hours) were estimated. Advantages and disadvantages were also reported for each system studied. Aerojet's assessment, based on a "forced decisions analysis," of the four shuttle car power systems as to their relative health and safety is that the exhausting or open cycle diesel is preferred, followed by the closed cycle diesel, the electric cable/motor and the rechargeable battery/motor. The assessment was based on ten parameters pertinent to the health and safety aspects of shuttle cars. Drawing layouts of two typical mine shuttle cars incorporating closed cycle diesel powerplant concepts are included in this report. The performance parameters established for the two concepts are tabulated. A study was made of the logisitics involved in transportion and replenishing the consumables needed to operate a shuttle car equipped

with a closed cycle diesel. The closed cycle diesel powerplant consumables--oxygen, potassium hydroxide, and diesel fuel--were analyzed as to their compatibility with materials found normally in a gassy coal mine. Spill tests simulating inadvertent leakage of liquid oxygen in a coal mine were performed. A critical evaluation of existing oxygen sensitivity data and the relationship to the use of oxygen on a shuttle car in a coal mine environment is presented.

Daft, C. H. J. Instruments Used in the Development of Diesel Engines. Accuracy of Electronic Measurements in Internal Combustion Engine Development (A Symposium arranged by the Internal Combustion Engines Group, Jan 20-21, 1966). The Inst. of Mech. Engs., London, Proceedings 1965-66, v. 180, pt. 3G, pp. 33-42.

An account is presented of some experiences of the various techniques and instruments used in the development of diesel engines. The measurement of mass fuel consumption by electronic methods to reduce testing time is detailed, together with a discussion on the elimination of the consequent inaccuracy. The accuracy of single-cycle techniques and the point-by-point method for dynamic pressure measurements are considered together with frequency-modulated techniques, direct current techniques, oscilloscopes, and galvanometer recorders. Details of the response time and repeatability of fast-response thermocouples for gas temperature measurements are discussed. The use of digital equipment such as voltmeters for strain and counters for speed and flow measurement is also described.

Diesel & Gas Turbine Progress. Combined Charging. March 1979, p. 16.

A combined charging system was adapted to a Saurer D 4KT engine. The system utilizes the resonance of the exhaust in combination with the turbocharger. The result is increased volumetric efficiency in the lower speed range and the quantity of scavenging air increases at higher engine speeds over the resonance speed.

Fraenkle, G., and H. O. Hardenberg. New Methods for Reducing Visible Emissions of Diesel Engines. See IV.I.

Hill, S. H. Automotive Diesel Technology Program--Final Report, June 1975-April 1977. U.S. Department of Energy, Division of Transportation Energy Conservation, Contract No. EY-76-C-03-1099, August 1977, Preprint SAN/1099, 122 pp.

The Diesel Technology Program was conducted during the June 1975 through April 1977 period. The program philosophy was to design and develop a diesel engine concept to meet the ERDA specification for a 3,000 pound car, and to demonstrate with existing hardware, that the technology of the concept engine could meet the specification goals. The program was structured into two phases: Phase I--Design Concept and Demonstration; Phase II--Applied Component Technology. Phase I was completed during this contract and included two significant achievements: 1) the preliminary design was finalized for a lightweight automotive diesel that can meet ERDA specification goals; 2) it was demonstrated that technology included in the concept design can meet the emission and fuel economy goals of .41 HC/3.4 CO/.4 NO_x and 25 miles per gallon on the Federal Urban Driving Cycle. Phase II was intended to apply the technology demonstrated in Phase I to component hardware. This phase of the program was initiated in June 1976, but was terminated at the completion of Phase I (December 1976). The major conclusions reached during this program are that a variable compression ratio (VCR) swirl chamber diesel with variable injection timing and exhaust gas recirculation (EGR) can: 1) achieve emissions of .41 HC/3.4 CO/.40 NO_x; 2) have fuel economy 55 pct better (mpg) than comparable gasoline engines; 3) have an early introduction into production over present gasoline engine lines; 4) have a broad fuel tolerance (unleaded gasoline was run; and 5) be smaller in size and comparable in weight to existing gasoline engines.

Hughes, D. W., J. R. Goulburn, N. R. Beale, and D. Hodgetts. Engine Induction Developments--Economic and Reduced Exhaust Emissions. Presented at the Ordinary Meeting of the Institution, Birmingham Chamber of Commerce Club, Edgbaston, Birmingham, Jan. 8, 1976, Inst. Mech. Engs. Proceedings 1976, v. 190 1/76, 21 pp.

This paper describes a simple system of controlling exhaust emissions from gasoline engined vehicles, using a coolant-heated fuel vaporizer in the inlet system. The object of complete vaporization of the fuel is to create a homogeneous inlet charge, giving improved cylinder-to-cylinder distribution and permitting operation with very lean mixtures. This leads to low exhaust emissions of carbon monoxide, hydrocarbons and nitric oxides. The effects of vaporization on the lean limit of operation, exhaust emissions, power output, fuel consumption and optimum spark ignition timing have been investigated and are discussed in the paper. Results of tests on a 1.6 litre car are also presented. It was found that exhaust emissions were effectively controlled while vehicle driveability remained acceptable. Engine power was reduced by 25 - 30 pct, although fuel consumption was not increased.

The Institute of Mechanical Engineers. Power Plants and Future Fuels: M.A.N. Activities in Power Plants for the Future. London and New York, 1976, pp. 179-193.

The paper describes the current development of vehicle power plants by M.A.N. and shows the problems involved and results obtained so far. An assessment of the characteristics of the various power plants is given in a summary which can be used as a basis for objective evaluation.

Izumi, S., T. Yano, I. Omotehara, and T. Kushiyama. Matching of Exhaust Turbochargers to Two-Cycle Diesel Engines. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Houston, Tex., May 12-16, 1968, ASME Preprint 68-DGP-9, 14 pp.

The mean effective pressure of marine diesel engines is apparently increasing. Along with the improvement in the technique of matching turbochargers to diesel engines, this paper describes the step-by-step calculation method of engine performance using the digital computer in considering the characteristics of the exhaust turbocharger. The calculated results indicate the effects of turbine nozzle area, heat release rate of gas in cylinder, and so forth, on engine performance. This calculation method has been verified by testing it on UE-type engines provided with non water-cooled MET-type turbochargers and by applying it in practice.

Low, S. C., R. S. Benson, and D. E. Winterbone. Computer Aided Design Package for Diesel Engine Manifold System. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790277, 20 pp.

An interactive computer program for predicting the performance of a total engine system is described. The facilities include the basic design of the valve time-area diagrams, starting from various cam profiles, wave action effects in inlet and exhaust manifolds and turbocharger matching. The program is accessed via visual display units (VDUs) and its interactive nature takes many activities from the realm of the research department into that of the design department. The results obtained from the program are validated by comparison with a well-known more sophisticated wave action program.

Martin, B., and G. Wright. High Output Diesel Engine Design Philosophy. See I.A.

Matsumura, T. Development of a Turbocharged Two-Cycle Air Cooled Diesel Engine. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wisc., Sept. 11-14, 1972, SAE Preprint 720783, 12 pp.

This paper describes the development of the turbocharged 2-cycle air-cooled diesel engine with 4, 6, and 10-cylinder engine series featuring unique designs in their respective component parts. Development was initially begun on a single-cylinder engine, on which tests were carried out. Following that, full-scale engine experimentation was carried out using a 4-cylinder prototype engine, after which successive tests were made on each cylinder series. The turbocharged 2-cycle air-cooled diesel engine is especially noteworthy for such features of its construction as its mechanically driven exhaust turbocharger, cooling methods for cylinder, cylinder head, and piston.

Oblander, K., M. Fortnagel, H. J. Feucht, and U. Conrad. The Turbocharged Five-Cylinder Diesel Engine for the Mercedes-Benz 300 SD. Presented at the Passenger Car Meeting, Troy Hilton, Troy, Mich., June 5-9, 1978, SAE Preprint 780633, 32 pp.

The engineering target was a suitable diesel engine for the largest available luxury sedan. After consideration of various alternatives, including the design of a completely new 6-cylinder engine, it was decided to equip the existing naturally aspirated 5-cylinder engine presently installed in the smaller sedan and the coupe with a turbocharger. Development time and cost as well as investment could thus be minimized. This paper describes in detail the complete engine and particularly the modifications required to cope with the higher thermal and mechanical loads, the installation and adaptation of the turbocharger, the adaptation of the fuel injection pump, and the refinements of the combustion process. This work, together with suitable turbocharger characteristics due to waste-gate control on the turbine side, resulted in an attractive power plant with very good stationary and transient operational behavior. Finally, engine and vehicle performance data including noise, exhaust emissions, and fuel economy are given.

Peters, W. W. Evolution of the General Electric 7FDL Locomotive Diesel Engine. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, St. Louis, Mo., April 16-20, 1972, ASME Preprint 72-DGP-7, 19 pp.

The author traces the design sequence and operational experience in the evolution of the General Electric 9-inch (228 mm) X 10.5 inch (266 mm), four-stroke, vee-form locomotive from 200 psi (14.1 kg/sq cm) bmep to 282 psi (19.9 kg/sq cm) bmep. Mechanical modifications required to improve reliability and to permit uprating are described and loading levels charted. Limitations encountered due to thermal loading and corrective measures taken are described. Component operating conditions are shown for original and later designs.

Roberts, D. I. 3-D Interactive Graphics Assist Diesel Engine Design. Mech. Eng., March 1978, pp. 40-45.

Here's how interactive graphics is applied to mechanical drafting and design in producing all drawings for a complete new diesel engine model. In continuous use since November 1974, the system described has provided reductions in drawing and drawing change response time, standardization of drafting symbols, and generation of a true three-dimensional data base. The drawings have also been used for numerical controlled machining of parts and finite element/finite difference stress and heat analysis. Future uses include basic engine design, layout, and installation and assembly drawings.

Scott, W. M. Recent Developments in Diesel Engine Research at the Ricardo Laboratories. Entropie, v. 8, No. 48, November-December 1972, pp. 69-79.

The diesel engine as a source of power covers a wide range of applications from the very large marine engines down to relatively small private car engines in competition with the gasoline engine. In the large marine and industrial engines the aims of research and development are towards higher ratings bringing the attendant combustion and thermal loading problems. In automotive sizes, the additional restraints of gaseous and noise emission regulations are tending to modify development trends in attempts to meet the legislative limits with minimum loss of performance. Current activities aimed at overcoming all these problems are described in this article with test results showing the effectiveness of measures taken. It is considered unlikely that the sphere of application of the diesel engine will be reduced as a result of these restraints within the forseeable future.

Setright, L. J. K. Some Unusual Engines. Mech. Eng. Pub. Ltd. for the Inst. Mech. Engrs., London, 1975, 138 pp.

This book is not only about old unusual engines but also about new ones, not only of engines that might have been but also of engines that might well be. It takes into account the pattern of history which is recognizable as dividing engines into classes that are unusual in some particular respect. There are those that are unusual in format, others unusual in construction; many are defiant of convention in their valve gear, some resolute in their divergence from normal means of translating power; there is an interesting class of engines whose designers have despaired of nature's inefficiency in charging and scavenging, relying instead on original and unnatural means of accomplishing these ends. There are a few engines that might be fitted into more than one of these categories, the Napier Deltic providing a good example--as it does of an unusual engine that is far from being a commercial failure. Several other engines included in the review proved quite conclusively that being unusual is no bar to being used.

Society of Automotive Engineers, Inc. Engineering Know-How in Engine Design Part 23--Engine Design to Meet New Social Obligations: Emission Formation Characteristics of the Diesel Combustion Process and Estimated Future Development Trends. August 1975, SAE Special Publications 396, pp. 15-23.

A review of the fuel consumption per capita and population trends is presented which suggests that any significant relaxation in diesel emission goals is undesirable. An analysis is then made of the chemical, thermodynamic and fluid dynamic factors which control the formation of nitric oxide, unburned hydrocarbon, carbon monoxide and exhaust smoke in diesel combustion. Based on this analysis it is hypothesized that a reduction in the quantity of fuel burned in diffusion flames and increased mixing rates of air and fuel vapor will significantly lower emission levels. It is suggested, therefore, that future trends in direct injection combustion development will need to incorporate increased fuel atomization and toroidal air motion to achieve the required favorable combustion conditions. A comparison is made of commercially acceptable, state-of-the-art diesel engines developed to meet low emission levels to allow an estimate of the potential improvements from combustion development. The comparison suggests that intense mixing and good fuel atomization, characteristic of the prechamber process, are the keys to lower emissions and can yield up to 40 pct reductions in HC + NO_2 levels for the direct injection diesel combustion process. A forecast of future engine requirements is made and indicates that hybrid engines combining the diesel and Rankine cycles are feasible for heavy duty engine applications. The combination of the highly efficient diesel cycle and a reciprocating steam engine using diesel engine exhaust energy is a potentially efficient, low emission, socially acceptable prime mover.

Sumner, J. Clean and Quiet Diesel Runs on Swinging Beams. The Engineer, Jan. 27, 1977, pp. 30-31.

The Armstrong Whitworth Co. developed a new two stroke, opposed-piston diesel engine that uses a swing beam and a half throw crankshaft. The advantages of the engine are its quiet operation and low exhaust emissions. The article explains the principles of operation of the engine along with why the emissions are low.

Thoma, F. The Fuel Delivery Indicator (FDI), a Useful Device for the Development of Diesel Engines. Presented at the Diesel & Gas Engine Power Conf. and Exhibit, Houston, Tex., April 28-May 2, 1974, ASME Preprint 74-DGP-5, 7 pp.

The fuel delivery indicator (FDI) is a device which is measuring at each revolution of the injection pump during the injection the volume leaving the injector. Construction and operation are described. The FDI can be applicated for measuring the total fuel delivery, the volume injected until a certain point of injection, the volume of pre- and secondary injection, fuel delivery fluctuations and for registration of fuel delivery characteristics. The applications are described.

Wallace, F. J., and G. Winkler. Very High Ouput Diesel Engines--A Critical Comparison of Two Stage Turbocharged, Hyperbar, and Differential Compound Engines. Presented at the Off-Highway Vehicle Meeting and Exhibition, MECCA, Milwaukee, Wisc., Sept. 12-15, 1977, SAE Preprint 770756, 20 pp.

It has come to the attention of the authors, that to achieve the objective of highest output in diesel engines for highway and off-highway applications, it is necessary to put forth suggestions dealing with combinations of specially adapted engines with their associated turbomachinery to reach this goal of high engine output. Three alternative solutions for higher output diesel engines and their specific advantages and disadvantages are discussed in this paper.

II. FUELS AND LUBRICANTS

A. Chemistry, specifications, properties of fuels

American Society for Testing and Materials. 1974 Annual Book of ASTM Standards Petroleum Products and Lubricants (1): Standard Classification of Diesel Fuel Oils. Philadelphia, Pa., 1973, Part 17, pp. 420-429.

This classification covers three grades of diesel fuel oils suitable for various types of diesel engines, they are No. 1, No.2, and No. 4 diesel fuel. The classification also prescribes the desired properties of the diesel fuel.

Bailey, B. K. Emergency Fuels Composition and Impact. Phase II: Formulation and Screening--Diesel Emergency Fuels, Executive Summary (Proceedings of the U.S. Dept. of Energy Automotive Technol. Development Contractor Coordination Meeting, Dearborn, Mich., Oct. 23-25, 1979). Contract No. EM-78-C-01-4269, 33 pp.

A variety of two-component diesel emergency fuels formulations are evaluated by means of blend property analyses, bench tests and single and multi-cylinder engine tests. API gravity, cetane number, and accelerated oxidation stability are presented as functions of blend concentration. Bench tests of certain blend combinations include measurements of friction and wear character and thermal stability. Relative engine performance curves are presented as percent of neat baseline performance.

Baines, T. M., J. H. Somers, and K. H. Hellman. Effects of Fuel Variables on Diesel Emissions. J. of the Air Pollution Control Association. v. 32, No. 8, August 1982, pp. 810-813.

This paper summarizes recent data obtained by EPA on identification and quantification of different emissions (i.e. characterization) from a variety of diesel engines. Extensive work has been done comparing emissions from some light duty diesel and gasoline passenger cars. The work on the diesel vehicles was expanded to include tests with five different diesel fuels to determine how fuel composition affects emissions. This work showed that use of a poorer quality fuel frequently made emissions worse. EPA has also tested a heavy duty Volvo diesel bus engine designed to run on methanol and diesel fuel, each injected through its own injection system. The use of the dual fuel resulted in a reduction in particulates and NO_x but an increase in HC and CO compared to a baseline Volvo diesel engine running on pure diesel fuel. Finally, some Ames bioassay tests have been performed on samples from the diesel passenger cars operated on various fuels and blends. An increase in Ames test response (mutagenicity) was seen when the higher aromatic blend was used and also when a commercial cetane improver was used. Samples from the Volvo diesel bus engine fueled with methanol and diesel fuel showed that use of a catalyst increased the Ames response.

Barry, E. G., F. J. Hills, and L. J. McCabe. Diesel Fuel--Availability, Trends and Performance. Presented at the Fuels and Lubricants Meeting, Hyatt Regency, Houston, Tex., Oct. 1-4, 1979, SAE Preprint 790921, 8 pp.

There is projected to be an increasing demand for the middle distillate (350-640°F) boiling range portion of the crude oil barrel. This is due to increased vehicle dieselization and increased demand for kerosine type jet fuel. To improve jet fuel supply, specifications have been relaxed permitting the use of diesel fuel boiling range material. Since no similar change has been made in diesel fuel specifications, its potential availability is reduced. Increases in the 90% recovery temperature to 680°F to improve diesel fuel supply in Europe have already been made. Similar changes should be made in the U.S. A review of the performance of fuels indicates that there should be no substantial adverse effects when these higher boiling fuels are used. This change could provide as much as 4-1/2% (on crude) more distillate.

Brandes, J. G. Diesel Fuel Specification and Smoke Suppressant Additive Evaluations. Presented at the Mid-Year Meeting, Detroit, Mich., May 18-22, 1970, SAE Preprint 700522, 12 pp.

There are numerous federal, military, and commercial diesel fuel specifications used by industry as guidelines for selection. Detroit Diesel Engine Div. divides the popular fuel specifications into four categories for the purpose of using terms and values of reference. These are CITE, jet-turbine, light, and heavy grade fuels. DDED manufactures engines to operate on fuels classified as grades 1-D and 2-D of ASTM D 975, and publishes a Fuel Oil Selection Chart in which fuels defined for specific service applications are indicated. Final boiling point, sulfur content, and cetane number limits are specified to assure fuel uniformity and satisfactory performance. The performance of barium containing smoke suppressant diesel fuel additives in dynamometer engines under sustained and cyclic operating conditions was investigated. The ash deposits obtained using additive treated fuel were relatively heavy compared to the levels obtained using untreated fuel.

Broering, L. C., and L. W. Holtman. Effect of Diesel Fuel Properties on Emissions and Performance. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wisc., Sept. 9-12, 1974, SAE Preprint 740692, 12 pp.

Tests were conducted with several production diesel engines and one prototype low-emission diesel engine to determine the effect of fuel properties on exhaust emissions and engine performance. Fuel cetane resulted in higher hydrocarbons and oxides of nitrogen and increased noise. Conversely, higher cetane fuels produced lower emissions and noise, and also improved engine starting characteristics. The degree of these effects was influenced by engine configuration. Although engine design changes can result in substantial emissions reduction, fuel properties can also influence achieveable levels.

Courtney, R. L., and H. K. Newhall. Automotive Fuels for the 1980s. SAE Preprint 790809. Society of Automotive Engrs., Inc., Engine Technology for the 1980s. Presented at the Twenty-Seventh Annual Milwaukee Lecture Series, Milwaukee, Wis., April 26, 1979, SAE Special Publictions 446, pp. 31-48.

This paper briefly reviews automotive transportation fuels and their important characteristics. Near-term demands for petroleum fuels are forecast, and certain compositional factors which may influence the availability of suitable fuels for future engines are listed. Engine design features which influence the fuel requirements of engines are surveyed.

Davidson, L. N., W. J. Lyman, D. Shooter, and J. R. Valentin. Technical Manual for the Analysis of Fuels. Arthur D. Little, Inc., Contract No. 68-02-2150, December 1977, 143 pp.; NTIS PB 279 196.

The manual is for use as a guide in research projects concerned with fuel combustion. Basically, it describes and discusses standard methods of sampling and analysis for a variety of hydrocarbon fuels. The analyses covered are those of prime concern to the combustion engineer; no attempt is made to cover all analyses that may be required in a complete environmental assessment of any fuel combustion process. For each fuel covered, the manual indicates the analyses that are likely to be required, the preferred method of analysis, and available sampling procedures. For each method of analysis listed (preferred plus alternates, in many cases), the manual summarizes the method, discusses its applicability, and describes its precision. The manual covers gaseous fuels, liquid petroleum fuels, waste lubricating oil, shale oil, coal liquids, methyl fuel, coal, coke, refuse-derived solid fuels, and peat. The appendices give: the availability of Standard Reference Materials for fuel-related analyses; laboratory directories; typical values (or ranges) of parameters specified for each fuel; and results of fuel analyses conducted by the contractor.

Goodger, E. M. Liquid Fuels for Transport. Prog. Energy Combust. Sci. v. 8, pp. 233-260.

Some controllable form of mechanical propulsion is virtually essential for the scheduled movements and large payloads of commercial transport, and for the speed and convenience of most leisure travel. Over the years, each branch of the transport sector has developed its individual combination of vehicle-engine-fuel, the fuel invariably being carried in the liquid phase in order to meet the constraints of storage and transfer in vehicular systems, and of vaporization and combustion in engines. Most liquid fuels for transport are derived from petroleum which, as a fossil fuel, must inevitably diminish, as foreshadowed recently by repeated price rises and occasional supply shortfalls. In addition to the conventional fuels adopted for transport purposes, therefore, this review also covers the alternatives that appear to offer potential for the future. Some related developments in engine combustors and fuel systems are included. The viewpoint is largely British, but specific references are made to American terminology and practice.

Hills, F. J., and C. G. Schleyerbach. Diesel Fuel Properties and Engine Performance. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770316, 16 pp.

It may be necessary to increase the percentage yield of diesel fuel from crude oil to meet demands if diesel powered passenger cars achieve increased sales penetration. To assess the performance properties of products that might be produced to meet this increased demand, tests were conducted with diesel fuels of varying 10 pct recovered point (365°-520°F), (185°-271YC), 95 pct recovered point (520°-750°F), (271°-399°C) and aromatics content 15-40 pct) in U.S. and European light- and heavy-duty engines. The effects on emissions, power and fuel consumption were relatively small indicating that fuels within the range tested provide satisfactory performance.

Hurn, R. W., and T. W. Chamberlain. Fuels and Emissions--Update and Outlook, 1974. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wis., Sept. 9-12, 1974, SAE Preprint 740694, 15 pp.

Profound change has been observed in automotive emissions since the late 1960's. This change is marked both in the amount and in the chemical make-up of the controlled emissions. In general, the trend toward decreased levels of the several categories of emissions is well known, but changes in the chemical character of the hydrocarbon component are less well recognized. The nature of these changes and implications for air pollution effects are discussed. As the absolute levels of emissions are reduced, small incremental changes become relatively more important. Such incremental changes are brought about by change in ambient temperature, and therefore the sensitivity of emission control systems to changes in ambient temperature takes on added significance. Data are presented to show that emissions control may deteriorate seriously at some temperatures at which

vehicles normally operate. Will emissions considerations force change in fuel usage, and if so, how are emissions affected? The question is examined both from the viewpoint of a switch from gasoline to other conventional fuels and from the viewpoint that gasoline composition may change. Moreover, with supplies of motor fuel from petroleum sources in long-term jeopardy, there is growing interest in the character of emissions to be expected in using alternative fuels. The more viable options for alternative fuels are identified, and emissions characteristics of these fuels are described.

Kane, E. D. Future Fuels and Lubricants. Presented at the Fuels and Lubricants Meeting, Baltimore, Md., Oct. 20-23, 1980, SAE Preprint 801342, 8 pp.

A rational scenario for likely fuels and lubricants trends over the next 20-25 years can be based on fairly precise knowledge of the technology that will be available. For the near term, increasing recognition of the constraints imposed by limited petroleum supplies, rising costs, and governmental regulations will result in efforts to maximize the efficient use of petroleum liquids as transportation fuels. These efforts will include optimization of the petroleum product mix, broadening of fuel specifications, greater use of fuel additives to provide acceptable fuel quality, and new lubricants including new chemical additives to improve overall vehicle fuel economy. Beyond 1990, synthetic fuels and advanced lubricants formulations will begin to make their contribution. Such inter-industry groups as the SAE Fuels and Lubricants Activity and the Coordinating Research Council will play increasingly important roles during this period of great change.

Lewis, A. Special Lubricants Solve Heat and Dust Problems. Rock Products, March 1976, pp. 80-82.

Conventional petroleum-based lubricants are limited by operating conditions due to exposure to dust and dirt. Solid lubricants, since they are dry, do not collect dust or dirt, therefore reducing machine wear. This paper discusses the characteristics of solid lubricants and also describes various applications where solid lubricants are used.

Losikov, B. V., K. N. Golovanov, and S. M. Livshits. Use of Fuel Additives to Reduce Diesel Exhaust Smoke. Chemistry and Technology of Fuels and Oils, No. 7-8, July-August 1970, pp. 634-638.

There are three types of exhaust smoke in diesel operating practice. There is white smoke which is emitted during cold starting, blue smoke due to lubricating oil reaching the combustion chambers and black smoke caused by carbon particles in the exhaust. The object of this report is to suppress the black smoke. The author first discusses the causes of black smoke and

how smoke intensity can be measured. He then looks at the effect of fuel cetane number on smoke intensity. He finally studies the effect of fuel additives on exhaust smoke, especially barium. He concludes that barium caused a significant reduction of smoke intensity.

Myers, P. S., and O. A. Uyehara. Fuel--Engine Research in Universities. SAE Preprint 680508. University of Wisc., 1968, SAE Special Pub. 340, 24 pp.

The reasons for conducting research in a university are presented and discussed. It is concluded that fuel-engine studies are compatible with these reasons and therefore are well suited for university research. Past studies in this field are summarized and unanswered questions and future topics suitable for university investigation are suggested. Included in the topics discussed are: instrumentation, thermodynamic description of working fluids, fuel vaporization and atomization, combustion, and instantaneous heat transfer and mass flow rates. The steps that need to be taken to ensure continuing university interest in fuel-engine studies are presented.

Ranney, M. W. Fuel Additives for Internal Combustion Engines: Recent Developments. Noyes Data Corporation, Park Ridge, N. J., 1978, 300 pp.

The descriptive information in this book is based on U.S. patents that deal with fuel additives for internal combustion engines. The processes detailed herein represent recent developments and date from January 1975. This book serves a double purpose in that it supplies detailed technical information and can be used as a guide to the U.S. patent literature in this field. By indicating all the information that is significant, and eliminating legal jargon and juristic phraseology, this book presents an advanced, technically oriented review of fuel additives for internal combustion engines as depicted in U.S. patents.

Schmidt, P. F. Fuel Oil Manual. Industrial Press, Inc., New York, 3rd ed., 1969, 263 pp.

This book covers all aspects of fuel oil. It has inductory chapters on the chemistry of petroleum, refining processes, and grades and types of fuel oil. It also explains all the different properties such as flash point, pour point, etc. The book also has chapters on fuel oil additives, blending of oils, and storage of fuel oil. The book consists of 26 chapters each on a different topic of fuel oil.

Shelton, E. M. Diesel Fuel Oils, 1977. U.S. Department of Energy, Report No. BERC/PPS-77/5, November 1977, 35 pp.

Properties of diesel fuels produced during 1977 were submitted for study and compilation under a cooperative agreement between the Department of Energy (DOE), Bartlesville Energy Research Center (BERC), Bartlesville, Oklahoma and the American Petroleum Institute (API). Tests of 215 samples of diesel fuel oils from 100 refineries throughout the country were made by 31 petroleum refining companies. The analyses of the fuels are listed in tables for four groups according to type of diesel fuel. Each group of analyses is subdivided into five tabulations according to five general regions of the country where the fuels are marketed. The regions, containing a total of 16 districts, are shown on a map in the report. A total of 13 laboratory tests are listed and arranged by geographic marketing districts in decreasing order of sales volumes. Charts are included showing trends of averages of certain properties for the four types of diesel fuels for the years 1960-1977. Summaries of the results of the 1977 survey, compared with similar data for 1976, are shown in tables 1 through 4 of the report.

Shelton, E. M. Diesel Fuel Oils, 1974. U.S. Department of the Interior, BuMines, Petroleum Products Survey, No. 87, November 1974, 33 pp.

In this survey 241 samples of diesel fuel are presented. The fuels were manufactured by 33 petroleum refining companies in 108 refineries, large and small, throughout the country. The data is divided into four groups according to type of diesel fuel, and each group is subdivided into five tabulations according to the geographic marketing distribution of the various fuels represented. Summaries of the results of the tests by type and by region are shown in tables, these are compared to 1973 data. Average values of selected properties are shown for the fuels represented, and minimum and maximum figures are given for all the tests indicated, where possible.

Society of Autmotive Engineers, Inc. Diesel Fuels. SAE Handbook, 1978, SAE J313b, pp. 13.22-13.25.

The ASTM has set up standard specifications for determining the grade of diesel fuel. The handbook explains the properties the fuel must meet to determine its grade of 1D, 2D, or 4D.

Society of Automotive Engineers, Inc. Energy and Transportation. February 1976, SAE Special Publications 406, 70 pp.

This special publication contains articles covering energy and transportation. By invitation, papers were prepared by people with extensive backgrounds in specific areas of interest. Six papers deal with the transportation energy needs of our nation. These papers covered passenger cars, heavy-duty trucks, aircraft, and other forms of transportation. Several of the papers delved into economic consideration and pointed out investment requirements associated with reducing our energy needs. The last six papers are on the availability of energy as petroleum and in alternate forms. The papers cover in considerable detail the investment requirements to meet our future energy needs.

Steere, D. E., and T. J. Nunn. Diesel Fuel Quality Trends in Canada. Presented at the Fuels and Lubricants Meeting, Hyatt Regency, Houston, Tex., Oct. 1-4, 1979, SAE Preprint 790922, 12 pp.

Diesel fuel is currently showing the most rapid growth rate of all petroleum fuel products and is projected to maintain this well into the 1980's. Middle distillates production in Canada has always been high because of heating oil requirements, resulting in a gasoline to middle distillate ratio fo 1:1. This ratio is expected to continue despite a decrese in the heating oil market because of the predicted increase in the diesel fuel market. In order to provide the volume needed for future diesel fuel demand, there will have to be a drop in initial boiling points, an increase in final boiling points as well as the use of more cracked stocks. Canada is also faced with the refining of synthetic crudes which currently represent about 10% of crude production. These produce middle distillates with low cetane numbers. In order to overcome the problems created by these changes, the authors see the increased use of cetane improver additives to raise the cetane number of the diesel pool and the use of flow improver additives to enable higher cloud distillates to be used. As diesel fuels are being blended closer to the minimum cetane requirements, there is a need for better techniques for the monitoring of cetane number.

Voorhies, A., Jr., L. R. Daniel, Jr., and L. Long. The Effect of Percent Hydrogen in Fuel on Smoke Emissions of a Compression-Ignition Engine. Transactions of the ASME, Journal of Eng. Power, v. 102, October 1980, pp. 842-846.

Six diesel fuels, varying in percent hydrogen from 12.36 to 14.38 pct and in cetane number from 37.5-55.5, were evaluated for pct opacity as a function of fuel-air ratio both at 800 and 1,000 rpm, in a Waukesha CFR diesel engine. In both cases, at a given fuel-air ratio, the smoke emissions (measured by pct opacity) decreased with increasing pct hydrogen in the fuel. In these studies, pct hydrogen was both a satisfactory and a unique parameter, since neither cetane number nor volatility of the various fuels could be correlated with smoke emissions. In these studies, pct hydrogen is apparently the essential index of diesel fuel quality for satisfactory smoke emissions.

B. Nonconventional Fuels

Automotive Engineering. Fuels for Transportation. v. 84, No. 1, January 1976, pp. 30-33.

In the United States we are using more oil than we are producing. In order to meet our demand, we have increased the amount of oil we import. In order to increase our production we must phase in crude oil substitutes such as shale, tar sands, or coal based liquids. The author of this article estimates the amount of energy available in the U.S. from oil, shale, coal, and tar sands. He looks at some of the problems and economics of converting these energy sources into usable fuels.

Baker, C. R. Efficiency and Economics of Large Scale Hydrogen Liquefaction. Presented at the National Aerospace Eng. and Manufacturing Meeting, Culver City, Los Angeles, Calif., Nov. 17-20, 1975, SAE Preprint 751094, 8 pp.

Liquid hydrogen is being considered as a substitute for conventional hydrocarbon-based fuels for future generations of commercial jet aircraft. Its acceptance will depend, in part, upon the technology and cost of liquefaction. The process and economic requirements for providing a sufficient quantity of liquid hydrogen to service a major airport are described. The design is supported by thermodynamic studies which determine the effect of process arrangement and operating parameters on the process efficiency and work of liquefaction.

Baker, Q. A., and J. O. Storment. Alternate Fuels for Medium-Speed Diesel Engines (AFFMSDE) Project--Off Specification Diesel Fuels, Simulated Coal-Derived Fuel and Methanol. Southwest Research Institute (San Antonio, Tex.), First Phase Report, January 1981, 152 pp.; NTIS PB 81-24256 2.

This report encompasses the first year of research activity of a multi-year research, development, and demonstration effort to investigate the use of alternate fuels in medium-speed diesel engines. Tests were performed on a laboratory two-cylinder medium-speed diesel engine in an attempt to define its ability to operate on alternate fuels and to define the performance and emission characteristics of the engine under such operation. Diesel fuel properties were systematically varied below Number Two specification to determine the fuel property limits of the test engine. Two non-diesel fuels, methanol and a simulated coal-derived fuel, were successfully tested in a dual-fuel mode using pilot diesel fuel to initiate combustion. The test engine demonstrated that the medium-speed diesel is a very fuel tolerant engine capable of operating on a wide range of fuel properties and fuel types.

Bertodo, R. Energy Economics of Alternate Fuels. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790430, 16 pp.

The energy crisis of the mid-1970's released a frantic search for alternative fuels. The present paper reviews the studies undertaken by the author's company and outlines experience with broad specification fuels, vegetable oils and alcohols. Tests were undertaken mainly with the diesel engine and its derivatives in mind. It is concluded that, in the medium term, the most effective engine/fuel combination is an injected stratified charge engine burning "wide-cut" fuel oils. Such oil could be obtained by a modification to present natural crude refining practices, or from shale and tar sand distillation, or by coal gasification and hydrogenation, or from oil bearing vegetation. Unfortunately, the energy scene is currently confused by the conflict between short term economic gain and long term conservation needs. As a result, attention is being focused on gasoline-like alternatives, notably methyl and ethyl alcohol. As a consequence it is thought that carburetted stratified charge engines, burning alcohol-based or alcohol extended fuels, are likely to become dominant in the mobile prime mover field. It is to be hoped that progressive depletion of natural crudes will promote the gradual introduction of a more efficient combination based on an injected stratified charge engine. In any case, eventual shortages of natural fuels will have far reaching implications on the choice of materials for both engine and vehicle manufacture. Government legislation and taxation policies will also be affected.

Billings, R. E. Survey of Hydrogen Energy Application Projects. Billings Energy Corp., Provo, Utah, 1976, Preprint 76009, 6 pp.

Contemporary U.S. hydrogen application research projects are reviewed. Specific emphasis is placed on aircraft, industrial and domestic applications, electrical generation and storage, vehicles, and farms. Although the study does not attempt to evaluate the techanical feasibility or status of individual projects, some prognostications are made as to future hydrogen energy applications.

Bowman, C. T., and J. Birkeland. Alternative Hydrocarbon Fuels: Combustion and Chemical Kinetics. American Institute of Aeronautics and Astronautics, Progress in Astronautics and Aeronautics, v. 62, 1978, 465 pp.

This publication is based on papers presented at the Project SQUID Workshop on Alternative Hydrocarbon Fuels for Engines--Combustion and Kinetics held at Loyola College Conference Center, Columbia, Md., Sept. 7-9, 1977. Chapter topics include: Alternative Fuel Availability Critical Processes in Combustion; Pyrolysis and Oxidation Kinetics; and Pollutant Emissions Considerations. The results of panel discussions on alternative fuel policy and technology are also summarized.

Brewer, G. D. Some Environmental and Safety Aspects of Using Hydrogen as a Fuel. Internat. J. Hydrogen Energy, v. 3, 1978, pp. 461-474.

At present, less than 7% of the hydrogen produced in the U.S. is delivered to users as "merchant" hydrogen. The balance is produced and used as "captive" hydrogen as a chemical intermediate. In the future, it is probable that this pattern will change and that the predominant use for hydrogen will be as fuel. In this paper the discussion of environmental and safety considerations related to the use of hydrogen is focused primarily on its use as a fuel for autos, trucks, and buses, and for aircraft. The objective is to bring some of the interesting generalities of the subject to the attention of those who are just acquiring an interest in the potential of hydrogen, as well as for those specialists in hydrogen technology who may not have given much thought to these considerations.

Bro, K., and P. S. Pedersen. Alternative Diesel Engine Fuels: An Experimental Investigation of Methanol, Ethanol, Methane and Ammonia in a D.I. Diesel Engine With Pilot Injection. Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770794, 16 pp.

The results of an experimental investigation of methanol, ethanol, methane and ammonia as primary fuels for a high speed direct injection diesel engine are described. The fuels were added to the intake air and ignited by injection of a small amount of pilot diesel fuel (30 pct on energy basis). All of the four fuels were found applicable with methane as the most suitable and ammonia as the least suitable. Experimental data are presented regarding engine power output, efficiency, smoke and gaseous emissions, and the different types of combustion observed during the experiments are discussed.

Cart, E. N., Jr., and J. Percival. Alternate Fuels and Alternate Prime Movers in Non-Highway Transportation. Presented at Fuels and Lubricants Conference, Hyatt Regency, Houston, Tex., Oct. 1-4, 1979, SAE Technical Paper Series 790957, 16 pp.

At some point in the future, the transportation system will have to start to use non-petroleum fuels. One area of the transportation system that is critical is the non-highway (marine, railroad, pipeline and aircraft) since it accounts for about 80% of the freight-ton miles moved in the U.S. With the long-life times of the engines used in this area, and the time it takes to introduce a new prime mover or new fuel, it is important to consider the use of alternate fuels now. This paper covers the factors considered in evaluating alternate fuels and prime movers for non-highway transportation and presents a future outlook on possible fuels and prime movers.

Cavagnaro, D. M. Alcohol Fuels (Citations From the NTIS Data Base). National Technical Information Service, July 1978, 187 pp.; NTIS PS-780673.

The bibliography covers Federally-funded research on alcohol based fuels that might have to be used in the future as a fuel source. The citations

cover synthesis, chemical analysis, performance testing, processing, pollution, economics, environmental effects, and feasibility. (This updated bibliography contains 187 abstracts, 59 of which are new entries to the previous edition.).

Cavagnaro, D. M. Alcohol Fuels (Citations From the Engineering Index Data Base). National Technical Information Service, July 1978, 190 pp.; NTIS/PS-78/0674.

Worldwide research citations discuss the new technology in the field of alcohol fuels. The bibliography covers the different blends, synthesis, processes used, properties, engine performance evaluations, economics, safety measures, pollution effects, and combustion stsudies. The research also covers sources from which alcohol fuels can be obtained; such as coal, solid wastes, industrial by-products, and agricultural wastes. (This updated bibliography contains 191 abstracts, 50 of which are new entries to the previous edition).

Coal Age. Coal-Fueled Engine Runs at 0.5¢ per Mile. February 1977, p. 27.

Owen Power Industries has developed a compact, rotary engine, fueled by powdered coal. The coal is used to heat the working fluid (a fluorocarbon) and then follows a cycle similar to a rankine cycle. The article explains the basic operating principles of the engine along with its operating characteristics. It was determined that the weight of the engine is comparable to the internal combustion engine and would get around 60 mpg.

Cox, K. E., and K. D. Williamson, Jr. (ed. by). Hydrogen: Its Technology and Implications, v. I Production Technology. CRC Press, Inc., Boca Raton, Fla., 1977, 193 pp.

This volume reviews and evaluates current efforts in research to produce hydrogen from a variety of energy sources and describes some of the newer approaches undertaken to decompose water into its elements, hydrogen and oxygen. Chosen for fuller coverage are water electrolysis and the novel cyclic thermochemical method that has generated considerable worldwide interest since the early 1970s. Energy sources were selected with the future in mind. Coal, nuclear energy, and a wide variety of renewable energy sources have been discussed in detail as potential suppliers of raw material or energy for the conversion processes. Lesser emphasis was placed on converison schemes that are in the early stages of research.

Cox, K. E., and K. D. Williamson, Jr. (ed. by). Hydrogen: Its Technology and Implications, v. II Transmission and Storage. CRC Press, Inc. Cleveland, Ohio, 1977, 142 pp.

This volume deals with transmission and storage technology. In Chapter 1, Mr. Garth Leeth discusses the transmission of gaseous hydrogen. Equations used by the industry are given and discussed for use in calculation of

power requirements and costs. It is concluded that costs for transmitting gaseous hydrogen are on the order of 50 pct greater than for natural gas on an equal energy basis. The chapter concludes with a discussion of pipeline safety and operating experience. Mr. James Reilly covers the subject of metal hydride storage media in Chapter 2. Metal hydride chemistry lays the foundation for a discussion of specific metal hydride systems. This is followed by an informative section on hydride applications, pointing up the versatility of such systems as energy storage media. More on this subject is, of course, given in Volume IV. Chapter 3 covers the subject of liquid hydrogen storage and transmission. Most of the technology presented here was developed from 1957 to the early 1970s as part of the space and nuclear rocket programs. It is a technology which is well developed and readily applicable to today's energy problems. The final chapter in the volume is by Dr. Anthony Thompson and is on the subject of materials for hydrogen service. In this chapter the subject of hydrogen embrittlement is covered, along with all other aspects related to the proper choice of materials for use in hydrogen systems.

Cox, K. E., and K. D. Williamson, Jr. (ed. by). Hydrogen: Its Technology and Implications, v. IV Utilization of Hydrogen. CRC Press, Inc., Boca Raton, Fla., 1979, 240 pp.

This volume deals with all facets of hydrogen utilization. In the first chapter, William Van Vorst and Ronald Wooley discuss the application of hydrogen as a fuel for surface transportation. Following a brief history of hydrogen engines, the authors discuss engine cycles, special considerations for hydrogen fueled engines and vehicles, and prototype hydrogen vehicles using liquid hydrogen, fuel cells, and metal hydrides. The chapter is concluded with a brief discussion of vehicle safety and the application of hydrogen to railroad transport. In chapter 2, Daniel Brewer presents the latest information on progress related to the development of both subsonic and supersonic hydrogen fueled aircraft. This chapter also includes a section on the history of hydrogen in aeronautics which covers everything from its use in airships to its use in the U.S. space program. Chapter 3 presents the current technical stature of the distribution and residential use of hydrogen. In this chapter, J. Pangborn, M. Scott, P. Ketels, and J. Sharer discuss the compatibility of hydrogen to the existing natural gas residential distribution systems, residential use patterns, the conversion of existing domestic appliances, and the development of catalytic appliances. Daniel Cooperburg discusses the current and potential future industrial uses of hydrogen in chapter 4 covering such processes as ammonia manufacture, oil shale liquifaction and ethylene glycol production. The concluding chapter is an in depth treatise by F. J. Edeskuty on the subject of safety.

Cox, K. E., and K. D. Williamson, Jr. (ed. by). Hydrogen: Its Technology and Implications, v. V Implications of Hydrogen Energy. CRC Press, Inc., Boca Raton, Fla., 1979, 129 pp.

This volume is the result of certain initial evaluations of the legal, and socio-economic factors that enter the energy arena as a transition from a

"capital-based" fossil fuel economy to an "income-based" renewable energy economy that uses hydrogen as an energy "medium" takes place. Chosen for fuller coverage are the economics of hydrogen production, transmission, distribution, and end-use; the effect of a "hydrogen economy" on the environment; a socio-political view of energy with emphasis on hydrogen as the major fuel; and the legal aspects of adopting a new hydrogen energy system. In part, the treatment has been qualitative rather than quantitative as befits the subject material. There is also an element of looking towards the future in terms of "scenarios" as the present energy situation deteriorates as regards fossil fuel reserves. With the rapidity of events occurring in the field of energy at the present, the authors are commended as to the foresight and intuition shown in their respective chapters.

Diesel & Gas Turbine Progress. Hydrogen - A Fuel for Engines. October 1976, pp. 22-23.

Billings Energy Corporation has designed a bus that runs on hydrogen. The bus is being tested by running a 13 mile loop between two cities. The article explains the modifications that had to be performed and the special system for storing the hydrogen. The bus was found to have low emission characteristics, but due to the lack of hydrogen it is not feasible at this time.

Dupree, W. G., Jr., and J. S. Corsentino. United States Energy Through the Year 2000 (revised). BuMines, December 1975, 65 pp.

This report is an update of earlier energy forecasts of the Bureau of Mines. The report is divided into 6 sectors which are each individually forecast. The individual sectors are: electrical; synthetic gas; synthetic liquid; commercial; industrial; and transportation. Each energy forecast is based on the assumption that existing patterns of resource utilization will continue.

Ecklund, E. E. Methanol and Other Alternative Fuels for Off-Highway Mobile Engines. Presented at the Earthmoving Ind. Conference, Central Ill. Section, Peoria, Ill., April 10-12, 1978, SAE Technical Paper Series 780459, 20 pp.

Considerable insight into alternatives to petroleum as fuels for earthmoving and other off-highway vehicles can be gained from investigations related to highway vehicles. At the same time, off-highway equipment has the potential of greater flexibility in choice of fuels because of simpler fuel logistics. Uncertainties in both petroleum resources and alternative supplies are reviewed, and implications for the remainder of this century are highlighted. However, technology to make alcohols is well established and a multiplicity of resources is available. Thus, the technical benefits and problems of using alcohols as a petroleum extender or substitute are detailed.

Ecklund, E. E., and W. J. D. Escher. Hydrogen-via-Electricity: A Candidate Transitional Transportation Energy System Concept. U.S. Energy Research and Development Administration, Report No. ERDA 77-13, September 1976, 10 pp.

There is an implacable need to move transportation off oil. However, the strategic alternatives for creating a non-petroleum energy base for transportation, as in the case of all other sectors, are all long-term, costly systems, each having technical and socio-economic limitations and constraints which will govern their eventual contributions. The eventual non-petroleum transportation energy base connot be specified today. To "preserve all options", yet take positive steps to obviate serious transportation energy shortfalls, transitional steps must be implemented beginning in the relatively near-term. The Hydrogen-via-Electricity (HVE) concept has been proposed as one candidate transitional system. This system utilizes the in-place electrical utility energy delivery systems to produce hydrogen energy via water electrolysis at selected vehicular fueling points. Vehicles, converted to operate on hydrogen, could then be operated indirectly on coal and nuclear energy primarily, thereby moving off oil. The HVE concept has relatively near-term potential for supporting a certain fraction of such critical transportation modes as the railroads, intercity trucking, buses and fleet vehicles of various kinds. Environmental benefits will also accrue.

Farmer, M. H. Feasibility of Automotive Fuels From Coal and Oil Shale. Presented at the Tenth Annual Intersociety Energy Conversion Eng. Conf., Newark, Del., Aug. 17-22, 1975, SAE Preprint 759129.

Alternatives to petroleum automotive fuels were studied for the 1975-2000 time period. The study was sponsored by the AAPS Division of the U.S. Environmental Protection Agency, and was completed in June 1974. Since then, follow-up work has been undertaken as part of an impact study for which Stanford Research Institute was the principal investigator. Feasible alternatives to petroleum fuels are liquids derived from domestic coal and oil shale, of which the United States has vast resources. The fossil energy content of these resources greatly exceeds that of indigenous petroleum resources. Hence, it is possible to conceive the production of "synthetic" fuels on a very large scale. However, the environmental acceptability of extracting and processing the coal and oil shale will be a major constraint to the rate at which the resources can be developed. Moreover, other factors such as the availability of capital, skilled manpower and water may cause additional limitations. Hence, complete replacement of petroleum with synthetic fuels is improbable until after the turn of the century. Rather, it appears that the "alternative" fuels will first be used in conjunction with petroleum, that usage will expand as supply capability increases, and that the approach to complete replacement will be evolutionary. There is an excellent chance of developing alternative fuels or blending components that can fit directly into the existing distribution and marketing system for automotive fuels, thereby avoiding the need to duplicate the multibillion dollar investment already in place.

Finegold, J. G. Hydrogen: Primary or Supplementary Fuel for Automotive Engines. Presented at the West Coast Meeting, Jack Tar, San Francisco, Aug. 9-12, 1976, SAE Preprint 760609, 16 pp.

Hydrogen, gasoline, and mixtures thereof were compared as fuels for lean-burn engines. Hydrogen for the mixed fuels tests was generated by partial oxidation of gasoline. Hydrogen combustion yielded the highest thermal efficiency at any NO_x level. Gasoline yielded the second highest thermal efficiency for NO_x levels greater than or approximately equal to two gm/mi. For lower NO_x levels and high vehicle inertia weights, progressively more hydrogen supplementation was the second most efficient system. For vehicle inertia weights below 5000 lbm (2300 kg), the statutory NO_x standard (0.4 gm/mi) could be met with 1 lb/hr (0.13 g/s) hydrogen supplementation.

Fleming, R. D., and T. W. Chamberlain, Methanol as Automotive Fuel, Part 1--Straight Methanol. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750121, 11 pp.

A study of methanol as an automotive fuel was conducted using a single-cylinder research engine, a 4-cylinder 122-CID (2,000 cc) engine, and an 8-cylinder 350-CID engine. Results showed that when using methanol as fuel, the single-cylinder engine could operate leaner than the multicylinder engines. This difference is attributable to air-fuel mixture maldistribution associated with the multicylinder engines. Steady-state fuel economy and emissions data are presented and discussed. Results indicate that fuel economy (on an energy input basis) using methanol fuel is about 5% improved as compared to gasoline fuel economy and with substantially lower nitrogen oxides emissions for methanol.

Foster, R. W. Overview of the Alternative Fuels for Medium Speed Diesel Engines Program Plan (Proceedings of the U.S. Department of Energy Automotive Technol. Development Contractor Coordination Meeting, Dearborn, Mich., Oct. 23-25, 1979). Contract No. DE-AC02-79CS50033, 12 pp.

Medium speed diesel engines are defined as those diesel engines with nominal operating speeds of 300 to 1000 rpm. These engines find use in marine, railroad and recently developed large-scale earth moving equipment (e.g. TEREX/GM) generation systems, industrial power systems and on-shore and off-shore oil drilling equipment systems. The Project Management Plan provides a description of a multi-year Research, Development and Demonstration Project. The objectives of the project are to explore the technical, business operations and business economics impacts that would be encountered in the conversion from conventional, petroleum based fuels to alternative, non-petroleum based fuel systems. While emphasis is placed on rail systems, it is anticipated that the problems to be encountered in other applications will be generally similar. In addition to the investigation of alternative fuel forms used in conventional medium speed diesel engines, alternative fuel forms used in conventional medium speed diesel engines, alternative engine designs, such as gas turbines, Stirling systems, fuel-cell systems, etc. will be investigated to determine the additional impact of both fuel form and engine form changes.

Gier, H. L. Hydrogen Fuel for the Railroads: A Proposal. Conference Proceedings: V. III. First World Hydrogen Energy Conference, Univ. of Miami, Coral Gables, Fla., 1976, pp. 7C-43.

One of the major difficulties in initiating the Hydrogen Economy is finding the appropriate place to initiate it. Dr. Gier proposes to convert the railroads to use hydrogen. He briefly discusses the advantages of converting the railroads to use hydrogen over converting the automobile.

Goodger, E. M. Alcohol Fuel Prospects. J. Inst. Fuel, September 1977, 7 pp.

Alcohols have long been of interest as high-performance fuels for the spark-ignition engine, and are now examined as alternative fuels for the continuous flow applications of gas turbines and boilers. The performance of the alcohols and conventional distillate petroleum fuels are compared on a basis of the various stages of the overall combustion process. Experimental results are quoted. Alcohols show advantages of finer atomization, more rapid vaporization, greater ignitability and flame stability, with lower production of NO_x, together with disadvantages of low caloric values, greater fire hazard, toxicity and water solubility, and higher production of carbon monoxide. On balance, alcohols show promise as alternative fuels for gas turbines used for peak power generation, but a substantial increase in alcohol production, and a decrease in price, would be necessary.

Goodger, E. M. Liquid Fuels for Transport. See II.A.

Gray, J. T., and A. A. Johnston. Engine Experiments with Fire Safe Fuels. U.S. Army Fuels and Lubricants Res. Lab., Contract No. DAAK02-73-C-0221, January 1975, 86 pp.; NTIS AD/A-031 123.

A single-cylinder research engine (CLR) was operated on diesel fuel containing a halon compound, bromochloromethane, added to the fuel at 5 percent by volume as a fire safe fuel additive. Basic diesel power comparisons were made using diesel fuel and diesel fuel plus additive. A series of experiments were then conducted to investigate injection system variables, including injector camshaft profile, barrel and plunger diameter, injection nozzle configuration, and nozzle hole size, in an effort to recover power losses noted when using the diesel fuel plus additive blend.

Hagen, D. L. Methanol as a Fuel: A Review with Bibliography. Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770792, 36 pp.

A survey of recent studies and research on methanol is given within the historical context. Fuel related properties are reviewed and compared

with isooctane. Combustion emissions and their variation with temperature and fuel preparation are similarly compared. Uses of methanol as a combustion fuel and recent tests in boilers, turbines, conventional and stratified charge Otto engines, and diesel engines are discussed emphasizing comparative efficiencies. Current developments on the uses of methanol directly and indirectly in fuel cells and as a feedstock for single cell protein are examined. The relevant biological, physical and chemical hazards of using methanol as a fuel are discussed together with safety precautions and treatment. A comprehensive bibliography is given covering the above topics.

Hord, J. Is Hydrogen Safe? National Bureau of Standards, October 1976, NBS Technical Note 690, 38 pp.

The safety aspects of hydrogen are systematically examined and compared with those of methane and gasoline. Physical and chemical property data for all three fuels are compiled and used to provide a basis for comparing the various safety features of the three fuels. Each fuel is examined to evaluate its fire hazard, fire damage, explosive hazard and explosive damage characteristics. The fire characteristics of hydrogen, methane and gasoline, while different, do not largely favor the preferred use of any one of the three fuels; however, the threat of fuel-air explosions in confined spaces is greatest for hydrogen. Gasoline is believed to be the easiest and perhaps the safest fuel to store because of its lower volatility and narrower flammable and detonable limits. It is concluded that all three fuels can be safely stored and used; however, the level of safety risk for each fuel will vary from one application to another. Generalized safety comparisons are made herein but detailed safety analyses will be required to establish the relative safety of different fuels for each specific fuel application and stipulated accident. The technical data supplied in this paper will provide much of the framework for such analyses. Hydrogen safety guidelines, regulatory codes applicable to the distribution of hydrogen, and safety criteria for liquid hydrogen storage are compiled and presented.

Hurn, R. W. Engineering Options in the Choice of Automotive Fuels in the Next Decade. Presented at the West Coast Meeting, Jack Tar, San Francisco, Calif., Aug. 9-12, 1976, SAE Preprint 760584, 9 pp.

Within the next decade there may be significant developments toward "new" automotive fuels--either alternative fuel forms or traditional fuels from non-petroleum sources. These include methanol as the most likely alternative fuel form, hydrocarbons from coal or from oil shale, and modified conventional fuels from either traditional or alternative sources. The characteristics of traditional fuels will not change significantly solely as a result of using synthetic crude in refinery feedstocks. Increased use of distillate transportation fuels could result in process energy savings, but, measured roughly, beyond a 1:1 distillate/gasoline ratio, increased process energy penalty.

Kant, F. H., R. P. Cahn, A. R. Cunningham, M. H. Farmer, W. Herbst, and E. H. Manny. Feasibility Study of Alternative Fuels for Automotive Transporation Volume 1--Executive Summary. Exxon Research and Engineering Co., Contract No. 68-01-2112, June 1974, 24 pp.; NTIS PB 235581.

Volume 1 is an executive summary comprising the report summary, highlights of the various sections and a list of conclusions. This study identifies feasible and practical alternatives to automotive fuels derived from petroleum for the 1975-2000 time period. The alternative fuels are liquids derived from domestic coal and oil shale---specifically gasolines, distillates, and methanol. While many uncertainties remain, initial production of the new fuels is likely within the next five to seven years. It appears that when the alternative fuels will begin to be used in conjuntion with petroleum that usage will expand as availability increases, and that the approach to complete replacement will be evolutionary. While differing in estimated cost, the individual fuels examined in detail may all be producible at a cost level or range projected for petroleum fuels. Fuels were screened on the basis of economic, technical, and performance criteria, with consideration given to the way in which each new fuel could be brought into general use. Consideration was also given to the environmental impact of producing and using the fuels. From a fairly comprehensive list of initial candidates, feasible and practical alternative automotive fuels were identified. Gasoline-type and distillate-type fuels from oil shale, together with gasoline-type, distillate-type, and methanol fuels from coal, are evaluated in detail. Safety, toxicity, reliability, compatibility with different engines and convenience of use are considered. Conclusions are included.

Kant, F. H., R. P. Cahn, A. R. Cunningham, M. H. Farmer, W. Herbst, and E. H. Manny. Feasibility Study of Alternative Fuels for Automotive Transportation Volume 2--Technical Section. Exxon Research and Engineering Co., Contract No. 68-01-2112, June 1974, EPA Preprint EPA-460/3-74-009-b, 231 pp.

This report identifies the feasibility and practical alternatives to automotive fuels derived from petroleum for the 1975-2000 time period. The alternative fuels are liquied derived from domestic coal and oil shale --specifically, gasolines, distillates, and methanol. While many uncertainties remain, initial production of the new fuels is likely within the next five to seven years. Volume II is a technical section, which gives a complete description of the work carried out under this contract.

Koenig, A., W. Lee, and W. Bernhardt. Technical and Economical Aspects of Methanol as an Automotive Fuel. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760545, 16 pp.

The results of basic test series conducted on a single-cylinder engine are used to establish the reasons that advocate the introduction of methanol or methanol-gasoline blends as alternative fuel for motor-vehicle

operation: lower exhaust emission concentrations, improved energy utilization, higher engine output, and improved knock-resistance. Fuel and energy consumption data are submitted for four vehicle concepts operated on methanol fuels, to establish data on the economic aspects of methanol-operated vehicles. It is apparent that the utilization of the anti-knock effects of methanol can lead to competitive gasoline-methanol blend vehicle operation at the present cost of gasoline and methanol. Vehicle operation of pure methanol would offer economic advantages over gasoline operation if gasoline is derived from coal.

Lestz, S. S., and K. R. Houser. Utilization of Alternate Fuels in Diesel Engines (Proceedings of the U.S. Department of Energy Automotive Technol. Development Contractor Coordination Meeting, Oct, 23-25, 1979). Contract No. EC-77-5-03-4530, 14 pp.

The purpose of this study is to determine effective means for using alcohol and/or blends of used lubricating oil as the primary fuel in light-duty high-speed compression ignition automotive engine service. To accomplish this will require investigation of engine performance characteristics as a function of the amount of alcohol and/or used lubricating oil and the method by which it is introduced. Fuel economy, exhaust emissions, constant volume combustion bomb work are used to provide support information. To date, the experimental equipment for this study has been designed and set up, baseline tests run, and the collection of alcohol data begun. The presentation will report further data acquisition and analysis techniques and some initial alcohol results. These results are for the fumigation of methanol into an Oldsmobile 5.7 1 V.8 diesel engine.

McCarty, R. D. Hydrogen: Its Technology and Implications. v. III. Hydrogen Properties. CRC Press, Inc., Cleveland, Ohio, 1975, 321 pp.

This document gathers together the available thermophysical properties of hydrogen. The work was performed at the Cryogenic Data Center of the National Bureau of Standards in Boulder, Colorado. The Cryogenic Data Center has been collecting data and documents pertinent to the field for 15 years and presently has about 100,000 coded entries which may be computer searched to give bibliographies on the physical properties of materials at low temperatures. A computer search of the data center holdings produced a bibliography for hydrogen of about 2,500 references. All of these references were considered; some of them do not appear in this report as a result of the review and editing process.

Marshall, H. P., and D. C. Walters, Jr. An Experimental Investigation of a Coal-Slurry Fueled Diesel Engine. Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770795, 12 pp.

A single cylinder 1360 cc diesel engine was operated on a slurry of 15 percent by weight solvent refined coal and jet fuel. The coal was pulverized to a nominal size of 2 micrometers. The initial investigation

began with nozzle bench tests which ascertained that the slurry would flow through the injection nozzle and form acceptable spray patterns. An instrumentation system was assembled to monitor and record engine operating conditions, which included pressure-time fluctuations in the combustion chamber, fuel consumption, power output, and noise. Photo-micrographs of the injection nozzle pin and injection pump plunger are presented for wear comparison before and after slurry operation. Test results indicate that the slurry fuel provides engine power and fuel consumption levels comparable to those of diesel and jet fuels. Although wear rates appeared moderate, conventional fuel injection systems are inadequate for long-term use because the clearances in the injection pump and nozzle are too small for slurry operation.

Marshall, H. P., S. M. Bhat, S. T. Mulvaney, and J. F. Sevelli. Performance of a Diesel Engine Operating on Raw Coal-Diesel Fuel Slurries. Society of Automotive Engineers, Alternate Fuels, SP-480, SAE Preprint 810253, 1981, pp. 59-71.

Performance tests at full rack and 1,400 rpm using a single cylinder diesel engine were made to determine the effects of three different micronized coal-fuel oil slurries being considered as alternative fuels. Slurries containing 20, 32, and 40 wt-pct micronized raw coal in No. 2 fuel oil were used. Results are presented indicating the changes in the fuel flow rates, concentrations of SO_x and NO_x in the exhaust, exhaust opacity, power and efficiency, and in wear rates relative to operation on fuel oil No. w. The engine was operated for 10 hrs on all fuels except the 40 wt-pct slurry. This test was discontinued because of extremely poor performance. Results indicate that the coal is largely inert in this situation and will cause a net increase in oil used and very rapid water.

Menrad, H., W. Lee, and W. Bernhardt. Development of a Pure Methanol Fuel Car. Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770790, 16 pp.

Methanol as a fuel for spark ignition engines offers a lot of advantages in comparison to gasoline. Results of a prototype passenger car fueled with pure methanol show promising aspects of lower energy consumption, higher energy output and more favorable emissions figures. Modifications on the engine are limited, the unfavorable cold start and warm up behavior of pure methanol can be eliminated by the use of suitable additives.

Mills, G. A. Alternate Transportation Fuels. Society of Automotive Engineers, Inc. Energy and Transportation. February 1976, SAE Special Publications 406, pp. 55-63

Because of the fuel shortage, research on synthetic fuels was increased in the late 1960s. This paper discusses the research and development progress of converting coal to liquid fuel. Projects on coal liquification are already being carried out by government, universities, and industry laboratories. The paper also discusses the characteristics of synthetic fuels and the manufacturing of synthetic fuels.

Moses, C. A., W. E. Likos, and T. W. Ryan. The Use of Hybrid Fuels in a Single Cylinder Diesel Engine (Proceedings of the U.S. Department of Energy Automotive Technol. Development Contractor Coordination Meeting, Dearborn, Mich., Oct. 23-25, 1979). Contract No. EM-78-C-04-4240, 8 pp.

A program has been developed to investigate hydrid fuels as potential transportation fuels. Such fuels are combinations of different energy sources and can be in the form of solutions, emulsions, or slurries. Potential components include alcohols, carbon, carbohydrates, and other soluble hydrocarbons derived from biomass. Extensive experiments have been conducted in a single-cylinder diesel engine with water/fuel emulsions and alcohol/fuel blends (solutions and emulsions). Fuels are compared in terms of specific energy consumption, specific diesel fuel consumption (a measure of petroleum conservation), and specific cost. Limited engine experiments have been conducted with carbon and carbohydrate slurries and soluble carbohydrates. The main problem with slurries is compatibility with pumps and injectors although some slurries of coke and of starch were successfully run in the engine. Future efforts will be primarily in the areas of slurries and developing soluble compounds from biomass that are less refined than alcohols.

O'Neal, G. B., and J. O. Storment, Control of Diesel Exhaust Emission in Underground Coal Mines--Single Cylinder Engine Experiments With Modified and Non-Conventional Fuels. See IV.A.

Panchapakesan, N. R., M. Rajendran, K. V. Gopalakrishnan, and B. S. Murthy. Investigation of Some Factors Affecting the Performance of an Alcohol-Diesel Oil Dual Fuel Engine. Proceedings of the Third National Conference on I. C. Engines and Combustion. Sarita Prakashan, Meerut, India, Dec. 10-12, 1976, pp. 167-177.

Some factors which affect the performace of a dual-fuel engine using ethyl alcohol and diesel oil have been experimentally investigated in this work. The optimum proportion between diesel oil and alcohol, the best injection timing and the effect of ignition accelerating additives in the fuels have been determined. The effect of higher compression ratio has also been investigated. The results show that the chief defects of this type of bi-fuel engine, namely lengthened delay period of the fumigated fuel and increased peak pressures can be at least partially overcome by optimizing these factors without sacrificing any of the significant advantages of this type of bi-fuel operation.

Pangborn, J. B., and T. D. Donakowski. Hydrogen Automotive Fuel: Production and Delivery. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760568, 12 pp.

Today's principal and cheapest source of hydrogen in the United States, steam-reformed natural gas, does not have attractive prospects in the long term future. Alternative procedures or processes therefore are in

various phases of research and development. Hydrogen can be produced by the electrolysis of water, and production of hydrogen from coal and water is under study. Thermochemical, photochemical, and biochemical procedures are being researched as long-term routes to hydrogen. Feasibility studies indicate the possibility of long-distance transmission of hydrogen gas via pipeline. Local distribution of hydrogen fuel presents a major problem that requires investigation and development. Technically and economically, other synthetic fuels, such as liquid hydrocarbons from coal or oil shale, are favored alternative automotive fuels for the mid-term future.

Paul, J. K. (ed. by). Methanol Technology and Application in Motor Fuels. Noyes Data Corp., Park Ridge, N.J., Chem. Technol. Rev., No. 114, Energy Technol. Rev., No. 31, 1978, 470 pp.

This publication contains descriptive information relating to methanol production technology for unusual sources, the utilization of methanol as an automotive fuel, and the conversion of methanol into gasoline. Feasibility studies for the production of methanol from coal, solid waste, and natural gas are presented but production from liquids hydrocarbons is not discussed in any detail.

Salzano, F. J., A. Mezzina, M. Beller, G. Strickland, and S. Srinivasan, Hydrogen Technology: An Overview. U.S. Department of Energy Contract No. 790415--16, 15 pp.

This paper is an overview of the key technologies needed for hydrogen to make major inroads into the U.S. energy economy as a fuel derived from renewable or abundant nonfossil resources. In addition, the unique relationship between hydrogen and the fuel cell is discussed. The state-of-the-art of hydrogen transmission and storage are presented and a scenario showing how the commercialization of the fuel cell as an electric generating device in urban areas could lead to the introduction and use of hydrogen in a wider variety of end uses. At the present time there is a great deal of international interest in hydrogen. A broad picture of the activities of a number of western European countries and Japan in the area of hydrogen and a summary of international interest in this area is presented.

Saxena, M., and K. K. Gandhi. Use of Methanol in Diesel Engine: An Experimental Study of Engine Performance. Proceedings of the Third National Conference on I. C. Engines and Combustion. Sarita Prakashan, Meerut, India, Dec. 10-12, 1976, pp. 139-147.

The paper discusses the performance of the engine with methanol as an auxiliary fuel. The effect of load on optimum methanol induction, input heat utilization, exhaust temperature and smoke density along with pressure-time diagrams were studied. The engine performance studies show that better heat utilization is achieved at and above rated load with

reduced exhaust smoke density. From the peak pressure, rate of pressure rise and a study of delay periods, it is concluded that for methanol-diesel operation the engine can run economically (energy basis), with reduced engine vibrations, and higher power/weight ratio. In addition, for the case of field operation, engine performance for a constant quantity of methanol induction at any load was also done.

Smithsonian Science Information Exchange, Inc. Alternative Fuels for Ground Vehicles. Washington, D.C., August 1977, SSIE Preprint GM18, 50 pp.

This is a collection of individual research descriptions selected as relevant to the topic of Alternative Fuels for Ground Vehicles. Each description gives the project title, performing organization and a summary of the project.

Smithsonian Science Information Exchange, Inc. Hydrogen as a Source of Energy for Fuel Cells. Washington, D.C., January 1979, SSIE Preprint FB02D, 300 pp.

This is a collection of individual research descriptions selected as relevant to the topic of Hydrogen as a Source of Energy for Fuel Cells. Each description gives the project title, performing organization and a summary of the project.

Society of Automotive Engineers, Inc. Alternate Portable Fuels for Internal Combustion Engines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790426, 28 pp.

This report summarizes a committee investigation and analysis of the supply/demand situation for fuels; short and long term changes in fuels as they impact on portable internal combustion engines; potential areas of research on alternate fuels; and identification of priorities for alternate portable fuel research and development.

Stewart, W. F. and F. J. Edeskuty. Liquid Hydrogen as a Vehicular Fuel: An Evaluation. Mechanical Engineering. May 1981, pp. 24-29.

This evaluation and state-of-the-art demonstration project for a hydrogen-fueled vehicle with liquid hydrogen on-board storage and refueling capabilities includes safety, economic, and energy assessments for the use of liquid hydrogen as a fuel. The project provides a baseline system representing present capabilities in engine conversion, liquid hydrogen storage, and liquid hydrogen refueling.

Technology Review. Coal-Burning Diesels. February 1979, p. 80.

Thermo Electron Corporation is designing a diesel engine to burn coal-derived fuels, which include liquids and solids. The article briefly explains the principles and economics involved of the the new engine. By employing a bottoming cycle a thermal efficiency of 45% can be obtained which is 4% better than a conventional diesel.

Tsaros, C. L., J. L. Arora, and K. B. Burnham. The Manufacture of Hydrogen from Coal. Presented at the National Aerospace Engineering and Manufacturing Meeting, Culver City, Los Angeles, Calif., Nov. 17-20, 1975, SAE Preprint 751095, 23 pp.

As part of a study for the conversion of coal to fluid fuels, we have developed three process designs for the conversion of Montana subbituminous coal to hydrogen based on three different gasifier technologies:

1. Koppers-Totzek suspension gasification,
2. U-GAS™ fluidized-bed gasification, and
3. Fluidized Steam-Iron Process

For comparison with methane from coal, a fourth design, based on the HYGAS Process has been prepared. Nominal plant capacities are 250 billion Btu/day of product gas. Overall plant efficiencies for conversion of coal to major gaseous products plus by-products are:

Koppers-Totzek	57.0%
U-GAS	66.4%
Steam-Iron	62.6% (includes 18% by-product electricity)
HYGAS	74.0%

Product liquification requirements are presented. Capital and operating costs (mid-1974) are presented for U-GAS and HYGAS. With coal at $0.30/million Btu, prices for hydrogen and methane are $2.17 and $1.77/million Btu. Methane is more attractive in both efficiency and cost.

U.S. Environmental Protection Agency. Advanced Fossil Fuels and the Environment. The Energy/Environment R&D Decision Series, Preprint EPA-600/9-77-013, June 1977, 23 pp.

This report reviews the environmental control technologies being developed in concert with advanced fossil fuel conversion processes. These control technologies are designed to eliminate the adverse health and ecological effects that are often by-products of energy conversion. While specific fuel conversion processes are examined in this report, it should be emphasized that EPA's major interest lies with the type and quantity of pollutants from the processes and the practicality and effectiveness of pollutant control methods. With its involvement in the actual conversion process, however, EPA is striving to assure that the new and evolving conversion processes will develop environmentally sound as well as efficient. Additionally, as the report reflects, EPA is working to prevent pollution from conversion processes already developed and in use. EPA also performs environmental assessment of control technologies; however, this report does not deal directly with this agency function.

Wagner, T. O., D. S. Gray, B. Y. Zarah, and A. A. Kozinski. Practicality of Alcohols as Motor Fuel. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790429, 29 pp.

Several alcohols have been or are being used as motor fuel in limited applications where their unique properties provide a specific benefit. Recently, proposals have been made to manufacture methyl and ethyl alcohols from nonpetroleum feedstocks for use as a primary energy source. Such a program, it is claimed, would reduce U.S. dependence on foreign oil; manufacturing ethanol would also stabilize prices of farm commodities. An economical and abundant feedstock for methanol manufacture is North Dakota lignite. In a plant consuming lignite and self-sufficient in utilities, energy in the methanol would represent about 45 percent of the energy in the feedstock. The cost of energy from the methanol produced would be about twice that from gasoline at 1979 prices. Liquefaction of lignite or coal to a synthetic crude with subsequent refining by conventional processes would provide motor fuel at somewhat higher energy efficiency and lower cost than by methanol sythesis. Municipal solid wastes could also be used as feedstock for methanol manufacture, but the cost would be even higher than with lignite as feedstock. The lowest cost and most abundant feedstock for ethanol manufacture is corn. With current farming and ethanol manufacturing practices, which use mainly petroleum-based fuels, energy in the ethanol plus that in the by-products is only about 55 percent of the energy in the petroleum fuels consumed. If the ethanol plant used only nonpetroleum fuels such as coal or agricultural wastes for process energy, the efficiency based on just the petroleum fuels used in farming and collection of wastes would range from 130 to 160 percent; overall efficiency would remain at 55 percent or less. Energy in the by-products represents about 40 percent of the energy output, which greatly complicates evaluation of the efficiency of the plant. In any event, the cost of energy from the ethanol produced would be at least four times that from gasoline. The high cost results from large capital charges, large operating costs and, especially, large raw material costs. While both methanol and ethanol have characteristics that complicate distribution and detract from product quality, poor energy yield and high cost are the most serious deterrents to commercialization of either alcohol. Methanol is definitely preferred, but neither represents a practical alternative unless the price of petroleum-based fuels rises markedly relative to that of the alcohols.

Wallace, W. B. The Development and Operational Experience of a Range of High Output Medium-Speed Diesel Engines Burning Residual Fuels. See I.D.

Wood, C. D. Alternative Fuels in Diesel Engines--A Review. Society of Automotive Engineers, Alternate Fuels, SP-480, SAE Preprint 810248, 1981, pp. 1-9.

A wide range of fuels, from hydrogen to slurries, has been tested in diesel engines. This paper reviews test results and concludes that the

diesel engine has an extraordinary capability to burn efficiently a wide range of fuel types. The problems of engine durability with such fuels now needs to be addressed.

Wrage, K. E., and C. E. Goering. Technical Feasibility of Diesohol. Presented at the 1979 Summer Meeting of ASAE and CSAE, Univ. of Manitoba, Winnipeg, Canada, June 24-27, 1979, Paper No. 79-1052, 13 pp.

Fuel properties essential to the proper operation of a diesel engine were studied for several ethanol-diesel fuel blends. A blend of 10 percent ethanol and 90 percent No. 2 diesel exceeded ASTM minimum specifications and was given the name diesohol. In engine tests, diesohol gave lower efficiency than No. 2 diesel fuel but also reduced exhaust smoke.

C. Fuel Economy

Buike, J., J. Davis, J. Marsh, and L. Ryder. Supercharging for Fuel Economy. Presented at the Internat. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 23-27, 1981, SAE Technical Paper Series 810006, 16 pp.

This paper explores the apparent dichotomy between the performance benefits of supercharging and fuel economy. Following an investigation of the tools available for fuel savings, especially drivetrain and engine alternatives, the desirable characteristics and optimum configuration of a supercharger are examined. Engine dynamometer data for a 1.7-liter gasoline engine equipped with a Bendix Supercharger and performance and test data from Bendix-supercharged test vehicles confirm that supercharging provides a means to achieve fuel economy, performance, driveability, and acceptable emissions.

Coal Age. Hints on Off-Highway Fuel Savings. April 1979, pp. 135-136.

Since the increase of fuel prices, surface mine vehicles must be operated at their optimum condition in order to reduce fuel consumption. This article explains what type of engine should be selected and how to operate the engine for optimum fuel economy.

French, C. C. J., and D. A. Pike. Diesel Engined, Light Duty Vehicles for an Emission Controlled Environment. Presented at the West Coast Internat. Meeting, Portland Hilton, Portland, Oreg., Aug 6-9, 1979, SAE Technical Paper Series 790761, 24 pp.

The diesel engined light duty vehicle shows a substantial improvement in fuel economy over its gasoline engined counterpart. It will, however, have very great difficulty in meeting proposed gaseous and particulate exhaust emission levels. The interactions between fuel economy, NO_x emissions, and exhaust particulate emissions as demonstrated by an extensive series of tests on a Mercedes Benz 300D car with modulated exhaust gas recirculation are correleted with published data from other diesel engined vehicles to predict levels which could be achieved with current technology and to estimate the fuel economy penalties.

Miller, B. The Changing Diesels. Rock Products, July 1978, pp. 82-86.

In order to improve fuel economy, engine manufacturers have been designing engines that operate at lower speeds. This article explains how engine manufacturers are obtaining sufficient horsepower at these lower speeds. The article covers the major manufacturers of diesel engines.

Nielson, R. The Impact of Energy Costs on Mobile Equipment Design. Society of Automotive Engineers, 1980, SAE Preprint 800990, 5 pp.

This paper identifies the cost of power consumed by a gas or diesel engine as $500 per hp over a 10,000 hour life. In addition, it shows how the rate of increase of fuel costs is affecting the end user's purchasing decisions. It also contains some general ideas on how mobile equip-ment can be designed to be more energy efficient. This paper should be of value to both the designers and the sales/marketing people at the mobile OEM's.

Oblander, K., M. Fortnagel, H. J. Feucht, and U. Conrad. The Turbocharged Five-Cylinder Diesel Engine for the Mercedes-Benz 300 SD. See I.F.

Pearce, J. F., R. J. Hames, and D. F. Merrion. Two-Stroke Cycle Diesel Engine Fuel Economy Improvement and Emission Reduction. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770255, 12 pp.

The 8V-71 TAE engine was developed to provide improved fuel economy and reduced emissions. The effects of turbocharger-blower matching, air charge cooling, and combustion system design changes are presented. Steady state smoke reductions achieved through improved air utilization are compared with improvements in transient smoke on the Federal smoke test cycle.

Russell, M. F. Recent CAV Research into Noise, Emissions, and Fuel Economy of Diesel Engines. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770257, 20 pp.

The contribution to the external noise from the combustion process has been considered in relation to the gaseous emissions, smoke and specific fuel consumption. To satisfy the requirements of proposed legislation in different markets, whilst maintaining economical operation, the fuel injection equipment for a diesel engine must compromise between several conflicting requirements. The conflicts are presented in the form of "trade-off" curves over a range of dynamic injection timings. Four means to achieve better "trade-off" curves have been investigated: higher rate of injection, fumigation, turbocharging, and turbocharging combined with a higher rate of injection.

Smiley, C. H. Getting the Most From Your Fuel Dollars. Rock Products, June 1976, pp. 88-90.

Ever since the energy shortage, fuel prices have been rising. This article explains how fuel costs for diesel engines can be reduced by having a properly tuned engine and a properly functioning fuel system. It also points out that a good, clean, quality fuel must be used to optimize fuel economy.

Springer, K. J., and R. C. Stahman. Emissions and Economy of Four Diesel Cars. See ID.

Tipler, W. Prospects for the Operation of Diesel Engines on Coal or Its Derivatives. Power Plants and Future Fuels (A conference sponsored by the Combustion Engines Group and the Automobile Div. of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 119-127.

Consideration of a fuel policy suggests that liquid fuels should be reserved for mobile application; liquid fuels from petroleum might be augmented by coal based fuels. Experience of operating diesel engines on coal suggests that new research programs on combustion and lubrication/wear might lead to a reliable coal fired low speed diesel engine. A wide range of liquid fuels can be derived from coal but the processes have low thermal efficiencies; the overall efficiency of conversion of chemical energy to shaft power would therefore be unacceptable under conditions of fuel scarcity. Combined studies of fuel production and utilization are needed to maximize the overall thermal efficiency of fuel usage.

D. Emulsified Fuels

Cook, D. H., and C. K. Law. A Preliminary Study on the Utilization of Water-In-Oil Emulsions in diesel engines. Combustion Science and Technology, v. 18, 1978, pp. 217-221.

A single cylinder diesel engine study of water-in-oil emulsions was conducted to investigate the effects of water emulsification on particulate emission and the IMEP, with the fuel-air ratio ranging from 0.02 to 0.07. Results indicate that an optimum water content for particulate reduction seems to be between 10 and 20 vol-pct, and that with equal amount of fuel injection the IMEP is minimally affected with water addition.

Dainty, E. D., A. Lawson, and J. P. Mogan. Synopsis of Contract Findings: The Ventilation Implications of the Reduction of Diesel Emissions Toxicity by Water-In-Oil Fuel Emulsification. CANMET, Energy, Mines and Resources, Ontario, Canada, Report MRP/MRL 80-15 (TR), February 1980, 32 pp.

The toxicity reduction of emissions from two diesel engines by the emulsification of water into fuel oil was investigated to determine the applicability of such systems to underground mining machinery. The engines studied were: (1) the Deutz F6L714, four-stroke, air cooled, 6-cylinder, V-configuration, indirect injection (IDI) engine, and (2) the Detroit Diesel V-configuration, direct injection (DI) engine. The application of emulsified fuel treatment to the two-stroke engine did not prove to be practicable. In the case of the Deutz engine, however, substantial benefit resulted. For a modest 15 pct water content in the fuel and an injection timing of 24°BTDC, approximate reductions of 40 pct in the concentrations of both particulate matter and nitric oxide were produced. These reductions were accompanied by insignificant changes in other toxic constituents. The net result was an approximate 30 pct reduction in the overall exhaust toxicity for typical LHD operation as assessed by the Health Effects Index criterion. This toxicity reduction represents a significant advance from the points of view of an improved underground environment and/or reduced ventilation costs. The SO_2 conversion characteristics of an Engelhard PTX-623 DF purifier were also documented. It was determined that 44 pct of the SO_2 was converted to H_2SO_4 for the integrated LHD machine cycle increasing the toxicity 3-fold relative to zero conversion as assessed by the Health Effects Index criterion.

Dooher, J., R. Genberg, R. Lippman, T. Morrone, S. Moon, and D. Wright. Emulsions as Fuels. Mech. Eng., November 1976, pp. 36-41.

This paper presents the results of recent studies at the Adelphi University Center for Energy Studies on the use of emulsions as fuels. The use of water-in-oil emulsions, possible with coal dispersed, in boiler furnaces, and the use of water-in-gasoline are reviewed. Mini-explosions of water-in-oil emulsion drops are suggested as a mechanism for improved atomization and oxidant-fuel mixing.

Dryer, F. L., and I. Glassman. Fundamental Combustion Studies of Emulsified Fuels for Diesel Applications, Final Report. Guggenheim Lab., Contract No. AER7608210, December 1977, 125 pp.; NTIS PB 287 386.

Improved understanding of the combustion properties of emulsified water-fuel mixtures could lead to better energy utilization/emission characteristics for energy conversion systems which employ spray combustion. The combustion properties of emulsified fuels required for guiding optimization of practical applications were studied. The program's goal was to define the combustion characteristics of water-in-fuel emulsions and to experimentally investigate the relationships of emulsion characteristics at the micro-explosion phenomena. Interest in improving operating characteristics of light vehicle diesel power plants to levels acceptable for large scale integration into the private transportation sector originally motivated this program. Aspects of the program are also relevant to use in other combustion systems. Research encompasses emulsion formation techniques, physical characteristics, emulsion coalescence kinetics (stability), single suspended and free droplet combustion, spray characterization and nucleate vaporization (of the internal phase) prediction. Results have been used to critically evaluate published practical results, predict favorable applications for emulsion combustion, and guide full scale implementation research and development elsewhere. This final report summarizes the results and accomplishments of the program.

Fogler, H. S., S. R. Reddy, M. L. Storbeck, J. B. Cross, and S. C. Siegmund. Physical Properties and Stability of Water in Fuel Oil Emulsions. Department of Chemical Eng., Contract No. DOT-OS-70056, Final Report, March 1979, 107 pp.; available from the U.S. Government Printing Office, Washington, D.C., Stock No. 050-005-00029-1.

This report presents the first year interim results from a two year effort to determine the physical properties of water-in-fuel oil emulsions. Ultrasonically induced cavitation was used to produce emulsions in gasoline, No. 2 diesel oil, No. 4 heating oil, and No. 6 fuel oil without the use of surfactants. Density and viscosity measurements for each of the four fuels used are presented for various temperatures in the range from 20°C to 90°C. Interfacial tension measurements, against water for each of the four fuels used are presented for temperatures in the range from 30°C to 79°C. Density measurements for water-in-gasoline emulsions are presented for volume fractions of water-in-No. 2 diesel oil, No. 4 heating oil, and No. 6 fuel oil are presented for volume fractions of water ranging from 0.00 to 0.10, at 30°C and 60°C. The viscosity and other rheological properties for similar emulsions at comparable temperatures are given. In addition, the stability of water-in-fuel oil emulsions has been studied. A scanning electron microscope and a spectrophotometer were used to study the aging of oil-in-water emulsions, while water-in-oil emulsions were studied using a creaming cell.

Fujisawa, T., and K. Yokota. A new Look at the Utilization of Alternate Fuels for Diesel Engines--IDIS. Presented at the Internat. Off-Highway Meeting and Exposition, Milwaukee, Wis., Sept. 14-17, 1981, SAE Technical Paper Series 810998, 7 pp.

Application of alternate fuels to diesel engines is much desired. A new and unique dual-fuel injection system has been developed for high speed automotive diesel engines. This system has two features. One is that alternate fuels such as methanol, ethanol and biomass, are directly inducted into the fuel injection pipe through one-way check valve under pressure, and blended fuels are simultaneously injected into the combustion chamber. The other is that various kinds of fuel can be easily adapted to this system not dependent upon the fuel properties such as viscosity. Using a single cylinder direct injection diesel engine and ethanol as an alternate fuel, injection characteristics and exhaust gas emissions were investigated. The results showed that ethanol could replace up to 50% of diesel fuel while keeping the normal engine operating stability. A better fuel economy was also obtained by applying both higher compression ratio and advanced injection timing. NO_x concentration was unchanged compared to diesel fuel only.

Gillberg, G., and S. Friberg. Microemulsions as Diesel Fuels. Chapter 15 of Advances in Chemistry Series, No. 166, Evaporation - Combustion of Fuels. American Chemical Society, 1978, pp. 221-231.

Microemulsions with greater than 15 wt-pct water and cetane numbers larger than 35 show simultaneous large decreases in emitted NO_x and smoke (soot) when used as diesel fuels. Important factors for microemulsion stability are described since these are essential to obtain thermodynamically stable microemulsions. The regions for these are found easily with a systematic knowledge of phase equilibria in surfactant systems. Most surfactants and the microemulsified water had a negative effect on the diesel fuel ignition performance. Conventional cetane number improvers yielded only minor improvements. However, certain emulsifiers function by themselves as cetane number improvers. Relations between emitted NO, smoke, and fuel consumption are given at various injection timings for microemulsions with 10, 20, and 30 pct water, and the effect in other types of emissions is discussed.

Gollahalli, S. R., M. L. Rasmussen, and S. J. Moussavi. Combustion of Drops and Sprays of No. 2 Diesel Oil and Its Emulsions With Water and Methanol, Volume I. Experimental. Department of Transportation, Contract No. DOT-RC-82011, July 1978-August 1979, 230 pp.

This report deals with an investigation directed to understand the combustion behavior of No. 2 diesel oil and its emulsions with water and methanol. This volume (I) of the report presents the experimental results of the study, whereas Volume II describes the theoretical analysis. The experiments are carried out in three parts: (a) a study of stability and microstructure of emulsions, (b) single drop combustion studies, and (c) spray combustion studies. In the first part, the effects of internal phase concentration, the surfactant concentration, and the time of

blending on the stability and microstructure of emulsions are examined. In the second part the effects of emulsion characteristics (internal phase concentration, surfactant concentration, and type of internal phase) and ambient variables (chamber temperature, chamber pressure, chamber oxygen concentration, and preheat temperature of emulsions) on the combustion behavior of unsupported single-isolated drops are studied. In the third part the effects of all the variables examined in part b on the combustion behavior and pollutant emission of sprays are studied. The results show that unsupported drops of No. 2 diesel oil emulsions with activity depends on emulsion and ambient variables. The ignition and pollutant emission characteristics of No. 2 diesel-oil sprays also are seen to be affected by emulsification.

Lawson, A., and A. J. Last. Modified Fuels for Diesel Engines by Application of Unstabilized Emulsions. Presented at the Fuels and Lubricants, Hyatt Regency, Houston, Tex., Oct. 1-4, 1979, SAE Technical Paper Series 790925, 20 pp.

An in-fuel-line mechanical emulsification has been developed at Ontario Research (the ORF HydroShear) which is compatible with installation in the fuel system of both light duty and heavy duty diesel engines. The HydroShear has been used to prepare both water/diesel and methanol/diesel emulsions having particle sizes of a few microns and with sufficient stability to be used in unstabilized form in the fuel management system of diesel engines. The installation of the HydroShear on 97 and 149 kW diesel engines is described, together with its mode of operation. A comparative study of water/diesel fuel emulsions applied to both two and four stroke cycle diesel engines has shown exhaust emissions and engine performance to be sensitive to the general engine design employed. Greatest benefits were achieved with the four-stroke engine. Particulate and NO_x emissions were reduced by up to 50%. Testing HydroShear capability to fuel engines with methanol/diesel emulsions has indicated that methanol can be used as a diesel fuel extender with this technique. Total particulate emissions were reduced 50%, with carbon black being reduced by 75%.

Murayama, T., Y. Morishima, M. Tsukahara, and N. Miyamoto. Experimental Reduction of NO_x, Smoke, and BSFC in a Diesel Engine Using Uniquely Produced Water (0-80%) to Fuel Emulsion. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780224, 16 pp.

With the aid of static mixer and non-ionic emulsifying agent, a comparatively stable water-fuel emulsion was obtained. Engine performance in a 4-cycle direct injection engine using these fuels was studied. A large reduction of NO_x concentration was obtained over the wide range of engine operation, in spite of increased ignition lag and rapid combustion. Furthermore, improvements of economy and reduction of exhaust smoke were obtained. The reduction of NO_x concentration, fuel consumption and smoke were even more remarkable when compared with operating same engine with water fumigation.

Owens, E. C., and B. R. Wright. Engine Performance and Fire Safety Characteristics of Water-Containing Diesel Fuels. U.S. Army Fuels and Lubricants Res. Lab., Contract No. DAAG53-76-C-0003, Interim Report AFLRL No. 83, December 1976, 20 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

Recent flammability evaluations conducted at U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) have shown that water-containing diesel fuels are more fire resistant (even at temperatures above the flash point) than the same fuel without the water added. These findings led to this project to evaluate the compatibility of such fuels with a full-scale diesel engine and to further assess the fire vulnerability reduction imparted by the water. Blends of base diesel fuel plus 2-pct surfactant plus as much as 10-pct water were evaluated in an unmodified LDT-465-IC engine, a multi-fuel diesel engine with wide field usage by the U.S. Army. No significant changes were observed in power output when operating the engine at equal base fuel flow rates. The smoke-reduction effects were inconclusive, but the nonvisible emissions were substantially altered. Oxides of nitrogen emissions were decreased as much as 30 pct but were accompanied by a 250 pct increase in unburned hydrocarbons. Ballistic tests conducted with 20 mm high-explosive incendiary tracer rounds demonstrated diminished fireballs and self-extinguishing ground fires at temperatures 14°C (25°F) above the base fuel flash point. Tests with the base fuel alone resulted in catastrophic fireballs and ground fires under such conditions. When 0.1 pct of a polymeric hydrocarbon antimist agent was added to the 10-pct (or 5-pct) water multiphase fuel, fire effects were almost totally eliminated. The potential fire-safety benefits and lack of major detrimental engine effects make these water/fuel blends attractive candidates for fire-resistant fuels.

Rasmussen, M. L., and S. R. Gollahalli. Combustion of Drops and Sprays of No. 2 Diesel Oil and Its Emulsions With Water and Methanol. Volume II. Theoretical. Department of Transportation, Contract No. DOT-RC-82011, July 1978-August 1979, 116 pp.

This report deals with an investigation directed to understand the combustion behavior of No. 2 diesel oil and its emulsions with water and methanol. This Volume (II) of the report presents the theoretical analysis, whereas Volume I describes the experimental studies. Two theoretical models to analyze the variation of drop temperature with emulsion parameters have been developed. The differential model considers the diffusion and specific heat effects inside the composite emulsion drop. The integral model does not consider the temperature variation inside the drop. Analytic solutions for both models have been developed assuming constant properties. The integral model has also been solved numerically considering the variation of properties and using some empirical input data. Both models predict the variation of drop disruption time with the internal phase content in qualitative agreement with the experimentally measured values for the drops of No. 2 diesel oil-water emulsion with water volume fractions up to 0.20.

Robustov, V. V. Problems and Prospects in Use of Emulsified Fuels. Chemmotology of Fuels and Lubricants (Chemistry and Technology of Fuels and Oils), v. 16, No. 9-10, Sept.-Oct. 1980, pp. 578-580.

In connection with the increasing demand for high-octane gasolines and distillate fuels, attempts have been made in recent years to convert automotive vehicles and tractors to operate on emulsified fuels, otherwise known as water-fuel emulsions (WFE). Theory and experience have shown that the feed of water to engine cylinders in the form of an emulsion of water with the fuel (with the same feed system as used for the fuel) tends to give more intense combustion, since the "microexplosions" of water drops coated with a fuel film tend to increase the completeness of fuel combustion. Lower fuel consumption and lower toxicity of the exhaust gas can be achieved by changing the parameters of the fuel combustion process. This paper describes some of the research performed in the area of emulsified fuels and some of the existing problems. The author states that the task of widespread conversion of engines to emulsified fuel is one that can be fully resolved.

Strait, J., J. J. Boedicker, and K. C. Johansen. Diesel Oil and Ethanol Mixtures for Diesel-Powered Farm Tractors. Presented at the Fuels and Lubricants Conference, Hyatt Regency, Houston, Texas, Oct. 1-4, 1979, SAE Technical Paper Series 790958, 16 pp.

Absolute ethanol can be mixed with No. 1 diesel oil without separation if the mixture remains free of water. Mixtures of diesel oil and up to 30 percent by volume of ethanol were used in laboratory and field experiments in diesel tractor engines. When engines were operated on fuels containing ethanol, the maximum power output of the engines was reduced, fuel consumption increased, engine noise increased, and the delay period was extended. These changes in engine operating characteristics increased in magnitude as the proportion of ethanol in the fuel increased. No significant performance characteristic of the diesel engine measured in this study was improved by the use of a diesel oil-ethanol blend to replace diesel oil to fuel the engine. Based upon this study, there appears to be no valid technical reason to recommend that diesel-powered farm tractors be operated on a mixture of diesel oil and ethanol in preference to diesel oil.

Valdmanis, E., and D. E. Wulfhorst. The Effects of Emulsified Fuels and Water Induction on Diesel Combustion. See IC.

Walter, R., and J. White (ed. by). Proceedings of Symposium on Water-in-Fuel Emulsions in Combustion. U.S. Department of Transportation, Report No. CG-D-12-78, Reprint September 1978, Final Report, 230 pp.

This volume contains the proceedings of a symposium on water-in-fuel emulsions held at the DOT Transportaion Systems Center April 20 and 21, 1977. This symposium sponsored by the DOT's U.S. Coast Guard and Office

of the Secretary, provided a forum for researchers involved in the use of water-in-fuel emulsions in combustion. Participants from academia, industry and government contributed papers and discussed the properties, production and utilization of water-in-fuel emulsions in boilers, diesels, and gas turbines. These proceedings contain the abstracts of 18 papers as well as the discussions on these papers and recommendations for needed research in emulsified fuel technology. Also included are a list of attendees and a bibliography on the subject of emulsified fuels.

Walter, R. (ed. by). Second Symposium on Water-in-Fuel Emulsions in combustion. U.S. Department of Transportation Final Report No. CG-D-50-79, August 1979, 136 pp.

This volume contains the proceedings of the second symposium on water-in-fuel emulsions held at the DOT Transportation Systems Center, September 12 and 13, 1978. This symposium sponsored by the DOT's U.S. Coast Guard and Research and Special Programs Administration, provided a forum for researchers involved in the use of water-in-fuel emulsions in combustion. Participants from academia, industry, and government contributed papers and discussed the properties, production, and utilization of water-in-fuel emulsions in boilers, diesels, and gas turbines. These proceedings contain the abstracts of 19 papers as well as the discussions on these papers and recommendations for needed research in emulsified fuel technology. Also included is a list of attendees.

Walter, R. A., J. O. Storment, and C. W. Coon. Single-Cylinder Diesel Engine Tests With Unstabilized Water-in-Fuel Emulsions. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Tex., June 25-30, 1978, APCA Preprint 78-54.1, 24 pp.

The primary objective of this effort was the performance of a thorough test program that would define the possible benefits associated with the use of water-fuel emulsions in diesel engines. Tests were conducted using a single-cylinder research engine to maximize the data potential and to determine the advisability of later pursuing a testing program with large scale engines. It should be noted that a comparison of particular devices was not the objective of this program. Both of the systems supplied to SwRI were thoroughly protected by nondisclosure agreements. Instead, the testing program was oriented toward evaluation of the possible benefits that might accrue from the use of the emulsions supplied by the selected systems.

Weatherford, W. D., Jr., G. E. Fodor, D. W. Naegeli, E. C. Owens, B. R. Wright, and F. W. Schaekel. Army Fire-Resistant Diesel Fuel. Presented at the Fuels and Lubricants, Hyatt Regency, Houston, Tex., Oct. 1-4, 1979, SAE Technical Paper Series 790926, 28 pp.

Various means have been investigated for reducing fuel fire vulnerability of Army combat vehicles by altering fuel compositions. Extensive

laboratory studies have yielded clear-to-hazy fire-resistant fuel micro-emulsions of water in surfactant-stabilized diesel fuel, with and without an antimist agent. The surfactant is a mixture of reaction products of diethanolamine and oleic acid. Flammability and ballistic tests reveal diminished mist flammability with self-extinguishing pool fires, even at temperatures above the base fuel flash point. No difficulties have been encountered in starting, idling, and running unmodified diesel engines on such fuels under typical operating conditions.

E. Chemistry, Specifications, Properties of Lubricants

Boone, E. F., and F. E. Didot. Field Experience of Extended Drain Interval in Diesel Lubricant Performance. Presented at the Automobile Eng. Meeting, Dearborn, Mich., Oct. 18-22, 1976, SAE Preprint 760719, 16 pp.

Four engine oils were field tested in three different types of truck diesel engines using 100,000 mile drain intervals. Periodic oil samples from each test vehicle were analyzed. After 100,000 miles, engines were dismantled, inspected and rated. Results of this test work indicate that drain intervals much longer than currently recommended are possible with current engine and oil technology. Also, filter change intervals can also be extended from current practice. Included in this paper are analytical data from the used oil samples and engine inspection reports for the four oil formulations tested.

Coant, P. M., C. E. Habermann, and H. V. Lowther. High Performance Medium-Speed Diesel Engine Oils. Presented at the Diesel & Gas Engine Power Conference and Exhibit, St. Louis, Mo., April 16-20, 1972, ASME Preprint 72-DGP-3, 11 pp.

This paper presents extensive lubricating oil technology obtained during the development of lubricants for high output medium-speed diesels. The oil requirements for present and future high output medium-speed diesels are analyzed with special emphasis on thermal stability, high temperature detergency, load-carrying capability, and oil life. The paper describes a study of base stock stability in a specially developed Spiral Coker Test and an evaluation of additive thermal stability in a Helix Coker Test. The influence of additive type and level on high temperature detergency is also presented under moderate and high severity diesel engine operation. Lubricant scuffing and wear protection properties are discussed in laboratory and field evaluations. The various parameters affecting the lubricating oil life such as oil consumption, oil deterioration, and additive retention are studied in laboratory bench and engine tests as well as in prolonged field tests.

Diesel & Gas Turbine Progress. New Multigrade Engine Oils for Vehicle Diesels. March 1976, pp. 62-63.

This article deals with Shell's new heavy duty 20W-40 multigrade lube oil for high speed diesel engines. The researchers tested the oil in various engines by operating them for 300,000 miles. The engines were disassembled and compared to an engine that used a straight grade oil. The results indicated that the multigrade oil had considerable less wear.

Diesel & Gas Turbine Progress. New Long-Life Lubricant for Heavy-Duty, High Speed Diesels. June 1976, pp. 26-27.

Exxon has developed a new extra long-life lubricant, called XD-3 Extra, which can be used for 50,000 miles. This article looks at the advantages of the new oil over a conventional oil in terms of oil properties and wear characteristics.

Kay, R. E., and J. A. O'Brien. New Multigrade SE/CD Lubricant. Presented at the Combined Commercial Vehicle and Fuels & Lubricants Meetings, Chicago, Ill., June 17-21, 1974, SAE Preprint 740523, 8 pp.

A new 20W-40 multigrade oil that meets SE/CD specifications promises to perform satisfactorily in both gasoline and heavy-duty diesel engines. It permits easy cold starts, and it has passed the Caterpillar Tractor CO. OL-1 and the Mack T-1 tests and all of the SE/CD test requirements. Comprising a low-viscosity base stock blended with a V.I. improver and an improved detergent-inhibitor additive package that minimizes ring sticking, this oil is probably the forerunner of a series of SE/CD oils with even wider crossgradings.

Kiefer, W. C. Synthetic Lubricants for Earthmoving Equipment. Presented at the Earthmoving Ind. Conference, Central Ill. Section, Peoria, Ill., Apr. 15-16, 1975, SAE Preprint 750556, 12 pp.

Synthetic lubricants are not new breeds of fluids which were suddenly developed because of scarce petroleum oils. They have been available for many years and utilized as lubricants for diversified ranges of specialized applications. These specific fluids were developed with tailored physical and chemical properties best suited to the severe demands of equipment operating under wide temperature ranges and other hostile environments. This paper covers applications on earthmoving equipment such as gear lubrication, hydraulic asnd torque convertor fluid, engine oils and greases exposed to wide temperature ranges and, especially, low temperatures. Large, heavy duty earthmoving equipment is being exposed to very low temperature environments, as low as -65°F in some remote areas of the world. This demands lubricants that have better low temperature properties than found in petroleum base types. This paper will cover only those that are best suited to this area of application and those which are economical and readily available.

Knight, C. H. A Turbocharged Diesel Engine Test for Evaluating Ring sticking Tendencies of High Quality Diesel Engine Oils. Presented at the Automobile Eng. Meeting, Dearborn, Mich., Oct. 18-22, 1976, SAE Preprint 760724, 16 pp.

The use of a European 5945 cc (363 cc cubic inch displacement, CID) engine and 300 hour test procedure is evaluated as a means of predicting the ring sticking tendencies of crankcase oils in turbocharged diesel engines.

Correlative data are provided with the Caterpillar OL-1 Test. The 5945 cc engine test identifies the ring sticking tendencies of two oils in the same manner as the known field histories of these lubricants. Progress is reported on test development and refinement. Test results show the superior ability of a selected oil formulation to minimize piston ring sticking tendencies.

Losikov, B. V., K. N. Golovanov, and S. M. Livshits. Use of Fuel Additives to Reduce Diesel Exhaust Smoke. See IIA.

McDonnell, T. F., and S. A. Tempe. The Effects of Engine Oil Additives on Vehicle Fuel Economy, Emissions, Emission Control Components and Engine Wear. Presented at the Internat. Fuels and Lubricants Meeting, Toronto, Can., Nov. 13-16, 1978, SAE Technical Paper Series 780962, 26 pp.

Legislated fuel economy standards have necessitated investigations to determine the cost-effectiveness of "low-friction" engine lubricants to assist in attaining these goals. Preliminary testing indicated friction reduction engine oil additives may provide potentially significant improvements in fuel economy over conventional and low viscosity engine oils. Vehicle test programs were undertaken to evaluate the effects of molybdenum disulfide, graphite and soluble additives on fuel economy, engine cleanliness and wear, as well as exhaust emission levels and engine and emission component durability. The significant fuel economy improvements and effects on all aforementioned variables are detailed in the paper.

Smith, M. F., Jr., N. Tunkel, H. E. Bachman, and W. J. Fernandez. A New Look at Multigraded Diesel Engine Oils. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760558, 13 pp.

Benefits of multigraded oils developed for diesel engine service have been found in performance areas such as low temperature engine cranking/starting, oil consumption rate, bearing wear, and fuel economy in stop-and-go service. Studies continue to indicate that multigraded diesel engine oils should be formulated with a minimum amount of pure polymer, consistent with desired viscometric targets, in order to minimize piston deposit formation. Premium multigraded, extended drain lubricants depend upon modern viscosity improved technology coupled with improved detergent-inhibitor additive technology.

Younghouse, E. C. Mixed Locomotive Fleets Require a Balanced Diesel Lubricant. Presented at the ASME Diesel & Gas Engine Power Conference and Exhibit, Dallas, Tex., April 12-16, 1970, ASME Preprint 70-DGP-8, 16 pp.

The demands now placed on the crankcase lubricant for railroad diesel locomotives in the U.S. span a very broad range of performance qualities. The builder of two-stroke cycle engines requires a medium VI oil with outstanding oxidation resistance and unique protection against corrosion and frictional failure of silver-plated bearings. For the suppliers of four-stroke cycle engines, the oil must control piston ring sticking, scuffing wear and filter plugging. Finally, the railroads insist on one oil listed by each of the builders and capable of extended drain periods and maximum engine life often with low quality fuel and extra severe service. A comprehensive development study was conducted to achieve a balanced lubricant for these specifications. This new lube oil features outstanding oxidation resistance, alkalinity retention, corrosion protection and detergency. This is achieved with an additive package containing an improved dispersant and an optimum combination of calcium detergent-inhibitors with limited ash content. The oil has further shown excellent control of wear of power assemblies and critical bearings in field service. The knowledge and experience developed in this test will serve to guide future studies leading to the next level of improved lubricant performance anticipated for future engines.

Zalar, F. V., and D. E. Nisbett. Current Developments in Diesel Engine Oil Technology. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780182, 13 pp.

Multifunctional or universal lubricating oils which service both gasoline and diesel engines have gained widespread commercial acceptance. Since 1970, numerous changes and additions have altered the performance tests and specifications which define the quality of these lubricants. New parameters include single cylinder and multicylinder diesel engine testing, valve train wear protection, clutch plate friction retention, extended drain interval and lubricant related fuel economy. In response to these requirements, new additive systems were developed. This paper discusses observed base oil-additive-engine test interactions and compares the performance of one of these additive systems to that of the old.

III. DIESEL ENGINE EMISSIONS

A. Laboratory Measurement and Instrumentation

1. HC, CO, NO_x, smoke

Anderton, D., and V. K. Duggal. Diesel Engine Emissions and Noise. J. Inst. Fuel, v. 49, No. 398, March 1976, pp. 20-25.

The paper states a criterion for a more socially acceptable diesel engine. A number of engines (100-350 bhp) have been assessed for combustion noise, overall noise, smoke and pollutant gases (CO, NO, HC) at the same test bed condition. The results show that turbocharging a four stroke naturally aspirated diesel engine goes some way toward reduced combustion noise, carbon monoxide, specific fuel comsumption, smoke and hydrocarbons emissions. These reductions can be obtained at the same time as an increase in power output. The exhaust nitric oxide levels are not significantly affected at the injection timings used. The specific emissions per litre capacity are observed to increase as the engine swept volume is decreased.

Bascom, R. C., W. S. Chiu, and R. J. Padd. Measurement and Evaluation of Diesel Smoke. Presented at the Internat. Automotive Eng. Cong., Detroit, Mich., Jan, 8-12, 1973, SAE Preprint 730212, 20 pp.

The development of smoke measurement procedures and instruments has been one of the significant factors contributing to the reduction of smoke from diesel-powered trucks. There is a need, however, for better information on the relation between measurements and the appearance of the smoke plume, for improved smokemeters, and for common international test procedures. Studies of smoke plumes using jet theory, alumina tracer, and hydraulic analog techniques indicate that the plumes are sometimes unstable and subject to large-scale shedding in the region where free-plume smokemeters are located. This introduces a significant random variation into smoke measurements made in this location. A future test procedure based on smoke measurements made with a long path (500 mm) in-line smokemeter during a dynamic cycle is suggested for consideration. Smoke limits would be based on tests similar to those conducted by MIRA to relate smoke levels and engine size to human response.

Black, F., and L. High. Methodology for Determining Particulate and Gaseous Diesel Hydrocarbon Emissions. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790422, 16 pp.

The 1977 Clean Air Act Amendments, which call for broad study of motor vehicles particulate emissions, coupled with requirements for improved fuel economy, have greatly increased the interest and study of diesel powered motor vehicles. Analytical procedures are described which permit measurement of diesel organic emissions, including the particulate and gas phases, from carbon number 1 to carbon number 40. The partitioning of the

emitted organics[1] between the gas and particulate phases is examined with a variety of controllable sampling parameters. These parameters include variations in particulate sampling probe configurations and sampling rates, variable dilution ratios and corresponding temperatures, and filter media.

[1] The term organics as used in this paper refers to a complex mixture of compounds including hydrocarbons and substituted hydrocarbons (e.g. O, N, and/or S substitution).

Black, F. M., L. E. High, and A. Fontijn. Chemiluminescence Measurement of Reactivity Weighted Ethylene-Equivalent Hydrocarbons. Environmental Science & Technology, v. 11, No. 6, June 1977, pp. 597-601.

A reactive hydrocarbon analyzer (RHA), based on the chemiluminescent reaction of hydrocarbons with oxygen atoms, is used to provide a rapid indication of reactivity weighted hydrocarbon mass in automobile exhaust. Samples are reported by their ethylene-equivalent concentration--the concentration of ethylene which would give the same mass-reactivity product as the exhaust hydrocarbon mixture. These are compared to ethylene-equivalent concentrations obtained by the much more cumbersome procedure of weighting the individual sample hydrocarbons, determined by gas chromatography (GC), by their respective relative short-term photochemical reactivities, summing these results, and equating them to ethylene. Procedures are also described to eliminate a negative interference to the RHA method resultant from H_2O quenching of the chemiluminescence emitter. The RHA and GC ethylene-equivalent concentrations correlate within 5%.

CONCAWE's Special Task Force on the Study of Air Pollution, Sampling and Survey Techniques. Methods for the Determination of Nitrogen Oxides in the Atmosphere. Report No. 5/75, March 1975, 75 pp.

A description is given of the many methods which are used for the determination of nitric oxide and nitrogen dioxide in the atmosphere. Problems which have been encountered with some of the generally applied procedures have been discussed. The report has the overall purpose of giving condensed information in this field and of providing guidance for selecting the most appropriate analytical method for the work in hand. In order to facilitate this, the methods are classified as discontinuous analysis methods or quantitative automatic field methods and descriptions of methods under these two classifications are grouped in two separate sections of the report. The section on field methods includes the recent but very important development of chemiluminescence analysers. Since many of the methods are specific to nitrogen dioxide, a short review is given of the oxidation techniques in use with the determination of nitric oxide. Calibration is recognized as a vital part of any intrumentation and techniques for calibrating the various instruments are described. Methods are assessed mainly on the principles involved since it would be impractical to give up-to-date objective assessments of all the instruments in current use. A listing of commercially available analysers has been given and the available specifications as given in the

manufacturers' technical bulletins have been tabulated. Whilst recognizing that cost is an important part in the assessment of an instrument, cost data have been given in the currency of the country of manufacturing as an approximate guide to prices.

Coordinating Research Council, Inc. Cooperative Evaluation of Techniques for Measuring Hydrocarbons in Diesel Exhaust. New York, October 1969, rev. February 1970, CRC Report No. 431, 31 pp.

The CRC-APRAC Program Group on composition of Diesel Exhaust conducted a cooperative experimental program from 1967 to 1969 to evaluate techniques for measuring total hydrocarbons in diesel exhaust. A small diesel engine was shipped to 13 laboratories in succession, and each laboratory measured exhaust hydrocarbon concentrations by methods of their own choosing. The standard deviation of the measured concentrations was on the order of 50% of the median values. Sources of the variation could be true differences in the exhaust samples from the engine, differences among laboratories in taking and handling the samples, and differences in instrument responses. While the contributions from these sources could not be separated completely, differences in sampling among laboratories appeared to be a major source of the variation. Errors with currently used procedures are unacceptable for engineering measurements and further work should be conducted at one laboratory with one multi-cylinder engine using all available techniques to locate and remedy as many of the sources of error as possible.

Coordinating Research Council, Inc. Cooperative Evaluation of Techniques for Measuring Hydrocarbons in Diesel Exhaust--Phase IV: 1972-1973. New York. November 1975. CRC Report No. 471, 34 pp.

In 1972 and 1973, the Coordinating Research Council, Inc. - Air Pollution Research Advisory Committee (CRC-APRAC) Program Group on Diesel Exhaust carried out a fourth program to evaluate techniques for measuring the concentration of hydrocarbons in diesel exhaust. A multi-cylinder diesel generating set was circulated among 15 participating laboratories, and each laboratory measured exhaust hydrocarbons by methods complied with the SAE Recommended Practice J215, "Continuous Hydrogen Analysis of Diesel Exhaust." The labs also analyzed the concentrations of hydrocarbons of two bottled gases having unknown compositions. The report gives the data from the different laboratories and determines the standard deviations of the results.

Coordinating Research Council. Cooperative Evaluation of Techniques for Measuring Nitric Oxide and Carbon Monoxide in Diesel Exhaust, Phase IV Test Results. New York, January 1975, CRC Report No. 472, 50 pp.

This is the fourth in a series of tests conducted as a CRC cooperative program to evaluate the measurement methods used to analyze diesel exhaust gas constituents. A multi-cylinder engine was circulated to 15 participants who measured emissions at three engine conditions. All 15 participants measured nitric oxide and carbon monoxide with several laboratories measuring nitric oxide by both NDIR and CHEMI. Some participants also measured carbon dioxide, nitrogen dioxide, oxygen and "unknown" span gases. These test results were compared with the Phase II cooperative tests which involved simultaneous measurement of emissions by participants. The precision of the results was poorer in Phase IV than Phase III.

Coordinating Research Council, Inc. Cooperative Study of Heavy Duty Diesel Emission Measurement Methods. New York, July 1976, CRC Report No. 487, 88 pp.; NTIS PB-257 137.

A cooperative test program was conducted by the CRC-APRAC CAPI-1-64 Emissions Subpanel to evaluate the technical aspects of a proposed EPA recommended heavy-duty diesel instrumentation and test procedure. Six laboratories participated in a series of eight tests using a multicylinder engine as the emission generator. The study compared the effects of different test instruments and different test procedures on the measurements of NO and NO_x concentrations. The report summarizes the results and makes several conclusions.

Engel, P. K., R. Silvestrini, and R. E. Thompson. Corrosion and Fouling Potential in Diesel Exhausts. See III.A.2.

Gibbs, R. E., J. D. Hyde, and S. M. Byer. Characterization of Particulate Emissions from In-Use Diesel Vehicles. See III.A.2.

Greig, J. D. Diesel Exhaust Emissions. J. of the Mine Ventilation Society of South Africa. v. 33, No. 6, June 1980, pp. 89-100.

The components of the emissions are characterized and ways and means of minimizing the concentration of the toxic components are discussed. It is shown that efficient maintenance of diesel engines is imperative to reduce the concentration of harmful gases and vapours to a minimum. More efficient atomization of preheating the fuel and, in addition, incorporating oxygenated additives into the fuel could be most advantageous.

Hare, C. T., and T. M. Baines. Characterization of Particulate and Gaseous Emissions From Two Diesel Automobiles as Functions of Fuel and Driving Cycle. Presented at the Cong. and Expòsition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790424, 44 pp.

Particulate and gaseous emissions from two light-duty diesel vehicles were measured over eight operating schedules, using five different fuels. Characterization included regulated exhaust emissions and a number of unregulated constituents. Non-routine gas measurements included phenols, hydrocarbon boiling range, and aldehydes. Particulate characterization included mass rates and concentrations, visible smoke, aerodynamic sizing, total organics, BaP, sulfate, phenols, trace elements, and major elements. Statistical analysis of emissions data was undertaken using fuel properties and operating schedule statistics as independent variables. Regressions were computed for a few variables, and analysis of variance and multiple comparisons were used where the data were not suitable for regression analysis.

Hare, C. T., and R. L. Bradow. Characterization of Heavy-Duty Diesel Gaseous and Particulate Emissions, and Effects of Fuel Compostion. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790490, 32 pp.

Gaseous and particulate emissions from two heavy-duty diesel engines were characterized while the engines were operated on five different fuels. Characterization included mass rates of major exhaust products, plus analysis of particulate matter for sulfate, trace elements, major elements, total solubles, and other properties. Analysis of rate and composition data was conducted with regard to fuel and engine effects on particulate. Two large particulate samples were also collected for later analysis on groups of organics present.

Hilliard, J. C., and R. W. Wheeler. Nitrogen Dioxide in Engine Exhaust. Society of Automotive Engineers, 1979, SAE Preprint 790691, 12 pp.

Nitrogen dioxide emissions from diesel and gasoline internal combustion engines have been measured over a range of speed, load and AFR conditions. Measured NO2 levels are very much higher than expected thermodynamically, with as much as 30 pct of the NO_x emission from a diesel engine at 15 pct load in the form of NO2. Stainless steel surfaces, platinum and copper chromite catalysts, when in the temperature range 400 to 500°C have been shown to oxidize NO to NO2 provided the CO concentration in the exhaust gas is below 0.1 pct. Analytical techniques and methods of removing NO2 have been considered.

Holtz, J. C., L. B. Berger, M. A. Elliott, and H. H. Schrenk. Diesel Engines Underground. BuMines RI 3700. See VII.A.

Holtz, J. C., L. B. Berger, M. A. Elliott, and H. H. Schrenk. Diesel Engines Underground: 1. Composition of Exhaust Gas From Engines in Proper Mechanical Condition. BuMines RI 3508, May 1940, 48 pp.

Because of the success of diesel locomotives in European coal mines, diesel engines are being considered for underground equipment. Therefore, a knowledge of the composition of exhaust gases under various operating conditions is essential. This report presents results of tests conducted to determine the composition of exhaust gases produced throughout the operating range of two commercial four-stroke diesel engines in proper mechanical condition. The author presents the results in graphs and tables and draws several conclusions.

Hurn, R. W., and W. F. Marshall. Techniques for Diesel Emissions Measurement. Presented at the Mid-Year Meeting, Detroit, Mich., May 20-24, 1968, SAE Preprint 680418, 12 pp.

Methods used in diesel emissions measurement at the Bartlesville Petroleum Research Center are described; limitations, adequacy, and needs for further development of each are discussed. Smoke measurements are reported from work with the Hartridge meter, as well as newly developed instruments that are used to view smoke plumes directly, and which seem to offer advantage over smoke meters previously used. Experience in odor assessment by a human panel using reference odor materials is reported as encouraging. Odor intensity is judged with much greater reliability than odor quality; capability to assess the latter remains wholly inadequate. Results in application of the methods for measuring diesel emissions are intended to illustrate the use of experimental techniques to reveal engine and fuel factors as they influence the character, amount, and air-polluting effect of diesel emissions. Although the data do not permit reliable assessment of any of the factors, they are useful in showing orders of magnitude and possible relative significance of the respective emissions in the several categories.

Hurn, R. W., and D. E. Seizinger. Air Pollutant Inventory--Enter the Diesel. American Petroleum Institute, Proceedings v. 45, No. 111, May 1965, pp. 127-132.

For years diesel exhausts have drawn attention from both industry and the general public. Therefore, this report is a brief study of diesel exhaust emissions. The report is based on findings in an experimental program of limited scope. The values that are reported can in no sense be considered to represent the diesel engine population, but should help to establish a better perspective of the possible contribution of diesel exhaust to photochemical air pollution.

Jeffery, P. G., and P. J. Kipping. Gas Chromatography for the Analysis of Exhaust Gases. Accuracy of Electronic Measurements in Internal Combustion Engine Development (A Symposium arranged by the Internal Combustion Engines Group, Jan. 20-31, 1966). The Inst. of Mech. Engs., London, Proceedings 1965-66, v. 180, pt. 3G, pp. 95-101.

The traditional methods for the analysis of vehicle exhaust gases have never been entirely satisfactory. The recent development of gas analysis by gas chromatographic methods offers considerable improvement in accuracy, precision, and also in time required. Difficulties still arise for certain constituents, notably sulphur dioxide and oxides of nitrogen, for which chemical methods of analysis are still preferred. The chromatographic analysis of the hydrocarbon fraction and the remaining inorganic fraction of exhaust gases, where this is required, is now a routine operation, calling for neither expert chromatographic knowledge, nor exceptional skill in manipulation. A typical gas chromatograph may be considered as comprising a number of simple building blocks, including a carrier gas flow system, a sample inlet mechanism, a chromatographic material for component resolution, a detector for those components of interest, and a display mechanism. Some form of electrical control is required; this may amount to little more than a Wheatstone bridge network, or may be a high quality linear amplifier and associated voltage-decade supply for the more sophisticated ionization detectors. Each of these building units is considered in detail, and the errors that can arise in the course of making an anlysis of an exhaust gas are noted. The possibility of gross errors arising from defective equipment is also considered.

Johnson, J. H., Dr. An Overview of Monitoring and Control Methods for Diesel Pollutants in Underground Mines Using Diesel Equipment. Presented at the 81st Annual General Meeting of CIM-1979, Montreal, Can., April 22-25, 1979, 98 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

Background information relative to the concerns for diesel particulate emissions is reviewed. A brief review of the most advanced methods for measuring ambient levels of diesel pollutants is presented. Measured pollutant levels in two metal mines are summarized including a ranking of pollutants based on their measured levels. The measured levels presented in the paper are related to the "health effects index." The various methods of controlling miner exposure to pollutant levels are reviewed. The control approaches are discussed relative to the (1) engine i.e., fuel, engine design, aftertreatment, (2) vehicle, and (3) ventilation system. A method of controlling diesel pollutant levels at the face for the load-haul-dump vehicle is proposed based on the continuous monitoring of CO2 concentration with a vehicle mounted instrument.

Johnson, J. H., E. J. Sienicki, and O. F. Zeck. A Flame Ionization Technique for Measuring Total Hydrocarbons in Diesel Exhaust. Presented at the Mid-year Meeting, Detroit, Mich., May 20-24, 1968, SAE Preprint 680419, 14 pp.

The method of flame ionization was used for measuring total hydrocarbons in both single-cylinder and multicylinder 4-cycle, direct injection diesel engine exhaust. Use of the emission parameters of hydrocarbon concentration, pct unburned fuel, specific hydrocarbon rate, mass of hydrocarbons per million cycles, mass of hydrocarbons per mile, and mass of hydrocarbons per ton-mile are discussed. The basic approach used in the flame ionization detector is shown. The hydrocarbon sample was transferred from the exhaust system through a heated sample line and oven operating at 375°F. The sample line was aspirated to reduce the sample residence time to 2 sec. The effect various sampling locations have on hydrocarbon measurements from a single-cylinder engine is shown and discussed.

Laresgoiti, A., A. C. Loos, and G. S. Springer. Particulate and Smoke Emissions From a Light Duty Diesel Engine. Environmental Science & Technology, v. 11, No. 10, October 1977, pp. 973-978.

Particulate and smoke emissions were studied in the exhaust of a Mercedes Benz type OM 616 diesel engine. The weight and size distribution of the particulate matter emitted and the intensity of the smoke were measured at different engine loads and at various constant speeds in the range 35-96 km/h. The level of the particulates emitted during a simulated seven-mode Federal Test Procedure was also determined. The results showed that both the particulate and smoke emissions were highly dependent on engine speed and load. The particulate matter collected was analyzed for its chemical composition, showing that 60-75 wt pct of the particulate matter was organic compounds.

Linnell, R. H., and W. E. Scott. Diesel Exhaust Analysis. See V.A.3.

Lipkea, W. H., J. H. Johnson, and C. T. Vuk. The Physical and Chemical Character of Diesel Particulate Emissions--Measurement Techniques and Fundamental Considerations. See III.A.2.

Marshall, W. F. No_x Emissions from Diesel Engines--Control and Measurement Techniques. AIChE, v. 71, No. 148, 1975, pp. 114-119.

Several different types of diesel engines have been studied in an experimental investigation to determine how emissions and engine

performance are affected by engine modifications and adjustments made to reduce NO_x emissions. Exhaust levels of NO_x were determined on a continuous basis by NDIR-NDUV and by chemiluminescence. Agreement between these methods was generally good and both are well suited to engine studies. The engine variable and modifications that were studied included fuel injection timing, exhaust gas recirculation, and aftercooling. Water induction and emulsified fuels were also tried in the experiments. The best results in terms of emissions reduction with least penalty to engine performance were obtained with water induction. Turbocharger aftercooling was found to reduce emissions with little or no adverse effect on engine performance.

Matthews, R. D. The Nature and Formation of Nitrogenous Air Pollutant Emissions from Combustion Systems. See III.B 1.

Newton, C. L. The DEMA Exhaust Emission Measurement Procedure for Low and Medium Speed Internal Combustion Engines. Pres. at the Diesel and Gas Engine Power Conference and Exhibit, Houston, Tex., April 28-May 2, 1974, ASME Preprint 74-DGP-9, 8 pp.

DEMA is an association of manufacturers of large, low and medium speed, diesel, dual fuel, and spark ignited gaseous fueled internal combustion engines. This paper describes DEMA's Exhaust Emission Measurement Procedure developed to meet the specific needs of the members of the association. The considerations in developing the procedure are set forth and discussed. What should be measured, what instruments should be used, and how the data should be presented are also discussed.

Perez, J. M., L. C. Broering, and J. H. Johnson. Cooperative Evaluation of Techniques for Measuring Nitric Oxide and Carbon Monoxide. Pres. at the Automotive Eng. Cong., Detroit, Mich., Jan, 10-14, 1972, SAE Preprint 720104, 12 pp.

A Coordinating Research Council cooperative program was conducted to evaluate the measurement methods used to analyze nitric oxide and carbon monoxide in diesel exhaust. Initially, a single-cylinder test engine was circulated among participants with poor results. Tests were then conducted at one site using a multicylinder diesel engine. Six organizations participated in the program. Exhaust analyses were conducted at steady-state engine conditions and on a 3 min cycle test. Span gases of unknown concentration were also analyzed. The participant's results varied but averaged less than ±5% standard deviation both within (repeatability) and among (reproducibility) the instruments. The short cycle test was in good agreement with the steady-state measurements. No significant difference in the use of Drierite, nonindicating Drierite, or Aquasorb desiccants was evident in sampling system tests. The instrumentation and methods used in this study were satisfactory for conducting emissions measurements of diesel exhaust.

Perez, J. M., W. C. Clemmens, L. C. Broering, and J. H. Johnson. Cooperative Study of Heavy Duty Diesel Emission Measurement Methods. Pres. at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780112, 24 pp.

A cooperative test program was conducted by the CRC-APRAC CAPI-1-64 Composition of Diesel Exhaust Program Group to evaluate the technical aspects of a proposed EPA recommended Heavy Duty Diesel Emission Measurement and Test Procedure. The proposed changes affected the sampling configurations and the types of instruments used. Six participants studied the effects of a number of variables on the proposed changes and evaluated some alternative systems that included both CHEMI and NDIR instruments. The tests were conducted at one site using a multicylinder engine operating on the 13-Mode Cycle. Equivalency of systems was demonstrated and the best performance was obtained with a special NDIR system.

Sejekan, B. G., P. S. Rao, and B. S. Murthy. Analytical Methods for the Determination of Benzo (A) Pyrene from Engine Exhaust. Proceedings of the Third National Conference on I. C. Engines and Combustion. Sarita Prakashan, Meerut, India, Dec. 10-12, 1976, pp. 421-248.

Polynuclear Aromatic Hydrocarbons are at present the most extensively studied trace components in the polluted air and in automobile engine exhaust. This paper reviews the methods which are available in literature. The merits and demerits of various analytical methods and more highly selective methods that have been found to be of use in air pollution research are discussed. This paper describes a new simple and specific method for the analysis of environmental carcinogen, benzo (a) pyrene, from the automobile engine exhaust. Column chromatography and thin layer chromatography are used for separation and spectrophotofluorimeter is used for the estimation of benzo (a) pyrene at an excitation wavelength of 365 mm and emission wavelength of 432 mm.

Shaffernocker, W. M., and C. M. Stanforth. Smoke Measurement Techniques. Pres. at the Air Transportation Meeting, New York, April 29-May 2, 1968, SAE Preprint 680346, 24 pp.

The measurement of the smoking characteristics of jet engines and jet engine components is necessary to evaluate the relative merits of proposed methods of smoke reduction, identify sources, and estimate the visibility of the exhaust plume. Several techniques have been employed by the General Electric Co. to collect data over a wide range of environment. Techniques evaluated included optical systems, quantitative gravimetric system, and soiled tape methods. Many of the soiled tape methods of measuring smoke are compared, and a calculation procedure is described for making a direct comparison of any two soiled tape methods. The soiled tape method used by General Electric to measure jet engine smoke is described in detail. The measurement system utilizes a GE spot meter which filters the smoke through Watman paper and produces a smoke

number that is based upon the diffuse reflection from the filtrate produced by filtering 0.3 cu ft of smoke through a square inch of filter paper.

Society of Automotive Engineers, Inc. Continuous Hydrocarbon Analysis of Diesel Emissions. SAE Handbook, 1978, SAE J215 pp. 25.16-25.20.

This SAE Recommended Practice provides for the continuous measurement of the hydrocarbon concentration in diesel exhaust. The method presented is the current recommendation for the use of flame ionization detectors to determine the hydrocarbon content of diesel engine exhaust, or exhaust of vehicles using diesel engines, when operating at steady-state. The requirements of the associated sampling system and a general procedure for a continuous measuring method are presented.

Society of Automotive Engineers, Inc. Diesel Engine Emission Measurement Procedure. SAE Handbook, 1978, SAE J1003, pp. 25.20-25.21.

This SAE Recommended Practice is intended for use as a test procedure to determine the gaseous emission levels of diesel engines. The test procedure consists of a prescribed sequence of engine operating conditions of an engine dynamometer with measurement of HC, NO, and CO during 13 steady-state modes with 5 modes at rated engine speed, 5 modes at an intermediate engine speed, and 3 modes at idle speed.

Society of Automotive Engineers, Inc. Diesel Engine Smoke Measurenent (Steady State). SAE Handbook, 1978, SAE J255, pp. 25.21-25.27.

The purpose of this report is to provide an understanding of the nature of diesel smoke, how it can be measured, and how the various measurement methods can be correlated. Except for defining the various types of smoke, the report deals solely with the steady-state measurement of black smoke. For the benefit of those who wish to study various aspects of the subject in greater depth, a list of useful references is included in the bibliography.

Society of Automotive Engineers, Inc. Diesel Smoke Measurement Procedure. SAE Handbook, 1978, SAE J35, pp. 25.38-25.40.

The SAE Recommended Practive provides a procedure for the assessment of transient and steady-state smoke emissions from vehicular diesel engines using an engine dynamometer cycle which simulates normal operating conditions. While intended for engine development and evaluation, it is similar to a procedure which has been used for regulatory approval by the United States government.

Society of Automotive Engineers, Inc. Measurement of Carbon Dioxide, Carbon Monoxide, and Oxides of Nitrogen in Diesel Exhaust. SAE Handbook, 1978, SAE J177a, pp. 25.01-25.06.

This SAE Recommended Practice provides for the measurement of carbon dioxide, carbon monoxide, and oxides of nitrogen in diesel exhaust. The method presented applies to the analysis of the indicated constituents in diesel engine exhaust, or exhaust of vehicles using diesel engines, when operating at steady-state conditions. The measurements of carbon monoxide, carbon dioxide, and nitric oxide are based on continuous sampling and analysis by nondispersive infrared methods. A supplementary batch sampling, wet chemistry method is described for analysis of the oxides of nitrogen.

Spearot, J. A., and N. E. Gallopoulos. Concentrations of Nitrogen Oxides in Crankcase Gases. See III.G.

Springer, K. J. Emissions From Diesel and Stratified Charge Powered Cars. Southwest Res. Inst. (San Antonio, Tex.), Environmental Protection Agency Contract No. PH-22-68-23, EPA Report No. EPA-460/3-75-001-a, December 1974, 314 pp.; available for consultation at Twin Cities Res. Center, Minneapolis, Minn.

A total of ten passenger cars, four powered by diesel engines, two by stratified charge gasoline engines, one by a stratified charge operating on gasoline and diesel fuel, two by control equipped conventional engines, and one powered by a gas turbine, have been subjected to a wide variety of emissions evaluations. The vehicles, all late model, low mileage, included a Nissan Datsun, a Mercedes 220D, a Peugeot 504D, an Opel Rekord 2100D, a standard Capri, a stratified charge (PROCO) Capri, a low emission prototype Ford LTD, the Texaco TCCS stratified charge powered Cricket operated on gasoline and on diesel fuel, a Honda CVCC stratified charge, and a Chrysler gas turbine car. All were 4-cylinder except the LTD and the gas turbine. Tailpipe emissions were measured by the 1975 light duty Federal Test Procedure for gaseous emissions. Smoke and fuel economy were also determined during this test cycle. Chassis dynamometer versions of the 1974 heavy duty diesel smoke and gaseous emissions tests were employed. Odor and related instrumental-chemical measurements were made under seven steady state and three acceleration conditions. The Ford LTD and Chrysler turbine car evaluations were limited to odor and related gaseous emissions. The prototype diesel odor analytical system, developed under CRC contract, was applied to the exhaust from both diesel and gasoline engines. Its use as a predictive method of diesel odor was investigated. Noise measurements were taken by SAE driveby as well as under a variety of exterior-interior conditions. Comparisons of the results of all vehicles are by emission category. The emissions from the group of diesel cars are compared to the conventional gasoline, Ford PROCO, Texaco TCCS, and Honda CVCC.

Springer, G. S., and D. J. Patterson (ed. by). Engine Emissions: Pollutant Formation and Measurement. Plenum Press, New York-London, 1973, 365 pp.

This book consists of 9 chapters on pollutant formation and measurement of both gas and diesel engines. Chapter 1 deals with the various kinds of emissions and their formation. Chapters 2, 3, 4, and 5 cover the emissions of gasoline engines. Chapter 6 covers the emissions of various designs of diesel engines. The last chapters explain the different techniques used for measuring the emissions.

Springer, K. J., and H. E. Dietzmann. An Investigation of Diesel-Powered Vehicle Odor and Smoke, Part IV. Southwest Res. Inst. (San Antonio, Tex.), Environmental Protection Agency Contract No. PH-22-68-23, April 1971, 100 pp; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

This is the fourth in a series of reports covering research findings in a number of diesel emissions areas. This project, of eighteen months duration, was sponsored by the Environmental Protection Agency, Air Pollution Control Office under Contract PH-22-68-23. Some items reported on are continuations of investigations started during previous parts of the long-range investigation of diesel emissions. Such a project is the correlation of instrumental and chemical analyses of the exhaust to odor ratings from a trained panel of observers. Progress has been made in extending the usefulness of the panel by direct sampling and analysis, and full-scale correlation equations (multiple linear regression) are offered and explained. Notable indicators of odor, though not in themselves necessarily odorous, are acrolein, carbon dioxide, hydrocarbons, nitric oxide, aliphatic aldehydes, and ethylene. A fleet test of improved needle-type fuel injectors has demonstrated their ability to reduce odor, smoke, hydrocarbons, and carbon monoxide, while increasing nitric oxide slightly, from two-cycle-powered city buses using old style crown valve-type injectors. A procedure for sampling and analyzing gaseous emissions of hydrocarbons, CO, and NO on a 13-mode steady state basis was perfected for use in comparing control device performance, etc. The procedure can be used with chassis- or stationary-operated engines with essentially equal results. Using this gaseous emissions procedure plus the odor and smoke measurement methods already in hand, several small studies were made. Two studies, the effect of inlet air humidity and fuel injection timing indicated a gross effect on nitric oxide with a countereffect on smoke. Another study of the effect of a barium-type smoke suppressant indicated no gross effect on odor, hydrocarbons, CO or NO, and a gross reduction in visible smoke. Six more diesel-powered vehicles were subjected to a limited series of tests to acquire baseline smoke, odor, and gaseous emissions measurements. Four of the vehicles were city-suburban delivery trucks powered by mid-range diesels. Two more smoke additives were given a screening test to determine their ability to reduce smoke. The conclusions and recommendations section suggests ways the research findings can be used to abate diesel emissions, and indicates a number of additional avenues of research, both control technology as well as measurement procedures.

Springer, K. J. An Investigation of Diesel-Powered Vehicle Emissions, Part V. Southwest Res. Inst. (San Antonio, Tex.), Environmental Protection Agency Contract No. PH-22-68-23, April 1974, 173 pp.; available for consultation at Twin Cities Res. Center, Minneapolis, Minn.

This is the fifth in a series of reports covering research findings in a number of diesel emissions areas. This report, covering three years of activity, was sponsored by the Environmental Protection Agency under Contract PH-22-68-23. The project investigated five areas including the fleet test of a turbocharger kit for reduced smoke from in-service diesel trucks, a parametric study of alternative methods to reduce oxides of nitrogen from a two-stroke bus type engine, the effect of a veritical stack on bus exhaust odor dilution and noticeability, preliminary evaluation of control methods such as experimental injectors and fuel additives, and analysis of odor correlation data specific to city bus type engines. The three truck, eight-month fleet test of the turbocharger retrofit kit was highly successful in essentially eliminating visible smoke from the Cummins NHC-250 engine popularly used in truck tractors. The parametric study of ways to reduce NO_x from the GM Detroit Diesel 6V-71 engine demonstrated the difficulty in meeting stringent future California limits without loss in performance, fuel economy, and increase in visible smoke. Methods employed included water induction, injection retard, exhaust gas recirculation, reduced scavenging, injector type and appropriate combinations thereof. The effect of vertically directed exhaust on dispersing exhaust and reducing perceived odor from a city bus was conducted under a variety of field and laboratory conditions. The vertical stack was found to be effective in reducing odor noticeability with a five-fold increase in dilution over that with the conventional bumper level horizontal turned-down exhaust. The vertical stack evaluated was the GM Environmental Improvement Proposal configuration.

Springer, K. J., J. T. White, and C. J. Domke. Emissions From In-Use 1970-1971 Diesel-Powered Trucks and Buses. Presented at the Automobile Eng. Meeting, Toronto, Can., Oct. 21-25, 1974, SAE Preprint 741006, 20 pp.

A fleet of 64 heavy-duty 1970-71 model trucks and buses powered by a variety of diesel engines were tested periodically to determine exhaust smoke behavior. Smoke tests were made when the vehicle was new or nearly new and at four month intervals thereafter, or until 160,934 km (100,000 miles) odometer reading was reached. Gaseous emissions of hydrocarbon (HC), carbon monoxide (CO), and nitric oxide (NO) were measured at one point early in the project. Both smoke and gaseous emission tests were performed with chassis versions of the engine dynamometer Federal Test Procedures (FTP). Results in terms of "a" (acceleration), "b" (lugging), and"c" (peak) smoke factors versus mileage are reported for the 13 engine-vehicle-application groupings.

Storment, J. O., K. J. Springer, and K. M. Hergenrother. NO_x Studies With EMD 2-567 Diesel Engine. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Houston, Tex., April 28-May 2, 1974, ASME 74-DGP-14, 12 pp.

Effectiveness of several methods for reducing oxides of nitrogen (NO_x) emissions from a two-cylinder version of an EMD series 567C locomotive engine is discussed. The effectiveness of a particular method was determined by the amount of NO_x reduction achieved, the observed effect of other emissions constituents and engine power, and by the ease and potential expense with which the method could be implemented. On this basis, it is shown that retarded injection timing was the most effective reduction method. The next most effective method was exhaust gas recirculation (EGR), with the recirculated exhaust cooled to 125-150°F. It was necessary to reduce engine power output to keep smoke opacity from increasing when either reduction method was used. Inlet air humidification, whether used with standard or retarded injection timing, produced moderate reductions in NO_x emission. Reduction of scavenging air volume and hot (uncooled) EGR resulted in much lower NO_x, but produced substantially higher levels of carbon monoxide and smoke and engine power derating was again required to control smoke opacity. Finally, it was found that the new needle valve and low-sac injectors were generally superior to the older spherical valve injectors in their emission characteristics. Although these various effects appear real, it is unknown whether the laboratory engine behavior and absolute emission levels are applicable to full-size series 567 engines in field service.

U.S. Bureau of Mines, Bartlesville Energy Research Center. Characterization and Control of Emissions From Heavy Duty Diesel and Gasoline Fueled Engines. December 1972, 233 pp.; NTIS PB-219 052.

The report covers results from experimental work in measurement of emissions from heavy duty diesel and gasoline fueled engines and an investigation of the effectiveness of engine modifications and/or auxiliary devices for reducing emissions. Definitive engineering information was obtained on the characteristics of seven diesel and two gasoline engines. The diesel engines were operated on a 13-mode procedure and a 23-mode procedure; the gasoline engines were operated on a 9-mode procedure and a 23-mode procedure for the baseline tests and the 23-mode procedure was used in the parametric study. For the diesel engines, the control parameters, engine modification, and auxiliary devices investigated for emission control were: injection timing; injector type; fuel pump and nozzle modifications; exhaust gas recirculation (EGR); aftercooling; turbocharging; and oxidation type catalytic converters. For the gasoline engines, the control parameters, engine modifications, and auxiliary devices studied were: manifold air injection; air-fuel ratio; exhaust gas recirculation; spark timing schedules; and oxidation type catalytic converters. The report describes the test equipment and fuels, and outlines the experimental procedures for analysis and measurement. The experimental results are presented in detail.

Voiculescu, I. A., and G. L. Borman. An Experimental Study of Diesel Engine Cylinder-Averaged NO_x Histories. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780228, 16 pp.

A method of rapidly removing and quenching more than 75 pct of the cylinder content of a running diesel engine has been developed and tested. The resulting data give total nitric oxide in the cylinder versus crank-angle. The data show that nitric oxide forms rapidly reaching a peak value in 20° CA or less. For higher loads and advanced timing the concentration overshoots the exhaust value by 14 pct before decreasing to the exhaust value. A few comparisons are made between the data and four existent models.

Voorhies, A., Jr., L. R. Daniel, Jr., and L. Long. The Effect of Percent Hydrogen in Fuel on Smoke Emissions of a Compression-Ignition Engine. See II.A.

Wadman, B. Trends with Exhaust Emissions Measurement Equipment. Diesel Progress North American, V. XLVII, No. 7, July 1981, pp. 24-26.

Beckman Instruments is a major supplier of exhaust emission measurement systems to the diesel engine industry. This article describes Beckman's new emission instruments. It describes their new microprocessor-controlled exhaust analyzer, their new dilution tunnel and their new particulate sampling system.

Wagner, T. O., L. C. Broering, and J. H. Johnson. CRC Evaluation of Techniques for Measuring Hydrocarbons in Diesel Exhaust--Phase IV. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich. Feb. 24-28, 1975, SAE Preprint 750203, 8 pp.

In 1972 and 1973, the CRC-APRAC Program Group on Diesel Exhaust carried out a fourth program to evaluate techniques for measuring concentrations of hydrocarbon in diesel ehxaust. The first two programs were conducted in 1967 and 1968. In them, a single cylinder diesel engine was shipped among 13 laboratories and each laboratory measured hydrocarbon emissions by their own method. Agreement among laboratories (instruments) was poor in both programs. The third program was conducted in 1970 at one laboratory on one engine. This time, agreement among instruments was much improved from the earlier programs. The fourth program was conducted to confirm these later results. In it, a multi-cylinder diesel generating set was circulated among 15 participating laboratories, and each laboratory measured exhaust hydrocarbon by methods that complied with SAE Recommended Practice J215, "Continuous Hydrocarbon Analysis of Diesel Exhaust." They also measured hydrocarbon concentrations of two bottled gases having unknown compositions. Analyses were fairly consistent within laboratories both on bottled gases and engine exhaust: the standard deviations were 3 pct and 10 pct of the grand averages,

respectively. However, analyses differed substantially among laboratories both on bottled gases and engine exhaust; the standard deviations were about 10 pct and 22 pct of the grand averages, respectively. These results scatter more than desirable for engineering measurements, and they indicate that further improvement should be sought in techniques for analyzing hydrocarbons in diesel exhaust.

A. Laboratory Measurement and Instrumentation
2. Particulate matter

Baines, T. M., J. H. Somers, and C. A. Harvey. Heavy Duty Diesel Particulate Emission Factors. J. Air Pollution Control Assoc., v. 29, No. 6, June 1979, pp. 616-621.

For the past several years, EPA has been measuring particulate emissions from a variety of heavy-duty diesel engines through contracts with Southwest Research Institute. Particulate emissions samples have been collected using an exhaust splitter to divert a fraction of the engine exhaust into a standard dilution tunnel. A small fraction of the diluted exhaust from the tunnel is pulled through a filter from which particulate mass and, in some cases organic content of the particulate is determined. This paper discusses the sampling system and gives particulate emission factors that have been computed from truck and bus fuel consumption data as well as average truck and bus speed data from New York and Los Angeles (freeway and nonfreeway usage). Average particulate emission test results (steady state tests) for 2-stroke engines were 4.74 g/kg fuel and for 4-stroke engines were 2.64 g/kg fuel. Using average particulate emissions results, a particulate emission factor range of 0.8 to 1.3 g/km was computed. Nationwide diesel particulate emissions were calculated to be 88,000 metric tons per year.

Bird, A. N., Jr., J. D. McCain, and D. B. Harris. Particulate Sizing Techniques for Control Device Evaluation. Presented at the 66th Annual Meeting of the Air Pollution Control Assoc., Chicago, Ill., June 24-28, 1973, APCA Preprint 73-282, 21 pp.

The body of information presented in this paper is directed to those individuals concerned with the measurement and control of fine particulate emissions. The work will be of special interest to engineers who are responsible for particulate control from stationary sources. Measurement of the concentration and distribution of particles smaller than about 5 μm is necessary for assessing the potential contributions of particulate emission sources to long term atmospheric turbidity problems and human respiratory effects. To design and apply control equipment effectively, information on mass loading as a function of particle size is needed for the small particles (e.g., 0.2 to 5 μm diameter). Field and laboratory tests were conducted to evaluate inertial sizing techniques, cascade impactors and cyclones, for field measurements of control device efficiency as a function of particle size. Over 300 particle size distribution measurements were made with 11 inertial classifiers on 12 stationary emission sources. It was concluded that no single inertial sizing device was suitable for all the sampling circumstances encountered on a wide variety of stationary emission sources. It was further concluded that reliable measurements of mass loading as a function of particle size for sizes below about 5 μm required sample weighing accuracy of at least 30 μg and 10 μg accuracy was desirable. To achieve this accuracy in the field, it was necessary to use low-tare-weight (10 to 500 mg) impaction substrates (e.g., metal, foil, or glass fiber filter material).

Black, F., and L. High. Methodology for Determining Particulate and Gaseous Diesel Hydrocarbon Emissions. See III.A.1.

Breslin, J. A., A. J. Strazisar, and R. L. Stein. Size Distribution and Mass Output of Particulates From Diesel Engine Exhausts. See III.F.

Bricklemyer, B. A., and R. S. Spindt. Measurement of Polynuclear Hydrocarbons in Diesel Exhaust Gases. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780115, 12 pp.

The development and evaluation of a sampling system and analytical technique for the measurement of PNA in diesel exhaust are described. The sampling system for steady state engine operation utilizes the dilution of exhaust gas with air, injection of 14C radioactive tracers and collection of the condensed particulates on a filter. An analytical procedure was developed which consists of extraction of the filter sample, separation of certain PNA by procedures including TLC and HPLC and measurement by ultraviolet spectrophotometry. BaP and BaA emissions were determined for one diesel engine at idle, half load and full load.

Brooks, A. L., and R. Royer. Status Report on Chemical and Biological Characterization of Diesel Exhaust Emissions (Proceedings of the U.S. Department of Energy Automotive Technol. Development Contractor Coordination Meeting, Oct. 23-25, 1979). Contract No. EY-76-C-04-1013, 38 pp.

A toxicology research program has been initiated to define the potential health impact of increased light duty diesel usage. The major elements of the research are: chemical and biological characterization of the particulate material; transport and transformation of diesel particles in the environment; deposition patterns and dose from inhalation of diesel particulates using both experimental animals and man and the biological effects observed in experimental animals following chronic exposure to diesel exhaust. The data derived from this research will be utilized to conduct an integrated assessment of the health impact of diesel exhaust exposure in man. A cooperative research program with the Bartlesville Energy Technology Center (BETC) and the Transportation Systems Center (TSC) is in progress to characterize how changes in engine type, fuel type, driving cycle, environmental conditions and emissions control devices alter the chemical composition and biological activity of the organic materials associated with the exhaust particulate aerosols. Filter samples of diesel particulates collected at TSC have been extracted with organic solvents and the biological activity measured using bacterial mutagenesis tests. The extracts were fractioned and the biological activity of each fraction was tested. The first two fractions contained the greatest mass of material and were not mutagenic. All the mutagenic activity was associated with the later fractions. The chemical

characterization of the fractions has been initiated. The chemical characteristics along with the biological activity of the crude and fractionated extracts are discussed in detail.

Carpenter, K., and J. H. Johnson. Analysis of Physical Characteristics of Diesel Particulate Matter Using Transmission Electron Microscope Techniques. Presented at the Spring Meeting, Central States Sections, The Combustion Institute, Columbus, Ind., April 9-10, 1979, Paper No. CSS/CI-79-07, 32 pp.

Operating a Caterpillar 3150 diesel engine at selected modes on the EPA 13-Mode Cycle, an Andersen Mark III Inertial Impactor was used to collect particulate samples in both the undiluted and diluted exhausts. These samples were subsequently examined using the transmission electron microscope. A total of 24 samples were studied and approximately 300 photomicrographs were taken. The microscope analysis and resulting photomicrographs revealed details concerning the physical characteristics of the particulate and permitted a direct comparison of the samples collected. Specifically, the photomicrographs were used to obtain size measurements of the basic individual spherical particles that comprise the much larger aggregates/agglomerates. Nearly 12,000 particles were measured and the observed range of diameters was 70-1200 A. The mean particle diameters in the undiluted exhaust samples were 479 A and 436 A respectively. Further, the size measurements were grouped, by operating mode, to provide size distributions. These results indicated a general shift to smaller size individual spherical particles on samples collected in the diluted exhaust. It is felt that this shift is due to the generation of a very large number of extremely small particles, probably resulting from the condensation of hydrocarbons and other exhaust species that would remain in the gaseous state at the elevated temperatures of the undiluted exhaust. Such hydrocarbon condensation is graphically illustrated in many of the photomicrographs. In some instances, the condensed coating is so heavy as to completely obscure all detail of the aggregate/agglomerate on which it is adsorbed and the differences between undiluted and diluted exhaust samples are quickly discerned. Several of the samples showed what appeared to by "droplets" or "pools of liquid."

Cleary, G. J. The Contribution of Different Sources to Pollution by Polycyclic Aromatic Hydrocarbons. Clean Air, March 1968, pp. 13-17.

The contribution from automobile exhausts, coal combustion sources, products from the combustion of gaseous and liquid fuels, tire rubber, and incinerator effluents to atmospheric pollution by polycyclic hydrocarbons is examined briefly. Concentration ratios for the compounds 3.4 benzopyrene/1.12 benzoperylene and for 3.4 benzopyrene/coronene are used to examine the mode of pollution in Sydney and to compare this pattern with other cities in Great Britain and the United States of America.

Coordinating Research Council--Air Pollution Research Advisory Committee. Program, Abstracts and Summary of Presentations for CRC-APRAC Diesel Exhaust Emission Measurement Symposium. April 5-6, 1977, 68 pp.; available for consultation at Twin Cities Res. Center, Minneaplis, Minn.

This is a collection of abstracts from the CRC-APRAC Diesel Exhaust Emission Measurements Symposium held on April 5-6, 1977. The Symposium consisted of 26 lectures from University Professors and Independent Research Supervisors. This report contains only the abstracts and summaries of these lectures.

Cornilsen, B. C. Preliminary Study of the Applicability of Raman Spectroscopy to the Analysis of Diesel Emission Particulates and Coal Dust in a Coal Mine. June 1978, 13 pp.; available for consultation at Twin Cities Res. Center, Minneapolis, Minn.

This preliminary study evaluates the potential of the Raman Spectroscopic technique to distinguish between coal and diesel graphites in coal mines. The researcher presents the general background of the Raman Spectral Technique and describes tests that would have to be performed in order to determine if the technique could be used. Based on the expected differences in structure and crystallinity of the coal and diesel particulate, it is expected that the relative amounts of the two materials can be obtained.

Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particulate Sizing Techniques for Control Device Evaluation: Cascade Impactor Calibrations. Southern Res. Institute, Contract No. 68-02-0273, October 1976, 78 pp. NTIS PB-262 849.

A calibration study of five commercially available cascade impactors has been conducted to determine sizing parameters and produce monodisperse ammonium flourescein aerosol particles 18 micrometers to 1 micrometer in diameter. A pressurized Collision Nebulizer System was used to disperse Dow Corning Polystyrene Latex (PSL) sphere 2 micrometers to 0.46 micrometer in diameter. When ammonium fluorescein was used the mass collected by each impactor surface was determined using absorption spectrophotmetry of washes from the various surfaces. When sizing with the PSL spheres a Climet Instruments Model 208A Particle Analyzer was used to determine particle number concentrations at the inlet and outlet of the test impactor. Results are reported showing stage collection efficiency as a function of the square root of the Stokes number, stage collection efficiency as a function of particle size, and impactor wall losses (total, nozzle, and inlet cone) as a function of particle size. It has been determined that the values of the Stokes number for the 50 pct collection efficiency are not generally the same for each impactor stage. A table of these values is presented. Published theories do not successfully predict these values, so empirical calibration is required before these devices can be accurately used in the field or laboratory.

Dolan, D. F. Experimental and Theoretical Investigation of Diesel Exhaust Particulate Matter. See I.C.

Dow Chemical Company. Effects of Fuel Additives on the Chemical and Physical Characteristics of Particulate Emissions in Automotive Exhaust. U.S. Environmental Protection Agency, EPA Preprint EPA-22-69-145, 1970.

The effect of emission control devices on the particulate emissions of an automotive power plant was investigated. The work was divided into five tasks as follows: TASK I was the characterization of a particulate trapping system, and the determination of what effects, if any, were noted as conditions within the system were controllably varied: TASK II was the definition of a particulate baseline for a 1972 400 DIC engine, using non-leaded and low lead fuel--no emission control devices were used for the baseline runs; TASK III was the evaluation of the particulate emissions from a 1972 400 CID engine equipped with the following control devices--three different oxidation catalysts, one NO_x catalyst, and one exhaust gas recirculation system; TASK IV involved testing automobiles equipped with control devices for particulate emissions--these vehicles were supplied by both the contractor and the Government; and TASK V was to define a preliminary collection system for diesel engine particulate sampling. In all tasks particulate mass emission rates were measured as well as particle mass size distribution, carbon and hydrogen, trace metal, and benzo-a-pyrene content of the particulate. Ammonia and aldehydes were measured in the exhaust gas condensate, and gaseous emissions were determined as a routine check on engine operating conditions.

Duleep, K. G. Survey of Particulate Sampling Techniques (Proceedings of the U.S. Department of Energy Automotive Technol. Development Contractors Coordination Meeting, Dearborn, Mich., Oct. 23-25, 1979). Contract No. EC-77-C-01-2167, 24 pp.

The current interest in diesel particulate emissions has led to proposed regulations by the EPA on particulate emissions. EPA has also issued a draft recommended practice to measure particulate emissions but has left many parameters uncontrolled or unspecified within the scope of the recommended practice. The paper (1) describes the particulate formation process and the rationale behind any particulate sampling technique; (2) identifies the various unspecified parameters in EPA's draft recommended practice with reference to in-use practices; and (3) determines the effects of these parameters on measured particulate emissions. The survey shows that significant errors are possible in measuring particulate emissions depending on how the unspecified parameters in EPA's draft recommended practice are chosen.

Engel, P. K., R. Silvestrini, and R. E. Thompson. Corrosion and Fouling Potential in Diesel Exhausts. Presented at the Winter Annual Meeting, San Francisco, Calif., Dec. 10-15, 1978, ASME Preprint 78-WA/FU-5, 12 pp.

The exhaust gases from five large diesel engines--1,500 to 6,400 kW (2,000 to 8,900 hp)--were sampled at three sites over a range of engine operating conditions using fuels with 0.05 to 0.8 pct sulfur. Measurements of SO_2, SO_3, CO, CO_2, H_2O, NO, NO_x, chlorides, acid dew point peak rate temperatue of acid deposition, particulate loading, particle sizing, particulate composition and smoke number were made to characterize the diesel exhaust. In the diesel exhaust, all of the fuel sulfur was converted to sulfur oxides (SO_x). The SO_3 as a fraction of the total SO_x ranged from 2 to 8 pct varying inversely with fuel sulfur content. The average conversion to SO_3 was 3 pct. Acid dew point measurements were successfully obtained for a medium sulfur fuel (0.8 pct) and were correlated within 4 C with empirical predictions. Under typical diesel operating conditions, the acid dew point varied from 112 to 117 C (234 to 242°F) for this fuel. Total particulate emissions varied directly with fuel sulfur content. Fifty pct or greater of the total particulate emissions were less than or equal to 0.3 micrometers in size. The fouling and corrosion potential of diesel exhaust gas can be approximated given the fuel analysis and engine operating conditions.

Faxvog, F. R., and D. M. Roessler. Optacoustic Measurements of Diesel Particulate Emissions. General Motors Res. Lab., Res. Pub. GMR-2987, May 4, 1979, 10 pp.

Infrared absorption by acetylene and diesel smoke particles was measured using a differential optacoustic cell driven by a 3.4 watt CO_2 laser. Real-time particle mass concentration measurements are demonstrated. In addition it was found that the average particle extinction cross-sections per unit mass of acetylene and diesel smoke were 0.94 ± 0.1 m^2/g and 0.83 ± 0.2 m^2/g respectively at the 10.6 m wavelength.

Frisch, L. E., J. H. Johnson, and D. G. Leddy. Effect of Fuels and Dilution Ratio on Diesel Particulate Emissions. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790417, 32 pp.

An experimental investigation of the effect of fuel variables and exhaust dilution on diesel particulate emissions from a Caterpillar 3208 direct injection naturally aspirated engine is presented. Three test fuels with widely varying gravity, volatility, aromatic and sulfur content were used. Exhaust dilution was varied from 50:1 volume dilution ratio to 1:1 (undiluted). Particulate characterization of the total particulates, sulfates, soluble organic fraction and the fractional break down of the soluble fraction are shown. Both fuel variables and exhaust dilution were shown to have a significant effect on the measured particulate emission levels.

Funkenbusch, E. F., D. G. Leddy, and J. H. Johnson. The Characterization of the Soluble Organic Fraction of Diesel Particulate Matter. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790418, 24 pp.

This paper is concerned with the demonstration of a methodology for chemically characterizing diesel particulate organic matter (POM) emissions. The procedure begins with a Soxhlet extraction of the POM with dichloromethane to obtain a soluble organic fraction (SOF). The acidic and basic portions of the SOF are isolated by liquid-liquid extraction techniques with aqueous base and aqueous acid, respectively. The neutral portion of the extract is separated into paraffin, aromatic, transitional and oxygenated fractions by column chromatography on silica gel. Two additional fractions, the ether insoluble and hexane insoluble fractions, are also separated by the procedure. Quantitative mass data are presented on the extraction and fractionation of twelve particulate samples from the exhaust of a medium-duty diesel engine collected in a dilution tunnel at a volume dilution ratio of 8 to 1. Three fuels with a range of properties and two steady-state engine conditions from the EPA 13 Mode Cycle were used as experimental variables in this study.

Gentel, J. E., O. J. Manary, and J. C. Valenta. Characterization of Particulates and Other Non-Regulated Emissions from Mobile Sources and the Effects of Exhaust Emissions Control Devices on These Emissions. Dow Chemical Co., Contract No. EHS-70-101, March 1973, 217 pp.; NTIS PB 224 243.

This report describes work carried out on a research program to determine the effect of emission cxontrol devices on the particulate emissions of an automotive power plant. Particulate mass emission rates were measured, as well as particle mass size distribution, carbon and hydrogen, trace metal, and benzo-a-pyrene content of the particulate. Ammonia and aldehydes were measured in the exhaust gas condensate, and gaseous emissions were determined as a routine check on engine operating conditions.

Gibbs, R. E., J. D. Hyde, and S. M. Byer. Characterization of Particulate Emissions from In-Use Diesel Vehicles. Presented at the Fuels and Lubricants, Baltimore, Md., Oct. 20-23, 1980, SAE Preprint 801372, 22 pp.

Particulate emissions data are presented from a group of 19 in-use diesel automobiles. Five driving cycles and three fuel/lubricating oil combinations have been used to obtain particulate emissions data and also to collect particulate samples for chemical and bioassay characterization studies. Particulate samples were solvent extracted with dichloromethane to obtain the soluble organic fraction (SOF) of the emitted particulate. Particulate and SOF data are presented for emission/distance, emission/time and emission/fuel consumed basis by vehicle manufacture, driving cycle, and fuel/oil subcategory. Some SOF samples have been used in the bioassay test of Ames, and these results are presented for different vehicles and driving cycles. Particulate emissions, SOF emissions and bioassay activity results are presented in terms of mileage accumulation effects.

Groblicki, P. J., and C. R. Begeman. Particle Size Variation in Diesel Car Exhaust. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790421, 12 pp.

The Electrical Aerosol Analyzer (EAA) has been used to measure the particle size-distribution of the exhaust aerosol produced by five diesel cars under a variety of steady-state operating conditions. A good correlation was found between simultaneous EAA and filter determinations of mass emission rate for these cars. For the entire range of cars, speeds, and loads tested, the mass median diameter was about 0.1 μm, with a range from 0.05 μm to 0.22 μm. There was no consistent effect of speed on particle size in this group of cars, but there was a slight tendency toward larger particle sizes as the load increased.

Habibi, K. Characterization of Particulate Matter in Vehicle Exhaust. Environmental Science & Tech., v. 7, No. 3, March 1973, pp. 223-234.

The particulate matter emitted from present-day cars is a complex mixture of inorganic salts, soot and carbonaceous material. Measurement and characterization of such particles require elaborate sampling systems and sophisticated analytical techniques. This paper is a review of the major contributions in this area. A number of systems suitable for sampling and characterization of the exhaust particles are described. Also included is a wide selection of data from a number of workers that, in the author's opinion, best represent the state of the art.

Hare, C. T., and T. M. Baines. Characterization of Particulate and Gaseous Emissions From Two Diesel Automobiles as Functions of Fuel and Driving Cycle. See III.A.1.

Hare C. T., and R. L. Bradow. Characterization of Heavy-Duty Diesel Gaseous and Particulate Emissions, and Effects of Fuel Composition. See III.A.1.

Hare, C. T. Methodology for Determining Fuel Effects on Diesel Particulate Emissions. Southwest Res. Institute, Contract No. 68-02-1230, March 1975, 150 pp.; NTIS PB-245 163.

To develop a methodology for characterizing particulate emissions from diesel engines, one 2-stroke cycle engine and one 4-stroke cycle engine were operated in both individual steady-state modes and according to a variation of the 13-mode diesel emissions measurement procedure. Both engines were operated on three fuel types, each of which was used with one of two available diesel fuel additives as well as by itself. The primary particulate sampling technique employed was a dilution tunnel; and secondary evaluation techniques included a diluter-sampler developed under contract to EPA by another organization, a light extinction smokemeter, and a filter-type sampling smokemeter. Gaseous emissions were also measured, providing a running check on engine condition. Particulate mass rates were calculated from gravimetric data; and analysis of particulate included determination of sulfur, carbon, hydrogen, nitrogen, phenols, nitrosamines, trace metals, and organic solubles. Analysis of the organic soluble fraction included NMR, IR, paraffin boiling point distribution, benz(a)pyrene, sulfur, carbon, hydrogen, nitrogen, and oxygen.

Hurn, R. W., and D. E. Seizinger. Air Pollutant Inventory--Enter the Diesel. See III.A.1.

Johnson, J. H., Dr. An Overview of Monitoring and Control Methods for Diesel Pollutants in Underground Mines Using Diesel Equipment. See III.A.1.

Johnson, J. H., and L. E. Frisch. The Effect of Fuels on Diesel Particulate Emissions. Environmental Protection Agency Symposium, Department of Mechanical Engineering--Engineering Mechanics, Mich. Technol. University, Houghton, Mich., 1978, 16 pp.; available for consultation at Twin Cities Res. Center, Minneapolis, Minn.

This paper studies the particulates formed from the Caterpillar 3208 diesel engine using 3 different diesel fuels. The 3 fuels were No. 1, No. 2, and a heavy gas oil blend diesel fuel. For each fuel, the particulate levels were measured for various volume dilution ratios and mixture temperatures. The author represents the results by using graphs and draws several conclusions.

Karasek, F. W., R. J. Smythe, and R. J. Laub. A Gas Chromatographic-Mass Spectrometric Study of Organic Compounds Adsorbed on Particulate Matter From Diesel Exhaust. J. of Chromatography, v. 101, May 1974, pp. 125-136.

A gas chromatographic-mass spectrometric analytical system is used to analyze the organic materials extracted from diesel exhaust particulates obtained by use of a direct sampling device. The analysis is performed by first subjecting the extracted organic mixtures to column chromatography, which yields four or more fractions. Each of these is further analyzed on a gas chromatographic-mass spectrometric system that employs high-resolution high-capacity support-coated open-tubular and large-bore open-tubular columns. Additional information is also obtained from an integrated gas chromatograph-mass spectrometer-computer system by identifying compound types via mass chromatography. Thirty-five hydrocarbons have been identified which include alkanes, polycyclic aromatic hydrocarbons, and six oxygenated compounds primarily of the phenolic type. Twenty-nine additional hydrocarbons and oxygenated compounds have also been tentatively identified.

Khatri, N. J., J. H. Johnson, and D. G. Leddy. The Characterization of the Hydrocarbon and Sulfate Fractions of Diesel Particulate Matter. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780111, 28 pp.

One of the more objectionable aspects of the use of diesel engines has been the emission of particulate matter. A literature review of combustion flames, theoretical calculations and dilution tunnel experiments has been performed to elucidate the chemical and physical processes involved in the formation of diesel particulate matter. A comparative dilution tunnel study of diluted and undiluted total particulate data provided evidence supporting calculations that indicate hydrocarbon condensation should occur in the tunnel at low exhaust temperatures. The sample collection system for the measurement of total particulate matter and soluble sulfate in particulate matter on the EPA 13 mode cycle is presented. A method to correct for hydrocarbon interferences in the EPA barium chloranilate method for the determination of sulfate in particulate matter is discussed.

Kittelson, D. B., D. F. Dolan, R. B. Diver, and E. Aufderheide. Diesel Exhaust Particle Size Distributions--Fuel and Additive Effects. Presented at the Off-Highway Vehicle Meeting and Exposition, MECCA, Milwaukee, Wisc., Sept. 11-14, 1978, SAE Preprint 780787, 16 pp.

Particle mass and size distribution measurements have been made on the exhaust of an Onan prechamber diesel engine. Seven fuels were examined: No. 1 and No. 2 diesel fuel, 40 and 50 cetane number secondary reference fuels, and No. 2 diesel fuel doped with three different concentrations of Lubrizol 565, a barium-based smoke suppressant. The No. 1 and No. 2 diesel fuels and the 50 cetane number reference fuels produced very similar emissions with emission indices in the range of 0.3-1.3 mg $(gm\text{-}fuel)^{-1}$ and volume mean diameters between 0.09 and 0.15 μm. The 40 cetane number reference fuel produced both smaller emission indices, 0.2 to 0.8 mg $(gm\text{-}fuel)^{-1}$, and particle diameters, 0.03 to 0.09 μm. These reductions were apparently related to the longer ignition delay period of the 40 cetane number fuel, which allowed better mixing of the fuel and air prior to combustion. Doping No. 2 diesel fuel with Lubrizol 565 led to decreases in particle size and Bosch smoke number, but in most cases, the emission index increased. The additive apparently suppresses the production of light absorbing carbon particles, but at the same time leads to the formation of dense but only weakly light absorbing barium-containing particles.

Kotin, P., H. L. Falk, and M. Thomas. Aromatic Hydrocarbons III. Presence in the Particulate Phase of Diesel-Engine Exhausts and the Carcinogenicity of Exhaust Extracts. AMA Archives of Industrial Health, v. 11, No. 2, February 1955, pp. 113-120.

This report first studies the various conditions when diesel engine exhaust emissions contain hydrocarbon products of incomplete combustion. The results indicated that increasing RPM increased soot and HC emissions enormously. With this information the researchers conducted an experiment on black mice to determine the carcinogenicity of diesel extracts. They performed various experiments by painting diesel engine exhaust extracts on the backs of the mice. From the results they concluded that carcinogenic hydrocarbons are present among diesel engine exhaust extracts. The report explains the different experiments performed on the mice and the results.

Lapson, W. F., and H. J. Dehne. Design, Development, and Fabrications of a Prototype High-Volume Particulate Mass Sampling Train. Contract No. 68-02-1339, May 1974, 40 pp.; NTIS PB-245 196.

The report gives results of a program to develop a high-volume sampling train with the following characteristics: 5-10 cfm sampling rate, modular, portable, 500°F probe/oven temperature, and conforming to Federal Register Method 5 basic requirements (standards of performance for new stationary sources). The program included a study of the overall requirements of stack sampling instrumentation, concluding with recommendations for portable, easier to use systems that are effective over a wide range of sampling rates.

Laresgoiti, A., A. C. Loos, and G. S. Springer. Particulate and Smoke Emissions From a Light Duty Diesel Engine. See III.A.1.

Leddy, D. G., and E. F. Funkenbusch. Characterization of the Soluble Organic Fraction of Diesel Particulates. Environmental Protection Agency Symposium, Department of Chemistry and Chemical Eng., Mich. Technol. University, Houghton, Mich., 1978, 12 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

This report studies the particulate matter produced from the Caterpillar 3208 diesel engine operated at two test modes (3, 5). The particulates from three diesel fuels were tested from the Chevron Research Co. and AMOCO. The particulate matter from each fuel was collected on 8 x 10 inch glass filters and analyzed. The scheme for extracting the diesel particulates is shown in a flow chart diagram. The results of the samples are presented in tables.

Linnell, R. H., and W. E. Scott. Diesel Exhaust Analysis. See V.A.3.

Lipkea, W. H., J. H. Johnson, and C. T. Vuk. The Physical and Chemical Character of Diesel Particulate Emissions--Measurement Techniques and Fundamental Considerations. SAE Preprint 780108. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Special Publications 430, 64 pp.

The techniques used to characterize the chemical and physical nature of particulates in diesel exhaust emissions are reviewed. The emphasis is on understanding the broader aspects of the fundamental nature of not only diesel particulates, but particulate systems in general. Consideration is given to the special nature of particulates which make them significant pollutants and to the relative place of the diesel in the formation of man-made particles. The underlying combustion processes leading to carbon and sulfur based particulates are reviewed. The important variables in steps of the combustion processes which lead to particulate formation are considered, as well as major fuel and engine factors. Collection methods are examined with examples given from current diesel dilution techniques. Probes, sampling lines, and instrumentation are considered. Methods of physical and chemical characterization are presented and examples from the current and prior diesel work at Michigan Technological University and elsewhere are given.

Menster, M., and A. G. Sharkey, Jr. Chemical Characterization of Diesel Exhaust Particulates. U.S. Energy Res. and Development Administration, RIMS No. 07032, December 1976, 50 pp.

High resolution mass spectrometry was applied as a direct, rapid method of analysis of the organic material associated with diesel exhaust particulates. Diesel fuels and respirable coal mine dusts were also surveyed. Data analysis of the spectrometric results enabled precise masses and molecular formulas of hundreds of organic components in each sample to be determined. The organic components were characterized by structural type and carbon number range. Mass spectra were obtained on approximately fifty samples of particulates from diesel engine tests. The distribution of hydrocarbons in particulates changed in a consistent and characteristic manner as the speed and loading of the engines were varied. The composition profiles were but little affected by the type of diesel engine or the type of fuel used in the tests. Studies were made of respirable coal dust sampled in areas of a mine where diesel and electrical haulage of coal were used. Respirable dusts from the diesel haulage entry exhibited an extended range of saturated aliphatics not found in the electrical haulage samples. This difference in composition is attributed to combustion of diesel fuel. The mass spectral data of all samples were screened for indications of the presence of toxic compounds. Screening was affected by computer matching of experimental masses with toxic compound masses contained in a reference list of substances having low threshold limit values. Formulas of possible toxic compounds in diesel particulates included saturated aliphatic hydrocarbons, oxygenates, and polynuclear aromatics.

Powel, S. F., III (ed. by). Edited Transcript of Proceedings of the Workshop On Unregulated Diesel Emissions and Their Potential Health Effects. Apr. 27-28, 1978, sponsored by the Department of Transportation National Highway Traffic Safety Administration, the Department of Energy, and the Environmental Protection Agency, 677 pp.

With the many unknowns concerning unregulated diesel emissions and their potential impact on human health, the National Highway Traffic Safety Administration, the Department of Energy, and the Environmental Protection Agency, have taken a cautious attitude regarding a major shift into diesel engines until more is learned. These proceedings include papers presented at a workshop sponsored by these three agencies to learn more about emissions and cover the following diesel-related topics: Emissions characterization and measurement, control technology, factors affecting human exposure, and health effects.

Sapienza, R., T. Butcher, C. Krishna, and J. Gaffney. Soot Reductions in Diesel Engines by Catalytic Effects. U.S. Environmental Protection Agency, BNL 27792, May 1980, 17 pp.

Recent tests at Brookhaven Nat. Lab. indicate that both small additions of alcohols to the fuel and the presence of platinum surfaces in the combustion chamber can reduce soot emissions in a diesel engine. These tests were conducted over a limited range of operation in a single cylinder CFR engine. Most of the testing was done using pure cetane as a fuel at constant speed and load. Possible major features of the reaction mechanisms for both fuel additives and surface catalyst effectiveness are presented.

Schreck, R. M., J. J. McGrath, S. J. Swarin, W. E. Hering, P. J. Groblicki, and J. S. MacDonald. Characterization of Diesel Exhaust Particulate for Mutagenic Testing. General Motors Res. Lab., Warren, Mich., GMR-2755, June, 1978, 20 pp.

Published research on the health effects of diesel exhaust has concentrated heavily on the biological responses being measured and given little or no attention to characterizing the engine operating conditions or the exhaust material itself. Consequently, the physiological responses under study are not usually related to the fuel, engine type, speed, and load conditions or other operational parameters which might be selected to minimize the health impact of the engine's emissions. In the present study, we have taken a standard production four-cycle diesel passenger car engine, characterized its particulate emissions at a well-defined operating condition, and, in the accompanying paper, measured the biological effect of the particulate material in the Ames microbial bioassay. Another sample, resulting from a number of diesel vehicle tests, was also subjected to the characterization and bioassay.

Seizinger, D. E., B. H. Eccleston, and R. W. Hurn. Particulates and Associated Emissions From Two Medium-Duty Diesel Engines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790420, 8 pp.

Experimental data were obtained from two medium-duty diesel engines derated to qualify for use in underground mines. Gaseous and particulate emissions from these engines were measured and results provide information on the effect of exhaust treatment devices on the emissions. The devices in the study were a catalyst, a particulate trap, and an exhaust gas cooler of the water scrubber type. Emission levels of carbon monoxide and hydrocarbons were observed to be very low in comparison with emissions levels of comparable engines in full-rated operation. Oxides of nitrogen and benzo(a)pyrene content of the exhaust also were found to be somewhat low in comparison with previous findings. For particulate reduction, the combination of a particulate trap and a scrubber was observed to be the more effective of the combinations tried; in some cases over 60 pct particulate reduction was effected by the trap/scrubber combination.

Sejekan, B. G., P. S. Rao, and B. S. Murthy. Analytical Methods for the Determination of Benzo(a)pyrene From Engine Exhaust. See III.A.1.

Society of Automotive Engineers, Inc. The Measurement and Control of Diesel Particulate Emissions. See III.B.2.

Spindt, R. S. First Annual Report on Polynuclear Aromatic Content of Heavy Duty Diesel Engine Exhaust Gases. Gulf Res. & Development Co. (Pittsburgh, Pa.), CRC-APRAC Contract No. CAPE-24-72(1-73), 731-CD003, July 1, 1974, 63 pp.

Extensive PNA studies have been made on gasoline engines with little work on the diesel engine. Therefore, the EPA and CRC-APRAC funded a project to investigate PNA in diesel exhaust gases. Gulf Research & Development Co. was awarded the two year project. This report covers the work done during the first year. The first objective of the report was to prescribe a standard technique for collecting and anlyzing samples to assure repeatability. Another objective was to survey a number of fuels and select a baseline fuel. These objectives are covered in detail in this report. All tests were conducted on a Detroit Diesel 3-35 engine. Results of the tests are presented in the form of tables and graphs. The report also contains appendices explaining in detail the analytical procedures, diesel exhaust analysis and the phenol analysis used in the report.

Spindt, R. S. Second Year Report on Polynuclear Aromatic Content of Heavy Duty Diesel Engine Exhaust Gases. Gulf Res. & Development Co. (Pittsburgh, Pa.), CRC-APRAC Contract CAPE 24-72 731CD004, Jan. 17, 1977, 42 pp.; NTIS PB267 774.

During the second year of this project we developed improved sampling and anlysis methods for PNA in diesel exhaust. To do this, we worked mainly with one engine at a few fixed speeds and loads and usually confined our emission measurements to two PNA species, namely, BaP and BaA. We used the C isotopes of BaP and BaA as tracers to compensate for losses in sampling and anlysis. We modified the sampling system that we had developed in the first year by diluting the exhaust sample with chilled air (2 to 4 times by volume). We switched from benzene-methanol to benzene as the filter extractant because pure benzene extracts fewer polar compounds. Isotopic dilution with C PNA's proved to be very valuable, even essential, in compensating for the PNA sampling and analysis losses. While the use of C PNA tracer compensated for PNA losses in sample collection and analysis and improved reproducibility of the PNA measurements, it did not reduce the PNA loss. We do not yet know whether these losses occur principally during sample collection or in analytical procedure.

Springer, G. S., and D. J. Patterson (ed. by). Engine Emissions: Pollutant Formation and Measurement. See III.A.1.

Springer, K. J. Exhaust Particulate--The Diesel's Achilles' Heel. Presented at the 71st Annual Meeting of the Air Pollution Control Assoc. Houston, Tex., June 25-30, 1978, APCA Preprint 78-14.3, 15 pp.

This paper summarizes the highlights of recent papers and reports from the Southwest Research Institute dealing with particulates from diesel powered vehicles, as collected using a dilution tunnel technique. The rate of emission, as well as the physical and chemical composition of the particulates, have been summarized. Particulates of several engines were measured and the results are presented in tabular form.

Springer, K. J., and R. C. Stahman. Diesel Car Emissions--Emphasis on Particulate and Sulfate. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich. Feb. 28-March 4, 1977, SAE Preprint 770254, 32 pp.

Diesel-powered cars afford some distinct advantages in fuel economy and certain exhaust emissions relative to the conventional Otto cycle engine. Particulate and sulfate emissions from light-duty diesels are two important unregulated emissions for which little is known. Five diesel-powered, light-duty vehicles, a Peugeot 204 D, a Mercedes 240D, and a Perkins 6-247 powered IH pickup, were used to quantify the range of particulate, sulfate as well as other unregulated emissions of odor, visible smoke, sulfur dioxide, aldehydes, and selected non-reactive hydrocarbons. Three transient driving cycles were employed including that used in emissions certification, sulfate testing, and highway fuel economy. Emission rates of particulate, sulfate, and other contaminants of a regulated and unregulated nature are presented in several ways: mass per unit of time, per unit of fuel consumed, and per unit of distance driven. Fuel consumption and economy values are also provided.

U.S. Department of Energy. Diesel Engine Research and Development Status and Needs. Contract No. EM-78-C-03-2184, September 1978, 138 pp.; NTIS SAN-2184-1.

This report, prepared by the Aerospace Corporation for the Office of Highway Systems of the U.S. Department of Energy, reviews, assesses, and summarizes the research and development status of the automotive diesel engine/vehicle sector, and identifies specific basic and applied research and development needs in the diesel technology and health effects areas where active participation by the government would be desirable. The report is divided into seven sections plus an executive summary. Section 1, entitled Introduction, provides a brief discussion of the study objectives, scope, and approach. Section 2, Diesel Engine Characteristics, examines the fuel economy and exhaust emissions trends of diesel

engines, with particular emphasis on light duty engine/vehicle configurations, and currently unregulated species. Section 3, Diesel Engine Emission Control Technology, describes emission control techniques, devices, and systems which have been or still are being considered by many investigators in industry, governmental agencies, and research organizations. Section 4, Diesel Engine Programs Conducted by Government Agencies, highlights major programs conducted or planned by the EPA, DOT, U.S. Army, and DOE in the areas of diesel engine technology and health effects. Section 5, Diesel Engine Programs Conducted by Industry, and Section 6, Diesel Engine Programs Conducted by Other Organizations, discuss diesel exhaust emissions characterization, health effects, and technology programs performed by a selected group of organizations. Finally, Section 7 identifies specific program areas in which aggressive government participation would be desirable to develop the information required for comprehensive assessments of the near-term and far-term emissions and fuel economy potentials of divided chamber and open chamber diesel engines.

Verrant, J. A., and D. A. Kittelson. Sampling and Physical Characterization of Diesel Exhaust Aerosols. Presented at the Off-Highway Vehicle Meeting and Exhibition, MECCA, Milwaukee, Wis., Sept. 12-15, 1977, SAE Preprint 770720, 16 pp.

Diesel exhaust aerosols are highly dynamic and, therefore, difficult to sample without introducing falsification. This paper describes a study of these aerosols using a rapid dilution sampling system and an electrical aerosol analyzer. An Onan single cylinder indirect injection engine was used as an exhaust source. The sampler diluted the exhaust with clean air in ratios of 400:1 to 600:1 in order to prevent sample falsification by condensation and coagulation. The electrical aerosol analyzer was used to determine particle size and concentration. Volume concentration in the exhaust ranged from 2,000 to 50,000 m^3 cm^{-3} which correspond to mass loadings of 2.0 to 50 mg m^{-3} (assuming a density of 1 gm cm^{-3}). Volume geometric mean diameters ranged from 0.12 to 0.19 m. Evaporation and coagulation effects on diesel aerosols were observed by aging in a Teflon holding bag. A simple evaporation model was fit to the decrease of aerosol volume concentration with time. The fit revealed that the aerosols evaporated as if they were composed of normal paraffins in the 350-500 molecular weight range. Although the sample dilution system used in this study may alter the sample somewhat, it is probably analygous to what happens at the tailpipe of a vehicle. Measurements taken on a test track in the exhaust plume of a Peugeot 504 diesel showed aerosol size distributions very similar to those measured in our laboratory studies.

Vo-Dinn, T., R. B. Gammage, A. R. Hawthorne, and J. H. Thorngate. Synchronous Spectroscopy for Analysis of Polynuclear Aromatic Compounds. American Chemical Society, v. 12, No. 12, November 1978, pp. 1297-1302.

The technique of synchronous excitiation is used to enhance the selectivity of luminescence spectrometry. The applicability of this simple methodology to the monitoring of trace organic pollutants such as the polynuclear aromatic compounds (PNA) originating from coal conversion processes is emphasized. Two specific examples are presented: the characterization of naphthalene derivatives in Synthane gasifier wastewater by synchronous fluorimetry, and multicomponent analysis of several PNA by synchronous room-temperature phosphorescence.

Vuk, C. T., M. A. Jones, and J. H. Johnson. The Measurement and Analysis of the Physical Character of Diesel Particulate Emissions. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760131, 43 pp.

One of the more objectionable aspects of the use of the diesel engine is its emission of particulate matter. Methods for collecting particulate matter samples in the undiluted exhaust gases with an Andersen Impactor for gravimetric and electron microscopy analysis are developed. A direct injection Vee-eight naturally aspirated diesel engine was used in the study. This paper presents the results of an in-depth study of the physical characteristics of diesel particles. The size distribution of the particulate matter was obtained using an Andersen Inertial Impactor for the engine conditions applicable to the SAE 13-mode cycle. The particulate matter was analyzed using both scanning and transmission electron microscopes and was found to be comprised of individual spherical particles ranging from 100 A to 800 A with a mean size of approximately 260 A. The particulate matter was analyzed for carbon, hydrogen and nitrogen. The solid particulate matter collected within the Andersen Sampler had a carbon/hydrogen ratio that is temperature dependent ranging from .75 at an exhaust temperature of 100 C to approximately 5.0 at exhaust temperatures greater than 300 C. A correlation between the number of individual spherical particles in an agglomerate and the agglomerate size reveals a particle number range from a single, 100 A particle to an agglomerate 30 m in diameter continuing an average of 4,000 of the individual spherical particles.

Wadman, B. Trends with Exhaust Emissions Measurement Equipment. See III.A.1.

Williams, R. L., and S. J. Swarin. Benzo(a)pyrene Emissions From Gasoline and Diesel Automobiles. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790419, 8 pp.

A data base was obtained for comparing the benzo(a)pyrene (BaP) emission rates from diesel automobiles with those from current-production, catalyst and noncatalyst gasoline automobiles. Exhaust particulate samples were collected on filters, using a large emission tunnel. The extractable portion of the exhaust particulate was removed by Soxhlet extraction, with a mixture of benzene and ethanol. The BaP determination was made by high-performance liquid chromatography, using fluorescence detection. The BaP emission rate from an Oldsmobile diesel car was the same as the average rate from seven noncatalyst gasoline cars, 2.7 mcirograms per mile. The BaP mass concentration in the diesel particulate was five parts per million, about twenty times lower than that in noncatalyst gasoline particulate. BaP emission rates showed no simple correlation with hydrocarbon or carbon monoxide emission rates. The catalytic converter reduced BaP emission by more than 95 pct on gasoline cars, but had no effect on BaP emission from a diesel car.

A. Laboratory Measurement and Instrumentation

3. SO_x and sulfates

Beltzer, M. Real-Time, Continuous Measurement of Automotive Sulfuric Acid Emissions. J. Air Pollution Control Assoc., v. 29, No. 1, January 1979, pp. 57-59.

This communication discusses preliminary work in which vehicular sulfuric acid emissions were monitored continuously and nondestructively by measuring the surface resistance of filters during collection of H_2SO_4 aerosol generated by an oxidation catalyst-equipped vehicle. Present methods for measuring this exhaust component are neither suitable, nor readily adaptable for continuous, real time measurement, as they are batch procedures, involving integrated samples collected over a specific time interval, followed by analytical determination.

Coordinating Research Council--Air Pollution Research Advisory Committee. Program, Abstracts and Summary of Presentations for CRC-APRAC Diesel Exhaust Emission Measurement Symposium. See III.A.2.

Engel, P. K., R. Silvestrini, and R. E. Thompson. Corrosion and Fouling Potential in Diesel Exhaust. See III.A.2.

Freedman, R. W., and F. A. Sharp. Determination of Sulfates in Diesel Exhaust. BuMines RI 8683, 1982, 7 pp.

This report describes sampling and analytical procedures used for measurement of sulfates in diesel tailpipes and in the diluted exhaust within dilution tunnels. A variety of methods exist for sulfate analysis for such systems, including ion exchange. Two chemical methods used by the Bureau of Mines are described in detail. These are based upon spectrophotometric measurement of chloranilic acid using barium chloranilate. The procedures are rapid and relatively inexpensive. In general, ion exhange is preferred by many analysts for sulfate analysis. However, it is more complex and expensive than chloranilic acid procedures, which are adequate for exhaust analysis.

Hare, C. T., and T. M. Baines. Characterization of Particulate and Gaseous Emissions From Two Diesel Automobiles as Functions of Fuel and Driving Cycle. See III.A.1.

Hare, C. T., and R. L. Bradow. Characterization of Heavy-Duty Diesel Gaseous and Particulate Emissions, and Effects of Fuel Composition. See III.A.1.

Holt, E. J., K. C. Bachman, W. R. Leppard, E. E. Wigg, and J. H. Somers, Control of Automotive Sulfate Emissions. Presented at the Fuels and Lubricants Meeting, Houston, Tex., June 3-5, 1975, SAE Preprint 750683, 12 pp.

The report describes a study made of potential methods for controlling $SO_4^=$ emissions from oxidation catalyst-equipped vehicles. The methods considered included operating condition and catalyst changes, as well as the use of a vehicle trap for $SO_4^=$. Emissions of $SO_4^=$ from non-catalyst cars were also measured.

Jeffery, P. G., and P. J. Kipping. Gas Chromatography for the Analysis of Exhaust Gases. See III.A.1.

Johnson, J. H., Dr. An Overview of Monitoring and Control Methods for Diesel Pollutants in Underground Mines Using Diesel Equipment. See III.A.1.

Khatri, N. J., J. H. Johnson, and D. G. Leddy. The Characterization of the Hydrocarbon and Sulfate Fractions of Diesel Particulate Matter. See III.A.2.

Powel, S. F., III (ed. by). Edited Transcript of Proceedings of the Workshop on Unregulated Diesel Emissions and Their Potential Health Effects. See III.A.2

Schuetzle, D., L. M. Skewes, G. E. Fisher, S. P. Levine, and R. A. Gorse, Jr. Determination of Sulfates in Diesel Particulates. Analytical Chemistry v. 53, No. 6, May 1981, pp. 837-840.

Analytical techniques for the determination of total sulfates in diesel particulates are described utilizing the techniques of total combustion/nondispersive infrared (NDIR) detection and modified extraction/barium perchlorate-thorin titration (BPT). The combustion technique utilizes a commercially available sulfur analyzer (LECO-IR32) that requires less than 15 min. for triplicate analysis and has a precision and accuracy of better than $\pm$5% for filter samples containing from 100 to 100,000 µg of sulfate. The combustion technique measures soluble and insoluble sulfate such as $BaSO_4$ and is not affected by the presence of large quantities of carbon in the particulate sample. The extraction efficiency for sulfates in diesel particulates usding standard procedures was found to average 67% for samples containing only trace quantities of anions and 59% for samples containing stoichiomertric levels of barium. These procedures have been modified to include ultrasonication with 2-proponal/water in order to overcome the problem of incomplete sulfate extraction. Extracted sulfate samples are then analyzed by using the BPT method. The extraction/BPT method showed an average recovery of 1.02 $\pm$ 0.12 (1σ) when compared to the combustion technique. ESCA studies showed that the chemical state of the surface sulfur species for the diesel particulates averaged 93 $\pm$ 3% elemental sulfur.

Springer, G. S., and D. J. Patterson (ed.). Engine Emissions: Pollutant Formation and Measurement. See III.A.1.

Springer, K. J., and R. C. Stahman. Diesel Car Emissions - Emphasis on Particulate and Sulfate. See III.A.2.

van der Zijden, M. F., J. E. van Hinte, and J. C. van den Ende. SO2 and SO3 in Exhaust Gases of Internal Combustion Engines. J. Inst. Petrol., v. 36, 1950, pp. 561-574.

Starting from the assumption that knowledge of the SO2 content of exhaust gases would assist the study of the influence of SO3 on wear and fouling of internal combustion engines, the SO2 content of exhaust gases of some spark ignition and diesel engines was determined. The quantity of SO2 present was found to be very low in all cases, by far the greater part of the sulphur being present as SO2. The correct determination of SO2 in addition to SO3 in the exhaust gas is, however, very difficult, because SO2 is rapidly oxidized during sampling and analyzing due to compounds of the peroxide type present in the exhaust gas and to water. Oxidation will also occur on cold cylinder walls, and the SO3 content thus formed is considered as a main source of wear and fouling engines. There is obviously

no relation between the true SO_3 content of the exhaust gas and the SO_3 found on the cylinder walls and SO_3 determinations of the exhaust gas are therefore of little use for the wear and fouling problem of engines.

Arthur D. Little, Inc. Chemical Identification of the Odor Components in Diesel Engine Exhaust. Contract No. EPA-EHSD-71-18, June 1971, 156 pp.; NTIS PB-204 421.

The results of a continuing effort to chemically identify the odor components of diesel exhaust are reported. The basic methodology for characterizing and analyzing the diesel exhaust odor was developed during the previous effort on this program. The approach developed involved sensory characterization as an integral part of the study. The experimental approach for analysis of the odor species was to collect large volumes of exhaust by condensation at 0°C, extract the organic portion of the exhaust from the non-odorous portion by liquid column chromatography. During this current program, the details of the methodology required for identification of the smoky-burnt odor fraction were completed and applied to the analysis of this fraction. All of the odor-significant species in this fraction have been identified. While several paraffinic oxidation products were recognized as important odor contributers, the most important smoky-burnt odor species are those associated with the partial oxidation products of compounds found in the aromatic fraction of the diesel fuel.

Barnes, G. J. Relation of Lean Combustion Limits in Diesel Engines to Exhaust Odor Intensity. Presented at the Mid-Year Meeting, Detroit, Mich., May 20-24, 1968, SAE Preprint 680445, pp. 144-162.

Exhaust gas odor threshold dilution ratios were measured during idle operation of a single-cylinder 4-stroke cycle diesel engine using n-heptane as a fuel. Odor threshold dilution ratios were determined by a single panelist using a sample presentation termed the Sniff-Mask technique. The effect of verious changes in the intake atmosphere composition on odor thresholds was determined. These composition changes fall into two general classes: (1) Substitution of the inert gases argon, helium, and carbon dioxide for the nitrogen contained in the normal intake air; (2) Addition of the inert gases argon, nitrogen, and carbon dioxide to the normal intake air. The substitutions of argon and helium produced a 15-fold reduction in the exhaust odor thresholds, while the substitution of carbon dioxide increased the odor threshold by a factor of 4. Directionally similar results were found for the addition experiments. The odor results could not be explained by expected changes in the diffusional processes, in the fuel spray patterns, or in the cycle temperatures. A good correlation was found between the measured exhaust odor thresholds and the lean flammability limits of premixed flames determined in the intake atmospheres used. The correlation between exhaust odor thresholds and the lean flammability limits suggests that diesel odor is caused by odorous products of partial oxidation that are produced in regions of fuel/oxidizer mixtures too lean to burn at the start of combustion.

Daudel, H. L., M. J. Fieber, D. M. Murthy, and H. O. Hardenberg. Detection and Instrumental Analysis of Diesel Engine Exhaust Gas Odorants--A New Approach to an Old Problem. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich. Feb. 26-March 2, 1979, SAE Technical Paper Series 790489, 16 pp.

An advanced and highly efficient analytical procedure enables the detection, quantitative determination and clarification of the category and molecular structure of those odorants, which are responsible for the exhaust gas odor from internal combustion engines. In the forseeable future this method will give the knowledge about the formation mechanism of odorants for the development of directive measures to reduce the formation of odorants or eliminating them. Furthermore, this procedure will help to determine which selected odorants groups should be measured to get a representative conclusion about exhaust gas odor.

Englund, H. M., and W. T. Beery (ed.). Proceedings of the Second International Clean Air Congress: Studies and Analysis of Diesel Engine Odor Production. Academic Press, New York and London, 1971, pp. 609-616.

Unfavorable odor and smoke are emitted from diesel engines. Therefore there have been standards and test procedures set up for the evaluation of smoke and various methods developed to minimize smoke. Unfortunately, the orgin and control of diesel odor is a difficult problem. This paper is divided into two sections. The first section is a review which covers experimental methods for odor measurement, determinations of the composition of diesel exhaust, experimental simulation studies, and proposed odor control techniques. The experimental facilities and results of simulation studies obtained at Drexel University are summarized in the concluding section.

Kotin, P., H. L. Falk, and M. Thomas. Aromatic Hydrocarbons III. Presence in the Particulate Phase of Diesel Engine Exhaust and the Carcinogenicity of Exhaust Extracts. See III.A.2.

Lesley, S., and C. C. J. French. Diesel Exhaust Odor. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760554, 24 pp.

The relationship between diesel exhaust odor and build and setting of the engine is reported. Odor was measured by a panel of observers, using a differential technique. Two odors were presented in each test, one from a reference engine, and one from an engine with variable characteristics. The observers were asked to score the difference between the two odors. This technique reduced the effect of random variations in the observers' sensitivity. The exhaust was passed through a coarse wire-wool filter before presentation to the observers. Thus the results apply to virtually

soot-free exhaust. The observers found that odor decreased as load increased, but increased as speed increased. The catalyst removed a substantial amount of odor, but the remaining variables had a far smaller effect.

Levins, P. L. Analysis of the Odorous Compounds in Diesel Engine Exhaust. Arthur D. Little, Inc., June 1972, 118 pp.; NTIS PB-220 392.

This report represents the beginnings of an effort to obtain appropriate means for measuring the odorous species in diesel exhaust and develop the quantitative relationships between these measurements and the exhaust odor. Through the integrated application of analytical chemistry and sensory methods, the major odorous species have been identified. Diesel exhaust odor can be described as having two major odor groups -- oily-kerosene and smoky burnt. The oily-kerosene odors are due principally to the alkyl-substituted indans, tetralins and alkyl benzenes in the aromatic portion of the unburned hydrocarbons. The smoky-burnt character is due primarily to the partial oxidation products of these same aromatic species, plus a smaller contribution form paraffin oxidation products--specifically; alkyl, hydroxy, and/or methoxy-substituted indanones, phenols, benzaldehydes and alkenones.

Levins, P. L., D. A. Kendall, A. B. Caragay, G. Leonardos, and J. E. Oberholtzer. Chemical Analysis of Diesel Exhaust Odor Species. Presented at the Autmotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740216, 12 pp.

Sensory studies have described diesel exhaust odor in terms of two major odor character groups--oily-kerosene and smoky-burnt. The odorous compounds have been identified in a detailed analytical chemistry-odor study. The oily-kerosene odor group is associated with the aromatic portion of the unburned fuel--principally, the alkyl susbstituted benzenes, indans, and tetralins. The smoky-burnt odors arise from partial combustion products of the paraffin and aromatic fuel components. Our studies have shown a good correlation between exhaust odor intensity and abundance of the partial combustion products. An analytical method has been developed, based on liquid chromatography, for the quantitative expression of exhaust odor intensity by measurement of the smoky-burnt odor group. Initial survey studies show the method to be applicable over a wide odor emission range. Fuel variation has little effect, whereas injector variables do influence odor intensity.

Petrow, E. D., M. N. Savliwala, F. T. Hsieh, N. P. Cernansky, and R. S. Cohen. An Investigation of Diesel Odor in an Air Aspirated Spray Burner and a CFR Diesel Engine. Presented at the Passenger Car Meeting, Troy Hilton, Troy, Mich., June 5-9, 1978, SAE Technical Paper Series 780632, 20 pp.

A single cylinder diesel engine test facility and an air-aspirated spray burner facility have been modified and instrumented for studying diesel odor formation. Odor sampling and analysis techniques, based on the Arthur D. Little, Inc., Diesel Odor Analysis System (DOAS), have been developed and refined. Emissions mapping of the burner and the engine operating at steady state conditions, as well as transient engine conditions, are presented and discussed. The engine mappings presented indicate that operating parameters, such as injection angle, exceptionally high or low compression ratio, and exceptionally rich or lean air-fuel ratio, can have a significant effect on odor production. The burner results presented indicate that stoichiometry as well as combustion aerodynamics can strongly influence odor formation.

Powel, S. F., (ed. by). Edited Transcript of Proceedings of the Workshop on Unregulated Diesel Emissions and Their Potential Health Effects. See III.A.2.

Savery, C. W., R. A. Matula, and T. Asmus. Progress in Diesel Odor Research. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740213, 16 pp.

Only 2 of the 11 laboratories which have had diesel odor research projects underway during the last 16 years are still active in this research area. Much of the earlier work was devoted to developing diesel odor sampling, standards, and measurement techniques. Subsequently, work became generally focused upon the chemical identification of the odorants, a very difficult task due to their large number and low concentrations. After three years of concentrated effort involving the development of new odor measurement, sampling, and diesel exhaust analysis and preparation techniques, odorants comprising the two major diesel odor characteristics were identified. Compounds which are also components of diesel fuel were shown to contribute to one odor characteristic. Oxydized derivatives, generally of the same classes of compounds as those shown to contribute to the first odor characteristic, were tentatively identified by structure to comprise the second major odor characteristic. The recent work has resulted in the development of a laboratory prototype instrument for determining diesel odor. Although research has been hindered by the requirement of subjective odor measurements, the limitation of analytical techniques, and the limited understanding of the diesel combustion process, significant progress has been made in diesel odor research which has already led to the reduction of diesel odor emissions.

Spindt, R. S., G. J. Barnes, and J. H. Somers. The Characterization of Odor Components in Diesel Exhaust Gas. Presented at the Mid-Year Meeting, Montreal, Quebec, Canada, June 7-11, 1971, SAE Preprint 710605, 9 pp.

The Coordinating Research Council and the Air Pollution Control Office of the Environmental Protection Agnecy have jointly supported the Air Pollution Research Advisory Committee Project CAPE-7-68 to analyze and identify the odor-relevant compounds present in diesel exhaust gases. This paper summarizes the experimental results obtained by Illinois Institute of Technology Research Institute and Arthur D. Little, Inc. Both contractors found certain fuel fractions to be odor relevant. Many mono and polyoxygenated partial oxidation products have been identified, at least by structural class. These odorous compounds occur at very low concentrations in the exhaust gases.

Springer, G. S., and D. J. Patterson (ed.). Engine Emissions. See III.A.1.

Springer, K. J., and H. E. Dietzman. An Investigation of Diesel-Powered Vehicle Odor and Smoke, Part IV. See III.A.1.

B. Ambient Measurement and Instrumentation

1. HC, CO, NO_x, CH_4, smoke

American Conference of Governmental Industrial Hygienists. Air Sampling Instruments. 4th ed., 1972, 550 pp.

This test is organized into five major parts. The first part consists of seven introductory papers which discuss basic considerations in sampling air for specific purposes. The second part contains discussions of sampler calibration, and instrumental factors. The third part is devoted to system components, the fourth part to sample collectors, and the fifth part to direct reading instruments. Each section in the third, fourth, and fifth parts consists of an introductory paper and a series of descriptions of air sampling instruments or system components in a standard format. Of the twenty-one technical discussions, eleven are newly prepared for this edition, and the other ten have had major revisions.

Antonette, J. F., and D. R. Strain. Calibration Gases for Automotive Emission Testing. Presented at the Passenger Car Meeting, Troy Hilton, Troy, Mich., June 5-9, 1978, SAE Technical Paper Series 780648, 12 pp.

Calibration gases are an essential element of pollution measurement. Their importance is emphasized because calibration errors are translated directly to the measured data. The concept of a calibration gas department responsible for filling the needs of all exhaust emission test facilities within an organization is a proven method for improving accuracy and precision, reducing test variability and assuring compliance with the law. Centralized handling of zero and span gases for multiple test sites within a facility is cost effective. In our case, installation costs were paid back in less than a year from the savings in product cost, cylinder rental and material handling.

Carlson, D. H., and J. H. Johnson. The Monitoring of Diesel Pollutants in Underground Mines. Presented at the 1979 AIME Annual Meeting, New Orleans, La., Feb. 18-22, 1979, AIME Preprint 79-69, 46 pp.

The paper presents background information including data on diesel exhaust pollutants, amounts produced and standards, a description of mine characteristics that affect air monitoring techniques and a review of portable measurement techniques and instruments for gas and particulate matter sampling. A general review of the laboratory and field research being conducted at Michigan Technological University in the area of diesel emissions is presented. The facilities involved with this research are also described. These are the Experimental Mine Air Monitoring Lab (MAML), the portable instruments and the production mines used.

Carroll, H. B., and F. E. Armstrong. Mine Air Monitor: Reliability and Performance Evaluation. U.S. Energy Research and Development Administration, Report No. BERC/RI-75/5, July 1975, 30 pp.

Performance capabilities of the mine air monitor, a multigas, direct-reading instrument were evaluated at operating temperature extremes in simulated industrial atmospheres generated in an environmental test chamber. Meter readings of the instrument response to NO_2 and CO in the test atmosphere were taken while the instrument was cycled from room temperature (75° F) to 40°F, back to room temperature, then to 110°F, and back to room temperature. Temperature probes mounted on the CO sensor cell indicated a lag time of 2 hours was necessary for the instrument to reach thermal equilibrium with the atmosphere being monitored. Response of the CO and NO_2 cells changed by an average of ± 15 pct and ±20 pct, respectively, as the temperature changed by ± 30°F. Calibrated and operated at constant temperature, the mine air monitor performed well and had a linear response to CO and NO_2 in its measuring range. Other variables that may significantly affect the instrument's performance were not evaluated.

Carroll, H. B., Jr., and F. E. Armstrong. Portable Detector Tube Reader: Reliability and Performance Evaluation. U.S. Energy Research and Development Administration, Report No. BERC/RI-76/5, April 1976, 15 pp.

Two lightweight, sensitive, optical stain tube readers suitable for field use were developed by Food Technology Corp. with National Institute for Occupational Safety and Health funds and technical assistance from Pittsburgh Mining and Safety Research Center and Bartlesville Energy Research Center. Evaluation of the instruments to determine their performance capabilities included comparison of their characteristics with standard criteria for portability, readout, stability, and ruggedness. The instruments were easy to use and simple to operate and produced excellent results with little or no operator training. Instrument readings from typical CO length-of-stain tubes showed a reproducibility improvement by a factor of 5 when compared with observer readings of the same length-of-stain tubes.

Carroll, H. B., Jr., R. M. Ray, and F. E. Armstrong. Controlled-Atmosphere System for Testing Gas Monitors. BuMines RI 7859, 1973, 10 pp.

The Bureau of Mines has designed and built a controlled-environment test chamber specifically for instrument evaluation in simulated work atmospheres. The atmosphere inside the 300 liter stainless steel chamber can be controlled at any selected temperature and relative humidity in the range of 2° to 93° C and 20 to 95 pct, respectively. Instruments placed inside the test chamber are subjected to an atmosphere at a preset temperature and humidity containing various concentrations of toxic gases such as CO, CO2, NO, NO2, SO2, and H2S. Toxic gas losses resulting from wall reactions, monitoring instruments, and instruments under evaluation are compensated by the use of a dynamic gas blending system.

Carroll, H. B., Jr., R. M. Ray, and F. E. Armstrong. Evaluation of an Electrochemical CO Monitor. U.S. Energy Research and Development Administration, Report No. BERC/RI-75/9, July 1975, 24 pp.

Two models of an electrochemical carbon monoxide (CO) analyzer were tested at the Bartlesville Energy Research Center in simulated work atmospheres at 75°F at 50 pct and 95 pct relative humidity. They demonstrated a linear response to CO in the 0 to 500 ppm range. Span and zero drifts were less than 2 pct of full-scale response measured over a 24-hour period. Setting the zero and span at 100°F, then slowly changing the temperature to 50°F, resulted in a 30 pct decrease in response to CO due to temperature. Interference from oxides of nitrogen to detection of CO was large, amounting to a response equivalent to 2 ppm CO per ppm of interfering compound.

Constant, P. G., Jr., M. C. Sharp, and G. W. Scheil. Collaborative Testing of Methods for Measurements of NO2 in Ambient Air: Volume 1--Report of Testing. Midwest Res. Inst., Contract No. 68-02-1363, June 1974, 105 pp. NTIS PB-244 902.

A report on the collaborative test, by 10 organizations, of the "Tentative Method for the Determination of Nitrogen Dioxide in the Atmosphere (Sodium-Arsenite Procedure)" to determine the precision and bias of the method. The report covers the NO2, ambient-air sampling system, test site, selection of collaborators, statistical design, collaborators' field sampling, their analysis of samples, statistical analysis of collaborators' results, conclusions and recommendations.

Coordinating Research Council, Inc. Informational Report on the Measurement and Characterization of Diesel Exhaust Emissions. See III.B.2.

Ferber, B. I., and A. H. Wieser. Instruments for Detecting Gas in Underground Mines and Tunnels. BuMines IC 8548, 1972, 16 pp.

Toxic and explosive atmospheres are discussed, along with some of the instruments commercially available for their detection. No attempt has been made to evaluate the accuracy of any one device. This circular has been prepared primarily to aid mine inspectors in selecting suitable instruments for underground gas detection.

Fink, Z. J., and D. T. Adler. Continuous Monitoring System for Mine Gas Concentrations Using Tube Bundles. BuMines RI 8060, 1975, 15 pp.

A continuous-monitoring system has been developed for analyses of mine gas concentrations associated with spontaneous combustion, mine fires, and explosive and toxic levels. The analysis center, which is linked to sample locations by polyethylene tubes in bundles, has been successfully field tested by the Federal Bureau of Mines for analyzing carbon monoxide and oxygen; a computational scheme has been developed to process the data at the site. This report contains information on the design, purchase, installation, and maintenance of the tube-bundle system. A brief comparison of the tube-bundle system with the underground-analysis system and plans for future research are also included.

Godbert, A. L., and E. Leach. A Preliminary Survey of the Pollution of Mine Air by Nitrogen Oxides from Diesel Exhaust Gases. Safety in Mines Research Establishment, Res. Report No. 265, 1970, 12 pp.; NTIS PB-196 988.

Mine air samples, representing the air breathed by men working in atmospheres polluted by diesel locomotive exhaust gases, have been analyzed to determine the concentration of nitrogen oxides present. Estimates have also been made of the concentrations of the two components of the total nitrogen oxides, i.e., the toxic gases nitric oxide and nitrogen dioxide. An attempt has also been made to determine the effect on the concentrations of toxic gases of variable factors such as the amount of ventilating air, the relative speed of the ventilating air and the locomotive, and the type of locomotive. In nearly all cases, the concentrations of nitrogen dioxide and nitric oxide were well below the recommended limits. Statistical analysis of the results has shown that none of the variable factors considered had a significant influence on the concentration of nitrogen oxides breathed by the men at risk.

Holland, W. D., and R. W. Freedman. Determination of Breathing Zone Concentrations of Contaminants from Emissions form Diesel Powered Vehicles in Underground Mines. Presented at BuMines Meeting on Diesel Emission Contaminants, Denver, Colo., May 18-19, 1976, Contract No. J0255001, 20 pp.

This is an interim report of industrial hygiene surveys for diesel emission contaminants in 16 metal and non-metal mines. Breathing zone samples for CO, CO2, NO, NO2, SO2, HCHO and total dust were collected and analyzed. The analytical results show CO2, NO^2, and HCHO were encountered in concentrations exceeding their standards. Some CO and NO concentrations were found between 1/2 and 1 times their standards. The study also found that the highest concentrations of diesel contaminants in underground mining operations are found near the working faces rather than in the haulage ways. It appears that the ventilation is poorer at working faces and in the other areas.

Holtz, J. C., and R. W. Dalzell. Diesel Exhaust Contamination of Tunnel Air. BuMines RI 7074, 1968, 23 pp.

The Bureau of Mines studied air contamination caused by diesel exhaust in a 10,000-ft ventilated tunnel. Sequential air samples were taken at the ends and middle of the tunnel during an operating cycle. Observed and calculated results for carbon dioxide, carbon monoxide, and nitrogen oxides were essentially in agreement. Nitrogen dioxide was present only in trace amounts. It was found that contamination was related to the volume of ventilating air, the number of haulage trips, train speed, and engine load.

Institute of Machinery and Institute of Chemistry of Westgalische Berggewerkschaftskasse. Reduction in the Content of Noxious Constituents in the Exhaust of Diesel Engines With Methane-Containing Intake Air. See IV.D.

Johnson, J. H., Dr. An Overview of Monitoring and Control Methods for Diesel Pollutants in Underground Mines Using Diesel Equipment. See III.A.1.

Johnson, J. H., D. H. Carlson, and B. G. Bunting. The Application of Advanced Mine Air Monitoring Techniques of Mines Using Diesel Powered Equipment. Mich. Technol. Univ., Grant No. G0166027, Feb. 1, 1977, Open File Report 132-77, 468 pp.; NTIS PB-272 456.

A study of mine air quality was conducted using the latest advanced continuous monitoring instruments. An overview of the various interacting variables in the mine that affect air quality is presented. One effort involves the evaluation of portable instruments, the development of measurement techniques, sample analysis procedures and computer programs for statistical analysis of measurement data, and the application of the instruments and techniques to the measurement of the concentrations of CO, CO2, NO, NO2 and particulate matter in a lead and a copper underground mine. A second effort involves the first application of the Mine Air Monitoring Laboratory (MAML), a mobile trailer containing laboratory type instruments, sampling and data systems for the measurement of CO, CO2, NO, NO2, and particulate matter. The data from the MAML for blasting and for operating diesel equipment are analyzed and presented in various plots.

Johnson, J., D. Carlson, B. Bunting, and J. Michelbacher. The Development and Application of Advanced Mine Air Monitoring Techniques to Mines Using Diesel Powered Equipment. Mich. Technol. Univ., MESA Contract No. S0144094, Feb. 15, 1976, Open File Report 132-77, 312 pp.; NTIS PB-272 456/AS.

The study involved the application and evaluation of the following instruments for measurement of airborne contaminants in an underground mine which employs diesel powered equipment: The Bartlesville Energy Research Center

Small Sample Analysis System for CO, CO_2, CH_4, and O_2, the Ecolyzer 2600 Carbon Monoxide Monitor, the Texas Instruments Mine Air Monitor for CO, NO_2, and O_2, the Beckman 868 Carbon Dioxide Analyzer, the McMillan 2100 Oxides of Nitrogen Meter for NO and NO_2, and the Palme's NO Dosimeter. The mine data collected with these instruments were analyzed in various ways and a number of significant trends and correlations were found. A computer program was developed for presentation of large quantities of grab sample measurement data as a log normal frequency plot for prediction of the frequency in which a specified 8 hour time weighted average concentration would be exceeded. Particulate matter samples were collected by three different methods including Nuclepore filters, the C. F. Casella thermal precipitator, the Anderson 2000 mini-sampler impactor. These were analyzed on the scanning and transmission electron microscopes. Both collection and analytical methods were compared and criteria were provided for selection of a particular method. A portable underground laboratory (trailer) employing state-of-the-art laboratory-type instrumentation was designed and constructed. It is designed to alternately monitor up to 4 preselected sample sites at distances up to 300 feet for gaseous and particulate airborne contaminants; to monitor for CO, CO_2, NO, and NO_2 with ranges suitable to cover concentrations produced both by diesel equipment and during blasting, and for particulate matter in number concentration for 10 geometric size increments ranging from 0.0032 to 1 micrometer in dust concentrations from 0 to 1 mg/m^3; and it will operate unattended and supply data both as recorder strip charges and digital printouts.

Lang, H. W., W. E. O'Neill, B. A. Coulehan, and R. W. Freedman. Continuous Monitoring of Diesel Exhaust Gas for Carbon Dioxide, Carbon Monoxide, Oxygen, Methane, and Nitrogen Oxides. BuMines RI 7241, March 1969, 14 pp.

This report describes a monitoring system applied by the Bureau of Mines to provide rapid, continuous determination of the main constituents of exhaust gas during the Bureau's approval schedule testing of diesel engines for underground use. Commercially available continuous analyzers with strip charge readout are employed for nitric oxide (mass spectrometric), carbon dioxide (nondispersive infrared), methane (NDIR), carbon monoxide (NDIR), and oxygen (polarographic). Good correlation is obtained between the continuous instrumental results and those obtained by batch chemical and gas chromatographic methods.

Lawter, J. R., and D. A. Kendall. Effects of Diesel Emissions on Coal Mine Air Quality. See V.A.3.

Matthews, R. D. The Nature and Formation of Nitrogenous Air Pollutant Emissions From Combustion Systems. Ph.D. Thesis, University Calif, Berkely, Calif., 1977, 224 pp.

This thesis studies in detail formation of nitrogenous air pollutants. Chapter 2 of this thesis discusses the atmospheric chemistry and toxicology of N-species that have been identified in the exhaust of combustion devices. Chapter 3 discusses the formation and emission of N-species during combustion of high nitrogen fuels such as coal, fuel oil, and many synthetic fuels. Nitrogen compounds emitted from other sources besides fuel nitrogen are discussed in chapter 4. Chapter 5 presents a discussion of potential solutions to the problem of NO emissions. The focus of the thesis is discussed in chapter 6 which investigates the conversion of fuel nitrogen during near stoichiometric catalytic combustion. Chapters 7 and 8 report on the experimental results. A summary of this investigation and significant conclusions are given in chapter 9.

Morgan, G. B. Energy Resource Development: The Monitoring Components. Environmental Science & Technology, v. 12, No. 1, January 1978, pp. 34-43.

At the same time that this nation is developing its coal resources in the western part of the U.S., it is developing air and water instrumentation and monitoring techniques to ensure adequate surveillance and safeguards protective of health and welfare. George Morgan, director of the EPA Environmental Monitoring and Surveillance Laboratory, summarizes the activities of eight different federal agencies to determine the source, the transport, and fate of environmental pollutants.

Morgan, G. B. Monitoring the Quality of Ambient Air. Environmental Science & Technology, v. 11, No. 4, April 1977, pp. 352-357.

Monitoring of ambient air quality permits the quantification of pollutants and the documentation of their effects on man and his environment. The article briefly explains the four types of monitoring ambient air which includes permanent-fixed-site monitoring, exposure monitoring, ambient-source monitoring and biological monitoring. Morgan then explains the essential components of a monitoring network which lead to data acquisition. He finishes the article by discussing the handling, storage, retrieval, and utilization of the data.

National Coal Board. The Continuous Monitoring of Mine Air by the Tube Bundle Technique. October 1972, 41 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

These notes on the use of tube bundles for the continuous monitoring of mine air for distances up to 5 miles (8km) are based on the accumulated experience of five years' research by Scientific Control and some 20 pit installations. They provide guidelines, not rules, and should be used in

this context for the techniques of continuous monitoring are still rapidly developing. When designing a new installation Scientific Control should be consulted as to the most recent developments and equipment available. The advantage of the tube bundle system lies in the inherent simplicity of the underground equipment and the fact that all the controls and analyzing instruments associated with it are on the surface where they can be conveniently serviced and are not restricted by the F.L.P. and I.S. regulations that apply to instrumentation underground. Continuous monitoring has greatly extended our knowledge on the occurrence of carbon monoxide in mine atmospheres and is making an important contribution to mine safety.

Pilkington, R., T. Kelly, and H. Wimette. Guidelines for Quality Assurance Programs for Mobile Source Emissions Measurement Systems - Phase II. Heavy-Duty Diesel Engines, Quality Assurance Guidelines. Olson Lab., Inc., Contract No. 68-02-1740, June 1975, 296 pp.; NTIS PB 251 332.

Quality Assurance guidelines for heavy-duty diesel engines mobile source emissions measurement systems are presented with the concept of a total quality assurance system. The guidelines apply to quality assurance principles and techniques in the areas of procurement, standards and calibration, test quality control, data validation and corrective action. Model quality management procedures are presented to describe the relationships and responsibilities of the various organizational elements in accomplishing the quality functions.

Ray, R. M., and F. E. Armstrong. Evaluation of an Electrochemical NO2 Analyzer. U.S. Energy Research and Development Administration, Report No. BERC/RI-75/6, October 1975, 24 pp.

A model N-346 NO2 analyzer, manufactured by International Biophysics Corp. was evaluated for design and performance by the Bartlesville (Okla.) Energy Research Center, U.S. Energy Research and Development Administration, in a testing facility specifically designed for such instrument-performance evaluations. The evaluation showed the analyzer to have a linear response to NO2 in the 0 to 10 ppm range. Zero drift was less than 1 pct of full scale during a 24-hour period; span drift was less than 4 pct of full scale over a similar period. Tests with interference gases such as NO, CO, and CO2 showed no significant effect on analyzer response to NO2. The instrument tested showed a 0.4 pct of full scale change in response per degree Fahrenheit. The signal noise level observed at all levels of response was excessive and severely limited the lower detection limit of the instrument. The signal noise level also increased with decreasing temperature.

Ray, R. M., and F. E. Armstrong. Evaluation of Gas-Monitoring Devices. U.S. Energy Research and Development Administration, Report No. BERC/IC-76/5, December 1976, 26 pp.

This report discusses the various parameters used to design and implement a program to evaluate gas-monitoring devices. The philosophy of testing and discussion of specific equipment utilized for performance evaluations at the Bartlesville Energy Research Center of the Energy Research and Development Administration are described in detail. Sample equations for statistical analysis of data collected and for calculation of gas concentrations in static and dynamic blending systems are given, but no rigorous treatment of the data or equations is offered. Most testing procedures are discussed in general terms, but some specific procedures are discussed in detail.

Reinbold, E. O., D. H. Carlson, and J. H. Johnson. Ambient Pollutant Concentrations in Two Underground Metal Mines Using Diesel Equipment. Presented at the 1979 AIME Annual Meeting, New Orleans, La., Feb. 18-22, 1979, AIME Preprint 79-77, 23 pp.

The paper presents the results of a study which involved collection and analysis of airborne pollutant concentration data in two producing underground room and pillar metal mines which use diesel powered equipment in the area near the face. The results include the concentrations of CO2, CO, NO, NO2 and respirable particulate matter measured with the latest portable instruments, and the carbon and hydrogen contents of the particulate matter samples determined by combusting them in a Elemental Analyzer. The carbon and hydrogen contents are used to estimate the amount of diesel particulate matter in the mine ambient air. The short term grab sample concentration data, although not suitable for determining compliance with ACGIH Threshold Limit Values (TLVs), are related to the TLVs so that they may be compared conveniently. Lognormal frequency distributions and the arithmetic mean of the concentration measurement data are used to compare different mine situations. Conclusions are drawn as to which pollutants are most important to control under actual mine production conditions.

Reinbold, E. O. Analysis of Air Quality Data in Two Underground Mines Using Diesel Powered Equipment. Thesis, Mich. Technol. Univ., Houghton, Mich., 1977, 289 pp.

The purpose of this thesis was to analyze air quality data in underground mines using diesel equipment. The White Pine Mine of Copper Range Company and the Brushy Creek Mine of St. Joe Minerals Company were the two mines used in the study. The pollutants studied were CO, CO2, NO, NO2, and particulate matter. Lognormal frequency distributions were used to analyze the data by determining the concentrations of the pollutants that are exceeded 1 pct of the time. The arithmetic and geometric means were also used to compare different data groups. The arithmetic means of the concentrations were all under 1/2 the Threshold Limit Value (TLV), except

in certain long headings. The worst pollutant was the combined CO + NO level. Of this combination, NO had higher concentrations than CO. If the ceiling limit for NO2 is lowered to 1 ppm, it may become the major pollutant. Under present standards, the NO2 levels did not cause air quality problems. Simple linear regressions of the pollutant concentrations on CO2 concentration showed that CO2 is a good tracer of adverse conditions. Particulate matter samples showed varying amounts of silica content. For one mine studied, the TLV level was near 1.50 mg/m^3 because of high silica content. At the other mine, the TLV was 10 mg/m^3. It was also found that both mines studied had about 60 pct Carbon + Hydrogen (diesel particulate matter) in the mine air. The Transmission Electron Microscope also showed a large amount of diesel generated particles in particulate matter samples. If standards for the diesel related fraction of the respirable particulate matter are developed, it may become the single most important pollutant in underground mines employing diesel equipment. Two portable particulate matter instruments were also evaluated for use in mines. Because of their insensitivity to diesel particulate matter, these instruments were found not to be suitable for use in mines using diesel equipment.

Rogers, S. J. Analysis of Noncoal Mine Atmospheres. MSA Research Corp., Contract No. S0231057, May 21, 1976, Open File Report 78-77, 118 pp.; NTIS PB 266 764.

The quantity and behavior of gases in metal and nonmetal mines were monitored to provide background information on feasibility of incipient fire detection systems. Monitoring was conducted during working and nonworking periods at intake air, return air and working places. Gases generated during diesel operations and shot firing were of particular interest. Gases which were monitored were CO, CO2, NO, NO2 and SO2: submicron particulate concentrations were monitored also. Commercially available instruments were used and included nondispersive infrared, electrochemical and chemiluminescent types. The ratios of the various gases generated during diesel operations and shot firing were similar to those expected from an incipient fire, with the exception of the $CO2/NO_x$ ratio, which is sufficiently different to be considered for early fire warning. Samples taken near leaking bulkheads showed high CO2 levels and low CO levels, the reverse of anticipated behavior in coal mines.

Schurmann, D., N. Krause, and D. Kinne. The Influence of Testing Parameters on Exhaust Gas Emissions. Presented at the Passenger Car Meeting, Troy Hilton, Troy, Mich., June 5-9, 1978, SAE Technical Paper Series 780649, 16 pp.

The ambient conditions in the test facilities, the dynamometer characteristics, and the test drivers influence the formation of the components in vehicular exhaust gas emissions. To quantify the specific effects a standard test vehicle which is equipped with a mechanized driver and a measuring system is used as a calibrating instrument. Variations of

the barometric pressure were found to influence the exhaust test results significantly. Systematic errors up to a factor of two may be caused by malfunctions of apparently well-adjusted dynos. Furthermore, the drivers can create large deviations without violating the tolerances of the driving schedule.

Scott, L. W. Remote Monitoring of Air Quality in Underground Mines. BuMines RI 8253, 1977, 14 pp.

This report presents several systems for continuously monitoring the quality of air in underground mines that are being developed by the Bureau of Mines. Underground stations measure methane, carbon monoxide and nitrogen dioxide concentrations, air velocity, and air temperature. This information is transmitted over a single telephone pair to central stations located on the surface. The central stations display alarms and the data is selectably displayed on digital panel meters.

Severs, R. K. Status of Problems in Sampling Ambient Air Quality. Chemosphere, v. 6, No. 10, pp. 617-623.

The article discusses the problems of taking air samples. The primary problems of air sampling are due to the nonrandom, periodic, nonpredictable dispersion of the factors of interest in time and space. The author discusses a few sample techniques and gives the response time of the instruments. The author points out that an awareness of these problems can lead to greater accuracy of data collection.

Stalder, A. F., and D. H. Collins. Mine Air Monitor. Texas Instruments, Inc., BuMines Contract No. H0122044, March 29, 1974, rev. June 17, 1974, Open File Report 43-75, 48 pp.; NTIS PB 242 488/AS.

This report prepared by Texas Instruments deals with the development of a Mine Air Monitor to measure O2, CO, and NO2 gases. The report includes sections on the constraints of the instrument, electrical design of the instrument and test results. The report also includes appendices describing in detail operation, maintenance and calibration of the instrument.

Turnbull, M. S. Analysis Techniques Available for Monitoring Mine Atmospheres. J. of the Mine Ventilation Society of South Africa. v. 33, No. 11, November 1980, pp. 189-196.

Techniques employed in both portable and on-line analyzers for gaseous measurement are diverse and numerous. This paper is intended to indicate the "state of the art" and describes the general methods of analysis. Such methods provide a basic means which been adapted by several companies to suit varying applications.

U.S. Department of Health, Education, and Welfare. The Use of Diesel Equipment in Underground Coal Mines. NIOSH Workshop Work Group Reports, Morgantown, W. Va., Sept. 19-23, 1977, 110 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

In order to assist in evaluating occupational health and safety problems associated with the case of diesel equipment in underground coal mines, the National Institute for Occupational Safety and Health (NIOSH) sponsored a workshop held in Morgantown, West Virginia, September 19-22, 1977. Representatives of industry, labor, government, and academia were divided into four work groups, each of which examined one of the following topics: emissions and control technology, environmental characterization and pollutant interactions, health effects, and safety and productivity. This report summarizes the discussions and conclusions of the work groups.

West, P. W., and K. D. Reiszner. Personal Monitor for Nitorgen Dioxide. U.S. Environmental Protection Agency, Report No. EPA-600/2-78-001, January 1978, 33 pp.

An attempt has been made to develop a personal monitor for assaying nitrogen dioxide in ambient air. NO is collected from the ambient air by permeation through a silicone membrane into an alkaline thymol blue solution. The NO is converted to nitrite and determined colorimetrically. Maintenance of a carefully controlled flow rate is not required because the rate of absorption is controlled by permeation. The monitor which is sealed may be worn in any orientation that does not restrict free air movement to the membrane. Although it is sensitive to ambient air concentrations of nitrogen dioxide and exhibits essentially linear response to this pollutant up to the OSHA limit of 10,000 ug/m^3, field evaluation indicates the monitor yields a much higher ambient air value than that obtained by the accepted EOA-TGS-ANSA method. The effect of temperature and sunlight on the monitor is minimal and other common pollutants including nitric oxide do not affect the response of the monitor.

B. Ambient Measurement and Instrumentation
2. Particulate matter

American Conference of Governmental Industrial Hygienists. Air Sampling Instruments, 4th ed. See III.B.1.

Carlson, D. H., and J. H. Johnson. The Monitoring of Diesel Pollutants in Underground Mines. See III.B.1.

Coordinating Research Council, Inc. Informational Report on the Measurement and Characterization of Diesel Exhaust Emissions. Atlanta, Ga. December 1980, CRC Report No. 517, 275 pp. Available from National Technical Information Service, Springfield, Va., PB 81-221251.

This report provides guidance on selection of methods for collection and analysis of the constituents in diesel exhaust to enable a complete chemical characterization of the exhaust. It was prepared by a thorough review of the state-of-the-art for measuring diesel emissions in 1980. An attempt was made to compile validated, or at least tested, methods and to evaluate their engineering applicability. Available methods were reviewed to establish the state-of-the-art and the status of each method is reported. If the methods review indicated the analytical procedures were adequate, one or more methods are recommended. In many cases, the need for additional research is evident and recommendations for further research are made. The methods allow complete assessment of the constituents that are of current interest in diesel exhaust. Many of the constituents are minor, but may be of interest in assessintg health effects and effects of control technology in other research studies.

Gibbs, R. E., J. D. Hyde, and S. M. Byer. Characterization of Particulate Emissions from In-Use Diesel Vehicles. See III.A.2.

Harris, D. B., J. W. Montgomery, and P. H. Garrett. Portable Particulate Sampler With Automatic Isokinetic Flow Control. Presented at the 71st Annual Meeting of the Air Pollution Control Assoc., Houston, Tex., June 25-30, 1978, APCA Preprint 78-35.4, 14 pp.

Pollution control sampling programs involve numerous sites without sufficient time to allow extensive sampling of the variables being investigated at each site. Therefore, a pre-survey particle sampling system was needed to obtain data in a short time. This article describes the operation and gives the percent error of a new portable particulate sampler with isokinetic flow control that accomplishes this task.

Holland, W. D., and R. W. Freedman. Determination of Breathing Zone Concentrations of Contaminants From Emissions From Diesel Powered Vehicles in Underground Mines. See III.B.1.

Johnson, J. H., Dr. An Overview of Monitoring and Control Methods for Diesel Pollutants in Underground Mines Using Diesel Equipment. See III.A.1.

Johnson, J. H., D. H. Carlson, and B. G. Bunting. The Application of Advanced Mine Air Monitoring Techniques of Mines Using Diesel Powered Equipment. See III.B.1.

Johnson, J., D. Carlson, B. Bunting, and J. Michelbacher. The Development and Application of Advanced Mine Air Monitoring Techniques to Mines Using Diesel Powered Equipment. See III.B.1.

Lindgren, J. L., H. J. Krauss, and M. A. Fox. A Comparison of Two Techniques for the Collection and Analysis of Polynuclear Aromatic Compounds in Ambient Air. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Tex., June 25-30, 1978, APCA Preprint 78-25.4, 14 pp.

This report compares two methods for the collection and analysis of PNA's in ambient air. The difference between the two methods are in the filters used. The standard method uses Polyurethane plugs and the newer method uses Bondapak C18 plugs. The article compares the methods in terms of air flow, PNA extracts collected, and analysis. Because of the savings of solvents, time and the efficiency of PNA collection, the authors conclude that the C18 material is superior to the polyurethane material.

Morgan, G. B. Energy Resource Development: The Monitoring Components. See III.B.1.

Pilkington, R., T. Kelly, and H. Wimett. Guidelines for Quality Assurance Programs for Mobile Source Emissions Measurement Systems - Phase II. Heavy Duty Diesel Engines. See III.B.1.

Reinbold, E. O., D. H. Carlson, and J. H. Johnson. Ambient Pollutant Concentrations in Two Underground Metal Mines Using Diesel Equipment. See III.B.1.

Rodgers, S. J. Analysis of Noncoal Mine Atmospheres. See III.B.1.

Schaller, R. E., R. T. Sedoff, and H. J. Paulus. A New Concept Size Selective Sampling System for Monitoring Particulate Air Pollution. Presented at the Winter Annual Meeting, Houston, Tex., Nov. 30-Dec. 4, 1975, ASME Preprint 75-WA/APC-4, 8 pp.

A new concept sampling system was designed and developed to monitor atmospheric particulates on the basis of their aerodynamic size. The fractionating head utilizes a jet driven centrifugal field for separation, so that any desired cut size in the range from 1.5 to 5μm can be set at a constant sampling rate of 20 standard liters per second by adjustment of jet pressure. This allows a sampling differentiation between coarse and fine particle mass frequency distribution modes occurring in atmospheric aerosols. At one point in its operating range, the unit simulates the standard respirable dust sampling criterion designed to approximate that portion of inhaled particulates capable of penetrating to the non-ciliated regions of the lung.

Schranze, B. A. Guide to Ambient Air Monitoring Systems. Instruments & Control Systems, November 1979, pp. 51-56.

There are many commercial instruments on the market for monitoring ambient and effluent air. This article contains comprehensive tables comparing the different procedures of monitoring the air in terms of range, precision, cost, EPA approval, and manpower and facility requirements. The author also discusses various monitoring methods so a cost effective system of monitoring the ambient air can be chosen.

Society of Automotive Engineers, Inc. The Measurement and Control of Diesel Particulate Emissions. SAE Progress in Technology Series, No. 17, 1979, 388 pp.

This book contains 16 selected SAE papers from 1976 through March 1979. The book is largely directed at measurement techniques and baseline data since a few papers have been presented that look at controls using advanced particulate characterization methods. A few papers in the controls area have been included where smoke and the gaseous emissions of hydrocarbons, carbon monoxide, and nitrogen oxides have been measured. These papers show the important engineering trade off between NO_x and particulates, i.e. low NO_x and high particulates or low particulates and high NO_x. The book also contains a listing of all the abstracts of SAE papers covering diesel particulate matter from 1968-1979 so the book is a complete reference dealing with diesel particulate emissions.

Treaftis, H. N., T. F. Tomb, and C. D. Taylor. Comparison of Respirable Coal Mine Dust Concentrations Measured with an MRE and a Newly-Developed, Two-Stage Impactor Sampler. J. AM. Ind. Hyg. Assoc., v. 39, No. 11, November 1978, pp. 891-897.

The design and laboratory evaluation of a two-stage aerosol sampler using an impaction plate for removing particles above 10 μm, has been reported. The unit was developed to provide an alternative to the two-stage sampling head used on approved coal mine personal respirable dust samplers. The new device offers the potential of increasing the analytical accuracy of samples, and of providing a device more suitable to the mining community for use in their mandated dust sampling program. This paper describes the underground sampling program conducted to establish the factor for converting respirable dust concentrations measured with this device to equivalent concentrations measured with an Isleworth 113A gravimetric dust sampler (MRE). This study demonstrated that the use of the immpactor sampling head provides a viable alternative to the currently used sampling head. The results showed that comparative measurements could be linearly related for MRE dust measurements ranging form 0.5 to 5.5 mg/m^3. The factor determined for converting measurements made with the new head to equivalent MRE measurements was approximately 0.5.

U.S. Department of Health, Education, and Welfare. The Use of Diesel Equipment in Underground Coal Mines. See III.B.1.

B. Ambient Measurement and Instrumentation

3. SO_x and sulfates

American Conference of Governmental Industrial Hygienists. Air Sampling Instruments, 4th ed. See III.B.1.

Coordinating Research Council, Inc. Informational Report on the Measurement and Characterization of Diesel Exhaust Emissions. See III.B.2.

Johnson, J. H., Dr. An Overview of Monitoring and Control Methods for Diesel Pollutants in Underground Mines Using Diesel Equipment. See III.A.1.

Johnson, J. H., D. H. Carlson, and B. G. Bunting. The Application of Advanced Mine Air Monitoring Techniques of Mines Using Diesel Powered Equipment. See III.B.1.

Kirk, B., and R. Seymour. Sulphuric Acid Protection by Diesel Mine Equipment. Canada Center for Mineral and Energy Technology, April 1978, Report MRP/MRL 78-45 (TR), 16 pp.

A series of measurements of the sulphuric acid produced by underground diesel mine equipment was carried out in the Elliot Lake mines. The filters were analyzed using a titrimetric method with a specific ion electrode as an end point detector. The results indicated that a minimum of 22,500 cfm is required to control the H_2SO_4 within the NIOSH guidelines and that, on average, 5.9 mg of sulphuric acid are produced for every ton of ore removed by an ST-8 scooptram.

Morgan, G. B. Energy Resource Development: The Monitoring Components. See III.B.1.

Rodgers, S. J. Analysis of Noncoal Mine Atmospheres. See III.B.1.

Schranze, B. A. Guide to Ambient Air Monitoring Systems. See III.B.2.

Turnbull, M. S. Analysis Techniques Available for Monitoring Mine Atmospheres. See III.B.1.

B. Ambient Measurement and Instrumentation

4. Noise

Adams, J. W., W. D. Bensema, and M. Kanda. Electromagnetic Noise in Grace Mine. Electromagnetics Div. of Nat. Bureau of Standards, BuMines Working Fund Agreement H0133005, June 1974, Nat. Bureau of Standards IR 74-388, Open File Report 37-75, 127 pp.; NTIS COM 741-1688/AS.

Two different techniques were used to make measurements of the absolute value of electromagnetic noise in an operating hardrock mine, Grace Mine, located near Morgantown, Pennsylvania. Diesel-powered haulage equipment is used in this mine, and the electromagnetic noise environment created by electric-powered haulage equipment. One technique measures noise over the entire electromagnetic spectrum of interest for brief time periods. Data are recorded using broadband analog magnetic tape and are later transformed to give spectral plots. The other technique records noise amplitudes at several discrete frequencies for a sufficient amount of time to provide amplitude probability distributions. The specific measured results are given in a number of spectral plots and in amplitude probability distribution plots.

Anderton, D., and V. K. Duggal. Diesel Engine Emissions and Noise. See III.A.1.

Anderton, D., and V. K. Duggal. Effect of Turbocharging on Diesel Engine Noise, Emissions, and Performance. SAE Preprint 750797. Society of Automotive Engineers, Inc. Diesel Engine Noise Conference. August 1975, SAE Special Publication 397, pp. 23-26.

The overall effect of two methods of turbocharging a direct injection four stroke diesel engine in terms of performance, smoke, a noise and gaseous emissions is described. It is shown that the effect of turbocharging is to produce a more socially acceptable engine. Matched turbocharging involving reduced compression ratios produces substantial emissions and combustion noise reductions (up to 16dB) at full load but can increase combustion noise levels considerably (8dB) at light load. Before full advantage can be taken, methods of controlling the characteristics of turbochargers to maintain short ignition delays at all conditions are required, together with reductions in engine mechanical noise levels.

Chung, J. Y., M. J. Crocker, and J. F. Hamilton. Measurement of Frequency Responses and the Multiple Coherence Function of the Noise-Generation System of a Diesel Engine. J. Acoust. Soc. Am., v. 58, No. 3, September 1975, pp. 635-642; also, Holmes, P. J., and C. A. Mercer. Comments on. J. Acoust. Soc. Am., v. 60, No. 4, October 1976, pp. 951-952.

A structural-acoustical system has been established to model theoretically the noise generation of a six-cylinder diesel engine. In this system, six-cylinder pressures have been treated as six mutually correlated inputs. The noise measured 3 ft away from the engine has been treated as the single output of the system. Six structural-acoustical frequency responses with respect to the six inputs were evaluated experimentally. The multiple coherence function between all the inputs and the single output has also been evaluated experimentally. Using the multiple coherence function, the engine noise which is coherent to the cylinder pressures was separated from the total engine noise. It has been found that, for the V-6 diesel engine studied, the coherent noise is almost equal to the total noise. From the structural-acoustical frequency responses, the contributions of the individual cylinder pressures to the coherent engine noise were assessed.

Clark, T. M., and R. A. Lauder. A Sound Level Survey in the New South Wales Coal Mining Industry. Proc. Aus. Inst. Min. and Metallurgy, No. 250, June 1974, pp. 9-16.

The mechanization of the coal industry in New South Wales involved the introduction of large face and transport machines. The trend is towards still higher capacity units with greater horsepower and it became apparent that a potential risk of damage to the hearing of workmen existed. In order to assess whether the sound levels were sufficiently high to impair the hearing of workmen, a sound level survey of all major operations in the industry was carried out by the Mining Engineering Division of the Joint Coal Board. The results indicated that the operations could be classified into three categories of risk--probably hazardous, of doubtful hazard due to the intermittency of the operations, and of low hazard. Legislation has subsequently been enacted requiring the wearing of hearing preservation aids in some of the probable risk operations.

Leipold, F. W., and H. O. Hardenburg. Noise, Emissions, and Performance of the Diesel Engine--A Comparison Between DI and IDI Combustion Systems. SAE Preprint 750796. Society of Automotive Engineers, Inc. Diesel Noise Conference. August 1975, SAE Special Publication 397, pp. 13-22.

A direct as well as an indirect injection system have been studied in regard to noise, exhaust emissions and fuel consumption on a V-10 diesel engine. The dependency of the sound pressure levels on engine speed, engine load and injection timing is described for both combustion systems. The noise reduction achieved by optimization of injection timing is shown in relation to the respective changes in exhaust and smoke emission output and fuel consumption.

Maxson, R. M. Simplified Occupational Noise Hazard Prediction for New Equipment. J. Am. Ind. Hyg. Assoc., v. 39, No. 11, November 1978, pp. 914-920.

A simplified yet accurate method has been developed to predict noise hazards for new equipment by using only dB(A) noise levels, calculating power levels by the Two Surface Method and plotting a predicted noise isopleth. Noise levels can be accumulated for multiple sources. Room constants and other parameters can easily be varied to determine the most feasible and economical solution for noise problems.

Norman, R. S. An Overview of Diesel Engine Noise. Presented before the Second Symposium on Underground Mining, Louisville, Ky., Oct. 19-21, 1976, pp. 248-252.

In recent years, the noise environment in underground and surface mines has received much attention from mine operators, workers, and the federal government. This paper briefly explains diesel truck noises from the exhaust, engine, fan, intake and tires. The author concludes that a truck can be built to have noise levels of 75-80 dBA measured at 50 ft. The paper also includes a table of the average noise levels in dBA of various aboveground and underground mining equipment.

Patterson, W. N., G. G. Huggins, and A. G. Galaitsis. Noise of Diesel-Powered Underground Mining Equipment: Impact, Prediction, and Control. Bolt Beranek and Newman, Inc., BuMines Contract No. H0346046, March 21, 1975, Open File Report 58-75, 227 pp.; NTIS PB243 896.

This report describes the results of the work performed under the Bureau of Mines contract No. H0346046. The report is divided into six sections. Section 2 discusses the numbers, types, and noise levels of diesel-powered mining machinery. Section 3 presents a method for predicting underground noise levels from above ground measurements. Section 4 investigates worker exposure to noise levels. Sections 5 and 6 discuss noise sources, noise control treatments, and the cost associated with noise control. Finally, a number of appendices provide supporting information for the material presented.

Pisarski, J. J. Exterior Truck Noise Measurements on Turbocharger Retrofit. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo. June 7-10, 1976, SAE Preprint 760549, 8 pp.

Exterior noise level measurements were conducted on a typical in-service diesel engine heavy duty truck to determine the noise level reduction resulting from a turbocharger retrofit. The tests were conducted in accordance with procedures recommended by the Society of Automotive Engineers and the United States Department of Transportation. Overall noise level measurements and a narrow-band spectrum analysis indicate that a significant noise level reduction is obtained from the installation of a

turbocharger kit. The lower noise level is the result of a smoother pressure development during combustion. The narrow-band analysis shows a significant amplitude reduction at the engine firing frequency and a general decrease in noise energy over the whole frequency range.

Priede, T. The Problems of Noise of Engines in Different Vehicle Groups. SAE Preprint 750795. Society of Automotive Engineers, Inc. Diesel Engine Noise Conference. August 1975, SAE Special Publication 397, pp. 1-12.

The paper classifies all current automotive engines into four distinct groups relative to engine usage and vehicle noise legislation. The noise characteristics of the engines in each group are widely different except that at their maximum rated speeds the overall noise levels approach the same value. The sources of noise rank in different importance according to the size and type of engine. Therefore quiet engine design must also vary. The importance of mechanical noise is emphasized and it is considered that this source could be a limiting factor to future low noise engines.

Russell, M. F. Automotive Diesel Engine Noise and Its Control. Presented at the Internat. Automotive Eng. Cong., Detroit, Mich., Jan. 8-12, SAE Preprint 730243, 20 pp.

There is now a growing interest in every means of reducing the noise of current diesel engines and designing even quieter engines for the future, perhaps as awareness of noise as a societal problem becomes widespread. This paper discusses the production of engine noise, its transmission through the structure, and its subsequent radiation as a sequence of events. Diesel engine noise can originate from several mechanical sources such as piston slap, timing gear rattle, etc. as well as from the sharp rise in cylinder pressure which attends combustion. The relative importance of these sources is affected by clearances between the working parts which are dictated by design and manufacturing constraints. If reduction of noise at source is contemplated, it is necessary to diagnose which of these sources are primarily responsible for the noise, bearing in mind that the relative importance of the sources varies with engine load and speed. The diagnosis of sources can be based upon measurements of combustion spectra at various engine conditions. Engine noise may be reduced either at source or by reducing the vibration of the external surfaces of the engine. If reduction of noise by treatment of the surface panels and covers is contemplated, it is generally necessary to treat all the thin section areas (for example, crankcase, water jacket, sump, valve gear covers, etc.). However, it is useful to be able to locate any areas which do not contribute significantly to the overall noise. Techniques to find the important noise-radiating areas of the engine surface are discussed prior to a brief consideration of noise reduction measures.

Russell, M. F. Recent CAV Research into Noise, Emissions, and Fuel Economy of Diesel Engines. See II.C.

Schneider, A. J. Measuring Noise--The State-of-the-Art. Presented at the Off-Highway Vehicle Meeting, Milwaukee, Wis., Sept. 13-16, 1976, SAE Preprint 760672, 8 pp.

New instruments and new measurement concepts continually evolve in support of programs to reduce operator noise exposure and produce noise emission. The purpose of this paper is to review new equipment and new measurement practices which can assist in the direction of programs to develop quieter vehicles. Opportunity is taken to also discuss the closely associated field of whole-body vibration.

Society of Automotive Engineers, Inc. Diesel Engine Noise Conference. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Proceedings P-80, 364 pp.

Diesel engines have the advantage of good fuel economy but the disadvantage of producing excessive noise. Therefore a Diesel Engine Noise Conference was held Feb. 26-March 2, 1978. This book contains 30 selected SAE papers covering all aspects of diesel engine noise. The papers cover the areas of engine design for low noise, engine noise measuring techniques, the relation between engine noise and engine vibration, and ways to reduce engine noise, etc.

Van Atta, F. A., Dr. Federal Regulation of Noise in Agricultural and Off-Highway Equipment. Presented at the Off-Highway Vehicle Meeting, Milwaukee, Wis., Sept. 13-16, 1976, SAE Preprint 760674, 8 pp.

This paper seeks to answer questions pertinent to Federal regulations of noise in agricultural and off-highway equipment. It discusses the statutes under which authority lies, and whether or not the regulations actually accomplish the purposes for which they are intended.

Young, T. C. The Effect of Bare Engine Noise on Diesel Trucks. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760548, 12 pp.

This study investigates the relative correlation between (1) bare engine sound levels, (2) engine contributing sound levels in the vehicle, and (3) total vehicle sound levels. Common statistical analytical programs are used as the method of correlation.

B. Ambient Measurement and Instrumentation

5. Oxygen

American Conference of Governmental Industrial Hygienists. Air Sampling Instruments, 4th ed. See III.B.1.

Lang, H. W., W. E. O'Neill, B. A. Coulehan, and R. W. Freedman. Continuous Monitoring of Diesel Exhaust Gas for CO_2, CO, O_2, CH_4, and NO_x. See III.B.1.

Ray, R. M., and F. E. Armstrong. An Evaluation of Several Portable, Direct-Reading, Electrochemical O_2 Meters. U.S. Energy Research and Development Administration, Report No. BERC/RI-76-7, September 1976, 50 pp.

Nineteen portable, electrochemical O_2 analyzers from six manufacturers were evaluated for design and performance by the Bartlesville (Okla.) Energy Research Center, Energy Research and Development Administration, in a testing facility specifically designed for such instrument-performance evaluations. The units tested would be acceptable tools for use in measuring oxygen deficiencies which may occur in mining operations. The evaluation showed that the analyzers have linear responses to oxygen in the 9 to 25 pct range and that their span drift measured over 24 hours was minimal. Changes in temperature and altitude were shown to affect analyzer response significantly, but no interference effects from CO, CO_2, NO_2, or H_2O were observed.

C. Refueling Emissions

Hochhauser, A. M., and R. J. Campion. An Experimental Study of Vehicle Refueling Emissions. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760307, 16 pp.

When automobiles are refueled, hydrocarbon vapors are displaced from the vehicle tank and emitted to the atmosphere. An experimental program was carried out to measure both the mass and the volume of these emissions as a function of three variables: vehicle tank temperature, dispensed fuel temperature, and fuel volatility measured as Reid vapor pressure. Based on the experimental results, regression equations were developed which can be used to accurately predict refueling emissions under a wide range of conditions. An analysis of the experimental results shows that the vapor balance system, the simpler, less expensive of the two systems being considered for control of refueling emissions, has the potential to meet strict standards under temperature conditions where ozone is likely to form in the atmosphere.

D. Physical and Chemical Factors Affecting Emissions Formation

Broome, D., and I. M. Khan. Mechanisms of Soot Release From Combustion of Hydrocarbon Fuels With Particular Reference to Diesel Engines. Air Pollution Control in Transport Engines. (A Symposium arranged by the Automobile Div. and the Combustion Engines Group of the Inst. of Mech. Eng., Nov. 9-11, 1971). Inst. Mech. Eng., London, Paper No. C140/71, 1971, pp. 185-197.

Information on the formation and combustion of soot in laboratory hydrocarbon flames is reviewed. Chemical and physical factors influencing soot release are discussed, including fuel composition and additives, and effects of temperature, pressure, and turbulence. An account of the mechanisms of carbon formation follows. The paper then considers how this fundamental information on soot release relates to the diesel combustion process. Soot formation in various types of diesel engines, augmented with the work done at the authors' companies, is also discussed.

Burley, H. A., and T. L. Rosebrock. Automotive Diesel Engines--Fuel Composition vs. Particulates. Presented at the Fuels and Lubricants Meeting, Hyatt Regency, Houston, Tex., Oct. 1-4, 1979, SAE Preprint 790923, 12 pp.

Forty-six experimental diesel fuels have been tested in a modern automotive diesel engine, and the effect of fuel characteristics on particulate emissions, gaseous emissions, and fuel economy has been studied. Regression analysis of results established a relationship between particulate emissions and two fuel characteristics: (1) aromatic content and (2) volatility, especially as described by the 90% boiling point. Particulates could be reduced by lowering either aromatic content or 90% boiling point. The foregoing conclusions were based on a weighted five-load dynamometer schedule but appear to be confirmed by limited vehicle testing on the Federal Test Procedure.

Bykowski, B. B. Characterization of Diesel Emissions as a Function of Fuel Variables. Southwest Research Institute, Contract No. 68-03-2707, U. S. Environmental Protection Agency, Report No. EPA-460/3-81-015, April 1981, 286 pp.

Several properties of a refinery "straight-run kerosene", which had a narrow boiling range approximating the middle of a No. 1 diesel fuel, were altered to study their effects on regulated and unregulated exhaust emissions. Eleven fuel blends, representing changes in nitrogen content, aromatic level, boiling point distribution, olefin content, and cetane number, were evaluated in a 1975 Mercedes-Benz 240D. Statistical analysis, including regression, was performed using selected fuel properties as independent variables. Higher aromatic levels were generally associated with increased emissions, while increased olefin levels were generally associated with decreased emissions.

Cernansky, N. P., C. W. Savery, I. H. Suffet, and R. S. Cohen. Physical and Chemical Phenomena Responsible for Odor Formation in Diesel Engines. Drexel Univ., Grant No. AER76-19752, Dec. 17, 1976, 42 pp.; NITS PB-263 173.

Light duty diesel engines have a potential for improved efficiency with lower emissions in comparison with the conventional spark-ignition engine. However, one of the major technical concerns associated with the widespread use of diesel engines as an alternate light duty motor vehicle power plant is associated with the odoriferous and acrid qualities of the diesel exhaust. Thus, a study of the physical and chemical phenomena responsible for odor formation in diesel engines has been initiated. A single cylinder diesel engine test facility has been modified and instrumented for studying odor formation and control. Also, an air aspirated spray burner facility has been redesigned and refurbished for use in this study. Odor sampling and analysis techniques and procedures have been developed and preliminary engine odor samples have been collected and analyzed. Supportive theoretical and modeling work has also been initiated. These theoretical and experimental tasks are reported in this interim progress report.

Duggal, V. K., T. Priede, and I. M. Khan. A Study of Pollutant Formation Within the Combustion Space of a Diesel Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780227, 16 pp.

The concentration of pollutants in the combustion space of an indirect injection swirl diesel engine have been studied on a time basis. A fast acting water-cooled gas sampling valve was used for the in-cylinder sampling. The measured concentrations have been used to visualize a simplified reaction zone structure of diesel combustion. The results show that carbon monoxide appears first in the reaction zone followed by nitric oxide and soot. The high soot concentration exists only for a short period of time (3 ms) and is rapidly reduced to a low level whereas carbon monoxide is gradually oxidized to carbon dioxide over the expanison cycle. The reaction zone is found to be 10-20mm wide and is widest near the chamber wall.

Greeves, G. Response of Diesel Combustion Systems to Increase of Fuel Injection Rate. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich. Feb. 26-March 2, 1979, SAE Technical Paper Series 790037, 20 pp.

Experimental data are presented to show how diesel combustion systems respond to increase of fuel injection rate. Concepts of a fuel spray entrainment parameter, a maximum usefuul injection rate, and a condition termed "impingement" are introduced to correlate and interpret widely differing responses. Best possible smoke and BSFC values in swirl type direct injection engines are obtained for injection rates 15 pct to 33 pct higher than normal values, but in practice lower rates must be used to satisfy emissions and other requirements. Engines with a high swirl rate and impingement give a superior "retardability" for normal injection rates. Computer model calculations also show that there is a maximum useful injection rate and explain the relative fuel economies for different diesel combustion systems.

Gross, G. P. The Effect of Fuel and Vehicle Variables on Polynuclear Aromatic Hydrocarbons and Phenol Emissions. Presented at the SAE Automotive Eng. Cong. and Exposition, Detroit, Mich., SAE Preprint 720210, 1972.

Exhaust emissions of polynuclear aromatic hydrocarbons (PNA) and of phenols has been studied with a variety of test fuels, using cyclic tests in five vehicles-including one without emission control (NC), two with engine modification (EM) control, and two with experimental very low emission systems. The experimental systems both reduced phenol emission to less than 0.5 pct and PNA emission to about 1 pct of the levels observed in the NC vehicle. Phenols were reduced 30 pct by one EM vehicle, but not by the other; while PNA emissions were reduced by 70 pct in both EM vehicles. Fuel composition influenced emissions both directly and through engine deposits. Direct effects included increased phenol emission from increased fuel aromatics and, generally, increased PNA emission from increased fuel aromatics, from increased fuel PNA, and from the presence of a high-boiling naphtha. However, these direct effects of fuel composition on emissions generally decreased, in both relative and absolute terms, in the emission-controlled vehicles. The PNA emissions from several test fuels differed by a factor of two between engine deposits formed from two different commercial premium gasolines. High PNA emissions occurred with deposits from a fuel containing lead and phosphorus; and unleaded fuel, of different hydrocarbon composition and without phosphorus, gave low emission deposity, but this same fuel, with lead added at 0.5 g/gal, still gave low emission. The exact fuel factors are not clear at this time.

Gross, G. P., and K. E. Murphy, Jr. The Effects of Diesel Fuel Properties on Performance, Smoke, and Emissions. Trans. of the ASME J. of Eng. for Power, v. 101, No. 4, October 1979, pp. 524-532.

Diesel fuels were blended from selected components to provide aromatics contents from 10 to 57 pct and viscosities from 2.21 to 6.95 cST (mm^2) at 100°F (38°C) in a 14 fuel set which included a commercial diesel fuel as a reference fuel. Tests of the fuels were conducted under full load at several speeds and in the Federal 13 mode and smoke-cycle procedures, using a 2 stroke naturally aspirated engine and a 4 stroke turbocharged engine. Fuel properties such as viscosity, aromaticity, cetane number, gravity, distillation points, and heat of combustion, some of which were partially correlated, were examined individually and in combinations as predictors of the engine performance data. The two test engines responded similarly to fuel variables, but with some differences in sensitivity. Power output (bhp) and fuel economy (bhp-h/lb) were correlated with the heats of combustion on volume and weight bases, respectively. Smoke increased with the amount of fuel boiling above 640°F (338°C) and was not apparently affected by fuel aromatic content. Emissions of nitrogen oxides and of nitrogen oxides plus hydrocarbons increased with increasing fuel aromatics by itself or with increasing fuel specific gravity and decreasing fuel 50 pct distillation temperature. Hydrocarbon emissions decreased with increasing viscosity or cetane number. Carbon monoxide emissions increased with increasing 90 pct distillation temperature and with decreases in cetane number.

Hare, C. T. Characterization of Gaseous and Particulate Emissions from Light-Duty Diesels Operated on Various Fuels. Southwest Research Institute (San Antonio, TX), Final Report, July 1979, 200 pp.

Gaseous and particulate emissions of a non-routine nature were measured in the exhausts of two light-duty Diesel-powered automobiles. These vehicles were a Mercedes 240D and a Volkswagen Rabbit Diesel. Visible exhaust smoke, regulated gaseous pollutants, and exhaust odor were also measured. Five fuels were used in this investigation, representing broad ranges in sulfur content, hydrocarbon-type composition, density, cetane index, and a number of other properties. Vehicle operating procedures used for test purposes included both those specified in Federal Regulations and several others simulating different driving situations. Gas samples were acquired from both direct and dilute exhaust streams. Particulate samples were taken using an exhaust dilution tunnel operating on the entire exhaust stream of each engine. Filter-collected particulate weights provided the basis for particulate mass emission calculations. The results of a statistical analysis of the particulate emissions data are included as is an analysis of gaseous emissions and particulate size data.

Hare, C. T. Light-Duty Diesel Emission Correction Factors for Ambient Conditions. Southwest Research Institute, San Antonio, Tex., Contract No. 68-02-1777, July 1977, 95 pp.; NTIS PB 272 549.

Since emission measurements from passenger cars are performed at one standard set of ambient conditions and since emission rates of HC, CO, and NO_x are sensitive to temperature and humidity, it is necessary to determine the influence of ambient conditions on emissions from major classes of vehicles. Although such information has been available for gasoline engine powered cars for sometime, no such data were available for diesel powered passenger cars. This report indicates that diesel HC and CO emissions are relatively insensitive to ambient conditions. Diesel NO_x emissions, however, are sensitive to humidity but to a smaller extent than gasoline engines. Humidity correction factors for NO_x emissions also appear to vary with vehicle power-to-weight ratios and are greater for higher powered vehicles.

Ivliev, A. V., Y. A. Knysh, and V. P, Lukachev. (Influence of Combustion Chamber Geometry on Toxic Compound Emissions). Soviet Aeronautics, v. 20, No. 1, 1977, pp. 60-65.

A study is made of combustion efficiency and toxic compound emission of several combustion chamber and injector modifications in model and full-scale conditions. We examine the relationship between the working process in the combustion chamber and exhaust gas toxicity. We obtain the toxic compound emission characteristics for the NK-12St engine with two injector types and show that replacement of the gas jet injectors by centrifugal injectors makes it possible to reduce the oxides of nitrogen emissions by 40 to 50 pct.

Jones, M. A. The Effect of Engine Load and Speed on the Physical Characteristics of Diesel Particulate Emissions. Thesis, Mich. Technol. Univ., Houghton, Mich., 1975, 218 pp.

One of the most objectionable aspects of the use of diesel engines is the emission of particulate matter. This thesis is an investigation of the characteristics of this particulate matter. A size distribution for particulate matter was obtained using an Andersen Inertial Impactor for the engine conditions applicable to the EPA, 13-mode cycle. The particulate matter was analyzed with a transmission electron microscope and found to be comprised of individual spherical particles ranging in size from 100 Å to 1000 Å with a mean size of approximately 300 Å. The particulate matter was analyzed for carbon, hydrogen and nitrogen. The solid particulate matter collected within the Andersen Sampler had a carbon/hydrogen ratio that is temperature dependent ranging from 0.6 at an exhaust temperature of 200°F to approximately 6 at exhaust temperatures greater than 600°F. A correlation between the number of individual spherical particles in an agglomerate and the agglomerate size reveals a particle number range from a single, 100 Å particle to an agglomerate 30 μ in diameter containing an average of 2,500 of the individual spherical particles. A survey of existing exhaust dilution systems and a discussion of dilution system design criteria precedes a description of the system now under construction at Michigan Technological University. This dilution tunnel was designed for simulating the exhaust particulate matter processes occurring in the atmosphere.

Kau, C. J., T. J. Tyson, and M. P. Heap. Study on Oxides on Nitrogen and Carbon Formation in Diesel Engines. Ultrasystems, Inc., Contract No. 68-01-0436, March 1976, 199 pp.; NTIS PB-262 712.

A mathematical model describing heat release and pollutant formation in direct injection diesel engines has been developed and tested. The model includes several empirical constants which can be tuned to fit the requirements of a particular engine. Sensitivity studies indicate that the model is most responsive to those constants which control fuel/air mixing. Numerical experiments strongly suggest that diffusion flames modelled by spherical droplet flames are unsuitable for this type of system. The model has been tested against results obtained with a single cylinder diesel engine. Reasonable predictions of the influence of engine design and operation parameters on NO_x were obtained. However, predictions of smoke emissions were not satisfactory.

Kau, C. J., and T. J. Tyson. Study on Oxides of Nitrogen and Carbon Formation in Diesel Engines--Computer Program User's Manual. Ultrasystems, Inc., Contract No. 68-01-0436, March 1976, 101 pp.; NTIS PB 262 713.

This document describes the computer program and serves as a user's manual for a numerical model on THE PREDICTION OF POLLUTANT FORMATION IN DIESEL ENIGNES. The model is capable of predicting both engine performance and formation of nitric oxide and soot in a direct injected diesel engine combustion process. The program is sufficiently versatile to investigate the influence of several engine parameters, such as geometry, injection timing, compression ratio, load, swirl, etc., and thus can be considered as a tool readily accessible to the design engineers. The physical and chemical processes, the detailed mathematical analysis and the assumptions upon which the model is based are discussed in the full report on this investigation. This manual contains brief descriptions of the program subroutines, program input and output. One sample case is also given to illustrate the use of the program which is designed to facilitate program check-out.

Khan, I. M. Formation and Combustion of Carbon in a Diesel Engine. Diesel Engine Combustion (A Symposium arranged by the Combustion Engines Group of the Institution of Mechanical Engineers, April 7-9, 1970). The Inst. of Mech. Eng., London, Proceedings 1969-70, v. 184, pt. 3J, pp. 36-44.

The effects of the shape of the injection diagram, injection period, and injection nozzle on diesel engine smoke have been studied for a wide range of injection timings and engine speeds on a 1-litre direct-injection type engine cylinder. Cycle temperatures were also varied by raising inlet air temperature and by introducing water mixed with diesel fuel. An analysis of these results shows that the exhaust smoke level is mainly determined by the concentration of soot at the end of heat release (net soot release), i.e., any subsequent combustion of the net soot release before exhaust valve opening is unimportant. The net soot release in a diesel engine cylinder, for a given fuel, is controlled by the amount and rate of diffusion burning and the flame temperatures.

Kirk, B., and R. Seymour. Sulfuric Acid Protection by Diesel Mine Equipment. See III.B.3.

Lavoie, G. A. HC Quench Layer Formation in Combustion Processes. Ford Motor Company, Dearborn, Mich., December 1980, 14 pp.; NTIS DOE/ET/15303-T5.

The project covered by this preliminary report was aimed at understanding wall quenching and other processes responsible for surface generated hydrocarbons in combustion under engine-like conditions. The study concerns the effects of turbulence on the evolution of hydrocarbons. At the conclusion of the program, significant new experimental information will have been generated and an analytical model of the fluid mechanics and some aspects of the chemistry of quenching will be formulated. The work was divided into three tasks: (I) combustion bomb experiments at Ford to measure the effect of turbulence on the chemical species near the cold surface, (II) combustion bomb experiments at U. of M., using a similar turbulence generating device, to fully characterize the flow and turbulence in the vicinity of the quenching surface, and (III) an analytical study, also at U. of M., to characterize fluid mechanical scales of interest in the boundary layer and to find an analytical solution to describe the evolution of the layer.

McConnell, G. The Influence of Fuel Quality and Combustion Characteristics on Diesel Exhaust Emissions. Presented at a Conference organized by IPC Business and Industrial Training Ltd. on Noise, Dirt, and the Diesel, London, March 23, 1972, 8 pp.

The dry components of diesel exhaust consists of 81 pct nitrogen, 18 pct oxygen and carbon dioxide, and 1 pct trace constituents. Therefore 99 pct of the diesel exhaust is innocuous and non-polluting. It is the remaining 1 pct which contains the potentially troublesome materials that must be studied. This paper examines the nature of these potential pollutants, the dangers which are associated with them, and how, if at all, they can be controlled by attention to the fuel's quality and combustion characteristics.

Marshall, W. F., and R. W. Hurn. Factors Influencing Diesel Emissions. See III.F.

Morris, C. J., and J. C. Dent. The Simulation of Air Fuel Mixing in High Swirl Open Chamber Diesel Engines. Proc. Inst. Mech. Eng., v. 190 47/76, 1976, pp. 503-513.

The air fuel mixing process in the high swirl open chamber diesel engine is simulated by a steady state gas jet injected into a steady air swirl flow. The results from the simulation show good agreement with engine studies using high speed photography. An attempt to quantify fuel disperison has been made through the introduction of a mixing parameter, which allows for combustion system geometry in addition to fuel jet and air swirl momenta.

Nightingale, D. R. A Fundamental Investigation into the Problem of NO Formation in Diesel Engines. Presented at the 1975 SAE Off-Highway Vehicle Meeting, Milwaukee, Wis., Sept. 8-11, 1975, SAE Preprint 750848, 20 pp.

In order to supplement the on-going development work aimed at reducing emissions levels, in particular NO, in the exhaust of diesel engines a research programme was initiated to investigate the fundamental nature of NO formation. A rapid acting sampling valve to obtain gas samples directly from the combustion chamber of a running diesel engine was developed concurrently with a mathematical model for the formation of NO in diesel engines, based on the extended Zeldovich mechanism. Gas samples were obtained from the following types of diesel engine: i) a single spray sector of a large quiescent direct injection combustion; ii) A deep bowl direct injection combustion chamber employing inlet induced swirl; iii) a Ricardo Comet V indirect injection combustion system. The temporal and spacial distribution of NO and the local air fuel ratio were determined in each case. The model depended heavily on the information provided by the gas samples which, in conjunction with high speed photography of the combustion process, indicated that NO was formed only in gases exposed to high temperature flame and that any NO found in cooler areas of fresh air or weaker mixture appeared there solely by mixing with the hot gases, despite the high oxygen concentration. In addition the delay between the combustion and the appearance of NO is clearly shown and this allowed considerable simplification of the model in that only the reactions involved in NO formation needed to be considered kinetically in order to give good correlation between experimental and theoretically predicted exhaust NO content over most of the engine operating range. It is concluded that the gas sampling valve proved to ba a valuable tool in understanding the fundamentals of NO formation in particular and combustion problems in general and greatly assisted in the formulation of a mathematical model for prediction of NO emissions from diesel engines.

Pinkerton, J. D. The Influence of Turbulence and Compounding on Unburned Hydrocarbons and Nitric Oxide in the Combustion Products From Internal Combustion Engines. Presented at the ASME Winter Annual Meeting, Nov. 29-Dec. 3, 1970, ASME Preprint 70-WA/DGP-2, 9 pp.

A CFR engine with special inlet and exhaust systems was used to investigate the influence of the amounts of unburned hydrocarbons and nitric oxide in the engine exhaust. The influence of turbulence on the exhaust gas emissions was determined by varying the engine speed and using a shrouded inlet valve. The effect of exhaust turbine compounding was simulated by throttling the exhaust gases and calculating the reversible adiabatic exhaust work. Specific hydrocarbon and nitric oxide emissions and specific fuel consumption were plotted against exhaust pressure.

Radovanovic, R. S., and M. S. Djordjevic. Diesel Precombustion Chamber Design and Its Influence on the Engine Performance and Exhaust Pollutants. See IV.B.

Rao, P. S., A. S. Subramaniam, and B. S. Murthy. Influence of Some Factors on the Emission of Benzo(A)Pyrene From Diesel Engines. Proceedings of the Third National Conference on I.C. Engines and Combustion Sarita Prakashan, Meerut, India, Dec. 10-12, 1976, pp. 231-241.

Internal Combustion Engine is known to be one of the sources of polynuclear aromatic hydrocarbons present in the atmospheric air. These are formed in a combustion process that does not require oxygen and in regions where overrich conditions exist. Among the various polynuclear aromatic hydrocarbons emitted by combustion engines, benzo(a)pyrene is rated as one of the most dangerous carcinogens. In the present work the emission levels of benzo(a)pyrene in a diesel engine exhaust have been studied under different conditions. The tests have been conducted on two diesel engines, one a single cylinder Kirloakar AV1 engine and the other an Ashok Leyland six cylinder automobile engine. The influence of variation of load, use of antismoke additives and fumigation with ethyl alcohol on the emission of benzo(a)pyrene from a diesel engine is studied. In addition, the multicylinder Ashok Leyland diesel engine is supercharged with an exhaust turbocharger and benzo(a)pyrene emissions have been measured at different loads.

Ryan, T. W., III, J. O. Storment, and B. R. Wright. The Effects of Fuel Properties and Composition on Diesel Engine Exhaust Emissions--A Review. Presented at the International Off-Highway Mtg. & Exposition, Milwaukee, Wis., Sept. 14-17, 1981, SAE Technical Paper Series 810953, 16 pp.

Due to the cost and mobility advantages of diesel-powered mine vehicles over electric vehicles, it is anticipated that the diesel engine will become more widely used in underground mines in this country. Concern has arisen, however, over the impact of diesel exhaust emissions on the air quality in the underground mine environment. A literature search has been conducted to identify known effects of fuel properties on the reduction of diesel exhaust emissions. Reductions can be obtained by optimizing fuel properties and by considering alternative fuels to standard diesel fuel. However, the data base is relatively small and the results highly dependent on engine type and operating conditions. Engine studies on a typical mine diesel are necessary to draw quantitative conclusions regarding the reduction of emissions, especially particulates and NO_2 which have not been generally addressed in previous studies.

Seizinger, D. E., T. M. Naman, W. F. Marshall, C. R. Clark, and R. O. McClellan. Diesel Particulates and Bioassay Effect of Fuels, Vehicles, and Ambient Temperature. Presented at the Passenger Car Mtg., Troy, Mich., June 7-10, 1982, SAE Technical Paper Series 820813, 10 pp.

Diesel particulate and gaseous emissions, fuel economy, and mutagenic activity of the particulate extracts were measured for 22 light-duty diesel vehicles representing 1979 through 1982 model-year production of domestics and imports. These vehicles were operated on a chassis dynamometer in a temperature controlled environment. The objectives of this study included measuring effects of fuel aromaticity (0 to 37%), ambient test temperature (25, 50, 75, and 100° F), and vehicle duty cycle on particulate emissions and associated biological activity. Results of this investigation showed that ambient temperature environmental changes on the operating vehicle had virtually no effect on particulate and mutagenicity measurements. Increasing fuel aromaticity in three test vehicles did not show a definitive relationship of particulate level verses fuel aromaticity. The influence of driving cycle on particulate emissions showed the particulate level and mutagenic activity were greater with the New York City Cycle than either Federal Test Procedure cycle or Highway Fuel Ecxonomy Test cycle. Mutagenic assessment of particulate extracts which had been separated into six HPLC fractions showed 90+ percent of the direct acting mutagenicity was contained in three of the six fractions.

Smith, O. I. Fundamentals of Soot Formation in Flames With Application to Diesel Engine Particulate Emissions, Prog. Energy Combus. Sci., v. 7, 1981, pp. 275-291.

A study of the fundamental mechanism of soot formation with particular application to diesel engine emissions is described. The researchers conclude that although soot formation is an inherent characteristic of the compression ignition engine, particulate emissions are not. A number of techniques described in the text show promise for particulate emission reduction through suppression of the soot formation rate and/or enhancement of the oxidation rate. At the present time, there is no way to tell if one or more of these methods may ultimately be able to effect complete oxidation in the engine cylinder. The state of scientific knowledge is such that modeling efforts aimed at determining the effectiveness of many of these techniques are feasible. The researchers state that some of the particulate control strategies discussed in the text may adversely effect the emissions of other harmful species. For instance, techniques used to enhance soot oxidation are likely to lead to increased emissions of nitric oxides. Moreover, their implementation into a practical (e.g. drivable, maintainable, etc.) engine in many cases poses a considerable engineering challenge.

Society of Automotive Engineers, Inc. Diesel Combustion and Emissions. Presented at the Con. and Exposition, Cobo Hall, Detroit, Mich., Feb. 25-29, 1980, SAE Proceedings P-86, 298 pp.

This book contains 23 selected SAE papers written by experienced people from Canada, Germany, Britain, Japan, and the United States. The papers cover all aspects of combustion and emissions of diesel engines. There are several papers on each topic of methods of generating data, the effect of changing engine variables, experimental results as a function of combustion chamber location and crank angle, and the effects on exhaust pollutant measurements.

Springer, G. S., D. J. Patterson (ed.). Engine Emissions: Pollutant Formation and Measurement. See III.A.1.

Taigel, P. G. Diesel Locomotives in Mines: The Production of Toxic Gases by the Diesel Engine. See VIII.1.

Voorhies, A., Jr., L. R. Daniel, Jr., and L. Long. The Effect of Percent Hydrogen in Fuel on Smoke Emissions of a Compression-Ignition Engine. See II.A.

Wagner, H. G. Soot Formation in Combustion. Presented at the Plenary Lecture at the 17th Internat. Combustion Symposium, Leeds, England, October 1978, 40 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

This lecture is an introductory course on soot formation. The author first discusses the appearance of soot and what the conditions must be for the formation of soot. By writing a chemical equation the theoretical limits of soot formation of several gases can be determined. The author compares these values to experimental values. The author then discusses particle burning, turbulent diffusion flames and fuel spray flames. By tying these topics together the author discusses the characteristics of soot formation in diesel engines. Lastly soot kinetics are discussed.

E. Computer Modeling Emissions

Chiu, W. S., S. M. Shahed, and W. T. Lyn. A Transient Spray Mixing Model for Diesel Combustion. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760128, 16 pp.

A transient spray mixing model forming the basis of heterogenous combustion in direct injection diesel engines is described. Experimental results of transient fuel sprays in a high pressure, high temperature chamber form the basis of spray growth equations. Use of similarity of concentration profile across the spray in conjunction with spray geometry and mass conservation yields a complete description of spatial and temporal fuel-air distribution. Fuel preparation and air entrainment rates are calculated from the history of fuel-air distribution. Progressive evolution of combustion zones is determined by the fuel-air mixing process. Energy conservation and chemical kinetics calculations in each zone yield cylinder pressure and local nitric oxide concentration. The role of fuel-air mixing in diesel combustion is discussed. The model results are compared with experimental data.

Dolan, D. F. Experimental and Theoretical Investigation of Diesel Exhaust Particulate Matter. See I.C.

Ghuman, A. S., M. A. Iwamuro, and H. G. Weber. Turbocharged Diesel Engine Simulation to Predict Steady-State and Transient Performance. See I.D.

Kannappan, A. On Model Investigations Pertaining to Scavenging in Two-Stroke Diesel Engines. Presented at the Diesel & Gas Engine Power Conf. and Exhibit, Toronto, Canada, April 18-22, 1971, ASME Preprint 71-DGP-8, 22 pp.

Investigations in models have been an important step in development of a suitable port design for two-stroke engines. These investigations provide a better insight to the flow process occurring during the different phases of the charge exchange process. In this report, a literature review of the studies hitherto conducted on models is presented, the point of view being the realization of the ideal ways in scavenging the engine cylinder.

Kau, C. J., and T. J. Tyson. Study on Oxides of Nitrogen and Carbon Formation in Diesel Engines--Computer Program User's Manual. See III.D.

Khan, I. M., G. Greeves, and C. H. T. Wang. Factors Affecting Smoke and Gaseous Emissions From Direct Injection Engines and a Method of Calculation. Presented at the Internat. Automotive Eng. Cong., Detroit, Mich., Jan. 8-12, 1973, SAE Preprint 730169, 24 pp.

This paper consists of two parts. Part I concerns the effects of injection timing, injection rate, and air swirl on emission of smoke and gaseous pollutants from direct-injection diesel engines. Studies show that fuel-injection equipment and variables such as nozzle configuration affect pollutant production and emission because they affect fuel-air mixing. An increased rate of injection or air swirl increases the rate of fuel-air mixing and reduces the amount of exhaust smoke and its dependence on injection timing. An increase in rate or swirl ratio increases nitric oxide emission at a given injection timing, but the increase is relatively small compared with reduction obtained by retarding injection timing. Substantial retard, in conjunction with increased rate of fuel-air mixing, limits loss in engine efficiency. Part II reports development of model for calculating soot and nitric oxide formation. The model predicts effects of injection timing, injection rate, fueling, air swirl ratio, and engine speed on exhaust concentrations of these pollutants. The efficacy of the model and its contribution toward understanding and control of pollutants is discussed.

McFarland, R. A., and C. D. Wood. An Analog Heat Release Computer for Engine Combustion Evaluation. See I.C.

Radtke, R., A. Frank, and N. Beachley. A Technique for Obtaining an Engine Emissions Model Based on Continuous EPA-CVS Test Data and a Dynamic Vehicle Model. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760156, 16 pp.

A new technique for obtaining engine emission flow rate maps has been developed. The maps are based on specific emissions data obtained on a continuous basis over a single EPA-CVS urban driving cycle test. The data are averaged for the various torque-speed ranges of the engine. It has been found that these dynamic average emission flow rate maps, which are functions only of engine torque and speed, allow instantaneous emissions to be fairly accurately predicted. It also appears that the technique might be used advantageously to determine engine calibration parameters.

Society of Automotive Engineers, Inc. Diesel Combustion and Emissions. See III.D.

Stefanko, R., R. V. Ramani, and G. W. Kenzy. Evaluation of Diesel Equipment Deployment in Underground Coal Mines. v. 1: Validation Experiments for Models of Diesel Exhaust Contamination of Mine Atmospheres. See VII.A.

F. Engine Emissions Maps (typical levels, characteristics)

Anderson, D., and V. K. Duggal. Diesel Engine Emissions and Noise. See III.A.1.

Ashby, H. A., R. C. Stahman, B. H. Eccleston, and R. W. Hurn. Vehicle Emissions--Summer to Winter. Presented at the Automobile Eng. Meeting, Toronto, Canada, Oct. 21-25, 1974, SAE Preprint 741053, 29 pp.

A test program was conducted to study the effect of ambient conditions on exhaust emissions from a wide variety of automobiles. Twenty-six cars, ranging from pre-control production cars to catalyst equipped prototypes, including rotary, diesel, and stratified charge cars, were tested at 20°, 50°, 75°, and 110°F. Ambient temperatures above and below 75°F were found to have significant effects on exhaust emissions. The diesel and stratified charge cars were affected less than production and catalyst-equipped cars by changes in ambient temperature. The use of air conditioners at the 110°F test temperature led to increased emissions and fuel consumption. Hydrocarbon reactivity and aldehyde emissions were not affected by temperature and were lower from the catalyst cars at all temperatures.

Baker, R. E., and E. E. Daby. Engine Mapping Methodology. Presented at the Internat. Automobile Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770077, 16 pp.

Developing engine calibrations to help achieve improved fuel economy, emissions and performance has become an increasingly complicated task as emission standards become more stringent and fuel economy standards become effective. A methodology was devised to project the economy that a specific vehicle could achieve over a selected driving cycle. This method can be used to determine the potential of control systems, exhaust treatment devices and drivetrain configurations to improve economy at specified emission levels. Optimum engine calibrations are defined to utilize these devices fully, from which automatic engine calibration strategies can be developed for vehicle verification.

Bascom, R. C., and G. C. Hass. A Status Report on the Development of the 1973 California Diesel Emissions Standards. Presented at the Nat. West Coast Meeting, Los Angeles, Calif., Aug. 24-27, 1970, SAE Preprint 700671, 16 pp.

This paper is a summary of the cooperative effort by the California Air Resources Board Staff, the Engine Manufacturers Association, and the SAE Diesel Emissions Subcommittee to develop the test procedures and measurement methods needed before adoption of emissions standards for unburned hydrocarbons, carbon monoxide, and nitrogen oxides from diesel engines. Emphasis is placed on the development of the 13 mode test cycle on the philosophy and reasoning behind the use of new or different procedures such as brake

specific emissions (gm/bhp-hr) and the expression of oxides of nitrogen as nitric oxide. An unapproved working draft of the Test Procedure is included as an appendix.

Bosecker, R. E., and D. F. Webster. Precombustion Chamber Diesel Engine Emissions--A Progress Report. Presented at the Nat. West Coast Meeting, Vancouver, B.C., Canada, Aug. 16-19, 1971, SAE Preprint 710672, 16 pp.

Precombustion chamber engines are among the lowest emission power sources available today. Due to excellent fuel-air mixing and complete combustion, HC and CO emissions are extremely low. NO_2 levels are also relatively low because of the divided chamber "quench effect." Because of the low HC and CO levels, effort has been concentrated on lowering NO_2 levels. Retarded timing, inlet air cooling, through the use of aftercoolers, water induction, and exhaust recirculation have all shown beneficial results. Smoke levels are minimized by selective matching of engine and turbocharger to assure adequate air for combustion.

Breslin, J. A., A. J. Strazisar, and R. L. Stein. Size Distribution and Mass Output of Particulates From Diesel Engine Exhausts. BuMines RI 8141[r], 1976, 10 pp.

Size distributions and concentrations of particulates emitted from diesel engine exhaust were measured with cascade impactors. Samples were taken from the exhaust of two types of engines using three types of fuel and operating under five different engine speed and load conditions. The measured mass median diameters of the diesel particulates were typically about 0.3 μm. There was no significant difference in mass median diameter between engines or fuels and only a slight dependence on operating mode. Concentration measurements ranged from 14.2 to 250.9 mg/cu μm, and calculated mass outputs, from 64 to 10,000 mg/min. Significant differences in mass output were found between engines, fuels, and especially between different operating modes. The quantity of clean dilution air that would be required to reduce the particulate mass concentration below the 2.0 mg/cu m respirable dust standard for coal mines was greater than the dilution air required to meet the standards for noxious gases for both engines tested.

Briggs, T., J. Throgmorton, and M. Karaffa. Air Quality Assessment of Particulate Emissions From Diesel-Powered Vehicles. See V.A.3.

Bryant, A. H., and T. A. Tennyson. Exhaust Emissions of Selected Railroad Diesel Locomotives. Presented at the Winter Annual Meeting, New York, Nov. 17-22, 1974, ASME Preprint 74-WA/RT-1, 7 pp.

Measurements were taken of the composition of exhaust gases from railroad diesel locomotives operating in normal service at various stages of their

respective maintenance cycles. A major objective was to determine how the exhaust quality of these engines related to emission standards for heavy-duty diesel powered highway vehicles. Results varied from unit to unit, but generally indicated that improvements would be necessary if such regulations were applied to railroad diesels. Another primary objective was to develop basic information on concentrations of important exhaust constituents and to determine whether existing analytical techniques and instrumentation were sufficiently developed to provide reliable data on the composition of diesel engine exhaust and the quality of visible emissions. Results indicate that specific concentration of exhaust constituents are a function of engine design and the physical condition of the engine. Furthermore, currently available analytical equipment can be used with confidence for measuring carbon monoxide, oxides of nitrogen, and unburned hydrocarbons in samples taken from the exhaust of diesel locomotives. Techniques and methodology were tested to the extent that reproducible results were obtained for the preceding constituents.

Cavagnaro, D. M. (ed.). Diesel Exhaust Emissions (Citations From the NTIS Data Base). Nat. Tech. Info. Service, February 1978, 267 pp.; NTIS PS-78/0109.

Aspects of exhaust gases from stationary and vehicular diesel engines are presented in these citations of Federally-funded research. This includes their pollution potential, composition, control, and formation processes in combustion reactions. The effects of achieving better fuel consumption on the types of exhaust gases formed is covered. Also cited is research concerned with the health effects of these exhaust gases. This updated bibliography contains 267 abstracts, 91 of which are new entries to the previous edition.

Dietzmann, H. E., K. J. Springer, and R. C. Stahman. Diesel Emissions as Predictors of Observed Diesel Odor. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wis., Sept. 11-14, 1972, SAE Preprint 720757, 20 pp.

The use of diesel exhaust-emissions measurements to predict the observed odor from diesel engine exhaust has been studied, using a group of 31 trucks and buses powered by a variety of diesel engines. Regression analysis of gaseous emissions at a variety of conditions has resulted in equations for use in predicting odor. Acrolein, carbon dioxide, total hydrocarbons, selected light hydrocarbons, nitric oxide, carbon monoxide, and aliphatic aldehydes have been related to perceived odor. Some of these exhaust products are odorous and some are nonodorous yet indicative of the completeness of combustion. The empirical method, however, is somewhat less reliable than the observed odor based on a trained panel rating supra-threshold levels in terms of the PHS Quality-Intensity Odor Rating kit. In general, the greater variety of measurements and the fewer types of engines will increase odor prediction accuracy.

England, G. C., D. W. Pershing, and M. P. Heap. Emission Characteristics of Petroleum and Alternative Liquid Fuels. Industrial Heating, v. XLVII, No. 11, November 1980, pp. 22-26.

The availability and use of coal and shale as alternative fuels will depend upon economic and environmental factors. This article is concerned with the impact on pollutant emissions associated with the use of coal or shale-derived liquid fuels as replacement for petroleum-derived fuels in boilers and process furnaces. The pollutants of major interest are nitrogen oxides and particulate matter, since both are related to fuel properties. Fuel-bound nitrogen can be readily oxidized in the heat release zone to produce nitric oxide, and the hydrogen-to-carbon ratio of liquid fuels influences their smoking tendencies.

Fairweather, R. G. Gas Emissions and Fuel Economy of the Light Duty Diesel Truck. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770256, 12 pp.

A computer program is used to predict the effect of engine emissions, vehicle gearing, test weight and driving technique on light duty diesel truck emissions levels. The predictions are correlated with actual tests and the vulnerability of using steady state instead of instantaneous emission data studied. An outline of the development of an engine to meet the latest EPA emission level requirement is given. It is concluded that the degree of emissions control required of an engine in order to meet specified legislation depends significantly on whether that engine is to be installed in a truck or a car.

Frey, J. W., and M. Corn. Diesel Exhaust Particulates. Nature, v. 216, Nov. 11, 1967, pp. 615-616.

This article explains one way of measuring exhaust particulates in a diesel engine. The engine was a single cylinder four stroke diesel that was just overhauled and reconditioned. Samples were taken 4 inches from the exhaust pipe. The researcher used electromicrographs to determine the size of the particulates and he presents his results in tabular form.

Goldberg, A. J. A Survey of Emissions and Controls for Hazardous and Other Pollutants. Environmental Protection Agency, February 1973, 185 pp.; NTIS PB-223 568.

A preliminary analysis was undertaken to prepare a control technology development plan for air pollution problems facing industry. A literature search was completed (with 144 references) to estimate toxicity levels of 18 pollutants, and the magnitude of control methods organized by pollutants as well as industry, offensive trades (animal processing), food industry (brewery and cannery), chemical industry (paint and rubber), metal industry (foundry and metal coating), other (paper, textile, cement, etc.) is included.

Minimum controls were often reported where sites were remote to populated areas. Emission hazard data are presented in 14 tables and appendices. Flow charts indicate emission allocations in major areas of processing. Identification and emission points are shown for principal emitting processes. The survey recommends that new R&D should focus on control of non-ferrous emitters, heat and energy generating sources, open pit mining, milling and materials handling as well as several lesser industrial sources, particularly those emitting large amounts of fine particulate material (less than 2 micron diameter particles).

Hangebrauck, R. P., D. J. von Lehmden, and J. E. Meeker. Sources of Polynuclear Hydrocarbons in the Atmosphere. U.S. Department of Health, Education, and Welfare, Nat. Air Pollution Control Admin., 1967, 44 pp.

Rates of emissions of polynuclear hydrocarbons were measured at several sources considered likely to produce such emissions. The sources included heat generation by combustion of coal, oil, and gas; refuse burning; industrial processes; and motor vehicles. The annual emissions of benzo-(a)pyrene in the United States were estimated for each of the sources surveyed, to provide a rough gauge of the importance of each source. Small, inefficient residential coal-fired furnaces appear to be a prime source of polynuclear hydrocarbons; other sources may be of local importance. Production of polynuclear hydrocarbons was generally associated with conditions of incomplete combustion.

Hoelzer, J. C. Emission Formation Characteristics of the Diesel Combustion Process and Estimated Future Development Trends. See I.C.

Hoffman, J. G., Jr., K. J. Springer, and T. A. Tennyson. Four Cycle Diesel Electric Locomotive Exhaust Emissions: A Field Study. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, New Orleans, La., April 6-10, 1975, ASME Preprint 75-DGP-10, 17 pp.

Exhaust emission measurements, both smoke and gaseous, of seven 4-cycle, 3,300 hp diesel electric locomotives ranging in age from 1 month to 36 months were made. The gaseous emissions studied were oxides of nitrogen, total hydrocarbons and carbon monoxide. Data developed in a previous study of a single locomotive of the same type were considered along with the new information to present an overall view of locomotive exhaust emission variability. In addition, modifications previously found to be beneficial in laboratory studies were tested on complete locomotives. These modifications included: engine rpm, low sac fuel nozzles and fuel injection timing. Full locomotive tests confirmed laboratory data.

Hurn, R. W., and T. W. Chamberlain. Fuels and Emissions--Update and Outlook, 1974. See II.A.

Kennedy, G. J., J. T. White, III, K. J. Springer, and M. N. Ingalls. Exhaust Emissions From Heavy-Duty Trucks Tested on a Road Course and by Dynamometer. Presented at the Automobile Eng. Meeting, Detroit, Mich., Oct. 13-17, 1975, SAE Preprint 750901, 24 pp.

This is a summary compilation and analysis of exhaust-emission results and operating parameters from forty-five heavy-duty gasoline and diesel-powered vehicles tested over a 7.24 mile road course known as the San Antonio Road Route (SARR); and, for correlative purposes, on a chassis dynamometer. Exhaust samples were collected and analyzed using the Constant Volume Sampler (CVS) technique similar to that used in emission testing of light-duty vehicles. On the road course, all equipment and instrumentation were located on the vehicle while electrical power was supplied by a trailer-mounted generator. In addition to exhaust emissions, operating parameters such as vehicle speed, engine speed, manifold vacuum, and transmission gear were simultaneously measured and recorded on magnetic tape. The forty-five vehicles tested represent various model years, GVW ratings, and engine types and sizes. The testing was performed under several EPA contracts with Southwest Research Institute during the years 1972 through 1975. This paper summarizes results from the road-route tests and the chassis-dynamometer tests, and makes comparisons between these two test procedures.

Kitson, C. E., and R. S. Egdall. Exhaust Emission Evaluation of Three Caterpillar Tractor D-398 Diesel-Electric Sets. York Res. Corp., Grant No. 2-35932, November 1977, 73 pp.; NTIS PB-276 102.

Gaseous and particulate emissions testing was conducted on three caterpillar D-398 600 kW-rated generator sets at varying operating loads which included 0 pct, 20 pct, 40 pct, 59 pct, 79 pct, 100 pct, 110 pct. These engines were designed to provide the dual functions of electric generation, and heat supply through exhaust heat exchangers. Water jacket cooling water temperatures were maintained at two levels depending on engine load; i.e., F 200°F at loads of 100 pct and 110 pct, and F 228°F at 79 pct and below. Measured parameters included carbon monoxide, nitrogen oxides, hydrocarbons, and particulate matter. The measurement techniques and resulting emission data are presented in the report.

Laresgotti, A., A. C. Loos, and G. S. Springer. Particulate and Smoke Emission From a Light Duty Diesel Engine. See III.A.1.

Marshall, W. F., and R. W. Hurn. Factors Influencing Diesel Emissions. Presented at the West Coast Meeting, San Francisco, Calif., Aug. 12-15, 1968, SAE Preprint 680528, 12 pp.

Smoke, odor, and other emissions of concern in environmental pollution from four diesel engines were studied experimentally; engine design, operational mode, and fuel characteristics were considered as variable factors influencing the emissions. The engine included a turbocharged 4-cycle unit, normally aspirated 4-cycle units, and air-scavenged 2-cycle engine. All were direct

injection, truck-type power units. Fuel characteristics differed widely among eight fuels used in the study, with principal differences occurring in sulfur and aromatic content. Results of the experimental study showed that emissions levels in all categories are markedly influenced by engine operation. Within the group of engines tested, generally high emissions of unburned hydrocarbon are associated with the 2-cycle design, high smoke levels with the 4-cycle normally aspirated engines, and high emissions of NO_x and oxygenates with the turbocharged 4-cycle engine. Exhaust odor intensity levels were roughly equivalent for all engine types. Emissions in all categories were surprisingly insensitive to variation in fuel characteristics, with the exception that smoke levels were significantly reduced with addition of a smoke suppressant additive to the fuel. Neither of the two odor inhibitors was found effective.

Mogan, J. P., D. B. Stewart, and E. D. Dainty. Analyzing LHD Exhausts. Can. Min. J., September 1974, pp. 35-36, 60.

This report uses a Deutz V-6 diesel engine for determining the changes in CO, NO, and CO_2 emissions for a typical duty cycle of a LHD vehicle. It was determined that NO concentrations reached a peak of 580 ppm at about 1/2 load then remained constant. CO concentrations reached a peak of 520 ppm but had no distinct maximum. The researchers also studied the particulate matter for both combustible and non-combustible fractions and concluded that most of the matter was non-respirable. Finally the effect of humidity on NO_x concentrations and the effect of different fuels were studied.

Mogan, J. P., E. D. Dainty, and D. B. Stewart. The Exhaust Emissions From Four Deutz F6L 714 Diesel Engines Derated for underground Service. Canada Center for Mineral and Energy Technology, November 1977, Report No. MRP/MRL 77-131, 30 pp.

This report tests 4 derated, air cooled indirect-injection, six cylinder, V-type diesel engines. The engines tested were all Deutz F6L 714 engines, but one was new, one rebuilt, one had special modifications, and one was equipped with an injection pump speed governor. Tests were conducted on each engine and the emissions of CO, NO, NO_2 and particulates were studied along with the exhaust toxicity. The authors present comprehensive tables and detailed graphs comparing the four engines.

Oblander, K., M. Fortnagel, H. J. Feucht, and U. Conrad. The Turbocharged Five-Cylinder Diesel Engine for the Mercedes-Benz 300 SD. See I.F.

Patterson, D. J., and N. Henein. Emissions From Combustion Engines and Their Control. Ann Arbor Science Publishers, Inc., Ann Arbor, Mich., 1974, 355 pp.

This publication delineates the fundamentals of combustion and emissions formation in both homogeneous and heterogeneous combustion systems with emphasis on the gasoline and diesel engines. These fundamentals are used to examine the emission control techniques which have been applied to control hydrocarbon, aldehyde, carbon monoxide, smoke, and oxides of nitrogen emissions. This book is designed for the research worker, engineer, or student who is concerned with the theory and practice of engine and vehicle emissions control but also includes a detailed account of how theory can be applied to the development of hardware. Numerous figures and tables are included to graphically portray key aspects, along with a complete list of pertinent published papers in the field.

Perez, J. M., and E. W. Landen. Exhaust Emission Characteristics of Precombustion Chamber Engines. Presented at the Mid-Year Meeting, Detroit, Mich., May 20-24, 1968, SAE Preprint 680421, 18 pp.

Diesel engine exhaust emission characteristics vary considerably with the overall design of the combustion and fuel injection systems. Emission measurements were made on total hydrocarbons, nitrogen oxides, carbon monoxide, carbon dioxide, and smoke. The hydrocarbon measurements of the precombustion chamber engine are considerably lower than the direct injection engine. Less than five pounds of total hydrocarbons per 1000 gal of fuel are produced at rated conditions by all precombustion chamber engines studied. Precombustion chamber engines produce smaller quantities of the oxides of nitrogen when compared to direct injection engines. All diesels produced low carbon monoxide emissions. A novel technique for qualitative and quantitative evaluation of diesel exhaust odors is introduced. Exhaust odor intensity from the precombustion chamber engine is much less than that from the direct injection engines.

Rehnberg, O. Project 1, Summary: The Analysis of Diesel Exhaust Gases. See VII.A.

Schaub, F. S., and K. V. Beightol. NO_x Emission Reduction Methods for Large Bore Diesel and Natural Gas Engines. Presented at the ASME Winter Annual Meeting, Washington, D.C., Nov. 28-Dec. 2, 1971, ASME Preprint 71-WA/DGP-2, 19 pp.

Test results showing exhaust-gas emission levels for three types of large bore nonvehicular engines are reported in this paper. Also reported are the effects of nonstandard engine operating conditions on emission levels. These results are being offered to the industry as introductory information. The authors also discuss solutions to several problems encountered in developing satisfactory analytical techniques.

Shelton, J. C. Exhaust Emissions From Twenty Light Duty Diesel Trucks. U.S. Environmental Protection Agency, Report No. EPA-AA-TEB-80-20, August 1980, 27 pp.

This paper describes the results of an exhaust emission testing program conducted for EPA by Automotive Testing Laboratories. Twenty diesel-powered light-duty trucks were tested. Gross vehicle weight ratings for these trucks ranged from 5300 to 6200 lbs. The primary purpose of this program was to provide data to establish emission factors for light duty diesel-powered trucks. Secondary objectives included an assessment of the emission durability of the engines and an evaluation of fuel economy. The test vehicles were randomly selected from the general public in the St. Louis area using direct appeals to individual owners and referrals from other test participants. The test sequence included the Federal Test Procedure, the Highway Fuel Economy Test and several short tests. Mass emissions were also measured during individual steady state and transient modes of operation. The work was conducted during March and April of 1980. The average emission test results were very low and similar to those from diesel engines in passenger cars. It appears that diesel engines in light duty truck service demonstrate virtually no emission deterioration while in-use over their "useful life" although two engines required major engine rebuilding before 50,000 miles.

Society of Automotive Engineers, Inc. Engineering Know-How in Engine Design Part 23--Engine Design to Meet New Social Obligations: Emission Formation Characteristics of the Diesel Combustion Process and Estimated Future Development Trends. See I.F.

Springer, K. J. Control of Visible Emissions. Presented at the Third Annual North American Motor Vehicle Emission Control Conf., San Antonio, Tex., Sept. 27, 1974, 8 pp.

The author discusses the positive measures that have been put to use by diesel manufacturers and users of diesel powered vehicles to control visible exhaust emissions. One way is by altering the fuel injection such as the injectors, spray tips, spray pattern, duration, and timing. Better turbo-charger matching and improved turbochargers will reduce the formation of smoke. The author also points out that operating the engine at the correct RPM and keeping the engine in good mechanical condition will minimize the visible emissions.

Springer, K. Smoke. Heavy Duty Equipment Maintenance, January-February 1973, pp. 1-6.

This article is an introduction on the topic of diesel exhaust smoke. The article explains how smoke is produced and what engine factors affect smoke content. Ways of reducing smoke are given, such as, derating the engine, increasing the air/fuel ratio, and by having an efficient fuel system. The author also explains the 3 types of smoke, the effect of altitude on smoke content and the effect of the induction and exhaust on smoke content.

Springer, K. J., and T. M. Baines. Emissions From Diesel Versions of Production Passenger Cars. Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770818, 28 pp.

The advent of diesel-powered versions of production passenger cars signals significant dieselization in the United States. Two vehicles, an experimental Oldsmobile diesel Cutlass and a Volkswagen diesel-powered Rabbit, were evaluated to determine their gaseous, particulate, smoke, odor, and noise emissions. For comparison, a 1977 Oldsmobile Cutlass powered by the 260 CID gasoline engine and a 1.6 liter gasoline fuel-injected Volkswagen Rabbit (California version) were similarly evaluated under most emission categories. Three transient driving cycles were employed including those used in emissions certification, sulfate testing, and highway fuel economy.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Diesel Emissions and Mine Ventilation. Canada Center for Mineral and Energy Technology. Presented at the 46th Annual Meeting and Technical Sessions of the Mine Accident Prevention Association of Ontario, Canada, May 25-27, 1977, Report MRP/MRL 77-59, 24 pp.; Can. Inst. Min. Bull., March 1978, pp. 144-151.

In the past few years much effort has been spent in elucidating the impact of diesel engines upon the mine environment. This paper summarizes diesel engine fundamentals, exhaust emissions and typical tailpipe concentrations. Mine sampling results and an evaluation of exhaust treatment systems are discussed. A review of changes in pollutant concentrations between the tailpipe and the mine exit is made and suggestions are given to reduce operator exposure to diesel contaminants.

Stewart, D. B., D. Dainty, and J. P. Mogan. Diesel Emissions With Respect to the Mine Environment. See VII.A.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Some Characteristics of Particulate Emissions in Diesel Exhaust. Can. Inst. Min. Bull., April 1975, pp. 62-69.

This paper summarizes particulate emission studies performed on three different diesel engines at the Canadian Explosive Atmospheres Laboratory (CEAL--Ottawa). Smokemeter determinations reported in the literature have provided considerable information about the effects of engine parameters on the smoke level of diesel exhaust. However, the operation of diesel engines in confined environments, such as underground workings, requires a more detailed assessment of exhaust particulate characteristics and associated hazards. Consequently, this paper includes relevant particulate size distribution, shape and respirability. Further, the generation of particulates by the three engines studied is presented, as is the action of catalytic purifiers on these particles and the contribution of the catalyst bed to the total particulate emission. Finally, the ventilation implications of the presence of these particulates are explored relative to the contribution to toxicity of the gaseous components of the exhaust.

Tupaj, T. A. Testing of Five Diesel-Powered Passenger Cars at High and Low Altitude. U.S. Environmental Protection Agency, Report No. EPA-AA-TEB-81-6, October 1980, 15 pp.

A group of five in-use diesel-powered passenger cars was tested for emissions and fuel economy at both high altitude and low altitude locations. The test sequence consisted of the current Federal Test Procedure (FTP) and the Highway Fuel Economy Test (HFET). Particulate emissions were also measured over both cycles at both locations. On the average, a substantial increase was noted at high altitude for hydrocarbons, carbon monoxide and particulates as compared to the low altitude measurements. As measured over the FTP, the average increases for these three pollutants were 130%, 75% and 45% respectively. Results of the HFET were in the same direction but were of a slightly smaller magnitude. The emission levels of oxides and nitrogen were approximately the same at each location. The average fuel economy values at high altitude were approximately 14% lower than those at low altitude.

U.S. Environmental Protection Agency. Exhaust Emissions and Fuel Consumption of a Heavy Duty Diesel Vehicle Over Various Driving Cycles--GMC Astro 95, 8V-71 NA. August 1978, 51 pp.; NTIS PB-293 766.

This report presents exhaust emissions and fuel economy measurements for one heavy-duty diesel vehicle operated over various driving cycles. These driving cycles were developed from actual in-use operational data collected in New York and Los Angeles under the CAPE-21 program. In each location, data collected for freeway and non-freeway operation were segregated. A data matrix (relation speed, acceleration and frequency of occurrence) was prepared for each city and type of operation. The test program was designed to evaluate the concept of chassis testing for large diesel vehicles. Along with this goal, it was desired to determine emission factors and fuel consumption by category of operation and to determine the variation with vehicle load. Also, to verify the cycle generation technique, the sensitivity of emissions and fuel consumption was to be established. Finally, the effect of "linearized" cycles, steady state tests cold start operation were evaluated.

Winterbone, D. E., R. S. Benson, G. D. Closs, and A. G. Mortimer. A Comparison Between Experimental and Analytical Transient Test Results for a Turbocharged Diesel Engine. Proc. Inst. Mech. Engrs., v. 190 22/76, 1976, pp. 267-276.

This paper describes a computer controlled diesel engine test bed which has been used to evaluate the off-design operating characteristics and the transient performance of a turbocharged diesel engine. The system was modeled on an analogue computer using steady-state data. A comparison between the test bed results and computer predictions shows that reasonable agreement can be achieved.

Zinger, D. E., and L. H. Hecker. Gaseous Emissions From Unregulated Mobile Sources. Mich. Univ., Contract No. EPA-R-803568-01-0, October 1976, 281 pp.; NTIS PB-267 551.

The impact of gaseous emissions are determined for unregulated mobile sources: farm equipment, merchant vessels, locomotives, lawn and units. All but farm equipment and snowmobiles appear to have negligible impact on total air burden. Future impact of these sources in certain areas is discussed. The current emission rates of each category are tabulated and compared to other emissions from both mobile and stationary sources in the study area. As significance of these unregulated sources will increase, projections are made as to the expected increase of emissions from each source category through 1980. Computer programs with instructions to estimate the rates in any Air Quality Control Region are given.

G. Crankcase Emissions

Baines, T. M. Nitrosamines and Other Hazardous Emissions from Engine Crankcases. U.S. Environmental Protection Agency, Ann Arbor, Mich., June 1981, 12 pp.; NTIS PB 82-12796 0.

This paper reviews the literature on nitrosamines of the general chemical form $R_2N{=}NO$ and particulates emitted from engine crankcases. N-nitroso compounds are broadly acting and among the most potent carcinogens. There are only two confirmed mobile sources of nitrosamine emissions--diesel engine crankcases and vehicle interiors. The major influence on crankcase emissions is the lubricating oil which is used to suspend foreign matter, widen the range of viscosity, and to prevent rapid oil deterioration. These additives contain nitrogen-containing compounds. According to one model, a roadway exposure of 1.1 $\mu g/m^3$ would cause an additional 0.36 cancers per 100,000 population. Less information is available concerning particulate emissions although it is known that benzo-a-pyrene is emitted adsorbed to the particulate. Benzo-a-pyrene is a known carcinogen. More data are required to confirm the limited data available on roadside concentrations and to define the atmospheric effects on these compounds.

Hare, C. T., and D. A. Montalvo. Diesel Crankcase Emissions Characterization. Southwest Research Institute, Contract No. 68-03-2196, September 1977, 77 pp.; NTIS PB 275 950.

The objective of this project was to characterize crankcase or "blowby" emissions from two in-service diesel engines, developing and demonstrating methodology for analyses where none existed. Methodology development and demonstration was performed using a dynamometer mounted Detroit Diesel 6V-71, and characterization was done on a Cummins NTC-350 and another 6V-71. Gaseous emissions measured included: emission mass rate; HC, CO, CO_2, and NO_x (both exhaust and crankcase emissions); individual hydrocarbons; aldehydes; and N-dimethylnitrosamine. Crankcase particulate measurements included: mass rate; concentration; size distribution; elemental composition; sulfate; total solubles; BaP in solubles; boiling range of solubles; and N-dimethylnitrosamine. These measurements were made using variations of the standard 13-mode diesel procedure.

Marshall, W. F., and R. W. Hurn. Factors Influencing Diesel Emissions. See III.F.

Spearot, J. A., and N. E. Gallopoulos. Concentrations of Nitrogen Oxides in Crankcase Gases. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760653, 20 pp.

The concentration of oxides of nitrogen in engine crankcases interests lubricant technologists because NO_x reactions with fuel and lubricant

components are partially responsible for engine deposits and oil deterioration. To provide information hitherto unavailable in the literature, concentrations of NO_x and NO_2 measured in the crankcase gas followed the same trends with changes in engine operating variables as the concentrations of NO_x and NO_2 in the exhaust gas. Specifically, increasing intake manifold pressure, spark advance, and compression ratio, generally increased the concentrations of NO_x and NO_2. Increasing the pct exhaust gas recirculation, however, decreased NO_x and NO_2. Changing air-fuel ratio (A/F) from rich to lean first increased and then decreased crankcase NO_x and NO_2 concentrations; the maximum NO_x and NO_2 concentration occurred at an A/F of about 16. Engine speed affected NO_x and NO_2 concentrations slightly and inconsistently. Measured NO_x and NO_2 concentrations in the crankcase gases were in the range 8.7 to 376 and 0.3 to 125 ppm, respectively. Crankcase NO_x and NO_2 concentrations could not be predicted from those measured in the exhaust gases because the sources of NO_x and NO_2 are not identical for both crankcase and exhaust gases. Quench gases in the combustion chambers appear to be a significant source of crankcase NO_x, and probably a primary source of crankcase NO_2. Some NO_2 is also formed in the crankcase itself from oxidation of NO.

Summers-Smith, D. Crankcase Explosions. Tribology Practical Reviews, Inst. Mech. Eng., London, 1975, pp. 4-6.

This paper investigates how crankcase explosions can occur. Oil mist or oil vapor can be generated inside the crankcase and if mixed in the right proportions with air, could cause an explosion if it reaches a hot spot. Some preventive measures are given such as eliminating the source of ignition, eliminating the air, or eliminating the flammable mist. Eliminating the air content can be accomplished by introducing large amounts of inert gas into the crankcase. The author finishes the paper by explaining some protective measures and some safety practices that should be followed.

IV. MEANS OF CONTROLLING DIESEL ENGINE EMISSIONS

A. Fuel, Fuel Additives, and Lubricant Effects

Anderson, D. N. Performance and Emissions of a Catalytic Reactor with Propane, and Jet A Fuels. See IV.L.

Apostolescu, N. Effect of Barium Additive on the Diesel Smoke. Revue Roumaine des Sciences Techniques, Serie Electrotechnique et Energetique, Bucarest, v. 21, No. 1, 1976, pp. 129-138.

The efficiency of a commercial barium additive on the mass concentration of smoke in the exhaust of a diesel engine was studied. Comparative experiments showed that the additive decreased the total mass of the particles emitted. The efficiency was different depending on the engine speed and load. Chemical analysis of the particles showed that the additive was eliminated mostly as $BaSO_4$, which is not harmful for the health.

Apostolescu, N. D., R. D. Matthew, and R. F. Sawyer. Effects of a Barium-Based Fuel Additive on Particulate Emissions From Diesel Engines. Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770828, 12 pp.

The use of barium-containing smoke suppressant diesel fuel additive was investigated. Effects on particulate reduction, other pollutant emissions, and performance were explored over a range of speed and load conditions. The particulate emissions were analyzed gravimetrically and reported in terms of particle concentration and emissions index. Public health aspects of use of the additive are discussed.

Baines, T. M., J. H. Somers, and K. H. Hellman. Effects of Fuel Variables on Diesel Emissions. See II.A.

Bechtold, R. L., and S. S. Lestz. Combustion Characteristics of Diesel Fuel Blends Containing Used Lubricating Oil. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760132, 16 pp.

An experimental program was conducted to determine the effect of burning used lubricating oil mixed with fuel oil in a single cylinder diesel engine. With increasing fuel costs, the prospect of using alternative fuels increases dramatically. Large quantities of used lubricating oil are currently available and could be used in fuel blends for diesel engines. The used lubricating oil-fuel oil ratios used in this study were 2.5, 5, 10, and 15 pct used lubricating oil by volume. The effect of burning these blends on

unburned hydrocarbons, carbon monoxide and oxides of nitrogen is reported along with a comparison to baseline values for pure diesel fuel. Tests were run at 1,800, 2,400, and 3,000 rpm at 1/4, 1/2, 3/4, and full rack positions for each fuel blend. The general condition of wear in the engine along with deposit formation and analysis is reported. The effect of the used lubricating oil on thermal efficiency and BSFC is shown for the blends studied.

Berger, L. B., M. A. Elliott, J. C. Holtz, and H. H. Schrenk. Diesel Engines Underground: V.--Effect of Sulfur Content of Fuel on Composition of Exhaust Gas. BuMines RI 3713, June 1943, 12 pp.

Among the hazards that may attend the use of diesel engines in mines, tunnels, or other underground operations, the presence of harmful or objectionable constituents in the exhaust gas must receive due consideration to prevent the formation of unsafe or unhealthful working environments in these places. This report studies the effect of a high sulfur fuel on SO_x emissions. The report describes the test equipment, test conditions, test procedures, and results of the tests. A discussion of the results and a summary is also given.

Brandes, J. G. Diesel Fuel Specification and Smoke Suppressant Additive Evaluations. See II.A.

Broering, L. C., and L. W. Holtman. Effect of Diesel Fuel Properties on Emissions and Performance. See II.A.

Bykowski, B. B., and T. M. Baines. Effects of Alternate Source Diesel Fuels on Light-Duty Emissions. Presented at the Passenger Car Mtg., Troy, Mich., June 7-10, 1982, SAE Technical Paper Series 820771, 35 pp.

Several alternate source diesel test fuels were studied to note their effects on regulated and unregulated exhaust emissions from a 1980 Volkswagen Rabbit. Nine fuel blends were tested, including a No. 2 petroleum diesel as base, base plus coal-derived liquids (via SRC=II and EDS processes), shale oil diesel and jet fuel, and other blends of coal-derived liquids, shale oil liquids, and petroleum stocks. Analyses performed include gaseous hydrocarbons, CO, NO_x, particulate mass, phenols, smoke, odor, Ames tests, BaP, and polarity profiles by HPLC. Smoke and particulate increases were generally associated with use of coal-derived liquids.

Cart., E. N., Jr., and J. Percival. Alternate Fuels and Alternate Prime Movers in Non-Highway Transportation. See II.B.

Cook, D. H., and C. K. Law. A Preliminary Study on the Utilization of Water-in-Oil Emulsions in Diesel Engines. See II.D.

Dietzmann, H. E. Protocol to Characterize Gaseous Emissions as a Function of Fuel and Additive Composition. Southwest Research Institute, Contract No. 68-02-1275, September 1975, 147 pp.; NTIS PB-253 363.

This project sought to validate an engine dynamometer test schedule for additive effects previously used in Dow and BuMines programs. Previous problems with vehicle-to-engine dynamometer comparability were solved by the use of a Clayton power absorption unit and a fixed flywheel as an inertia simulator. Thus, adequate road simulation was achieved. Numerous analytical techniques were developed including analysis for SO_2, H_2S, COS, methyl and ethyl mercaptan, ammonia, N, N-dimethylnitrosamine, hydrocarbon distribution, and sulfate. No additive-derived products were found in the study of two commercial additive packages with either catalyst or noncatalyst engine configurations. The mileage accumulation schedule used resulted in overly high rates of accumulation of intake manifold deposits for both additive and base fuels. It is suggested that greater mileage accumulations over a heavier duty cycle will be necessary to detect the effects of additives on catalyst deterioration.

Dow Chemical Company. Effects of Fuel Additives on the Chemical and Physical Characteristics of Particulate Emissions in Automotive Exhaust. See III.A.2.

Frisch, L. E., J. H. Johnson, and D. G. Leddy. Effect of Fuels and Dilution Ratio on Diesel Particulate Emissions. See III.A.2.

Fujisawa, T., and K. Yokota. A New Look at the Utilization of Alternate Fuels for Diesel Engines--IDIS. See II.D.

Gause, E. M., M. L. Meltz, and N. D. Greene. Possible Approaches to the Health Effects Testing of Fuels and Fuel Additives. Southwest Foundation for Research and Education (San Antonio, Texas). EPA Contract No. 68-02-2286, October 1981, 216 pp. Available from National Technical Information Service, Springfield, Va., PB 82-132 002.

This document describes possible approaches to the testing of fuels and fuel additives for potential health effects. Such health effects testing is required of the manufacturer of a fuel or fuel additive. The health effects tests must include, but are not limited to, carcinogenic, teratogenic, or mutagenic effects. In order to determine the appropriate protocol for health effects testing, the following areas are discussed: (1) test materials, (2) relationship of physical and chemical properties of test

materials to phsiological distribution and biological activity, (3) weighing factors involved in determining an approach to appropriate health effects testing, and (4) route and mode of exposure. The possible health effects tests described are organized into the following areas: (1) toxicity (with an emphasis on pulmonary effects), (2) mutagenesis, (3) carcinogenesis, and (4) teratogenesis and reproductive performance. The final chapter describes two possible approaches to testing. The report is a technical background document and is not intended to serve as a health effects testing protocol for fuels and fuel additives.

Golothan, D. W. Diesel Engine Exhaust Smoke: The Influence of Fuel Properties and the Effects of Using Barium-Containing Fuel Additives. Presented at the Automotive Eng. Cong., Detroit, Mich., Jan. 9-13, 1967, SAE Preprint 670092, 26 pp.

Even though the combustion gases of diesel fuel are much less toxic than those of gasoline, exhaust smoke has increased proportionately with the number of diesels in use and has become a major problem. This paper describes the influence of base fuel composition on smoke, and the results of using a barium-containing additive in the fuel. The toxicological aspects of using the additive are considered, together with certain other side effects that might arise. Details are also given of the various means for measuring smoke, and of existing legislation to control the nuisance.

Gross, G. P. The Effect of Fuel and Vehicle Variables on Polynuclear Aromatic Hydrocarbons and Phenol Emissions. See III.D.

Gross, G. P., and K. E. Murphy, Jr. The Effects of Diesel Fuel Properties on Performance, Smoke, and Emissions. Trans. of the ASME J. of Eng. for Power, v. 101, No. 4, October 1979, pp. 524-532. See III.D.

Hames, R. J., D. F. Merrion, and H. S. Ford. Some Effects of Fuel Injection System Parameters on Diesel Exhaust Emissions. Presented at the West Coast Meeting, Vancounver, B. C., Canada, Aug. 16-19, 1971, SAE Preprint 710671, 12 pp.

The effect of injection timing was investigated relative to gaseous emissions, smoke, and fuel economy. It was determined that retarding the timing significantly reduced NO levels and had little effect on CO levels. The BSFC decreased slightly for the retarded timing. By increasing the rate of injection, it was found that NO emissions decreased. By increasing the rate of injection from 5.7 mm^3/degree caused an overall NO reduction

of 20 pct. Finally, a study was made on the effect of changing the injector tip orifices. The test consisted of 3 injectors each with 8 orifices but each injector had different size orifices. The results showed that the largest size orifices had the lowest levels of NO. The author summarizes the paper by combining all the injector changes and discusses the results.

Hare, C. T. Methodology for Determining Fuel Effects on Diesel Particulate Emissions. See III.A.2.

Hare, C. T., and T. M. Baines. Characterization of Particulate and Gaseous Emission From Two Diesel Automobiles as Functions of Fuel and Driving Cycle. See III.A.1.

Hare, C. T., and R. L. Bradow. Characterization of Heavy-Duty Diesel Gaseous and Particulate Emissions, and Effects of Fuel Composition. See III.A.1.

Hare, C. T., K. J. Springer, and R. L. Bradow. Fuel and Additive Effects on Diesel Particulate Development and Demonstration of Methodology. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760130, 32 pp.

To develop a methodology for characterizing particulate emissions from diesel engines, one 2-stroke cycle engine and one 4-stroke cycle engine were operated in both individual steady-state modes and according to a variation of the 13-mode diesel emissions measurement procedure. Both engines were operated on three fuels, each used with one of two available diesel fuel additives as well as by itself. The primary particulate sampling technique employed was a dilution tunnel, and secondary evaluation techniques included a diluter-sampler developed under contract to EOA by another organization, a light extinction smokemeter, and a filter-type sampling smokemeter. Gaseous emissions were also measured, providing a running check on engine condition. Particulate mass rates were calculated from gravimetric data; and analysis of particulate included determination of sulfur, carbon, hydrogen, nitrogen, phenols, nitrosamines, trace metals, and organic solubles. Analysis of the organic soluble fraction included NMR, IR, paraffin boiling point distribution, benz(a)pyrene, sulfur, carbon, hydrogen, nitrogen, and oxygen. The results of this study are the first of their type to be widely distributed, so it is imperative that the use of emissions values computed be treated with caution until other laboratories can confirm these findings. This caution is especially important for materials like nitrosamines and BaP, for which analysis is difficult and as yet not thoroughly documented in the literature as applied to emissions from diesels.

Henein, N. A., and J. A. Bolt. Correlation of Air Charge Temperature and Ignition Delay for Several Fuels in a Diesel Engine. Presented at the Internat. Automotive Eng. Cong., Detroit, Mich., Jan. 13-17, 1969, SAE Preprint 690252, 16 pp.

A correlation between the ignition delay, based on the start of pressure rise due to combustion, and the mean air charge temperature has been obtained for diesel, "CITE," and gasoline fuels. The experimental work was done on a single cylinder open combustion chamber research engine. The intake air temperature was varied over a wide range from atmospheric to about 750°F. The experimental data indicated that the best correlation of the ignition delay and the reciprocal of the absolute temperature is of an exponential form. The apparent activation energy for the three fuels was found to have a straight line relationship with the cetane number of the fuel.

Henein, N. A., and J. A. Bolt. The Effect of Some Fuel and Engine Factors on Diesel Smoke. Presented at the Nat. West Coast Meeting, Seattle, Wash., Aug. 11-14, 1969, SAE Preprint 690557, 8 pp.

Possible mechanisms for smoke formation in the diesel engine are discussed. Emphasis is placed on the effects of some engine and fuel factors on carbon formation during the course of combustion, including cetane number, fuel volatility, air charge temperature, and after-injection. The tests were made with a single-cylinder, open chamber research engine, with three fuels, covering a wide range of inlet air temperatures and pressures. There is evidence that smoke intensity increased with increase in the cetane number of the fuels with inlet air temperatures near atmospheric. Increase in the air charge temperature caused an increase in smoke intensity for volatile fuels and had an opposite effect on less volatile fuels for the open chamber engine used. The smoke intensity was found to increase dramatically with after-injection, with all other parameters kept constant. The concept that flame cooling is the main cause for smoke formation is examined. The experimental results obtained in the study indicate that the chemical properties of the fuel are the main controlling factors in smoke formation.

Hills, F. J., and C. G. Schleyerbach. Diesel Fuel Properties and Engine Performance. See II.A.

Howard, J. B., and W. J. Kausch, Jr. Soot Control by Fuel Additives--A Review. Massachusetts Institute of Technology. September 1978, 34 pp.; NTIS AD-A074 870.

A review of studies conducted in practical combustion systems such as oil fired domestic and utility boilers, gas turbines, and diesel engines has demonstrated that metallic fuel additives can be effective in reducing soot emissions. Manganese, iron, and barium are the metals most often reported to be highly effective, although problems with metal oxide deposits on combustor surfaces sometimes prohibit their use. Evaluation of laboratory

burner flame experiments revealed three distinct mechanisms by which the various metallic additives function to remove soot. Several mathematical models of soot reduction through additive use are discussed. Iron additives and their combustion products are relatively non-toxic, whereas the popular manganese additives and their oxides are fairly hazardous. Generally, only water soluble barium compounds are toxic and these typically constitute only 25 pct of the barium compounds in diesel engine exhaust. Additives are only recommended for short-term use, combustor design modifications being the economically preferred long-term solution.

Hurn, R. W. Fuel: A Factor in Internal Combustion Engine Emissions. Presented at the ASME Winter Annual Meeting, Los Angeles, Calif., Nov. 16-20, 1969, ASME Preprint 69-WA/APC-8, 5 pp.

Characteristics of fuel used in an internal combustion engine influence both the amount and the nature of air pollutants associated with engine use. Fuel composition directly governs the amount and character of pollutants from the fuel system and exerts varying influence upon the products of combustion. Fuels could be changed (from typical current practice) to reduce the pollution that results from their use; however, comparable or greater reduction could also be realized through mechanical or engine design changes. The fuel factor is, therefore, only one of several factors that should be considered. But is important that fuel characteristics be considered in any concept of emission control.

Hurn, R. W., B. H. Eccleston, and D. B. Eccleston. Fuel Volatility as an Adjunct to Auto Emission Control. American Chemical Society Symposium Series, No. 1: Approaches to Automotive Emissions Control. American Chemical Society, 1974, pp. 60-68.

Late-model vehicles were used in an experimental study of the interaction of fuel volatility with emissions and associated fuel economy. Volatility characteristics of the test fuels ranged between 7 and 14 lb Reid vapor pressure; 50 pct point between 130°F and 240°F; and 90 pct point between 190°F and 370°F. Choke settings of each vehicle were adjusted as needed for choke action appropriate to each fuel's volatility. Midrange and back-end volatility were found to influence emissions but in a possible complex interaction of the two. The principal influence is upon emissions during cold start and warmup. Within the vapor pressure limits traditional of U.S. fuels, vapor pressure and fuel front-end volatility were found to have only slight effect upon either emissions or fuel economy. Results show that in this study, reduced hydrocarbon and carbon monoxide emissions are associated with the fuels of lower back-end volatility. Among the fuels tested, higher fuel economy values were found with the heavier fuels. However, the differences in mixture stoichiometry and fuel heating value rather than from differences in fuel volatility, per se.

Johnson, J. H., and L. E. Frisch. The Effect of Fuels on Diesel Particulate Emissions. See III.A.2.

Kittelson, D. B., D. F. Dolan, R. B. Diver, and E. Aufderheide. Diesel Exhaust Particle Size Distributions--Fuel and Additive Effects. See III.A.2.

Krause, H. H., L. J. Hillenbrand, A. E. Weller, and D. W. Locklin. Combustion Additives for Pollution Control--A State-of-the Art review. Environmental Protection Agency, Contract No. 68-02-0262, January 1977, 95 pp.; NTIS PB-264 068.

The report is a state-of-the-art review of the potential of combustion-type fuel additives in reducing air pollutant emissions from oil and coal firing. It contains two complementary parts: a review of the relation of combustion mechanisms to additive action in controlling emissions; and a review of experimental investigations of combustion-type fuel additives. The technical literature review revealed relatively limited quantitative data from experimental investigations on combustion additives in which conditions are well defined. However, there is evidence for some measure of control of emissions by fuel additives. The evidence for control by fuel additives of visible smoke and carbon particulate is relatively strong; that for control of polycyclic organic matter is somewhat weaker. The evidence for control of NO_2 is quite weak. Significant control of SO_2 or total sulfur emissions by fuel additives does not appear to be possible, although SO_3 emissions can be reduced. Practical considerations and other possible limitations to the use of additives are also reviewed.

Kukin, I. Chemical Supplements for Diesel Air Pollution Control Programs. Presented at the Diesel and Gas Engine Power Conference and Exhibit, Houston, Tex., May 12-16, 1968, ASME Preprint 68-DGP-14, 10 pp.

Field evaluations with a smoke-suppressing diesel fuel oil supplement were carried out with a 4-cycle diesel truck, a 2-cycle intracity diesel bus, a diesel-powered generating plant, and a standby diesel. The maximum reduction in smoke, soot, and odor occurred when the original Ringlemann Smoke Numbers were greatest, over 3. The field data were found to correlate well with a rapid and simple laboratory screening test. The latter measures the smoke tendency of commercial diesel fuels as well as the effectiveness of chemical fuel supplements to reduce the polluting smoke. In many cases, the use of the diesel supplement resulted in an overall savings from a reduction in specific fuel consumption or reduced diesel maintenance.

Lang, H. W., A. J. Sippel, III, and R. W. Freedman. Effect of Cetane Improvers in the Fuel on Nitrogen Oxides Concentration in Diesel Exhaust Gas. BuMines RI 7310, October 1969, 5 pp.

The Bureau of Mines conducted an investigation to observe the effect of cetane improvers upon nitrogen oxides concentration in diesel exhaust gas. Amyl nitrite and amyl nitrate were used as additives to the fuel used in

a four-cycle, single cylinder type test engine. It was concluded that nitrogen oxide concentrations were not enhanced at fuel-air ratios above 0.03 pound of fuel per pound of air.

Lestz, S. S., and K. R. Houser. Utilization of Alternate Fuels in Diesel Engines. See II.B.

Marshall, W. F., and R. D. Fleming. Diesel Emissions as Related to Engine Variables and Fuel Characteristics. Presented at the Nat. Combined Fuels and Lubricants, Powerplant and Truck Meetings, St. Louis, Mo., Oct. 26-29, 1971, SAE Preprint 710836, 8 pp.

The influences of fuel characteristics and engine parameters on exhaust emissions were studied experimentally using four diesel engines. All engines utilized direct-injection combustion systems and included a 2-cycle, air-scavenged unit and three 4-cycle engines. Two of the 4-cycle engines were naturally aspirated, and one was turbocharged. Seven fuels were selected to cover the broad compositional ranges of diesel fuels marketed throughout the country. Aside from the effect of fuel density on carbon monoxide (CO) emission, no fuel property showed an influence on emissions that was consistent for all engines tested. The study of engine variables included modifications to the fuel-injection system, variations in intake air temperature and density, exhaust recirculation, and water injection. As diesel engines generally emit large quantities of nitrogen oxides (NO_x) and little CO or unburned hydrocarbon (HC), this study was aimed primarily at reducing NO_x emissions while maintaining engine performance and an otherwise favorable emission pattern. Levels of emissions other than NO_x are near minimum when the engine is adjusted for peak performance. Exhaust gas recirculation and addition of water to the intake air were found quite effective in limiting emissions of NO_x with little sacrifice in engine performance or increase in CO and HC levels.

Mather, H. B. Exhaust Odor and Smoke Emission From Diesel Engines and Their Control. J. Institution of Engineers (India) Mechanical Engineering Division, v. 55, March 1975, pp. 169-173.

This paper analyzes the different types of diesel emissions and examines the effect of various operating parameters on the nature and composition of diesel exhaust pollutants. Diesel exhaust test results show that it is less harmful than the invisible exhaust from gasoline-powered engines of the automobiles where the major problem is the repulsive color and odor of the exhaust. The author considers several methods for the control of diesel smoke and odor.

McConnell, G. The Influence of Fuel Quality and Combustion Characteristics on Diesel Exhaust Emissions. See III.D.

McConnell, G., and H. E. Howells. Diesel Fuel Properties and Exhaust Gas--Distant Relations? Presented at the Automotive Eng. Cong., Detroit, Mich., Jan. 9-13, 1967, SAE Preprint 670091, 18 pp.

This paper examines the question of whether or not significant improvements in the condition of a diesel engine's exhaust can be practically achieved by altering the quality of the fuel. Engine test results from a variety of investigations are presented, and they are examined on a fuel quality/exhaust quality basis. Black smoke, white smoke, odor, oxides of nitrogen, and carbon monoxide are the exhaust constituents discussed in conjunction with fuel volatility, viscosity, and ignition quality. It is suggested that a change in base fuel quality is not, at present, a practical means of insuring an improvement in exhaust condition.

McCreath, C. G. The Effect of Fuel Additives on the Exhaust Emissions From Diesel Engines. Combustion and Flame, v. 17, 1971, pp. 359-366.

Experimental evidence has been obtained from a working diesel engine to show that small quantities of various fuel additives can reduce the nitrogen-oxides emission from diesel engines. The physical mechanism is thought to involve a reduction in ignition delay and subsequent alteration of the engine heat-release pattern. The additives which reduce the ignition delay also increase the carbon-monoxide and carbonyl emission. However, additive aging prior to use is capable of inducing beneficial effects in all three constituents simultaneously. The results obtained are discussed in the light of observations made by other investigators.

McDonnell, T. F., and S. A. Tempe. The Effects of Engine Oil Additives on Vehicle Fuel Economy, Emissions, Emission Control Components and Engine Wear. See II.E.

Mickel, B. L., and L. D. Fergesen. Dimensions of Diesel Fuel Performance: Design, Depressants, and Response. Presented at the Mid-Year Meeting, Detroit, Mich., June 6-10, 1966, SAE Preprint 660371, 8 pp.

The ability of a diesel vehicle to utilize the improved cold flow properties imparted by pour depressant additives depends upon fuel system design and fuel type. The most critical part of the diesel fuel feed system is the suction filter or screen. Pure point depressants, when used in responsive fuels, delay blocking of this filter by wax. In a well-designed system, depressants extend the warmup period sufficiently to permit continued operation. At the threshold temperature for unsatisfactory operating conditions, the extra margin provided by depressants can be all important.

Milkins, E. E., H. C. Watson, M. Considine, and G. Sprigg. Emission Control by Dual-Fuelled Operation of a Diesel Engine. Department of Mech. Eng., Univ. Melbourne, Parkville, Victoria, Australia, July 1974, Report No. T/16/74, 17 pp.

This paper describes the performance of a diesel truck engine when operated in a dual-fuelled mode. In this mode of operation up to 40 pct, calorifically, of LP gas may be added to the aspirated air of a diesel engine, while reducing liquid fuel quantities so as to maintain approximately the same power output. Dual fuel conversions are marketed in Australia primarily to take advantage of the lower cost of LP gas. Our investigations were initiated to find if there were other incentives or disincentives from dual-fuelling. A Cummins V-6 diesel was operated with up to 40 pct gas addition over its complete speed and load range. Calorific based thermal efficiency was measured together with exhaust emissions: NO_x, CO, HC, CO_2 and smoke density. It was found that, generally, CO and HC emissions worsened with increasing gas addition while smoke density changed only slightly. In contrast, NO_x emissions were reduced by as much as 50 pct and a 12 pct improvement in thermal efficiency could be maintained over half the speed range when 20 to 30 pct of fuel supplied was gas. Qualitative mechanisms are proposed to explain the observed results. While there is evidence that the improved efficiency and NO_x emissions recommend LP gas conversions, it was observed that under low speed operation, combustion was harsher and therefore engine durability may be reduced.

Moran, J. B., and O. J. Manary. Effect of Fuel Additives on the Chemical and Physical Characteristics of Particulate Emissions in Automotive Exhaust. Dow Chemical Co., Contract No. CPA-22-69-145, July 1970, 175 pp.; NTIS PB-196 783.

Methods were developed of generating, collecting, and analyzing particulates in automotive engine exhaust by a means sufficiently accurate and reproducible to allow determination of the effects of fuel additives on exhaust particulate size, concentration, and composition. The clean (new) engine must be conditioned with the test fuel for a period of at least 75 hours under cycled conditions before stable gaseous and particulate emissions are achieved. An air dilution chamber was designed which allows for cooling, dilution, and mixing so that representative particulate samples can be obtained at a sampling station which is essentially equivalent to 8-10 feet downstream of the end of the exhaust pipe on a vehicle at highway speeds. Temperature of the diluted exhaust at the sampling station was around 100°F. A 1970 Chevrolet 350 CID engine of 9.0:1 compression ratio with a standard exhaust system attached, was loaded by means of an engine dynamometer. Sampling was conducted with the engine operating at 2250 RPM and 17.0" Hg manifold vacuum from 4 of the 8 cylinders. A few sampling runs were conducted under mild cycled conditions consisting of several cruise modes. Special analysis techniques were developed for the analysis and characterization of exhaust particulates. The data suggest a very significant effect of fuel additives, primarily TEL, on exhaust particulate size, concentration and composition. Significant differences are observed with minor changes in other fuel additives.

Norman, G. R. A New Approach to Diesel Smoke Suppression. Presented at the Southern California Section, Nov. 8, 1965, SAE Preprint 660339, 8 pp.

Through proper treatment of diesel fuel, using a barium containing additive, exhaust smoke can be effectively suppressed in a wide variety of diesel engines. This additive has been found to produce no adverse effects on engine components and often results in additional benefits, including greater engine cleanliness and piston ring wear reduction.

O'Neal, G. B., and J. O. Storment. Control of Diesel Exhaust Emissions in Underground Coal Mines--Single Cylinder Engine Experiments with Modified and Non-Conventional Fuels. Presented at the Internat. Off-Highway Mtg. & Exposition, Milwaukee, Wis., Sept. 14-17, 1981, SAE Technical Paper Series 810954, 16 pp.

Because the diesel engine is becoming an increasingly attractive power plant for use in underground mines, concern arises about exhaust emission levels in this environment. The effects of fuel properties and composition on emissions of particulate matter, oxides of nitrogen, unburned hydrocarbons, and carbon monoxide were investigated in this study. Fuels and fuel blends evaluated included DF-1, DF-2, and JP-7; a solution and an emulsion of ethanol with DF-2; emulsions and fumigation of water with DF-2; and LPG with DF-2 pilot injection. All tests were performed on a diesel engine (Caterpillar 3304) representative of underground mining equipment. A micro-emulsion of water in DF-2 proved to be the most attractive fuel based upon availability, reduction of particulates and oxides of nitrogen, and inherent fire-safe characteristics.

Patterson, D. J., and N. Henein. Emissions From Combustion Engines and Their Control. See III.F.

Paul, J. K. (ed. by). Methanol Technology and Application in Motor Fuels. See II.B.

Pedersen, P. S., J. Ingwersen, T. Nielsen, and E. Larsen. Effects of Fuel, Lubricant, and Engine Operating Parameters on the Emission of Polycyclic Aromatic Hydrocarbons. Environmental Science & Technol., v. 14, No. 1, January 1980, pp. 71-79.

The effects of fuel, lubricant, and engine operating parameters on the emission of polycyclic aromatic hydrocarbons associated with particles were studied by means of an automobile engine operated with a number of special fuels under steady-state conditions. More than 90 pct of the mass of the heavier PAHs (e.g., benzo(a)pyrene) was found on particles with a diameter below 1 μm, while for the light PAHs, a substantial part was in the vapor phase. The aromatic content, the type of aromatic fraction, and the PAH content of the fuel and lubricant had a strong effect on particle-bonded PAH emission; in comparison to this, the lead content of the fuel was of

minor importance. The lubricant itself had only slight influence on particlebonded PAH emission. This varied with the air-fuel ratio in a manner similar to particulate matter and to unburned hydrocarbons, showing high emissions at very rich as well as very lean mixtures. On increasing the engine load, the particle-bonded PAH emission increased.

Ranney, M. W. Fuel Additives for Internal Combustion Engines: Recent Developments. See II.A.

Saito, T., and M. Nabetani. Surveying Tests of Diesel Smoke Suppression With Fuel Additives. Presented at the Internat. Automotive Eng. Cong. Detroit, Mich., Jan. 8-12, 1973, SAE Preprint 730170, 12 pp.

The diesel smoke-depressant effects of 26 fuel additives marketed in Japan were tested with the cooperation of the Fuel and Lubricants Committee of the Japan Automobile Research Institute (JARI) and the Tokyo Metropolitan Office. These bench tests were carried out with a compound on several types of engines under the conditions of overload with heavy smoke; the four effective barium-containing additives were tested under further conditions which included improper engine maintenance, transient operation, and exhaust gas recirculation (EGR). The exhaust gas compositions and emitted barium solids were analyzed. Also over-the-road tests were performed with 12 city buses for two years.

Shamah, E., and T. O. Wagner. Fuel Quality or Engine Design: Which Controls Diesel Emissions? Presented at the Internat. Automotive Eng. Cong., Detroit, Mich., Jan. 8-12, 1973, SAE Preprint 730168, 21 pp.

Federal standards on diesel exhaust smoke are currently in force, and standards on carbon monoxide, oxides of nitrogen and hydrocarbon emissions for the 1974 model year were issued recently by EPA. Except for smoke, relatively little information is available on the relation of fuel quality to emissions from diesel engines, but control of diesel emissions via fuel has been suggested by users, control agencies and public interest groups. To provide information on effects of fuel quality, we measured emissions from three diverse engines with fuels that exceeded the commercial range in quality of No. 1 and 2 diesel fuels. We found that fuel properties have measurable effects on emissions, but the effects are much smaller than those of engine design and operating conditions. We conclude that changing fuel quality does not represent an effective way to control emissions from today's diesel engines.

Smithsonian Science Information Exchange, Inc. Reduction of Pollution by Internal Combustion Engines. See IV.L.

Steffenson, D. M., D. H. Stedman, and D. J. Patterson. Effect of Fuel Additives Study. Mich. Univ., Grant No. R-802419-01, May 1974, 50 pp.; NTIS PB-240 169.

Studies were carried out on the optimization of a chemiluminescent NO detector. This detector has been used to study the effect of N containing fuel additive combustion using a gas chromatographic technique. Progress so far indicates N selective GC detection down to 1.6 ng of diethyl nitrosamine (0.5 ppm in a 1 ml gas sample). Similar data are obtained for amines. The detector has at least two orders of magnitude more sensitivity currently not realized due to problems with the GC columns. Preliminary studies have been made of rapid determination of total N in gasoline, and of combustion products in a flat flame propane-air burner.

Tessier, K. C., and H. E. Bachman. Fuel Additives for the Suppression of Diesel Exhaust Odor and Smoke. Part 1: Proposed Mechanism for Smoke Suppression, and Part 2: Field Trials. Presented at the ASME Winter Annual Meeting and Energy Systems Exposition, New York, Dec. 1-5, 1968, ASME Preprint 68-WA/DGP-4, 5, 12 pp.

A combination of odor mask and barium containing additive in diesel fuel is effective in reducing smoke, odor and irritation from diesel exhaust. It has shown no injurious effects on fuel systems, exhaust systems or engines. This paper discusses the engine evaluation and field testing of these additives in American diesel engines. The major implications of using barium additives in the fuel are discussed as well as possible mechanisms for their action. Of special interest is a description of the results of using the Ricardo, high speed cine technique to visually study the combustion of additive treated fuel.

Thornburg, D. W. An Investigation of Engine and Test Cell Operating Conditions on the Effectiveness of Smoke Suppressant Fuel Additives. Master's Thesis, Naval Postgraduate School, Monterey, Calif. December 1981, 102 pp.

Tests were conducted in a one-eighth scale turbojet test cell with a ramjet type combustor to investigate the effects of fuel additives on smoke reduction. Particle size and mass concentrations were determined at the engine and stack exhausts using three wavelength optical detector systems. Particulate samples were also collected at the engine exhaust and analyzed with a scanning electron microscope. Combustor temperature and fuel additives were found to significantly affect particulate mass concentrations emitted from the engine while particle size appeared to be unaffected. No significant changes in the particulate size or mass occurred from the engine exhaust to the stack exhaust. The optical determination of exhaust mean particulate size/mass concentration with three wavelength optical detector systems appears to be a good and reasonably accurate technique for evaluating the effects of engine and test cell operating conditions and fuel composition changes on the emitted particulates.

Torpey, P. M., M. J. Whitehead, and M. Wright. Experiments in the Control of Diesel Emissions. Inst. Mech. Engrs. Preprint C124, 1971, 13 pp.

This paper presents some results of a comprehensive investigation into the emissions of gaseous pollutants from diesel engines. Tests on direct-injection and swirl-chamber engines are described, and the characteristics of each compared. The effects of water induction, exhaust recirculation, and change of compression ratio on the swirl-chamber engine were studied. It is concluded that emissions of oxides of nitrogen are most likely to cause concern: these emissions were found to be very dependent on injection timing. In general, the direct-injection engine emissions were twice as high as those of the indirect-injection engine. Water induction and cold exhaust recirculation were found to be powerful methods of reducing oxides of nitrogen.

Turley, C. D., D. L. Brenchley, and R. R. Landolt. Barium Additives as Diesel Smoke Suppressants. J. Air Pollution Control Assoc., v. 23, September 1973, pp. 783-787.

The body of information presented in this paper is directed to those individuals concerned with the emission of smoke from diesel engines. A series of tests was performed on a Petter Type AA1 diesel engine using barium smoke suppressant additives. An Andersen cascade type sampler was used to collect samples and thus study the effect of the additive upon the total smoke emission, smoke size distribution and smoke composition. For a portion of the tests radioactive barium and scintillation counting techniques were used. Type 1-D fuel was used for all tests. Baseline tests were performed to determine the smoke emission characteristics using nontreated fuel, 0.5 vol-pct of Bryton additive, and 0.75 vol-pct of Lubrizol additive. For the radioactive additive, tests were conducted using dosages of 0.13, 0.26, 0.41, and 0.82 vol-pct. The results of these tests revealed that the additive does not alter the particle size distribution, but the total mass emission from the engine is reduced by approximately 50 pct at the dosages tested. The dosage level of the additive does not influence the distribution of barium within the exhaust particles. Also it seems that the soluble percentage (in 0.1 N HCl) is influenced by the dosage level. The results of the solubility tests at low dosage levels seem to imply that the smoke inhibition mechanism occurs within the fuel droplet.

Tyler, J. C., J. T. Gray, and W. D. Weatherford, Jr. An Investigation of Diesel Fuel Composition--Exhaust Emission Relations. October 1974, 17 pp.; NTIS AD/A-005 077.

Although diesel exhaust emissions are known to be influenced by diesel engine physical parameters, the influence of fuel hydrocarbon-type composition has not been fully explored. The present investigation has been conducted to study the effects of hydrocarbon composition and additive content of diesel fuels on exhaust pollutant emissions. The reported results were obtained using a two-cylinder, four-stroke cycle Onan diesel engine-generator unit instrumented for exhaust emissions measurements. Seven

different fuels and fuel blends having aromatic contents varying from 0 to 74 pct and cetane numbers from 37 to 71 were investigated. The results of this study demonstrate that increasing concentrations of aromatic hydrocarbons in the fuel significantly increase emission of oxides of nitrogen while slightly decreasing the emission of unburned hydrocarbons, while other fuel characteristics, including cetane number, remain essentially constant. A full-scale, six-cylinder military engine (LDT-465) was used to verify the aromatics vs NO_x relationship obtained with the Onan motor-generator unit.

U. S. Department of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

Urban, C. M., K. J. Springer, and D. A. Montalvo. Emissions Control Technology Assessment of Heavy Duty Vehicle Engines. Southwest Research Institute, Contract No. 68-01-0472, December 1973, 200 pp.; NTIS PB-236 899.

This project investigated the reductions in exhaust emission levels attainable using various control techniques appropriate to gasoline and diesel engines used in vehicles over 14,000 lb GVW. A total of eight gasoline and one diesel engines were evaluated in the laboratory phase of the project. Of the eight gasoline engines, two were evaluated parametrically. Evaluation of the gasoline configurations included: three engine emissions test procedures using an engine dynamometer, a determination of vehicle driveability, and one vehicle emission test procedure using chassis dynamometer. The diesel engine evaluation differed only in that two emission test procedures were used on the engine dynamometer. To investigate transient vehicle operation, emissions were measured by the 1975 Federal procedure normally used for certification of cars and light trucks below 6,000 lb GVW. The driveability evaluations, performed in appropriately sized trucks, included a cold start driveaway, warm driveability and acceleration performance. A limited study of various economic aspects was made to investigate the cost to control and resultant economic impact.

Wrage, K. E., and C. E. Goering. Technical Feasibility of Diesohol. See II.B.

B. Engine Design and Operating Variables

Amano, M., H. Sami, S. Nakagawa, and H. Yoshizaki. Approaches to Low Emission Levels for Light-Duty Diesel Vehicles. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760211, 20 pp.

Approaches to low emission levels for a light-duty diesel vehicle were studied according to the 1975 FTP using Toyota Land Cruiser which is in the 4,000 lb inertia weight class, equipped with a Toyota model B diesel engine, 4-stroke, 4-cylinder and 3-liter displacement with a swirl chamber. A simulation method, which is based on an emission map proved to be very useful for an efficient study on the effects of various vehicle design factors. The attainable emission levels of smaller diesel passenger cars were also estimated using this method. It is concluded that the primary target of HC 0.41, CO 3.4, NO_x 1.0 g/mile could be achieved by engine modifications and appropriate transmission and final gear ratio choice for the 4,000 lb class vehicle with some penalty in power and fuel economy. However, the ultimate target of HC 0.41, CO 3.4, NO_x 0.4 g/mile is impossible to be achieved for the 4,000 lb class vehicle and very difficult for smaller passenger cars, even if an EGR system and an oxidation catalyst are adopted.

Automobile Engineer. Reducing Exhaust Emissions From Diesels. September 1971, pp. 16, 21-22.

Diesel engines have no problem meeting the 1973 emission standards for HC and CO but are close to the NO limit. Therefore, Ricardo and Co. studied ways to reduce the NO emissions. Since CO emissions are low, it is possible to use a richer mixture that has the effect of increasing CO and reducing NO emissions. One way to reduce NO is to use an indirect injection chamber. The prechamber has a rich fuel-air ratio, therefore, it produces low NO emissions. The article suggests other ways to reduce NO emissions and concludes that by using these methods the 1975 regulations can be met.

Bascom, R. C., L. C. Broering, and D. E. Wulfhorst. Design Factors that Affect Diesel Emissions. Presented at the National Business Aircraft Meeting, Wichita, Kans., March 24-26, 1971, SAE Preprint 710484, 15 pp.

Although diesels, as a group, are a relatively small source of air pollutants, emissions standards which limit emissions from diesels have been adopted by California and the federal government. Test procedures and instrumentation for measuring diesel emissions have been developed, and an understanding of how engine design parameters affect emissions is evolving. Smoke and carbon monoxide are primarily functions of fuel-air ratio. Smoke is also affected by injection timing, air motion, and fuel spray characteristics. Hydrocarbon emissions are most affected by details of injector design and matching of the spray geometry with the combustion chamber shape. Nitric oxide emissions are controlled by local oxygen availability in regions of high temperature and residence time at the high temperature. Retarded injection timing, rich local fuel-air ratios, lower mixing rates of fuel and air, lower compression

ratio, and lower intake air temperature tend to reduce nitric oxide emissions but may increase smoke. Smoke suppressant additives, water induction, exhaust gas recirculation, and catalytic converters reduce one or more of the emissions but are less desirable than emissions control through engine modifications.

Bryzik, W., and C. O. Smith. Relationships Between Exhaust Smoke Emissions and Operating Variables in Diesel Engines. Presented at the Off-Highway Vehicle Meeting and Exhibition, MECCA, Milwaukee, Wis., Sept. 12-15, 1977, SAE Preprint 770718, 40 pp.

The study relates air/fuel ratio, fuel injection timing, and engine speed to exhaust smoke levels and performance of the diesel engine. Additional data were obtained under supercharged and turbocharged inlet air conditions to investigate the applicability of the derived relationships under these conditions. Limited data using a variance in fuel type were obtained. Insight into the basic mechanism of smoke formation in diesel engines was gained. The relative percentages of fuel injected before ignition (i.e., premixed fuel), and after initiation of combustion (i.e., unmixed diffusion burning fuel) were found to be extremely significant in determining smoke levels. A smoke factor (the ratio of equivalence ratio in the combustion chamber at initial ignition to overall equivalence ratio) was formulated and found to be useful in predicting smoke phenomena in diesel engines.

Eltinge, L., F. J. Marsee, and A. J. Warren. Potentialities of Further Emissions Reduction by Engine Modifications. Presented at the Automotive Eng. Cong., Detroit, Mich., Jan. 8-12, 1968, SAE Preprint 680123, 16 pp.

The combination of lean mixtures to provide oxygen in the exhaust and of exhaust heat conservation to enhance exhaust reactions yields significant exhaust reaction and lower hydrocarbon emissions. It requires adequately uniform mixtures, but does not require injection of additional air into the exhaust. A vehicle with this combination exhibits low emissions and good performance and fuel economy. Full evaluation of this approach must await general application. The results of this experimental exploration are presented as a contribution to the multi-industry effort to provide the public with acceptable atmospheric cleanliness at minimum vehicle and fuel cost.

Felt, A. E., and S. R. Krause. Effects of Compression Ratio Changes on Exhaust Emissions. Presented at the Nat. Combined Fuels & Lubricants, Powerplant and Truck Meetings, St. Louis, Mo., Oct. 26-29, 1971, SAE Preprint 710831, 6 pp.

The results of a comprehensive test program using a 1969 383 CID V8 engine at two compression ratios, 9.5:1 and 7.6:1, are reported. Compression ratio changes were effected by piston changes only. Except for necessary ignition timing modifications, no other changes were made in the engine. The effects of compression ratio changes on exhaust emissions and fuel consumption were studied in steady-state dynamometer tests and in vehicle

tests. At MBT ignition timing or at the same percentage power loss from MBT timing at each compression ratio and with identical carburetion, decreasing the compression ratio from 9.5:1 to 7.6:1 produced the following results: In steady-state dynamometer tests, NO (ppm) and CO (pct) emissions were unchanged, HC (ppm) were decreased, and fuel consumption was increased when equal power was developed at both compression ratios. In vehicle tests using the 7-mode Federal Test Procedure, NO and CO emissions were unchanged and HC increased somewhat. Additional vehicle tests showed 6 pct higher road-load fuel consumption and 6 pct longer full-throttle acceleration times for the lower compression ratio. Thus, tests in this engine show that decreasing compression ratio cannot be justified on the basis of reducing NO emissions.

Freeman, M. A., and R. C. Nicholson. Valve Timing for Control of Oxides of Nitrogen (NO_x). Presented at the Automotive Eng. Cong., Detroit, Mich., Jan. 10-14, 1972, SAE Preprint 720121, 16 pp.

Three engine camshaft approaches to the reduction of oxides of nitrogen were investigated; increased valve overlap, variable camshaft timing, and variable valve overlap. The interaction of these systems with emissions, fuel consumption, and power was evaluated on a dynamometer engine. The effects of air-fuel ratio and exhaust backpressure were also reported. Results of the dynamometer study were verified with vehicle tests. Oxides of nitrogen levels of 1.2-2.0 g/mile were attained through camshaft design with acceptable drivability on the 1970 federal test procedure.

Grinberg, L., and L. Morgan. Effect of Temperature on Exhaust Emission. See V.B.2.

Henein, N. A., and J. A. Bolt. The Effect of Some Fuel and Engine Factors on Diesel Smoke. See IV.A.

Karim, G. A., and S. Khanna. The Effect of Very Low Air Intake Temperature on the Performance and Exhaust Emission Characteristics of a Diesel Engine. See V.B.2.

Khan, I. M., and A. C. Green. Scheduling Injection Timing for Reduction of Diesel Emissions. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750337, 12 pp.

This paper deals with the requirements for scheduling injection timing as a function of speed and load for high-speed light-duty diesel engines and also for larger diesel engines. A combined speed and load timing device developed for the CAV DPA pump is presented. Work on two passenger cars powered with swirl chamber diesel engines initially having standard DPA

pumps and later fitted with pumps incorporating the timing scheduling device is then described and discussed. Some examples of timing scheduling requirements for larger direct injection engines are also given. It is shown that injection timing scheduling is essential to minimize gaseous and visible emissions while satisfying the noise and fuel economy aspects of engine or vehicle performance.

Khan, I. M., G. Greeves, and C. H. T. Wang. Factors Affecting Smoke and Gaseous Emissions From Direct Injection Engines and a Method of Calculation. See III.E.

Lee, R. C. Effect of Compression Ratio, Mixture Strength, Spark Timing, and Coolant Temperature Upon Exhaust Emissions and Power. Presented at the Nat. Combined Fuels and Lubricants Powerplant and Truck Meetings, St. Louis, Mo., Oct. 26-29, 1971, SAE Preprint 710832, 16 pp.

A single-cylinder engine operating at constant speed using gasoline as fuel was used to study the effects of compression ratio, mixture strength, spark timing, and coolant temperature upon exhaust emissions and power for a part-throttle condition. Of these variables, mixture strength and spark timing had the largest effect upon exhaust emissions, followed by coolant temperature with compression ratio having minor effects. Spark timing followed by compression ratio had the largest effect upon power and fuel consumption.

Marshall, W. F. NO_x Emissions From Diesel Engines--Control and Measurement Techniques. See III.A.1.

Marshall, W. F., and R. D. Fleming. Diesel Emissions as Related to Engine Variables and Fuel Characteristics. See IV.A.

Marshall, W. F., and R. W. Hurn. Modifying Diesel Engine Operating Parameters to Reduce Emissions. BuMines RI 7579, 1971, 14 pp.

The effect of engine parameters on exhaust emissions from two diesel engines was studied experimentally. Fuel injection characteristics and intake air conditions were considered as parameters influencing the emissions. Emphasis was placed on the effect of parameter variations on nitrogen oxide (NO_x) emissions, because diesels generally emit very low levels of carbon monoxide (CO) and unburned hydrocarbons. Emissions other than NO_x were at lowest levels when the engines were adjusted for best performance. NO_x emissions can be diminished somewhat through variation in fuel injection characteristics, but there generally are penalties in emissions of CO, smoke, and unburned hydrocarbons or in engine performance. Temperature and composition of intake air have a significant effect on NO_x emissions. Levels of NO_x are reduced by recirculating the exhaust gas or by adding water to the intake

air stream. However, the rate of water added or exhaust gas recirculated must be limited to prevent the degradation of engine performance and increased emissions of CO and smoke. At high exhaust recirculation rates, levels of CO and smoke were increased such that it was necessary to derate the engine and also to use a catalytic system for oxidation of CO.

Meacham, G. B. K. Variable Cam Timing as an Emission Control Tool. Presented at the Nat. West Coast Meeting, Los Angeles, Calif., Aug. 24-27, 1970, SAE Preprint 700673, 18 pp.

Automatic variation of internal combustion engine valve timing in response to load and speed is an effective technique for reducing emission of oxides of nitrogen and unburned hydrocarbons. The variation employed is cam advance, which causes part of the exhaust gases normally expelled near the end of the exhaust stroke to be retained and mixed with the fresh air-fuel mixture during the following inlet stroke. Part of the unburned hydrocarbons normally emitted are contained in these recirculated end-of-stroke gases, and are oxidized further by re-exposure to combustion. The peak flame temperature is reduced by the diluent, and formation of oxides of nitrogen is suppressed. A prototype vehicle equipped with an automatic cam advance system shows that emissions measured by the Federal Test Procedure are reduced by the following amounts: nitric oxide 64 pct, unburned hydrocarbons 32 pct, and carbon monoxide 16.5 pct. Only minimal changes in vehicle operating characteristics are caused, and potential durability is good since the existing engine valves and pistons are used to handle the recirculated exhaust. The cylinder-to-cylinder distribution of the diluent is inherently uniform, and the amount of recirculation is repeatable.

Melton, R. B., Jr., and A. R. Rogowski. The Interaction of Air Motion, Fuel Spray, and Combustion in the Diesel Combustion Process. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Toronto, Ontario, April 18-22, 1971, ASME Preprint 71-DGP-2, 4 pp.

This paper is pertinent mainly to combustion in open-chamber diesel engines employing air swirl. It is shown how an increase in air swirl rate can cause a marked loss of combustion efficiency unless fuel spray penetration is increased. High swirl reduces radial fuel spray penetration with central injection and the resulting excess fuel in the central area may be trapped by buoyance forces following ignition, becoming isolated for as much as a tenth of a second in a chamber of four in. diameter. A brief explanation of fuel injection in terms of the mechanics of fluid jets is given and circumstances described in which buoyancy forces assist fuel-air mixing following ignition.

Newhall, H. K., and I. A. El Messiri. A Combustion Chamber Designed for Minimum Engine Exhaust Emissions. Presented at the Mid-Year Meeting, Detroit, Mich., May 8-12, 1970, SAE Preprint 700491, 16 pp.

Experimental work has demonstrated that spark ignition engine exhaust emissions can be controlled through basic modification of the combustion process, and that such control can be achieved without serious compromise of the efficiency of fuel utilization. The combustion process investigated in this work is designed to exploit the finite time dependence of nitric oxide formation in high temperature combustion products. Through use of a divided combustion chamber, it has been possible to quench nitric oxide formation reactions so that little nitric oxide formation occurs. Further, it has been possible to simultaneously promote complete oxidation of hydrocarbons and carbon monoxide in combustion products. The combustion process, therefore, results in total control of exhaust emissions.

Parker, R. F., and J. W. Walker. Exhaust Emission Control in Medium Swirl Rate Direct Injection Diesel Engines. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wis., Sept. 11-14, 1972, SAE Preprint 720755, 8 pp.

This paper reports test work conducted on a family of medium swirl, direct injection diesel engines in the 50-200 hp range, typical of those used in FCIM equipment. An analysis of emissions reporting techniques is discussed. including a comparison of on-highway and agricultural weighting factors for the 13 mode cycle. Naturally aspirated, turbocharged, and turbocharged-intercooled versions of a basic engine family are compared, along with possible emissions reductions by exhaust gas recirculation on a naturally aspirated engine and retarded injection timing on turbocharged engines. The increase in fuel cost for NO_2 reduction by retarded timing is presented.

Patterson, D. J., and N. Henein. Emissions From Combustion Engines and Their Control. See III.F.

Pischinger, R., and W. Cartellieri. Combustion System Parameters and Their Effect Upon Diesel Engine Exhaust Emissions. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wis., Sept. 11-14, 1972, SAE Preprint 720756, 16 pp.

Exhaust emission characteristics of a production automotive diesel engine were studied. The particular engine was chosen because it is being marketed with a prechamber as well as with a direct-injection combustion system, and in both configurations, either naturally aspirated or turbocharged. In addition, an aftercooler was fitted to the turbocharged direct-injection engine. Methods for reducing exhaust emissions are discussed. A brief survey is given of potential emission control by catalytic converter, exhaust recirculation, and LPG dual-fuel operation. Basic investigations, conducted on single-cylinder direct-injection engines are reported. It is concluded that direct injection is the most promising combustion system for

low emission commercial automotive diesel engines, particularly when turbocharged and aftercooled, and that this type of engine can satisfy the 1975 California standards.

Radovanovic, R. S., and M. S. Djordjevic. Diesel Precombustion Chamber Design and Its Influence on the Engine Performance and Exhaust Pollutants. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790496, 12 pp.

One-cylinder Lister SRI, four-stroke, air-cooled engine, with direct injection was redesigned and reworked into an indirect injection engine, precombustion chamber type. Basic design features and the limitation of the test head and of the precombustion chamber in particular are described. Fifteen different prechambers were tested; the results are presented and discussed. A correlation of the prechamber design parameters such as ratio of height to diameter; number, size, downward and spread angle of connecting passageways, and ratio of prechamber volume to total compression volume has been made with engine performance and exhaust pollutants.

Sapienza, R., Butcher, T. Krishna, C., and J. Gaffney. Soot reductions in Diesel Engines by Catalytic Effects. See III.A.2.

Scott, D. High-Swirl Combustion Chamber Cuts Emissions and Consumption. Automotive Eng., June 1976, pp. 22-24.

A new concept gasoline combustion chamber claimed to give low exhaust emissions without any loss of power has been developed by Antipollution Industry Research in Switzerland. They accomplished this by recessing a burn space that includes the exhaust valve and the spark plug. The geometry induces high velocity gas swirl which allows high compression ratios without knock. With the recessed combustion chamber, lean air-fuel ratios can be used, therefore reducing emissions. The article briefly explains the design and the advantages of the new design.

Shamah, E., and T. O. Wagner. Fuel Quality or Engine Design: Which Controls Diesel Emissions? See IV.A.

Siewert, R. M. How Individual Valve Timing Events Affect Exhaust Emissions. Presented at the Mid-Year Meeting, Montreal, Quebec, June 7-11, 1971, SAE Preprint 710609, 20 pp.

The effects of individual valve timing events on the exhaust emissions of a single-cylinder engine were determined at part-load, low-speed, test conditions. The time of opening and closing of the intake and exhaust valve was varied independently over a wide range while maintaining the other three

valve timing events at conventional values. Significant changes in the induction, combustion, and exhaust processes resulted from valve timing changes. Of particular interest are the changes in engine exhaust emissions of hydrocarbons and nitric oxide under part load operation. The interactions between numerous engine parameters and valve timing are also discussed. Engine load, speed, spark advance, exhaust pressure, intake system configuration, mixture temperature, and external exhaust gas recirculation effects are included in this paper.

Smithsonian Science Information Exchange, Inc. Reduction of Pollution by Internal Combustion Engines. See IV.L.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Diesel Emissions and Mine Ventilation. See III.F.

Stewart, D. B., A. D'Aoust, E. D. Dainty, and J. P. Mogan. Reduction in Noxious Exhaust Burden by Some Minor Modifications to a Diesel Powered LHD Mining Vehicle. Canada Center for Mineral and Energy Technology, August 1975, Report MRP/ERL 75-102, 14 pp.

This paper studies noxious emissions emitted from a LHD vehicle with a Deutz F6L 714 (140 hp) engine. The vehicle was tested for 3 cases. Case I the governor was set at 2,300 rpm, in second gear (565 ft/min). Case II the governor was set at 1,800 rpm, in second gear (442 ft/min). Case III the governor was set at 1,800 rpm but the gear changed to obtain 565 ft/min. The researchers compared the noxious emissions emitted from the three cases. Case II indicated the greatest reduction of emissions along with a 27 pct increase in fuel savings but had a 12 pct increase in cycle time over case I. Case III was next in emissions with a 19 pct decrease from case I and fuel consumption reduced to 22 pct. The results are presented in tables.

Suzuki, T., and K. Usami. A Modification of Combustion Systems for Low Exhaust Emission and Its Effects on Durability of Prechamber Diesel Engine. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760213, 20 pp.

Described here is the tuning of the combustion systems of a precombustion chamber diesel engine for lower level of exhaust gas emission. The key points of the tuning are the decrease of the prechamber volume, the selection of the combustion chamber configuration, the injection nozzle characteristics and the optimum injection timing. It was made clear, in the results of investigation, that the degradation of lubricating oil and the cavitation pitting on the outer wall of cylinder liner were directly concerned with the combustion characteristics of low emission systems, and both problems have been solved. The result of combustion tuning of the engine shows less than 5 g/hp-h of NO_x plus HC with CARB 13 mode test cycle without deterioration of performance or durability.

Taigel, P. G. Diesel Locomotives in Mines: The Production of Toxic Gases by the Diesel Engine. See VIII.I.

Torpey, P. M., M. J. Whitehead, and M. Wright. Experiments in Control of Diesel Emissions. See IV.A.

U.S. Department of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

Urban, C. M., K. J. Springer, and D. A. Montalvo. Emissions Control Technology Assessment of Heavy Duty Vehicle Engines. See IV.A.

Walder, C. J. Reduction of Emissions From Diesel Engines. Presented at the Internat. Automotive Eng. Cong., Detroit, Mich., Jan. 8-12, 1973, SAE Preprint 730214, 20 pp.

The proposed federal and California regulations affecting emissions from on-highway diesel-powered vehicles have stimulated a critical examination of many forms of combustion chambers in search for a solution to the 5 g/bhp-h combined HC and NO_2 requirement. Results of tests made on indirect and direct injection systems are presented. It has been shown that with a simple modification to the injection timing of a production engine equipped with a swirl chamber combustion system, combined emission on the order of 4 g/bhp-h can be achieved under both naturally aspirated and turbocharged conditions. These results are achieved without significant sacrifice of smoke-limited power. Data on heat loss to coolant with the engine tuned for low emissions are presented. The influence of injection and engine variables on the emission characteristics of direct injection systems has been investigated and it is shown that, in general, the measures required to generate low exhaust emissions result in a loss of smoke-limited power and a depreciation in specific fuel consumption. The superiority of the direct injection system over indirect injection chambers in regard to fuel economy is therefore reduced. The effects of exhaust gas recirculation and water injection on emissions are reviewed and it is concluded that neither is very attractive in regard to the reduction of emissions for the complication involved. The possible use of the high-speed diesel engine for use in passenger cars to meet the 1976 Federal Emission Requirements is also discussed.

C. Exhaust Scrubbers

Chandler, R. H., Ltd. (Essex, England). Automotive Emission Control: Volume VI. Mechanical Aspects of Emission Control, Monitoring, and Public Health, 1974. Scrubbing and Cooling Exhaust Gases. 1977, pp. 64-68.

This reference contains 19 listings of papers on scrubbing and cooling exhaust gases. Each listing includes the title, author, date and the abstract from the paper.

Davis, R. F., and M. A. Elliott. The Removal of Aldehydes From Diesel Exhaust Gas. Transactions of the ASME, Paper No. 47-A-108, August 1948, pp. 745-750.

This report presents the results of studies (a) to determine the relation between aldehyde content of diesel exhaust gas and the odorous and irritating properties of that gas; and (b) to determine the effectiveness of different scrubbing media for removing aldehydes from diesel exhaust gas. Observations on the odor and irritation produced by diesel exhaust gas have shown that both of these properties can be correlated with the concentration of aldehydes in the exhaust gas. The threshold concentration for perception of odor is approximately 0.2 to 0.3 ppm of aldehydes (expressed as equivalent formaldehyde). The threshold of nasal and eye irritation occurs at about 1 ppm of aldehydes (expressed as equivalent formaldehyde). A series of full-scale tests on the removal of aldehydes by scrubbing with water showed that, as the concentration of aldehydes in the scrubbing solution increases, the percentage removal of aldehydes decreases. At elevated temperatures, the removal was nil, and under no conditions was complete removal obtained. From a series of laboratory tests, it appeared that aqueous solution of sodium sulphite might be used in removing aldehydes from diesel exhaust gas if hydroquinone was added to inhibit the oxidation of sodium sulphite. A full-scale test showed that an aqueous scrubbing solution, containing 10 pct sodium sulphite by weight and 0.5 pct hydroquinone, removed substantially all aldehydes for a period of 7 hr, and 90 pct or more of the aldehydes for a period of 15 hr. In this test, approximately 3,000 cu ft of dry exhaust gas (at 60°F and 29.92 in Hg) was scrubbed per hour at a scrubbing temperature of 133°F. Estimates of the cost of scrubbing diesel exhaust gas indicate that the cost of materials would be approximately 80 cents for an engine operating continuously for 8 hr and producing an average of 5,000 cu ft of dry exhaust gas (at 60°F and 29.92 in. HG) per hour.

Eccleston, B. H., D. E. Seizinger, and J. M. Clingenpeel. Diesel Exhaust Emissions From Engines for Use in Underground Mines. Bartlesville Energy Technology Center, U.S. Dept. of Energy, Report No. DOE/BETC/RI-80/6, April 1981, 42 pp.

Experimental data were obtained from two medium-duty diesel engines derated to qualify for use in underground mines. Gaseous and particulate emissions from these engines were measured and results provide information on the effect

of exhaust treatment devices on the emissions. The devices in the study were a catalyst, a particulate trap, and an exhaust gas cooler of the water scrubber type. Emission levels of carbon monoxide and hydrocarbons were observed to be very low in comparison with emission levels of comparable engines in full-rated operation. Oxides of nitrogen and benzo(a)pyrene content of the exhaust also were found to be somewhat low in comparison with previous findings. For particulate reduction, the combination of a particulate trap and a scrubber was observed to be the most effective combination tried; in some cases, over 60% particulate reduction was effected by the trap-scrubber combination.

Lawson, A., and H. Vergeer. Analysis of Diesel Exhaust Emitted From Water Scrubber and Catalytic Purifiers, Executive Summary. Ontario Research Foundation, Report ORF 77-01, 1977, Mississauga, Ontario, 6 pp.

Evaluation of the efficiencies of two water scrubbers, a catalytic purifier and combination of catalytic purifier with a water scrubber has been carried out to determine the emission characteristics from each exhaust treatment device when connected to a Deutz F6L 714 diesel engine which is commonly used in underground workings. The emission characteristics found with each device have revealed certain shortcomings which represent potential health hazards to underground personnel and make these devices unacceptable in their present form. The results have, however, shown how advantage can be taken of these emission characteristics, so that it is clear what measures might be taken to make these devices more acceptable to mine operators.

Mallette, F. S. Problems and Control of Air Pollution. See VI.B.2.

Rail Engineering International. Diesel Exhaust Conditioning for Underground Mines and Potentially Hazardous Environments. July/August 1974, pp. 289-290.

Because of the potentially hazardous gases in underground mines, diesel engine exhaust must be cooled to reduce the risk of an explosion. The article describes how the Hunslet Jet type exhaust gas conditioner, with water as the cooling fluid, operates. The article describes the design, advantages, and the routine maintenance that must be performed on the conditioner.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Diesel Emissions and Mine Ventilation. See III.F.

Taigel, P. G. Diesel Locomotives in Mines: The Production of Toxic Gases by the Diesel Engine. See VIII.I.

Underground Mines Locomotive Group of the Locomotive and Allied Manufacturers Association of Great Britain. British Diesel Mines Locomotives. See VI.B.1.

U.S. Department of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

U.S. Department of Health, Education, and Welfare. The Use of Diesel Equipment in Underground Coal Mines. See III.B.1.

Waytulonis, R. W., S. D. Smith, and L. C. Mejia. Failure Analysis of Diesel Exhaust-Gas Water Scrubbers. BuMines RI 8682, 1982, 19 pp.

The Federal Bureau of Mines contacted 29 organizations--mine maintenance departments and equipment manufacturers--concerning service experience and construction of diesel exhaust-gas water scrubbers. Scrubbers are used primarily on mobile diesel-powered mining equipment subject to 30 CFR 36. Because the scrubbers cool exhaust gas and act as flame arresters, their failure would compromise safety in underground mines. Scrubber maintenance problems and frequency and modes of failure were identified, and construction materials and techniques were evaluated. Three failed scrubbers were randomly selected from two cooperating mines, and their modes of failure were determined. In conjunction with failure analyses, mine water and scrubber water solution samples were chemically analyzed to characterize corrosive properties. Sludge and mineral deposits and different types of corrosion and metal fatigue were identified as problems leading to scrubber failure. The corrosion process is explained; maintenance practices, construction materials, and manufacturing methods that could be used to reduce premature failures and allow longer effective scrubber life are identified; and basic changes in scrubber design are suggested. If type 304 stainless steel is used throughout the scrubber and regular maintenance is performed, long, dependable service can be expected. Other materials such as 304L, 316, or other more exotic steel alloys may be necessary under certain conditions.

D. Catalytic Converters

Acres, G. J. Platinum Catalysts for Diesel Engine Exhaust Purification. Platinum Metals Review, v. 14, No. 3, July 1970, pp. 78-85.

This article briefly discusses how emissions are formed in the diesel engine. The diesel engine produces small amounts of HC and CO but larger amounts of NO. The engine can be modified to reduce NO emissions but a water scrubber or a catalytic system must be used to reduce CO and HC emissions. The article discusses the THT catalyst system that combines the high activity/low ignition temperature properties of platinum with the unique properties of a honeycomb ceramic support. The article describes the tests that were performed to determine the effectiveness of the catalytic system. The results indicate that the catalyst reduced the emissions of ethane and CO but had no effect on the emissions of NO_x.

Anderson, D. N. Effect of Inlet Temperature on the Performance of a Catalytic Reactor. See IV.L.

Banerjee, B. R. (ed.). Proceedings of the First National Symposium on Heterogeneous Catalysis for Control of Air Pollution. Nat. Air Pollution Control Administration, Philadelphia, Penn., Nov. 21-22, 1968, pp. 209-234.

This paper studies diesel engine pollutants. The paper is divided into two parts. The first part studies the various methods of identifying each exhaust pollutant. Part II explains how an exhaust catalyst is used to reduce exhaust odor and CO, HC emissions. The test procedure is described and the results are presented in graphs.

Barth, E. A. Investigation of the Effects of the Installation of an Oxidation Catalyst on a Diesel Powered Vehicle. Environmental Protection Agency, March 1979, 18 pp.; NTIS PB-299 928.

Since there is limited experience with the effects of installing an oxidation catalyst on a diesel powered vehicle, the EPA decided to investigate this configuration for its effects on both regulated and unregulated pollutants. Two catalysts were tested on a Mercedes 300D. The catalysts were manufactured by Ford and Englehard. The catalysts were tested under various operating conditions and measurements were made of HC, CO, CO_2, NO_x and particulates. The tests indicated that both catalysts had a significant reduction of CO, no change in NO_x emissions compared to the baseline engine and had a slight decrease in fuel economy. The Ford catalyst showed substantial reductions of HC while the Englehard showed an increase in HC emissions. Both catalysts showed an increase in particulate emissions. The various test procedures are described and the results are presented in tables.

Chandler, R. H., Ltd. (Essex, England). Automotive Emission Control--Volume VI. See IV.C.

Criteria and Special Studies Office. Second Annual Catalyst Research Program Report Summary. Health Effects Res. Lab., Office of Res. and Development, January 1977, 72 pp; NTIS PB-262 696.

This report constitutes the second Annual Report of the ORD Catalyst Research Program required by the Administrator as noted in his testimony before the Senate Public Works Committee on November 6, 1973. It includes all research aspects of this broad multi-disciplinary program including: emissions characterization, measurement method development, monitoring, fuels analysis, toxicology, biology, epidemiology, human studies, and unregulated emissions control options. Principal focus is upon catalyst-generated sulfuric acid and noble metal particulate emissions.

Demmler, A. W., Jr. Automotive Catalysis. Automotive Eng., v. 85, No. 3, March 1977, pp. 26-32.

Most cars built after 1974 have a catalytic converter to reduce the emissions of HC and CO. This article briefly explains the chemical reactions that take place to convert CO to CO2 and HC to CO2 and water vapor. The paper also studies various substances that are used as a catalysis and the availability of the substance.

Eccleston, B. H., D. E. Seizinger, and J. M. Clingenpeel. Diesel Exhaust Emissions from Engines for Use in Underground Mines. See IV.C.

Fleming, R.D., and T. R. French. Durability of Advanced Emission Controls for Heavy Duty Diesel and Gasoline Fueled Engines. Fuels Combustion Res. Group, Bartlesville Energy Res. Center, Interagency Agreement No. EPA-IAG-082 (D), September 1973, EPA Preprint EPA-460/3-73-010, 120 pp.

This report covers results from experimental work in a durability study using engines mounted on dynamometer stands to determine the effectiveness of advanced emission controls on heavy-duty engines over 1,200 hours of operation. The two engines tested were a 636 CID diesel and a 345 CID gasoline engine. The engines were operated on cyclic duty schedules with 40 pct load factors to simulate heavy-duty driving patterns. To reduce emissions the diesel engines injection timing was retarded 3 degrees crank angle, catalytic converters were installed and exhaust gas recirculation (EGR) was used. The gas engine used catalytic converters, manifold air injection and EGR. The results indicated that NO_x emissions could be reduced using EGR and also maintain good durability. The catalytic converters reduced CO and HC emissions but further testing is needed to determine its durability.

Gruber, A., and A. Walitt. Development of the Catalytic Chamber Process. Tyco Lab., Inc., Waltham, Mass., Contract No. 68-02-003, September 1972, 210 pp.; NTIS PB-220 436.

The results are presented of a contract period. The goal of the contract was to continue the development of the Tyco Catalytic Chamber Process for the simultaneous removal of SO2 and NO_x from power plant flue gases. More specifically, the contract goals were as follows: (1) modification of the existing 10 SCFM miniplant to permit integrated operation; (2) experimentation in the integrated miniplant to determine probable design ranges of critical engineering parameters. A parametric study showing the effect of the various parameters was planned; (3) preliminary design of a 2,000 to 5,000 SCFM pilot plant; (4) evaluation of control levels of SO2 and NO_x attainable through use of the Catalytic Chamber Process and comparison with desired levels; (5) evaluation of the economic feasibility of the overall process and comparison with EOA standards; (6) preliminary process control evaluations; (7) determination of a site for the pilot plant; (8) evaluation of the fly ash problem. The most significant results of the program were: (1) the SO2 gas phase oxidation by NO2 was found to proceed too slowly to permit the use of practical-sized equipment; (2) absorption of equimolar quantities of NO and NO2 was not to be controlled by a conventional absorption mechanism probably dependent on a gas phase interaction of the two oxides. As a result, the large equipment needed to provide long residence times makes the process appear relatively expensive for removing SO2 and NO_x together or NO_x alone.

Harrison, R. T. Catalytic Converter Temperature Tests. Presented at the Automobile Eng. Meeting, Dearborn, Mich., Oct. 18-22, 1976, SAE Preprint 760781, 16 pp.

In June 1975, the Forest Service Equipment Development Center at San Dimas, Calif., conducted tests to determine exhaust system temperatures on late-model vehicles. For normal operation, test results showed only small temperature differences at any point on a vehicle's exhaust system between those equipped with catalytic converters and those without catalytic converters. Also, test results indicate that the direct forest fire hazard from catalytic converter-equipped vehicles is essentially the same as with other exhaust systems, except when the vehicle engine malfunctions.

Institute of Machinery and Institute of Chemistry of Westgalische Berggewerkschaftskasse. Verminderung des Gehaltes an schadlichen Bestandteilen in den Abgasen von Dieselmotoren bei methanhaltiger Ansaugluft (Reduction in the Content of Noxious Constituents in the Exhausts of Diesel Engines with Methane-Containing Intake Air). Final Report, 1981, 53 pp.

The exhaust from vehicles with diesel engines has been gaining in importance with the increasing use of such vehicles underground. This is especially true in cases where the ventilation currents contain methane, which negatively influences the emission of noxious substances. Therefore the Institute for Chemistry of the Westphalian Miners Union Fund studied the effect of engine design, fuel injection, supercharging, fuel additives, and water-diesel fuel emulsion on the exhaust emissions with the intake air containing methane. Extensive studies were also done on the effectiveness of using a monolithic catalytic converter in the exhaust system. Bench tests indicated that the conversion efficiency decreased as time passed and also depended on the duty cycle of the vehicle. To determine the durability, the converters were placed on several different mining equipment and used in the mines. The tests indicated that several of the converters broke before 1,500 hours could be accumulated. Several of the converters accumulated over 3,000 hours before the testing was completed.

Jones, G. T. Evaluation of Restorative Maintenance and Catalyst Replacement on Exhaust Emissions from Eight Very High Mileage Passenger Cars in St. Louis. U.S. Environmental Protection Agency, Ann Arbor, Mich., June 1979, 19 pp.; NTIS PB 81-216368.

The purpose of this effort was to gather information on catalyst-equipped passenger cars which had exceeded their defined "useful life". The following areas were addressed: 1.) Emission performance in as-received condition, 2.) Extent of malperformance in the emission control system, 3.) Capability of restorative maintenance in reduction of emission levels, 4.) Effectiveness of both old and new catalysts on emission levels. A total of eight catalyst-equipped passenger cars were procured from private owners in the St. Louis area. Vehicles of each of the three major domestic manufacturers were chosen to constitute the test fleet. The actual vehicles were sought to obtain a general representation of popular models and engines with the final selection based on odometer reading. Each vehicle was subjected to a prescribed series of tests, inspections, and maintenance actions.

Kummer, J. T., Y. Yao, and D. McKee. Honeycomb Auto Exhaust Catalysts Containing Copper Chromite and Palladium. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760143, 20 pp.

A copper chromite ZrO2 honeycomb catalyst has been evaluated in the laboratory and to a limited extent on vehicles. When 650-850 grams of this catalyst (1.4-1.9 lb) is dispersed on two honeycombs and used to catalytically treat the exhaust of a 4,500 lb, 400 in^3 Torino, the percent oxidation of CO and hydrocarbons during the Federal Test Procedure are close to, but less than that produced by present noble metal production catalysts. The total active catalyst surface area available with copper chromite ZrO2 catalyst is somewhat marginal and this leads to pronounced susceptibility to lead deactivation during durability even at very low lead levels if the peak catalyst operating temperature is high (900°C). It is desirable to operate below 700-750°C. Catalyst operating temperatures greater than 550-600°C are necessary to suppress sulfur deactivation without special operating procedures so that this leaves only a narrow temperature range of operation if the catlyst activity is to be preserved. Catalysts containing a low level of palladium appear to offer a competitive alternate to the use of a high catalyst loading base metal catalyst. The problem of a limited total active catalyst surface area and susceptibility to lead are still present but other constraints are eased.

Lawson, A. Progress in the Control of Underground Diesel Emissions. CIM Bull. v. 74, No. 835, November 1981, pp. 68-73.

Continued and expanded use of underground diesel-powered equipment is considered desirable in order to achieve necessary production capability, particularly when coal becomes increasingly in demand as an energy source. Although diesel engines are derated for underground use, concern has been expressed in many quarters regarding the health effects of worker exposure to diesel-generated particulate and NO_x emissions. This concern will increase as Canadian diesel fuel quality becomes heavier and with higher sulphur content. This could result in a requirement to increase ventilation rates by 50%. This paper describes the results of studies of various approaches designed to reduce diesel emissions. Two major approaches have been followed: fuel modification, and emission control hardware development. The results of progress in the development of these approaches are described.

Lawson, A., and H. Vergeer. Analysis of Diesel Exhaust Emitted From Water Scrubber and Catalytic Purifiers, Executive Summary. See IV.C.

Lee, R. E., Jr., and F. V. Duffield. EPA's Catalyst Research Program: Environmental Impact of Sulfuric Acid Emissions. J. of the Air Pollution Control Assoc., v. 27, No. 7, July 1977, pp. 631-635.

A sulfuric acid review conference sponsored by EPA's automotive Catalyst Research Program was held recently at Hendersonville, N.C., for researchers whose work is funded by EPA. Emissions characterization research indicated that in-use catalyst-equipped vehicles emit low levels of H_2SO_4, averaging 2.7 mg/mile for 49 state cars and 15 mg/mile for California cars. Research on measurement methodology for H_2SO_4 and other sulfate compounds has led to the development of several promising techniques based on selective volatilization. In-roadway and off-roadway monitoring programs are providing sulfate data which can lead to improved mathematical predictive models. Acute toxicity studies to date indicate that morphological, biochemical, physiological, and pharmacological alterations due to inhaled H_2SO_4 alone do not appear to occur at levels less than 1 mg/m3. However, striking effects are noted with combinations of H_2SO_4 and other pollutants. Participants identified the need for long term chronic H_2SO_4 exposure studies.

Marshall, W. F. Emission Control for Diesels Operated Underground: Catalytic Converters. U.S. Energy Res. and Development Admin., Report No. BERC/RI-75/8, August 1975, 10 pp.

The Energy Research and Development Administration is conducting a series of experiments for the BuMines to determine the influences of emission controls on exhaust emissions from diesel engines. Tests were conducted with engines typical of those used in underground mines and catalysts specifically designed for diesel engines, and results showed marked differences in catalyst efficiencies for reducing carbon monoxide, hydrocarbon, and odor levels. Although catalysts decrease emissions of oxidizable toxicants, they can produce unwanted or hazardous products (for example, SO3). Subsequent exhaust treatment may be necessary for a complete control system.

Marshall, W. F., D. E. Seizinger, and R. W. Freedman. Effects of Catalytic Reactors on Diesel Exhaust Composition. BuMines TPR 105, April 1978, 9 pp.

This BuMines report discusses tests conducted with four different catalytic reactor designs to determine the influences of exhaust treatment systems on emissions from diesel engines. Although there was significant differences in oxidation efficiencies at light to intermediate engine loads, all four catalysts were very effective in reducing emissions at heavy loads. Compositional determinations included carbon monoxide, carbon dioxide, unburned hydrocarbons, oxides of nitrogen, aldehydes, sulfur dioxide, sulfates, and particulate loading. Particulate size, exhaust odor intensity, and the character of the unburned hydrocarbon component were also determined.

McDermott, J. Catalytic Conversion of Automobile Exhaust. Noyes Data Co., Park Ridge, N.J., Pollution Control Review No. 2, 1971, 208 pp.

The detailed descriptive information in this book is based on U.S. patents relating to catalysts and catalytic devices for converting automobile exhaust fumes into less polluting gases. Because of the actuality of the problem, most patents are of very recent date, but some older, basic patents were included, in order to give a complete technological picture of the state of the art. This book serves a double purpose in that it supplies detailed technical information and can be used as a guide to the U.S. patent literature in this field. By indicating all the information that is significant, and eliminating legalistic phraseology, this book presents an advanced industrially oriented review of the catalytic conversion of automobile exhausts.

Mertens, Hans, Dr.-Ing., and Dipl-Ing. Hans-Georg Schlitt. Exhaust Behaviour on Diesel Engines Where Intake Air Contains Methane. Gluckauf and Translation, v. 115, No. 11, 1979, pp. 244-247.

Increasing attention has been paid to the emission of toxic matter following the trend towards the use of diesel powered vehicles in deep mines. This is particularly so if the intake air contains methane, thus adversely affecting the emission of toxic mastter from diesel engines. The Institute of Mechanical Engineering and the Institute for Chemistry at the Westfalische Berggewerkschaftskasse (WBK) accordingly carried out investigations into different types of diesel engines aimed at improving exhaust emissions even when methane is present in the intake air. This can be achieved by design modifications, by measures within the engine, by using fuel additives, or by catalytic secondary combustion. The objective of this project and report is to clarify the effects of such measures on the emission of toxic matter, especially where methane is present in the intake air.

Murphy, M. J., L. J. Hillenbrand, and D. A. Trayser. Assessment of Diesel Particulate Control: Direct and Catalytic Oxidation. Battelle Columbus Lab., Columbus, Ohio, Contract No. 68-02-2629, October 1979, 30 pp.

The technology and potential for disposal of diesel particulate by oxidation are discussed. Relevant properties of typical diesel particulate are given; particular note is taken of the small size and the presence of a portion extractable with an organic solvent. Available reaction rate data is used to derive particle lifetimes at various temperatures; these exceed likely exhaust system residence times. The use of catalysts to increase oxidation rates and lower ignition temperatures is discussed. Small amounts of many metals are effective in increasing the rate of oxidation by 2 to 5 orders of magnitude. Chemical reactor theory is used to derive ignition and operational characteristics of trap/oxidizers. Special note is taken of the tendency of these devices to go rapidly from a cold

unignited state to an ignited state close to the adiabatic flame temperature of the fuel. Design techniques to ameliorate undesirable temperature excursions are presented.

Patterson, D. J., and N. Henein. Emissions From Combustion Engines and Their Control. See III.F.

Pierson, W. R., R. H. Hammerle, and J. T. Kummer. Sulfuric Acid Aerosol Emissions From Catalyst-Equipped Engines. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740287, 8 pp.

It has been reported by Dow Chemical Co. that oxidation catalysts cause increased particulate emissions from automotive exhausts. We find that this particulate consists of aqueous H_2SO_4 droplets. Current work undertaken between Ford and Battelle Columbus Lab., using an engine dynamometer, shows that the fuel sulfur emerges from the engine as SO_2. At 60 mph road load, a monolithic oxidation catalyst converts almost half of the SO_2 into SO_3, the bulk of which is emitted from the tailpipe as H_2SO_4. The mass median diameter is smaller than 0.25 μm. Some ammonium sulfate is present, but the predominant sulfate species is H_2SO_4, totalling some 40 pct of the gross particulate mass depending on humidity. The rest is primarily water, associated with the hygroscopic H_2SO_4. Without a catalyst, the H_2SO_4 is <1/50 as much as with catalyst the bulk of the fuel sulfur being emitted as SO_2.

Sercombe, E. J. Exhaust Purifiers for Compression Ignition Engines. Catalytic Control of Diesel Exhaust Gases. Platinum Metals Review, v. 19-20, No. 1, January 1975, pp. 2-11.

A new platinum catalyst system has been developed at the Johnson Matthey Research Lab. for the oxidation of hydrocarbons and carbon monoxide emitted by compression ignition internal combustion engines. The catalyst was evaluated during tests on a direct injection diesel engine using the 13 mode cycle devised by the California Air Resources Board, thereby assisting the design of catalyst systems to meet specific emission control targets in particular industrial applications. The new catalyst combined with retardation of injection timing can provide overall control of exhaust emissions, including the nitrogen oxides, from diesel engines.

Smithsonian Science Information Exchange, Inc. Catalytic Converters. See X.B.

Stara. J. F., W. Moore, and A. W. Breidenbach. Toxicology of Atmospheric Pollutants Resulting From Fuel Additives and Emissions Associated With the Use of Automobile Catalytic Converters. See V.A.3.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Diesel Emissions and Mine Ventilation. See III.F.

U.S. Department of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

U. S. Department of Health, Education and Welfare. The Use of Diesel Equipment in Underground Coal Mines. See III.B.1.

U.S. Environmental Protection Agency. Emission Control of Engine Systems: Consultant Report to the Committee on Motor Vehicle Emissions Commission on Sociotechnical Systems National Research Council. Washington, D. C., September 1974, 260 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

The consultant report on "Emissions Control of Engine Systems" represents the findings of the Panel on Internal Combustion Engines and the Panel on Alternative Engines. The first panel evaluated the potential of conventional, spark-ignition internal-combustion engines and other internal-combustion engines, such as the rotary, diesel and stratified charge engines for meeting levels of NO_x, CO, and HC. The second panel assessed the potential of alternative, more advanced automotive engines, such as the gas turbine, Stirling, and Rankine power plants, for meeting similarly strict levels of emission controls. Primary consideration was given to cost, in terms of fuel consumption, associated with the achievement of various NO_x levels by different engine systems. The Panels were concerned with emission levels attainable in certification with vehicles tested according to the 1975 Federal Test Procedure (FTP). Other consultant reports deal with performance in customer use, alternate testing procedures, catalytic converters, and the manufacturability and costs of low-emission engine systems.

U.S. Environmental Protection Agency. Third Annual Catalyst Research Program Report. EPA-600/3-78-012, January 1978, 272 pp.

This report constitutes the Third Annual Report of the ORD Catalyst Research Program required by the Administrator as noted in his testimony before the Senate Public Works Committee on November 6, 1973. It includes all research aspects of this broad multi-disciplinary program including: emissions characterization, measurement method development, monitoring, fuels analysis, toxicology, biology, epidemiology, hyman studies, and un-regulated emissions control options. Principal focus is upon catalyst-generated sulfuric acid and noble metal particulate emissions.

Urban, C. M., K. J. Springer, and D. A. Montalvo. Emissions Control Technology Assessment of Heavy Duty Vehicle Engines. See IV.A.

Yaverbaum, L. H. Nitrogen Oxides Control and Removal, Recent Developments. Noyes Data Corporation, Park Ridge, N.J., Pollution Technol. Rev. No. 60, Chem. Technol. Rev. No. 136, 1979, 388 pp.

The detailed descriptive information in this book is based on U.S. patents, issued since April 1975, that deal with nitrogen oxides, their control and removal from stack gases (Section I) and automobile exhausts (Section II). The first section is preceded by introductory information on commercial processes for NO_x removal and burner modifications that can be applied to stationary equipment. This book serves a double purpose in that it supplies detailed technical information that is significant, and eliminating legal jargon and juristic phraseology, this book presents an advanced, technically oriented review of recent advances in nitrogen oxides control and removal.

E. Turbochargers and Intercoolers

Buike, J., J. Davis, J. Marsh, and L. Ryder. Supercharging for Fuel Economy. See II.C.

Institute of Machinery and Institute of Chemistry of Westgalische Berggewerkschaftscasse. Reduction in the Content of Noxious Constituents in the Exhaust of Diesel Engines With Methane-Containing Intake Air. See IV.D.

Marshall, W. F. NO_x Emissions From Diesel Engines--Control and Measurement Techniques. See III.A.1.

Mertens, Hans, Dr.-Ing., and Dipl.-Ing. Hans-Georg Schlitt. Exhaust Behaviour on Diesel Engines Where Intake Air Contains Methane. See IV.D.

Oblander, K., M. Fortnagel, H. J. Feucht, and U. Conrad. The Turbocharged Five-Cylinder Diesel Engine for the Mercedes-Benz 300 SD. See I.F.

Patterson, D. J., and N. Henein. Emissions From Combustion Engines and Their Control. See III.F.

Pearce, J. F., R. J. Hames, and D. F. Merrion. Two-stroke Cycle Diesel Engine Fuel Economy Improvement and Emission Reduction. See II.C.

Wilson, R. P., Jr., E. B. Muir, and F. A. Pellicciotti. Emissions Study of a Single-Cylinder Diesel Engine. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740123, 45 pp.

Exhaust measurements of NO, soot, and hydrocarbons were made on a 2,340-cm^3 displacement, single-cylinder diesel engine operated over a range of speed, fuel-air ratio, and timing. Modifications systematically tested include (1) chamber shape (open and divided chamber, prechamber volume ratio, and compression ratio); (2) air swirl; (3) thermodynamic state of the intake charge (EGR, turbocharging, water injection, and air temperature); and (4) fuel injection parameters (orifice size, rate of injection, cam shape, pilot injection). Exhaust data suggest that the phenomena of air swirl, fuel spray, and diffusion flames are key elements in diesel combustion behavior. The sensitivity of emissions to time-dependent phenomena such as mixing rates, ignition, heat transfer, and burning rates is apparently connected to the extent to which heat release is delayed.

F. Noise Control

Anderkay, G. A. Techniques for Quieting the Diesel. SAE Preprint 750839. Society of Automotive Engineers, Inc. Diesel Engine Noise Conference. August 1975, SAE Special Publication 397, pp. 195-203.

Reduction of diesel engine noise in a cost-effective manner requires quantitative identification of the noise levels radiated by the different engine surfaces. The source identification enclosure technique and test variation effects are discussed. In addition, the techniques of optimum mass and stiffness distribution, shielding, damping and isolation are discussed and results of typical treatments are shown.

Automotive Engineering. Lowering Diesel Noise Through Hardware Modifications. v. 81, No. 6, June 1973, pp. 41-47.

Diesel engine noise can be reduced by using three methods. The first method is by isolation which can be accomplished by introducing a relatively flexible material between two vibrating structures to minimize transmitted vibrations. The second method is by damping which can be done by bonding a rubber material to the component to eliminate the resonant condition. The last method is by shielding which consists of covers that have a 3/4 to 1 in fiberglass backing material to reduce the noise. The article discusses how these methods can be applied to the various engine components. The results indicated that by using these methods the overall engine noise can be reduced by 3-6 dBA.

Barnes-Moss, H. W. Engine Design for the Future. Presented at the Truck Meeting, Troy, Mich., Nov. 4-7, 1974, SAE Preprint 741130, 17 pp.

Engine design is now increasingly influenced by environmental legislation in addition to the traditional commercial and economic factors. The controlling parameters are identified and their effect on engine specification discussed. Proposals are made for the design of future power plants to meet these needs.

Coulson, J., and R. Southall. Diesel Engine Noise-Basic Studies Lead to Practical Reductions. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760550, 16 pp.

Early work aimed at diesel engine noise reduction is described. This has led to an intensive research program to develop a method of predicting engine noise. A special research engine incorporating the latest noise control features is described. The research engine is additionally used to verify the predictive technique, and the analysis completed to date is discussed.

Holvenstot, C. Designing Safety into Underground Mining Equipment--Noise Abatement. See VI.A.

Lane, R. S., and S. E. Timour. Techniques of Structural Vibration Analysis Applied to Diesel Engine Noise Reduction. SAE Preprint 750835. Society of Automotive Engineers, Inc. Diesel Noise Conference. August 1975, SAE Special Publication 397, pp. 146-156.

This paper presents several techniques used to define quantitatively the problem of excessive noise through engine structural vibration. These techniques include both operating engine tests and bench tests. In addition, analytical techniques are shown which give a better understanding of how the critical components within the engine cause this vibration. Through the use of analytical and experimental techniques, examples illustrate practical solutions for diesel engine noise reduction.

LeCreurer, M., and M. Marty. Practical Means for Reducing the Noise of Fast Diesel Engines. SAE Preprint 750837. Society of Automotive Engineers, Inc. Diesel Noise Conference. August 1975, SAE Special Publication 397, pp. 168-178.

Substantial efforts have been made for the last ten years with a view to reducing the noise level of private cars equipped with high speed diesel engines. Among others, such efforts resulted in a substantial reduction of the characteristic diesel engine noise at idling speed as well as in a substantial improvement of acoustical comfort within the vehicle passenger compartment. More recently, systematic studies were conducted with a view to reducing the external noise level of such vehicles under urban traffic conditions. The main criterion retained was the noise level as measured under conditions specified by ISO Standard R 362. Significant progress has already been made to reduce noise connected with fuel injection and combustion. With current engines, engine high speed noise is primarily mechanical. It is not contemplated, at least in the short term, to put in production an engine designed on a fundamental new basis, on account of the large investments involved, and of the required time for resolving technical and industrial problems. Under such conditions, possibilities for reducing noise directly at its source remain very limited, since they mainly concern modifications to housings, especially the timing cover and oil pan. Also studied was the possibility of reducing noise by means of insulating screens and absorbing materials in the engine compartment. The impact of a reduction in the noise from the engine itself is substanital only provided that the noise from other sources is also limited, such as from the exhaust system, intake system, cooling fan and clutch-gearbox transmission assembly. As from now, the noise level of private cars equipped with high speed diesel engines under legislated conditions currently in force in Europe, is no higher than for other vehicles of the same class. In spite of difficulties inherent to the diesel engine, the fact is stressed that most solutions retained or contemplated with a view to reducing outer noise levels are applicable to private cars equipped with spark ignition engines.

Mason, R. L. Progress in the Reduction of Diesel Engine Noise. Sound and Vibration, February 1974, pp. 16-19.

Two companies invvestigated the reduction of diesel exhaust noise by testing seven engines (3 Cummins, 3 Detroit Diesels, 1 Mack) each which was installed with their optimum muffler. The two companies were the Stemco Manufacturing Co. of Longview, Texas, and the Donaldson Co. of Minneapolis, Minn. The article briefly describes the testing facilities and testing techniques of each company and compares the sound level of the engines in dBA of various tests.

Patterson, W. N., G. G. Huggins, and A. G. Galaitsis. Noise Control of Underground Diesel-Powered Mining Equipment. Contract No. H0346046, Jan. 23, 1975, 100 pp.; NTIS PB-243 896.

This report surveys underground diesel-powered mining equipment and details their noise levels and subsequent worker noise exposure. The noise mechanisms for these machines is characterized and control techniques are discussed. Additionally, a method for predicting underground noise levels from surface measurements is presented.

Patterson, W. N., G. G. Huggins, and A. G. Galaitsis. Noise of Diesel-powered Underground Mining Equipment: Impact, Prediction, and Control. See III.B.4.

Russell, M. F. Automotive Diesel Engine Noise and Its Control. See III.B.4.

Shrader, J. T., and N. Priadka. Truck Noise IV-D: The Reduction of Intake and Exhaust Noise on Heavy Duty Diesel Trucks. Internat. Harvester Co., Contract No. DOT-OS-20222, October 1974, 140 pp.; NTIS PB-238 361.

The exhaust and intake systems are often major contributors of noise on heavy duty diesel trucks. Using a systematic approach, the sources of exhaust and intake noise are identified and studied. The noise radiated from the surface of the exhaust pipe (pipe shell noise) was the major cause of exhaust noise. Pipe shell noise was partially controlled by muffler design, however, the principles are not fully understood. A reduction in exhaust noise of more than 10 dBA was achieved by utilizing a large volume, wrapped muffler along with leak resistant exhaust joints. Intake noise was generated by the Roots type blower used on the engine. The noise was transmitted out the inlet opening of the intake system. Intake noise was reduced 8 dBA by adding a silencer to the system which was tuned to be the critical blower frequency.

Society of Automotive Engineers, Inc. Energy and the Automobile. See X.A.

Srivastava, N. S., and S. Kumar. Application of Cross-Correlation Technique to the Casing Noise Investigation of a High Powered Diesel Engine. Presented at the Winter Annual Meeting, Houston, Tex., Nov. 30-Dec. 4, 1975, ASME Preprint 75-WA/DGP-3, 8 pp.

The importance of structural vibration related noise in high-powered diesel engines is discussed in view of its significant contribution to the overall engine noise generation. A cross-correlation technique for noise investigation due to structural vibrations is briefly described and then applied successfully to GM 645 E Series 20 cylinder turbocharged diesel engine operating in a semi-reverberant environment of a test cell. Implications of cross-correlograms and cross-correlation coefficients have been discussed. This technique can be applied to other vibrating structures for establishing an order of importance of elements of the structure in a noise abatement program.

Thien, G. E., and H. A. Fachbach. Design Concepts of Diesel Engines With Low Noise Emission. SAE Preprint 750838. Society of Automotive Engineers, Inc. Diesel Noise Conference. August 1975, SAE Special Publication 397, pp. 179-194.

The sources of diesel engine noise and methods for its abatement are analysed and described. Typically, the overall engine noise is determined by the engine surface noise which, however, can hardly be reduced by more than 5 dBA with conventional noise abatement techniques. For reductions of 10 dBA or more, it is necessary to attenuate the noise of all external engine parts by a complete encasing of the engine. Various concepts for light weight acoustic engine casings which are closely fitted to the engine without acoustical lining or even integrated into the engine structure and which provide a 15 to 20 dBA noise reduction are demonstrated, including one concept for future light weight engines featuring a sound attenuating housing.

G. Thermal Reactors

Chandler, R. H., Ltd. (Essex, England). Automotive Emission Control - Volume VI. Mechanical Aspects of Emission Control, Monitoring, and Public Health: 1974. Afterburners, 1977, pp. 40-52.

This reference contains 64 listings on emission control using afterburners. Each listing contains an abstract of the article and the information needed to obtain the article.

Fleming, R. D., and T. R. French. Durability of Advanced Emission Controls for Heavy Duty Diesel and Gasoline Fueled Engines. See IV.D.

Herrin, R. J. Lean Thermal Reactor Performance Characteristics--A Screening Study. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760319, 12 pp.

The automotive thermal reactor may be suitable for controlling the hydrocarbon (HC) and carbon monoxide (CO) emissions from lean-mixture engines. Little is known about the performance characteristics of "lean" reactors, however, since much of the previous research on reactors considered only rich-engine operation. This study screened the effects of six operating variables on lean-reactor performance by means of a fractional factorial experiment. Also, spatial temperature and species concentration distributions within the experimental two-pass reactor were obtained at several operating conditions. Of the variables screened, reactor insulation had the largest effect on emissions performance. Higher engine speed, retarded spark timing, and a less lean air-fuel ratio were also shown to improve reactor performance significantly. Within the range of this study, exhaust flow rate and engine exhaust-port liners did not significantly affect reactor performance. High HC conversion efficiencies were obtained at many combinations of the six variables. CO conversion efficiencies were generally lower, and at several conditions CO was produced within the reactor from the partial oxidation of HC. Internal sampling revealed that most of the HC oxidation occurred in the reactor core, which was both larger and hotter than the surrounding annulus.

Sakai, Y., Y. Nakagawa, S. Tange, and R. Maruyama. Fundamental Study of Oxidation in a Lean Thermal Reactor. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-Mar. 4, 1977, SAE Preprint 770297, 12 pp.

The oxidation mechanism in a lean thermal reactor was studied with a number of basic experiments. It depends neither on engine speed nor airflow rate, but only on the residence time of the gas. It was shown that in a lean thermal reactor CO first increases by an HC->CO reaction and then decreases by a $CO \rightarrow CO_2$ reaction. The effect of NO on oxidation was also

studied, and it was concluded that oxidation is affected by NO and that there exists a certain NO concentration which most accelerates oxidation.

U.S. Department of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

U.S. Environmental Protection Agency. Emission Control of Engine Systems. See IV.D.

H. Exhaust Gas Recirculation

Berger, L. B., M. A. Elliott, J. C. Holtz, and H. H. Schrenk. Diesel Engines Underground: II. Effect of Adding Exhaust Gas to Intake Air. BuMines RI 3541, November 1940, 18 pp.

Studies showing the effect of mixing hot exhaust gases with the intake air of a four-stroke-cycle diesel engine are described. The results indicate a marked increase in carbon monoxide in the exhaust gases, a decrease in oxides of nitrogen, and no significant effect on aldehydes. The increase in carbon monoxide was greater at higher fuel-air ratios and was caused partly by the increase in fuel-air ratio and partly by the decrease in oxygen concentration resulting when exhaust gas was added. The application of these results to the use of diesel engines underground is considered.

Chandler, R. H., Ltd. (Essex, England). Automotive Emission Control--Volume VI. Mechanical Aspects of Emission Control, Monitoring, and Public Health: 1974. Exhaust Gas Recirculation, 1977, pp. 52-64.

This reference contains 68 listings on the topic of exhaust gas recirculation (EGR). Each listing contains the abstract along with the information needed in order to obtain the listing.

Fleming, R. D., and T. R. French. Durability of Advanced Emission Controls for Heavy Duty Diesel and Gasoline Fueled Engines. See IV.D.

French, C. C. J., and D. A. Pike. Diesel Engined, Light Duty Vehicles for an Emission Controlled Environment. See II.C.

Gat, N., and C. W. Kauffman. Some Effects of Exhaust Gas Recirculation on Combustion. Presented at the 1978 Spring Technical Meeting of Central States Section/The Combustion Institute, April 3-4, 1978, the 17 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

The provisions of the clean air act dictate the control of automotive emisssions. A method used for the control of oxides of nitrogen emissions is exhaust gas recirculation (EGR) where a fraction of the exhaust gases are recycled into the combustibles of the intake charge. These inert gases lower the peak flame temperature, a major factor in the formation of NO_x. Dilution of the combustible mixture with the exhaust gases causes several problems--the burning velocity of the mixture is lowered, the wall quench layer is thickened, and the required ignition energy is increased. These

effects may lead to an undesirable increase in hydrocarbon and carbon monoxide emissions. A mechanism partially compensating for the first two problems may be control of cylinder turbulence although its effect on the third problem may be detrimental. The purpose of this research program was to study the effects of exhaust gas recirculation and turbulence on the burning velocity, single wall quench distance, and ignition energy of a natural gas/air mixture.

Gumbleton, J. J., R. A. Bolton, and H. W. Lang. Optimizing Engine Parameters With Exhaust Gas Recirculation. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740104, 12 pp.

In addition to designing and developing hardware to control EGR rate, it is equally important to tailor the other engine variables. Optimization of air-fuel ratio and spark timing is required to achieve the best combination of NO_x, HC, and CO control, while minimizing the losses in fuel economy and drivability. This paper describes an engine dynamometer and vehicle study which defines the relationship between the above parameters. In general, increasing the spark advance with increasing EGR rates will minimize the losses in fuel economy and vehicle drivability while achieving significant reductions in NO_x emissions. This approach is limited be a deterioration in HC emission control. The loss in HC control can be minimized by spark retard, but with a loss in fuel economy. The air-fuel ratio must be tailored to maintain good combustion for HC emission control without excessive richness and loss of CO emission control.

Hill, S. H., and J. L. Dodd. A Low NO_x Lightweight Car Diesel Engine. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-Mar. 4, 1977, SAE Preprint 770430, 28 pp.

A new automobile diesel engine concept has been developed to the preliminary engine design level and demonstrated by simulating vehicle tests with a computer model using steady state engine dynamometer data. The preliminary design is a six cylinder, swirl chamber diesel of 209 CID and 130 GHP. This concept engine weighs 495 pounds and employs turbocharging, variable compression ratio, high prechamber-main chamber volume ratio and exhaust gas recirculation. An existing automobile diesel was modified to simulate the concept engine and steady state engine tests were conducted. Test results were converted to urban cycle results for a 3000 pound GVW vehicle through the use of a computer model. Emission results (Grams/Mile) are .21 NO_x, .24 HC, and 1.24 CO. Fuel consumption (Miles/Gallon) is 30.3 urban cycle and 36.4 highway cycle. Vehicle cycle results at 3700 pounds GVW meet all emission requirements and exceed the future 27.5 MPG requirement by ten percent. Multifuel capability and 175 PSI BMEP power levels were also demonstrated.

Lawson, A. Progress in the Control of Underground Diesel Emissions. See IV.D.

Lombardi, C. Gaseous Emissions Control for Heavy Duty Diesel Engines. Proceedings of the Fourth Internat. Symposium on Automotive Propulsion Systems, April 18-22, 1977. U.S. Department of Energy, Report No. CONF-770430/1, UC-96, v. 1, February 1978, pp. 319-329.

This report was prepared by the Fiat Research Center which studied the emissions of their DI 8060, DI 8210 naturally aspirated and their 8210 turbocharged engine. They investigated the possibility of reducing the emissions by EGR, variable compression ratio, and using dual fuel of gas, oil and methanol. The results indicated that EGR is an effective method of obtaining an emission level of 4.5 g/hp-h for the 8060 engine. The 8210 engine showed higher NO2 and HC levels than the baseline emissions hence, more sophisticated testing techniques are required. The 8210 turbocharged variable compression ratio engine showed a high specific output and low NO2 plus HC emissions. Using the dual fuel the NO2 plus HC emissions were lower than 5 g/hp-hr.

Marshall, W. F. NO_x Emissions From Diesel Engines--Control and Measurement Techniques. See III.A.1.

Mayer, E. A. Elctro-Pneumatic Control Valve for EGR/ATC Actuation. Presented at the Internat. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 23-27, 1981, SAE Technical Paper Series 810464, 8 pp.

The dual solenoid control valve was initially designed as a low cost interface element between digital electronics and an automotive vacuum-spring motor such as the one found on Exhaust Gas Recirculation (EGR) valves. By using two coaxially located normally closed solenoids, continuous air bleed is not required from the vacuum source. The direct acting solenoids have a large 0.5 SCFM flow capacity and a quick six millisecond opening and two millisecond closing time. The unit is well suited for pulse width modulation control. Ambient tests were conducted from -40°F to +250°F without any significant change in the performance characteristics of the unit. Possible applications for this electro-vacuum interface are in EGR valve control, Automatic Temperature Control (ATC), and as a remote throttle actuator on diesel engines.

Patterson, D. J., and N. Henein. Emissions From Combustion Engines and Their Control. See III.F.

Pike, D. A. Modulated Exhaust Gas Recirculation System for Light Duty Diesel Engines. U.S. Environmental Protection Agency, Contract No. 68-03-2465, EPA Preprint 460/3-78-007, August 1978, 250 pp.

This report describes a system of exhaust gas recirculation, modulated to reduce the NOx emission of a Mercedes 300D light duty diesel vehicle, to within defined limits of other parameters, such as HC and CO emissions, and performance loss, etc. To offset losses in performance due to the application of EGR a turbocharger was fitted to the vehicle to provide excess air. No extra fuel was supplied. A comprehensive test bed calibration of the engine was carried out in both N/A and T/C form with additional tests to establish the response of the turbocharged engine to injection retard. During these calibrations, steady state measurements of gaseous emissions, fuel consumption and exhaust smoke density were obtained and graphical presentations of brake specific emissions and fuel consumption developed. A system of controlled exhaust gas recirculation to the intake of the turbocharger compressor inlet was devised. The EGR flow rate was determined by the reduction of air flow from that of the standard engine. Calibration of the engine was carried out with manual control of EGR with curves plotted showing the response of the engine in respect of gaseous emissions, smoke and performance. At high levels of EGR the amount of fuel supplied to the engine had to be restricted in order to maintain inlet manifold temperatures and exhaust smoke within reasonable limits. From the curves produced from the EGR calibration, various hypothetical modulations of EGR were deduced from which variations in gaseous emissions, fuel consumption and exhaust smoke were tabulated. These tabulations were computed to provide synthesized vehicle results. A second type of EGR valve was developed allowing a method of matching some of the synthesized EGR modulations. This system consisted of a mechanical linkage to modify the lifting of a poppet type valve. The linkage was actuated by direct connection to the engine fuel pump control giving a load sensitive using exhaust pressure to modify the valve lift. Computations from test bed results obtained with various builds of this system indicated that the target constraints of the contract could be achieved. The engine was then re-installed in the Mercedes 300D vehicle complete with EGR system and tests carried out to verify the synthesized results obtained on the test bed. It was shown that 0.4 gpm NO_x could be achieved, at the expense of exceeding the legislated limits of HC and CO emissions, with the aid of modulated EGR and injection retard. 1.0 gpm NO_x was achieved with standard injection timing and less EGR, with HC and CO emissions within the legislated limits. At all levels of EGR particulate emissions were adversely affected, as were fuel economy, performance and drive-by noise.

Stumpp, G., and W. Banzhaf. An Exhaust Gas Recirculation System for Diesel Engines. Presented at the Congress and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780222, 16 pp.

Exhaust gas recirculation is an effective means to reduce NOx emissions of diesel engines. Unfortunately too high EGR rates increase the emissions of hydrocarbons, carbon monoxide and soot. So EGR has to be controlled precisely. The paper describes an EGR-system for diesel engines which

senses the air-flow and fuel-flow of the engine and limits the EGR-rate so, that the air-fuel-ratio is lean enough for a clean combustion. Furthermore, the paper shows the emission results which have been obtained with the described EGR-system on different diesel passenger cars.

Torpey, P. M., M. J. Whitehead, and M. Wright. Experiments in the Control of Diesel Emissions. See IV.A.

U.S. Department of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

U.S. Environmental Protection Agency. Emissions Control of Engine Systems. See IV.D.

Wilson, R. P., Jr., E. B. Muir, and F. A. Pellicciotti. Emissions Study of a Single-Cylinder Diesel Engine. See IV.E.

I. Fuel Injection Systems

Fleming, R. D., and T. R. French. Durability of Advanced Emission Controls for Heavy Duty Diesel and Gasoline Fueled Engines. See IV.D.

Fraenkle, G., and H. O. Hardenberg. New Methods for Reducing Visible Emissions of Diesel Engines. Presented at the 1975 SAE Off-Highway Vehicle Meeting, Milwaukee, Wis., Sept. 8-11, 1975, SAE Preprint 750772, 12 pp.

From engine test results, methods can be derived for reducing visible emissions of diesel engines, particularly under such operating conditions which so far are not yet subject to environment protection legislation. It is general practice today when starting diesel engines, to inject excess fuel, i.e., an additional amount of fuel in excess of the full load quantity, independent of ambient and engine temperatures and regardless of whether this is necessary or not. It is demonstrated that excess fuel should only be injected when starting a cold engine at ambient temperatures below freezing point and that the quantity of excess fuel should increase with falling temperature, reaching its maximum at the minimum engine starting temperature. The excess fuel quantity injected can be controlled with the aid of a wax element, so that, when the engine is warm, only the full load fuel quantity is injected. This eliminates the well-known cloud of black smoke emitted when starting a warm engine and considerably improves smoke emission when accelerating at low engine speeds. A burner starting aid of simple design and fully automatic operation is described, which has been newly developed and is used to suppress, or even to eliminate, the emission of white and blue smoke during cold start and warmup.

Gaal, S. L., J. P. Perr, G. L. Muntean, and H. L. Wilson. The PT-ECON: A New Injector Concept for the D.I. Diesel to Improve Smoke and Fuel Consumption at Low Emission Levels. Presented at the Diesel and Gas Engine Power Conf. and Exhibit, Chicago, Ill., April 4-8, 1976, ASME Preprint 76-DGP-13, 8 pp.

The paper describes a new open nozzle fuel injector for direct injection (D.I.) diesel engines. The injector improves smoke and fuel consumption on naturally aspirated engines. On turbocharged engines, fuel consumption is improved, especially at low emission levels: (a) desired injection characteristics are defined; (b) new injector concept is described; and (c) test results on naturally aspirated and turbocharged engines are presented. Capabilities of the new injector are discussed in the conclusion.

Grigg, H.C. The Role of Fuel Injection Equipment in Reducing 4-Stroke Diesel Engine Emissions. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760126, 16 pp.

A penetration is forecast of the diesel engine, in both direct and indirect form, into the medium and pick-up truck market in the U.S. and the light

truck, van and car market in Europe. This penetration, together with the advent of legislation in the field of gaseous emissions, smoke and noise, and the energy crisis, leads to the need for changes in diesel fuel injection equipment. The paper considers the technical requirements that arise in terms of engine and fuel injection equipment performance. Some developments that are in hand at the author's company to satisfy those requirements are described.

Holtz, J. C., L. B. Berger, M. A. Elliott, and H. H. Schrenk. Diesel Engines Underground. See VII.A.

Lombardi, C. Gaseous Emissions Control for Heavy Duty Diesel Engines. See IV.H.

Marshall, W. F. NO_x Emissions From Diesel Engines--Control and Measurement Techniques. See III.A.1.

Nakagawa, H., M. Tateishi, and M. Sekino. Application of Fuel Spray Theory to Exhaust Emission Control in a D.I. Diesel Engine. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760214, 17 pp.

Recently diesel engines are required to get not only high performance but also low pollution gas quality (oxides of nitrogen, carbon monoxide, unburned hydrocarbons and smoke). Our approach to this requirement is based on the fuel spray theory that good fuel-air mixing in the fuel spray developed into the quiescent air depends upon high kinetic energy of the spray motion. From the theoretical analysis of fuel spray motion in the quiescent air and the photographic study of the fuel spray combustion, it was found that higher rate of air entrainment into the fuel spray by its own kinetic energy gives a very important effect on the increasing of combustion efficiency in the diesel engine and the reduction of soot formation. So, we designed the high volumetric efficiency but low swirl generating intake port in order to charge sufficient air into the cylinder, and an imporved fuel injection system to attain high injection rate and high injection pressure so as to obtain high cycle efficiency and good fuel-air mixing in the quiescent air. As a result of many tests on this system using a single cylinder engine, a D.I. multi-cylinder diesel engine with high cycle efficiency and low smoke density was developed. The fuel injection timing of this engine is retarded to reduce the oxides of nitrogen in the exhaust gas. The fuel injector and fuel injection timing at light loads are improved to reduce the hydrocarbons in the exhaust gas.

Parker, R. F. Future Fuel Injection System Requirements of Diesel Engines for Mobil Power. See I.B.5.

Pozniak, D. J. Exhaust-Port Fuel Injection for Chemical Reduction of Nitric Oxide. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750173, 8 pp.

Nitric oxide can be chemically reduced in a vehicle exhaust system if hydrocarbons are supplied to high-temperature exhaust gas near the engine exhaust valves. Ethane was injected into the exhaust ports of engines equipped with either stainless steel or ceramic thermal reactors. Thermal decomposition of the ethane provided hydrogen and hydrocarbon radicals for the gas phase chemical reduction of nitric oxide formed in the engines. Although significant reductions of nitric oxide were achieved, severe spark retard was required to attain the elevated exhaust temperatures required to effect the nitric oxide reduction. Furthermore, carbon monoxide, hydrogen cyanide, and ammonia were formed, especially with the stainless-steel reactors. In view of these findings, this scheme for reducing nitric oxide emissions is not felt to be practicable for automotive application at this time.

Walder, C. J. Reduction of Emissions From Diesel Engines. See IV.B.

Wilson, R. P., Jr., E. B. Muir, and F. A. Pellicciotti. Emissions Study of a Single-Cylinder Diesel Engine. See IV.E.

Wing, R. D. The Rotary Fuel-Injection Pump as a Source of Cyclic Variation in Diesel Engines and Its Effect on Nitric Oxide Emissions. Proc. Inst. Mech. Engrs., v. 189, 50/75, 1975, 12 pp.

Cyclic combustion variations have been demonstrated to exist in a direct injection diesel engine to a surprisingly large extent. With the aid of an on-line computer engine-test facility statistical and correlation analyses were carried out to verify a strong relationship between the cyclic combustion variations and variations in the timing of fuel injection. The importance of these cyclic variations in the reduction of nitric oxide emissions from the engine is shown by experimental results and computer combustion model predictions. The overall effect on nitric oxide emissions is, however, small over most of the operating range of the engine.

J. Related Control Technology

1. Stationary source technology

Beecham, B., B. Fulton, and L. Broz. Investigation of Emerging Technology for Hydrocarbon and Particulate Emissions From Stationary Sources. Acurex Corp., Mountain View, Calif., Contract No. 68-01-4142, February 1979, 78 pp.; NTIS PB-294 467.

The objective of this project is to identify emerging control technologies that are or may become commercially available by 1985 for stationary hydrocarbon and particulate emissions sources. The report details a matrix of availability, and costs. Emphasis is on identifying control techniques more stringent than the LAER techniques previously defined for EPA's policy study of nonattainment areas. This study finds that: (1) for most ducted emissions from particulate sources fabric filters and electrostatic precipitators will remain the most advanced control filters and electrostatic precipitators will remain the most advanced control technology; (2) there are a range of hydrocarbon control techniques that offer the potential for reducing emissions through 1985 and beyond, the more important of these being the activated carbon and wet scrubbing control technologies. Contains tables, diagrams, and references.

Calvert, S. Engineering Design of Fine Particle Scrubbers. J. Air Pollution Control Assoc., v. 24, No. 10, October 1974, pp. 929-934.

A concise, quantitative picture of the state of the art of particle scrubbing is presented in the form of performance prediction methods. A new relationship between the particle diameter collected at 50 pct efficiency and scrubber pressure drop for several of the most common scrubber types is a design tool of great utility. Scrubber capability for the collection of submicron particles by diffusion is described in a graph for several scrubber types.

Calvert, S., J. Goldshmid, D. Leith, and D. Mehta. Wet Scrubber System Study: Volume II. Final Report and Bibliography. Contract No. CPA-70-95, July 1972, 171 pp.; NTIS PB-213 017.

A set scrubber system study was undertaken to achieve the following objectives: (1) evaluate current engineering technology; (2) evaluate existing scrubbers systems; (3) investigate present usage problems; (4) determine potential new applications; (5) develop specific research recommendations. The products of this study are: (1) Scrubber Handbook; (2) Final Report; (3) Bibliography; (4) R & D Plan. The Scrubber Handbook brings together previously scattered material and makes clear its applicability to scrubber use and present engineering design methods based on a unifying concept. Actual experience on hundreds of scrubber installations is presented in a condensed form. Many related topics such as auxiliaries, materials of construction, physical and chemical data, cost estimation and optimization techniques, and the disposal of liquid and solid wastes are all covered thoroughly in the Scrubber Handbook.

Calvert, S., I. L. Jashnani, and S. Yung. Entrainment Separators for Scrubbers. J. Air Pollution Control Assoc., v. 24, No. 10, October 1974, pp. 971-975.

Liquid entrainment separation was studied experimentally for packed bed, knitted mesh, zigzag baffle, tube bank, and cyclone type apparatus. Primary collection efficiency data compare well with theoretical predictions but reentrainment of the collected liquid did not agree with theoretical models. Separation efficiency, drop size, and pressure drop data are presented.

Calvert, S., N. C. Jhaveri, and S. Yung. Fine Particle Scrubber Performance Tests. A.P.T., Inc., Riverside, Calif., Contract No. 68-02-0285, October 1974, 270 pp.; NTIS PB-240 325.

The report gives the results of fine particle scrubber performance tests on industrial installations and the comparisons of experimental data with mathematical models. Particle size and concentration in the inlet and outlet scrubber gas streams were measured by means of cascade impactors and other apparatus. Tests were completed for a valve-type tray on a urea prilling tower, vaned centrifugal on a potash dryer, mobile bed on a coal-fired boiler, venturi on a coal-fired boiler, wetted fibrous filter on a salt dryer, impingement plate on a salt dryer, and venturi rod on a cupola. Performance is reported as particle penetration as a function of particle diameter. Mathematical models are satisfactory for all the scrubbers tested except the mobile bed. Information on costs, operating problems, maintenance, and other system characteristics are reported.

Calvert, S., S. C. Yung, H. Barbarika, and R. G. Patterson. Evaluation of Four Novel Fine Particulate Collection Devices. Air Pollution Tech., Inc. Contract No. 68-02-1496, March 1978, 105 pp.; NTIS PB-281 320.

The report gives results of an experimental performance evaluation of four novel fine particulate control devices: the Johns-Manville Cleanable High-Efficiency Air Filtration (CHEAF) System, the APS Electrostatic Scrubber, the AOS Electrotube, and the TRW Charged Droplet Scrubber. The evaluations included measurement of inlet and outlet particle size distribution and concentration with cascade impactor and diffusion battery. Fine particle collection efficiencies were computed from the data, as functions of particle size. Mathematical performance models were developed for the CHEAF system and the AOS scrubber. The models gave satisfactory predictions.

Cavagnaro, D. M. (ed.). Nitrogen Oxide Air Pollution. Part 1. Control Technology. v. 2, 1975-August 1978 (A Bibliography with Abstracts). National Technical Information Service, September 1978, 300 pp.; NTIS PS-78/0971.

Nitrogen oxide air pollution control is covered from both mobile and stationary sources. Fluidized bed combustion, boiler combustion modification, and engine design are discussed, as they relate to emissions reduction. (Contains 299 abstracts, 106 new entries to the previous edition).

Chemical Engineering. Charged Scrubber Snags Submicron Particles. May 9, 1977, pp. 107-108.

Emission particulates from diesel exhaust can be cleaned by using exhaust scrubbers. This article briefly explains the new Electro-Dynactor Electrified Wet Scrubber that ionizes the particulates before the water scrubber stage. By ionizing the particulates the scrubber is 96-98 pct efficient in the range of 0.1-0.8 μm particulate size.

Ctvrtnicek, T. E., T. F. Walburg, C. M. Moscowitz, and H. H. S. Yu. Application of Foam Scrubbing to Fine Particle Control, Phase I. Contract No. 68-02-1453, May 1976, 147 pp.; NTIS PB-261 075.

The report summarizes knowledge and data obtained during the first phase of investigations into foam scrubbing. It gives detailed information concerning foam scrubber theory, experimentation, and economics. The theory pertains to mechanisms influencing the behavior of fine particles and the possibilities of their capture by foam. Collection efficiencies obtained on a bench scale foam scrubber show that foam scrubbing can be a viable fine particle control device. Preliminary economic analysis indicates that foam scrubbing can be competitive with other fine particle collection devices if the surfactant solution is recycled effectively. The report recommends that surfactant recycle be verified, using a bench scale foam scrubber.

Drehmel, D. C. Fine Particle Control Technology: Conventional and Novel Devices. J. Air Pollution Control Assoc., v. 2, February 1977, pp. 138-140.

This report by the EOA briefly discusses ways to reduce diesel exhaust particles. The methods discussed are; Electrostatic Precipitators (ESP), Scrubbers, Fabric Filters, and Novel Devices. The method chosen depends on what particles must be collected and what percent must be collected. If the ash ressivity is 10^{10} ohm-cm, 90 pct collection of all sizes can be accomplished by using ESP. If space is available, fabric filtration provides greater than 95 pct collection. The article also compares 10 novel devices in percent collected and the particle size that can be collected.

Drehmel, D. C., C. H. Gooding, and G. B. Nichols. Particulate Control Highlights: Recent Developments in Japan. U.S. Environmental Protection Agency, Research Triangle Park, N.C., November 1979, 43 pp.; NTIS PB80-148802.

The report describes results of visits to Japan to assess research and development of new particulate control technology, and to evaluate the applicability of the Aut-Ainer particulate control device to diesel engines. New technology observed includes hooding systems for coke oven charging and pushing, fugitive emissions control in a Q-BOP furnace building, novel electrostatic precipitators (ESPs), magnetic separators,

and hybrid control devices. Fugitive emissions are well controlled in two iron and steel plants visited. Fugitive emissions are prevented by road watering and process hooding. Fugitives in a large building are collected by a special lightweight ESP. Novel ESPs utilize approaches such as wide plate spacing, advanced charging systems, and water-cooled collection electrodes. Magnetic separators are currently used for water pollution control and are under consideration for air pollution control. The Aut-Ainer device has evolved from an experimental approach to the device development stage over several years. The device currently has limited applicability to particulate control from diesel engines; however, its basic collection characteristics seem to be based on sound principles. With limited additional development in the general area of removing the previously collected material, the device appears promising.

Ewan, T. K. Recent Advances in Liquid Scrubbing for Fine Particulate Collection. J. Air Pollution Control Assoc., v. 27, No. 11, November 1977, pp. 1083-1085.

Lone Star Steel has developed a family of high performance, long life, low capital, and low operating cost Hydro-Sonic cleaers. A choice of driving mediums is available; either a compressible fluid ejector or fan may be used. The ejector models have no moving parts in the gas stream. Where available, waste heat may be used to power the cleaners. Cleaning levels are adjustable by the user by the selective input of energy. The Coalescer model employs a unique pressure recovery device for separation thereby reducing energy requirements for the cleaner. The Hydro-Sonic cleaners are operational in the steel, paper, and other industries.

Faulkner, M. G., E. B. Dismukes, J. R. McDonald, D. H. Pontius, and A. H. Dean. Assessment of Diesel Particulate Control: Filters, Scrubbers, and Precipitators. Southern Research Institute, Birmingham, Ala., Contract No. 68-02-2610, October 1979, 152 pp.; NTIS PB80-128655.

The report discusses an investigation of three types of devices that might be used for the aftertreatment of diesel exhaust to lower particulate emissions from light-duty vehicles. The devices are filters, electrostatic precipitators (ESPs), and wet scrubbers. The conclusions reached are that filters and ESPs merit further consideration, but wet scrubbers do not. Wet scrubbers were eliminated from further consideration on the basis of excessive size, low efficiency, and excessive fluid loss by evaporation (assuming that water is the fluid of choice). Filters and ESOs, although appearing to offer significant potential, have possible disadvantages that can only be assessed experimentally. Prototype filters and electrostatic devices that appear worthy of experimental study are described.

Frederick, E. R. Fibers, Electrostatics, and Filtration: A Review of New Technology. J. Air Pollution Control Assoc., v. 30, No. 4, April 1980, pp. 426-431.

This symposium sponsored by the Fiber Society and Filtration Society has

provided a clear indication that the "black-art" era of filtration has passed or is on its way out. The R & D efforts reviewed here by investigators from diverse disciplines provide evidence that these high efficiency particulate control devices can be made to function not only more consistently at high levels but now with even better control of the fine, health damaging particles. The outstanding improvement in every filtration parameter, reliably attainable by aerosol charging and/or by imposing an electric field on the filter, indicates clearly that fabric filtration has now reached an even higher plateau in particulate control technology.

Gibbons, R. A., and Dr. B. A. Wolf. Optimizing Diesel Combustion: Improving Fuel Economy, Engine Life, and Reducing Particulate and NO_x Emissions with Electrostatic Fluid Processors. Presented at the First Internat. Automotive Fuel Economy Res. Conf. of the U.S. Department of Transportation, Washington, D.C., Oct. 31, 1979, Technical Session 3, 12 pp.

Emissions legislation has adversely affected fuel economy of gasoline engines, and threatens similar effect upon diesel-powered vehicles. This would be unfortunate, for diesel automobiles can have a significant fuel conservation impact, improving fuel economies by as much as 100 pct over comparable gasoline engines in actual use-modes. Increasing application of diesel power to autos and light trucks has been somewhat inhibited by two related emissions concerns: speculative concern about health effects of components of diesel particulates, and technical difficulty of simultaneous achievement of proposed particulate and nitrogen oxides emission levels. This paper illustrates the positive potential of Electrostatic Fluid Processing systems (EFP) to substantially reduce both particulate and NO_x emissions without a fuel economy penalty, and, with added benefit of extending engine/component life. Also, as diesel fuels continue to deteriorate in quality, and as manufacturers are under pressure from emissions proposals to develop increasingly sensitive microprocessor-controlled fuel injection equipment and/or such wear-inducing techniques as exhaust-gas recirculation, the role of EFP is expected to asssume critical importance in diesel power applications.

Goel, K. C., and K. G. T. Hollands. Optimum Design of Venturi Scrubbers. Atmospheric Environment, Pergamon Press, v. 11, 1977, pp. 837-845.

Although venturi scrubbers are capable of removing submicron particles, they do this at the expense of a high pressure drop in the gas stream, with a coincident high fan operating cost. Designs of venturi scrubbers which for a given gas flow rate and particulate removal efficiency, have minimum pressure drop, may be called optimal. This paper considers design procedures for optimized design. On the basis of a straight duct model, the optimum combination of liquid flow rate and gas velocity at point of liquid injection is treated. Using this combination, and using a multi-duct analysis, the optimum distance upstream of throat where nozzles for injecting the scrubbing liquid should be located is treated. Optimized design charts, based on air-water systems and pneumatic atomization are presented. An important result of this treatment is the prediction of very low pressure drops if an atomization system giving the "optimum" droplet size is used.

Melcher, J. R., K. S. Sachar, and E. P. Warren. Overview of Electrostatic Devices for Control of Submicrometer Particles. Proceedings of the IEEE, v. 65, No. 12, December 1977, pp. 1659-1669.

The electrostatic precipitator (ESP) is the most widely used of a family of air pollution control devices that primarily exploit electrical forces in the control of particulate emissions. Others are the space-charge precipitator (SCP) (where the electric precipitation field is generated by the particles being collected), the self-agglomerator (SAG) (where oppositely charged particles are induced to agglomerate by the mutual force of attraction), the charged-droplet scrubber (CDS-I) (where drops charged to one polarity collect pollutant particles charged to the opposite polarity), charged-droplet scrubber (CDS-II) (where bipolar drops collect oppositely-charged fine pollutant particles), and charged-drop precipitators (CDP) (where fields generated by charged drops are used to precipitate like-charged fine particles onto electrodes). Using gas-residence time for effective cleaning as a dominant criterion, a broad overview of the relative merits of each of these systems in the control of submicrometer particles is given. Experiments illustrate the SCP and SAG modes. The CDS and CDP configurations are modeled and tested in experiments designed to isolate the relevant collection processes. The characteristic-time approach to interrelating diverse systems identifies the electrofluidized bed (EFB) as yet another configuration, one that is especially attractive for obtaining high efficiency with extremely short residence times.

Pilat, M. J., and D. F. Meyer. University of Washington Electrostatic Spray Scrubber Evaluation. Grant No. R-803278, April 1976, 66 pp.; NTIS PB-252 653.

The report gives results of an evaluation of the effectiveness of a 1700 cu m/hr (1,000 cfm) portable electrostatic spray scrubber in controlling fine particle emissions. The multiple-pass scrubber, designed, constructed, and tested by the University of Washington, combines oppositely charged aerosol particles and water droplets in two water spray towers. Negatively energized aerosol charging sections (coronas) precede each spray tower. The pilot plant was tested on artificially generated dioctyl phthalate (DOP) aerosol and on emissions from a pulverized coal-fired boiler. Collection of a 0.5 micron diameter DOP particle ranged from 10.0 to 99.8 pct. The 10 pct test was conducted with all high voltage sources inactive. The overall mass collection efficiency for the two COP tests was 24.98 pct and 99.6 pct, respectively. The boiler emission tests showed a collection efficiency for a 0.5 micron diameter particle ranging from 47.0 to 98.0 pct. Conditions during the 47.0 pct test included a low water spray rate. Because of the relatively large inlet size distribution, the overall mass collection efficiency decreased only from 99.58 to 96.09 pct for the two boiler emission tests.

Potter, E. C. Electrostatic Precipitation Technology: A Different Viewpoint. J. Air Pollution Control Assoc., v. 28, No. 1, January 1978, pp. 40-46.

This paper presents a viewpoint on electrostatic precipitation derived from Australian experience, particularly with fly ash collection from low sulfur coals. The customary expression of precipitability as an effective migration velocity calculated from the Deutsch equation is replaced by a performance line (or equation) obtained from a semi-logarithmic plot of collection efficiency against a combined function of specific collection area and operating voltage. The important effect of voltage, particle size, and carrier gas additives clearly emerge from the extended Deutsch equation, and the proper value of pilot plant testing is realized. Inclusion of particulate resistivity in the equation is straightforward, and an original calculation of loss of collection efficiency caused by high resistivities is presented. This hindrance is much less than generally thought, because the precipitator field reduces particulate resistivity by a long-known effect hitherto ignored in precipitation technology. The operational resistivity (i.e., with the precipitator working) has been measured and is often 100-1,000 times less than the so-called in situ resistivity observed at low applied field. Contrary to entrenched belief, the evidence is strongly against any general association of low sulfur in coal with poor fly ash precipitation.

Schaub, F. S., and K. V. Beightol. NO_x Emission Reduction Methods for Large Bore Diesel and Natural Gas Engine. See III.F.

Schoeck, V. E. In Mechanical Dust Collectors, It's the Fabric That Really Counts. Eng. and Min. J., January 1972, pp. 98-99.

Filters in the mining industry are used for reducing emissions and also to recover valuable ore dust. Therefore improving the present filter and designing new ones is important. This article briefly discusses the fabrics that have been used in filters since 1940 to the present. The article describes what each fabric is used for and gives the limitations of each fabric.

Schrag, M. P. (ed. by). Proceedings: Fine Particle Emissions Information System User Workshop. Midwest Research Institute, Contract No. 68-02-1324, Task 46, January 1977, 143 pp.; NTIS PB-263 468.

The proceedings document a User Workshop for the Fine Particle Emissions Information System (FPEIS), sponsored by EPA's Industrial Environmental Research Center, Research Triangle Park, NC. Purpose of the Workshop was to introduce the user community to FPEIS. FPEIS is a computerized information system on fine particle emissions from stationary sources and may contain source test data including particle size distribution; chemical, physical, and bioassay testing results; design and performance data on particle control systems; process descriptions; and descriptions of the sampling

equipment and techniques employed. The Proceedings contain the text of the Workshop presentations, as well as that of the discussion period following each presentation. The Workshop consisted of sessions on the background and purpose of FPEIS, the data base structure, the input data requirements, and the output formats.

Schrag, M. P., A. K. Rao, G. S. McMahon, and G. L. Johnson. Fine Particle Emissions Information System Reference Manual. Contract No. 68-02-1324, Task 47, June 1976, 50 pp.; NTIS PB-262 721.

The report is a basic reference manual on the Fine Particle Emissions Information System (FPEIS), a computerized data base on primary fine particle emissions to the atmosphere from stationary sources, designed to assist engineers and scientists engaged in fine particle control technology development. The FPEIS will contain source test data including particle size distributions; chemical, physical, and bioassay testing results performed on particulate samples; design and typical operating data on particle control systems applied; process descriptions of the sources; and descriptions of the sampling equipment and techniques employed. The FPEIS a successor to the MRI Fine Particle Inventory developed in 1971, report describes in detail the data types contained in the data base. It identifies and discusses the input data requirements and protocol. For reference, it includes a list of available information request procedures, and describes the general data base management system used to implement the FPEIS.

Shannon, L. J. Control Technology for Fine Particulate Emissions. Grant No. R-801615, May 1974, 211 pp.; NTIS PB-236 646.

The report gives results of a study to assess the state-of-the-art of control technology for fine particulates emitted from stationary sources. It emphasizes the analysis of control technology for primary particulates. The initial activity was a general review of collection and agglomeration mechanisms for particulates. Both theoretical and experimental facets were reviewed with attention on forces or collection mechanisms expected to be of importance for fine particles. The analysis of control technology for fine particulates centered on conventional control equipment, on emerging control technology, and on proposed or conceptual control systems.

Teller, A. J. A Fresh Look at the Technology of Particulate Removal Via Scrubbing. Eng. and Min. J., April 1971, pp. 81-82.

Using conventional scrubbers, as the particle size decreases the cost of collecting the particle increases. This article looks at a new cross flow nucleation scrubber that takes advantage of the excess free energy of the submicron particles. The excessive energy is reflected in a charge that results in a higher rate of condensation on that particle compared with the larger particles. Therefore the small particle acts like a larger one. Because of this the power consumption of the new scrubber is independent of

the particle size, therefore, the cost remains the same for collecting various size particles. The author also looks at the advantages and disadvantages of a new type of dry scrubber used for collecting solid particles.

Tesarek, H. Investigations Concerning the Employment Possibilities of the Diesel-Gas Process for Reducing Exhaust Emissions, Especially Soot (Particulate Matters). Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750158, 12 pp.

In an attempt to abate soot emissions, deisel fuel for a direct-injection, single-cylinder diesel engine was step-by-step replaced with natural gas. The gas was introduced into the intake system. As a result of this, soot emissions were decidedly improved and maximum power was increased. As an undesirable secondary effect, especially at small loads, there was unacceptable increase in brake specific gas-diesel fuel consumption and an increase in emission of harmful gaseous exhaust components. Exhaust gas recirculation and throttling were investigated as possible countermeasures. Both are capable of reducing the emission of poisonous gaseous exhaust components at high gas rates, without essentially increasing soot emission. Also, higher part-load consumption could be reduced by these countermeasures.

Walker, A. B. Principles of Collecting Particulates: Dry, Wet or Electrostatically. Eng. and Min. J., April 1971, pp. 83-91.

This article studies four distinct basic types of particulate collectors. They are, the cyclone which is a basic dry inertia collector, wet scrubbing which uses water to collect the particulates, fabric filters which uses various configurations of porous fabrics and electrostatic collectors which have a high efficiency rate of collection. The article has a section on each collector. Each section describes the system, how it collects the particles and the general situation where the collector is used. Each section also gives an approximate cost so a person can choose the correct system for his situation.

J. Related Control Technology

2. Aerospace technology

Burge, H. L., W. Krieve, R. Koppang, and M. Huberman. Commercial Applications of Rocket Technology: The Charged Droplet Scrubber. Presented at the Aerospace Eng. and Manufacturing Meeting, Americana Hotel, Los Angeles, Calif., Nov. 17-20, 1975, SAE Preprint 751097, 25 pp.

An electric propulsion research program funded by the Air Force has provided the technology basis for a new environmental control system called the Charged Droplet Scrubber. To date, the Charged Droplet Scrubber has demonstrated that it is a low-cost, highly effective method of removing particulates from industrial sources of gas pollutants. The Charged Droplet Scrubber was conceived during the early development of an electrostatic colloid thruster for low thrust propulsion of spacecraft. The thruster research program is managed by the Air Force Systems Command's Rocket Propulsion Laboratory and is conducted by TRW Systems Group. A joint venture company, with TRW and Mitsubishi Corp. as partners, is developing and commercializing the new scrubber device. The colloid thruster operates by accelerating charged droplets through an electrostatic field. These droplets leave the thruster at a very high velocity, thus providing the small amount of thrust required for certain spacecraft operations, such as stationkeeping. The operating principle of the scrubber is similar to that of the colloid thruster; the primary difference is that charged water droplets are used to impact and collect dust particles instead of being discharged to provide thrust. The water containing the trapped particles is collected for subsequent treatment. A comparison between the Charged Droplet Scrubber and the more conventional electrostatic precipitator, both operating at the same high collection efficiency, indicates that the new scrubber system requires less volume and lower first cost. Additionally, the power, and therefore the operating costs, are lower for the Charged Droplet Scrubber. The Charged Droplet Scrubber program has advanced from laboratory evaluation, through pilot scale evaluations, to a total of seven commercial installations. During laboratory tests, a number of tests and industrial dusts were evaluated in a program to develop design data to assess the commercial feasibility of the concept. Subsequently, eight pilot scale systems were fabricated and installed in asphalt plants, pulp and paper plants, electric utilities, and steel mills. The results of these pilot scale tests met all technical objectives. To date, seven commercial installations have been completed and are in operation.

Chalpin, E. S., R. E. Anderson, J. J. Shore, J. L. Smith, D. M. Jarsowski, and R. A. Hewitt. Research in Advanced Power Systems for Mining Health and Safety. See I.F.

Coal Age. How to Run a Shuttle Car on Diesel Power...Without Any Polluting Exhaust Fumes. v. 77, July 1972, p. 120.

This article briefly explains how a shuttle car equipped with a diesel

engine can recondition and recirculate its exhaust gas therefore emitting no pollutants to the atmosphere. The closed cycle diesel system (CCD) was developed by the Aerojet Liquid Rocket Co. The article also explains the advantages of the CCD system over an electric shuttle car.

Cooper, L. P. Effect of Degree of Fuel Vaporization Upon Emissions for a Premixed Prevaporized Combustion System. Presented at the AIAA/SAE/ASME 15th Joint Propulsion Conf., Las Vegas, Nev., Preprint No. 79-1320, June 18-20, 1979, 12 pp.

An experimental and analytical study of the combustion of "partially" vaporized fuel/air mixtures was performed to assess the impact of the degree of fuel vaporization upon emissions for a premixing-prevaporizing flametube combustor. Data collected in this study showed near linear increases in NO_x emissions with decreasing vaporization at equivalence ratios of 0.6. For equivalence ratios of 0.72, the degree of vaporization had very little impact on NO_x emissions. A simple mechanism which accounts for the combustion of liquid droplets in partially vaporized mixtures was found to agree with the measured results with fair accuracy with respect to both trends and magnitudes.

Daley, P.S., and D. A. Lundgren. Particle Collection by Water Injection in Test Cells. Civil and Environmental Engineering Development Office, Report No. CEEDO-TR-78-51, November 1978, 5 pp.

This report summarizes the mechanisms by which particles may be removed when water is injected into turbine engine test cell exhaust streams. The report concludes that impaction between soot particles and droplets is the most important mechanism and that there is an optimum flow rate at which water should be injected to assure maximum removal efficiency.

Macnaughton, M. G., J. J. Tarquinio, and J. A. Martone. Control of Particulate Emissions From Turbine Engine Test Cells by Cooling Water Injection. Eng. and Services Lab., Tyndall Air Force Base, Fla., ESL-TR-79-19, July 1979, 70 pp.

This study concentrated on determining the particle removal efficiency of the water spray by analysis of water sampler collected in the test cell that would normally drain from the test cell when a J75-P17 engine is being tested. Solids in the water were analyzed by the Environmental Sciences Branch of the Engineering and Services Laboratory (ESL) and independently by the Fine Particles Group of the IIT Research Institute (IITRI). IITRI also performed particle sizing and counting and provided photomicrographs of the particles. It can be concluded from this study that water injection as practiced at McClellan AFB test cell results in significant (50 wt-pct) control of turbine engine particulate emissions. It is postulated that the process could be made more efficient by the use of better designed spray

nozzles which would increase water droplet particle contact and inclusion of a demister to increase water removal from the exhaust. This is being studied in a separate project by the Engineering and Services Laboratory.

Mularz, E. J. Lean, Premixed, Prevaporized Combustion for Aircraft Gas Turbine Engines. Presented at the AIAA/SAE/ASME 15th Joint Propulsion Conf., Las Vegas, Nev., Preprint No. 79-1318, June 18-20, 1979, 12 pp.

The application of lean, premixed, prevaporized combustion to aircraft gas turbine engine systems can result in benefits in terms of superior combustion performance, improved combustor and turbine durability, and environmentally acceptable pollutant emissions. Lean, premixed prevaporized combustion is particularly attractive for reducing the oxides of nitrogen emissions during high altitude cruise. The NASA Stratospheric Cruise Emission Reduction Program will evolve and demonstrate lean, premixed, prevaporized combustion technology for aircraft engines. This multiphased program is described. In addition, the various elements of the Fundamental Studies Phase of the program are reviewed, and results to date of many of these studies are summarized.

National Aeronautics and Space Administration. Aircraft Engine Emissions. Presented at a Conference held at Lewis Research Center, Cleveland, Ohio, May 18-19, 1977, NASA Conference Publication 2021, 460 pp.

The Lewis Research Center is the National Aeronautics and Space Administration's principal field installation for research and development of advanced aerospace-propulsion and power-generating systems. As such, a substantial part of the Center's activities is devoted to progress in the technology of aircraft propulsion. This work includes such diverse areas as components, controls, energy efficient engine designs, and noise and pollution reduction. The results of this work are published in NASA reports and as articles in the technical journals. In addition, an occasional technical conference assists us in communicating more directly with others in the engineering field. Accordingly, this conference on aircraft engine emissions was held to present the results of recent and current work.

Olson, W. T. Making Aerospace Technology Work for the Automotive Industry--Introduction. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780072, 8 pp.

The paper introduces a session that reviews some NASA derived technology that may be useful in the automotive industry. Several examples in the paper illustrate aerospace technology already at work in that industry. Services offered by NASA to facilitate access to its technology are described.

J. Related Control Technology

3. Automotive industry technology

Brands, M. C., J. R. Werner, J. L. Hoehne, and S. Kramer. Vehicle Testing of Cummins Turbocompound Diesel Engine. Presented at the Internat. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 23-27, 1981, SAE Technical Paper Series 810073, 24 pp.

Two turbocompound diesel engines were assembled and dynamometer tested in preparation for vehicle tests. Both engines met the 1980 California gaseous emission requirement and achieved a minimum BSFC of 0.313 lb/bhp-hr and a BSFC at rated conditions of 0.323 lb/bhp-hr. These engines were then installed in Class VIII heavy-duty vehicles to determine the fuel consumption and performance characteristics. Fuel consumption testing showed a 14.8 pct improvement for the turbocompound engine in comparison to a production NTC-400 used as a baseline. The turbocompound engine also achieved lower noise levels, improved driveability, improved gradeability, and moderately increased engine retardation. The second turbocompound engine was placed in commercial service and accumulated 50,000 miles on a cross-country route without malfunction. Tank mileage revealed a 15.92 pct improvement over a production NTCC-400 which was operating on the same route. A number of component modifications were incorporated into the turbocompound engine which resulted in fuel consumption reductions which exceeded the expected benefit from turbocompounding alone. Previous laboratory testing showed a 6 pct reduction in fuel consumption for a turbocompound engine over an equivalent NH engine operating along the torque curve. Using these test results, the incremental fuel consumption improvement strictly due to the turbocompounding alone was estmated at 4.2 pct to 5.3 pct depending upon the terrain or mission load factor.

Cavagnaro, D. M. (ed. by). Diesel Exhaust Emission Control for Motor Vehicles (Citations From the Engineering Index Data Base). National Tech. Information Service, February 1978, 206 pp.; NTIS PS-78/0110.

Worldwide citations were selected that discuss the control of exhaust gases from diesel motor vehicle engines. Most of the studies are concerned with emission control through engine design, however, some studies also cover the use of fuel additives for pollution control.

Cavagnaro, D. M. (ed.by). Nitrogen Oxide Air Pollution, Part 1. See IV.J.1.

Cilibraise, G. A Practical Application of Microprocessors in the Automotive Environment. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780119, 12 pp.

The development of Ford Motor Company's microprocessor based electronic engine control has identified a number of fundamental issues and general observations regarding the application of microprocessors to the automotive environment in the areas of microprocessor selection, cost partitioning and design objectives.

Diesel and Gas Turbine Progress. Combined Charging. See I.F.

Emission Control Technology Division U.S. EPA. Automobile Emission Control --The Development Status, Trends and Outlook as of December 1976. Environmental Protection Agnecy, April 1977, 280 pp.; NTIS PB-267 865.

This report is sixth in a series of reports on automobile control technology and is based on information submitted to EPA from automobile manufacturers during the time period of December 1976 through February 1977. The report contains conclusions about emission standards and the years in which they could be implemented, the relationship between fuel economy and emission control, the potential differences in emission control technology at different emission levels, the possible impact of MMT, unregulated emissions of concern, the impact of a non-methane hydrocarbon standard, and the rate of progress in the emission control area. Significant development trends are highlighted in the following areas: 3-way catalysts; improved fuel metering; electronic controls; non-catalytic emission control technology; vehicle space requirements for emission controls; turbocharging; and diesel engine developments. A review of each manufacturer's emission control development efforts is included.

Faulkner, M. G., E. B. Dismukes, J. R. McDonald, D. H. Pontius, and A. H. Dean. Assessment of Diesel Particulate Control. See IV.J.1.

Freedman, M. D. Microprocessor Systems for On-Board Automotive Applications. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770002, 8 pp.

In examining the alternatives for a cost-effective system design for an on-board automotive microprocessor, standard and specialized architectures are examined as to their ability to perform basic control functions at low cost while retaining the ability for system expansion to handle additional control functions cost-effectively. In all cases, the real-time system requirements must be met despite the computational load on the microprocessor. A philosophy is presented so that the reader can gain an insight into the different possible design approaches.

Gast, R. A. Pulsair--A Method for Exhaust System Induction of Secondary Air for Emission Control. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750172, 15 pp.

The Pulsair concept utilizes inherent exhaust system pressure pulsations to induce secondary air into reciprocating engine exhaust ports for oxidation of unburned hydrocarbons and carbon monoxide. High-speed check valves are actuated by subambient exhaust pressures which arise from reflected exhaust "blowdown" pressure waves. For multicylinder engines, a single check valve set can be used effectively to supply air to an entire exhaust manifold. Experiments with V-8 engines and simple acoustic wave theory have been used to define system fundamentals and design techniques for obtaining high induced airflow rates at specified engine speeds. Procedures are outlined for adapting the concept to L-4, L-6, and V-6 engines. The Pulsair system does not affect net engine power and is potentially less complex than typical air pump systems. Sufficient air can be induced to meet the expected secondary air requirements for many exhaust aftertreatment systems; however, some modifications to conventional exhaust systems may be necessary. For example, Pulsair rates as high as 60 pct of engine airflow have been demonstrated by modifying the exhaust crossover of a V-8 engine.

Gibbons, E. F., A. H. Meitzler, L. R. Foote, P. J. Zacmanidis, and G. L. Beaudoin. Automotive Exhaust Sensors Uing Titania Ceramic. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 24-28, 1975, SAE Preprint 750224, 12 pp.

The resistivity of titania (TiO2) ceramic depends upon the partial pressure of oxygen in the atmosphere surrounding the ceramic. Because there is a functional relationship between the partial pressure of oxygen of the equilibrated exhaust gas and the air to fuel ratio (A/F) operating point of the internal combustion engine, the resistance of a TiO2 ceramic sensor, when temperature controlled, can be used to determine quantitatively the A/F. TiO2 sensors utilizing these principles have been built and found to work particularly well in the region rich of stoichiometry. Control of the A/F in the region rich of stoichiometry is desirable for engine/catalyst systems designed to meet low NO_x emission levels. This paper reports on the design

details and operating features of an experimental TiO_2 sensor and its associated electronic controller. In addition, experimental results are reported for the sensor/controller combination operating in engine dynamometer tests and on vehicles with feedback-controlled, electronic fuel injected engines. These results indicate that feedback control using the TiO_2 sensor represents a possible means of achieving the precision A/F control required to obtain efficient performance of vehicles using NO_x catalysts.

Holzhausen, G., F. J. Pekar, and A. F. Jeney. Integral Air-to-Air Intercooling: A New Way to Improve Fuel Economy, Gaseous Emissions, and Increase Output. Presented at the Diesel and Gas Engine Power Conference and Exhibit, Chicago, Ill., April 4-8, 1976, ASME Preprint 76-DGP-12, 12 pp.

Intercooling turbocharged diesel engines are utilized to increase the intake manifold air density. The use of air as the cooling medium results in the lowest possible charging temperatures. The particular air-to-air intercooler system described here employs a high effectiveness intercooler and a cooling air fan which is driven by bleed air from the turbocharger compressor through a partial admission impulse turbine located on the periphery of the fan. The integrated air-to-air intercooling system benefits are illustrated by comparing the performance of the same engine in turbocharged only form versus the integral air-to-air intercooling form. Actual engine data will show an increase in power of 27 pct, a decrease in gaseous emissions of over 40 pct, with a small increase in peak cylinder pressures and an improvement in fuel economy.

Howitt, J. S., and M. R. Montierth. Cellular Ceramic Diesel Particulate Filter. Presented at the Internat. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 23-27, 1981, SAE Preprint 810114, 9 pp.

An innovative design of ceramic filter for diesel engine exhaust particulate matter is described. It is a cellular ceramic honeycomb with porous walls which act as the filter medium. Test results relating the effects of wall thickness, cell density, porosity, and filter volume on collection efficiency, pressure drop and filter capacity are described. Regeneration of the filter by ignition of the accumulated soot has been accomplished with conclusions drawn about the influence of exhaust temperature, oxygen content, and the effect of the filter design.

Klockner-Humboldt-Deutz (Cologne, West Germany). Environmental Protection By Pollution Control Technology. Pub. No. W0156-1, October 1974, 25 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

The paper by Deutz first explains the emissions emitted by diesel engines and discusses their effect on the environment. Therefore, legislation has set up emission standards that must be met by diesel engine manufacturers. A section describing the Deutz air cooled engine and why it meets the emission standards is given. Finally a section covers sources of noise, noise reduction and noise attenuation.

Kotwicki, A. J., J. M. Farrell, N. W. Laursen, and J. E. Stevens. A Microprocessor Based Vehicular Engine Control System Testbed. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770009, 12 pp.

A microprocessor based vehicular engine control system testbed has been developed to make possible complex, interactive engine control experiments in the vehicle environment. Designed for flexibility, the onboard vehicle system incorporates two microprocessors, a variety of engine instrumentation, and controls over spark advance, air-fuel ratio, and exhaust gas recirculation. The two microprocessors have been linked to form an efficient computational network with sufficient capacity to implement most, if not all, engine control experiments. Also included in the vehicle are video displays which provide operator control and interaction with experimental engine control systems.

Kvamme, E. F., and J. R. Crowley. Microprocessors in the Automobile. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770004, 8 pp.

Engineers faced with the problem of designing automotive digital processors and control units with microprocessor chips must select from standard or custom designs. A new type of microprocessor which can be uniquely modified to tailor its performance to the specific needs of the automotive control system is presented. Examples of performance improvement are given for spark timing and dwell computations. Trade-offs in cost, performance, risk and development time for standard, modified standard and custom microprocessors are discussed. Various development approaches are reviewed and conclusions reached for future applications.

Nicholls, J. E., I. A. El-Messiri, and H. K. Newhall. Inlet Manifold Water Injection for Control of Nitrogen Oxides--Theory and Experiment. 1969, SAE Preprint 690018, 9 pp.

Parallel theoretical and experimental studies of the influence of inlet manifold water injection on nitric oxide emission from spark ignition engines have been performed. Theoretical analysis based on chemical equilibrium calculations indicates that the reduction of combustion temperature due to water injection at rates comparable to the engine fuel consumption rate is sufficient to yield significant reductions in nitric oxide emissions. Theoretical results further show that water injection may be accompanied by increased volumetric efficiency due to evaporative cooling of the inlet charge during induction. Experimental results obtained through modification of a CFR test engine confirm the predicted effectiveness of water injection on nitric oxide control. For a water injection rate 1-1/4 times the engine fuel consumption rate, nitric oxide reductions of over 90 pct were achieved. While no change was observed in volumetric efficiency with water injection, modest improvements in bmep and bsfc were observed.

Novis, G., and J. Bryant. Microprocessors Perform Engine Control Functions. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770005, 24 pp.

An overview of Digital Engine Controls is presented in light of the various phases required to develop an engine control microcomputer system. Topics include breadboarding techniques, vehicle mounted hardware, preproduction circuit sets, custom LSI circuit development and advanced integration. A brief review of depletion mode NMOS technology is presented along with details of a suitable family of 16 bit microprocessors, memories, and digital/analog input/output functions that can be implemented with LSI IC's to perform real time engine control. Finally, a development time table is presented which highlights program milestones in a two year development cycle.

Reddy, J. N. Application of Automotive Sensors to Engine Control. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780210, 12 pp.

This paper describes the application of automotive sensors to electronic control of the internal-combustion engine, with emphasis on sensor-signal characteristics and utilization. Manifold absolute pressure, crankshaft position, throttle position, temperature, and exhaust-gas recirculation are among the parameters monitored to electronically regulate engine inputs. Also presented are a number of control concepts realized with these sensors.

Roessler, W. U., A. Muraszew, and R. D. Kopa. Assessment of the Applicability of Automotive Emission Control Technology to Stationary Engines. Urban Programs Division, The Aerospace Corporation. Grant No. R-802270, July 1974, 364 pp.; NTIS PB 237 115.

The report gives a review of the emission characteristics of uncontrolled stationary diesel, spark ignition, and gas turbine engines, including an analysis and evaluation of the applicability of automotive emission control technology to stationary engines. Nitrogen oxides have been identified to be the principal pollutant species emitted from these engines. In principle, the emission control techniques developed or evaluated for spark ignition, diesel, and gas turbine engines are applicable to stationary engines. However, in most cases, the emission reductions achieved with these techniques are accompanied by sizeable losses in specific fuel consumption and uncertainties relative to the effect of these techniques on engine life and control system durability.

Sittig, M. Automotive Pollution Control Catalysts and Devices. Noyes Data Corp., Park Ridge, N.J., 1977, Pollution Technol. Rev., No. 37, 322 pp.

This publication supplies detailed technical information and serves as a guide to the U.S. patent literature in this field. The author provides a review of catalytic converter technology including topics in: general techniques, regeneration and recovery, catalyst compositions, systems and their components, and converter control devices. Indexes by subject, company, inventor, and patent number help in providing easy access to the information.

Society of Automotive Engineers, Inc. Inter Industry Emission Control: Program 2 (IIEC-2): Progress Report No. 1. January 1975, SAE Special Publications 395, 200 pp.

The Inter-Industry Emission Control Program (IIEC) was established in April, 1967 by Ford Motor Company and Mobil Oil Corporation as a cooperative effort to accelerate development of a virtually emission-free, gasoline powered vehicle by combining expertise from both the petroleum and automotive industries. The Program continued for nearly eleven years as an excellent and unique example of inter-industry and international cooperation in research. IIEC-1 Progress Report No. 1 contains seven papers that were published by SAE. The papers cover the topics on exhaust gas recirculation, trade offs between emission control and fuel economy, NO_x reduction catalyst development, fuels of methanol-gasoline blends, and combustion and emission characteristics of methanol.

Society of Automotive Engineers, Inc. Inter-Industry Emission Control: Program 2 (IIEC-2): Program Report No. 2. Presented at the 1976 SAE Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 23-27, 1976, SAE Special Publications 403, 80 pp.

This is a continuation of IIEC-2. This special publication contains eight papers on the topics of octane requirements of vehicles, performance of stratified charge vehicles, exhaust gas recirculation, catalytic converter development, three-way catalysts and exhaust gas sensors for air/fuel feedback control systems.

Society of Automotive Engineers, Inc. Inter-Industry Emission Control: Program 2 (IIEC-2): Progress Report No. 3. Presented at the Internat. Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 28-March 4, 1977, SAE Special Publications 414, 150 pp.

This is a continuation of IIEC-2. This special publication contains eight papers on the topics of effect of compression ratio on fuel economy and emissions, effect of engine variables on emissions, effect of combustion chamber design on emissions, evaluation of three-way catalysts and the formation and control of sulfuric and emissions over automotive catalysts.

Society of Automotive Engineers, Inc. Inter-Industry Emission Control Program 2 (IIEC-2): Progress Report No. 4. Presented at the Passenger Car Meeting, Troy Hilton, Troy, Mich., June 5-9, 1978, SAE Special Publications 431, 189 pp.

This is the last report of the IIEC-2 program. It contains 14 papers. The first paper gives an overview of the entire program. It explains the goals that were accomplished and all the companies that participated. The other papers presented cover the topics on optimizing fuel economy, PROCO stratified charge engine, octane requirements, three way catalysts, fuel volatility and the influence of fuel characteristics on vaporization in the S.I. engines.

Spedding, P. L., and A. J. Madden. Simple Device for Reduction of Pollution From Motor Vehicles. Environmental Science & Technology, v. 11, No. 4, April 1977, pp. 399-402.

A simple retrofit device is developed to reduce the exhaust emission from a spark ignition internal combustion engine, and complies with the U.S. Federal 1973 requirements and the current European maximum emission levels. The device aims at improving the vaporization and atomization of the air/fuel mixture fed to the engine by incorporating a second venturi and an air bleed under the existing carburetor. No fuel or power penalties are incurred; in fact, fuel savings and increased drivability are in evidence. Other benefits such as decoking of the engine and a reduction in wear accrue from the use of the device.

Springer, K. J. Investigation of Diesel-Powered Vehicle Emissions: VIII. Removal of Exhaust Particulate From Mercedes 300D Diesel Car. Southwest Research Institute, Contract No. 68-03-2116, June 1977, 200 pp. NTIS PB-274 554.

The objective of the project was to investigate the potentialities of reducing the particulate exhausted from diesel-powered passenger cars by the use of available lead trap technology. The particulate exhausted from diesels is one of several currently non-regulated emissions that is of concern, especially if the anticipated growth in diesel cars occurs. A system including front and rear agglomerator devices, packed with alumina coated steel wool, and an inertial separator, were mounted in place of the usual front resonator and rear muffler. When relatively new, the system was found to be effective on particulates and also reduced exhaust hydrocarbons, odor, smoke, benzo(a)pyrene, and sulfate, Acceleration performance suffered due to increased backpressure from the system. The life of the system is relatively short, less than 5,000 km.

Taylor, G. W. A Review of Automotive Emission Control Programs Around the World. Presented at the Internat. Fuels and Lubricants Meeting, Royal York, Toronto, Nov. 13-16, 1978, SAE Technical Paper Series 780950, 16 pp.

Emission control programs for automobiles have now been in existence for almost two decades in some jurisdictions. In addition, the approach to regulation and enforcement varies from country to country thus creating a large array of policy alternatives which can be evaluated. This paper attempts to review the strengths and weaknesses of the major control programs around the world and evaluate the costs and effectiveness of the existing standards in reducing emission levels. The data that form the basis for this paper are from an OECK report on the subject prepared by the author in 1977 and contain data from the ECE, Japanese, US, Canadian, Swedish and Australian automotive emission control programs. A method of comparing the major test standards is presented in order that the standards can be quantitatively and qualitatively related to each other.

Toelle, A. D. Microprocessor Control of the Automobile Engine. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770008, 12 pp.

This paper addresses the advantages and constraints associated with microprocessor control of the automotive engine. The advantages center around the power of the microprocessor to compute virtually any complex control law, and the ease with which it permits the development of new calibrations and new control laws. The constraints relate to the speed of computation and the fact that the digital concept provides input/output relationships in finite increments rather than as continuous functions. We examine here in some detail the functional power of a digital controller to manipulate these input/output relationships, whether in the form of closed-form mathematical expressions, polynomial-series approximations, or multi-dimensional tables for linear interpolation.

U.S. Environmental Protection Agency. Emissions Control of Engine Systems. See IV.D.

Wolber, W. G. A Worldwide Overview of Automotive Engine Control Sensor Technology. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Tech. Paper Series 780207, 24 pp.

The paper presents an overview of developments on the principal sensors applicable to automotive engine control through brief descriptions of the more important sensor concepts for the various parameters, and an indication of sensor status. The parameters covered are manifold absolute pressure (MAP), manifold vacuum (MV), ambient absolute pressure (AAP), crankshaft position (speed), mass air flow, fuel flow, coolant temperature, air temperature oxygen partial pressure, and throttle position. Special sections are included covering sensor developments overseas, and describing noteworthy efforts of the SAE and the International Standards Organization with respect to engine sensor standards.

Wolber, W. G. New Sensors for Automobile Engine Control. Instrumentation Tech., August 1978, pp. 47-53.

New sensors are nearing production for use in automotive engine control systems. The sensed parameters include absolute and differential pressure, contacting and noncontacting angle pickoffs, air and fuel flow, oxygen partial pressure and temperature. These sensors have moderate but long-term accuracy. Generally self-contained, they produce a high level output and can survive in a near military environment. Their mass production at low cost will produce major changes in the instrumentation industry.

K. Mine and Tunnel Ventilation

Adams, L. Diesels Built Highest, Longest Auto Tunnel. Diesel & Gas Turbine Progress, October 1973, 2 pp.

Colorado's Eisenhower Memorial Tunnel is the world's highest and longest U.S. vehicular land tunnel. The article briefly explains how diesel engines were used in the construction equipment. In order to keep air contamination to a minimum the engines used Oxy-Catalyst units installed below the muffler to purify the diesel exhaust and eliminate up to 95 pct carbon monoxide and up to 90 pct hydrocarbons. Another problem with the engines was engine deration. At 11,000 ft the engines were derated 33 pct. Therefore, the engines had to be turbocharged to obtain their original power. The rest of the article briefly explains the specific equipment used.

American Conference of Governmental Industrial Hygienists. Ventilation System Testing From Industrial Ventilation: A Manual of Recommended Practice. Committee on Industrial Ventilation, Lansing, Mich., 23 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

Every air handling system should be thoroughly tested upon completion and before acceptance by the customer. Periodic tests should also be made throughout the life of the system to insure continuing performance. The tests described in this manual pertain to air handling systems only. At this time it may be necessary or desirable to conduct tests of the environment to determine whether the system is providing the desired environmental control. In these cases the services of a trained industrial hygienist may be required. The value of obtaining ventilation test data is noted in the following applications: (1) to record the initial performance of the system and determine if it is functioning in accordance with specifications; (2) to determine the degree of compliance with applicable codes or trade association standards; (3) to provide data upon which to base any necessary changes in the system; (4) to obtain data to assist in the design of future systems; (5) to determine whether the system has sufficient capacity for additional ductwork or other alterations; (6) to obtain data through periodic checks to determine when maintenance or repairs are necessary.

BHRA Fluid Engineering. International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels: Review/Introductory Paper--Design of Ventilation Systems for Road Tunnels. Cranfield, Bedford, England, April 10-12, 1973, Paper A1, pp. A1-1--A1-6.

The paper describes the factors to be considered in designing the ventilation system for a road tunnel. The primary decision to be taken is the rate of air supply necessary to dilute to a safe level the pollutants discharged by vehicle engines. The major pollutant to be considered is carbon monoxide from petrol engines, but smoke from heavy diesel engined

vehicles is of increasing importance. The principal systems--longitudinal, transverse, and semi-transverse--are analysed, followed by description of structural problems and energy considerations. The very high cost of providing large volumes of air through long ducts of small cross-section is emphasized. The factors determining type of fans and their size and number are examined with brief reference to the capital costs of the ventilation system as a whole. Control of fans must be such as to effect economical operation in accord with traffic requirements and to cope with emergencies. Different types and situations of tunnels are briefly described in relation to their ventilation problems.

BHRA Fluid Engineering. International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels: Research into the Control of Vehicular Tunnel Ventilation Systems. Cranfield, Bedford, England, April 10-12, 1973, Paper B2, pp. B2-17--B2-32.

The paper describes the research work being carried out in the Department of Civil and Structural Engineering, University of Sheffield, in connection with the economics of vehicular tunnel ventilation and the automatic control of tunnel systems. The extent of the problem is discussed first followed by a description of suitable methods of analysis of the pollutants discharged from the exhausts of the petrol and diesel engined vehicles. Recent developments in the analysis of both carbon monoxide and nitrogen oxides are described and the problems of obscuration caused by the smoke from the exhausts are discussed. The paper then deals with data logging experiments which have been carried out in the Blackwall and Second Mersey (Kingsway) tunnels and an attempt has been made to correlate the observed data. The final section discusses a mathematical model of tunnel ventilation and shows how this can be used to determine pollutant profiles, to study the dynamics of the systems and to assist in the choice of the best measuring points. The conclusions indicate the savings in cost which can be obtained by a judicious use of the fan speeds combined with an increase in the maximum allowable concentrations of the pollutants.

BHRA Fluid Engineering. International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels: Research for Optimal Ventilation at the Holland and Lincoln Tunnels. Cranfield, Bedford, England, April 10-12, 1973, Paper B3, pp. B3-33--B3-54.

Over the nearly fifty years since the Holland Tunnel opened and demonstrated the feasibility of ventilating long subaqueous tunnels for highway traffic, numerous changes affecting tunnel ventilation have occurred. This paper reviews the main recent efforts by the Port Authority to assure that ventilation equipment and procedures remain effective and appropriate. After describing briefly the major features of the ventilation system for the Holland and Lincoln Tunnels, and the major changes which have affected ventilation at these tunnels since the Holland Tunnel opened in 1927, the paper summarizes research to influence four principal elements of the ventilation system: emissions; measures; standards; and dilution of pollutants. Control of traffic flow has been found most effective to influence vehicle emissions, and the tunnels are

now equipped with automatic traffic control systems which furnish an important base for automating ventilation control. Research to influence the process of measuring tunnel air contaminants includes both a comprehensive review of tunnel exhaust constitutents, and testing of new sensing equipment. Research to influence standards used in ventilating the tunnels includes establishment of comfort level analogs, and a comprehensive study of the relation between employee health and work assignments. To influence the dilution of pollutants, research has been conducted on the aerodynamic efficiency of the tunnel ventilation system, as well as on the ability to operate the tunnels in event of complete power failure. Building on this research work is under way now to automate control of the tunnel ventilation and utility systems.

BHRA Fluid Engineering. International Symposium on the Aerodynamics and Ventilation of Vehicle Tunnels: Study on Semi-Transverse Ventilation of Automobile Tunnels. Cranfield, Bedford, England, April 10-12, 1973, Paper E1, pp. E1-1--E1-19.

Although semi-transverse ventilation with a fresh air duct has the advantages of reliable dilution of exhaust gas, low investment and operating costs etc., this method creates, in some cases, environmental pollution problems near the exit portal caused by the jet-like stream of vitiatied air from the portal. In order to find a ventilating system which can assure the necessary traffic safety in the tunnel with the least impact on the environment outside the tunnel, the operation of four types of semi-transverse ventilation applied to a uni-directional tunnel was compared, that is, semi-transverse with a full length on the entrance and exit side, and with fresh and vitiated air ducts of half length in the reverse arrangement. Distributions of pollutant concentration were calculated theoretically at various combinations of operational parameters for each of the four variations. Using a uni-directional tunnel in actual service, measurements were also made on the distribution of longitudinal velocity and opacity in the tunnel when ventilated by each of the four variations. The experimental results were compared with the corresponding calculations. Semi-transverse ventilation with partial or full length vitiated air duct presents the possibility that an exhaust neutral point will emerge in the tunnel under certain traffic conditions. To cope with this difficulty, the fluctuation of the neutral point was examined by studying the statistical nature of the self-ventilating action of the traffic.

Burrows, J. H., J. R. Hemp, F. H. Lancaster, and J. H. Quilliam. The Ventilation of South African Gold Mines. The Mine Ventilation Society of South Africa, 1974, 485 pp.

Despite the advantages of low geothermal gradient and a temperature climate, South African gold mines are faced with considerable ventilation problems. These arise primarily because of the depth of the mines and the necessity for using water for dust suppression purposes; methane is also found on some mines, and siliceous dust is a problem in all the mines. Very few textbooks have been published dealing with mine ventilation

therefore, the Mine Ventilation Society decided to produce a textbook. Sixteen authors have been responsible for twenty-one chapters in the book, and all are experts in their respective fields. The book is based on the fundamentals and will not date with the years.

Canadian Mining Journal. Concerns in Modern Ventilation Design and Practice--Part 1. July 1978, pp. 28-34.

Canadian Mining Journal and TLT-Babcock Inc. jointly sponsored a roundtable discussion among leading ventilation engineers on modern mine ventilation and practice and how the introduction of axial flow fan technology can help solve these problems. The discussion is presented in two parts: Part One, in this issue, deals with ventilation design methods, effects of temperature, resistance factors and effects of diesel exhausts. Part Two will be presented in the August issue.

Divers, E. F. Guidelines for the Selection and Use of In-Mine Dust Collectors. Coal Age, November 1976, pp. 105-108.

Scrubbers are generally accepted as one approach for controlling dust in coal mines. This article explains 3 ways of evaluating the efficiency of a scrubber, they are the gross gravimetric method, gravimetric respirable size method and the fractional breakdown method. The author describes the design and application of four scrubbers. They are: (1) the wetted fan scrubber; (2) the venturi scrubber; (3) the small-diameter cyclone type scrubber; and (4) the wetted fiberous-bed type scrubber.

Fermor, R. B. A Study of the Factors Present in Planning the Ventilation Needs of Diesel Vehicles in Operating Mines in Quebec. Can. Inst. Min. Bull., February 1977, pp. 55-61.

Attention is drawn to the ventilation problems arising from the use of diesel vehicles underground, especially in view of the fact that diesel fumes in combination with other pollutants may be more harmful than diesel fumes alone or the other pollutants alone. Means for minimizing the harmful effects of using diesels underground are listed, and the quantities of air required in mines in which diesel-powered vehicles are used are discussed. Mines are classified in three categories on the basis of severity of ventilation problems, and statistics are given for these categories. Details of the various components contributing to total ventilation needs are given, and the ventilation needs of individual mines in the three categories are listed. A description is given of the principles according to which main ventilation coursing is planned and the selection and siting of main fans is discussed.

Gilbert, S. The Use of Diesel Engines Underground in British Coal Mines. See VIII.J.

Harrington, D., and J. H. East, Jr. Diesel Equipment in Underground Mining. See VII.A.

Hoskins, J. R., and C. E. Gregory. Development of Improved Ventilation Technology for Non-Coal Mines and Other Underground Excavations. Univ. Idaho Bureau of Min. Res., BuMines Contract No. G0101300, November 1971, Open File Report 3-72, 70 pp.

This is the final report by the University of Idaho Mining Research Bureau on mine ventilation. The researchers visited 29 non-coal mines and wrote a report that deals with the present conditions of vein-type multi-level mine ventilation technology, in respect to practices, equipment, planning and needs. This report contains conclusions and recommendations to guide future programs of research to up-grade operational programs technology.

Janelid, I. Ventilation of Diesel Exhaust in Drifts and Tunnels. J. Mine Ventilation Society of South Africa, v. 29, No. 5, May 1976, pp. 89-93.

Normally drifts and tunnels are ventilated by blowing fresh air through a duct, but because of blasting this duct can't be located to the face otherwise damage will result during blasting. The method described here consists of a ventilating device mounted on the mobile machine itself. The principal of operation is to supply fresh air close to the floor and a fan on the vehicle pulls air past the engine and heats up the air. The air rises and leaves the mine close to the ceiling. The concentration of NO_x at the driver seat is given for several ventilating designs.

Johnson, J. H., E. O. Reinbold, and D. H. Carlson. The Engineering Control of Diesel Pollutants in Underground Mining. See IV.L.

Journal of the Mine Ventilation Society of South Africa. Presidential Address: Occupational Health and Safety in Underground Mines. v. 29, No. 1, January 1976, pp. 1-29.

Three occupational hazards are identified as being common to all underground mines, viz. atmospheric aberrations, collapse of workings, and inrushes. After tracing the histories of some representative hazards in specific mining fields it is suggested that greater use should be made of probabilistic risk of injury as the principal criterion for design and control purposes for all three hazards. Factors which might be used to determine the social acceptability of occupational risks are examined along with the employer's duty of care. Finally the U.S. Federal Coal Mine Health and Safety Act of 1969 is discussed because of the important role it is likely to play in mine health and safety in other mining jurisdictions for the rest of this century.

Le Roux, W. L. Mine Ventilation Notes for Beginners. The Mine Ventilation Society of South Africa, 3rd ed., 1979, 213 pp.

The purpose of this book is not to teach a beginner how to do his daily work or to prepare him for any particular examination. The intention is rather to explain in a systematic way most of the basic facts and principles involved in the science of mine ventilation, with a view to stimulating constructive thinking and its application to routine observations. More specifically the purpose of this book is to lay a sound foundation of basic knowledge upon which a student can build by reading more advanced text-books and technical articles. The basic principles have been stated as simply and clearly as possible and even commonly known scientific and technical expressions are explained when they are used for the first time. Where comparatively advanced subjects are dealt with in a few cases, they are explained by means of basic principles in order to show that most of the problems encountered can be solved without a knowledge of higher mathematics. The author hopes that this book will assist readers in their endeavours to provide safe, healthy and congenial underground working conditions as economically as possible.

National Coal Board, Mining Department. Control of Harmful Dust in Coal Mines. London, 1973, 85 pp.

The issue of this handbook comes at a time when in all walks of life we are being made more and more aware of the importance of the environment. Dust control in coal mines poses problems to management and men as dust is created at many points and in a variety of circumstances during most mining operations. The book is an indication of the valuable and constructive study which has been and is still being devoted to the problems of dust prevention and control. Years of continuous research, development, investigation and experience have produced a number of techniques and a variety of equipment which can be applied to limit and control the production of dust.

Sadik, W. A., and E. B. Jensen. Air Quality Control in Diesel Equipment Operations at the Henderson Mines. See VII. A.

Stefanko, R., R. V. Ramani, P. C. Thakur. Digital Simulation of Diesel Exhaust Contamination of Mine Ventilation Systems. Penn. State Univ., BuMines Contract No. G0133064, Sept. 15, 1974, Open File Report 90-75, 246 pp.; NTIS PB-246 299.

This study concerns itself with the effects of diesel exhaust on mine ventilation systems. The approach here consisted of development of mathematical models for emissions, dilution, and dispersion of gaseous pollutants from diesels. The general scheme was to use partial differential equations to predict concentration growths. Five typical situations involving diesel engines in underground mines were modeled. The models were then programmed for computer solution. The diesel emission and

dilution models were incorporated into a ventilation network program for analyzing exhaust concentrations in all the roadways. The report describes in detail the procedure, mathematical model of exhaust dispersion, computer programs and draws several conclusions.

Stewart D. B., J. P. Mogan, and E. D. Dainty. Diesel Emissions and Mine Ventilations. See III.F.

L. Effectiveness of Emission Controls

Anderson, D. N. Effect of Inlet Temperature on the Performance of a Catalytic Reactor. Presented at the Third Workshop on Catalytic Combustion, Asheville, N.C., Oct. 3-4, 1978, Report No. NASA TM-78977, 20 pp.; NTIS N78-31534.

A 12-cm diameter by 15-cm long catalytic reactor was tested with No. 2 diesel fuel in a combustion test rig at inlet temperatures of 700, 800, 900, and 1,000 K. Other test conditions included pressures of 3 and 6 x 10^5 Pa, reference velocities of 10, 15, and 20 m/s, and adiabatic combustion temperatures in the range of 1,100 to 1,400 K. The combustion efficiency was calculated from measurements of carbon monoxide and unburned hydrocarbon emissions. Nitrogen oxide emissions and reactor pressure drop were also measured. At a reference velocity of 10 m/s, the CO and unburned hydrocarbons emissions, and, therefore, the combustion efficiency, were independent of inlet temperature. At an inlet temperature of 1,000 K, they were independent of reference velocity. Nitrogen oxides emissions resulted from conversion of the small amount (135 ppm) of fuel-bound nitrogen in the fuel. Up to 90 pct conversion was observed with no apparent effect of any of the test variables. For typical gas turbine operating conditions, all three pollutants were below levels which would permit the most stringent proposed automotive emissions standards to be met. The pressure drop increased linearly with reference velocity and decreased slightly as the inlet temperature was raised. Pressure drop increased linearly with velocity to a maximum value of 1.5 pct at a reference velocity of 20 m/s.

Anderson, D. N. Performance and Emissions of a Catalytic Reactor With Propane, and Jet A Fuels. September 1977, 24 pp.; NTIS N78-14177.

As part of the ERDA-funded Gas Turbine Highway Vehicle Systems project, tests were made to determine the performance and emissions of a catalytic reactor operated with propane, No. 2 diesel, and Jet A fuels. A 12-cm diameter and 16-cm long catalytic reactor using a proprietary noble metal catalyst was operated at an inlet temperature of 800 K, a pressure of 3/10^5 Pa and reference velocities of 10 to 15 m/s. No significant differences between the performance of the three fuels were observed when 98.5 pct purity propane was used. The combustion efficiency for 99.8 pct purity propane tested later was significantly lower, however. The diesel fuel contained 135 ppm of bound nitrogen and consequently produced the highest NO_x emissions of the three fuels. As much as 85 pct of the bound nitrogen was converted to NO_x. Steady-state emissions goals based on half the most stringent proposed automotive standards were met when the reactor was operated at an adiabatic combustion temperature higher than 1,350 K with all fuels except the 99.8 pct purity propane. With that fuel, a minimum temperature of 1,480 K was required.

Barth, E. A. Investigation of the Effects of the Installation of an Oxidation Catalyst on a Diesel Powered Vehicle. See IV.D.

Bastress, E. K., K. M. Chng, D. M. Dix, and R. J. Murad. Control of Nitrogen Oxide Emissions From Diesel Engines: A Theoretical Analysis. 1971, 106 pp.; NTIS PB206 005.

The objective was to correlate engine design, performance, and emission characteristics by theoretical analysis, and to develop NO_x-control criteria. Mathematical models of combustion and NO formation in diesel engines were developed; engine design, performance, and emission characteristics were correlated; and methods for controlling NO emissions were identified and evaluated. In direct-injection engines, NO emission rate is found to vary monotonically with fuel injection time, injection rate, and over-all fuel-air ratio. These design variables also affect engine performance factors including specific fuel consumption, specific power, peak pressure, pressure rise rate, and smoke emission. Qualitative guidelines have been defined for reducing NO emissions by manipulation of these design variables while minimizing the associated penalties in engine performance. The tendency for indirect-injection engines to produce lower NO emissions than direct-injection engines has been confirmed by the model. However, this effect is strongly influenced by the fuel injection pattern of the IDI engine. If a significant fraction of the injected fuel passes directly into the main chamber, the advantage of the prechamber in reducing NO emissions is reduced. The direct-injection engine model has been used to evaluate turbocharging, pilot injection, and fumigation as methods for reducing NO emissions. Of the approaches considered, only fumigation was found to decrease NO emissions.

Bird, A. N., Jr., J. D. McCain, and D. B. Harris. Particulate Sizing Techniques for Control Device Evaluation. See III.A.2.

Cushing, K. M., G. E. Lacey, J. D. McCain, and W. B. Smith. Particulate Sizing Techniques for Control Device Evaluation. See III.A.2.

Davis, R. F., and M. A. Elliott. The Removal of Aldehydes From Diesel Exhaust Gas. See IV.C.

Eley, N. G. Evaluation of the Existing Designs and Shortcomings of Flameproof Exhaust Systems of Diesel Engines Used in Underground Coal Mines. Department of Mech. Eng., Univ. of British Columbia, Vancouver, B.C., 125 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

This paper reviews the flameproofing exhaust systems currently available

for use on underground coal mining equipment. The shortcomings are evaluated as related to regulations, current research, and use in the underground coal mining operations. A design proposal is presented in the light of recent research and mining experience with the expectation of building a prototype model in the future.

Fleming, R. D., and T. R. French. Durability of Advanced Emission Controls for Heavy Duty Diesel and Gasoline Fueled Engines. See IV.D.

Freedman, R. W., W. H. Duerr, and C. D. Litton. Construction and Preliminary Evaluation of a Diesel Exhaust Particulate Filter for Underground Use. BuMines TPR 106, March 1979, 10 pp.

In the Bureau of Mines study, a filter with a 20 x 20 square inch cross section was inserted into the exhaust ducting of a 4-stroke cycle, 90 hp diesel engine, and the efficiency of removal of total particulate was measured gravimetrically as a function of time. Removal efficiencies were close to 90 pct during the main portion of several extended runs employing several combinations of filter beds. Variations in engine load had little effect on collection efficiency. Particle size as measured by a Bureau developed online instrument centered on 0.07 μm based on number count. Removal efficiency increased rather sharply for both larger and smaller particles.

Gaal, S. L., J. P. Perr, G. L. Muntean, and H. L. Wilson. The PT-ECON--A New Injector Concept for the D.I. Diesel to Improve Smoke and Fuel Consumption at Low Emission Levels. See IV.I.

General Motors Corporation. Status Report: Diesel Particulate Emission Control Technology, NHTSA Diesel Particulate Emission Workshop, Washington, D.C., April 27-28, 1978, 35 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

With the increasing concern for energy conservation, the potential for increased usage of diesel engines in a wide variety of transportation usage is becoming more apparent. In concert with these opportunities, GM is tentatively planning to use diesel engines extensively in passenger cars and light duty trucks and has therefore intensified its on-going programs to investigate control of particulate emissions, among others. This report describes the status of the diesel particulate control technology program as it stands today.

Gentel, J. E., O. J. Manary, and J. C. Valenta. Characterization of Particulate and Other Non-Regulated Emissions from Mobile Sources and the Effects of Exhaust Emissions Control Devices on These Emissions. See III.A.2.

Harrington, D., and J. H. East, Jr. Diesel Equipment in Underground Mining. See VII.A.

Johnson, J. H., E. O. Reinbold, and D. H. Carlson. The Engineering Control of Diesel Pollutants in Underground Mining. Presented at the Earthmoving Industry Conf., Peoria, Ill., April 6-8, 1981, SAE Preprint 810684, 48 pp.

A review of mine air pollutant standards and the important pollutants to control in underground mines using diesel powered equipment is presented. The underground Mine Air Quality Laboratory instrumentation is discussed. This includes the Mine Air Monitoring Laboratory (MAML) and the instrumented Load Haul Dump (LHD) vehicle. The MAML measures CO, NO2, NO, CO2, particulate and temperatures while the LHD instrumentation measures and records engine speed, rack position (fuel rate), vehicle speed, CO2 concentration, exhaust temperature and operating mode with transducers and a Sea Data Corporation data logging and reader system. The mine LHD cycle data are related to the EPA 13 mode cycle data. Engine and aftertreatment emission control methods are reviewed including recent laboratory NO, NO2, sulfate and particulate data for a monolith catalyst. Maintenance of the LHD vehicle by engine subsystems in relation to component effects on emissions is presented. The design of a tailpipe Emissions Measurement Appartus (EMA) for underground exhaust measurements of CO, CO2, NO, NO2, and particulate under loaded conditions is discussed including the method of loading the engine. Emissions data for several vehicles in two underground mines are given. The EMA is envisioned as a quality control measurement method to assist mine maintenance personnel in maintaining low emissions vehicles. CO and CO2 data from the MAQL are presented for several ventilation control methods: a fan, a fan with vent tubing, fume Diluters and two exhaust system designs. The modified exhaust system involved a rearward directed exhaust system pointed at a 20-30° angle towards the roof. This system was shown to enhance the natural ventilation in that the cool mine air flowed into the drift at the bottom of the drift and the diluted exhaust gases flowed out of the drift at the top. The modified system was shown to reduce pollutant concentrations by 50 pct over the standard system which was directed out the side of the vehicle at the floor level.

Lee, R. E., Jr., and F. V. Duffield. EPA's Catalyst Research Program. See IV.D.

Marshall, W. F. NO_x Emissions From Diesel Engines--Control and Measurement Techniques. See III.A.1.

Mertens, Hans, Dr.-Ing., and Dipl.-Ing. Hans-Georg Schlitt. Exhaust Behaviour on Diesel Engines Where Intake Air Contains Methane. See IV.D.

Miles, D.L., and M. F. Homfeld. The Effect of Ambient Temperature on Exhaust Emissions of Cars With Experimental Emission Controls. Presented at the Automobile Eng. Meeting, Toronto, Can., Oct. 21-25, 1974, SAE Preprint 741052, 19 pp.

Three production cars and seven cars with various experimental exhaust emission control systems were tested to determine the effect of winter weather ambient temperatures on exhaust emissions. All of the cars were tested at 70, 40, and $20^{o}F$, and one was tested at $0^{o}F$ using the 1972 EPA test schedule. Modal and bag emission data as well as catalytic converter temperature data were obtained. The results of these tests are presented in this paper. There was an increase in HC and CO emissions as ambient temperature was reduced. Most of the increase came from the first cycle of the 18 cycle test and was the result of additional time required to reach operating temperatures. NO_x emissions did not vary substantially with ambient temperature.

Mining Engineering. Diesel Power Underground-Productivity Potential Sparks Health Controversy. April 1979, pp. 370-375.

The U.S. lags behind other nations in using diesel powered equipment in coal mines. This is because people think the diesels are more dangerous than electric vehicles and that the exhaust emissions will cause a long term health effect on the operators. The article studies the health hazards of diesel exhaust, and no long term health effects were found. The diesel equipment in terms of safety, economy, and flexibility which translates into increased productivity.

Mogan, J. P., and E. D. Dainty. Emission Control Performance of Diesel Exhaust Treatment Devices. Canada Center for Mineral and Energy Technology. Presented at the American Conference of Governmental and Industrial Hygienists Symposium, Denver, Colo., Nov. 6-7, 1978, Report No. MRP/MRL 78-69, 27 pp.

The performance of state-of-the-art emission control devices was determined for the five commonly measured exhaust pollutants: soot, hydrocarbons, carbon monoxide, oxides of nitrogen, and sulphur oxides. Efficiencies varied from 90 pct to zero. The performance of the devices has been expressed in terms of a combined "health effects index" which can be useful in the selection of emission improvement strategies.

Musser, G. S., J. A. Wilson, R. G. Hyland, and H. A. Ashby. Effectiveness of Exhaust Gas Recirculation With Extended Use. Presented at the Automotive Eng. Cong., Detroit, Mich., Jan. 11-15, 1971, SAE Preprint 710013, 32 pp.

Exhaust gas recirculation (EGR) was found to be an effective means of reducing automotive NO_x levels with no major unsolvable problems over 52,000 miles under city/suburban driving conditions. Compatible with air injection and engine modification systems for HC and CO control, EGR effectively reduced the NO_x levels with no decrease in reduction over the 52,000 miles. Engine wear and engine cleanliness with EGR was normal for the mileage and driving regime. However, the throttle area and exhaust valves were found to be sensitive to leaded fuels.

Patterson, D. J., and N. Henein. Emissions From Combustion Engines and Their Control. See III.F.

Rehnberg, O. Project 1, Summary: The Analysis of Diesel Exhaust Gases. See VII.A.

Smithsonian Science Information Exchange, Inc. Reduction of Pollution By Internal Combustion Engines. Washington, D.C., March 1979, SSIE Prepring GA04, 30 pp.

This information source contains a current listing of research projects dealing with the reduction of pollutants from internal combustion engines. The source lists the project title, supporting organization, and the performing organization. It also includes a project summary describing the project.

Springer, K. J. Field Demonstration of General Motors Environmental Improvement Proposal (EIP) - A Retrofit Kit for GMC City Buses. Southwest Res. Inst. (San Antonio, Tex.), Environmental Protection Agency Contract No. PH 22-68-23, December 1972, 107 pp.; available for consultation at Twin Cities Research Center, Minneapolis, Minn.

The Environmental Protection Agency, in support of the Department of Transportation's Urban Mass Transit Administration, sponsored a two-year demonstration of an Environmental Improvement Program (EIP) proposed by General Motors Corporation. This report describes the results of a two-year test of three GM city buses on which the parts which comprise the EIP kit had been installed. Inspections were made at the beginning, after 5, 10, 16, and 24 months (115,000 miles) of routing city bus operation by the San Antonio Transit System. Of importance was the nuisance odor, smoke and noise emissions and unburned hydrocarbons, carbon monoxide, and oxides of nitrogen pollutants. Also investigated was the effect of fuel. In most instances, the claims made by the manufacturer for the retrofit kit,

applicable to about 25,000 in-service buses, were verified. Significantly less odor, smoke, unburned hydrocarbons, partially oxygenated compounds, and carbon monoxide were produced while a slight increase in oxides of nitrogen was found. The slight decrease in interior noise, claimed by the manufacturer, seemed to be offset by a slight increase in exterior noise. Of the three principal items that affect exhaust emissions, the oxidation catalyst was found to be ineffective and was dropped from the test after one year of operation. The vertically-directed exhaust improves the dilution of the exhaust, thereby reducing the observed odor at street level while tending to make any smoke discharge more visible. The component effective in reducing emissions was the Low Sac Needle (LSN) injector, which has been required standard equipment on all Detroit Diesel Engines in road use beginning in 1970. Immediate retrofit of older buses with LSN injectors has been recommended along with replacement of the injector rocker arm actuator which is subject to wear.

Springer, K. J., and C. T. Hare. Four Years of Diesel Odor and Smoke Control Technology Evaluations--A Summary. Presented at the ASME Winter Annual Meeting, Nov. 16-20, 1969, Los Angeles, Calif., Asme Prepring 69-WA/APC-3, 16 pp.

The authors consider several methods for control of smoke and odor from diesel powered vehicles. In the case of smoke, it appears that reduction of its emission from new engines may be effected by engine design, rating, fueling, and combustion. New engines are being certified for 1970 production with reduced levels of smoke. Maintaining these reduced smoke levels will depend, of course, on maintenance, driver, and fleet practices among other factors. Effective control of diesel odor, however, continues to be elusive although a few approaches such as catalytic mufflers, and improved fuel injection for one type of engine, have demonstrated merit. Much remains to be done in both smoke and odor areas of diesel emission-control technology to identify new control methods and to investigate their performance and cost-effectiveness relationships. Accordingly, this paper is a status report of a continuing long-range program.

Springer, K. J., and R. C. Stahman. Control of Diesel Exhaust Odors. Presented at the Conference on Odors: Evaluation, Utilization and Control. The New York Academy of Sciences, New York, Oct. 1-3, 1973, Paper No. 26, 40 pp.

This paper explains the major work performed in the fields of measuring diesel exhaust odors, reducing diesel exhaust odors and finally how reducing diesel odor benefits the public. The report also includes test results of various odor control methods that were investigated on diesel equipped city buses.

Stara, J. F., W. Moore, and A. W. Breidenbach. Toxicology of Atmospheric Pollutants Resulting From Fuel Additives and Emissions Associated With the Use of Automobile Catalytic Converters. See V.A.3.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Diesel Emissions and Mine Ventilation. See III.F.

Sudar, S., and L. Grantham. Diesel Exhaust Emission Control Program. Atomics Internat., January 1974, 142 pp.; NTIS PB-234 752.

The purpose of the report was to demonstrate a prototype of the Atomics International diesel exhaust control system in a Southern California Rapid Transit District bus (a Flexible coach equipped with a Detroit Diesel 6V-71N engine). The program objectives were to meet the Calif. 1975 heavy-duty vehicle standards and to establish the economics of the system. Emission reduction objectives were attained except for the reduction of NO_x. To meet Calif. requirements of less than 5 gm/B-hp-hr of combined HC and NO_x larger residence times were required. The resulting muffler size may not be compatible with bus installation constraints. Alternative technologies of NO_x control under development by diesel engine manufacturers may prove to be more cost effective. Advantages and disadvantages of the Atomics International diesel exhaust emission control system (DEEC) in vehicle application are discussed. Recommendations are offered and conclusions reached. Tables and figures are numerous. Appendices include the tabulation of laboratory test data, muffler performance test reports provided by the California Air Resources Board, Air Resources Laboratory, and a market analysis for the DEEC muffler.

Taigel, P. G. Some Experiments in Removal of Toxic Gases From Diesel Engine Exhausts. Safety in Mines Research Establishment, Research Report No. 48, September 1952, 23 pp.

Current practice in the design of exhaust conditioner boxes for the diesel engines of mining locomotives is described, and the chemical engineering problems of exhaust gas scrubbing are discussed. A series of tests is described in which two representative designs of exhaust scrubbers, and an experimental scrubbing tower, deal with the exhaust from a multi-cylinder direct injection diesel engine. Measurements are made of the efficiency of oxides of nitrogen with a plain water bath and baths of various aqueous solutions.

Trayser, D. A., F. A. Creswick, E. R. Blosser, W. R. Pierson, and R. F. Bauer. Effect of Catalyst Operating History on Sulfate Emissions. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760036, 24 pp.

This paper describes a chassis-dynamometer study of sulfate formation on a

catalyst-equipped automobile under steady-speed and cyclic operating conditions, with particular attention to the effects of preconditioning on sulfate emission rates. The vehicle was a 1973 Ford Torino equipped with monolithic noble metal catalysts and secondary air injection to simulate a 1975 catalytic system. The fuel used was unleaded certification gasoline with a nominal 0.025 wt-pct sulfur content. The experimental program consisted of (1) protracted steady-speed driving at five different road speeds up to 60 mi/hr and at idle, ordered in such a way as to show storage/release effects and stabilized sulfate and SO2 emission rates; and (2) a series of hot-start FTP-cycle tests initiated with a cold-start FTP tests. Sampling for sulfate and SO2 measurement was from a dilution tube in which the vehicle exhaust gases were diluted 10:1 with filtered air. Total mass, size distribution, and light scattering properties of the exhaust particulates were also determined. Sulfate emissions increased with decreasing catalyst temperature down to 500°C, approaching 0.1 g/mi under stabilized conditions at the optimum speed, which on this system was 40 mi/hr. At this speed, sulfate comprised 75 to 80 pct of the emitted sulfur and 90 pct of the fuel sulfur consumed. Conversion closely approached the thermodynamic-equilibrium limit at the highest catalyst temperatures. Sulfur storage was evident at idle following operation at 50 mi/hr, and also at 20 mi/hr following 60 mi/hr operation. Storage and release integrated over a 2-hour period were less than ±20 pct of fuel sulfur under most of the other changes from one steady speed to another. The storage/release transients were of the order of a few hours. Storage was also evident in the series of 1972 FTP cycles (one cold-start and ten hot starts in succession), which began after 60 mi/hr preconditioning. Sulfate emission was initially 0.27 g/mi and continued to climb for several cycles towards an asymptote of 0.08 g/mi or 50 pct of the fuel sulfur consumed. There are a number of additional results concerning the acidity, water content, and size distribution of the emitted sulfate aerosol; noble-metal and nitrate emissions; and sampling and analysis methodology, all confirming previously-published information.

U.S. Bureau of Mines, Bartlesville Energy Research Center. Characterization and Control of Emissions From Heavy Duty Diesel and Gasoline Fueled Engines. See III.A.1.

U.S. Environemntal Protection Agency. Emissions Control of Engine Systems. See IV.D.

Urban, C. M., K. J. Springer, and D. A. Montalvo. Emissions Control Technology Assessment of Heavy Duty Vehicle Engines. See IV.A.

V. INDUSTRIAL HYGIENE (HEALTH EFFECTS) OF DIESEL EQUIPMENT USAGE

A. Emissions Concentrations and Toxicity

1. Noise

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1977. Cincinnati, Ohio, 1977, 94 pp.

This handbook lists the standard adopted values for contaminants that may be found in workroom air. It also contains several appendices that explain how the values were calculated.

Burrows, J. H. J., R. Hemp, F. H. Lancaster, and J. H. Quilliam. The Ventilation of South African Gold Mines. See IV.K.

Harris, J. D., B. J. Lindgren, and R. L. Mann. Assessment of Occupational Noise Exposure and Associated Hearing Damage Risk for Agricultural Employees. Presented at the Off-Highway Vehicle Meeting, Milwaukee, Wis., Sept. 13-16, 1976, SAE Preprint 760673, 12 pp.

This paper describes background information, measurement procedures, data analysis techniques, and results pertaining to assessment of agricultural employee occupational noise exposure. The criteria on which the proposed OSHA 85 dB(A) 16 hour general industry noise regulation is based has been applied to predict hearing damage risk. Analysis of 237 man days of measured noise exposures shows that annual occupational noise exposure must be established to assess hearing damage risk. No evidence was found that agricultural employees are exposed to noise levels/durations which exceed the criteria for annual and lifetime noise exposure on which the proposed OSHA general industry regulation is based.

Holding, W. Environmental Problems Associated With Mechanization at Prieska Copper Mines (Pty.) Limited. J. Mine Ventilation Society of South Africa, v. 32, No. 6, June 1979, pp. 106-113.

One of the difficulties in preparing a paper under the above title is to decide which problems are the direct result of mechanization, which ones are an indirect result of mechanization and which are completely divorced from mechanization. It must also be borne in mind that the overall effect of mechanization is generally to simplify ventilation problems by virtue of concentration, while acknowledging that some problems are created or aggravated by mechanization. The conclusion one reaches is that all the environmental problems encountered are in some way affected by the method of mining, which is highly mechanized and concentrated.

Patterson, W. N., G. G. Huggins, and A. G. Galaitsis. Noise of Diesel-Powered Underground Mining Equipment. See III.B.4.

A. Emissions Concentrations and Toxicity
2. Heat

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment With Intended Changes for 1977. See V.A.1.

Burrows, J. H. J., R. Hemp, F. H. Lancaster, and J. H. Quilliam. The Ventilation of South African Gold Mines. See IV.K.

Holding, W. Environmental Problems Associated With Mechanization at Prieska Copper Mines. See V.A.1.

Journal of the Mine Ventilation Society of South African Presidential Address. See IV.K.

Kuhlemeier, K. V., and T. B. Wood. Laboratory Evaluation of Permissible Exposure Limits for Men in Hot Environments. J. Am. Ind. Hygiene Assoc., v. 40, December 1979, pp. 1097-1103.

There is a long history of debate among physiologists, public health officials and physicians regarding the levels of heat and work to which industrial workers can be exposed without danger to their health. An objective physiological criterion for establishing environmental limits for everyday work was proposed. Based on this criterion permissible exposure limits (PEL) for American industrial workers were proposed. These PEL use the wet bulb globe temperature (WBGT) as an index for heat stress and make an allowance for endogenous heat production at low, medium or high work rates. The assumption is made that below the PEL the worker's core temperature and heart rate should be at or below established safety limits. These limits were set at 38°C for rectal temperature and a mean heart rate of 110 beats per minute during prolonged work by a World Health Organization Study Group. This present study was conducted to determine if the PEL system protects the workers so that heart rate and rectal temperature observations made in environments below the PEL are less than or equal to 110 bpm and 38°C, respectively. More specifically we have tried to determine whether (1) there is a difference in this regard between men who were work-acclimated to heat stress and those who were not, (2) the PEL guidelines protect workers adequately at different levels of work stress and (3) there is a seasonal difference in the degree of protection the PEL system affords.

Misaqi, F. L., J. G. Inderberg, P. D. Blumenstein, and T. Naiman. Heat Stress in Hot U.S. Mines and Criteria for Standards for Mining in Hot Environments. Mine Safety and Health Administration, Arlington, Va., December 1976, 67 pp.; NTIS PB-299 357.

The Mining Enforcement and Safety Administration conducted a comprehensive environmental study in underground and surface mines of the U.S. to determine the prevalent combinations of air temperature, humidity, radiative heat, and wind speed in hot mines. The study has shown that most of the surveyed mines are "hot" in terms of existing industrial hygiene standards for hot work sites. This publication proposes standards for hot mine areas and refuge chambers; it familiarizes readers with the nature of heat stress and strain-related physiological disorders; it provides information about heat stress indices, heat sources and heat control measures in mines.

Taussig, S. G. Notes on the Heat Produced by Diesel and Battery Locomotives. J. Mine Ventilation Society of South Africa, v. 27, No.1, January 1974, p. 52.

These notes describe the operating conditions of diesel and battery locomotives and calculate the amount of heat they produce. It was discovered that the diesel locomotive produces 4 times the heat of the electric vehicle.

A. Emissions Concentrations and Toxicity
3. Diesel exhaust pollutants

Amdur, M. O. Animal Studies. Nat. Academy of Sciences--Nat. Research Council, Proceedings of the Conference on Health Effects of Air Pollutants, Serial No. 93-15, November 1973, pp. 175-205.

This report studies the effects of sulfur dioxide, sulfuric acid and sulfates on different animal species. Dr. Andur conducted tests on guinea pigs, rabbits, monkeys and even humans. The short term acute effects of SO2 were studied by exposing several animal species to different concentrations of SO2 for a one hour period. It was shown that SO2 increased the flow resistance of the lungs and airways. The long term health effects of sulfates and H_2SO_4 was determined by exposing animals at different concentrations for two years. For the concentration of 0.38 mg/m^3 there were no significant alterations. For concentrations of 2.43 mg/m^3 there were moderate alterations. Dr. Andur performed several other experiments and the results are explained in detail.

American Conference of Governmental Industrial Hygienists. Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment With Intended Changes for 1977. See V.A.1.

American Conference of Governmental Industrial Hygienists. Industrial Hygiene for Mining and Tunneling. Proceedings of a Topical Symposium, Denver, Colo., Nov. 6-7, 1978, 170 pp.

The proceedings cover a number of topics, including the following seven papers on various aspects of the use of diesels in mining: (1) Summary report of the environmental results of the MSHA and NIOSH silica/diesel exhaust study; (2) Acute changes in pulmonary function in salt miners; (3) The effect of exposure to silica and diesel exhaust in underground metal and nonmetal miners; (4) Diesels as a power source in mines; (5) Monitoring for diesel exhaust emissions; (6) Emission control performance of diesel exhaust treatment devices, and (7) Future control technology capability: What can be done about diesel particulate?

Anderson, I., G. R. Lundqvist, P. L. Jensen, and D. F. Proctor. Human Response to Controlled Levels of Sulfur Dioxide. Archives of Environmental Health, v. 28, January 1974, pp. 31-39.

Nasal mucus flow rate, airway resistance, and subjective response was studied in 15 young men during six-hour exposures to 1, 5, and 25 ppm sulfur dioxide (SO2). A significant decrease in nasal mucus flow rate during 5 and 25 ppm exposures was observed. This decrease was greatest in the anterior nose and in subjects with an initially slow mucus flow rate. Pharyngeal air samples yielded less than 1 pct of the SO_2 inhaled, even after a six hour exposure to 25 ppm SO2. An increased nasal airflow resistance and a fall in forced expiratory volume in one second and forced expiratory flow during the middle half of expired volume was found at all exposure levels, but there was no change in "closing volume." Discomfort was proportional to SO2 concentration, but never excessive. Subjects with initially slow nasal mucus flow rates experienced the greatest discomfort. The acute effects of SO2 exposure appear to justify reduction of the present threshold limit value of 5 ppm to 1 ppm, and provide support for a nasobronchial reflex bronchoconstriction.

Apol, A. G. Health Hazard Evaluation/Toxicity Determination Report 74-1-160, White Pass and Yukon Railroad, Skagway, Alaska. Nat. Inst. for Occupational Safety and Health, November 1974, 10 pp.; NTIS PB 246 478.

Determination: The exposures of train crew workers to diesel engine exhaust gases were evaluated by NIOSH. Diesel exhaust gases, including nitrogen dioxide, sulfur dioxide, carbon monoxide, aldehydes, and total particulates, were measured in the leading and trailing train engine cabs. It was determined that diesel exhaust gases were not toxic at the concentrations measured during this investigation.

Ashby, J., and J. A. Styles. Does Carcinogenic Potency Correlate With Mutagenic Potency in the Ames Assay? Nature, v. 271, No. 5644, Feb. 2, 1978, pp. 452-455.

At the present time to detect mutagenic and carcinogenic potency in animals the Salmonella and the Ames assay tests are used. These tests can give both false positive and false negative results when compared with animal tests. Therefore, they are regarded as an early warning system rather than the final arbiter of animal and possible human carcinogenicity. If a correlation between mutagenic and carcinogenic could be determined, then a strong positive response in the Ames assay would define a potentially potent carcinogen and would suggest that some compounds give positive results in this assay but fail to induce cancer in animals because of their mutagenic potency is too low. To determine this correlation, tests were performed on mice, rats and guinea pigs. The results indicated that any correlation made at this time should be studied in great detail.

Barth, D. S., and S. M. Blacker. The EPA Program to Assess the Public Health Significance of Diesel Emissions. J. Air Pollution Control Assoc., August 1978, v. 28, No. 8, pp. 769-771.

The U.S. Environmental Protection Agency's program to assess the public health significance of diesel emissions is described. The reasons for the EPA concern over diesel exhaust products are discussed. Some results of EPA research efforts over the last nine months are summarized and preliminary conclusions are drawn. Finally, the planned future health experiments which will hopefully fill some remaining gaps in our knowledge are identified.

Battigelli, M. C. Effects of Diesel Exhaust. Archives of Environmental Health, v. 10, February 1965, pp. 165-167.

The School of Public Health in Pittsburgh has studied the possible detrimental effects brought about through exposure to diesel engine exhaust. They studied railroad workers that were employed in locomotive repair shops. They concluded that neither respiratory complaints nor pulmonary function could be related to this type of occupational exposure. A second study was also performed that exposed volunteers to diesel exhaust for short periods of time. Again no pulmonary resistance was measured.

Battigelli, M. C., R. J. Mannella, and T. F. Hatch. Environmental and Clinical Investigation of Workmen Exposed to Diesel Exhaust in Railroad Engine Houses. Industrial Medicine and Surgery, v. 33, March 1964, pp. 121-124.

This report compares, in terms of clinical and physiological assessment, a group of locomotive repairmen currently exposed to diesel exhaust, with a control group of railroad workers matched for age, body size, past extrapulmonary medical history and comparable job status but were not exposed to diesel exhaust. The report describes in detail the methods of sampling, number sampled, time of year and results. The results indicated there was no significant difference in pulmonary function but there was a higher frequency of respiratory complaints from the workers that smoked than nonsmokers that were exposed to diesel exhaust.

Blackwood, T. R., S. R. Archer, and G. E. Wilkins. Status Assessment of Toxic Chemicals: Polynuclear Aromatic Hydrocarbons. Monsanto Research Corp., Dayton, Ohio, Contract No. 68-03-2550, December 1979, 33 pp. NTIS PB 80-146418.

This report identifies the origins, applications, environmental effects, and health effects of polynuclear aromatic hydrocarbons. Ways to reduce polynuclear aromatic hydrocarbon (PNA) emissions and problems associated with PNA derived effluents in the dye industry are discussed. Finally, various regulatory actions are listed and recommendations are made for further areas of study.

Breuer, H. Health in Mines. Synthesis report on research in the third program, 1971-1976. Commission of the European Communities Industrial Health and Safety Report, EUR 5931, 1978, 3 pp.

Between 1971 and 1976 a total of 92 research projects were put forward by the Research Committee "Health in Mines" and after endorsement by several committees they were finally approved by the Commission of the European communities. The projects were divided into four areas of dust control (1) winning operations, (2) dust measurement, (3) pneumoconiosis and environmental factors, (4) health in iron-ore mines. A list of the individual projects and the institutes commissioned to carry them out is appended in this report.

Briggs, T., J. Throgmorton, and M. Karaffa. Air Quality Assessment of Particulate Emissions From Diesel-Powered Vehicles. U.S. Environmental Protection Agency, Contract No. 68-02-2515, March 1978, EPA Preprint EPA-450/3-78-038, 154 pp.

The Clean Air Act amendments require the setting of particulate emission standards for various classes and categories of vehicles, beginning with 1981 models. In support of proposed standards for particulate emissions from light and heavy duty diesel vehicles, this report presents a preliminary assessment of the impact of diesels on projected air quality and the potential public health effects associated with total suspended particulate (TSP) and particulate polycyclic organic matter (PPOM) in diesel exhaust.

Brooks, A. L., and R. Royer. Status Report on Chemical and Biological Characterization of Diesel Exhaust Emissions. See III.A.2.

Burchard, J. K. The Significance of Particulate Emissions. J. Air Pollution Control Assoc., v. 24, No. 12, December 1974, pp. 1141-1142.

Fine particulates are the subject of increasing concern as one of the major air pollutants. They contribute to smog formation. They are a health hazard because they bypass the respiratory filters and penetrate deep into the lungs, and because they may act synergistically with other pollutants. The sources of submicron particle size pollutants are discussed.

Burrows, J. H., R. Hemp, F. H. Lancaster, and J. H. Quilliam. The Ventilation of South African Gold Mines. See IV.K.

Campbell, K., E. George, I. Washington, and Y. Yang. Enhanced Susceptibility to Respiratory Infection in Mice Exposed to Automotive Diesel Emissions. U.S. Environmental Protection Agency, 1978, 4 pp.

An important aspect of toxicologic assessment of environmental contaminants is that concerning effects on host defense capabilities and resistance (or susceptibility) to infection. Experimental exposures to automotive exhaust and to important exhaust pollution constituents such as ozone and nitrogen dioxide have been reported to enhance susceptibility to infection by inhaled bacterial pathogens. Since diesel engines are being considered for future general use in automobiles and diesel exhaust may thus impact considerably on transportation-related environmental pollution, studies of diesel exhaust toxicity with respect to effect on susceptibility to infection have been undertaken. This report concerns the initial study and results thus far available.

Cralley, L. V., and L. J. Cralley (Ed.). Patty's Industrial Hygiene and Toxicology, v. III--Theory and Rationale of Industrial Hygiene Practice. John Wiley & Sons, New York, N.Y., 1979, 752 pp.

Volume III of Patty's Industrial Hygiene and Toxicology focuses on the theory and practice of industrial hygiene in the recognition, evaluation, and control of environmental hazards in the workplace. Evaluation of exposures to chemical, physical, and biological agents are comprehensively reviewed and chapters on data analysis, engineering control, personal protection, and compliance are also included. The subject areas are based on information and legal interpretation of regulations available and necessitates a continual updating.

Cummins, B. T., R. E. Wallace, and P. J. Lawther. Air Pollution in Diesel Bus Garages. British J. of Industrial Medicine, v. 14, 1957, pp. 232-239.

Air pollution in two London Transport diesel bus garages was studied. Results of determinations of smoke, polycyclic hydrocarbons, nitrogen dioxide, aldehydes, carbon monoxide, and sulphur dioxide are given in the report. These results are compared with analyses of the outside air. Despite large differences in the concentrations of smoke inside and outside each garage, only small differences in the amounts of 3 : 4-benzpyrene were noted. Concentrations of nitrogen dioxide and aldehydes did not approach the threshold limit values for eight-hour shift exposures adopted by the American Conference of Governmental Industrial Hygienists in 1956. The carbon monoxide concentrations were negligible; there was no evidence of abnormal concentrations of sulphur dioxide. The significance of these findings is discussed.

Cornfield, J. Carcinogenic Risk Assessment. Science, v. 198, Nov. 18, 1977, pp. 693-699.

Carcinogenic risk assessment involves a mixture of statistical, scientific, and public policy considerations. Concepts in current use, such as "no observed effect levels" and "virtual safety," and the problems in implementing them by means of dose-response models, particularly the probit-log dose and linear models are reviewed. The upper limits to risk provided by some conservative procedures are inconsistent with coherent balancing of risks and benefits. A common basis to the dose-response curves describing both carcinogenic and noncarcinogenic effects is to be found in deactivating reactions. A simplified model in which a toxic substance is activated and deactivated in separate and simultaneous reactions is presented and the dose response curve implied by the model is deduced. this curve has the general form of a hockey stick, with the striking part flat or nearly flat until the dose administered saturates the deactivation system, after which the probability of a response rises rapidly. Such a curve describes the Bryan-Shimkin methylcholanthrene-tumor incidence dose response curve as well as the probit log-dose model. The concept of a saturation dose is relevant to risk assessments for carcinogenic and noncarcinogenic substances alike.

Dehnen, W., N. Pitz, and R. Tomingas. The Mutagenicity of Airborne Particulate Pollutants. Cancer Letters, v. 4, 1977, pp. 5-12.

The mutagenic effect of extracts derived from airborne particulate matter was investigated with the Ames-test. The whole extract proved to be distinctly mutagenic. To find out whether the content of polycyclic aromatic hydrocarbons may be responsible for the mutagenic effect, the extract was split into several fractions. The fraction containing the polycyclic compounds showed the lowest mutagenic rate that was enzymatically mediated. The other fractions required metabolic activation for some of their components, but some components were active without metabolic activation.

Elliott, M. A., J. C. Holtz, L. B. Berger, and H. H. Schrenk. Diesel Engines Underground: III. Effect on Exhaust-Gas Composition of Operating Engines in Mixtures of Normal Air and Natural Gas. BuMines RI 3584, September 1941, 39 pp.

The present report is confined to a study of the effect on exhaust-gas composition of operating either of two 4-stroke-cycle diesel engines in mixtures of normal air and natural gas to simulate conditions that might exist if diesel mine locomotives were operated in atmospheres containing methane or other hydrocarbon gas. The studies were limited to mixtures of natural gas and normal air in which the concentration of natural gas ranged from 0.2 to 4.7 vol-pct. Concentrations generally were below the lower inflammable limit under ordinary conditions of pressure and temperature (4.7 vol-pct).

Environmental Health Associates, Inc. Health Effects of Diesel Exhaust Emissions: A Comprehensive Literature Review, Evaluation and Research Gaps Analysis. Berkeley, Calif., Jan. 25, 1978, 186 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

The purpose of this report is to provide a comprehensive review of the pertinent medical literature on the human health consequences of exposure to diesel exhaust emissions with particular reference to the use of diesel engines in underground mines and to define those areas of deficiency in current scientific knowledge which require further clarification. In addition, the report was prepared as a means to advise the American Mining Congress (AMC) concerning the nature of future research programs.

Environmental Science & Technology. NO2: the Air Standard and Health Effects. v. 13, No. 6, June 1979, pp. 642-644.

The EPA is currently reviewing and possibly revising the ambient air quality standard for NO2. This article is a review of the current knowledge of the health effects of nitrogen oxides. The article discusses ways of measuring NO_x, health effects and presents the results of animal studies. The EPA is considering changing the short term air standard to 0.25-0.5 ppm for one hour exposure.

Ferris, B. G. Health Effects of Exposure to Low Levels of Regulated Air Pollutants, A Critical Review. J. Air Pollution Control Assoc., v. 28, No. 5, May 1978, pp. 482-497.

This report studies in detail six regulated pollutants found in diesel engine exhaust. The report studies the pollutants of carbon dioxide, nitrogen dioxide, hydrocarbons, sulfur oxides, particulate matter and photochemical oxidants and decides if the present standards are sufficient. From the information it was decided that the six regulated pollutants seem adequate to protect the health of the public. Some of the standards do offer a greater degree of protection than others. Until more data is available the standards should not be changed. There seems to be a need to establish a 24 hour standard for NO2. There is inadequate data to establish a standard for sulfates at this time.

French, I. W., and C. A. Mildon. Health Implications of Exposure of Underground Mine Workers to Diesel Exhaust Emissions; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

The Canadian Dept. of Energy Mines and Resources contracted with Ian W. French and Associates Limited to review the relevant scientific literature describing the occupational environment to which underground mines are

exposed and the potential for this environment to adversely affect the mine workers pulmonary function and health. From the literature search a health effects formula was recommended. It includes the pollutants of CO, NO, respirable combustible dust (RCD) and SO2. It was suggested that a value of 3 to 4 be considered to pose a moderate threat to health and ventilation should be stepped up.

Gage, S. J., and G. J. Rausa. Overview of the Health Effects of Alternate Energy Sources. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Tex., June 25-30, 1978, APCA 78-23.1, 16 pp.

This article briefly discusses the future trends in alternative energy sources. The article discusses coal, nuclear fission, geothermal and small solar systems. It points out that coal usage will increase and coal pollution will be a major contributor to environmental problems.

Gilbert, S. The Use of Diesel Engines Underground in British Coal Mines. See VII.J.

Goldberg, A. J. A Survey of Emissions and Controls for Hazardous and Other Pollutants. See III.F.

Government Executive. EPA: Headed for Trouble on Trucks and Cars. October 1979, pp. 32-35.

This article criticizes the emission standards set forth by the EPA. The automakers are currently having trouble meeting the current standards and the EPA proposes to increase the standards to unattainable limits by 1983. The article briefly explains how the EPA arrives at these limits and speculates on what is going to happen in the near future.

Holding, W. Environmental Problems Associated With Mechanization at Prieska Copper Mines. See V.A.1.

Holland, W. D. Determination of Breathing Zone Concentrations of Contaminants From Emissions From Diesel Powered Vehicles in Underground Mines. Final Report. LFE Corporation, LFE Environmental Analysis Division, Richmond, Calif., Contract No. J0255001, August 1978, 143 pp.

This study was undertaken to determine miners' breathing zone concentrations of diesel exhaust components, to investigate any

relationships between these concentrations and vehicle type, the presence of emission controls, vehicle usage, and ventilation conditions, and to make recommendations for monitoring and ventilation requirements. Twenty-four mines including two coal mines were surveyed. Sampling was done for CO_x, NO_x, SO_x, PNA, aldehydes, and particulates. In most mines, concentrations of at least one contaminant exceeded one half the standard or TLV. The concentrations of gases are probably sufficiently reduced by a minimum air velocity of 50 rpm. A sufficient reduction of particulate concentrations may require as high as 400 rpm air velocity. Vehicle age, type, or usage appear to have little or no effect on contaminant concentrations. PNA levels were below detection limits in all but a very few samples. Minimum requirements for routine monitoring should include formaldehyde, CO_x, NO2. It is further recommended that better definition of the minimum ventilation requirement be obtained.

Holliday, M. G., John W. Sifton, F. R. Engelhardt, S. W. Langdon, and R. A. Meng. Occupational Health Aspects of Diesel Exhaust Emissions in Ontario. Prepared by Michael Holliday & Associates under contract to the Occupational Health and Safety Division, Ontario Ministry of Labour, November 1981, 272 pp.

This report provides a background overview of the occupational health aspects of diesel exhaust emissions in Ontario. The factors, both chemical and physical, contributing to the formation of noxious pollutants in diesel exhaust are discussed and methods to reduce quantities of pollutants emitted are identified. A review of literature pertinent to a health assessment of individual exhaust constituents and of whole diesel exhaust is provided. A description of diesel equipment use in Ontario is given; and the control and monitoring techniques used to reduce worker exposure to exhaust gases are outlined. The attitudes of management and labour representatives, and of the scientific and occupational-health communities towards the hazards of diesel exhaust are presented. Regulatory options available to the Ontario government are discussed and compared to regulatory approaches adopted by other jurisdictions. Finally, the factors to be considered in assessing the economic impact of controls are outlined.

Holtz, J. C. Safety With Mobile Diesel-Powered Equipment Underground. See VII.A.

Holtz, J. C., and R. W. Dalzell. Diesel Exhaust Contamination of Tunnel Air. See III.B.1.

Horvath, S. M., and L. J. Folinsbee. The Effect of Nitrogen Dioxide on Lung Function in Normal Subjects. U.S. Environmental Protection Agency, Report No. EPA-600/1-78-006, January 1978, 81 pp.

Cardiopulmonary and metabolic responses of three groups, each consisting of five adult males (age 19-29) were determined before, during, and after a 2 hour exposure to 0.62 ± 0.12 ppm NO2 at 25°C and 45 pct RH. The three groups exercised during exposure at 40 pct of $VO2_{max}$ for either 15, 30 or 60 min for groups C, A, and B, respectively. During the exercise periods the ventilation was about 33 liters/ min, a four-fold increase over the resting level. There were no physiologically significant cardiovascular, metabolic, or pulmonary function changes which could be attributed to exposure to this level of NO2 (0.62 ppm). There were no differences between the groups in their response despite the fact that groups A and B received more NO_2 as a result of 28 pct and 84 pct greater ventilations, repsectively.

Hunter, D. The Diseases of Occupations. The English Universities Press, Ltd., Warwick Lane, London, 5th ed., 1975, pp. 780-788; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

This article discusses occupational diseases that are caused by being exposed to various oils, such as shale oil, rangoon oil, sumatra oil, etc. It describes several specific case examples and also describes how the diseases can be treated.

Hurn, R. W. Air Pollution and the Compression-Ignition Engine. The Combustion Institute, Twelfth Symposium (International) on Combustion (Japan), Pittsburgh, Pa., 1969, pp. 677-687.

The compression-ignition engine, popularly known as the diesel, is examined as a contributor to metropolitan air pollution. Smoke and odor are recognized as the primary targets of public objection to the diesel, and factors relevant to the smoke and odor problem are discussed. Problems that involve diesel smoke are seen by the author as readily manageable but a satisfactory solution to the diesel odor problem is not yet evident. Other pollutants--unburned hydrocarbon, partially burned hydrocarbon, oxides of nitrogen, and in lesser degree, carbon monoxide--are significant in the products of diesel combustion. Of these, only oxides of nitrogen and possibly the aldehydes typically are discharged in quantities that in equivalent volumes of combustion product may exceed the quantities discharged by spark-ignition reciprocating internal combustion engines. Features both inherent and unique to the diesel combustion process are discussed as factors relevant to generation or avoidance of objectionable pollutants. In this context the high temperatures and oxygen availability in diesel combustion are seen as serious impediments to satisfactory reduction of the yield of oxides of nitrogen in the diesel process, but they are favorable in holding concentrations of pollutants in other categories to acceptably low levels. Except for the problem of odor and of

oxides of nitrogen, it would appear that the combustion processes of the compression-ignition engine inherently are favorable toward engine design and operation for reduction in pollutants to meet environmental needs.

Jorgensen, H., and A. Svensson. Studies on Pulmonary Function and Respiratory Tract Symptoms of Workers in an Iron Ore Mine Where Diesel Trucks are Used Underground. J. Occupational Medicine, v. 12, No. 9, September 1970, pp. 348-354.

An investigation of workers in a mine where diesel-driven vehicles are used is presented. Half of the subjects were underground workers while the control group consisted of surface workers. Half of each group were smokers, half nonsmokers. A younger group was compared with an older group. In the underground group there were more who reported that the air was bad than in the surface group. They were found predominantly among the smokers and the older workers. The results indicated that bronchitis is higher among underground workers than surface workers, much higher among smokers than nonsmokers, and also higher among older than among young workers. The effects of underground work and smoking seem synergic.

Jorgensen, H. S. A Study of Mortality From Lung Cancer Among Miners in Kiruna 1950-1970. Work-Environmental-Health, v. 10, 1973, pp. 126-133.

Mortality from lung cancer among workers in the iron ore mines in Kiruna has been studied retrospectively. Thirteen cases of lung cancer were observed while only 4.5 were expected on the basis of the proportional mortality from lung cancer among the rest of the male population in Kiruna. Lung cancer mortality among non-mine workers was equal to the mortality in Sweden in general. Twelve of the 13 cases were smokers. Previously the radon daughter level in the mine has probably been 30 pCi/liter or less and exposure to diesel exhaust gas has had no influence on the results since only one of the thirteen men who died of lung cancer was working when diesels were used. Because of the possibility of interaction between radon and some of the elements of diesel exhaust gas, in the future this study should be followed up in 5-10 years.

Journal of the Air Pollution Control Association. Health Effects of Exposure to Low Levels of Regulated Air Pollutants. v. 28, No. 9, September 1978, pp. 883-897.

The article consists of four discussion papers, floor discussion, and correspondence received at APCA headquarters pertaining to a paper prepared by Dr. Benjamin G. Ferris, Jr., and published in the May 1978 Journal. Ferris's paper, entitled "Health Effects of Exposure to Low Levels of Regulated Air Pollutants," was the subject of the Critical Review Session at the 71st Annual Meeting of APCA in Houston and is cited elsewhere in this bibliography.

Journal of the Mine Ventilation Society of South Africa. Presidential Address: Occupational Health and Safety in Underground Mines, v. 29, No. 1, January 1976, pp. 1-29. See IV.K.

Journal of the Mine Ventilation Society of South Africa. Presidential Address: Occupational Health and Safety in Underground Mines (conclusion). v. 29, No. 2, February 1976, pp. 29-56. See IV.K.

Karagianes, M. T., R. F. Palmer, and R. H. Busch. Effects of Inhaled Diesel Emissions and Coal Dust in Rats. Am. Ind. Hyg. Assoc. J., May 1981, pp. 382-391.

Rats were exposed to coal dust and diesel exhaust emissions, separately and in combination, for 20 months to evaluate the potential health effects of these specific mine air materials. The diesel exhaust was produced by an engine operated in a load, no-load mode and acceleration, deceleration cycle. It was also modified to simulate an inefficiently tuned engine. Exposure to coal dust was performed in a whole-body rodent inhalation system. Mortality, body weight, and hematologic parameters examined were normal compared with those of control rats. Lesions observed were primarily restricted to the lungs and were similar to those described for simple coal workers' pneumoconiosis (CWP). Lesion progression and severity was related to exposure duration and exposure material. Alveolar bronchiolization, though not reported in human CWP, was present in the lungs of some rats in all exposure groups except the control animals.

Kerr, H. D., T. J. Kulle, M. McIlhany, and P. Swidersky. Effects of Nitrogen Dioxide on Pulmonary Function in Human Subjects. Univ. Md. School of Medicine, Contract No. 68-02-1745, April 1978, 20 pp.; NTIS PB-281 186.

Twenty human subjects with asthma and chronic bronchitis and ten normal, healthy adults were exposed to 0.5 ppm of nitrogen dioxide (NO_2) for two hours in an environmental chamber. They engaged in one 15-minute, light to medium-exercise stint on a bicycle ergometer during this period. The subjects with asthma experienced the greatest symptoms with exposure to NO_2,

i.e., seven of thirteen noting slight burning of the eyes, slight headache, and chest tightness or labored breathing with exercise. One each of the subjects with chronic bronchitis and the healthy, normal group experienced slight nasal discharge. Significant changes from control values for the group as a whole with exposure to NO_2 were observed for the following pulmonary function tests: quasi-state compliance for the twenty subjects with asthma and chronic bronchitis as well as for the ten normal subjects, and functional residual capacity for the twenty subjects with asthma and chronic bronchitis. Subjects with asthma and chronic bronchitis as separate groups (n = 13 and 7 respectively) did not show any significant changes in pulmonary function with the NO_2 exposure, even though the group of thirteen subjects with asthma experienced the greatest symptoms.

Ketcham, B., and S. Pinkwas. Diesels and Man: Are We Creating a New Environmental Problem by Solving an Old One? New Engineer, April 1978, pp. 23-32.

The article states that in asking for good fuel economy and low pollution, Congress may help push automakers into widespread dieselization, but preliminary data suggest that diesel emissions, while low, may be disproportionately dangerous. Although diesel engines emit only a small fraction of the hydrocarbons exhausted by gasoline engines, the authors contend that diesel hydrocarbons--at least from the larger engines tested--are potentially far more carginogenic. Diesel emissions include far more particulate matter than does exhaust from gasoline engines. The particles are especially fine, and can easily carry absorbed gaseous pollutants deep into human lungs. Preliminary studies by the Federal Environmental Protection Agency are not detailed enough to determine at what specific level diesel exhausts may become harmful. The time to examine the possible health effects of diesel engines is now, before too much tooling and design effort is committed to making the diesel commonplace in automobiles and light trucks. Diesel fuel is less highly refined than gasoline; it contains more sulfur and nitrogen compounds, and even trace amounts of many metals.

Kotin, P., H. L. Falk, and M. Thomas. Aromatic Hydrocarbons III. Presence in the Particulate Phase of Diesel-Engine Exhausts and the Carcinogenicity if Exhaust Extracts. See III.A.2.

Kramkowski, R. S. Health Hazard Evaluation Toxicity Determination. Diesel Equipment Division, General Motors Corp., Wyoming, Mich., NIOSH, 1973, 150 pp.; NTIS PB-232 580.

In response to a request received from a representative of employees per the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard survey to determine exposure to noxious fumes in four work areas of Diesel Equipment Division, GMC, Wyoming, Mich. It has been determined that the airborne concentrations of carbon dioxide,

carbon monoxide, nitrogen dioxide, and sulfur dioxide are not toxic as measured in the work areas. This determination is based upon observation of the work areas and environmental samples collected in these departments.

LFE Corporation Environmental Analysis Laboratories. Industrial Hygiene Survey Report of Paraho Oil Shale Mining Processing Facility Development Engineering, Inc. BuMines Contract No. J0255001, Jan. 12, 1976, Open File Rept. 62-77; NTIS PB-265 360/AS, 76 pp.

LFE Environmental performed an industrial hygiene survey of the Paraho Oil Shale Mining and Processing facility in Anvil Points near Rifle, Colorado, on August 6 and 7, 1975. The survey consisted of an investigation of the underground operations for diesel emission contaminants and of the above ground work areas for all inhalation contaminants other than silica dust. Samples were collected to investigate the following contaminants: respirable dust, total dust, NO_2, NO, H_2SO_4, formaldehyde, CO_2, SO_2, and CO. The report includes information on sampling conditions and analytical results, as well as on the elemental composition of selected dust collections.

Larson, W. C., and H. W. Zeller. Airborne Dust Assessment at Three Metal Mines and a Silica Mine. BuMines TPR 94, April 1976, 8 pp.

The Bureau of Mines is conducting respirable dust surveys in metal and nonmetal mining operations to determine personal exposure levels and to define dust control problems requiring research and development. To date, four different underground mines (gold, lead-zinc, iron, and silica) have been sampled for specific occupations and/or locations to determine airborne dust concentrations. In these studies, time-weighted, full-shift samples were taken for gravimetric analysis. All dust samples were taken with MESA-approved dust samplers. Flow rates of samplers were calibrated for 2.0 liters per minute in the iron and silica mines and 1.7 liters per minute in the lead-zinc and gold mines. Three types of dust-sampling packages were used: (1) Personal, (2) machine mounted, and (3) area. Results show that dust concentrations vary significantly from mine to mine and within specific mining operations. At two underground mines (silica and lead-zinc) diesel exhaust emission contributed substantially to the dust concentrations. The gold mine had two locations (ore chute and ore bypass) that were above threshold limit value (TLV) of 0.66 mg/m^3 as determined by the free-silica content.

Laskin, S., M. Kuschner, and R. T. Drew. Studies in Pulmonary Carcinogenesis. Proceedings of a Biology Division, Oak Ridge National Laboratory, Gatlinburg, Tenn., Oct. 8-11, 1969, sponsored by National Cancer Institute and U.S. Atomic Energy Commission. Published as Inhalation Carcinogenesis, M. G. Hanna, Jr., P. Netteshein, J. R. Gilbert (ed. by), U.S. Atomic Energy Commission--Div. of Technical Information, April 1970, pp. 321-351.

Epidemiological and experimental evidence has increasingly indicated that the interplay of multiple environmental factors is responsible for the induction of lung cancer. Man is exposed to a complex mixture of potentially hazardous materials, including specific carcinogens and a variety of agents which may modify the manner in which the lung handles inhaled materials or responds to them. The New York University Medical Center has been engaged in a program to isolate and identify these environmental factors and to evaluate their effects. Bronchogenic carcinoma, similar to that seen in man, has been successfully produced in rodents in high incidences in this program. Compounds of chromium have, for the first time, been demonstrated to be capable of producing bronchogenic carcinoma of the lungs in experimental animals. Inhalation of benzo(a)pyrene in combination with exposure to sulfur dioxide has resulted in the production of squamous cell carcinomas. These findings are of particular significance since both materials have been implicated in community air pollution problems and since these represent the first duplication of human lung cancer in animals by inhalation exposures to polycyclic hydrocarbons.

Lawter, J. R., and D. A. Kendall. Effects of Diesel Emissions on Coal Mine Air Quality. Arthur D. Little, Inc. (Cambridge, Mass.), BuMines Contract J0166009, May 1977, 276 pp.

The purpose of the work described in this report was to measure the effects of diesel engine emissions on the air quality of work areas in a coal mine. Concentration measurements of a number of diesel-related air contaminants were made at the Martin County Coal Corporation Mine in Inez, Kentucky. Compounds measured included carbon dioxide, carbon monoxide, formaldehyde, nitric oxide, and nitrogen dioxide. In addition, concentrations of the two classes of odorous compounds, aromatic hydrocarbons, and oxygenates were obtained along with aldehyde concentrations. Surveys were made of the mine by odor analysts to determine the perceived intensity of diesel-produced odors. It was found that the concentrations of the measured species were well below their Threshold Limit Values. Odor intensity levels in the moderate to strong range were observed in the mine.

Lee, S. D., K. I. Campbell, D. Laurie, R. G. Hinners, M. Malanchuk, W. Moore, R. J. Bhatnagar, and I. Lee. Toxicological Assessment of Diesel Emissions. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Tex., June 25-30, 1978, APCA Preprint 78-33.4, 16 pp.

Due to increasing use of diesel-powered vehicles, it became necessary to assess possible hazards of increased diesel emissions in our environment. This report describes the diesel-related health effects research program and preliminary results obtained thus far at the EPA Health Effects Research Laboratory in Cincinnati. The purpose of the three-year program, Toxicological Assessment of Diesel Emissions, is to evaluate biological effects associated with inhalation exposures of experimental animals to irradiated and nonirradiated diesel emissions. The initial two-month study was conducted to obtain a preliminary toxicological assessment using four species of animals exposed to relatively high concentrations of diesel emissions. Exposure of experimental animals to diesel exhaust resulted in altered lung protein metabolism and aryl hydrocarbon hydroxylase activity. Biological effects due to exposure to diesel exhaust described in this presentation and other reports strongly indicate a necessity for longterm studies under conditions which more closely simulate ambient pollution and with added emphasis on emphsemateous changes and carcinogenesis-related effects.

Leslie, A. C. D., M. S. Ahlberg, J. W. Winchester, and J. W. Nelson. Aerosol Characterization for Sulfur Oxide Health Effects Assessment. Atmospheric Environment, v. 12, No. 1-3, 1978, pp. 729-733.

The mean concentrations of sulfur in six particle size fractions from <0.25 um to >4 μm aerodynamic dia. have been determined in Florida during July, August, and December 1976 sampling seasons. A trend of decreasing concentration along the length of Florida, at ten sites from Pensacola to Miami, is found for sulfur in the fine particle mode, <2 μm dia. but not for >2 μm coarse mode sulfur. The trend is most regular for 0.5 1 μm particles and urban concentrations show no consistent departure from the nonurban trend in this size range. Smaller and larger particle concentrations are more locally variable. The trends are interpreted in terms of a flow of continental air, containing a pollution-derived fine particle sulfur component into Florida during northerly wind regimes and of less polluted maritime air with southerly flow. The magnitude of the apparent decrease in average concentration from north to south is dependent on the mix of air flow regimes at various locations in the state during the sample collection periods. The qualitative finding of the decreasing trend, however, may be typical in Florida over much of the year and may be useful for designing epidemiological studies of the relation between fine particle sulfur and public health.

Lewis, T. R., W. J. Moorman, W. F. Ludmann, and K. I. Campbell. Toxicity of Long-Term Exposure to Oxides of Sulfur. Archives of Environmental Health, v. 26, 1973, pp. 16-21.

Hematological and pulmonary function data were collected on 32 female beagles exposed to 13.4 mg/cu m of sulfur dioxide and 0.9 mg/cu m of sulfuric acid alone and in combination. Exposures averaged 21 hours daily for 620 days. Sixteen of these dogs had prior exposure to 48.9 mg/cu m of nitrogen dioxide for 191 days. Exposure NO_2 altered several hematological indexes and produced hyperinflated lungs. Hematological indexes were not affected by exposure to oxides of sulfur. Exposure to SO_2 significantly increased mean nitrogen washouts, $P<.01$, in dogs without prior exposure to NO_2. Exposure to 0.9 mg/cu m of H_2SO_4 significantly reduced carbon monoxide diffusion capacity, residual volume, total lung volume, and heart weights, and increased total expiratory resistance, $P<.05$. Histopathologic lung changes were nonspecific for oxides of sulfur exposures; renal changes noted in non-NO_2 exposed animals were equivocal.

Linnell, R. H., and W. E. Scott. Diesel Exhaust Analysis. Archives of Environmental Health, v. 5, No. 6, December 1962, pp. 102-111.

The article describes work by the Scott Research Laboratories, Inc., Perkasie, Pa., to identify the components of diesel exhaust that are responsible for its odor and eye irritation and to determine the relationship of the concentration of these components to the type of engine and engine operating conditions. The particulate matter or aerosol portion of the exhaust is of interest in this research as well as are the gaseous components. The paper outlines the sampling and anlysis techniques, and results are discussed and presented in tabular form.

McFarland, R. A., W. H. Forbes, H. W. Stoudt, J. D. Dougherty, T. J. Crowley, R. C. Moore, and T. J. Nalwalk. A Study of the Effects of Low Levels of Carbon Monoxide Upon Humans Performing Driving Tasks. Guggenheim Center for Aerospace Health and Safety, Harvard School of Public Health, May 15, 1973, 64 pp.; NTIS PB-233 894.

This research was to determine the effects of low levels of carbon monoxide on human performance in driving-related laboratory tasks and in over-the-road vehicle driving. Twenty-seven subjects ranging in age from 20 to 50 years participated in these experiments under conditions of 17% COHb, 11% COHb, and "Control," or no-administered CO. The laboratory tests measured: Complex psychomotor reactions involving simultaneous performance of a primary and secondary task; dark adaptation and glare recovery; peripheral vision; and depth perception. The driving task was designed to evaluate driver visual information needs and the steering wheel movements required to keep a vehicle properly positioned within the driving lane at different speeds.

McGrath, J. J., R. M. Schreck, and J. S. Siak. Mutagenic Screening of Diesel Particulate Material. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Tex., June 25-30, 1978, APCA Preprint 78-33.6, 11 pp.

Diesel engine technology was developed by Rudolph Diesel near the turn of the century. Since that time, the diesel engine has been widely used in various applications including ships, locomotives, mining operations, and to power automobiles. As further use of the diesel is envisaged, a concern has been expressed for possible health effects that may be associated with the assured rapid increase in total diesel emissions. Therefore, General Motors Research Laboratory has begun a widely based study to evaluate the potential of diesel exhaust material to produce or develop adverse health effects. These studies have been initiated even though earlier skin painting studies and human epidemiology studies did not demonstrate an unusual health hazard. This paper reports the first result of preliminary assessment of the mutagenic potential of diesel particulates in a pilot study.

McJilton, C., R. Frank, and R. Charlston. Role of Relative Humidity in the Synergistic Effect of a Sulfur Dioxide-Aerosol Mixture on the Lung. Science, v. 182, November 1973, pp. 503-504.

Environmental evidence concerning the physicochemical and biological factors involved in the potentiation of the irritant property of sulfur dioxide in combination with an aerosol is reported. Relative humidity is an important variable for those aerosols capable of absorbing water at relative humidities below 95%.

Marshall, W. F., and R. W. Hurn. Hazard From Engines Rebreathing Exhaust in Confined Space. BuMines RI 7757, 1973, 16 pp.

The Bureau of Mines conducted a series of experiments to determine the influence of exhaust rebreathing on emissions from various gasoline and diesel engines. Tests were conducted that simulated operation of engines in nonventilated spaces as well as in spaces with partially restricted ventilation. Results of these tests showed that exhaust rebreathing can have a marked effect on exhaust emissions and thus on the composition of the air in the working space. For the case of restricted ventilation, unacceptably high (greater than 50 ppm) levels of CO in the air of the working space resulted from exhaust rebreathing rates as low as 8 pct exhaust in the engine's intake. Operation in a nonventilated space resulted in highly critical CO levels (fatal in a few minutes) at times corresponding to 1 to 3 pounds of fuel consumed per 1,000 cu ft of space. Tests involving spaces of various sizes showed that volume of the air space per se is not important--the primary variable is fuel consumed per unit volume of air space.

Matthews, R. D. The Nature and Formation of Nitrogenous Air Pollutant Emissions From Combustion Systems. See III.B.1.

Moore, W., J. Orthoefer, J. Burkart, and M. Malanchuk. Preliminary Findings on the Deposition and Retention of Automotive Diesel Particulate in Rat Lungs. Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, Tex., June 25-30, 1978, APCA 78-33.7, 15 pp.

Suckling rats were exposed by inhalation to a 1:13 dilution of automotive diesel exhaust for varying intervals of time. On necropsy, the lungs showed a grey to black discoloration due to the deposition of the diesel particulate. The intensity of pigmentation was in direct correlation with the duration of exposure. The most consistent histological observation seen in the lungs of the various groups was the retention of particulate material in the pulmonary macrophages. All exposed animals, whether the exposure was for 8 hours or 54 days, demonstrated a black particulate material in the cytoplasm of the macrophages.

National Cancer Institute. Current Cancer Research on Effects of Chemical Carcinogens on Nucleic Acids, Proteins, and Chromosomes. Dec. 15, 1976, 25 pp.; NTIS PB-262 831.

This report is a summary of more than 100 cancer research projects being conducted in the mid-1970's relating to the effects of carcinogens on nucleic acids, proteins, and chromosomes. In addition to identifying the names and locations of the researchers, the summaries generally provide information on the project's objectives, approaches, and progress.

Obert, E. F. Internal Combustion Engines and Air Pollution. See I.A.

Pepelko, W., J. Mattox, Y. Y. Yang, and W. Moore. Effects of 28 days Exposure to Diesel Exhaust Emissions Upon Arterial Blood Gases and Pulmonary Function in Rats. U.S. Environmental Protection Agency, 1978, 12 pp.

With increasing numbers of diesel-powered vehicles on the road, the health effects of exposure to diesel exhaust emissions has become an increasing concern. Since the lung is a primary target organ, it was considered important to assess the toxicological effects of diesel exhaust emissions upon lung function and pathology. In order to assess effects upon lung function more accurately and allow for more valid extrapolation of results to humans, several studies were conducted by the EPA using cats, guinea pigs and rats. This report describes methods and results of a study designed to evaluate the effects of 28 days exposure to rats to a high concentration of diesel exhaust emissions upon arterial blood gases, pH bufffering capacity, residual volume, total lung capacity, static compliance, and hematological parameters.

Pepelko, W. E., J. K. Mattox, Y. Y. Yang, and W. Moore, Jr. Pulmonary Function and Pathology in Cats Exposed 28 Days to Diesel Exhaust. U.S. Environmental Protection Agency, 1978, 16 pp.

Young adult male cats were exposed for 28 days, 20 hours per day, to a 1.14 dilution of diesel exhaust emissions. Following termination of exposure, the following pulmonary function measurements were carried out: lung volumes, maximum expiratory flow rates (MEF), MEF at 50%, 25%, and 10% of vital capacity (VC); forced expiratory volume (FEV) after 0.2, 0.3, and 0.4 seconds, dynamic compliance, resistance and helium washout at 25, 50, 75, and 100 breaths per minute. The only significant functional change was a decrease in MEF at 10% of VC ($P = .02$). The lungs of the exposed cats appeared charcoal grey with frequent focal black spots visible from the pleural surface. Pathologic changes in the exposed cats included a predominantly peribronchiolar localization of black-pigmented macrophages within the alveoli producing a focal pneumonitis or alveolitis. In general, evidence of serious lung damage was not observed following the 28-day exposure period.

Powel, S. F., III (ed. by). Edited Transcript of Proceedings of the Workshop on Unregulated Diesel Emissions and Their Potential Health Effects. See III.A.2.

Rockette, H. Mortality Among Coal Miners Covered by the UMWA Health and Retirement Funds. Pittsburgh Univ., Pa., Dept. of Biostatistics, Contract No. HSM-99-73-80, December 1975, 144 pp.; NTIS PB-262 472.

This report presents the results of a cause-specific mortality study of the U.S. coal mining industry in which mortality of U.S. coal miners is compared with that of the total U.S. male population. A cohort of 23,233 miners was investigated during the period June 30, 1973, through December 31, 1975. The study indicates that excessive mortality from accidents, several categories of respiratory diseases, and stomach cancer is apparent in the miner cohort. Mortality from lung cancer was found to be moderately higher in the miner cohort than in the total U.S. male population.

Samfield, M. Hazardous and Toxic Air Pollutants. Energy Sources, v. 3, No. 2, 1977, Crane, Russak & Co., Inc., New York, Presented at the Am. Chemical Society Nat. Meeting, Philadelphia, Pa., April 1975, pp. 111-124.

Background and current state of knowledge with regard to hazardous and toxic air pollutants are reviewed. Secondary pollutants formed from the interaction of primary pollutants are likely to be the major hazard. Their formation and biological effects are discussed. The need for a uniform strategy and a realistic cost/risk/benefit analysis of the problem is pointed out.

Sandtodonato, J., D. Basu, and P. Howard. Health Effects Associated With Diesel Exhaust Emissions, Literature Review and Evaluation. U.S. Environmental Protection Agency, Contract No. 68-02-2800, EPA Preprint EPA-600/1-78-063, November 1978, 155 pp.

This literature review was compiled by the Health Effects Research Laboratory, Research Triangle Park, N. Car., to provide a background and reference on literature pertaining to the physical and chemical characteristics and biological effects of diesel exhaust emissions. The report is divided into various areas of research and points out where research gaps exist and makes recommendations.

Schatz, G. S. Diesel Exhaust and Human Health. News Report, July 1981, v. XXXI, pp. 8-11.

The article summarizes findings presented by the Health Effects Panel, Diesel Impacts Study Committee of the National Research Council in its 1981 report entitled Health Effects of Exposure to Diesel Exhaust (Impacts of Diesel-Powered Light-Duty Vehicles). The panel reported that some of the components of diesel exhaust have been shown in laboratory tests with bacteria, animal cells, and tissues to be toxic, mutagenic, or carcinogenic and many of these substances are adsorbed on diesel exhaust particulates small enough to be inhaled and deposited deep within the lungs. The panel concluded, however, that research results are not definitive enough to prove whole diesel exhaust either harmful or relatively innocuous. Information is needed on how mutagenic and carcinogenic substances from diesel diesel exhaust particulates act in the body and studies of the carcinogenicity of diesel-exhaust gases are needed. The article also cites other observations and recommendations.

Schreck, R. M. Health Effects of Diesel Exhaust. Biomedical Sciences Dept., General Motors Research Laboratories, Warren, Mich., GMR-2684, May 1978, 17 pp.

Because of the sooty black exhaust smoke it can generate, the diesel engine has operated for many years under a dark cloud of fear of potential health effects. The purpose of this report is to acquaint the reader with the claimed health effects of exposure to diesel exhaust and to analyze the validity of these claims. Regulated gaseous emissions from diesels are relatively low, and do not represent an unusual hazard compared to gasoline engines. Particulate emissions, although shown to contain trace amounts of carcinogens, have not been demonstrated to represent any significant additional hazard to the respiratory system of human subjects. However, since wider use of diesel engines is anticipated, additional carefully planned, well instrumented health effect studies are needed to adequately establish their health impact.

Schreck, R. M., J. J. McGrath, S. J. Swarin, W. E. Hering, P. J. Groblicki, and J. S. MacDonald. Characterization of Diesel Exhaust Particulate for Mutagenic Testing. See III.A.2.

Sinha, B. P., and S. Pande. Hazards in Diesel Smoke. J. Indian Medical Assoc., v. 49, No. 7, Oct. 1, 1967, pp. 330-332.

Four mongrel dogs with control group of animals having standard meals were subjected to diesel fume exposures in a closed chamber, every day for 15 minutes for 5-8 weeks, developed anorexia, dermatitis, conjunctivitis, scleritis, ulceration in the extremities, generalized wasting, dullness, tonic and clonic convulsions, emphasema, pulmonary oedema, and death. The autopsy revealed lung and liver congestions. The microscopic findings had marked congestions of pulmonary vessels, thickening of Ressiessen's muscles interalveolar walls, extensive bullous emphasema with ateletasis, pulmonary oedema with atelectasis, pulmonary oedema with hyaline membrane formation, hyperplasia of septal cells but absence of leucocytic infiltrations. The liver elicited central and portal vein congestions, disruption of cord pattern and centrilobular degenerations.

Society of Automotive Engineers, Inc. Medical Aspects of Air Pollution. Detroit, Mich., Jan. 14, 1971, SAE Publications 36, 74 pp.

The collection of papers included in this report deals with a variety of medical issues relating to air pollution. Titles of papers presented are:

Anatamony and physiology of the respiratory system
Biological significance of nitrogen oxides
Sulfur oxides and particulates
Basic physiology of carbon monoxide
Health aspects of airborne polycyclic hydrocarbons
Health aspects of atmospheric exposure to lead
From air quality criteria to control regulations.

Speizer, F. E., and N. R. Frank. A Comparison of Changes in Pulmonary Flow Resistance in Healthy Volunteers Acutely Exposed to SO_2 by Mouth and by Nose. British J. of Industrial Medicine, v. 23, 1966, pp. 75-79.

On separate occasions, healthy male volunteers were exposed either by nose or by mouth to one of two concentrations of sulphur dioxide, 15 and 28 ppm. Exposure to SO_2 lasted 10 minutes. Pulmonary flow resistance (RI) was measured by the oesophageal catheter method, and the lung volume was measured by a modification of the gas-compression method; when SO_2 was administered by nose, nasal flow resistance (Rn) was measured by means of a catheter placed in the posterior pharynx. The increase in RI was greater when SO_2 was administered by mouth than when it was administered by nose. Similarly, irritative symptoms of the posterior pharynx and chest were more common during exposure by mouth. These findings suggest that the mouth is less effective than the nose as an absorptive surface for SO_2.

Stara, J. F., W. Moore, and A. W. Breidenbach. Toxicology of Atmospheric Pollutants Resulting From Fuel Additives and Emissions Associated With the Use of Automobile Catalytic Converters. Proceedings of an International Symposium, Paris. Recent Advances in the Assessment of the Health Effects of Environmental Pollutants, v. II, June 24-28, 1974, pp. 751-772.

The purpose of this paper is to present the definitive toxicologic investigative approach employed in EPA's Cincinnati laboratory for testing automotive emissions, fuel additives, and emission components related to the catalytic converter emission control system. A matrix for investigating the toxicology of individual pollutants and emissions from mobile sources has been used to determine the potential toxic effects. The presented data are illustrations of the response of selected animal models to the catalysttreated exhaust and to individual components such as platinum and palladium. The biological parameters studied were markedly influenced by the use of the converter.

Stefanko, R., R. V. Ramani, P. C. Thakur. Digital Simulation of Diesel Exhaust Contamination of Mine Ventilation Systems. See IV.K.

U.S. Dept. of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

U.S. Dept. of Health, Education, and Welfare. The Use of Diesel Equipment in Underground Coal Mines. See III.B.1.

U.S. Dept. of Health, Education, and Welfare. Criteria for a Recommended Standard....Occupational Exposure to Oxides of Nitrogen (Nitrogen Dioxide and Nitric Oxide). National Institute for Occupational Safety and Health, HEW Pub. No. (NIOSH) 76-149, March 1976, 195 pp.

This report presents the criteria and the recommended standards based thereon prepared to meet the need for preventing occupational diseases arising from exposure to oxides of nitrogen. The document fulfills the responsibility of the secretary of Health, Education, and Welfare, under the Occupational Safety and Health Act of 1970 to "...develop criteria dealing with toxic materials and harmful physical agents and substances which will describe... exposure levels at which no employee will suffer impared health or functional capacities or diminished life expectancy as a result of his work experience." The proposed standards apply only to the processing, manufacture, and use of the oxides of nitrogen, or to their release as intermediates, byproducts, or impurities therefrom. The standards are designed to protect the health and safety of workers for up to a 10-hour workday, 40-hour workweek over a working lifetime. In addition to the detailed criteria and standards, the report lists deficiencies in data revealed during the development of the recommended standard for occupational exposure to oxides of nitrogen.

U.S. Environmental Protection Agency. An Ordering of the NIOSH Suspected Carcinogens List Based on Production and Use Data. Contract No. EPA 68-01-4103, March 1978, 67 pp.; NTIS PB 278 015.

Building on an earlier EPA report entitled "On Ordering of the NIOSH Suspected Carcinogens List Based Only On Data Contained in the List" (EPA 560/1-76-001), the present document represents the second OTS effort to arrange the substances presented in the NIOSH Suspected Carcinogens Subfile in a meaningful and useful way for EPA purposes. Employing readily available information on the uses and commercial significance of the chemicals listed in the NIOSH Subfile, OTS has further refined the initial ordering into four tables contained in this report.

U.S. Environmental Protection Agency. Research Highlights 1978. See X.B.

Viadana, E., I. D. Bross, and L. Houten. Cancer Experience of Men Exposed to Inhalation of Chemicals or to Combustion Products. J. of Occupational Medicine, v. 18, No. 12, 1976, pp. 787-792.

This article identifies instances of excess cancer in men who were exposed to the inhalation of chemicals or combustion products. The survey covers 13 occupations and 17 cancer sites. It is based on a detailed statistical analysis of the relevant subseries from an overall series of approximately 17,000 patients admitted to Roswell Park Memorial Institute in Buffalo, New York, between 1956 and 1965. Where necessary, the analysis takes into account other collateral variables, such as age at time of diagnosis, smoking habits, and duration of employment. It was found that the occupations most highly associated with an increased incidence of cancers belonged to the chemical subgroup. The occupations in the combustion subgroups appeared to be less associated with an increased incidence of cancers.

Volkwein, J. C., and P. F. Flink. Respirable Dust Survey of an Underground Oil Shale Mine and Associated Mining Facility. BuMines IC 8728, 23 pp.

The Bureau of Mines conducted a field study of respirable dust concentrations at an underground room-and-pillar oil shale mine and at the above-ground milling facility to determine the dust generation sources, personal respirable exposure, characteristic minerals, and size distribution of the dust. Major dust sources in the mine were the scaling and blasthole drilling operations, and major dust sources in the processing mill were the screening and crushing operations. Principal minerals found in the airborne respirable dust were albite, analcite, calcite, dolomite, quartz, and orthoclase. Average alpha-quartz content of mine and mill respirable dust samples was 4.1 pct and 15.5 pct, respectively. Carbonaceous material such as diesel particulate accounted for approximately 75 pct of the respirable particulate found in the mine. The average coefficient of variance of respirable dust concentrations measured with approved personal dust samplers in the mine and mill was 7.6 pct, the best precision observed to date with the personal dust sampler operated in the field.

Wei, E. T., Y. Y. Wang, and S. M. Rappaport. Diesel Emissions and the Ames Test: A Commentary. J. of the Air Pollution Control Assoc., v. 30, No. 3, March 1980, pp. 267-271.

The decision by the U.S. Environmental Protection Agency (EPA) to examine diesel exhaust products for carcinogenic as well as other toxic properties has alarmed users of diesel engines because controls on diesel emissions will be costly. The principal new evidence that triggered the EPA's concern over the carcinogenic properties of diesel emissions was the observation that organic extracts of diesel particulates from medium and heavy duty engines had mutagenic activity in the Ames microbial assay, a short-term, standardized test which estimates the mutagenic and carcinogenic potential of some chemicals. In this article, the limitations and value of the Ames test data on the mutagenic properties of diesel emissions are critically reviewed and discussed.

Wenberg, R. V. Underground Mines and Diesels--The Health and Safety Aspects. Min. Cong. J., January 1979, pp. 21-25.

The author reviews the historical conflicting viewpoints regarding the possible health and safety hazards posed by dieselization of underground mines. The following are specifically cited as evidence of the diesel's safe and productive performance: (1) Results of AMC's 1977 survey of a broad cross section of the U.S. mining industry; (2) a study (by the Mining Association of France) of 30 underground iron mines and of the production and safety record improvements that occurred in those mines over a 25-year period during which dieselization occurred; and (3) the experience of St. Joe Minerals Corp. with diesel machinery in underground mines in Missouri.

Wiester, M. J., R. Iltis, J. F. Swan, and W. Moore. Altered Function and Histology in Guinea Pigs After Inhalation of Diesel Exhaust. U.S. Environmental Protection Agency, 1978.

Health effects of inhaled diesel engine exhaust were evaluated in infant guinea pigs following 4 and 8 weeks of exposure. Animals were exposed to 1 part exhaust diluted by 13 parts clean air for 20 hours/day, 7 days/week. Lung function, ECG, growth rate and histopathology were assessed following exposure. After 4 weeks, animals exposed to exhaust showed a 35% increase in pulmonary air flow resistance, and a small but significant decrease in heart rate. Necroposy, after 8 weeks, showed exhaust-exposed animals to have black discoloration of the lungs and increased lung to body weight ratios. Microscopic examination of the lungs from these animals revealed goblet cell hypertrophy of the trachealbronchial tree and black pigmented macrophages in alveoli and in draining lymph nodes.

B. Environmental Factors Affecting Emissions

1. Humidity

Burrows, J. H. J. The Ventilation of South African Gold Mines. See IV.K.

Gaur, R. R., and R. D. Garg. On Testing and Performance Prediction of Naturally-Aspirated and Turbocharged Automotive Diesel Engines Under Varying Ambient Conditions. Proceedings of the Third Nat. Conf. on I.C. Engines and Combustion. Sarita Prakashan, Meerut, India, Dec. 10-12, 1976, pp. 75-87.

A knowledge of the performance of engines under varying ambient conditions is essential for accurate site rating of high altitude-operating engines and for making day-to-day corrections for normal engines. This paper considers the two important aspects of altitude performance study of automotive diesel engines, viz, testing and performance prediction under varying ambient conditions. The methods discussed and the test facility developed at I.I.T. Delhi are described. The criteria for site rating are given and various prediction methods are discussed. Finally, typical derating factors for different types of engines and important prediction formulae are given which are useful for derating of naturally aspirated and turbocharged automotive engines.

Krause, S. R. Effect of Engine Intake--Air, Humidity, Temperature, and Pressure on Exhaust Emissions. See V.B.2.

B. Environmental Factors Affecting Emissions
2. Temperature

Burrows, J. H. J., R. Hemp, F. H. Lancaster, and J. H. Quilliam. The Ventilation of South African Gold Mines. See IV.K.

Dicksee, C. B. Influence of Atmospheric Pressure and Temperature Upon the Performance of the Naturally Aspirated Four-Stroke C.I. Engine. Proc. Inst. Mech. Engrs., No. 3, 1959-60, pp. 83-99.

The compression-ignition (C.I.) engine differs from other types of internal-combustion (I.C.) engines in that the fuel supply is entirely independent from the air supply and, further, that at all times a large excess of air is present. It is to be expected therefore that although the weight of air received will be influenced by atmospheric changes, the effect of these changes will be much less than in the case of an engine in which the fuel supply is dependent upon the air flow. Basically the effect is a change in air utilization, that is air/fuel ratio. This is not universally realized as is shown by the fact that, quite frequently, a formula developed for correcting petrol-engine test results for atmospheric changes is applied to C.I. engine figures. The experiments described were designed to show the absurdity of this procedure and, if possible, to provide information from which a method of correcting C.I. engine results could be derived. The first objective is very definitely achieved; for the second, it is shown that a change in air utilization has precisely the same effect upon the indicated horsepower no matter whether the change is caused by the fuel delivery being varied while the air supply remains the same or the fuel supply is kept constant and the air supply varied by a change in temperature or in pressure.

Gaur, R. R., and R. D. Garg. On Testing and Performance Prediction of Naturally-Aspirated and Turbocharged Automotive Diesel Engines Under Varying Ambient Conditions. See V.B.1.

Grinberg, L., and L. Morgan. Effect of Temperature on Exhaust Emissions. Presented at the Combined Commercial Vehicle and Fuels & Lubricants Meetings, Chicago, Ill., June 17-21, 1974, SAE Preprint 740527, 12 pp.

A program has been completed to study the effects of ambient temperature on exhaust emissions. It consisted of determining the cold start emission levels of two late model passenger cars at temperatures of +70, +40, and -10°F with two test fuels of different midrange volatility characteristics. The ambient temperature was found to have a pronounced effect on exhaust emissions. A reduction of the test temperature from +70 to -10°F resulted in a manyfold increase in hydrocarbon and carbon monoxide emissions. Most of this increase in emissions, as well as an associated deterioration in

fuel economy, occurred during the initial 5 min period after a cold start. The ambient temperature was found to have no major effect on the levels of pollutants emitted during the fully warmed-up operation of cars. Relative to the effects of ambient temperature and the vehicle characteristics, the midrange volatility of the fuel was concluded to have only a minor effect on exhaust emissions.

Karim, G. A., and S. Khanna. The Effect of Very Low Air Intake Temperature on the Performance and Exhaust Emission Characteristics of a Diesel Engine. Presented at the Nat. Combined Farm, Construction & Ind. Machinery and Powerplant Meetings, Milwaukee, Wis., Sept. 9-12, 1974, SAE Preprint 740718, 12 pp.

The paper describes some of the operational and exhaust emission characteristics of a single-cylinder direct-injection diesel engine that was operated warm under a wide range of intake air temperatures extending down to -45°F and occassionally -60°F. The operating range considered included the no-load and partially motored regions.

Krause, S. R. Effect of Engine Intake-Air Humidity, Temperature, and Pressure on Exhaust Emissions. Presented at the Nat. Combined Fuels & Lubricants, Powerplant and Truck Meetings, St. Louis, Mo., Oct. 26-29, 1971, SAE Preprint 710835, 42 pp.

Variations in atmospheric humidity, temperature, and barometric pressure substantially affect almost all engine mass and volume exhaust emissions. Emission measurements were conducted on seven engines in accordance with the Gasoline Fueled Heavy-Duty Engine procedures in the 1970 Federal Register. Equations with satisfactory correlation were derived to adjust NO mass and volume emissions taken at test conditions to a standard condition of 75 grains of moisture. Less satisfactory equations were derived to similarly correct HC emissions for moisture effects and to correct CO emissions to standard conditions of 90°F and 29.92 in Hg. Unfortunately, no other equations could be derived to describe the behavior of all seven engines because engine-to-engine variation was too great. Emissions from different engines are affected differently at various atmospheric conditions. Therefore, accurate emission testing on some engines can only be accomplished by controlling inlet air temperature and by testing on days of similar barometric pressure.

World Health Organization. Health Factors Involved in Working Under Conditions of Heat Stress. Geneva, 1969, WHO Technical Report Series No. 412, 32 pp.

In industries such as mining, steel or glass manufacture, agriculture, and road building, workers are often exposed to severe environmental heat stress. Hard physical work or exercise in hot surroundings is rightly considered the main hazard, for the total heat load on the body is in fact

the sum of environmental and metabolic heat. In this paper physiologists, engineers, and doctors evaluate what is known about heat stress in three important aspects. These are (1) the components of heat stress, (2) man's responses to working in heat, in terms of body temperature, heart rate and sweat loss, and (3) the kind of hot conditions that men tolerate well, not so well, or for strictly limited periods of time.

B. Environmental Factors Affecting Emissions
3. Altitude

Burrows, J. H. J., R. Hemp, F. H. Lancaster, and J. H. Quilliam. The Ventilation of South African Gold Mines. See IV.K.

Dennis, J. W. Turbocharged Diesel Engine Performance at Altitude. Presented at the Nat. Combined Fuels & Lubricants Powerplant and Truck Meetings, St. Louis, Mo., Oct. 26-29, 1971, SAE Preprint 710822, 20 pp.

The effect of altitude on the performance of two turbocharged prechamber diesel engines and one direct-injection diesel engine has been studied in a test cell. One prechamber engine was tested at altitudes up to 16,000 ft. The data from these tests are presented and compared with performance at standard conditions. Using the data, an analytical method of predicting the performance of turbocharged diesel engines at altitude has been developed. An iterative computer program, using part-load data taken at standard conditions, is used for the prediction. Comparison is made with the simulated altitude data and with other calculation methods.

Dicksee, C. B. Influence of Atmospheric Pressure and Temperature Upon the Performance of the Naturally Aspirated Four-Stroke C.I. Engine. See V.B.2.

Gaur, R. R., and R. D. Garg. On Testing and Performance Prediction of Naturally-Aspirated and Turbocharged Automotive Deisel Engines Under Varying Ambient Conditions. See V.B.1.

Krause, S. R. Effect of Engine Intake-Air Humidity, Temperature, and Pressure on Exhaust Emissions. See V.B.2.

Mallette, F. S. Problems and Control of Air Pollution. See VI.B.2.

Schmidt, W., D. Venhuis, and S. Hinkle. Prediction and Measurement of Two-Stroke Cycle Diesel Engine Performance and Smoke at Altitude. Presented at the Energy Technol. Conference and Exhibit, Houston, Tex., Sept. 18-22, 1977, ASME Preprint 77-DGP-3, 12 pp.

A simplified mathematical model for predicting the altitude performance and smoke of a turbocharged two-stroke cycle diesel engine is developed utilizing a baseline perturbation methodology. The predicted performance at altitude is compared to the actual performance of an engine obtained from test results in an altitude chamber. Considering the simplifying assumptions made in developing the model, the results are satisfactory. This paper describes the modeling and testing procedure of a turbocharged two-stroke cycle diesel engine at altitude.

Sorrels, D. E., D. R. Liljedahl, and J. L. Terry. Impact of Altitude on Vehicular Exhaust Emissions. Presented at the Automobile Eng. Meeting, Toronto, Canada, Oct. 21-25, 1974, SAE Preprint 741033, 12 pp.

The body of information presented in this paper is directed to those individuals concerned with the effects that changing altitude has on vehicle exhaust emissions. Emission data were developed from a sample of resident vehicles in Leadville, Colo., at a nominal elevation of 10,000 ft above sea level. Emissions-concentration sampling was performed on each vehicle in the sample at loaded and unloaded engine operating conditions. Concentration data were then converted to mass data using equations developed from keymode and mass emissions testing of vehicles operating in the Denver area. Mass emissions data were then combined with mass data developed from vehicles operating in a metropolitan area situated near sea level (Chicago) to define the emissions versus altitude relationships for exhaust hydrocarbons (HC), CO, and NO_x. HC and CO emissions at idle were also examined with respect to the applicability of a statewide minimum HC/CO idle emission standard for the State of Colorado. Contrary to expectations both mass CO emissions and CO emissions at idle were found to be lower from 1967 and older model-year vehicles operating in the Leadville area than from a similar sample of vehicles operating in the Denver area. These findings would indicate that vehicles operating at the higher elevations were probably modified in an attempt to improve vehicle operating characteristics. Also, since idle CO emissions were generally lower from vehicles operating at the extremely high elevations than from vehicles operating at lower elevations, a minimum HC/CO idle emission standard appears to impractical for statewide application.

VI. INDUSTRIAL HAZARDS OF DIESEL EQUIPMENT USAGE

A. Operational Safety and Accidents

Alcock, K. Safe Use of Diesel Equipment in Coal Mines. See VII.A.

Allen, V. H. The Safe Operation of Diesel Scooptrams in Emergency Situations. Presented at the Annual Meeting of the Mines Accident Prevention Association of Ontario, Toronto, Canada, May 1977, 7 pp.; available for consultation at Twin Cities Research Center, Minneapolis, Minn.

This paper discusses some emergency situations that could happen on a scooptram vehicle. The paper includes such situations as runaway, fire, upsetting, and structural design. The article explains the causes and recommends preventive measures that should be observed in order to avoid such accidents.

American Mining Congress. Summary: AMC Diesel Mine Equipment Safety/Productivity Survey. See VII.A.

Coward, H. F., and H. T. Ramsay. Ignition of Firedamp by Means Other than Electricity and Explosives: A Review. Safety in Mines Research Establishment, Research Report No. 231, October 1965, 64 pp.

The first line of defense against the possibly disastrous results of a firedamp explosion in a coal mine is abundant ventilation in roadways and working places. Good ventilation by itself cannot, however, provide a complete solution for the problem at all times and in all places, for between the place of release of firedamp from the strata and the region where it has become diluted enough for safety there must always be a more or less extensive fringe of inflammable mixture. Hence the need to know, in order to eliminate as far as possible, all the potential sources of ignition of firedamp in a mine. The large amount of research done on this subject is summarized in this report.

Desy, D. H., L. A. Neumeier, and J. S. Risbeck. Methane Ignition by Frictional Impact Between Aluminum Alloys and Rusted Steel. BuMines RI 8005, 1975, 30 pp.

The Bureau of Mines has conducted research on the ignition of methane-air mixtures by sparks caused by frictional impact of aluminum alloys on rusted steel at typical coal mine fan speeds. The objectives were to establish the incendivity of aluminum alloys under these conditions, to investigate differences between aluminum alloys, and to evaluate substitute materials for the aluminum-steel combination. With a specially designed apparatus, three commercial aluminum casting alloys and a number of experimental aluminum alloys were tested for incendivity of the frictional impact against rusted steel in flammable methane-air mixtures. All aluminum alloys tested produced some ignitions. Of the experimental alloys, the harder alloys and those containing silicon tended to be more incendive than the others. With the normal experimental conditions, constructional steel, stainless steel, brass, and plastic did not cause ignition of methane-air mixtures in frictional impact against rusted steel. Some ignitions occurred with constructional steel at high speed in more flammable gas mixtures enriched with oxygen. From these findings, it is suggested that constructional material combinations other than the aluminumm-steel combustion would minimize this incendive hazard. A detailed description is given of previous research, and comparison is made with present results where appropriate.

Fife, W. E. Designing Safety Into Underground Mining Equipment--Dust Control. Min. Cong. J., September 1973, pp. 44-48.

The continuous miner has become the dominant machine in underground mining and also the biggest generator of coal dust. The article discusses ways of reducing coal dust. Water sprays are the most effective and water and chemicals has been used with varying success. The author also discusses two techniques to control dust. The most developed technique is the "wet head" technique. This applies water at the point where the mining tool is cutting the coal from the face. The second technique discussed is to remove the dust by using a coal dust collection device built into the mining machine. Based on the information to date, the machine mounted dust collector is the most effective method of dust control currently available to the mine operator.

Fowle, T. I. Air Compressor Fires and Explosions. Tribology Practical Reviews, Inst. Mech. Eng., London, 1975, pp. 7-12.

The causes of compressor fires and explosions have not, until recently, been fully appreciated but in the main they arise from the ignition of oil mist or vapor. This is spontaneous and occurs when heat is generated more rapidly than it can be dissipated. In this contribution some of the factors which create hazard conditions and the mechanisms by which ignition occurs, are described, with advice on good operational practice which, if followed, will prevent the formation of combustible masses.

Gilbert, S. The Use of Diesel Engines Underground in British Coal Mines. See VIII.J.

Greene, P. Designing Safety Into Underground Mining Equipment--Fire Suppression on Face Machinery. See VI.B.1.

Holtz, J. C. Safety With Mobile Diesel-Powered Equipment Underground. See VII.A.

Holvenstot, C. Designing Safety into Underground Mining Equipment--Noise Abatement. Min. Cong. J., September 1973, pp. 39-43.

Noise from mining machinery is quite complex. The noise produced by a continuous miner comes from the conveyor chain, friction, scraping, vibration, gear noise, hydraulic noise from pumps, engine noise and noise due to the picks acting on the coal. This article studies ways of reducing these noises and the author presents a list of 23 ways to reduce noise on mining machinery.

Journal of the Mine Ventilation Society of South Africa. Presidential Address. See IV.K.

Journal of the Mine Ventilation Society of South Africa. Presidential Address (conclusion). Cited under part 1, January 1976 issue. See IV.K.

Karlovsky, J., Jr. Designing Safety Into Underground Mining Equipment--Cabs and Canopies. Min. Cong. J., September 1973, pp. 55-57.

The Federal Coal Mine Health and Safety Act of 1969 and amendment in the Federal Register of October 3, 1972, require that in all coal mines substantially constructed cabs and canopies will be required on electric face equipment, including shuttle cars, to protect operators of such equipment from falls of the roof, face and rib. Therefore, this article describes the advantages and disadvantages of cabs and canopies. The Bureau of Mines has compiled data from 1966-1972 on fatalities from roof falls. There was a total of 575 fatalities and it was determined that if

cabs and canopies would have been used, this number would have decreased to 354. The biggest disadvantage is that the cabs and canopies reduce the vision of the operator.

Knight, G. C., S. F. Jones, and P. Kenny. Hydraulic Fluid Fires. (Tribology Practical Reviews, Inst. Mech. Eng., London), 1975, pp. 18-22.

The use of hydraulically-actuated transmissions has increased considerably in the past 10 years but fire risk has been much diminished by successful research resulting in a range of fire-resistant hydraulic oil formulations. But the fluid used must be carefully selected to ensure compatibility with a particular equipment in terms of materials, lubricating properties, auto-ignition at high temperatures, and so on, if a maximum operating efficiency is to be obtained parallel with decreased fire hazard. This article is an edited version of a fuller survey on the subject written by the three authors, all of whom have been closely concerned with research in fluid fire problems.

Mason, W. A. Electrical Hazards in Underground Bituminous Coal Mines. MESA IR 1018, 1975, 5 pp.

An investigation of 1,404 injuries related to electricity in underground bituminous coal mines revealed that more than 96 pct of all electrical accidents were caused by; (1) arcs resulting in burns, (2) electrically generated heat resulting in burns and scalds, and (3) electrocution and shock. Data analysis indicates that a reduction in electrical accidents is immediately possible by reducing defective splices and insulation breaks and by proper placement of trolley poles. Sixty-six pct of the mine fires investigated by the Bureau of Mines through 1972 and 21 pct of all methane ignitions can be attributed to electrical ignition sources and inadequate design of electrical equipment used in the mining environment.

Mining Enforcement and Safety Administration. Injury Experience in Coal Mining. 1972, MESA IR 1074, 139 pp.

This Mining Enforcement and Safety Administration (MESA) report reviews in detail accident, injury, and illness experience in the anthracite and bituminous coal industries of the United States for 1972. Forty-eight tables summarize the reported work injuries by work location, principal cause of injury, degree of injury, part of body injured, and nature of injury, and also present correlative information on employment, worktime, and operating activity. Concise historical information is presented in nine tables.

Mining Enforcement and Safety Administration. Injury Experience in Coal Mining. 1974, MESA IR 1076, 136 pp.

This Mining Enforcement and Safety Administration (MESA) report reviews in detail accident, injury, and illness experience in the anthracite and bituminous coal industries of the United States for 1974. Fifty-seven tables summarize the reported work injuries by work location, principal cause of injury, degree of injury, part of body injured, and nature of injury, and contain correlative information on employment, worktime, and operating activity. Concise historical information is presented in nine tables.

Mining Engineering. Diesel Power Underground--Productivity Potential Sparks Controversy. See IV.L.

Mogan, J. P. Frictional Hazard Criteria for Mobile Diesel Powered Mining Equipment. See VI.B.1.

Ramani, R. V., and G. W. Kenzy. Safety Considerations With Diesels in Underground Coal Mines. Presented before the Second Symposium on Underground Mining, Louisville, Ky., Oct. 19-21, 1976, pp. 13-35.

This paper examines some aspects of diesel power in mines. The introduction and use of diesels in the mining industry is reviewed. The health and safety aspects are discussed. Potential application areas are enumerated with a discussion of the advantages and disadvantages. Laws and regulations pertaining to air quality and quantity are presented. Since control of toxic atmospheres necessitates monitoring of the exhaust concentrations, the general area of diesel exhaust monitoring is reviewed. The present controversy regarding the introduction of diesels in coal mines is discussed.

Rock Products. Safer Refueling of Heavy Equipment. May 1969, pp. 31-32.

This article describes a closed connection refueling system for construction equipment. Because it is a closed system the fuel can be filled at the bottom of the tank allowing the attendant to fuel the equipment while standing on the ground. This is safer and much faster than the conventional way of refueling.

Strawson, H. Electrostate Explosions and Fires. (Tribology Practical Reviews, Inst. Mech. Eng., London). 1975, pp. 13-17.

Scientists and engineers have been aware of the potential hazard from the production of static electricity for over 80 years. For example, Richter published recommendations on additives to benzine designed to reduce "static" in 1893, and Shell's researches into "electrostatic phenomena accompanying the flow of liquids" go back to 1929. In this article, the third in the present series of Tribology Practical Reviews, the author reviews the mechanism of "static" production from charge generation through to the creation of spark, the ranges of composition of explosive mixtures, and measures for the avoidance of hazard through control, prevention and the limiting of spark energy. Space limitations dictate a wide and generalized review but an extensive bibliography will enable any engineer working with constituents that may constitue an explosive mixture, to make further study of this subject.

U.S. Department of Health, Education, and Welfare. The Use of Diesel Equipment in Underground Coal Mines. See III.B.1.

U.S. Department of Labor. Occupational Safety and Health: A Bibliography. U.S. Department of Labor, March 1974, 360 pp.; NTIS PB 230 147.

This publication consists of an annotated bibliography of published sources treating occupational safety and health both generally and specifically. The literature included deals primarily with causes, and possible prevention, of occupational injury and disease, thus indicating the thrust, in its compilation, toward providing information contributory to the total understanding of preventing illnesses and injuries, and eliminating potential hazards in American occupational activity. References listed comprise essentially English-language books and pamphlets published since 1950, and articles from periodicals published since 1970. To afford maximum ease of utilization, subjects are classified in keeping with topical treatment of the occupational safety and health standards.

B. Control of Diesel-Related Mine Hazards

1. Flameproofing and fire protection

Atkinson, E. L., and G. W. Leach. The Replacement of Conventional Gathering-Arm Loaders and Shuttle Cars With Diesel-Operated Load-Haul-Dump Units at Greenside Colliery. See VI.B.2.

Brown, G. K. List of Certified Electrical Apparatus, Certified Fire-Resistant Conveyor Belting, and Certified Diesel Engines for Coal Mine Use (4th ed). Canada Center for Mineral and Energy Technol., November 1975, Report ERP/ERL 75/130, 69 pp.

The information presented in this circular is a complete list of the electrical apparatus certified by the Department of Energy, Mines and Resources as being suitable for use in coal mines. Also listed are conveyor belting certified fire-resistant by the Department and diesel engines and machines certified for use underground in coal mines. The period covered is from the opening of the certification service in September 1955 until October 31, 1975. This report is the fourth of a series of lists of certified apparatus which will be issued from time to time. The scope and background of the certification service are covered briefly in the introduction and references are given for those interested in obtaining more detailed information.

Gray, J. T., and A. A. Johnston. Engine Experiments With Fire Safe Fuels. U.S. Army Fuels and Lubricants Res. Lab., Contract No. DAAK02-73-C-0221, January 1975, 86 pp.; NTIS AD/A-031 123. See II.B.

Greene, P. Designing Safety Into Underground Mining Equipment--Fire Suppression on Face Machinery. Min. Con., September 1973, pp. 49-54.

Face machine fires have been around ever since electrically-powered face equipment has been employed. This article explains what must be considered when designing a fire suppression system that is to be used on mining equipment. The article explains the standards set up by the U.S. Bureau of Mines that the system must meet. The article describes a system that uses dry chemicals and also one that uses water. The report explains the advantages and disadvantages of these systems.

Holtz, J. C. Safety With Mobile Diesel-Powered Equipment Underground. See VII.A.

Institute of Machinery and Institute of Chemistry of Westgalische Berggewerkschaftskasse. See IV.D.

James, R. S. Effect of Temperature on Flame-Arresting Properties of Flat Joints in Explosion-Proof Mine Equipment. BuMines RI 4639, January 1950, 27 pp.

In explosion-proof mine equipment, the design of the flange joints is especially important. Considerable investigation has been carried on by safety agencies regarding the flame-arresting properties of various types of flange joints for different conditions of explosive mixtures, ignition location, volume of container, length of flame path, spacing or separation of the flanges, and other variables. This report studies the influence of joints in stopping flame propagation of explosions of methane-air mixtures. The results indicated that the safety of flat joints is reduced when the joint is heated to temperatures above ambient. For example, at 80°F a separation of 0.045 inch caused flame to propagate through the joint, when heated to 500°F flame propagated through the joint at 0.035 inch. Therefore it is important to keep the separations of joints to an absolute minimum.

Mining Engineering. Diesel Power Underground-Productivity Potential Sparks Health Controversy. See IV.L.

Mogan, J. P. Frictional Hazard Criteria for Mobile Diesel Powered Mining Equipment. Canada Center for Mineral and Energy Technol., Energy Res. Program, Min. Res. Lab., Report No. ERP/MRL 78-38 (TR), February 1978, 9 pp.

Certified mobile diesel equipment intended for use in coal mines is equipped with ancillary components which prevent propagation of intake and exhaust backfires and excessive exhaust and coolant temperatures. Variations in requirements from jurisdiction to jurisdiction reflect differing opinions as to the appropriate level of safety rather than disagreement on the basic principles. There is no similar unanimity in regard to the potential hazards which may result from frictional or impact heating which may be produced from normal or abnormal operation of brakes, clutches, and starters. Examination of the literature, however, suggests that there may be sufficient information available to estimate "go-no-go" criteria for the ignition of methane-air or coal dust by these sources. The energy input available from equipment which is in actual or proposed use may then be calculated or experimentally assessed, so that a comparison with these "go-no-go" criteria can indicate an appropriate level of precaution. This report describes the first stage of the process assessment of suitable "go-no-go" criteria from the literature.

National Fire Protection Association, Inc. (Boston, Mass.). Stationary Combustion Engines and Gas Turbines. NFPA 37, 1979, 23 pp.

This standard applies to the installation and operation of stationary combustion engines and gas turbines. The standard also applies to portable engines which remain connected for use in the same location for a period of one week or more and which is used instead of or to supplement stationary engines. The standard does not apply to engines used to propel any mobile structure.

National Fire Protection Association, Inc. (Boston, Mass.). Storage and Handling Liquefied Petroleum Gases. NFPA 58, 1979, 180 pp.

This book explains the standards required for most liquid petroleum gas systems. It explains the components of the system such as, what types of containers to use, piping and tubing, valves, etc. It also explains how different liquid petroleum systems should be installed along with other detailed information.

Oil Companies Materials Association. Recommendations for the Protection of Diesel Engines Operating in Hazardous Areas. Publication No. MEC-1, Heyden and Son Ltd., London, 1977, 14 pp.

A number of incidents which have occurred in the petroleum, petrochemical and allied industries have shown that diesel engines can provide a source of ignition for flammable vapors and also create a hazard by overspeeding through ingestion of these vapors. Therefore, the OCMA set up recommendations for the protection of diesel engines operating in hazardous areas which are presented.

Underground Mines Locomotive Group of the Locomotive and Allied Manufacturers' Association of Great Britain. British Diesel Mines Locomotives. London, 1st ed., 1959, pp. 24-33.

This article briefly explains the emissions emitted from a diesel engine, such as CO, CO2, SO2, NO_x, O2 and aldehydes. One way to reduce SO2 is to use an exhaust water scrubber. This forces the exhaust gas through a layer of water which cools the exhaust gas and dissolves the SO2 in the water. The emissions of O2, CO, CO2 and NO_x are only slightly reduced by the process. The article also discusses flame traps which are to be used on exhaust and intake manifolds so that if there is a valve failure the trap won't allow any flame to pass through. The results indicated that a gap size of 20 thousandths of an inch should be used for the flame trap.

B. Control of Diesel-Related Mine Hazards

2. Certification and approval

Atkinson, E. L., and G. W. Leach. The Replacement of Conventional Gathering-Arm Loaders and Shuttle Cars With Diesel-Operated Load-Haul-Dump Units at Greenside Colliery. J. of the South African Institute of Min. and Metallurgy, v. 79, No. 9, April 1979, pp. 241-248.

The paper discusses the reasons for the introduction of load-haul-dump (LHD) units into Greenside Colliery, and the circumstances leading to the replacement of conventional mechanized equipment on a trial basis in the mining operations on No. 2, 4, and 5 seams. An outline is given of the factors governing the selection and introduction of these units into coal mining, and the associated mining and engineering aspects involved in the optimization of their use. Operating statistics comparing the performance of conventional and LHD equipment are included.

Brown, G. K. Certification of Diesel Apparatus for Underground Use in Mines. Certification Memorandum No. 3, 1st ed., October 1971, Energy, Mines and Resources Department, Fuels Res. Center, Ottawa, Canada, 13 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

This memorandum is published for the guidance of those who may desire to submit diesel apparatus, designed for use underground in mines, for certification.

Brown, G. K. List of Certified Electrical Apparatus, Certified Fuel-Resistant Conveyor Belting, and Certified Diesel Engines for Coal Use. See. VI.B.1.

Davis, R. F. Mobile Diesel-Powered Equipment for Nongassy Noncoal Mines and Tunnels Approved by the Bureau of Mines, 1951-1966. BuMines IC 8363, 1968, 29 pp.

This publication has been prepared to supply manufacturers and industrial users a listing of mobile diesel-powered equipment and subassemblies approved and certified by the Bureau of Mines for use in nongassy noncoal mines and tunnels. This revised and supplemented listing supersedes an earlier publication released in 1963.

Davis, R. F., J. J. Seman, G. A. Hindman, and W. E. O'Neill. Mobile Diesel Powered Equipment for Noncoal Mines Approved by the Bureau of Mines, 1951-1962. BuMines IC 8183, 1963, 20 pp.

This publication has been prepared to supply manufacturers and industrial users a listing of mobile diesel-powered equipment and subassemblies approved and certified by the Bureau of Mines for use in noncoal mines.

Davis, R. F., J. J. Seman, J., R. Zelonka, and F. E. Scott. Mobile Diesel Powered Transportation Equipment for Gassy Noncoal Mines and Tunnels Approved by the Bureau of Mines, 1961-1966. BuMines IC 8354, November 1967, 6 pp.

This publication has been prepared to supply manufacturers and industrial users a listing of mobile diesel powered transportation equipment approved or certified by the Bureau of Mines for use in gassy noncoal mines and tunnels.

Environmental Science and Technology. Diesel Exhaust: Regulations and Health Effects. v. 14, No. 2, February 1980, pp. 135-137.

The EPA has set proposed standards for light-duty diesel particulates which call for a maximum of 0.6 grams per mile for 1981 and 1982 models and 0.2 grams per mile for 1983 and later years. This article studies the particulate problem to determine if the new standards are necessary. The EPA believes the total suspended particulates emitted from future diesels will be significant and could cause a health problem. Studies performed by General Motors Research Lab indicate that diesel exhaust is not harmful according to their research methods. The conclusion drawn was that it is too early to decide the health effects of diesel exhaust. More research must be performed.

Holtz, J. C. Safety With Mobile Diesel-Powered Equipment Underground. See VII.A.

Holtz, J. C., and E. J. Gleim. State Regulations Pertaining to the Use of Internal-Combustion Engines Underground. BuMines IC 7789, June 1957, 24 pp.

This report includes abstracts of State laws and regulations in effect as of 1957 as they affect the use of internal-combustion engines underground, particularly diesel engines. The substance of comments from State officials also are included when these appear to be helpful to interpretation of the regulations.

Ilsley, L. C., and E. J. Gleim. State Regulations Pertaining to the Use of Internal-Combusion Engines in Coal and Metal Mines and in Tunnels. BuMines IC 7019, June 1938, 8 pp.

This report was prepared at a time when the increasing use of diesel engines for operating equipment on trunkline railroads and for power plant units was stimulating interest in the diesel engine's use for other lines of work, including the possibility of substituting diesel locomotives for trolley locomotives in mines. Because of known hazards of operating gasoline locomotives underground, regulations in a number of States limited or prohibited the use of gasoline locomotives underground. It was felt that some of that legislation would be construed to prohibit the use of any type of internal-combustion engine in underground workings. This paper contains abstracts of the various State regulations in effect in 1938 which could have a bearing on whether or not diesel locomotives would be permitted in mines and tunnels of those States.

Knopp, R. A. The Effect of Different Regulations in Various Parts of the World on the Design and Certification of Diesel Equipment for Underground Coal Mines. Can. Inst. Min., June 1978, pp. 84-86.

This paper discusses how design differences in FLP diesel equipment in uderground coal mines came about. "Design standards" tend to create differences between countries while fostering uniformity among products of competing manufacturers. "Performance requirements," on the other hand, tend to eliminate differences between countries while encouraging competitive development of better products. Examples of regulations from the U.S., Canada, Great Britain, Australia, South Africa, etc., are used to illustrate differences in the design and certification of diesel equipment for underground coal mines.

Mallette, F. S. Problems and Control of Air Pollution (Proceedings of the First Internat. Cong. on Air Pollution, New York, March 1-2, 1955). Reinhold Publishing Corp., New York, 1955, pp. 74-93.

Research by the Bureau of Mines on exhaust gases from diesel engines has been extensive and directed chiefly to determination of information required to guide the safe use of diesel-powered equipment underground. Results from these studies are the basis for Schedules 22 and 24, which promulgate the requirements for approval of diesel machines to be used in underground coal and noncoal mines, respectively. In underground applications, forced ventilation with fresh, clean air is required to avoid undesirable pollution of the atmosphere. The volume of fresh air is determined by the quantity of harmful and objectionable consituents in the exhaust gas produced in the combustion of diesel fuel. Some of the factors affecting the nature and concentration of these products of combustion are discussed herein. Experiments on removal of objectionable constituents by scrubbing the exhaust with chemical solutions are also described.

Mining Engineering. Diesel Power Underground--Productivity Potential Sparks Health Controversy. April 1979, pp. 370-375. See IV.L.

Wadman, B. Emission Regulations and the Engine Industry. Diesel and Gas Turbine Progress. July 1979, p. 11.

This article discusses the proposed government regulations for new emission test procedures. The author states that these regulations are overwhelming and driving the engine industry to the point of desperation. A Caterpillar representative said the new regulations would increase the cost of a new engine by $513. The author expresses that knowledgeable people in the engine industry write to their lawmakers and regulators expressing their point of view on the subject.

VII. CASE EXAMPLES OF DIESEL ENGINE USAGE

A. Industry Experience

Alcock, K. Diesel-Powered Mine Equipment: Tips on Servicing and Trouble-shooting. See VIII.F.

Alcock, K. Safe Use of Diesel Equipment in Coal Mines. Presented at the 1967 Mining Convention of the American Mining Congress, Denver, Colo., Sept. 26-29, 1976, 33 pp.; Min. Cong. J., February 1977, pp. 53-62.

There are many misconceptions about the safety of underground diesel equipment in spite of its use for many years in mines all over the world. The author of this paper identifies 10 common misconceptions and concentrates on clarifying these misconceptions. Some of these misconceptions are that the hot exhaust gases represent serious fire hazards, that all diesels are equally bad for emissions, that catalytic converters are better than water scrubbers, etc. The author also discusses the future of diesels in coal mines and believes that they will play an important role in the development of a safer underground environment for the American coal miner.

Allen, J. C. Evolution of Underground Mining Equipment. Quarterly of the Colorado School of Mines. Colo. School of Mines, 1968, pp. 135-141.

With the need for supplementary fuel, fuel from oil shale may be feasible. Therefore, this article briefly explains new methods of drilling, blasting, loading, hauling, scaling and roof bolting that would be required for large oil shale mines. With complete cooperation between government, business, management, and labor, using highly sophisticated machines, oil shale mining costs can be achieved that will be attractive to the petroleum industry.

Allen, L. R. Engines Can Increase Productivity. Mining Equipment International, May 1978, pp. 34-41.

Engines are the key to maximizing machine efficiency and minimizing operating costs, while meeting today's heavy-duty demands with the use of larger, more productive pieces of equipment. This article briefly discusses three factors to consider to increase engine productivity. These are, choose engines with a high torque rise (these provide a constant high power output over a wide engine speed range), choose engines that have high reliability, high durability, and fast serviceability. If these factors are followed when selecting an engine, productivity can be maximized.

Allen, V. H. The Safe Operation of Diesel Scooptrams in Emergency Situations. See VI.A.

American Mining Congress. Facts and Fallacies About the Use of Diesel Equipment in Underground Coal Mines. Washington, D.C., 1978, 16 pp.

This brochure is aimed at clearing up the most common fallacies of using diesel engines in underground mines and states that diesel equipment in underground mines is as safe as any mode of mining underground, either from a health or physical safety point of view provided four conditions prevail: Use certified equipment, follow adequate maintenance program, have an adequate monitoring system, and provide adequate ventilation.

American Mining Congress. The Use of Diesel Equipment in Underground Coal Mines. Washington, D.C., Sept. 15, 1977, 21 pp.

This is an informative brochure stating the basic facts of using diesel engines in underground mines. It also discusses the health and safety aspects of using diesel equipment in underground mines. It is concluded that by following simple guidelines the use of diesel equipment in underground coal mines is as safe as any mode of mining underground.

American Mining Congress. Summary: AMC Diesel Mine Equipment Safety/Productivity Survey. March 1978, 2 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

In order to study the subject of the relative safety and productivity of dieselized mines as compared to other mining systems, the AMC conducted a safety/productivity survey. The results indicated that 1) equipment operators perceived significant safety advantages in using diesel equipment as opposed to other types of equipment and 2) metal/nonmetal mines that are designed for diesel equipment are 3.77 times as productive per manshift as mines that are not dieselized.

Ash, S. H., and L. L. Nans. Use of Diesel Locomotives in Tunnels. BuMines IC 7222, October 1942, 26 pp.

This paper was written in 1942, just when diesel locomotives were beginning to be used for haulage in underground tunnels. The paper studies the hazards of diesel engines and how they affect the tunnel's atmosphere. The authors also give a detailed analysis on how to determine the amount of ventilating air required, taking into account the emissions of NO_2, CO, and CO_2. The authors conclude that the controlling emission is NO_x and in order to keep emissions at a minimum, the engine should be maintained in proper mechanical condition.

Atkinson, E. L., and G. W. Leach. The Replacement of Conventional Gathering-Arm Loaders and Shuttle Cars with Diesel-Operated Load-Haul-Dump Units at Greenside Colliery. See VI.B-2.

Bauman, H. C. Engineering and Material Factors Resulting in Increased Availability for LHD's. Proceedings of Symposium Material for the Mining Industry, Vail, Colo., July 30-31, 1974.

The mining industry demands increased machine availability in order to reduce operating costs. While a good maintenance program is indispensable to high machine availability, the design and development of improvements to production equipment have been primary goals of manufacturers and users of these machines. Therefore, Eimco Mining has redesigned its Load-Haul-Dumps (LHD's) in order to increase the machine's availability. The article discusses the new design in terms of the frame, bucket, exhaust treatment system, drive train, and brakes. The article also includes a chart of the different types of material used and the material's ultimate and yield strengths.

Bode, D. Standardized Trucks for Underground Mining. Diesel and Gas Turbine Progress, June 1979, pp. 42-43.

Mining equipment must have a high rate of availability, therefore, Getman Corp. designs its vehicles with this in mind. This article describes Getman's three basic vehicles--utility, small ore carriers, and drill carriers. The vehicles are described in terms of dimensions, steering, braking, drive train, and operator's instrumentation. A principal equipment list is also given.

Boengier, M. Walk-Through Survey Report of International Minerals and Chemicals, Incorporated, at Potash Mine, Carlsbad, New Mexico. Mar. 10, 1980, 15 pp.; NTIS PB81-241804.

Worker exposures to diesel exhaust were surveyed at the Potash Mines of International Minerals and Chemicals, Incorporated (SIC-1474) in Carlsbad, New Mexico, on February 8, 1979. The facility was under consideration for inclusion in a NIOSH epidemiological study of potash workers exposed to diesel exhaust. The company employed 245 underground miners, and the ore produced from the mine contained sylvite, langbeinite and halite. Mining was performed 800 to 900 feet underground. Sixty-seven diesel units were used underground and 19 were used above ground. Ventilation in the mine was provided by two exhaust and two intake shafts. Personnel records provided demographic data, date of hire, and information of preemployment physical status. Preemployment physicals were provided, but no periodic examinations were offered. Concentrations of carbonmonoxide (630080) and nitrogen-dioxide (10102440) at a field station were 5 and 0.8 parts per million, respectively, while concentrations of carbonmonoxide and carbon-dioxide (124389) at an active entry face were 8 to 9 and 250 ppm, respectively. Nitrogen-dioxide concentrations had to fall below 4 ppm after blasting before workers could reenter the area. The author concludes that information concerning exposures prior to 1967 is needed, since the use of diesel equipment by this company occurred primarily after 1967.

Bradbury, R. A. Diesel Haulage Equipment in Underground Coal Mines. Presented at the SME Fall Meeting and Exhibit, Oct. 18-20, 1972, Birmingham, Ala., Society of Mining Engineers of American Institute of Mining Engineers Preprint 72-F-345, 14 pp.

Following Schedule 31 approval of the Caterpillar D-333-CNA engine in November 1969 by the Federal Bureau of Mines, officials of Martin County Coal Corp., Martin County, Ky., elected to introduce the first such diesel-powered mining equipment into a deep coal mine in North America, east of the Mississippi. The author of this article evaluates the acquisition of a load-haul-dump vehicle (ScoopTram) and 12 tractor trailers in use nearly one year at the time this paper was prepared. Based on their operating experience during this period, company officials expressed belief that diesel haulage equipment is safer than either cable powered or battery powered haulage equipment and recommended its use to any coal operators from the standpoint of safety, reliability, and productivity.

Bradbury, R. A. Experience to Date with Diesel Powered Underground Mining Equipment. Presented at the SME Fall Meeting and Exhibit, Pittsburgh, Pa., Sept. 19-21, 1973, Society of Mining Engineers of American Institute of Mining Engineers Preprint 73-F-352, 11 pp.

Initial experiences of the Martin County Coal Corp. in acquiring and using diesel powered haulage equipment at its underground operations in Martin County, Ky., were described by the author in a paper presented in October 1972 at an AIME meeting in Birmingham, Ala. (work previously cited). This paper updates the company's experiences in this area, describing the performance of the diesel powered haulage equipment during the longer time period and describing additional equipment purchased. A diligent preventative maintenance program had kept engine problems at a minimum and exhaust emissions had not been a problem. The main problems with the diesel haulage equipment had resulted from wet roadways, one steep grade (25%), and occasional humps in the bottom which affected some underside parts of the low ground-clearance vehicles. It was anticipated that equipment modifications by the manufacturer would prevent recurrences of some problems. The company continued to view its decision to use rubbertired diesel haulage equipment as sound from the standpoint of safety, reliability, and productivity.

Chironis, N. P. Diesels...A Giant Step Underground. Coal Age, March 1973, pp. 60-64.

The article summarizes some of the highlights of a Bureau of Mines-sponsored symposium held in Pittsburgh, January 30-31, 1973, on the use of diesel-powered equipment in underground coal mines. A presentation by R. A. Bradbury of Marion County Coal Corp. on the company's two years of experience, using diesel haulage equipment at its Inez, Ky., mine is recapped. The company was using underground tractor-trailers with a telescopic box for a bed and a ScoopTram. Components and safety features of the equipment are described. The maintenance of the units was not a problem from the standpoint of faulty mechanical units or machine components. Overall, the company endorsed the use of diesel powered equipment in underground

coal mines from the standpoint of safety, reliability, and productivity. Other symposium presentations summarized in the article pertained to new trends in diesel engine design, the medical effects of diesels underground, and the Bureau of Mines endeavors regarding developing regulations and researching the use of diesels in underground coal mines.

Clark, D. A. Experience With Diesel Tractors at Dawdon Colliery. The Mining Engineer, November 1970, pp. 104-107.

The paper gives an excellent description of the use of Hunslet MT.25 diesel tractors for materials haulage at the Dawdon Colliery on the east coast in the South Durham area of England. In addition to describing the component features, the paper also presents the problems, limitations, and advantages of the system. Conclusions in the paper were tuned more to the mechanical capabilities of the tractor than to the performance of the diesel engine. The conclusions stated: (1) A materials handling system using the MT.25 tractor is limited in length of run and volume of material; (2) the system gives a high degree of flexibility within these limits and is satisfactory for handling normal materials requirements; (3) a maintenance system for the vehicles must be established and carefully controlled in its operation; (4) attention must be paid to the road surfaces on which the tractors operate; (5) tractor drivers must be adequately trained; (6) abnormally heavy loads are not easily handled by this system; and (7) to improve the application of the system, thought should be given to: (a) making the tractor ancillaries more accessible and so improve maintenance; (b) reducing the track pressure of the machine, possibly by fitting crawlers; and (c) greater reliability of the tractor and its component parts could be obtained by improving the design and construction of the vehicle.

Coal, Gold and Base Minerals of Southern Africa. Trackless Mining 4,5M Tons Later. v. 23, No. 1, March 1975, pp. 28-41.

Production systems and equipment used at the O'okiep Copper Company's underground mines in South Africa are described, with a brief cost analysis made of the diesel haulage equipment operations. Scooptrams and 10-ton tractor-trailer units were the predominant types of diesel equipment used in the trackless mining sections which accounted for approximately 65% of the production. The following safety devices, developed at O'okiep, were fitted to scooptrams engaged in inclined workings: (1) A device which causes the application of the brakes automatically in the event of engine failure; (2) an overspeed device designed to cause automatic brake application at speeds in excess of 10 kilometers per hour; and (3) a first gear transmission lock.

Coal Mining & Processing. The Deisel-Powered Load/Haul/Dump. December 1973, pp. 52-56, 70.

When this article was written in 1973, a total of 33 diesel powered units were in use at seven underground coal mines in the United States. At that time, the UMWA's traditional stand against diesels had held back their widespread use in underground coal mines; however, their operational capabilities had been attested to by the Bureau of Mines in its endorsement of such equipment and by coal companies using it. Experiences of two companies using diesel haulage are detailed in the article, namely, Southern Utah Fuel Co. and Martin County Coal Corp. Both companies expressed satisfaction with their decisions to use diesel LHD equipment and were optimistic about its expanded use in the future.

Coal Mining & Processing. The War Over Diesels. June 1978, pp. 102-104.

Opposition to using diesels in underground mines because of possible health risks has been voiced by the UMWA since the inception of their use. In 1976, the National Institute for Occupational Safety & Health joined the contention, stating that preliminary studies indicated that exposure to diesel powered equipment in underground mines may result in permanent lung damage. In defense of diesel engine use, the American Mining Congress (AMC) and various mining companies began their own research on the health effects of diesel emissions. The AMC studies and findings of Great Britain's National Coal Board and the U.S. Bureau of Mines supported the use of diesels. Summarily, it was believed that advances in mining technology, with attendant stringent safety regulations, and work procedures had virtually negated the validity of the opposition argument.

Commission of the European Communities. Underground Transport in Coal Mines, Vol. 1. Information Symposium, Luxembourg, May 24-26, 1978. Colliery Guardian, Redhill, Surrey (United Kingdom), 1978, 412 pp.

The publication consists of a collection of papers presented at the Commission of the European Communities symposium on underground transportation in the coal industry. Virtually all modes of underground transportation are described and evaluated. Six of the presentations included significant discussions of some form of diesel engine use in the United Kingdom, France, or Germany. Titles of diesel-related papers included: Actual State and Trends of Locomotive Haulage in the Coal Mines of the Ruhr Area; High Speed Manriding Trains; Locomotive Haulage--Steep Gradients; Rubber-Tyred Vehicles; Trapped Rail Transport; and Trackless Transport in West German Coal Mines.

Commission of the European Communities. Underground Transport in Coal Mines, Vol. 2. Information Symposium, Luxembourg, May 24-26, 1978. Colliery Guardian, Redhill, Surrey (United Kingdom), 1978, 150 pp.

Volume 2 includes transcripts of round-table discussions of topics cited earlier for Volume 1.

Countryman, D. L. Diesel Powered Underground Mining Equipment. Presented at the Off-Highway Vehicle Meeting, Milwaukee, Wis., Sept. 13-16, 1976, SAE Preprint 760651, 8 pp.

This paper describes the challenges and limitations involved in the design and manufacture of rubber-tired, diesel powered, underground mining equipment, particularly in the areas where they differ from surface equipment. It outlines and describes the environment and usage of this equipment underground in both metallic and nonmetallic mines. Specifically, the two main areas covered are: The underground confinements for design and operation; and MESA regulations for diesel exhaust emissions underground.

Deniau, R., and O. Lionet. Reduction of the Harmfulness of Diesel Engine Exhaust Gases. Conference on Technical Measures of Dust Prevention and Supression in Mines, (Luxembourg), Oct. 11-13, 1972, 10 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

Pollution caused by the gaseous emissions of diesel engines is an important problem at the Lorraine iron ore mines and has been under study since 1960. The Lorraine mines use nearly 200 vehicles underground, equipped with diesel engines of 30-300 HP. The paper details various studies undertaken to reduce the toxicity of the emissions. The four courses outlined to obtain a low toxicity were: (1) Select a "clean" engine-engines with indirect injection and a low fuel oil/air ratio are best in this respect; (2) tune the engine and keep it in good condition; (3) change the setting--the iron ore mines showed that decreasing the injection advance is often favorable, especially under low operating regimes and low loads and it also showed that recycling a fraction of the exhaust gases to the intake reduced the toxicity by decreasing the volume of emission and lowering the nitrous vapor contents; and (4) purify the emission.

Diesel and Gas Turbine Progress. An Analysis of the Markets for Diesel and Related Engine Power Systems Equipment in North America and Worldwide, 1976-1980. A Report From the Power Systems Marketing Division, Milwaukee, Wis., February 1977, 17 pp.

Presents 10-year production figures on various types of diesel equipment and projections of sales by various categories to assorted markets to the year 1980. The report provides data not only on mining equipment but also on passenger cars, farm tractors, trucks and buses, single cylinder engines, and other types of industrial engines. Market competition and economic factors affecting sales are discussed. Because of the documented cost effectiveness of the diesel engine--its superior efficiency, longevity and lower maintenance--it is expected that diesels will supply an increasing share of the power demand around the world.

East, J. H. Jr., Operating Diesel Locomotives Underground in European Mines. BuMines IC 7378, September 1946, 13 pp.

The report discusses diesel locomotives working underground in gassy and nongassy coal mines and in metal mines of several European countries and gives a brief description of mining conditions observed. The number of diesel locomotives in use was increasing faster than either compressed air or electric types, perhaps because of their adaptability and lower cost of operation. The extent of the use of spark arresters and washers at that time was discussed. It was concluded that diesel locomotives appeared to be safer to use in underground gassy coal mines than electric locomotives, provided that an adequate amount of ventilating air was circulated through the haulageways. It was felt that provision for adequate ventilation to dilute and carry away the toxic gases from the exhaust fumes was more important than the use of washers or gas absorbers without providing increased ventilation since, in practice, the washers were often removed or were inoperative which was not believed to be harmful if there was an adequate supply of ventilating air.

Engineering and Mining Journal. Volvo Offers Low-Emissions Underground Equipment. v. 179, No. 9, September 1978, pp. 273-274.

To meet strict emissions standards in force in the U.S. and elsewhere and tougher standards being enacted worldwide, Volvo developed new exhaust gas cleaning systems, which do not use catalytic converters, to be coupled with their existing low-emissions engine. The new units described are a 4-wheel drive dumper which employs water dilution rather than the conventional scrubber tank for the gases, and an underground loader whose exhaust gases are controlled by cooling, using water injection.

Espach, T. M. Improvements to the Trackless-Mining Equipment and Operation at Prieska Copper Mines (Proprietary) Limited. See VIII.F.

Fermor, R. B. A Study of the Factors Present in Planning the Ventilation Needs of Diesel Vehicles in Operating Mines in Quebec. See IV.K.

Gilbert, S. The Use of Diesel Engines Underground in British Coal Mines. See VIII.J.

Goldrath, B. Diesels in Underground Mining. Diesel and Gas Turbine Progress, August 1977, pp. 33-34.

Wagner Mining Co. builds more than 35 different models of diesel-powered work vehicles. As a pioneer in trackless mining, the firm used its hard rock experience in developing diesel-powered equipment especially designed for underground coal mining. The company pioneered a concept that drastically changed underground mining--the load-haul-dump system, involving one machine for all three functions. Features and capabilities of equipment manufactured by Wagner are described in the article.

Gunderman, R. J. Underground Trials of a Diesel-Powered Face Haulage Vehicle. See IX.D.

Harrington, D., and J. H. East, Jr. Diesel Equipment in Underground Mining. BuMines IC 7406, April 1947, 57 pp.

Provides information as to the successful use of diesel-powered equipment in some underground mines in the United States and Europe, and briefly discusses characteristics of some of the toxic gases found in the exhaust of diesel engines. The report was prepared at a time when diesel usage was very limited in U.S. underground mines. As of Feb. 1, 1947, only four diesel locomotives were known to be used in underground mines in the U.S.--two in metal mines and two in nonmetal mines--with the use of other types of diesel equipment somewhat common in noncoal underground mines of the Central States. At the same time, it was estimated that 1,300 diesel locomotives were in use in European underground mines. The need for American manufacturers to develop diesel engines for safe and efficient underground use was recognized and the report cited that an average of 52 persons per year had been killed in U.S. coal mines during the previous years because of accidents directly related to the trolley-locomotive system.

Hermansson, L. Trackless Mining at LKAB, Sweden. J. of the South African Institute of Mining and Metallurgy, August 1973, pp. 11-17.

Because the usual means of transporting men and material to the working sites was time-wasting and uneconomical, inclined subways were installed in the Kiirunavaara iron ore mine that permitted the access of rubber-wheeled vehicles to all underground working sites. Men and material could now be transported directly to the working site with no reloading. An increase of 8 to 12 percent in underground productivity was obtained by the use of the new transportation system. Rubber-wheeled vehicles were also used in development, production drilling, and loading. In December 1958, the management of the Luossavaara Mine decided to cut the costs of waste-rock haulage. The system of waste transport was the conventional one of shuttle car, rail haulage, and skip hoisting. After consideration of other methods, it was decided to re-equip the mine completely for a system of trackless transport. Results show that mining costs per ton of ore were reduced by 27 percent, and mining costs per ton of waste were reduced by a spectacular 80 percent. The new system has proved to be more flexible, and ore grading has been simplified since there is no longer any mixing in ore passes and chutes.

Hews, C. F. Trackless Mining at the International Nickel Company of Canada, Limited. J. of the South African Institute of Mining and Metallurgy, August 1973, pp. 1-10.

An account is given of the evolution and advantages of trackless equipment in the underground operations of International Nickel's Ontario Division, with special reference to fill-method mining, development practice, sub-level caving, and induced block caving. Details of maintenance of diesel equipment, environmental control, and operator training are also given. The introduction of diesel equipment at the operation was necessitated by a labor shortage and the need to improve working conditions and safety. Continued success in the use of this equipment was cited as being dependent on the following: (1) good engineering design for proper application of equipment; (2) ongoing cooperation with manufacturers to improve equipment; (3) good employee training; and (4) proper maintenance and environmental control.

Holmquist, R. C. Are Better Days Ahead for Diesels? Presented at the AIME Annual Meeting, New Orleans, La., Feb. 18-22, 1979, AIME Preprint 79-60, 4 pp.

Although the record of diesel equipment used in underground mines is favorable from the standpoints of both productivity and safety when compared with other mining systems, concern is expressed that government regulations could preclude the growth or the use of diesels in the mining industry. The paper presents (1) statistics on productivity and safety experience in various types of mines, comparing diesel and other types of power; (2) positions of various governmental agencies on the health and safety effects of diesel engines and how some of these positions have affected the growth of diesel use; and (3) emissions tests results and their relevancy. The report stresses the importance of reasonable judgment in governmental regulatory decisions.

Holtz, J. C. Safety With Mobile Diesel-Powered Equipment Underground. BuMines RI 5616, 1960, 87 pp.

Describes Bureau of Mines research on diesel engines as of 1960. Gives precautions recommended by the Bureau in using diesel-powered equipment underground in noncoal mines and tunnels. The report states that safety with mobile diesel-powered equipment in noncoal mines and tunnels depends chiefly upon proper adjustment and maintenance of the engine, suitable rapid dilution of the exhaust, and adequate ventilation to dilute and remove the exhaust from the mine and to restore oxygen used in the combustion process. The report discusses the relationship of various harmful exhaust gases to the fuel:air ratios used in operating the engine and other factors.

Holtz, J. C., and R. W. Dalzell. Diesel Exhaust Contamination of Tunnel Air. BuMines RI 7074. See III.B.1

Holtz, J. C., L. B. Berger, M. A. Elliott, and H. H. Schrenk. Diesel Engines Underground: IV. Effect on Composition of Exhaust Gas of Variables Influencing Fuel Injection. BuMines RI 3700, April 1943, 24 pp.

The report discusses the effect of certain variables influencing fuel injection on the composition of the exhaust gas produced by two 4-stroke-cycle diesel engines. To determine whether there was significant variation with properly functioning injection valves, tests were conducted with two sets of injection valves. In addition, the effects of injection and spray pattern were studied. Tests were made also to determine the effect of leaking injection valves on the composition of the exhaust gas. The importance of adequate maintenance for diesel engines used underground was emphasized.

Hurn, R. W. The Problem of Diesel Engine Exhaust in Underground Mines. Proceedings of Conference on the Underground Mining Environment, Univ. Mo., Rolla, Mo., Oct. 27-29, 1971, pp. 241-250.

The operation of diesel engines in underground areas requires careful attention to space ventilation in order that the concentration of toxic combusion products be held within acceptable limits. These ventilation requirements and the basis for calculating them are reviewed in the paper. A special hazard is identified and described in the case of an engine rebreathing its own exhaust as a result of inadequate ventilation. This special case is shown to result in progressively accelerated carbon monoxide discharge with possibilities for very rapid development of extremely hazardous CO levels in the vicinity of an inadequately ventilated engine. Overall, the problem of maintaining safe atmospheres is lessened as the amounts of toxic pollutants from engines are reduced. Methods used to approach the minimal pullutant yield--and thereby minimal air poisoning hazard--are also discussed.

J. of the South African Institute of Mining and Metallurgy. Trackless Mining. August 1973, pp. 39-55.

Four African mining operations are described, namely: Oamites copper and silver operations; Union Corporation, Limited gold mines; Rokana Division copper mine; and O'okiep Copper Company Limited copper mines. The paper discusses, in varying degrees, the inventory, utilization, maintenance, and performance of diesel-powered equipment. An excellent description of the mining system used at each of the operations is presented.

Kibble, J. D. Some notes on Mining Diesels. Mining Technology, October 1978, pp. 393-400.

The paper presents information about diesel use in the United Kingdom and other countries, together with information about the effect of engines on the mine environment. Regulations governing diesel engine use in the United Kingdom is outlined in particular, and it is pointed out that through compliance with these regulations during diesel operations extending over a period of more than 40 years in that country, there has been no reported case of any mine worker being injured by diesel fumes or any part of the engines as such. There were, of course, a small number of accidents such as could happen with vehicles using any form of power. Relevant research and development work is also outlined.

Krause, Klaus, Dipl.-Ing. Wathlingen. New Large Capacity Trackless Vehicles. Gluckauf and Translation, v. 114, No. 21, 1978, 454-456.

Load, haul, and dump operations in the West German potash and rock salt mining industries in 1978 when the article was written, were industries mainly carried out using LHD's with payloads of 9 to 10 tons, and in a few cases of 18 tons. Their productivity was considerably reduced over longer transport distances. The prime cost of LHD's as a function of payload was substantially greater than that of trucks. The same applied to running costs. Therefore, in some circumstances truck haulage with separate loading was more economical. Two different systems using trucks specially developed for underground operation were being employed in the salt mining industry. The article describes the two systems used at Kali and Salz AG's Niedersachsen-Riedel Mine and at Deutsche Solvay-Werke GmbH's Borth rock salt mine.

Mining Congress Journal. Application of Diesel Units Underground. June 1961, pp. 42-45.

The article describes Tennessee Coal & Iron Division of U.S. Steel Corp.'s success in using diesel shuttle cars and other diesel equipment in its underground ore and limestone mines. The company stated it was difficult to measure all of the benefits it had derived from the use of diesel equipment in its underground mining operations but credited it as being a major factor in obtaining increased tonnages at lower cost with increased safety in the ore mines.

Mining Engineering. Diesel Power Underground--Productivity Potential Sparks Health Controversy. See IV.L.

Mining Magazine. Diesel Power. November 1977, pp. 511-529.

Some manufacturers of mining equipment build both vehicles and diesel engines. In many cases, however, there is a choice of engine within basic parameters for horsepower, torque, and other factors. Selection is influenced by varying characteristics, and this article presents a very comprehensive discussion of many of the options as well as standard components, such as two-stroke engines, four-stroke engines, fuel injection, direct or indirect combustion, flame-proofing, air or water cooling, turbochargers, etc. The article states that although "research is continuing to develop alternatives to the diesel engine, such as the gas turbine or the stirling and Rankine cycle engines, it is generally agreed by engine technologists that at least for the next decade the diesel will be paramount. Diesels are the most efficient and pollution-free source of prime motive power now available, and the manufacturers are striving to improve power, reliability, fuel economy, and exhaust emission to match market demands."

Ogden, S. O. Economics, Safety, and Operating Advantages of Diesels in Underground Coal Mines. Min. Cong. J., September 1978, pp. 237-242.

The article acknowledges that, depending on the mining situation, electric-powered or diesel-powered equipment may be most appropriate. Includes a discussion of the growth of diesel usage in the U.S. and other countries and cites opposition from various agencies and groups to its use, primarily in U.S. underground coal mines. Much of the report is dedicated to the results of an American Mining Congress safety/productivity survey of various underground mining operations in the U.S. in 1977. A time series giving coal mine injury and fatality statistics by source is also presented. The marked improvement in safety records and sharply increased productivity with the advent of diesel engine use indicated by these and other surveys reflect the important role diesels play.

Palmer, A. J. The Development of Trackless Mining at Kambalda. Presented at the Aus. Inst. Min. and Metallurgy Conference, Western Australia, May 1973, pp. 331-337.

This paper describes Western Mining Corporation's use of diesel equipment in mining of shallow flat dipping narrow orebodies in the Otter/Juan area (Australia). Though in most cases the stoping method chosen relies on hand held conventional equipment, the ore handling systems have been designed to allow for a relatively high degree of mechanization. The use of diesel loaders and trucks, along with three boom jumbos is described. A single one-in-nine decline driven as the means of access to the various ore surfaces at Otter/Juan resulted in the first ore being produced 15 weeks after the first round was fired in the ore decline.

Pfannenstiel, Philipp-Kaspar, Dipl.-Ing. Marl. Die Zukunft von Dieselantrieben sowie Probleme bei ihrem Betrieb im Kohlenbergbau (The Future for Diesel Drives, and Problems Relating to Their Operation, in Coal Mines). Gluckauf and Translation, v. 114, No. 5, 1978, pp. 120-123.

Internal combustion engines, particularly for locomotives, have been in service underground for more than 80 years, and diesel drives have been used for the past 50 years. Well-proved designs are, therefore, available. Diesel trolleys and free-steering trackless vehicles have opened up a new field for diesel engines, but this has also created new problems. The stringent demands which are made in respect of ecological compatibility and safety are met by the latest designs of water-cooled diesel engines with pre-combustion chambers. In this connection, particular importance is to be attached to the improvement of exhaust-gas regimes. The minimum ventilation airstreams for diesel operations, to be fixed by the mines inspectorates, should be graded not only according to the CH_4 in the intake air but also according to the maximum basic CO emission. Compared to electric motors, diesel drives have a big effect on the mine climate. However, precise figures from the operational field, and precise planning methods, are not yet available on this subject.

Ramani, R. V., and G. W. Kenzy. Evaluation of Diesel Equipment Deployment in Underground Coal Mines. v. III: Analysis of Diesel Deployment Schemes. Penn. State Univ., Final Report, USBM Grant No. G0166052, Dec. 31, 1978, 200 pp.

Procedures have been developed which permit determining in either existing or new mines the optimum diesel equipment deployment schemes and the effect of diesel exhaust on mine-air quality. Specifically, the following areas are covered in the report:

1. Description of diesel deployment schemes in four underground coal mines.
2. Description of the analysis procedure to determine the number of shuttle cars required to maintain maximum theoretical continuous miner (or loader) production rates in typical room-and-pillar mining systems and of exhaust contamination resulting from the deployment of diesel powered shuttle cars. Sensitivity analyses to determine the effect of changes in input variables on production and contaminant concentrations are also discussed.
3. Description of the analysis procedure to develop the locomotive operating paramaters. Assessment of both production performance as well as estimates of the magnitude of diesel exhaust contamination of the mine air are also made.
4. Recommendations for extensions of this research are outlined and include developing and testing procedures for 1) determining equipment duty cycles for the diesel equipment, and 2) studying the exhaust contamination of mine air on the basis of these duty cycles.

Ramani, R. V., G. W. Kenzy, and R. Stefanko. Evaluation of Diesel Equipment Deployment in Underground Coal Mines. v. II. Diesel Bibliography. Penn State Univ., Final report, USBM Grant No. G0166052, May 31, 1977, 73 pp.

The industrial hygiene and safety aspects with internal combustion engines in mining systems is truly interdisciplinary and encompasses many fields such as mine ventilation, exhaust gas and particulate analyses, mine atmospheric environment monitoring, mathematical modeling of generation, dilution and dispersion of pollutants in ventilation systems, and engine testing and approval. This bibliography, therefore, is a compilation of references from interdisciplinary sources pertaining to diesels and related areas. Related areas are defined as those concerned with: (i) mine ventilation system design and operation; (ii) description, measurement, modeling and monitoring of mine atmosphere contaminants, and (iii) tests, standards, selection procedures, and operational practices for internal combustion engines in underground mines. References cited from source materials span the years 1900 to early 1977. Total number of references cited is 511. Subjective criteria governed the definition and selection of references. Therefore, this bibliography is not claimed to be all-inclusive nor does it purport to be an exhaustive search of all sources.

Rao, K. V., C. Haycocks, and J. R. Lucas. Coal Productive Potential of Diesel Load-Haul-Dump Equipment and Systems. Min. Cong. J., December 1975, pp. 18-23.

The authors give a very comprehensive presentation of their findings regarding the possible application of diesel-powered load-haul-dump equipment in underground coal mining operations, including several charts that make productivity and cost comparisons between LHD and shuttle car systems. It was concluded that the introduction of diesels into coal mines would improve safety by decreasing the number of underground fires caused by cables, trolley wires, and electrical power distribution systems. The historical disadvantages of diesels, namely the emission gases, are being largely overcome with improved diesel engine technology and higher standards of ventilation. Diesel haulage has the potential to be safer than battery haulage and trolley wire haulage. Also, it was noted that metal mining experience had indicated that diesel power for face haulage is far more productive, economical, and flexible than cable power systems.

Rehnberg, O. Project 1, Summary: The Analysis of Diesel Exhaust Gases. Research Report Tulea 1975:05, Univ. Lulea, Lulea Sweden, 1975, 4 pp.; available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

This report studies and measures the chemical composition of diesel exhaust gases and the effect of different exhaust cleaning systems. Tests were conducted on a Volvo TD 100A direct injected diesel engine. Four different exhaust cleaning units were tested by taking measurements of NO_2, CO, and

HC before and after the cleaning units. The results indicated that CO, HC, and NO_2 emissions decreased for all the units except the platina unit showed an increase in NO_2. The results are presented in tables and graphs.

Reinbold, E. O. Analysis of Air Quality Data in Two Underground Mines Using Diesel-Powered Equipment. See III.B.1

Rice, G. S., and F. E. Harris. Diesel Mine Locomotives--Development and Use in European Coal Mines. BuMines RI 3320, November 1936, 52 pp.

Describes the use of and experience with diesel locomotives in Germany, Belgium, France, and Great Britain. In those countries it was claimed that diesel locomotives provided cheaper haulage, measured on a ton-mile basis, than other kinds of locomotives but that they require constant inspection to maintain them in an efficient condition. At the time this report weas prepared, diesel engines had been used extensively in the United States in tractors and to a limited extent in buses, trucks, and railway locomotives, but not as diesel mine locomotives. The Bureau of Mines had indicated in its Mine Safety Recommendatory Decision No. 19, approved Jan. 20, 1932, that with proper ventilation and other conditions, it would not condemn the use in mines of internal-combustion engines not employing a highly volatile inflammable fuel like gasoline. In view of the possible extensive field of usefulness in the U.S. for diesel mine locomotives, the authors said it seemed desirable that a schedule of tests for permissibility and advisable requirements for their use be formulated. The report summarizes reasons why diesel engines had not been adopted for use in U.S. mines at that time and points out their advantages.

Rodford, I. G. Diesel-Powered Trackless Vehicle Developments. Colliery Guardian, May 1982, pp. 213-221.

During the past five years the NCB, in conjunction with several manufacturers, has initiated the development of a range of rubber-tired, free-steered vehicles for a variety of duties connected with the underground transport of coal, stone, materials, and men. This development has been concentrated on five basic types of vehicle (load/haul/dump, articulated lorry, long load transporter, manrider, and roadway floor maintenance). The role of the Mining Research and Development Establishment has been to sponsor and undertake development, to carry out surface trials and recommend modification of equipment on the basis of user experience. This article contains some of the results of these trials.

Sadik, W. A., and E. B. Jensen. Air Quality Control in Diesel Equipment Operations at the Henderson Mine. Presented at the 2nd Internat. Mine Ventilation Cong., Reno, Nev., Nov. 4-8, 1979, 14 pp.

The report describes mine ventilation and production systems, and diesel equipment at the Henderson Mine operated by Climax Molybdenum Co., AMAX, Inc., at Empire, Colorado. The mine ventilation system of the Henderson Mine provided a case study of designing and maintaining high-quality respirable air in a large underground mine with over 200 units of diesel-powered equipment. This system was designed with concern for minimizing exposure to personnel of siliceous dust, diesel exhaust, smoke, and potential fire hazards while optimizing general environmental air quality throughout the multilevel/multiheading operation. The majority of the ventilation problems at the mine have been solved by long-range planning and continued system monitoring. Gas concentrations in the mine rarely exceed TLV's as established by law, and when that did occur, it was reportedly attributable to mechanical malfunction of ventilating equipment for periods of short duration.

Schonfeld, H., and H. Nocke. Initial Experiences With Trackless Haulage Systems at Schlagel and Eisen Colliery. Gluckauf and Translation, v. 115, No. 9, May 10, 1979, pp. 198-203.

The paper describes trials underway at Schlagel and Eisen Colliery to test new trackless haulage systems as part of a development project sponsored by the West German Minister for Economic Affairs. At the time the report was prepared, a travelling loader, a service vehicle, and a shothole drilling jumbo, all powered by diesel motors, were operating in a lateral drivage in level 7. The machines had driven about 800 m. of roadway. The technical objectives set for the introduction of diesel-powered, rubber-tired vehicles had been successfully achieved. They included: (1) Construction and maintenance of a suitable travelling surface; (2) operating reliability and the possibility of accident-free manuveuring in the restricted space underground; and (3) a satisfactory solution to the problem of exhaust gases. It was stated, however, that having been applied in just one drivage to date, trackless technology had not yet proved itself economically superior to conventional methods.

Schroeder, J. L. Mines Utilizing Rubber-Tired Haulage. SME Mining Engineering Handbook, Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, v. 1, 1973, p. 14.50.

The excerpt focuses on rubber-tired vehicles used for transporting personnel and supplies, providing limited information on costs, speeds attained, design, etc.

Scott, F. E. Diesels Underground: Overcoming a Bad Image. Coal Mining and Processing, v. 19, No. 8, August 1982, pp. 45-51.

The article reviews the history of dieselized mining from the aspects of safety and health issues. A number of health and safety studies and some of the current government research projects are discussed.

Smithsonian Science Information Exchange, Inc. Engine Exhaust in Mines. Washington, D.C., SSIE Preprint LM38-51, 17 pp.

The report consists of a collection of 16 "Notice of Research Project" summaries relating to engine exhaust research. Provides project title, names of the organization performing the research and the supporting organization, time period of project, and a brief description of the project. Project titles and performing organizations covered are:

(1) Diesel Engines for Operation in High CH_4 Content
(Ruhr Coal Co., Nordrhein Westfalen, Federal Republic of Germany)
(2) Monitoring, Evaluation and Storage of Measured Values and Other Data on Underground Mineworking with the Use of a Process Computer
(Ruhr Coal Co., Nordrhein Westfalen, Federal Republic of Germany)
(3) Personal Samplers for CO, NO, NO_2 in Air
(New York University, New York, NY)
(4) A Portable Compact Low-Cost NO_2, CO, and CH_4 Gas Analyzer for In-Mine Personnel Safety Mornitoring (Andros, Inc., Berkeley, CA)
(5) Sampling Methodology for Inhalation Contaminants in Surface Work Areas of Metal and Nonmetal Mines and Processing Operations
(LFE Corp., Richmond, CA)
(6) The Measurement of Effects of Diesel Emission on Coal Mine Air Quality
(Arthur D. Little, Inc., Cambridge, MA)
(7) Evaluation of Diesel Equipment Evaluation in U.S. Coal Mines
(Penn State University, University Park, PA)
(8) Improved Portable Instruments for Measuring Methane and Other Gases
(U.S. Dept. of the Interior, Bureau of Mines, Pittsburgh, PA)
(9) Alarm Systems for Engines Operated Underground
(U.S. Dept. of the Interior, Bureau of Mines, Bartlesville, OK)
(10) Reduction of Pollutants From Engines Operated Underground
(U.S. Dept. of the Interior, Bureau of Mines, Bartlesville, OK)
(11) Characterization and Environmental Significance of Gases and Particles in Uranium Mine Exhaust Ventilation Air
(Battelle Memorial Institute, Richmond, WA)
(12) Demonstration of a Steam Powered Face Haulage Vehicle
(Scientific Energy Systems Corp., Watertown, MA)
(13) Carcinogens of Aromatic Polycyclic Hydrocarbon (APH) Family; Identification and Separation in Industrial Products and Environments
(National Inst. of Res. & Safety, Paris, France)
(14) Inhalation Hazards to Coal Miners
(Battelle Memorial Institute, Richland, WA)
(15) Airborne Dust Control
(U.S. Dept. of the Interior, Bureau of Mines, Twin Cities, MN)
(16) Control of Diesel Exhaust Contaminants
(U.S. Dept. of the Interior, Bureau of Mines, Pittsburgh, PA)

Stefanko, R., R. V. Ramani, and G. W. Kenzy. Evaluation of Diesel Equipment Deploy ment in Underground Coal Mines. v. I: Validation Experiments for Models of Diesel Exhaust Contamination of Mine Atmospheres. Penn State Univ., Final Report, USBM Grant No. G0166052, May 31, 1977, 291 pp.

The industrial hygiene and safety aspects with internal combustion engines in mining systems is truly interdisciplinary and encompasses many fields such as mine ventilation, exhaust gas and particulate analyses, mine atmospheric environment monitoring, mathematical modeling of generation, dilution and dispersion of pollutants in ventilation systems, and engine testing and approval. Mathematical models of the dilution and dispersion of diesel exhaust contaminants can be useful only if these models can be validated. In this research report, experiments that were specially designed for the above purpose are described. These experiments were conducted in the U.S. Bureau of Mines, Safety Research Coal Mine, in Bruceton, Pa. On the basis of this study, the data collected, and further review of available literature, it is concluded that mathematical models of dilution and dispersion are useful tools for mine ventilation planning. Additional objectives of this study about which conclusions and recommendations are reported here include: (a) evaluation of mine atmosphere contaminant monitoring systems; (b) optimum sampling site locations; (c) model sensitivity and error analyses; (d) computer coding of mathematical models; and (e) development of a diesel bibliography. While an extensive bibliography on diesels is provided in this report, Volume II of this final report has 511 references.

Stewart, D. B., A. D'Aoust, E. D. Dainty, and J. P. Mogan. The Determination of Diesel Engine Parameters Underground for a Load-Haul-Dump Vehicle. Canada Center for Mineral and Energy Technology, August 1975, Report MRP/ERL 75-101, 12 pp.; Canadian Min. and Metallurgical Bull., June 1976, pp. 1-4.

Work described in the report constituted one phase of a cooperative research program of the Canadian Explosive Atmospheres Laboratory with The International Nickel Company of Canada, Limited and Deutz Limited. A portable instrumentation package to monitor diesel engine loading in underground mining machinery was designed and constructed. The report describes the results of field tests in which the monitored Deutz F6L 714 diesel engine was installed in a 4-yard load-haul-dump machine, permitting accurate in-situ monitoring of the engine load and speed conditions for the various segments which constitute actual underground mining operations. The field instrumentation package evolved to a functional format for invehicle engine load monitoring; it was hoped that the equipment would be modified to test other engine-vehicle combinations. It was planned that results of this study would also be used to calculate engine emissions and required dilution air rates in a subsequent report.

Stewart, D. B., E. D. Dainty, and J. P. Mogan. Diesel Emissions With Respect to the Mine Environment. Can. Inst. Min. Bull., January 1976, pp. 85-89.

This paper, originally presented at a Professional Development Seminar on the Mine Environment held at McGill University in October of 1975, begins by describing the principles of diesel engines and their exhaust products. Load-haul-dump cycle emissions are discussed, the various exhaust treatment systems in use and under test are detailed, and ventilation requirements for underground mining are described.

Stewart, D. B., and N. N. Kallio. Auto-Ignition of Methane-Air in a Diesel Engine. Canada Center for Mineral and Energy Technology, August 1976, Report ERP/MRL 76-113 (R), 9 pp.

The auto-ignition of methane-air mixtures in an ASTM-CFR cetane engine has been investigated to determine if it is possible for diesel engines to continue to operate on a methane-air mixture after the fuel injection pump delivery is shut off. Test results suggest that such auto-ignition is possible over a fairly wide range of methane concentrations with the most sensitive methane-air mixture being about 8.8% by volume. As a result of this work it is suggested that a quick closing intake valve should continue to be required on flameproof diesel-powered equipment certified for use in coal and gassy non-coal Canadian underground mines.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Diesel Engines and the Mine Environment. Canada Center for Mineral and Energy Technology, November 1976, Report MRP/MRL 76-163, 30 pp.

During the few years prior to the preparation of this report, much effort had been spent in elucidating the impact of diesel engines upon the mine environment. The paper summarizes diesel engine fundamentals, exhaust emissions and typical tailpipe concentrations. Mine sampling results, a toxicological assessment and an evaluation of exhaust treatment systems are discussed. A review of changes in pollutant concentrations between the tailpipe and the mine exit is made and a summary is given of foreign diesel regulations.

Stewart, D. B., A. D'Aoust, E. D. Dainty, and J. P. Mogan. Reduction in Noxious Exhaust Burden by Some Minor Modifications to a Diesel-Powered LHD Mining Vehicle. See IV.B.

Stewart, D. B., and J. P. Mogan. Modifications to Improve LHD Type Vehicles. Canada Center for Mineral and Energy Technology, June 1976, Report MRP/MRL 76-82, 8 pp.; Can. Inst. Min. Bull., March 1977, pp. 151-153.

Under a cooperative study between The Canadian Explosives Atmospheres Laboratory and Deutz Canada Limited, load-haul-dump machines equipped with a torque converter and hydraulic pumps were field tested by means of an engine monitoring instrumentation package. It was found that owing to parasitic losses in the ancillaries and drivetrain, maximum available useable power may peak at less than full engine speed. Simple reduction of engine speed may save 15 to 25 percent on fuel consumption with no significant loss of available power. On some machines speed reduction will require modifications of the torque converter. Cost of this modification, when necessary, would be offset by reductions in exhaust emissions, ventilation requirements, fuel consumption, heat, noise, hydraulic system maintenance and by increased life of rotating components and filters and machine availability.

Stewart, D. B., J. P. Mogan, and E. D. Dainty. Canadian Diesel Experience. Canadian Center for Mineral and Energy Technology, August 1977, Report ERP/MRL 77-89, 15 pp.

When this paper was written, diesel-powered equipment was in wide use in Canadian noncoal underground mines, and although diesels had been used in Canadian coal mines for nearly 30 years, its use in that segment was still very limited. During the five years prior to this paper's presentation, a number of diesel-powered trackless mining vehicles had been approved for use in Canadian coal mines, including load-haul-dump units, shuttle cars, and utility vehicles. The report gives statistics on the number and size of diesel units in use in Canadian noncoal and coal underground mines and summarizes diesel engine fundamentals, exhaust emissions, typical tailpipe concentrations, mine sampling results, and exhaust treatment systems. It was concluded that in the transition to a more widespread use of diesel equipment in underground coal mines, operators could benefit from the experience of diesel use in noncoal mines. While there were unanswered questions in the areas of flameproofness, exhaust emissions, operator exposure, and health effects, the noncoal experience suggested that diesel equipment is both economically attractive and capable of operating safely in the underground mine environment.

Thompson, G. D., and P. G. Henderson. The Organization and Management of a Large Mechanized Colliery. J. of the South African Inst. of Min. and Metallurgy, v. 75, No. 8, March 1975, pp. 193-206.

A comprehensive description is given of the operation and management of Usutu Colleries Limited, the largest single producer of coal in South Africa at the time the article was written. The company was operating three mines and producing 435,000 tons of coal per month by conventional mechanized methods from "bord-and-pillar" workings. Very little mention is made of diesel engines, except that diesel tractors were used to draw specially constructed personnel carriers.

Toler, V. D. Diesel Shuttle Cars in an Underground Coal Mine. Coal Age, January 1965, pp. 56-58.

The article reports on the successful use of diesel shuttle cars for more than one year at the Scotia Coal Co. in eastern Kentucky. The company considered the diesel car's safety features to be its biggest advantage, but also listed several operational advantages over the electric cars, inasmuch as the diesels are not limited in their distance or directional movement by cables. The need for a rigid maintenance and inspection program was stressed and necessary routine maintenance procedures were listed.

U.S. Department of Health, Education, and Welfare. The Use of Diesel Equipment in Underground Coal Mines. See III.B.1.

Willrodt, P. Trends in Load-Haul-Dump Technology. Mining Magazine, November 1979, pp. 462-465.

Trackless mining methods have become established at many types of noncoal mining operations due to the flexibility of the equipment and the ability to haul ore between levels on ramp inclines, using either load-haul-dump machines or haulage trucks. Recently it has seen increased use in coal mining and in tunneling as its capabilities and advantages become increasingly established. The article discusses design facets and general performance comparisons of the various vehicle drive systems. For diesel engines, exhaust and flameproof requirements and options to be considered in engine selection are discussed.

B. Equipment Duty Cycles

Alcock, K. Duty Cycles and Load Factors of Diesel-Powered Vehicles in Underground Mines. Reviewed by the American Mining Congress Diesel Committee, 1977, 150 pp.

The paper contains results of studies of duty cycles and load factors for shuttle, load-haul-dump, and personnel vehicles operating both in typical coal mines and typical hard rock mines. In any given set of operating conditions, it is relatively easy to predict the overall time that the duty cycle will take and the mode at which the engine will be working at any particular part of the cycle. There are an infinite number of operating modes between engine idle and full load full speed, but because of the nature of the work done by a mining machine, the engine only operates at a few distinct modes. These modes are identified in this paper and recommendations on use of these modes for certification testing are made. Load factors for each type of vehicle are defined, and methods of calculating load factors and various elements considered in the calculations are described, as well as load factor results and study conclusions. A series of comprehensive data comparisons are made for electric shuttlecars and diesel shuttle vehicles operating in various situations.

Baker, R. E., and E. E. Daby. Engine Mapping Methodology. See III.F.

Bascom, R. C., and G. C. Hass. A Status Report on the Development of the 1973 California Diesel Emissions Standards. See III.F.

Douglas, W. J., and A. J. Herhal. Duty Cycle Description of Diesel Engines Operating in Underground Mines, March 1978, 15 pp.

Results of the duty cycle analysis for underground diesel equipment provided an initial assessment of machine loads which can be used in evaluating the effects of diesels on underground miners. Utilizing the results of underground time studies, duty cycles for four operating sections and two different machine configurations were obtained. The results indicated short machine cycles of 3 to 5 minutes and duty cycles of about 75% to 80% were found with LHD equipment, while longer machine cycles of 7 to 10 minutes and duty cycles between 37% and 45% were representative of tractor-trailer type haulage vehicles. Comparative information on energy utilization and shift duty cycles for the LHD's and tractor-trailer haulage vehicles is also presented. Further investigation was recommended in a number of areas to provide estimates of distribution of emissions and their interaction with miners in an underground environment.

East, J. H., Jr. Operating Diesel Locomotives Underground in Euorpean Mines. See VII.A.

Gunderman, R. J. Underground Trials of a Diesel-Powered Face Haulage Vehicle. See IX.D.

Ramani, R. V., and G. W. Kenzy. Evaluation of Diesel Equipment Deployment in Underground Coal Mines. v. III: Analysis of Diesel Deployment Schemes. See VII.A.

Ramani, R. V., G. W. Kenzy, and R. Stefanko. Evaluation of Diesel Equipment Deployment in Underground Coal Mines. v. II: Diesel Bibliography. See VII.A.

Rehnberg, O., P. A. Lindqvist, A. Sundgren, M. Norlund, and B. Schmidtbauer. Controlling Diesel Emissions Underground. World Mining, June 1982, pp. 48-52.

The use of diesel engines underground poses many questions about emissions and their effects. This is especially true in Sweden, where diesel power, particularly on LHD's, is very common. In this article, a simulated duty load cycle for diesel-powered machines in underground operation is described as a partial result of research being conducted at the University of Lulea at Lulea, Sweden, in the area of diesel exhaust purification. The aim of this specific project has been to establish a test cycle that can serve as a model for both mining engineers and engine manufacturers in their future selection, testing, and development of diesel-powered machines.

Simanaitis, D. J. Emission Test Cycles Around the World. Automotive Engineering, v. 85, No. 8, August 1977, pp. 34-43.

The article discusses the emission control test cycle philosophy, design, and operation as practiced in the United States, Japan, and Europe, and details the various mode cycles of each. It is stated that in addition to certifying that a car meets a country's set of standards, the test procedure also mirrors driving conditions around the world and has an influence on automotive design and development. The pros and cons of a worldwide certification procedure are discussed.

Stefanko, R., R. V. Ramani, and G. W. Kenzy. Evaluation of Diesel Equipment Deployment in Underground Coal Mines. v. 1: Validation Experiments for Models of Diesel Exhaust Contamination of Mine Atmospheres. See VII.A.

Stewart, D. B., A. D'Aoust, E. D. Dainty, and J. P. Mogan. The Determination of Diesel Engine Parameters Underground for a Load-Haul-Dump Vehicle. See VII.A.

Taigel, P. G. Diesel Locomotives in Mines: The Production of Toxic Gases by the Diesel Engine. See VII.A.

U.S. Code of Federal Regulations. Title 40--Protection of Environment; Chapter I--Environmental Protection Agency; Part 86--Control of Air Pollution From New Motor Vehicles and Motor Vehicle Engines: Certification and Test Procedures. Federal Register, v. 42, No. 174, Sept. 8, 1977, pp. 45132-45174.

This rule prescribes more stringent gaseous emission standards for heavy-duty gasoline-fueled and diesel engines for the 1979 and later model years and revises parts of the instrument requirements and test procedures. Although there have been gains in control of air pollution, there are many air quality control regions which will not be able to meet ambient air quality standards with currently implemented control strategies. Heavy-duty vehicles contribute a significant percentage of the total hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) in the air. This regulatory action will result in significant reductions in gaseous emissions from heavy-duty vehicles. This action is forecast to result in a reduction by 1990 in nationwide emissions of .18 to .30 million tons of HC, up to .80 million tons of CO, and .12 to .22 million tons of NO_x. These reductions correspond to urban air quality improvements of 2 to 5 percent for oxidants, 1 percent for carbon monoxide and 1 to 2 percent for nitrogen dioxide.

VIII. DIESEL ENGINE MAINTENANCE

A. Cooling System

Bolis, D. A., J. H. Johnson, and D. A. Daavetilla. The Effect of Oil and Coolant Temperatures on Diesel Engine Wear. See VIII.H.

Diesel & Gas Turbine Progress. Cooling System Additive Helps Extend Engine Life. October 1976, p. 31.

It has been proven extensively that engine life and performance can be extended, warranties protected, and operating costs reduced through efficiently operating cooling systems. The advantage of proper water treatment in cooling systems can be applied to any vehicular and stationary use. This brief article is an advertisement for a cooling system additive and describes its properties and functions.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

Schulz, E. J. Diesel Mechanics. See I.B.1a.

B. Lubrication System

Boone, E. F., and F. E. Didot. Field Experience of Extended Drain Interval in Diesel Lubricant Performance. See II.E.

Claycomb, J. W. Lubrication Survey Program Improves Equipment Availability. Pit & Quarry, May 1976, pp. 79-81.

The article describes a program of predictive maintenance adopted by New Enterprise Stone & Lime Co., Inc., in the operation of its quarries, sand plants, concrete plants, coal mines, and contract construction activities in widespread locations in Pennsylvania. The program covers portable and stationary quarry equipment and a mobile fleet of more than 400 vehicles. Scheduled periodic on-site testing asnd analysis are performed to determine lubricant conditions, and with test results watched carefully, the company has increased oil drain intervals and cut engine oil use in half. A reduction in the use of other types of lubricants has also been realized through measures achieved by laboratory testing and reclaiming. On-site check of systems such as hydraulics, transmissions, rear ends, and final drives for lubricant and wear status has enabled the company to predict and prevent equipment failures and a marked improvement in equipment availability has been experienced.

Highway & Heavy Construction. The SA, SB, Etc. About Engine Oil. October 1976, pp. 33-34.

To assist contractor service and maintenance people in selecting the right oil for lightweight truck engines, the Society of Automotive Engineers and the American Petroleum Institute have established a five-point classification system for oils. These organizations have agreed on nine quality designations for gasoline-fueled automotive engines--SA, SB, SC, SD, and SE. The API also has four service classifications for diesel engine oils. While some of these lubricants can be used in gasoline engines, too, their primary use is in diesel engines. These classifications are CA, CB, CC, and CD. Almost a quart in every gallon of motor oil consists of selected additives designed to improve engine performance and efficiency. A description of the various engine oils and the types of additives and the role they play in protecting the engine are discussed in the article.

Knight, C. R., and H. Weiser. Lubrication Requirements of European Automotive Diesel Engines. Presented at the Automobile Eng. Meeting, Dearborn, Mich., Oct. 18-22, 1976, SAE Preprint 760721, 28 pp.

A survey of production statistics, design types and application of high speed automotive diesel engines (rated speed >1800 rpm) in Western Europe has been conducted, together with a forecast in market trends. Lubrication problems of these engines have been under review by the CEC Investigation Group IGL-5, highlighting lubricant-related problem areas such as bore polishing, valve train wear, oil thickening, and ring sticking. These problems have been analyzed within the IGL-5 Group and the suitability of existing standardized test methods for present and anticipated European needs has been reviewed. This has shown the necessity to develop specific test methods covering bore polishing and valve train wear. Further examination in the other problem areas identified has been initiated.

Lewis, A. Special Lubricants Solve Heat and Dust Problems. See II.A.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

McDonnell, T. F., and S. A. Tempe. The Effects of Engine Oil Additives on Vehicle Fuel Economy, Emissions, Emission Control Components and Engine Wear. See II.E.

Mueller, B. The Application of Centralized Lubrication Systems to Mobile Equipment. Presented at the Earthmoving Ind. Conference, Central Ill. Section, Peoria, Ill., Apr. 15-16, 1975, SAE Preprint 750585, 8 pp.

Recent developments in centralized lubrication systems have made them more compatible with the operational demands of the construction industry. This system delivers the correct amount of lubrication to each bearing, can warn the operator in the event of a lubrication failure and directs maintenance personnel to the problem area during a scheduled downtime. It has a wide variety of pumping methods, controls, and monitors. Safety of personnel, continuous lubrication, reduced downtime, reduced usage of lubricants, longer machine life and higher profits are the results of a good lubrication program.

Rock Products. Central Lube Systems Help Sand Producer Halve Repair and Maintenance Costs. November 1977, pp. 68-70.

Centralized lubrication systems are the heart of a 3-part preventive maintenance and equipment trade-in program at the New Jersey sand operations of Jesse S. Morie & Sons, Inc. In the 3-part program, 1--each of the company's eight wheel-loaders was equipped with an automatic lubrication system, 2--all routine maintenance and repairs are handled by the local equipment dealer for service, and 3--the company and the dealer determined an optimum time to trade in each machine. The central lube systems consist of an air or hydraulic-powered pump, a central oil reservoir, a pressure gauge, master feeder and secondary feeder assemblies, a DC timer, and miscellaneous hose and fittings. The company operates more than 100 pieces of equipment with with internal combustion engines, and does not have one mechanic on the payroll. In addition, the company doesn't maintain a spare parts inventory, except for minor expendable items. The operators maintain only a visual check on the equipment and fill the oil reservoirs daily. The rest is handled by the local servicing company. Through the program, annual repair and maintenance costs have been reduced more than 50% and loader availability is at 98%.

Sakamoto, K. Trends in Japanese Diesel Engines and Their Lubrication. Presented at the Automobile Eng. Meeting, Dearborn, Mich., Oct. 18-22, 1976, SAE Preprint 760720, 12 pp.

In Japan there is a large and growing number of diesel engines used in commercial vehicles and construction equipment. This paper reports the recent Japenese trends related to these automotive diesel engines and diesel engine oils. In addition, Japanese diesel engine emission regulations are discussed as well as the relation between lubricant performance and emissions. Promising methods for controlling emissions and future trends in lubricant quality are also discussed.

Schulz, E. J. Diesel Mechanics. See I.B.1a.

C. Fuel System

Hambright, R. N. Fuel Injection Diagnostic Techniques for Shop Applications. Presented at the Combined Commercial Vehicle and Fuels & Lubricants Meetings, Chicago, Ill., June 17-21, 1974, SAE Preprint 740533, 12 pp.

Four basic shop techniques for diagnosing diesel fuel injection systems are described, along with remarks concerning the advantages and disadvantages of each. Standard fuel injection systems in current use are treated in the discussions and design suggestions are offered that can expedite diagnosis. Argument is given for the application of the complete system diagnosis technique. The requirements for obtaining this diagnostic technique are related for both current and future fuel injection systems.

Henein, N. A., and J. D. Rozanski. A Technique for the Diagnosis of Malfunctions in Diesel Injection Systems. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-Mar. 3, 1978, SAE Technical Paper Series 780033, 16 pp.

Many diagnostic parameters have been studied for the detection of malfunctions in two types of diesel injection systems: the unit injector and the distributor pump system. It has been found that the peak fuel pressure in the unit injector pressure chamber (measured by a strain gage mounted on the injector rocker arm), and the peak fuel pressure in the line near the injector on the distributor injection system are very useful parameters for fault diagnosis. Figures and charts relating the fuel peak pressure and engine speed have been developed to identify a healthy as well as a faulty injection system.

Highway & Heavy Construction. Trouble-Shooting Fuel Systems. October 1976, pp. 48-51.

The components of a diesel engine's fuel system--tank, filter, pump, and injector--are part of a highly complex, precision system and need two distinct levels of maintenance. First, some components can be checked and replaced in the field without affecting the calibration of the system. The second level, in which most component repair falls, is shop repair and calibration. The article outlines procedures for trouble shooting, and lists a series of corrective actions for engine problems identified in three basic categories: (1) The engine will not start under any circumstances; (2) the engine will start but with great difficulty or it may start then stop, or it may misfire, surge, and run roughly even at idle; and (3) the engine will start and run well at low power settings or idle, but will not develop power at full load, or the engine will develop power but shows excessive smoke.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

Schulz, E. J. Diesel Mechanics. See I.B.1a.

Smiley, C. H. Getting the Most From Your Fuel Dollars. See II.C.

Smiley, C. H. Preparing Equipment for Winter Operation. Coal Mining & Processing, November 1979, pp. 76-80.

Winter weather imposes unusual stresses on diesel engines and other systems of heavy trucks and equipment. It has been estimated that during cold weather maintenance costs double and fuel consumption costs increase as much as 50%. This article outlines a program of actions and preventive maintenance for cooling systems, start/charge systems, and fuel systems in preparing mobile equipment for winter operation. A number of operating tips for reducing fuel consumption and breakdowns during the winter are also presented.

D. Induction System

Bly, R. L. Tips on Turbochargers. See I.B.2.

Bly, R. L. Your Diesel Air Induction System Needs Good Preventive Maintenance. Pit & Quarry, November 1975, pp. 103-105.

The author presents comprehensive guidelines in preventive maintenance and troubleshooting in the use of air induction systems.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

Schulz, E. J. Diesel Mechanics. See I.B.1a.

E. Engine Rebuild

Diesel & Gas Turbine Progress. A "Fountain of Youth" for Diesels. February 1977, pp. 33-35.

The article describes the operations of Precision National Corp., which specializes in the remanufacture of large cylinder liners and crankshafts for stationary, marine, and locomotive diesels, plus the complete rebuilding of diesel locomotives. The company claims that because it incorporates new improvements and developments in materials, processes, and design, remanufactured parts are restored not only to their original efficiency but are actually better than new and at great savings compared with the cost of new equipment.

Diesel & Gas Turbine Progress. Computerized Evaluation of Engine Overhaul Operation. January 1977, pp. 10-11.

A computerized system for testing and evaluating rebuilt diesel engines has reduced costs and improved efficiency at the Long Beach, Calif., Naval Shipyard, the U.S. Navy's principal overhaul point for diesel engines. The Diesel Engine Analyzer (DEA), which is the key element in the shipyard's remodeled diesel engine facility, permits twice as many engines to be tested by half as many technicians. It also prevents costly engine failures that were common using the former method of manually controlled testing and shakedown. The article details the capabilities and the operation of the DEA.

Diesel & Gas Turbine Progress. Diesel Rebuilding Activity Expanding. April 1976, p. 69.

The article describes a boring machine recently added to the line of engine reconditioning equipment by Cedar Rapids Engineering Co., of Cedar Rapids, Ia. The new unit is capable of boring a vee-type block up to 40" long and an in-line block up to 47" long and will accommodate a Detroit Diesel Allison V-12 engine block. The addition was prompted by the increasing number of larger vehicular diesels.

Diesel & Gas Turbine Progress. Reconditioning Extends Big Engine Service Life. October 1976, pp. 42-43.

The L. V. Haynes Corp., Jackson, Mich., specializes in reconditioning and supplying large engine parts. Its ADECO Division manufactures fuel injection equipment for large engines. Operations of both segments of the company and services provided to various types of diesel equipment operators are discussed.

Fellberg, H. W. The Rebuilt Engine. SAE Preprint 690545. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 20-24.

This paper discusses in detail the recommended procedures for rebuilding internal combustion engines; explains how decisions to rebuild, replace, or reuse engine parts are arrived at by experts, and describes how each part of the engine is examined, cleaned, and tested to insure maximum performance. When an engine should be rebuilt, what rebuilding entails, how to evaluate a repair shop by its equipment, and similar valuable information regarding engines and their maintenance are topics considered.

Krieger, R. Special Tools for Diesels. Coal Age, February 1978, pp. 197-205.

Experience has shown that proper tools are the key to successful engine maintenance and repair. A guide to various specialized tools that can make overhauling or repairing diesels easier is provided, along with a description of their use.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

Osenga, M. Custom Air-Cooled Diesel Rebuilding Program Expanded. Diesel & Gas Turbine Progress, June 1976, pp. 46-47.

D. A. MacPherson, Inc., specializes in custom rebuilding of Deutz air-cooled engines used extensively for vehicle and industrial power in northern U.S. and Canadian mines. Some work has been done on other makes of diesels. The article is an overview of the company's rebuilding procedures and capabilities.

Schulz, E. J. Diesel Mechanics. See I.B.1a.

Springer, K. J. Exhaust Emissions From Rebuilt Heavy Duty Truck Engines. Southwest Research Institute, San Antonio, Tex., July 1976, Contract No. 68-03-2196, 50 pp.; available for consultation at Twin Cities Res. Center, Minneapolis, Minn.

This report describes the laboratory test and evaluation results of Task No. 3 by Southwest Research Institute to EPA Contract 68-03-2196. Using two heavy-duty engines, one a 1972 IHC VS549 gasoline engine and the other a 1970 Mack ENDT 675 diesel engine, a series of gaseous, smoke, and related performance tests were made. The gasoline engine was tested in four configurations, two before being reconditioned by a factory rebuild center and

two after having been overhauled. The diesel engine was likewise tested in two configurations before being factory rebuilt and then retested. Gaseous emission rates in terms of grams per kilowatt-hour and grams per brake horsepower-hour of hydrocarbons, carbon monoxide, and oxides of nitrogen were determined in replicate. Current Federal gaseous emissions tests for heavy-duty engines were modified to incorporate major features of the newly proposed test procedures by EPA.

F. Preventive Maintenance

Alcock, K. Diesel-Powered Mine Equipment: Tips on Servicing and Trouble-Shooting. Coal Age, October 1975, pp. 122-124.

The author recommends procedures for initiating a preventive maintenance program for diesels, and a trouble-shooting list for checking various parts of the diesel system to determine the reason for engine malfunctions. Several misconceptions regarding the maintenance of underground diesel vehicles are cited and maintenance information provided that would dispel these misconceptions.

Bly, R. L. Preventive Maintenance Adds Life to Diesel Air Induction Systems. World Coal, February 1976, pp. 28-30.

Diesel air induction systems are normally comprised of one or more air cleaners and required piping to channel filtered air to the combustion chambers. Trouble-shooting and preventive maintenance of these systems in both pressurized and naturally aspirated air induction systems are critical to a diesel engine's efficient and economic operation. A breakdown of the system will seriously affect performance, or worse, it can contaminate the engine with dirt, causing severe damage to pistons, rings, sleeves, or other components. Constant care of the air induction system will pay off in profitability over the life of a machine. Of prime importance is regular inspection. The author provides extensive guidelines to facilitate an effective preventive maintenance program.

Espach, T. M. Improvements to the Trackless-Mining Equipment and Operation at Prieska Copper Mines (Proprietary) Limited. J. of the South African Institute of Mining and Metallurge, v. 79, No. 9, April 1979, pp. 249-254.

The paper gives an account of changes that have taken place since the publication of an August 1973 paper on the trackless mining operations at Prieska Copper Mines, Prieska, Cape Province, South Africa. Details are given of the modification to the equipment, the maintenance of equipment and roadways, the training of operators, and the operating costs.

Hall, O. P., Jr., and N. A. Richardson. The Economic Effectiveness of Vehicle Inspection/Maintenance as a Means for Reducing Exhaust Emissions: A Quantitative Appraisal. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740131, 12 pp.

A program of vehicle inspection and maintenance has emerged as potential strategy for reducing harmful exhaust emissions from automobiles. Of the several short-term aproaches now available for controlling vehicular emissions, an inspection program has the capacity for affecting the largest number of vehicles within the population. The purpose of this study is to attempt to characterize the economic effectiveness of a

mandatory inspection maintenance program. Results from this analysis show that under proper conditions, an inspection program can serve as a viable component of an emission control strategy.

Heavy Duty Equipment Maintenance. Improving Production With Predictive Maintenance. February 1976, pp. 32-37.

The article describes the predictive maintenance program of Allied Chemical Corp.'s limestone quarry at Jamestown, New York. Equipment maintenance scheduling, actions, and cost savings and other benefits are related. The advantages and disadvantages of an automatic centralized lubrication system used on front-end loaders are also discussed.

Helmich, M. J. Maintenance and Operation of Nuclear Diesel Generator Systems. Presented at the Energy Technol. Conference and Exhibit, Houston, Texas, Sept. 18-22, 1977, ASME Preprint 77-DGP-14, 12 pp.

Heavy duty, medium speed diesel engines have characteristically been applied to applications demanding continuous service with high load factors. The maintenance, inspection and replacement parts programs that have been formulated for this class of machinery reflect this type of operation. The purpose of this paper is to recommend a new approach for these programs when this class of engine is applied to Nuclear Diesel Generator systems, stressing the need for progressive, periodic, and preventive maintenance. It is recommended that the system should be based upon a reliable design, and provision should be made to utilize valid diagnostic procedures during operation and periods of dormancy. The packaged engine-generator-auxilary concept is an important feature since it insures system readiness, and the interrelation of all systems is properly de-bugged during acceptance testing prior to actual operation. Other recommendations are also cited.

IRD Mechanalysis, Inc. Preventive Maintenance in Rotating Machinery Using Vibration Analysis. Columbus, Ohio, Technical Paper No. 102, 1975, 14 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

Many companies and machinery manufacturers are using a simple technique to detect hidden rotating machinery trouble before failure can occur and in time to schedule necessary repairs. "Mechanalysis," a registered trademark, is the name given this technique by IRD Mechanalysis, Inc. It works this way. Each kind of trouble--unbalance, misalignment, bad gears, worn bearings, defective spindles, and mechanical looseness--produces vibration in a unique way. Mechanalysis uses a machine's vibration and noise to determine what is wrong while the machine operates. This paper describes the portable vibration analysis instrumentation, guidelines, and preventive maintenance procedures developed by IRD that are being utilized throughout industry to insure quality products and uninterrupted machinery operation. In addition, a new quick diagnostic technique utilizing the machine's pulse or vibration signature to pinpoint mechanical defects is discussed.

Judge, A. W. Modern Smaller Diesel Engines: In Theory, Construction, Operation and Maintenance. See I.A.

Kolbe, J. F. Abrasive Wear-Identification and Prevention. SAE Preprint 690544. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. See VIII.G.

McElroy, W. J. Preventive Maintenance Through Engine Analyzing. Diesel & Gas Turbine Progress, April 1977, pp. 10-11.

Panhandle Eastern Pipe Line Co.'s main gas gathering operations are located in the panhandles of Texas and Oklahoma, and in Western Kansas. The Liberal, Kansas Station is the first of 13 main line compressor stations extending to Fort Wayne, Ind. Numerous markets are served enroute to the primary market area of Detroit. Skid-mounted engine compressor units used in the gas gathering service range from 55 to 2000 hp. The company's objectives in instituting its engine analyzing program were to reduce maintenance costs, extend the periods between maintenance by finding mechanical faults at an early stage of development and remedy them before the engine required extensive repair, thus increasing the overall operating efficiency and improving fuel consumption. The article describes the various types of equipment used in the analyzing program and the steps that are followed.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

Mueller, B. The Application of Centralized Lubrication Systems to Mobile Equipment. See VIII.B.

Novak, J. B. Preventive Maintenance--What, How Much, and Why? Society of Mining Engineers, AIME, Transactions--v. 252, September 1972, pp. 266-270.

The program describes preventive maintenance practices and controls applicable in situations where maintenance actions are triggered primarily by breakdown or part failure and specification and documentation of detailed maintenance practices are minimal or nonexistent. The presentation describes requirements of organization structure, program administration, implementation and operation, type of benefits expected, and actual benefits derived in selected areas. The principle objectives of the program are to provide quick, inexpensive, and effective controls over maintenance practices and requirements and to establish a nucleus of controls that subsequently can be expanded to cover all maintenance activities.

Obits, W., and D. Ancona. Maintenance Indicator System for Military Trucks. Presented at the Combined Vehicle Eng. & Operations and Powerplant Meetings, June 18-22, 1973, Chicago, Ill., SAE Preprint 730657, 8 pp.

The Maintenance Indicator System (MIS) is a completely automatic system that monitors the condition and performance of critical subsystems and accessories of a vehicle and its engine. Although designed specifically for the military 2-1/2 ton and 5 ton trucks, the indicator system can be adapted to most military and commercial vehicles with minor modifications to suit the particular requirements. MIS consists of a dashboard-mounted display panel located in full view of the operator and connected through a wiring harness to sensors permanently mounted on or within various systems and accessories of the engine and vehicle. The sensors monitor critical parameters and alert the driver or mechanic by a light activated on the panel when service is required or a malfunction has occurred. Maintenance functions indicated by MIS include: fuel supply pressure to engine, engine primary fuel filter condition, radiator coolant level, engine coolant temperature, engine oil level, engine oil pressure, engine oil filter condition, alternator/generator output, vehicle battery voltage, vehicle air/hydraulic brake system condition, transmission operating temperature, air cleaner condition, and transfer case operating temperature.

Schneider, E. H. How the Vehicle Maintenance Reporting Standards Help a Fleet. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780273, 8 pp.

E. I. DuPont de Nemours and Co. (by whom the author is employed) operates a medium-sized fleet consisting of 200 tractors and 450 trailers. The company has three basic goals in establishing programs for its fleet's operation: low maintenance costs, fuel economy, and safety. To maintain its program and to work toward improved results, DuPont makes use of a variety of management tools, one of which is the "Burlington reports." Every maintenance dollar spent is programmed into the system. The reports provide the company with all fuel and maintenance data to accurately determine costs and to develop methods to improve existing cost and fuel savings programs. Three examples are given to show how the reports are used to make some significant decisions in the company's operation. The first two deal with replacement of equipment and the third with driver influence.

Smith, D. J., and A. H. Babb. Maintainability Engineering. Halsted Press, a Division of John Wiley & Sons, Inc., New York, N. Y., 1973, 119 pp.

This publication examines the factors which determine the maintainability of a system: design, human factors, and the maintenance environment. The authors identify these essential activities and provide a checklist of design and maintenance support features which influence repair time. Methods of evaluating the maintainability of proposed designs are described and pitfalls inherent in contractual agreements concerning maintainability and reliability are highlighted. The book refers largely to electronics equipment with a small mechanical content but the principles discussed have wider applications.

Stewart, D. E. Preventive Maintenance Program Holds Costs at Similkameen Mining Operations. Western Miner, July 1976, pp. 9-12.

Consistent and careful preventive maintenance, with detailed readily-accessible records of each test and its results, are the keys to holding the line on maintenance costs for Similkameen Mining Company Ltd., of Princeton, B.C. The article details the company's preventive maintenance routine and also presents an inventory of its equipment.

TRW Systems Group. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. IV. Experimental Characterization of Vehicle Emissions and Maintenance States. July 1972, 270 pp.; NTIS PB-220 729.

The Economic Effectiveness Model is a tool by which any state, air basin, or region can determine the most effective vehicle maintenance and inspection program to reduce vehicle exhaust emission contributions to air pollution. Three distinct experimental programs were conducted to characterize vehicle emissions and maintenance states: (1) A large scale fleet evaluation to determine vehicle engine parameter setting distributions and component deterioration characteristics with time and mileage; (2) Statistically designed test (orthogonal experiments) of 1971 California and pre-emission controlled vehicles to determine the main effects and first order interactions of emission response to engine parameters; and (3) a survey to determine the maintenance condition (state of tune-up) of vehicle engine tune-up parameters and emission control systems and components of vehicles in the Detroit area. The designs and results of each of these experiments are discussed.

U.S. Environmental Protection Agency. Questions and Answers Concerning the Technical Details of Inspection and Maintenance. April 1979, 40 pp.; NTIS PB 301 215.

Report includes questions and answers broken down into categories of benefits, costs and implementation of the details of inspection and maintenance. Issues discussed are emission reductions, maintenance costs, repairs, cost analysis, economic and social impact, vehicle/engine life, load/idle tests, heavy duty inspection/maintenance, funding, delays, public information, emission control devices (catalysts, fuel switching, and physical inspection), mechanics training, warranty, and EPA reports and rules.

G. Diagnostics

Alar, C. D. Challenges and Problems in a Truck Diagnostic Center. Presented at the Truck Meeting, Indianapolis, Ind., Nov. 1-4, 1976, SAE Preprint 760836, 8 pp.

Although the utilization of diagnostics in automotive service is nothing new, heavy duty truck service presents a significantly different challenge for the service center, as well as the diagnostic equipment manufacturer. There exists a broad area of potential for diagnostics for both a truck service and sales operation. This paper examines these specific areas including their beneficial potential, as well as the related problem considerations that are equally significant. The information presented is based on the personal experience of the writer, along with his association with, and observances of, truck service centers and other automotive service facilities utilizing diagnostic equipment.

Bly, R. L. Clean Exhaust--Good Diesel Performance: Smoke Points to Need for Maintenance, Color Clue to Causes. Pit & Quarry, October 1973, pp. 75-79.

Dark smoke from a diesel engine exhaust is not a sign of power but of an engine that is not operating efficiently as a result of an improper fuel-to-air ratio or a malfunctioning combustion system. In addition to quantity, color of exhaust can be analyzed to determine if the engine is operating efficiently with clean combustion. The author describes various characteristics of abnormal exhaust and suggests probable causes for these conditions. The importance of an air induction maintenance system which minimizes air pollution and maintains maximum efficiency and fuel economy is stressed.

Cafarelli, N. E., and R. J. Zanic. Engine Performance Analysis With Modern Instrumentation as Related to Vehicle Maintenance. SAE Preprint 690542. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 1-6.

This paper presents the results of a survey made concerning modern test equipment as it is related to various fleet preventive maintenance programs in the Chicago area. The survey explains how a profitable and satisfying fleet operation is made possible, from a maintenance standpoint, through the utilization of modern electronic test equipment and proper test procedures. Included are the areas of testing, types of test equipment needed, and fleet shop maintenance procedures.

Carothers, R. C. Temperature Monitoring Cuts Fuel Bill, Aids Maintenance. Diesel & Gas Turbine Progress, April 1977, pp. 40-41.

The article describes the diesel engine monitoring system of a central energy complex in California that provides refrigerant, steam, and hot ammonia gas to seven food processing companies through underground pipelines. The task of keeping the four diesel engines that generate heating and cooling products running smoothly and economically is aided by the use of a microprocessor-controlled digital instrument designed to monitor cylinder exhaust gas temperatures. Each engine has its own engine monitoring and control system which monitors critical performance characteristics, including: lube oil pressure and temperature; gear oil pressure and temperature; turbocharger oil pressure; fuel gas pressure; fuel oil pressure; and jacket water temperature.

Denson, L. Modular Solid-State Controls Minimize Maintenance Requirements. Coal Age, October 1975, p. 168.

Solid-state electronics is used in a variety of ways in underground mining. The products developed by one company, their application, and the benefits of solid-state controls are described.

Diesel & Gas Turbine Progress. Engine Maintenance Monitoring System. April 1978, pp. 32, 34.

A newly developed engine maintenance, monitoring and analysis system (EMMA), is a microcomputer-controlled data acquisition and analysis system designed for heavy duty industrial and marine diesel and gas engines. Its function is to continuously scan a wide variety of engine sensors and automatically analyze the mechanical condition of the engine, as well as keep track of preventive maintenance required. The results of the engine analysis are transformed into an advisory-diagnostic output in the form of printed text. Using EMMA, diesel engines are analyzed as frequently as once every three seconds for safety limits and good operation. Details of its functions are provided.

Eberle, M. K. Diagnostic System for Diesel Engines. Sulzer Technical Review, April 1976, pp. 163-167.

The reasons for the development of the Sulzer Engine Diagnostic System (SEDS) are outlined in this article, together with its mode of operation, including various diagrams. SEDS is an on-line automatic data acquisition and interpretation system using a digital minicomputer. The system gives an analysis of the instantaneous performance and running condition of the engine. Performance analysis indicates the kind of maintenance work required to keep the engine performance at optimum level. The built-in alarm limits prevent an eventual breakdown and the trend analysis gives indications when and which components have to be replaced or overhaul has to be carried out.

Faller, E. K. Automated Diagnostic System for Military Trucks. Presented at the Truck Meeting, Indianapolis, Ind., Nov. 1-4, 1976, SAE Preprint 760835, 8 pp.

It is the German philosophy of automatic diagnostic systems for military trucks to use as little as possible on board test equipment and to use as much as possible regularly built-in transducers. The present design of such a diagnostic system is explained in this paper by some examples.

Fuller, E. J. The Practical Realization of an Automated Diagnostic System for Diesel-Powered Vehicles. Presented at the Truck Meeting, Indianapolis, Ind., Nov. 1-4, 1976, SAE Preprint 760838, 20 pp.

This paper describes a microprocessor-controlled test system which has been developed by PRD Electronics to fulfill the increasing need for an automated diagnostic test system for diesel-powered vehicles. The rationale for a diagnostic analyzer which fully utilizes the mechanic in the test loop and rapidly provides diagnostic information on faults which are difficult and time consuming to accurately isolate manually is set forth. The translation of these requirements into realizable hardware is fully delineated. An operational test sequence as actually implemented for the testing of several different diesel engine types is given, along with a presentation of the test results.

Goodwin, E. Diagnostic Studies of Lubricants. See VIII.H.

Hadden, S. C., L. R. Hulls, and E. M. Sutphin. Non-Contact Diagnosis of Internal Combustion Engine Faults Through Remote Sensing. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760146, 12 pp.

A method has been developed for obtaining engine speed and diagnostic information for a diesel engine without mechanical or electrical connections to the engine. This non-contact technique has the potential for making diesel

engine power measurement and fault detection extremely simple and rapid. The method employs a single transducer held near the engine and special purpose circuitry which extracts the engine speed information from the signal and performs spectral analysis for diagnostic purposes. Circuit outputs are engine speed, a digital pulse train with repetition rate proportional to engine speed, and a harmonic ratio which sensitively indicates the degree of non-uniformity among engine cylinders. By this method, diesel engines with minor compression losses or fuel injection faults can readily be identified without vehicle contact in less than one minute of testing. With additional signal processing, the power producing capability of the engine can also rapidly be evaluated.

Hambright, R. N. Fuel Injection Diagnostic Techniques for Shop Applications. See VIII.C.

Hambright, R. N., and H. S. Benson. Diagnostics of Diesel Engines Using Exhaust Smoke and Temperature. Presented at the Truck Meeting, Indianapolis, Ind., Nov. 1-4, 1976, SAE Preprint 760833, 12 pp.

An experimental sensor array that measures dynamic exhaust temperature and dynamic smoke for the purpose of diagnosing diesel engine fuel injection equipment was designed, built, and tested. The sensor array is portable and easily installed on truck tailpipes, and was tested using two 6V-53 Detroit Diesel engines. The dynamic temperature sensor is a very high response instrument capable of measuring changes in gas temperature in excess of 104°F/second. The dynamic smokemeter is an optical device designed to measure very low levels of light opacity in the smoke plume, with a response compatible with the engine firing frequency. Dynamic exhaust temperature data had more diagnostic significance than dynamic smoke in the detection of maximum power degrading fuel injection faults. Gaseous exhaust emissions (CO, CO_2, O_2, NO_x, and hydrocarbons) were also evaluated for their diagnostic merit and were found to be less significant than the dynamic temperature and smoke data under the no-load test constraints common to shop and field diagnosis.

Hambright, R. N., and C. D. Wood. Vehicle Diagnostic Systems; the State-of-the-Art. Presented at the 1973 Annual Meeting, American Society of Agricultural Engineers, Univ. Ky., Lexington, Ky., June 17-20, 1973, ASAE Paper No. 73-144, 13 pp.

Diagnostic system fundamentals are defined in basic terms, and current activity is discussed for governmental, military, industrial, and commercial organizations. Physical and operational descriptions of example diagnostic systems are given for end-of-assembly-line, shop, portable, and built-in applications. Current diagnostic capabilities are related to instrumentation, parameters, and human factor design options. Significant increases in cost-effective uses of diagnostic systems require some built-in diagnostic equipment. The possible diagnostic systems and capabilities in the near future are a function of technological advances and comprehensive engineering.

Henein, N. A., and J. D. Rozanski. A Technique for the Diagnosis of Malfunctions in Diesel Injection Systems. See VIII.C.

Johnston, S. C., C. W. Robinson, W. S. Rorke, J. R. Smith, and P. O. Witze. Application of Laser Diagnostics to an Injected Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790092, 21 pp.

Measurements taken in a special, single cylinder, direct injection stratified-charge engine are presented. The optical measurement techniques employed include continuous-wave laser Raman Spectroscopy for density fluctuations, high-speed cinematography for flow visualization, and laser Doppler velocimetry for velocities and turbulence intensities. More conventional data on cylinder pressure, power, and emissions levels are also given. The purpose of the study was to demonstrate the types of detailed measurements that are now possible within an engine cylinder.

Kolbe, J. F. Abrasive Wear--Identification and Prevention. SAE Preprint 690544. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 15-20.

Abrasive wear, pertaining to the internal combustion engine, has been the subject of numerous technical investigations, papers, and articles. The majority of these presentations are in the area of filtration and the prevention of excessive or abnormal wear. Maintenance men must learn to determine if abrasive wear is present and then take corrective measures. This paper is intended to aid mechanics in identifying abrasive wear from a practical standpoint and in applying the proper remedy.

Mackey, G. The Exhaust Smoke Opacimeter--A Certifying and Maintenance Tool. Diesel & Gas Turbine Progress, July 1976, pp. 30-31.

One of the most perceptive indications of diesel engine conditions is exhaust smoke density. A technique for measuring exhaust smoke of in-use diesel-powered trucks was developed at Clayton Manufacturing Co. in 1973. It consists of operating a vehicle on a chassis dynamometer and subjecting the engine to various modes of operation, i.e. idle, acceleration and lug-down modes as required for certification testing, and recording both the speed and exhaust opacity on a strip chart. Details of its operation are provided.

Musil, N. J. Engine Failure Fingerprints. SAE Preprint 690543. Society of Automotive Engineers, Inc. Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 6-14.

In this paper, the author points out the importance of diagnosing failures to prevent a recurrence. Emphasis is placed on looking for the tell-tail markings and clues that will aid in tracing the cause of various engine parts failures; also, on the inspection of used parts and the selection of new parts. It is also pointed out that the selection of premium relacement parts may be necessary under certain operating conditions.

Muzi, A. Sensor Selection for Automatic Diagnosis of Vehicles. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770403, 12 pp.

Improvements in vehicle diagnostics are evolving both from the development of new sensors and from the extension of standard sensor capabilities made possible by modern electronics and processing techniques. Accordingly, the effective application of sensors to vehicles is an overall system problem. Foremost among the design considerations are the test paramaters that are the indicators of faults, the accuracy with which they must be measured, and the methods available for evaluating, processing and displaying those parameters. Next are the considerations of survival and performance in the automotive environment, the operator's method of performing the test, and applicability to a broad spectrum of vehicles. This paper discusses criteria for sensor selection from the viewpoint of a developer of systems for the malfunction diagnosis of vehicles with spark or compression ignition engines. The focus is on pressure transducers. The considerations, however, are generally applicable to all sensors.

Obits, W., and D. Ancona. Maintenance Indicator System for Military Trucks. See III.F.

Parker, K., and P. D. Miller. The First Digital Automotive Diagnostic System-Autosense. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760144, 16 pp.

The purpose of this paper is to describe a new approach to vehicle test and diagnosis, the first digital automotive diagnostic system--Autosense®. The Autosense® Computerized Digital Diagnostic System is designed to assist mechanics, at all levels, test and diagnose today's newest vehicles. The system can run individual tests, and thus be used by the mechanics as a tool, or automatically step the mechanic through a sequence of tests to diagnose a specific vehicle problem, totally check a vehicle or its individual systems. The system compares actual vehicle performance to manufacturer's vehicle specifications and provides the mechanic with recommended repairs. The system also provides the mechanic and the customer with a hard-copy printout of all test performed, the actual vehicle specifications and all recommended repairs.

Pratt, G. W., Jr. An Opto-Electronic Torquemeter for Engine Control. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760070, 4 pp.

An optical means of measuring torque is described having high accuracy and reliability combined with modest cost. Details of an instrument which was adapted to a transmission output shaft are given. Torque, rpm, and their time rates of change are envisaged as inputs to a microprocessor for the generation of feedback control signals for timing, fuel-air ratio, and fuel.

Sarna, D. S., and J. W. Steyaert. Diagnostic Equipment Development for Military Vehicle Applications. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Technical Paper Series 780029, 16 pp.

Simplified Test Equipment for Internal Combustion Engine Powered Material (STE/ICE) is being developed by the U.S. Army with emphasis on test capability and ease of use. This paper discusses the man/equipment interface as well as the test capabilities of STE/ICE. Emphasis is placed on the unique test capabilities available and a concept for defining a built-in interface for the Army vehicle fleet. The focus is on the Tank-Automotive area but the applications extend to all internal combustion engine powered equipment.

Young, A. E., D. H. Locher, and W. G. Wolber. An On-Line Pressure Monitor for EFI-Control Test Diagnostics. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760246, 12 pp.

This paper describes an on-line pressure-monitoring system, designed to meet an urgent need for constant accuracy surveillance on the precision pressures that are applied to EFI Electronic Control Units during production calibration and test. Design requirements and approach are discussed, and system implementation and performance are detailed. The pressure monitor, which operates in both a SCAN and a SET mode, detects and measures pressure deviations in up to 39 precision pressure sources, and activates an alarm to alert test personnel should an out-of-tolerance condition develop. It has significantly reduced the incidence of test-operator error, and has played a major role in substantially increasing production yields.

H. Oil and Wear Analysis

Bolis, D. A., J. H. Johnson, and D. A. Daavetilla. The Effect of Oil and Coolant Temperatures on Diesel Engine Wear. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770086, 16 pp.

A study has been made of piston ring wear and total engine wear using literature data and new experimental results. The main purpose of the study was to establish the effects of oil and coolant temperatures on engine wear. Wear trends that were found in the early 1960's may not be valid any longer because of the development of higher DMEP turbocharged diesel engines, better metallurgical wear surfaces and improved lube oil properties. New data are presented for the purpose of describing present wear trends. A direct-injection, 4-cycle, turbocharged diesel engine was used for the wear tests. The radioactive tracer technique was used to measure the top piston ring chrome face wear. Atomic emission spectroscopy was employed to determine the concentration of wear metals in the oil to determine total engine wear based on iron and lead. The data were analyzed and compared to the results found in the literature from previous investigators. After the results of the analysis are presented, an explanation of the results using some fundamental concepts is made.

Boone, E. F., and F. E. Didot. Field Experience of Extended Drain Interval in Diesel Lubricant Performance. See II.E.

Brown, K. L., Jr., and N. D. Bohner. Valve Wear, Statistically Speaking. Presented at the Energy Technol. Conf. & Exhibit, Houston, Tex., Sept. 18-22, 1977, ASME Preprint 77-DGP-6, 12 pp.

Excessive inlet-valve face wear occurred during early durability testing of a new cylinder head arrangement. The program to correct this wear problem resulted in considerable valve-face wear data exhibiting large scatter. Statistical techniques were used to define, correct, group, and compare these data in order to draw conclusions. Particular emphasis was placed on the use of Weibull statistics. Variables dealing with valve geometries, materials, and mechanism dynamics were tested in order to solve the valve-wear problem encountered. Valve-wear data for these variables are analyzed by the above statistical techniques. The results are presented and show that Tribaloy® 400 valve-face material, 20-deg valve-face angle, and proper valve-mechanism dynamics each offered a significant improvement to the valve-wear problem. The results also illustrate the significance of the subject analytical tool as a means for solving valve-face wear problems and for design optimization.

Diesel Equipment Superintendent. Saves Time and Engines. January 1977, pp. 36-38.

The article describes the experiences of one over-the-road trucking firm with the Gulf-Check oil analysis program. Benefits--both general and case specific--derived from this diagnostic program are discussed.

Engineering and Mining Journal. How Oil Analyses Saved 28 Engines. May 1978, pp. 108-110.

Laboratory analyses of oil samples taken from diesel equipment can help mine operators avoid breakdowns, downtime, and repair costs. The article lists 28 examples of early warnings from Mobil Oil Corp.'s EM/PA system, giving oil sample test results, sources of trouble, and action taken.

Goodwin, E. Diagnostic Studies of Lubricants. Can. Inst. Min. Bull., May 1978, pp. 124-126.

The mechanics of formation of wear-metal suspensions in lubricants is discussed along with the relationship of the concentration of the metals and other particles to the wear of lubricated machinery parts. The importance of particle and suspension analysis of used lubricants in a preventative maintenance program is stressed, in particular with regard to mobile equipment in a mining operation.

Hofman, M. V., and J. H. Johnson. The Development and Application of Ferrography to the Study of Diesel Engine Wear. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Technical Paper Series 780181, 32 pp.

This paper covers the development of Ferrographic oil analysis techniques for the study of diesel engine wear. A brief overview of the various wear analysis techniques now commonly used in laboratory and field engine wear studies is discussed. Also included in this paper is an in-depth description of the Ferrographic oil analysis techniques and the various applications of the techniques to the study of engine wear. A comparison of the commonly used wear measurement methods, Ferrography, spectroscopy and the radioactive tracer methods, and their abilities to measure wear is also discussed. A direct injection, 4-cycle, turbocharged diesel engine was used in the testing and data are presented indicating the abilities of the Ferrographic oil analysis techniques to detect changes in wear rates. The effects of operating time on engine oil and the effects of the variation of oil and coolant temperatures on engine wear is presented. The effects of oil filtration on engine wear is also discussed and data are presented contrasting the filtered versus the non-filtered diesel engine lubrication system.

Hofman, M. V., and J. H. Johnson. The Development of Ferrography as a Laboratory Wear Measurement Method for the Study of Engine Operating Conditions on Diesel Engine Wear. Wear, v. 44, 1977, pp. 183-199.

Ferrographic oil analysis techniques were used in a laboratory study of diesel engine wear. Data were developed supporting the concept of using the Severity Index I_s to rank the effect of engine operating conditions on wear. Results analyzing the Severity Index as a function of time and as a function of engine operating variables are presented. The Severity Index is also linearly

correlated to spectrometric data (iron and lead concentrations in the used oil samples). Engine wear tends to increase with increase of either oil or coolant temperature. However, brake specific fuel consumption tends to decrease as oil and coolant temperatures increase, indicating a need for accurate temperature control for both mediums to minimize fuel consumption and wear. The heated Ferrogram analysis (HFA) technique was used to determine changes in the wear rates of specific engine parts with variation of the oil and coolant temperatures.

Rounds, F. G. Carbon: Cause of Diesel Engine Wear? Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770829, 12 pp.

Diesel soot (carbon) contamination of engine oil appears to be the cause of higher valve train wear in diesel engines than in gasoline engines with similar metallurgy. Four-ball wear studies to determine the mechanism by which carbon reduces the antiwear benefit of zinc dithiophosphates (ZDP's) indicate that the higher wear is due to preferential adsorption of the ZDP decomposition products by the soot thus reducing the formation of the antiwear surface coating. Adsorption of undecomposed ZDP, changes in ZDP decomposition reactions and abrasive removal of the surface coating were eliminated as significant contributors to higher wear.

Strigner, P. L., and N. N. Kallio. A Study of Oil and Filter Change Periods and Engine Oil Monitoring for GM 6V-71 Diesel Bus Engines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780184, 20 pp.

Thirteen new 1965 buses having GM 6V-71 diesel engines were put on various oil/filter change periods from 6000/6000 to 25000/25000 miles, and operated in normal passenger service for seven years (1966-1973). Crankcase oil was tested periodically, and oil filters were examined after scheduled removal. Maintenance and operation records were kept. Finally, at the overhaul point, some engine parts were examined. The optimum oil/filter change period was judged to be 25000/12500 miles, in conjunction with field testing for solids load, water, and dilution. Correlations and oil test data, suitable for reference, are given.

Wiles, R. C. Mobile Plant Maintenance With Special Reference to Wear Analysis and Analytical Inspection. Quarry Management and Products, October 1977, pp. 276-280.

Rather than covering the routine issues of maintenance charts, procedures, and record systems--which are exhaustively dealt with in a host of previous publications--this paper presents relatively new techniques of analysis, and diagnostics are presented which detect and isolate problems of wear and malfunction before these can significantly affect performance. The subject is considered particularly in relation to the maintenance of heavy earthmoving equipment, since this is the area in which the author's organization has a special interest. But the principles can be related to all types of mobile equipment.

I. Maintenance Effects on Emissions

Bly, R. L. Clean Exhaust--Good Diesel Performance: Smoke Points to Need for Maintenance, Color Clue to Causes. See VIII.G.

Hall, O. P., Jr., and N. A. Richardson. The Economic Effectiveness of Vehicle Inspection/Maintenance as a Means for Reducing Exhaust Emissions: A Quantitative Appraisal. See VIII.F.

Springer, K. J. Exhaust Emissions From Rebuilt Heavy Duty Engines. See VIII.E.

Taigel, P. G. Diesel Locomotives in Mines: The Production of Toxic Gases by the Diesel Engine. Transactions--The Inst. of Min. Eng., v. 111, No. 3369, 1951-1952, pp. 85-108.

The paper deals mainly with the production of carbon monoxide and oxides of nitrogen by the direct-injection diesel engine. Field investigations on locomotives in service provide information on the toxic-gas production of 20 locomotives at 6 collieries, and tests on 7 different diesel engines at the maker's works show a marked difference between the production of oxides of nitrogen with direct- and indirect-injection engines. New engines and used engines are compared and the rise and fall of production of carbon monoxide and oxides of nitrogen with use are measured. Some wear data are given and correlated with toxic-gas production. The absorption of toxic gases in water bath conditioners is discussed and tests are described in which exhaust-gas scrubbers deal with diesel exhaust, and the absorption of NO_2 is measured. These investigations, concerned with the health hazard associated with the production of toxic gases in diesel engine emissions, were carried out over the four years, February 1947 to February 1951, by the Haulage Section of the SAFETY IN MINES RESEARCH ESTABLISHMENT of the Ministry of Fuel and Power in Buxton, England.

TRW Transportation and Environmental Operations. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. I. Executive Summary. July 1973, 50 pp.; NTIS PB-225 024.

This volume summarizes the general objectives, approach, and results of an overall five year program whose objective was to examine the feasibility of using mandatory vehicle inspection and maintenance as a means for controlling automobile exhaust emission levels. Both the achieveable exhaust emission reductions and total program cost were used in the feasibility assessment.

TRW Transportation and Environmental Operations. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. II. Mandatory Inspection/Maintenance Systems Study. July 1973, 52 pp.; NTIS PB-225 025.

This report summarizes the final results obtained from a systems study of mandatory vehicle inspection and maintenance. The report focuses on two areas of general importance which were not examined in early analyses. The first area involves studying the impact on procedure effectiveness of the rate with which engine adjustments and exhaust emissions deteriorate with vehicle use while the second area is concerned with determining the cost effectiveness of alternate program strategies including mandatory maintenance only. The study was conducted using the Economic Effectiveness Model and the complete experimental data base. The report is composed of five sections which cover the evaluation of alternative programs, system sensitivity analysis, and study conclusions.

TRW Systems Group. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. III. A Documentation Handbook for the Economic Effectiveness Model. July 1972, 85 pp.; NTIS PB-220 728.

The primary purpose of the Economic Effectiveness Model is to serve as a research and design tool for assessing the various implications of a mandatory program of vehicle inspection/maintenance. The model is designed to both analyze the regional feasibility of vehicle inspection/maintenance as well as to specify an optimal system design. Input data for several regional areas covering the gamut of auto-related air quality problems are incorporated into the model. The model can also be used to analyze the sensitivity of system performance to various model assumptions and basic data inputs. The model is best used for evaluating the attractiveness of alternative policies, e.g., engine inspection or emission inspection, which govern and control the operation of an inspection/maintenance system. The main function of the model is in simulating the behavior of the inspection/maintenance process over time. Here, the economic effectiveness of various strategies can be measured in terms of emission reductions and program costs at each time interval.

TRW Systems Group. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. V. Experimental Investigation of Service Organization Maintenance Performance. July 1972, 91 pp.; NTIS PB-220 730.

The overall objective of this experiment was to develop measures of service organization effectiveness in correcting engine part failures, malfunctions, and tune-up parameter maladjustments which cause high exhaust emissions. Subsidiary objectives were to assess the capability of service organizations to (1) detect specific malfunctions, (2) return malfunctions, maladjustments, and failures to manufacturer's specifications, and (3) respond to the type of information which might be provided by mandatory vehicle inspection and the resulting impact on cost and performance effectiveness. Statistics were developed on (1) cost to accomplish maintenance, (2) maintenance cost and performance effectiveness of garages organizations in different

communities, (3) influence of service organization type (independent, dealership, and service station) on cost and performance effectiveness, and (4) the amount of unnecessary maintenance performed by service organizations.

TRW Systems Group. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. VI. A Comparison of Oxides of Nitrogen Measurements Made With Chemiluminescent and Non-Dispersive Radiation Analyzers. July 1972, 27 pp.; NTIS PB-220 731.

The purpose of this report is to describe an experimental study which was undertaken to describe differences between CL and NDIR/NDUV measurements, as applied to dilute samples of automotive exhaust gas. There are two distinctly different types of instrumentation used to measure automotive exhaust emissions of the oxides of nitrogen (NO and NO_2); (1) non-dispersive infrared (NDIR) analyzers for NO and non-dispersive ultraviolet (NDUV) analyzers for NO_2; and (2) chemiluminescence (CL) analyzers for the measurement of both NO and NO_2 (NO_x).

Welstand, J. S., and C. H. Oki. The Economic Effectiveness of Vehicle Inspection and Maintenance for Reducing Exhaust Emissions: A Supporting Experimental Program. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740132, 16 pp.

A series of experimental programs was conducted to provide an empirical data base for a computer model of the economic effectiveness of mandatory inspection and maintenance of light-duty vehicles. The experimental programs provided four basic data sets: 1. The frequency and extent of engine maladjustments and component failures of in-use vehicles. 2. The change in exhaust emission levels that results from changes in engine adjustments and component condition. 3. The deterioration of engine adjustments and components and the associated deterioration in exhaust emissions with the accumulation of time and mileage. 4. The ability of automotive service organizations to detect and repair engine maladjustments and failures. The data that resulted from these experiments were effectively employed in the computer model.

J. Economic Impact, Costs

Barnett, R. M., and P. D. Tomlingson. Maintenance Program for Mobile Equipment Cuts Costs at Henderson Moly Mine. Eng. and Min. J., May 1978, pp. 94-98.

The article describes the maintenance program for mobile equipment at the Henderson underground molybdenum mine of Climax Molybdenum Co., about 50 miles west of Denver, Colorado. Examples of various cost and maintenance status reports are provided, along with details of the program's implementation which has resulted in lower costs, improved availability, and good control of maintenance.

Blue, G. B. Internal Combustion Engine Failures: A Statistical Analysis. Presented at the Diesel and Gas Engine Power Conference and Exhibit, New Orleans, La., April 6-10, 1975, ASME Preprint 75-DGP-16, 7 pp.

The paper is a recapitulation of engine failure statistics from the files of The Hartford Steam Boiler Inspection and Insurance Co., and represents a total of 180 failures over a period of 3 1/2 years. The equipment involved includes diesel and dual-fuel engines, spark-ignited gas and gasoline engines and internal combustion engines driving reciprocating compressors. The failures are categorized by 1) type of accident, 2) initial part to fail, and 3) primary cause of failure. Through recognition of these problem areas, it was hoped that preventive measures could be taken by manufacturers and operators to reduce their occurrences and thus cut production and operating costs.

Carothers, R. C. Temperature Monitoring Cuts Fuel Bill, Aids Maintenance. See VII.G.

Espach, T. M. Improvements to the Trackless-Mining Equipment and Operation at Prieska Copper Mines (Proprietary) Limited. See VIII.F.

Gilbert, S. The Use of Diesel Engines Underground in British Coal Mines. The Mining Engineer, June 1974, pp. 395-406.

The paper outlines the introduction and growth of the diesel-powered vehicles operating underground in British coal mines and describes general experience over the last three decades. The major requirements of the law relating to safety and health are defined; and the methods of sampling and analyzing exhaust gases and mine air are described; all of these provide a means of controlling existing applications and assist in the planning of future installations of diesel-powered locomotives and vehicles. The potential hazards associated with the diesel engine are described, and there is included a summary of safety records since the nationalization of British mines in January 1947. The design criteria of the diesel engine and its associated ancillary equipment are discussed and an average cost analysis has been drawn up.

Holmes, V. H. Diesel and Gas Engine Power Costs and Trends. Presented at the Diesel & Gas Power Conference and Exhibit, St. Louis, Mo., April 16-20, 1972, ASME Preprint 72-DGP-13, 5 pp.

Under the sponsorship of both the Diesel and Gas Power Division of ASME and the Diesel Engine Manufacturers Association, the author has collected 1968, 1969, and 1970 data for the 1971 and 1972 reports on diesel and gas engine power costs. The procedure of collection and preparation of data for the report is explained. The reasons for the trends in power costs--downward in many instances--are enumerated with respect to load growth and progressive developments of internal combustion engines.

Rock Products. Central Lube Systems Help Sand Producers Halve Repair and Maintenance Costs. See VIII.B.

Smiley, C. H. Make Maintenance a Profit Center. Rock Products, January 1977, pp. 66-68.

Spiraling equipment and labor costs are directing more attention towards making equipment last longer and reducing maintenance costs. The article refers to a variety of improved maintenance techniques and materials that can lead to better equipment performance, longer service life, and greater profits and suggests factors that should be taken into consideration in developing a maintenance program.

Smith, D. J., and A. H. Babb. Maintainability Engineering. See VIII.F.

U.S. Environmental Protection Agency, Inspection and Maintenance Staff. Effects of Inspection and Maintenance Programs on Fuel Economy. U.S. Environmental Protection Agency, Ann Arbor, Mich., March 1979, 11 pp.; NTIS PB-297 583.

The primary goal of inspection and maintenance (I/M) programs is to improve air quality by reducing emissions from motor vehicles. Many studies have indicated that I/M programs will achieve this goal. In addition several studies have indicated that fuel economy improvement can be expected to occur as a result of maintenance performed on vehicles failing an I/M test. Most studies which have been performed have looked at pre-1975 model year vehicles and have had expert mechanics performing the maintenance work. This report considers both the results from past studies and the results from more recent studies in order to provide EPA's best estimates of fuel economy benefit which can be attributed to I/M programs.

Welstand, J. S., and C. H. Oki. The Economic Effectiveness of Vehicle Inspection and Maintenance for Reducing Exhaust Emissions: A Supporting Experimental Program. See VIII.I.

IX. ALTERNATIVE POWER SOURCES

A. Stratified Charge Engine

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Mining Machinery. Nat. Aeronautics and Space Administration (Cleveland, Ohio), NASA TM-82695, BuMines Agreement J0100026, December 1981, 101 pp.

The NASA Lewis Research Center, under Interagency Agreement J0100026 with the Department of Interior, Bureau of Mines, performed an assessment of alternative power sources for mining applications, primarily mobile underground equipment. This report presents the results of that assessment. Each candidate alternative power source was assessed in terms of the following requirements, which were established as a first step in the assessment: (1) ability to achieve the duty cycle, (2) ability to meet Government regulations (MSHA certification), (3) availability (production readiness), (4) market availability, and (5) packaging capability. An initial screening reduced a variety of possible candidates to the following, which were evaluated in more detail: (1) improved diesel, (2) Stirling, (3) gas turbine, (4) Rankine (steam), (5) advanced electric (batteries), (6) mechanical energy storage (flywheel), and (7) use of hydrogen evolved from metal hydrides. The candidate power sources were divided into two categories--heat engines and energy storage systems--since the basic constraints are different for each. Each alternative power source is described briefly, including its current development status, specific problem areas, and possible future improvements. Each candidate is then evaluated against the requirements initially established. Research and development efforts for each candidate power source are discussed and evaluated in terms of potential. Recommendations are made for each power source in terms of possible near-term or future application to mining use and the specific problem areas that must be addressed prior to that application.

Dimick, D. L., S. L. Genslak, R. E. Greib, and M. J. Malik. Emissions and Economy Potential of Prechamber Stratified Charge Engines. Presented at the Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790436, 15 pp.

In order to meet stringent government emissions standards without penalizing the fuel economy of gasoline engine cars, a number of alternative engine concepts have been investigated. This paper describes a research investigation and parallel development activity on prechamber stratified charge engines. Single-cylinder engine investigations are first described. Alternative design and operating parameters are investigated and compared in these engines. Design and development of two multicylinder engine designs incorporating prechamber 3-valve configurations are next described. Finally, a car development and evaluation program is outlined, using both small and large cars with alternative engine configurations and after-treatment devices. Results of the above prechamber stratified charge engines are

compared with conventional engines in order to assess and evaluate the emission and economy potential of this type of engine. The authors conclude that this type of stratified charge engine possesses NO_x emission and fuel economy performance similar to a conventional engine but a high HC emission level.

Dowdy, M., and A. Burke. Automotive Technology Projections. Presented at the Congress and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-Mar. 2, 1979, SAE Technical Paper Series 790021, 20 pp.

Results of an automotive technology assessment study are presented to provide a basis of comparison for vehicles with alternative power systems. Factors considered include fuel economy, exhaust emissions, multi-fuel capability, advanced materials, and cost/manufacturability for both conventional and advanced alternative power systems. To insure valid comparisons of vehicles with alternative power systems, the concept of an Otto-Engine-Equivalent (OEE) vehicle is utilized. Each engine type is sized to provide equivalent vehicle performance. Fuel economy projections are made for each engine type considering both the legislated emissions standards (0.4 g/mi HC, 3.4 g/mi CO, 1.0 g/mi NO_x) and possible future emissions requirements (0.4 g/mi NO_x). The sensitivities of the fuel economy projections to factors such as engine torque boundary, rear axle ratio, performance criteria, and engine transient response are discussed. Using the OEE vehicle concept, projected fuel economies of both small and full-sized vehicles with Stirling engines are up to 40 percent better than baseline vehicles with conventional engines. Vehicles with Brayton engines show up to a 30 percent better fuel economy than the baseline in full-sized vehicles, but offer little fuel economy advantage in small vehicles. Advanced continuous combustion power systems (Brayton and Stirling) offer advantages over the baseline vehicles in the areas of exhaust emissions and multifuel capability; however, their initial costs are projected to be substantially higher.

Gruden, D. Combustion and Exhaust Emission of an Engine Using the Porsche-Stratified-Charge-Chamber-System. Presented at the Automobile Eng. Meeting, Oct. 13-17, 1975, Detroit, Mich., SAE Preprint 750888, 15 pp.

The development of vehicle combustion engines today is characterized by the effort to reduce exhaust gas emission and fuel consumption and to conserve the good properties of the combustion engine at the same time. As, at least for the years to come, there will be no chance for the utilization of the alternative special drives, PORSCHE is intensely dealing with the further development of the conventional combustion engine as well as of the stratified-charge-chamber engine. With their stratified-charge engine (SKS) PORSCHE has tried to create optimum conditions for each of the combustion phases. The result was a divided combustion chamber with a three-stage combustion. The system was tried on single-, six-, and eight-cylinder engines and led to good results under stationary conditions on the testing rig as well as under unstationary driving conditions.

Heywood, J., and J. Wilkes. Is There a Better Automobile Engine? Technology Review, November/December 1980, pp. 19-29.

The authors examine the operation, advantages, and disadvantages of conventional and less familiar automobile propulsion systems. Current research and factors affecting potential development of alternative power sources are discussed.

Jet Propulsion Laboratory. Should We Have a New Engine? An Automobile Power Systems Evaluation: v. II. Technical Reports. Cal. Inst. of Technol., August 1975, SAE Spec. Pub. 400, 538 pp. (also, v. I--Summary. SAE Spec. Pub. 399, 109 pp.)

Alternative automotive powerplants were examined for possible introduction during the 1980-1990 time period. Technical analyses were made of the Stratified-Charge Otto, Diesel, Rankine (steam), Brayton (gas turbine), Stirling, Electric, and Hybrid powerplants as alternatives to the conventional Otto-cycle engine with its likely improvements. These alternatives were evaluated from a societal point of view in terms of energy consumption, urban air quality, cost to the consumer, materials availability, safety, and industry impact. The results show that goals for emission reduction and energy conservation for the automobile over the next 5-10 years can be met by improvements to the Otto-cycle engine and to the vehicle. This provides time for the necessary development work on the Brayton and Stirling engines, which offer the promise of eliminating the automobile as a significant source of urban air pollution, dramatically reducing fuel consumption, and being saleable at a price differential which can be recovered in fuel savings by the first owner. Specifically, the Brayton and Stirling engines require intensive component, system, and manufacturing process development at a funding level considerably higher than at present.

Mortimer, J. Alternative Engines for Tomorrow's Car. The Engineer. May 13, 1976, pp. 32-37.

The article is a summary of findings of a $500,000 study by a team of engineers and scientists from the Jet Propulsion Laboratory, Calif. Inst. of Technology, and the Caltech Environmental Quality Laboratory to determine developments that should be pursued to replace the present-day piston engine running on hydrocarbon fuels. In the Ford Motor Co.-sponsored study, the investigators were concerned with alternative automotive powerplants suitable for possible introduction in the 1980's and 1990's, including the stratified charge Otto-cycle engine, the diesel engine, the Rankine or steam engine, the Brayton or gas turbine, the Stirling engine, electric propulsion and various hybrid powerplants. The article summarizes on a comparative basis a variety of information on the various engines, including costs, fuel economy potential, emissions, weight, and horsepower.

Renner, R. A. Alternate Engines State of the Art Study. See IX.C.

Richardson, R. W. Automotive Engines for the 1980's: Eaton's Worldwide Analysis of Future Automotive Power Plants. Eaton Corp., Word Headquarters, Cleveland, Ohio, 1976, 17 pp.

There are five major contenders to replace or supplement today's piston engine. Changing social requirements and new technological developments the Eaton Corp. feels will lead to major changes in automotive powerplants. This study makes projections through the 1980's of the market penetration of Wankel, Stirling, turbine, stratified charge, and diesel engines for passenger car, heavy duty, and small engine applications. These engines are compared on the basis of ten major selection parameters. Major factors affecting the rate of commercialization of new engines are reviewed, including social, political, and economic forces of change and historical perspective. Major inputs came from more than 60 worldwide in-depth interviews.

Saga, K., and S. Furuhama. Performance and Emission Control in Stratified Charge Hydrogen Fueled Engines. Stratified Charge Engines (A conference sponsored by the Automobile Division and the Combustion Engines Group). The Inst. of Mech. Engrs., London, Nov. 23-25, 1976, pp. 29-37.

Three types of stratified hydrogen fueled systems were applied in several single-cylnder engines, both for control of emissions and abnormal combustion. First, hydrogen was injected into the cylinder directly by the two processes. In one of them, the injection was finished at an early part of compression stroke. Then the maximum output could be increased but not with lower NO_x emission; the thermal efficiency was lower because the mixing was incomplete. In the other process, high pressure hydrogen was induced into the intake manifold, which gave good control of NO_x emission, but further improvement of the thermal efficiency and durability of the injection system were required. Second, a single-cylinder engine was operated by injecting only low-pressure hydrogen into an auxiliary chamber during the early part of the compression stroke. In the case of the air-hydrogen engine, however, the combustion was accelerated excessively by the stratification.

Scussel, A. J., A. O. Simko, and W. R. Wade. The Ford PROCO Engine Update. Presented at the West Coast Meeting, San Diego, Calif., Aug. 7-10, 1978, SAE Technical Paper Series 780699, 39 pp.

The Ford PROCO stratified charge engine combines the desirable characteristics of premixed charge and Diesel engines. The outstanding characteristics of premixed charge engines are their high specific output, wide speed range, lightwight and easy startability but they exhibit only modest fuel economy and relatively high exhaust emissions. The desirable characteristic of the diesel engine is its outstanding fuel economy. However, the disadvantages of the diesel, which include noisy operation, limited speed range, exhaust odor, smoke, hard startability, and particulate emissions have tended to limit their acceptance. In the gasoline fueled, PROCO stratified charge engine, direct cylinder fuel injection permits operation at overall lean mixture ratios and higher compression ratio. These features enable the PROCO engine to achieve brake specific fuel consumption values in the range of prechamber diesel engines. Information is presented on the development of the PROCO engine and a variety of test results are provided.

Tierney, W. T., E. Mitchell, and M. Alperstein. The Texaco Controlled-Combustion System--A Stratified Charge Engine Concept. Review and Current Status. Power Plants and Future Fuels (A Conference Sponsored by the Combustion Engines Group and the Automobile Division of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 1-15.

The Texaco Controlled-Combustion System, a stratified charge engine concept, utilizes a coordinated arrangement of fuel injection, positive ignition and air swirl within the combustion chamber to yield "patch burning" of a combustible mixture. The resulting ability to burn unthrottled, overall lean fuel-air mixtures produces engines having excellent fuel economy with inherently low emissions of exhaust pollutants. Equally important, the unique coordinated arrangement prevents combustion knock without regard to fuel octane or cetane rating and permits the use of high compression ratios and/or inlet pressure charging. The basis of the concept, the general operating characteristics associated with the system and the development background over a period of many years are reviewed. The results of recent work on vehicle-installed TCCS engines, both in naturally aspirated and turbocharged configurations, are discussed.

Wall, J. C., and J. B. Heywood. The Influence of Operating Variables and Prechamber Size on Combustion in a Prechamber Stratified-Charge Engine. Presented at the International Fuels & Lubricants Meeting, Toronto, Ont., Nov. 13-16, 1978, SAE Technical Paper Series 780966, 21 pp.

This paper describes the results of experimental and computer simulation studies of the combustion process in the prechamber three-valve stratified-charge engine. Prechamber and main-chamber pressure data and matched computer simulation calculations are used to determine the effects of variations in overall air/fuel ratio, engine speed and load, and prechamber volume and orifice diameter on the parameters which define the combustion process (spark advance for optimum torque, ignition delay, combustion duration), on cylinder pressure diagrams (mean main-chamber pressure, mean pressure difference across the orifice, and cycle-by-cycle pressure fluctuations) and on exhaust emissions. General correlations are derived from the data for the shape of the combustion rate profile and the extent of the combustion duration.

Wood, C. D. Performance of a Stratified Charge Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790434, 10 pp.

An experimental study of a single-cylinder direct-injected stratified charge engine is described, with emphasis upon influence of configuration and injection system details upon performance and exhaust emissions.

B. Stirling Engine

Bjerklie, J. W., E. J. Cairns, C. W. Tobias, and D. G. Wilson. An Evaluation of Alternative Power Sources for Low-Emission Automobiles. Presented at the Automobile Eng. Meeting, Detroit, Mich., Oct. 13-17, 1975, SAE Preprint 750929, 20 pp.

Two successive surveys and round-robin interviews were conducted to determine if there might be in the offing for automobiles an alternative engine which would meet the most stringent emissions requirements. In comparing engines, overall acceptability was evaluated considering emissions, customer requirements and manufacturers' requirements for an engine, and engine efficiency and fuel varsatility. An attempt was made to establish a time scale as to R and D requirements and eventual production. Comparison of all engines was made with equivalent pre-control Otto cycle engines as the standard. Alternative engines were deemed to be any powerplant that was not based on spark ignition Otto cycle engines, or diesel engines. The remaining heat engines largely used continuous combustion as the heat source. Electrical powerplants considered were batteries and fuel cells. Hybrid engines and fuel-less stored energy powerplants were given some consideration.

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Miling Machinery. See IX.A.

Carlqvist, S. G., and G. S. K. Lundholm. Stirling Engines: Their Potential Use in Commercial Vehicles and Their Impact on Fuel Utilization. Power Plants and Future Fuels (A conference sponsored by the Combustion Engines Group and the Automobile Division of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 35-47.

Recent results and current development of double-acting Stirling engines are reviewed in this paper. Special emphasis is laid on the application of the Stirling engine to commercial vehicles for urban traffic. The paper presents the design features of experimental V4 engines, as well as the unique environmental characteristics and fuel versatility of Stirling engines in general.

Diesel and Gas Turbine Progress. RV Has Stirling TE System. December 1978, pp. 10-11.

A number of Winnebago recreational vehicles have been equipped with Stirling engines as a power source for electrical, heating, and air conditioning systems. Equipping these prototype models was a joint effort of Stirling Power Systems Corp., Ann Arbor, Mich., and Winnebago Industries, Forest City, Iowa. The new Stirling engine developed for this total energy system is called the V160 series. An external combustion engine, the 10.7 horsepower engine features low noise, low vibration, and clean, odorless exhaust emissions. The article details the engine's design and its operation.

Dowdy, M., and A. Burke. Automotive Technology Projections. See IX.A.

Fenton, J. E. An Air/Fuel Control System for the Stirling Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790328, 8 pp.

A repeatable air/fuel control system has been developed for the Stirling engine. This control system provides a wide range of metered fuel flows and adjustable air/fuel ratios, a requirement for mapping and optimization of Stirling engine components which placed limitations on conventional fuel metering systems.

Hallare, B. The Development of 40-150 kw Stirling Engines in Sweden and Their Application in Mining Equipment. Total Energy Systems and Road Vehicles. Proceedings of Fourth International Symposium on Automotive Propulsion Systems, Apr. 18-22, 1977. U.S. Dept. of Energy, Rept. No. CONF-770430/1, UC-96, v. 1, February 1978, pp. 248-268.

United Stirling is a Swedish corporation, owned by FFV, a government-owned industrial group, and Kockuma, a publicly owned company having its main business in shipbuilding and lumber industries. The corporate goal of United Stirling is to commercialize the Stirling engine. Special emphasis has been put on special market segments, but a considerable effort has also been made to further increase the specific performance of the Stirling engine, allowing the engine to be one of the most attractive candidates for the future volume engine markets. This paper describes the effort made in Sweden to: Develop Stirling engine components acceptable to the market; develop suitable engine configurations; and approach special market segments for the Stirling engine.

Hirschfield, F. The Resurrection of the Stirling Engine. Mech. Eng. v. 100, No. 10, October 1978, pp. 38-44.

The article is a feature interview with Dr. Beno Sternlicht, Board Chairman and Technical Director at Mechanical Technology, Incorporated, in which Dr. Sternlicht gives a detailed insight into the $100 million government-sponsored program for making the 150-year-old Stirling concept a viable commercial proposition in the late 20th century. Research objectives are stated. Early history of the Stirling engine and the role of various companies or individuals in its development are outlined. In comparing the Stirling engine with the spark ignition engine, the Stirling engine's advantages were listed as very high efficiency potential, multifuel capability, low emissions, very low noise, and the fact that much of the existing tooling and manufacturing service know-how can be used since it is a piston engine. Some of the problem areas were listed as high cost, high weight, and unproven reliability.

Jet Propulsion Laboratory. Should We Have a New Engine? An Automobile Power Systems Evaluation: v. II. Technical Reports. See IX.A.

Marshall, W. F. The Stirling Engine--An Option for Underground Mines. U.S. Dept. of Energy, BERC RI 78/3, March 1978, 5 pp.

The use of heat engines for powering mobile equipment in underground mines offers advantages over electric power in terms of mobility and electric shock hazards. However, exhaust is discharged into the working environment; thus there is a potential hazard associated with toxic combustion products. Although diesel engines are in use in underground mines, other heat engines might be considered for use because of potentially lower emission rates. The Stirling engine is a possible alternative to the diesel because it shows promise as a low emission, high power density engine. In order to assess the potential of the Stirling for mining applications, performance data are required. To fill this need, data on the composition of the exhaust from a Stirling engine were obtained. The results of this work indicate that the Stirling engine compares very favorably with "low emission" diesels with respect to emissions characteristics.

Martini, W. R. Stirling Engine Diesel Manual. Univ. of Wash., Contract No. NSG-3152, April 1978, 360 pp.; NTIS N78-23999.

This manual is intended to serve both as an introduction to Stirling engine analysis methods and as a key to the open literature on Stirling engines. Over 800 references are listed and these are cross referenced by date of publication, author and subject. Engine analysis is treated starting from elementary principles and working through cycle analysis. Analysis methodologies are classified as first, second, or third order depending upon degree of complexity and probable application; first order for preliminary engine studies, second order for performance prediction and engine optimization, and third order for detailed hardware evaluation

and engine research. A few comparisons between theory and experiment are made. A second order design procedure is documented step by step with calculation sheets and a worked out example to follow. Current high power engines are briefly described and a directory of companies and individuals who are active in Stirling engine development is included.

Mortimer, J. Alternative Engines for Tomorrow's Car. See IX.A.

Renner, R. A. Alternate Engines State of the Art Study. See IX.C.

Renner, R., and H. M. Siegel. Fuel Economy of Alternative Automotive Engines--Learning Curves and Projections. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790022, 16 pp.

This paper describes a distinct approach in making technological forecasts. From historical data, fuel economy learning curves have been constructed for alternatives such as the diesel, gas turbine, Stirling, stratified charge, and rotary engines. Assuming that evolutionary development will take place, projections of these learning curves are extended to the 1990 era. The investigation found that no engine is likely to exceed the fuel economy of the diesel in the next 10-15 years. However, serious questions are being raised regarding the feasibility of controlling nitrogen oxides and unregulated emissions in future diesel engines.

Richardson, R. W. Automotive Engines for the 1980's: Eaton's Worldwide Analysis of Future Automotive Power Plants. See IX.A.

Rosenqvist, K., T. Lia, and B. Goldwater. The Stirling Engine for the Automotive Application. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790329, 16 pp.

Both kinematic and free-piston Stirling engine technology is currently under development and, although the fundamentals are the same, each configuration demands unique engineering that is applied to the specific application. This paper discusses the current technology as it applies to the automotive application being addressed at United Stirling of Sweden and Mechanical Technology Incorporated in their respective Stirling engine fields.

Smithsonian Science Information Exchange, Inc. Alternative Fuels for Ground Vehicles. See II.B.

Tew, R. C., Jr., L. G. Thieme, and D. Miao. Initial Comparison of Single Cylinder Stirling Engine Computer Model Predictions With Test Results. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790327, 20 pp.

A Stirling engine digital computer model developed at NASA Lewis Research Center has been configured to predict the performance of the GPU-3 single-cylincer rhombic drive engine. Revisions to the basic equations and assumptions previously reported on are discussed. Initial comparisons of the model predictions with the early results of the Lewis Research Center GPU-3 tests are made.

Thieme, L. G., and R. C. Tew, Jr. Baseline Performance of the GPU-3 Stirling Engine. Technical Paper presented at the Highway Vehicle Systems Contractors Coordination Mtg., Sponsored by the U.S. Dept. of Energy, Dearborn, Mich., Oct. 17-20, 1978, 8 pp.

The NASA Lewis Research Center has converted a 10 horsepower single-cylinder rhombic-drive Stirling engine to a research configuration to obtain data for validation of Stirling computer simulations. The engine was originally built by General Motors Research Laboratories for the U.S. Army in 1965 as part of a 3 kW engine-generator set, designated the GPU-3 (Ground Power Unit). This report presents test results for a range of heater gas temperatures, mean compression-space pressures, and engine speeds with both helium and hydrogen as the working fluids. Also shown are initial data comparisons with the NASA-Lewis computer simulation predictions.

van Beukering, H. C. J. Stirling Engines for Passenger Cars: Modern Developments and Potential Future Applications. Power Plants and Future Fuels (A conference sponsored by the Combustion Engines Group and the Automobile Division of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 159-169.

A review is given of research work performed at the Philips Research Laboratories in the field of Stirling engine development. Specific reference is made to the current work on the Stirling engine as designed for cars. This is a potentially interesting application of Stirling engines because of their high efficiency, their good environmental compatibility, and their ability to utilize a variety of heat sources.

van Beukering, H. C. J., and H. Fokker. Present State-of-the-Art of the Philips Stirling Engine. 14 pp.

This paper deals with the progress in research, development, and engineering of the Stirling engine at Philips, which has lead to the present state-of-the-art. After a review of the performance and features of some selected types of engines built and projected at Philips in the last two decades, a survey is given of typical characteristics of engines that can be realized now and which are envisaged for a variety of applications, including the automotive field.

C. Brayton Cycle (turbine) Engine

Bjerklie, J. W., E. J. Cairns, C. W. Tobias, and D. G. Wilson. An Evaluation of Alternative Power Sources for Low-Emission Automobiles. See IX.B.

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Mining Machinery. See IX.A.

Dowdy, M., and A. Burke. Automotive Technology Projections. See IX.A.

Flanigan, E. E., and D. N. Nigro. Field Experience With the Detroit Diesel Allison 404/505 Industrial Gas Turbine Engines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790129, 28 pp.

Detroit Diesel Allison Division of General Motors Corporation has been conducting a field evaluation program on the 300 hp GT-404-3 and the 390 hp GT-505-3 Industrial Gas Turbine Engines over the time period from late 1974 until late 1977. This paper describes the overall program plan which involved installations in trucks, coaches, marine and industrial applications and the field experience which has been accumulated to date. Emphasis is placed on operator reaction, environmental effects, performance, and field-revealed problems. Two particular applications are explored in considerable detail: bulk hauling trucks with self unloading capabilities and the Greyhound inter-city coach operation with gas turbine power and automatic transmissions.

Huebner, G. J., Jr. Energy and Pollution vs Alternative Piston and Gas Turbine Powerplants. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790020, 16 pp.

The over-riding social importance of automotive fuel economy and power plant exhaust emissions is discussed in relation to proposed alternatives to the spark-ignition passenger car engine. Some engineering and use criteria for the selection of alternatives are proposed, and several alternative power plants are explored in their framework. Three gas

turbine types are discussed as alternatives, and a brief history of two-shaft turbines is presented. The influence of various automatic transmissions on passenger-car fuel economy and driveability is summarized. This paper concludes that automatic, continuously variable transmission functions can be achieved with a three-shaft turbine power plant with excellent fuel economy and at lower cost.

Jet Propulsion Laboratory. Should We Have a New Engine? An Automobile Power Systems Evaluation: v. II. Technical Reports. See IX.A.

Mercure, R. A. Some Design Considerations of Automotive Gas Turbines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790128, 12 pp.

An examination of some design considerations of gas turbine automobile engines is made including an overview of the unsolved problems. Emphasis is placed on the design and manufacturing aspects. Performance penalties due to size effects are discussed. The gains in cycle thermal efficiency with increasing peak temperatures are examined in view of these penalties. A cursory investigation of thermal efficiency is performed on a 75 hp and a 150 hp gas turbine. This was done considering both current and advanced design and manufacturing technology with regard to rotor clearances and blade thicknesses. Design and manufacturing limits used in defining the penalties in engines with advanced technology are qualified.

Mortimer, J. Alternative Engines for Tomorrow's Car. See IX.A.

Renner, R. A. Alternate Engines State of the Art Study. South Coast Technol., Inc., Santa Barbara, Calif., Contract No. DOT-HS-7-01790, November 1978, 78 pp.; NTIS PB-293 940.

Eleven different advanced automobile engine types were examined as to the possibilities for introduction prior to 1990. An assessment was made based on extensive literature survey and extrapolation of learning curves toward future values of fuel economy and emissions. Gas turbines and external combustion engines are unlikely to be in general use prior to 1990. Stratified charge engine, the advanced diesel, and internal combustion engines with variable displacement features were considered to be likely candidates for use prior to 1990. These engines were analyzed and learning curves were determined for fuel economy predictions with exhaust emission constraints.

Renner, R., and H. M. Siegel. Fuel Economy of Alternative Automotive Engines--Learning Curves and Projections. See IX.B.

Richardson, R. W. Automotive Engines for the 1980's: Eaton's Worldwide Analysis of Future Automotive Power Plants. See IX.A.

Rosenbaum, B. B. Closed Cycle Brayton Turbomachinery Research. Final Report for Contract No. N00014-76-C-0554, Mod. P00002, Line Item 0001AB (AA, AB, AC), Sept. 30, 1977, 13 pp.

This report summarizes and appraises the technical and managerial aspects of the closed cycle Brayton turbomachinery (CCBT) research effort sponsored by the ONR Power Program. Specifically, it considers the first year's CCBT contractual efforts at: (a) Westinghouse Astronuclear Laboratory, Contract No. N00014-76-C-0706 entitled "Compact Closed Cycle Brayton System Feasibility Study; and (b) United Technologies Research Center, Contract No. N00014-76-C-0542, "Lightweight Propulsion Systems for Advanced Naval Ship Application--System Studies." The report also mentions several related research efforts.

Shih, T., G. Smith, and G. Springer. Gaseous, Particulate, and Smoke Emissions from a Heavy Duty Automotive Gas Turbine Engine. Environmental Science & Technology, v. 13, No. 7, July 1979, pp. 855-859.

Gaseous, particulate, and smoke emissions were studied in the exhaust of a heavy duty automotive gas turbine engine. The effects of brake horsepower (bhp), gasifier rotor angular speed, overall mass air-fuel ratio, and combustor exit temperature were evaluated at engine loads ranging from 136 to 542 N·m and at constant output shaft angular speeds ranging from 1500 to 2700 rpm. The results were compared to emissions previously reported for a heavy duty spark ignition engine and a heavy duty compression ignition engine, both of which had platinum oxidation catalysts and EGR. The hydrocarbon emissions from the gas turbine engine were lower, while the NO_x and CO emissions were comparable to the emissions from the spark and the compression ignition engines. Under all test conditions, the amount of particulate matter emitted was less than 0.001 $g \cdot bhp^{-1} \cdot h^{-1}$, and the smoke opacity of the exhaust gas was less than 0.3 Bosch unit. The brake specific fuel consumption of the gas turbine engine was also measured and was 40-50% higher than the consumption of a heavy duty spark and a heavy duty compression ignition engine operating at corresponding conditions.

Fellberg, H. W. The Rebuilt Engine. SAE Preprint 690545. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 20-24.

This paper discusses in detail the recommended procedures for rebuilding internal combustion engines; explains how decisions to rebuild, replace, or reuse engine parts are arrived at by experts, and describes how each part of the engine is examined, cleaned, and tested to insure maximum performance. When an engine should be rebuilt, what rebuilding entails, how to evaluate a repair shop by its equipment, and similar valuable information regarding engines and their maintenance are topics considered.

Krieger, R. Special Tools for Diesels. Coal Age, February 1978, pp. 197-205.

Experience has shown that proper tools are the key to successful engine maintenance and repair. A guide to various specialized tools that can make overhauling or repairing diesels easier is provided, along with a description of their use.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

Osenga, M. Custom Air-Cooled Diesel Rebuilding Program Expanded. Diesel & Gas Turbine Progress, June 1976, pp. 46-47.

D. A. MacPherson, Inc., specializes in custom rebuilding of Deutz air-cooled engines used extensively for vehicle and industrial power in northern U.S. and Canadian mines. Some work has been done on other makes of diesels. The article is an overview of the company's rebuilding procedures and capabilities.

Schulz, E. J. Diesel Mechanics. See I.B.1a.

Springer, K. J. Exhaust Emissions From Rebuilt Heavy Duty Truck Engines. Southwest Research Institute, San Antonio, Tex., July 1976, Contract No. 68-03-2196, 50 pp.; available for consultation at Twin Cities Res. Center, Minneapolis, Minn.

This report describes the laboratory test and evaluation results of Task No. 3 by Southwest Research Institute to EPA Contract 68-03-2196. Using two heavy-duty engines, one a 1972 IHC VS549 gasoline engine and the other a 1970 Mack ENDT 675 diesel engine, a series of gaseous, smoke, and related performance tests were made. The gasoline engine was tested in four configurations, two before being reconditioned by a factory rebuild center and

two after having been overhauled. The diesel engine was likewise tested in two configurations before being factory rebuilt and then retested. Gaseous emission rates in terms of grams per kilowatt-hour and grams per brake horsepower-hour of hydrocarbons, carbon monoxide, and oxides of nitrogen were determined in replicate. Current Federal gaseous emissions tests for heavy-duty engines were modified to incorporate major features of the newly proposed test procedures by EPA.

F. Preventive Maintenance

Alcock, K. Diesel-Powered Mine Equipment: Tips on Servicing and Trouble-Shooting. Coal Age, October 1975, pp. 122-124.

The author recommends procedures for initiating a preventive maintenance program for diesels, and a trouble-shooting list for checking various parts of the diesel system to determine the reason for engine malfunctions. Several misconceptions regarding the maintenance of underground diesel vehicles are cited and maintenance information provided that would dispel these misconceptions.

Bly, R. L. Preventive Maintenance Adds Life to Diesel Air Induction Systems. World Coal, February 1976, pp. 28-30.

Diesel air induction systems are normally comprised of one or more air cleaners and required piping to channel filtered air to the combustion chambers. Trouble-shooting and preventive maintenance of these systems in both pressurized and naturally aspirated air induction systems are critical to a diesel engine's efficient and economic operation. A breakdown of the system will seriously affect performance, or worse, it can contaminate the engine with dirt, causing severe damage to pistons, rings, sleeves, or other components. Constant care of the air induction system will pay off in profitability over the life of a machine. Of prime importance is regular inspection. The author provides extensive guidelines to facilitate an effective preventive maintenance program.

Espach, T. M. Improvements to the Trackless-Mining Equipment and Operation at Prieska Copper Mines (Proprietary) Limited. J. of the South African Institute of Mining and Metallurge, v. 79, No. 9, April 1979, pp. 249-254.

The paper gives an account of changes that have taken place since the publication of an August 1973 paper on the trackless mining operations at Prieska Copper Mines, Prieska, Cape Province, South Africa. Details are given of the modification to the equipment, the maintenance of equipment and roadways, the training of operators, and the operating costs.

Hall, O. P., Jr., and N. A. Richardson. The Economic Effectiveness of Vehicle Inspection/Maintenance as a Means for Reducing Exhaust Emissions: A Quantitative Appraisal. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740131, 12 pp.

A program of vehicle inspection and maintenance has emerged as potential strategy for reducing harmful exhaust emissions from automobiles. Of the several short-term aproaches now available for controlling vehicular emissions, an inspection program has the capacity for affecting the largest number of vehicles within the population. The purpose of this study is to attempt to characterize the economic effectiveness of a

mandatory inspection maintenance program. Results from this analysis show that under proper conditions, an inspection program can serve as a viable component of an emission control strategy.

Heavy Duty Equipment Maintenance. Improving Production With Predictive Maintenance. February 1976, pp. 32-37.

The article describes the predictive maintenance program of Allied Chemical Corp.'s limestone quarry at Jamestown, New York. Equipment maintenance scheduling, actions, and cost savings and other benefits are related. The advantages and disadvantages of an automatic centralized lubrication system used on front-end loaders are also discussed.

Helmich, M. J. Maintenance and Operation of Nuclear Diesel Generator Systems. Presented at the Energy Technol. Conference and Exhibit, Houston, Texas, Sept. 18-22, 1977, ASME Preprint 77-DGP-14, 12 pp.

Heavy duty, medium speed diesel engines have characteristically been applied to applications demanding continuous service with high load factors. The maintenance, inspection and replacement parts programs that have been formulated for this class of machinery reflect this type of operation. The purpose of this paper is to recommend a new approach for these programs when this class of engine is applied to Nuclear Diesel Generator systems, stressing the need for progressive, periodic, and preventive maintenance. It is recommended that the system should be based upon a reliable design, and provision should be made to utilize valid diagnostic procedures during operation and periods of dormancy. The packaged engine-generator-auxilary concept is an important feature since it insures system readiness, and the interrelation of all systems is properly de-bugged during acceptance testing prior to actual operation. Other recommendations are also cited.

IRD Mechanalysis, Inc. Preventive Maintenance in Rotating Machinery Using Vibration Analysis. Columbus, Ohio, Technical Paper No. 102, 1975, 14 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

Many companies and machinery manufacturers are using a simple technique to detect hidden rotating machinery trouble before failure can occur and in time to schedule necessary repairs. "Mechanalysis," a registered trademark, is the name given this technique by IRD Mechanalysis, Inc. It works this way. Each kind of trouble--unbalance, misalignment, bad gears, worn bearings, defective spindles, and mechanical looseness--produces vibration in a unique way. Mechanalysis uses a machine's vibration and noise to determine what is wrong while the machine operates. This paper describes the portable vibration analysis instrumentation, guidelines, and preventive maintenance procedures developed by IRD that are being utilized throughout industry to insure quality products and uninterrupted machinery operation. In addition, a new quick diagnostic technique utilizing the machine's pulse or vibration signature to pinpoint mechanical defects is discussed.

Judge, A. W. Modern Smaller Diesel Engines: In Theory, Construction, Operation and Maintenance. See I.A.

Kolbe, J. F. Abrasive Wear-Identification and Prevention. SAE Preprint 690544. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. See VIII.G.

McElroy, W. J. Preventive Maintenance Through Engine Analyzing. Diesel & Gas Turbine Progress, April 1977, pp. 10-11.

Panhandle Eastern Pipe Line Co.'s main gas gathering operations are located in the panhandles of Texas and Oklahoma, and in Western Kansas. The Liberal, Kansas Station is the first of 13 main line compressor stations extending to Fort Wayne, Ind. Numerous markets are served enroute to the primary market area of Detroit. Skid-mounted engine compressor units used in the gas gathering service range from 55 to 2000 hp. The company's objectives in instituting its engine analyzing program were to reduce maintenance costs, extend the periods between maintenance by finding mechanical faults at an early stage of development and remedy them before the engine required extensive repair, thus increasing the overall operating efficiency and improving fuel consumption. The article describes the various types of equipment used in the analyzing program and the steps that are followed.

Maleev, V. L. Diesel Engine Operation and Maintenance. See I.B.1a.

Mueller, B. The Application of Centralized Lubrication Systems to Mobile Equipment. See VIII.B.

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Dark smoke from a diesel engine exhaust is not a sign of power but of an engine that is not operating efficiently as a result of an improper fuel-to-air ratio or a malfunctioning combustion system. In addition to quantity, color of exhaust can be analyzed to determine if the engine is operating efficiently with clean combustion. The author describes various characteristics of abnormal exhaust and suggests probable causes for these conditions. The importance of an air induction maintenance system which minimizes air pollution and maintains maximum efficiency and fuel economy is stressed.

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A method has been developed for obtaining engine speed and diagnostic information for a diesel engine without mechanical or electrical connections to the engine. This non-contact technique has the potential for making diesel

engine power measurement and fault detection extremely simple and rapid. The method employs a single transducer held near the engine and special purpose circuitry which extracts the engine speed information from the signal and performs spectral analysis for diagnostic purposes. Circuit outputs are engine speed, a digital pulse train with repetition rate proportional to engine speed, and a harmonic ratio which sensitively indicates the degree of non-uniformity among engine cylinders. By this method, diesel engines with minor compression losses or fuel injection faults can readily be identified without vehicle contact in less than one minute of testing. With additional signal processing, the power producing capability of the engine can also rapidly be evaluated.

Hambright, R. N. Fuel Injection Diagnostic Techniques for Shop Applications. See VIII.C.

Hambright, R. N., and H. S. Benson. Diagnostics of Diesel Engines Using Exhaust Smoke and Temperature. Presented at the Truck Meeting, Indianapolis, Ind., Nov. 1-4, 1976, SAE Preprint 760833, 12 pp.

An experimental sensor array that measures dynamic exhaust temperature and dynamic smoke for the purpose of diagnosing diesel engine fuel injection equipment was designed, built, and tested. The sensor array is portable and easily installed on truck tailpipes, and was tested using two 6V-53 Detroit Diesel engines. The dynamic temperature sensor is a very high response instrument capable of measuring changes in gas temperature in excess of 104°F/second. The dynamic smokemeter is an optical device designed to measure very low levels of light opacity in the smoke plume, with a response compatible with the engine firing frequency. Dynamic exhaust temperature data had more diagnostic significance than dynamic smoke in the detection of maximum power degrading fuel injection faults. Gaseous exhaust emissions (CO, CO_2, O_2, NO_x, and hydrocarbons) were also evaluated for their diagnostic merit and were found to be less significant than the dynamic temperature and smoke data under the no-load test constraints common to shop and field diagnosis.

Hambright, R. N., and C. D. Wood. Vehicle Diagnostic Systems; the State-of-the-Art. Presented at the 1973 Annual Meeting, American Society of Agricultural Engineers, Univ. Ky., Lexington, Ky., June 17-20, 1973, ASAE Paper No. 73-144, 13 pp.

Diagnostic system fundamentals are defined in basic terms, and current activity is discussed for governmental, military, industrial, and commercial organizations. Physical and operational descriptions of example diagnostic systems are given for end-of-assembly-line, shop, portable, and built-in applications. Current diagnostic capabilities are related to instrumentation, parameters, and human factor design options. Significant increases in cost-effective uses of diagnostic systems require some built-in diagnostic equipment. The possible diagnostic systems and capabilities in the near future are a function of technological advances and comprehensive engineering.

Henein, N. A., and J. D. Rozanski. A Technique for the Diagnosis of Malfunctions in Diesel Injection Systems. See VIII.C.

Johnston, S. C., C. W. Robinson, W. S. Rorke, J. R. Smith, and P. O. Witze. Application of Laser Diagnostics to an Injected Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790092, 21 pp.

Measurements taken in a special, single cylinder, direct injection stratified-charge engine are presented. The optical measurement techniques employed include continuous-wave laser Raman Spectroscopy for density fluctuations, high-speed cinematography for flow visualization, and laser Doppler velocimetry for velocities and turbulence intensities. More conventional data on cylinder pressure, power, and emissions levels are also given. The purpose of the study was to demonstrate the types of detailed measurements that are now possible within an engine cylinder.

Kolbe, J. F. Abrasive Wear--Identification and Prevention. SAE Preprint 690544. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 15-20.

Abrasive wear, pertaining to the internal combustion engine, has been the subject of numerous technical investigations, papers, and articles. The majority of these presentations are in the area of filtration and the prevention of excessive or abnormal wear. Maintenance men must learn to determine if abrasive wear is present and then take corrective measures. This paper is intended to aid mechanics in identifying abrasive wear from a practical standpoint and in applying the proper remedy.

Mackey, G. The Exhaust Smoke Opacimeter--A Certifying and Maintenance Tool. Diesel & Gas Turbine Progress, July 1976, pp. 30-31.

One of the most perceptive indications of diesel engine conditions is exhaust smoke density. A technique for measuring exhaust smoke of in-use diesel-powered trucks was developed at Clayton Manufacturing Co. in 1973. It consists of operating a vehicle on a chassis dynamometer and subjecting the engine to various modes of operation, i.e. idle, acceleration and lug-down modes as required for certification testing, and recording both the speed and exhaust opacity on a strip chart. Details of its operation are provided.

F. Preventive Maintenance

Alcock, K. Diesel-Powered Mine Equipment: Tips on Servicing and Trouble-Shooting. Coal Age, October 1975, pp. 122-124.

The author recommends procedures for initiating a preventive maintenance program for diesels, and a trouble-shooting list for checking various parts of the diesel system to determine the reason for engine malfunctions. Several misconceptions regarding the maintenance of underground diesel vehicles are cited and maintenance information provided that would dispel these misconceptions.

Bly, R. L. Preventive Maintenance Adds Life to Diesel Air Induction Systems. World Coal, February 1976, pp. 28-30.

Diesel air induction systems are normally comprised of one or more air cleaners and required piping to channel filtered air to the combustion chambers. Trouble-shooting and preventive maintenance of these systems in both pressurized and naturally aspirated air induction systems are critical to a diesel engine's efficient and economic operation. A breakdown of the system will seriously affect performance, or worse, it can contaminate the engine with dirt, causing severe damage to pistons, rings, sleeves, or other components. Constant care of the air induction system will pay off in profitability over the life of a machine. Of prime importance is regular inspection. The author provides extensive guidelines to facilitate an effective preventive maintenance program.

Espach, T. M. Improvements to the Trackless-Mining Equipment and Operation at Prieska Copper Mines (Proprietary) Limited. J. of the South African Institute of Mining and Metallurge, v. 79, No. 9, April 1979, pp. 249-254.

The paper gives an account of changes that have taken place since the publication of an August 1973 paper on the trackless mining operations at Prieska Copper Mines, Prieska, Cape Province, South Africa. Details are given of the modification to the equipment, the maintenance of equipment and roadways, the training of operators, and the operating costs.

Hall, O. P., Jr., and N. A. Richardson. The Economic Effectiveness of Vehicle Inspection/Maintenance as a Means for Reducing Exhaust Emissions: A Quantitative Appraisal. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740131, 12 pp.

A program of vehicle inspection and maintenance has emerged as potential strategy for reducing harmful exhaust emissions from automobiles. Of the several short-term aproaches now available for controlling vehicular emissions, an inspection program has the capacity for affecting the largest number of vehicles within the population. The purpose of this study is to attempt to characterize the economic effectiveness of a

mandatory inspection maintenance program. Results from this analysis show that under proper conditions, an inspection program can serve as a viable component of an emission control strategy.

Heavy Duty Equipment Maintenance. Improving Production With Predictive Maintenance. February 1976, pp. 32-37.

The article describes the predictive maintenance program of Allied Chemical Corp.'s limestone quarry at Jamestown, New York. Equipment maintenance scheduling, actions, and cost savings and other benefits are related. The advantages and disadvantages of an automatic centralized lubrication system used on front-end loaders are also discussed.

Helmich, M. J. Maintenance and Operation of Nuclear Diesel Generator Systems. Presented at the Energy Technol. Conference and Exhibit, Houston, Texas, Sept. 18-22, 1977, ASME Preprint 77-DGP-14, 12 pp.

Heavy duty, medium speed diesel engines have characteristically been applied to applications demanding continuous service with high load factors. The maintenance, inspection and replacement parts programs that have been formulated for this class of machinery reflect this type of operation. The purpose of this paper is to recommend a new approach for these programs when this class of engine is applied to Nuclear Diesel Generator systems, stressing the need for progressive, periodic, and preventive maintenance. It is recommended that the system should be based upon a reliable design, and provision should be made to utilize valid diagnostic procedures during operation and periods of dormancy. The packaged engine-generator-auxilary concept is an important feature since it insures system readiness, and the interrelation of all systems is properly de-bugged during acceptance testing prior to actual operation. Other recommendations are also cited.

IRD Mechanalysis, Inc. Preventive Maintenance in Rotating Machinery Using Vibration Analysis. Columbus, Ohio, Technical Paper No. 102, 1975, 14 pp.; available for consultation at the Twin Cities Res. Center, Minneapolis, Minn.

Many companies and machinery manufacturers are using a simple technique to detect hidden rotating machinery trouble before failure can occur and in time to schedule necessary repairs. "Mechanalysis," a registered trademark, is the name given this technique by IRD Mechanalysis, Inc. It works this way. Each kind of trouble--unbalance, misalignment, bad gears, worn bearings, defective spindles, and mechanical looseness--produces vibration in a unique way. Mechanalysis uses a machine's vibration and noise to determine what is wrong while the machine operates. This paper describes the portable vibration analysis instrumentation, guidelines, and preventive maintenance procedures developed by IRD that are being utilized throughout industry to insure quality products and uninterrupted machinery operation. In addition, a new quick diagnostic technique utilizing the machine's pulse or vibration signature to pinpoint mechanical defects is discussed.

Judge, A. W. Modern Smaller Diesel Engines: In Theory, Construction, Operation and Maintenance. See I.A.

Kolbe, J. F. Abrasive Wear-Identification and Prevention. SAE Preprint 690544. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. See VIII.G.

McElroy, W. J. Preventive Maintenance Through Engine Analyzing. Diesel & Gas Turbine Progress, April 1977, pp. 10-11.

Panhandle Eastern Pipe Line Co.'s main gas gathering operations are located in the panhandles of Texas and Oklahoma, and in Western Kansas. The Liberal, Kansas Station is the first of 13 main line compressor stations extending to Fort Wayne, Ind. Numerous markets are served enroute to the primary market area of Detroit. Skid-mounted engine compressor units used in the gas gathering service range from 55 to 2000 hp. The company's objectives in instituting its engine analyzing program were to reduce maintenance costs, extend the periods between maintenance by finding mechanical faults at an early stage of development and remedy them before the engine required extensive repair, thus increasing the overall operating efficiency and improving fuel consumption. The article describes the various types of equipment used in the analyzing program and the steps that are followed.

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A method has been developed for obtaining engine speed and diagnostic information for a diesel engine without mechanical or electrical connections to the engine. This non-contact technique has the potential for making diesel

engine power measurement and fault detection extremely simple and rapid. The method employs a single transducer held near the engine and special purpose circuitry which extracts the engine speed information from the signal and performs spectral analysis for diagnostic purposes. Circuit outputs are engine speed, a digital pulse train with repetition rate proportional to engine speed, and a harmonic ratio which sensitively indicates the degree of non-uniformity among engine cylinders. By this method, diesel engines with minor compression losses or fuel injection faults can readily be identified without vehicle contact in less than one minute of testing. With additional signal processing, the power producing capability of the engine can also rapidly be evaluated.

Hambright, R. N. Fuel Injection Diagnostic Techniques for Shop Applications. See VIII.C.

Hambright, R. N., and H. S. Benson. Diagnostics of Diesel Engines Using Exhaust Smoke and Temperature. Presented at the Truck Meeting, Indianapolis, Ind., Nov. 1-4, 1976, SAE Preprint 760833, 12 pp.

An experimental sensor array that measures dynamic exhaust temperature and dynamic smoke for the purpose of diagnosing diesel engine fuel injection equipment was designed, built, and tested. The sensor array is portable and easily installed on truck tailpipes, and was tested using two 6V-53 Detroit Diesel engines. The dynamic temperature sensor is a very high response instrument capable of measuring changes in gas temperature in excess of 104°F/second. The dynamic smokemeter is an optical device designed to measure very low levels of light opacity in the smoke plume, with a response compatible with the engine firing frequency. Dynamic exhaust temperature data had more diagnostic significance than dynamic smoke in the detection of maximum power degrading fuel injection faults. Gaseous exhaust emissions (CO, CO_2, O_2, NO_x, and hydrocarbons) were also evaluated for their diagnostic merit and were found to be less significant than the dynamic temperature and smoke data under the no-load test constraints common to shop and field diagnosis.

Hambright, R. N., and C. D. Wood. Vehicle Diagnostic Systems; the State-of-the-Art. Presented at the 1973 Annual Meeting, American Society of Agricultural Engineers, Univ. Ky., Lexington, Ky., June 17-20, 1973, ASAE Paper No. 73-144, 13 pp.

Diagnostic system fundamentals are defined in basic terms, and current activity is discussed for governmental, military, industrial, and commercial organizations. Physical and operational descriptions of example diagnostic systems are given for end-of-assembly-line, shop, portable, and built-in applications. Current diagnostic capabilities are related to instrumentation, parameters, and human factor design options. Significant increases in cost-effective uses of diagnostic systems require some built-in diagnostic equipment. The possible diagnostic systems and capabilities in the near future are a function of technological advances and comprehensive engineering.

Henein, N. A., and J. D. Rozanski. A Technique for the Diagnosis of Malfunctions in Diesel Injection Systems. See VIII.C.

Johnston, S. C., C. W. Robinson, W. S. Rorke, J. R. Smith, and P. O. Witze. Application of Laser Diagnostics to an Injected Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790092, 21 pp.

Measurements taken in a special, single cylinder, direct injection stratified-charge engine are presented. The optical measurement techniques employed include continuous-wave laser Raman Spectroscopy for density fluctuations, high-speed cinematography for flow visualization, and laser Doppler velocimetry for velocities and turbulence intensities. More conventional data on cylinder pressure, power, and emissions levels are also given. The purpose of the study was to demonstrate the types of detailed measurements that are now possible within an engine cylinder.

Kolbe, J. F. Abrasive Wear--Identification and Prevention. SAE Preprint 690544. Society of Automotive Engineers, Inc., Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 15-20.

Abrasive wear, pertaining to the internal combustion engine, has been the subject of numerous technical investigations, papers, and articles. The majority of these presentations are in the area of filtration and the prevention of excessive or abnormal wear. Maintenance men must learn to determine if abrasive wear is present and then take corrective measures. This paper is intended to aid mechanics in identifying abrasive wear from a practical standpoint and in applying the proper remedy.

Mackey, G. The Exhaust Smoke Opacimeter--A Certifying and Maintenance Tool. Diesel & Gas Turbine Progress, July 1976, pp. 30-31.

One of the most perceptive indications of diesel engine conditions is exhaust smoke density. A technique for measuring exhaust smoke of in-use diesel-powered trucks was developed at Clayton Manufacturing Co. in 1973. It consists of operating a vehicle on a chassis dynamometer and subjecting the engine to various modes of operation, i.e. idle, acceleration and lug-down modes as required for certification testing, and recording both the speed and exhaust opacity on a strip chart. Details of its operation are provided.

Musil, N. J. Engine Failure Fingerprints. SAE Preprint 690543. Society of Automotive Engineers, Inc. Guidelines for Engine Maintenance--Analysis, Repairs, Overhauls, Rebuilding. June 1969, SAE Special Pub. 349, pp. 6-14.

In this paper, the author points out the importance of diagnosing failures to prevent a recurrence. Emphasis is placed on looking for the tell-tail markings and clues that will aid in tracing the cause of various engine parts failures; also, on the inspection of used parts and the selection of new parts. It is also pointed out that the selection of premium relacement parts may be necessary under certain operating conditions.

Muzi, A. Sensor Selection for Automatic Diagnosis of Vehicles. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770403, 12 pp.

Improvements in vehicle diagnostics are evolving both from the development of new sensors and from the extension of standard sensor capabilities made possible by modern electronics and processing techniques. Accordingly, the effective application of sensors to vehicles is an overall system problem. Foremost among the design considerations are the test paramaters that are the indicators of faults, the accuracy with which they must be measured, and the methods available for evaluating, processing and displaying those parameters. Next are the considerations of survival and performance in the automotive environment, the operator's method of performing the test, and applicability to a broad spectrum of vehicles. This paper discusses criteria for sensor selection from the viewpoint of a developer of systems for the malfunction diagnosis of vehicles with spark or compression ignition engines. The focus is on pressure transducers. The considerations, however, are generally applicable to all sensors.

Obits, W., and D. Ancona. Maintenance Indicator System for Military Trucks. See III.F.

Parker, K., and P. D. Miller. The First Digital Automotive Diagnostic System-Autosense. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760144, 16 pp.

The purpose of this paper is to describe a new approach to vehicle test and diagnosis, the first digital automotive diagnostic system--Autosense®. The Autosense® Computerized Digital Diagnostic System is designed to assist mechanics, at all levels, test and diagnose today's newest vehicles. The system can run individual tests, and thus be used by the mechanics as a tool, or automatically step the mechanic through a sequence of tests to diagnose a specific vehicle problem, totally check a vehicle or its individual systems. The system compares actual vehicle performance to manufacturer's vehicle specifications and provides the mechanic with recommended repairs. The system also provides the mechanic and the customer with a hard-copy printout of all test performed, the actual vehicle specifications and all recommended repairs.

Pratt, G. W., Jr. An Opto-Electronic Torquemeter for Engine Control. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760070, 4 pp.

An optical means of measuring torque is described having high accuracy and reliability combined with modest cost. Details of an instrument which was adapted to a transmission output shaft are given. Torque, rpm, and their time rates of change are envisaged as inputs to a microprocessor for the generation of feedback control signals for timing, fuel-air ratio, and fuel.

Sarna, D. S., and J. W. Steyaert. Diagnostic Equipment Development for Military Vehicle Applications. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Technical Paper Series 780029, 16 pp.

Simplified Test Equipment for Internal Combustion Engine Powered Material (STE/ICE) is being developed by the U.S. Army with emphasis on test capability and ease of use. This paper discusses the man/equipment interface as well as the test capabilities of STE/ICE. Emphasis is placed on the unique test capabilities available and a concept for defining a built-in interface for the Army vehicle fleet. The focus is on the Tank-Automotive area but the applications extend to all internal combustion engine powered equipment.

Young, A. E., D. H. Locher, and W. G. Wolber. An On-Line Pressure Monitor for EFI-Control Test Diagnostics. Presented at the Automotive Eng. Cong. and Exposition, Detroit, Mich., Feb. 23-27, 1976, SAE Preprint 760246, 12 pp.

This paper describes an on-line pressure-monitoring system, designed to meet an urgent need for constant accuracy surveillance on the precision pressures that are applied to EFI Electronic Control Units during production calibration and test. Design requirements and approach are discussed, and system implementation and performance are detailed. The pressure monitor, which operates in both a SCAN and a SET mode, detects and measures pressure deviations in up to 39 precision pressure sources, and activates an alarm to alert test personnel should an out-of-tolerance condition develop. It has significantly reduced the incidence of test-operator error, and has played a major role in substantially increasing production yields.

H. Oil and Wear Analysis

Bolis, D. A., J. H. Johnson, and D. A. Daavetilla. The Effect of Oil and Coolant Temperatures on Diesel Engine Wear. Presented at the Internat. Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 28-March 4, 1977, SAE Preprint 770086, 16 pp.

A study has been made of piston ring wear and total engine wear using literature data and new experimental results. The main purpose of the study was to establish the effects of oil and coolant temperatures on engine wear. Wear trends that were found in the early 1960's may not be valid any longer because of the development of higher DMEP turbocharged diesel engines, better metallurgical wear surfaces and improved lube oil properties. New data are presented for the purpose of describing present wear trends. A direct-injection, 4-cycle, turbocharged diesel engine was used for the wear tests. The radioactive tracer technique was used to measure the top piston ring chrome face wear. Atomic emission spectroscopy was employed to determine the concentration of wear metals in the oil to determine total engine wear based on iron and lead. The data were analyzed and compared to the results found in the literature from previous investigators. After the results of the analysis are presented, an explanation of the results using some fundamental concepts is made.

Boone, E. F., and F. E. Didot. Field Experience of Extended Drain Interval in Diesel Lubricant Performance. See II.E.

Brown, K. L., Jr., and N. D. Bohner. Valve Wear, Statistically Speaking. Presented at the Energy Technol. Conf. & Exhibit, Houston, Tex., Sept. 18-22, 1977, ASME Preprint 77-DGP-6, 12 pp.

Excessive inlet-valve face wear occurred during early durability testing of a new cylinder head arrangement. The program to correct this wear problem resulted in considerable valve-face wear data exhibiting large scatter. Statistical techniques were used to define, correct, group, and compare these data in order to draw conclusions. Particular emphasis was placed on the use of Weibull statistics. Variables dealing with valve geometries, materials, and mechanism dynamics were tested in order to solve the valve-wear problem encountered. Valve-wear data for these variables are analyzed by the above statistical techniques. The results are presented and show that Tribaloy® 400 valve-face material, 20-deg valve-face angle, and proper valve-mechanism dynamics each offered a significant improvement to the valve-wear problem. The results also illustrate the significance of the subject analytical tool as a means for solving valve-face wear problems and for design optimization.

Diesel Equipment Superintendent. Saves Time and Engines. January 1977, pp. 36-38.

The article describes the experiences of one over-the-road trucking firm with the Gulf-Check oil analysis program. Benefits--both general and case specific--derived from this diagnostic program are discussed.

Engineering and Mining Journal. How Oil Analyses Saved 28 Engines. May 1978, pp. 108-110.

Laboratory analyses of oil samples taken from diesel equipment can help mine operators avoid breakdowns, downtime, and repair costs. The article lists 28 examples of early warnings from Mobil Oil Corp.'s EM/PA system, giving oil sample test results, sources of trouble, and action taken.

Goodwin, E. Diagnostic Studies of Lubricants. Can. Inst. Min. Bull., May 1978, pp. 124-126.

The mechanics of formation of wear-metal suspensions in lubricants is discussed along with the relationship of the concentration of the metals and other particles to the wear of lubricated machinery parts. The importance of particle and suspension analysis of used lubricants in a preventative maintenance program is stressed, in particular with regard to mobile equipment in a mining operation.

Hofman, M. V., and J. H. Johnson. The Development and Application of Ferrography to the Study of Diesel Engine Wear. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Technical Paper Series 780181, 32 pp.

This paper covers the development of Ferrographic oil analysis techniques for the study of diesel engine wear. A brief overview of the various wear analysis techniques now commonly used in laboratory and field engine wear studies is discussed. Also included in this paper is an in-depth description of the Ferrographic oil analysis techniques and the various applications of the techniques to the study of engine wear. A comparison of the commonly used wear measurement methods, Ferrography, spectroscopy and the radioactive tracer methods, and their abilities to measure wear is also discussed. A direct injection, 4-cycle, turbocharged diesel engine was used in the testing and data are presented indicating the abilities of the Ferrographic oil analysis techniques to detect changes in wear rates. The effects of operating time on engine oil and the effects of the variation of oil and coolant temperatures on engine wear is presented. The effects of oil filtration on engine wear is also discussed and data are presented contrasting the filtered versus the non-filtered diesel engine lubrication system.

Hofman, M. V., and J. H. Johnson. The Development of Ferrography as a Laboratory Wear Measurement Method for the Study of Engine Operating Conditions on Diesel Engine Wear. Wear, v. 44, 1977, pp. 183-199.

Ferrographic oil analysis techniques were used in a laboratory study of diesel engine wear. Data were developed supporting the concept of using the Severity Index I_S to rank the effect of engine operating conditions on wear. Results analyzing the Severity Index as a function of time and as a function of engine operating variables are presented. The Severity Index is also linearly

correlated to spectrometric data (iron and lead concentrations in the used oil samples). Engine wear tends to increase with increase of either oil or coolant temperature. However, brake specific fuel consumption tends to decrease as oil and coolant temperatures increase, indicating a need for accurate temperature control for both mediums to minimize fuel consumption and wear. The heated Ferrogram analysis (HFA) technique was used to determine changes in the wear rates of specific engine parts with variation of the oil and coolant temperatures.

Rounds, F. G. Carbon: Cause of Diesel Engine Wear? Presented at the Passenger Car Meeting, Detroit Plaza, Detroit, Mich., Sept. 26-30, 1977, SAE Preprint 770829, 12 pp.

Diesel soot (carbon) contamination of engine oil appears to be the cause of higher valve train wear in diesel engines than in gasoline engines with similar metallurgy. Four-ball wear studies to determine the mechanism by which carbon reduces the antiwear benefit of zinc dithiophosphates (ZDP's) indicate that the higher wear is due to preferential adsorption of the ZDP decomposition products by the soot thus reducing the formation of the antiwear surface coating. Adsorption of undecomposed ZDP, changes in ZDP decomposition reactions and abrasive removal of the surface coating were eliminated as significant contributors to higher wear.

Strigner, P. L., and N. N. Kallio. A Study of Oil and Filter Change Periods and Engine Oil Monitoring for GM 6V-71 Diesel Bus Engines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780184, 20 pp.

Thirteen new 1965 buses having GM 6V-71 diesel engines were put on various oil/filter change periods from 6000/6000 to 25000/25000 miles, and operated in normal passenger service for seven years (1966-1973). Crankcase oil was tested periodically, and oil filters were examined after scheduled removal. Maintenance and operation records were kept. Finally, at the overhaul point, some engine parts were examined. The optimum oil/filter change period was judged to be 25000/12500 miles, in conjunction with field testing for solids load, water, and dilution. Correlations and oil test data, suitable for reference, are given.

Wiles, R. C. Mobile Plant Maintenance With Special Reference to Wear Analysis and Analytical Inspection. Quarry Management and Products, October 1977, pp. 276-280.

Rather than covering the routine issues of maintenance charts, procedures, and record systems--which are exhaustively dealt with in a host of previous publications--this paper presents relatively new techniques of analysis, and diagnostics are presented which detect and isolate problems of wear and malfunction before these can significantly affect performance. The subject is considered particularly in relation to the maintenance of heavy earthmoving equipment, since this is the area in which the author's organization has a special interest. But the principles can be related to all types of mobile equipment.

I. Maintenance Effects on Emissions

Bly, R. L. Clean Exhaust--Good Diesel Performance: Smoke Points to Need for Maintenance, Color Clue to Causes. See VIII.G.

Hall, O. P., Jr., and N. A. Richardson. The Economic Effectiveness of Vehicle Inspection/Maintenance as a Means for Reducing Exhaust Emissions: A Quantitative Appraisal. See VIII.F.

Springer, K. J. Exhaust Emissions From Rebuilt Heavy Duty Engines. See VIII.E.

Taigel, P. G. Diesel Locomotives in Mines: The Production of Toxic Gases by the Diesel Engine. Transactions--The Inst. of Min. Eng., v. 111. No. 3369, 1951-1952, pp. 85-108.

The paper deals mainly with the production of carbon monoxide and oxides of nitrogen by the direct-injection diesel engine. Field investigations on locomotives in service provide information on the toxic-gas production of 20 locomotives at 6 collieries, and tests on 7 different diesel engines at the maker's works show a marked difference between the production of oxides of nitrogen with direct- and indirect-injection engines. New engines and used engines are compared and the rise and fall of production of carbon monoxide and oxides of nitrogen with use are measured. Some wear data are given and correlated with toxic-gas production. The absorption of toxic gases in water bath conditioners is discussed and tests are described in which exhaust-gas scrubbers deal with diesel exhaust, and the absorption of NO_2 is measured. These investigations, concerned with the health hazard associated with the production of toxic gases in diesel engine emissions, were carried out over the four years, February 1947 to February 1951, by the Haulage Section of the SAFETY IN MINES RESEARCH ESTABLISHMENT of the Ministry of Fuel and Power in Buxton, England.

TRW Transportation and Environmental Operations. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. I. Executive Summary. July 1973, 50 pp.; NTIS PB-225 024.

This volume summarizes the general objectives, approach, and results of an overall five year program whose objective was to examine the feasibility of using mandatory vehicle inspection and maintenance as a means for controlling automobile exhaust emission levels. Both the achieveable exhaust emission reductions and total program cost were used in the feasibility assessment.

TRW Transportation and Environmental Operations. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. II. Mandatory Inspection/Maintenance Systems Study. July 1973, 52 pp.; NTIS PB-225 025.

This report summarizes the final results obtained from a systems study of mandatory vehicle inspection and maintenance. The report focuses on two areas of general importance which were not examined in early analyses. The first area involves studying the impact on procedure effectiveness of the rate with which engine adjustments and exhaust emissions deteriorate with vehicle use while the second area is concerned with determining the cost effectiveness of alternate program strategies including mandatory maintenance only. The study was conducted using the Economic Effectiveness Model and the complete experimental data base. The report is composed of five sections which cover the evaluation of alternative programs, system sensitivity analysis, and study conclusions.

TRW Systems Group. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. III. A Documentation Handbook for the Economic Effectiveness Model. July 1972, 85 pp.; NTIS PB-220 728.

The primary purpose of the Economic Effectiveness Model is to serve as a research and design tool for assessing the various implications of a mandatory program of vehicle inspection/maintenance. The model is designed to both analyze the regional feasibility of vehicle inspection/maintenance as well as to specify an optimal system design. Input data for several regional areas covering the gamut of auto-related air quality problems are incorporated into the model. The model can also be used to analyze the sensitivity of system performance to various model assumptions and basic data inputs. The model is best used for evaluating the attractiveness of alternative policies, e.g., engine inspection or emission inspection, which govern and control the operation of an inspection/maintenance system. The main function of the model is in simulating the behavior of the inspection/maintenance process over time. Here, the economic effectiveness of various strategies can be measured in terms of emission reductions and program costs at each time interval.

TRW Systems Group. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. V. Experimental Investigation of Service Organization Maintenance Performance. July 1972, 91 pp.; NTIS PB-220 730.

The overall objective of this experiment was to develop measures of service organization effectiveness in correcting engine part failures, malfunctions, and tune-up parameter maladjustments which cause high exhaust emissions. Subsidiary objectives were to assess the capability of service organizations to (1) detect specific malfunctions, (2) return malfunctions, maladjustments, and failures to manufacturer's specifications, and (3) respond to the type of information which might be provided by mandatory vehicle inspection and the resulting impact on cost and performance effectiveness. Statistics were developed on (1) cost to accomplish maintenance, (2) maintenance cost and performance effectiveness of garages organizations in different

communities, (3) influence of service organization type (independent, dealership, and service station) on cost and performance effectiveness, and (4) the amount of unnecessary maintenance performed by service organizations.

TRW Systems Group. A Study of Mandatory Engine Maintenance for Reducing Vehicle Exhaust Emissions: v. VI. A Comparison of Oxides of Nitrogen Measurements Made With Chemiluminescent and Non-Dispersive Radiation Analyzers. July 1972, 27 pp.; NTIS PB-220 731.

The purpose of this report is to describe an experimental study which was undertaken to describe differences between CL and NDIR/NDUV measurements, as applied to dilute samples of automotive exhaust gas. There are two distinctly different types of instrumentation used to measure automotive exhaust emissions of the oxides of nitrogen (NO and NO_2); (1) non-dispersive infrared (NDIR) analyzers for NO and non-dispersive ultraviolet (NDUV) analyzers for NO_2; and (2) chemiluminescence (CL) analyzers for the measurement of both NO and NO_2 (NO_x).

Welstand, J. S., and C. H. Oki. The Economic Effectiveness of Vehicle Inspection and Maintenance for Reducing Exhaust Emissions: A Supporting Experimental Program. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740132, 16 pp.

A series of experimental programs was conducted to provide an empirical data base for a computer model of the economic effectiveness of mandatory inspection and maintenance of light-duty vehicles. The experimental programs provided four basic data sets: 1. The frequency and extent of engine maladjustments and component failures of in-use vehicles. 2. The change in exhaust emission levels that results from changes in engine adjustments and component condition. 3. The deterioration of engine adjustments and components and the associated deterioration in exhaust emissions with the accumulation of time and mileage. 4. The ability of automotive service organizations to detect and repair engine maladjustments and failures. The data that resulted from these experiments were effectively employed in the computer model.

J. Economic Impact, Costs

Barnett, R. M., and P. D. Tomlingson. Maintenance Program for Mobile Equipment Cuts Costs at Henderson Moly Mine. Eng. and Min. J., May 1978, pp. 94-98.

The article describes the maintenance program for mobile equipment at the Henderson underground molybdenum mine of Climax Molybdenum Co., about 50 miles west of Denver, Colorado. Examples of various cost and maintenance status reports are provided, along with details of the program's implementation which has resulted in lower costs, improved availability, and good control of maintenance.

Blue, G. B. Internal Combustion Engine Failures: A Statistical Analysis. Presented at the Diesel and Gas Engine Power Conference and Exhibit, New Orleans, La., April 6-10, 1975, ASME Preprint 75-DGP-16, 7 pp.

The paper is a recapitulation of engine failure statistics from the files of The Hartford Steam Boiler Inspection and Insurance Co., and represents a total of 180 failures over a period of 3 1/2 years. The equipment involved includes diesel and dual-fuel engines, spark-ignited gas and gasoline engines and internal combustion engines driving reciprocating compressors. The failures are categorized by 1) type of accident, 2) initial part to fail, and 3) primary cause of failure. Through recognition of these problem areas, it was hoped that preventive measures could be taken by manufacturers and operators to reduce their occurrences and thus cut production and operating costs.

Carothers, R. C. Temperature Monitoring Cuts Fuel Bill, Aids Maintenance. See VII.G.

Espach, T. M. Improvements to the Trackless-Mining Equipment and Operation at Prieska Copper Mines (Proprietary) Limited. See VIII.F.

Gilbert, S. The Use of Diesel Engines Underground in British Coal Mines. The Mining Engineer, June 1974, pp. 395-406.

The paper outlines the introduction and growth of the diesel-powered vehicles operating underground in British coal mines and describes general experience over the last three decades. The major requirements of the law relating to safety and health are defined; and the methods of sampling and analyzing exhaust gases and mine air are described; all of these provide a means of controlling existing applications and assist in the planning of future installations of diesel-powered locomotives and vehicles. The potential hazards associated with the diesel engine are described, and there is included a summary of safety records since the nationalization of British mines in January 1947. The design criteria of the diesel engine and its associated ancillary equipment are discussed and an average cost analysis has been drawn up.

Holmes, V. H. Diesel and Gas Engine Power Costs and Trends. Presented at the Diesel & Gas Power Conference and Exhibit, St. Louis, Mo., April 16-20, 1972, ASME Preprint 72-DGP-13, 5 pp.

Under the sponsorship of both the Diesel and Gas Power Division of ASME and the Diesel Engine Manufacturers Association, the author has collected 1968, 1969, and 1970 data for the 1971 and 1972 reports on diesel and gas engine power costs. The procedure of collection and preparation of data for the report is explained. The reasons for the trends in power costs--downward in many instances--are enumerated with respect to load growth and progressive developments of internal combustion engines.

Rock Products. Central Lube Systems Help Sand Producers Halve Repair and Maintenance Costs. See VIII.B.

Smiley, C. H. Make Maintenance a Profit Center. Rock Products, January 1977, pp. 66-68.

Spiraling equipment and labor costs are directing more attention towards making equipment last longer and reducing maintenance costs. The article refers to a variety of improved maintenance techniques and materials that can lead to better equipment performance, longer service life, and greater profits and suggests factors that should be taken into consideration in developing a maintenance program.

Smith, D. J., and A. H. Babb. Maintainability Engineering. See VIII.F.

U.S. Environmental Protection Agency, Inspection and Maintenance Staff. Effects of Inspection and Maintenance Programs on Fuel Economy. U.S. Environmental Protection Agency, Ann Arbor, Mich., March 1979, 11 pp.; NTIS PB-297 583.

The primary goal of inspection and maintenance (I/M) programs is to improve air quality by reducing emissions from motor vehicles. Many studies have indicated that I/M programs will achieve this goal. In addition several studies have indicated that fuel economy improvement can be expected to occur as a result of maintenance performed on vehicles failing an I/M test. Most studies which have been performed have looked at pre-1975 model year vehicles and have had expert mechanics performing the maintenance work. This report considers both the results from past studies and the results from more recent studies in order to provide EPA's best estimates of fuel economy benefit which can be attributed to I/M programs.

Welstand, J. S., and C. H. Oki. The Economic Effectiveness of Vehicle Inspection and Maintenance for Reducing Exhaust Emissions: A Supporting Experimental Program. See VIII.I.

IX. ALTERNATIVE POWER SOURCES

A. Stratified Charge Engine

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Mining Machinery. Nat. Aeronautics and Space Administration (Cleveland, Ohio), NASA TM-82695, BuMines Agreement J0100026, December 1981, 101 pp.

The NASA Lewis Research Center, under Interagency Agreement J0100026 with the Department of Interior, Bureau of Mines, performed an assessment of alternative power sources for mining applications, primarily mobile underground equipment. This report presents the results of that assessment. Each candidate alternative power source was assessed in terms of the following requirements, which were established as a first step in the assessment: (1) ability to achieve the duty cycle, (2) ability to meet Government regulations (MSHA certification), (3) availability (production readiness), (4) market availability, and (5) packaging capability. An initial screening reduced a variety of possible candidates to the following, which were evaluated in more detail: (1) improved diesel, (2) Stirling, (3) gas turbine, (4) Rankine (steam), (5) advanced electric (batteries), (6) mechanical energy storage (flywheel), and (7) use of hydrogen evolved from metal hydrides. The candidate power sources were divided into two categories--heat engines and energy storage systems--since the basic constraints are different for each. Each alternative power source is described briefly, including its current development status, specific problem areas, and possible future improvements. Each candidate is then evaluated against the requirements initially established. Research and development efforts for each candidate power source are discussed and evaluated in terms of potential. Recommendations are made for each power source in terms of possible near-term or future application to mining use and the specific problem areas that must be addressed prior to that application.

Dimick, D. L., S. L. Genslak, R. E. Greib, and M. J. Malik. Emissions and Economy Potential of Prechamber Stratified Charge Engines. Presented at the Automotive Eng. Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790436, 15 pp.

In order to meet stringent government emissions standards without penalizing the fuel economy of gasoline engine cars, a number of alternative engine concepts have been investigated. This paper describes a research investigation and parallel development activity on prechamber stratified charge engines. Single-cylinder engine investigations are first described. Alternative design and operating parameters are investigated and compared in these engines. Design and development of two multicylinder engine designs incorporating prechamber 3-valve configurations are next described. Finally, a car development and evaluation program is outlined, using both small and large cars with alternative engine configurations and after-treatment devices. Results of the above prechamber stratified charge engines are

compared with conventional engines in order to assess and evaluate the emission and economy potential of this type of engine. The authors conclude that this type of stratified charge engine possesses NO_x emission and fuel economy performance similar to a conventional engine but a high HC emission level.

Dowdy, M., and A. Burke. Automotive Technology Projections. Presented at the Congress and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-Mar. 2, 1979, SAE Technical Paper Series 790021, 20 pp.

Results of an automotive technology assessment study are presented to provide a basis of comparison for vehicles with alternative power systems. Factors considered include fuel economy, exhaust emissions, multi-fuel capability, advanced materials, and cost/manufacturability for both conventional and advanced alternative power systems. To insure valid comparisons of vehicles with alternative power systems, the concept of an Otto-Engine-Equivalent (OEE) vehicle is utilized. Each engine type is sized to provide equivalent vehicle performance. Fuel economy projections are made for each engine type considering both the legislated emissions standards (0.4 g/mi HC, 3.4 g/mi CO, 1.0 g/mi NO_x) and possible future emissions requirements (0.4 g/mi NO_x). The sensitivities of the fuel economy projections to factors such as engine torque boundary, rear axle ratio, performance criteria, and engine transient response are discussed. Using the OEE vehicle concept, projected fuel economies of both small and full-sized vehicles with Stirling engines are up to 40 percent better than baseline vehicles with conventional engines. Vehicles with Brayton engines show up to a 30 percent better fuel economy than the baseline in full-sized vehicles, but offer little fuel economy advantage in small vehicles. Advanced continuous combustion power systems (Brayton and Stirling) offer advantages over the baseline vehicles in the areas of exhaust emissions and multifuel capability; however, their initial costs are projected to be substantially higher.

Gruden, D. Combustion and Exhaust Emission of an Engine Using the Porsche-Stratified-Charge-Chamber-System. Presented at the Automobile Eng. Meeting, Oct. 13-17, 1975, Detroit, Mich., SAE Preprint 750888, 15 pp.

The development of vehicle combustion engines today is characterized by the effort to reduce exhaust gas emission and fuel consumption and to conserve the good properties of the combustion engine at the same time. As, at least for the years to come, there will be no chance for the utilization of the alternative special drives, PORSCHE is intensely dealing with the further development of the conventional combustion engine as well as of the stratified-charge-chamber engine. With their stratified-charge engine (SKS) PORSCHE has tried to create optimum conditions for each of the combustion phases. The result was a divided combustion chamber with a three-stage combustion. The system was tried on single-, six-, and eight-cylinder engines and led to good results under stationary conditions on the testing rig as well as under unstationary driving conditions.

Heywood, J., and J. Wilkes. Is There a Better Automobile Engine? Technology Review, November/December 1980, pp. 19-29.

The authors examine the operation, advantages, and disadvantages of conventional and less familiar automobile propulsion systems. Current research and factors affecting potential development of alternative power sources are discussed.

Jet Propulsion Laboratory. Should We Have a New Engine? An Automobile Power Systems Evaluation: v. II. Technical Reports. Cal. Inst. of Technol., August 1975, SAE Spec. Pub. 400, 538 pp. (also, v. I--Summary. SAE Spec. Pub. 399, 109 pp.)

Alternative automotive powerplants were examined for possible introduction during the 1980-1990 time period. Technical analyses were made of the Stratified-Charge Otto, Diesel, Rankine (steam), Brayton (gas turbine), Stirling, Electric, and Hybrid powerplants as alternatives to the conventional Otto-cycle engine with its likely improvements. These alternatives were evaluated from a societal point of view in terms of energy consumption, urban air quality, cost to the consumer, materials availability, safety, and industry impact. The results show that goals for emission reduction and energy conservation for the automobile over the next 5-10 years can be met by improvements to the Otto-cycle engine and to the vehicle. This provides time for the necessary development work on the Brayton and Stirling engines, which offer the promise of eliminating the automobile as a significant source of urban air pollution, dramatically reducing fuel consumption, and being saleable at a price differential which can be recovered in fuel savings by the first owner. Specifically, the Brayton and Stirling engines require intensive component, system, and manufacturing process development at a funding level considerably higher than at present.

Mortimer, J. Alternative Engines for Tomorrow's Car. The Engineer. May 13, 1976, pp. 32-37.

The article is a summary of findings of a $500,000 study by a team of engineers and scientists from the Jet Propulsion Laboratory, Calif. Inst. of Technology, and the Caltech Environmental Quality Laboratory to determine developments that should be pursued to replace the present-day piston engine running on hydrocarbon fuels. In the Ford Motor Co.-sponsored study, the investigators were concerned with alternative automotive powerplants suitable for possible introduction in the 1980's and 1990's, including the stratified charge Otto-cycle engine, the diesel engine, the Rankine or steam engine, the Brayton or gas turbine, the Stirling engine, electric propulsion and various hybrid powerplants. The article summarizes on a comparative basis a variety of information on the various engines, including costs, fuel economy potential, emissions, weight, and horsepower.

Renner, R. A. Alternate Engines State of the Art Study. See IX.C.

Richardson, R. W. Automotive Engines for the 1980's: Eaton's Worldwide Analysis of Future Automotive Power Plants. Eaton Corp., Word Headquarters, Cleveland, Ohio, 1976, 17 pp.

There are five major contenders to replace or supplement today's piston engine. Changing social requirements and new technological developments the Eaton Corp. feels will lead to major changes in automotive powerplants. This study makes projections through the 1980's of the market penetration of Wankel, Stirling, turbine, stratified charge, and diesel engines for passenger car, heavy duty, and small engine applications. These engines are compared on the basis of ten major selection parameters. Major factors affecting the rate of commercialization of new engines are reviewed, including social, political, and economic forces of change and historical perspective. Major inputs came from more than 60 worldwide in-depth interviews.

Saga, K., and S. Furuhama. Performance and Emission Control in Stratified Charge Hydrogen Fueled Engines. Stratified Charge Engines (A conference sponsored by the Automobile Division and the Combustion Engines Group). The Inst. of Mech. Engrs., London, Nov. 23-25, 1976, pp. 29-37.

Three types of stratified hydrogen fueled systems were applied in several single-cylnder engines, both for control of emissions and abnormal combustion. First, hydrogen was injected into the cylinder directly by the two processes. In one of them, the injection was finished at an early part of compression stroke. Then the maximum output could be increased but not with lower NO_x emission; the thermal efficiency was lower because the mixing was incomplete. In the other process, high pressure hydrogen was induced into the intake manifold, which gave good control of NO_x emission, but further improvement of the thermal efficiency and durability of the injection system were required. Second, a single-cylinder engine was operated by injecting only low-pressure hydrogen into an auxiliary chamber during the early part of the compression stroke. In the case of the air-hydrogen engine, however, the combustion was accelerated excessively by the stratification.

Scussel, A. J., A. O. Simko, and W. R. Wade. The Ford PROCO Engine Update. Presented at the West Coast Meeting, San Diego, Calif., Aug. 7-10, 1978, SAE Technical Paper Series 780699, 39 pp.

The Ford PROCO stratified charge engine combines the desirable characteristics of premixed charge and Diesel engines. The outstanding characteristics of premixed charge engines are their high specific output, wide speed range, lightwight and easy startability but they exhibit only modest fuel economy and relatively high exhaust emissions. The desirable characteristic of the diesel engine is its outstanding fuel economy. However, the disadvantages of the diesel, which include noisy operation, limited speed range, exhaust odor, smoke, hard startability, and particulate emissions have tended to limit their acceptance. In the gasoline fueled, PROCO stratified charge engine, direct cylinder fuel injection permits operation at overall lean mixture ratios and higher compression ratio. These features enable the PROCO engine to achieve brake specific fuel consumption values in the range of prechamber diesel engines. Information is presented on the development of the PROCO engine and a variety of test results are provided.

Tierney, W. T., E. Mitchell, and M. Alperstein. The Texaco Controlled-Combustion System--A Stratified Charge Engine Concept. Review and Current Status. Power Plants and Future Fuels (A Conference Sponsored by the Combustion Engines Group and the Automobile Division of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 1-15.

The Texaco Controlled-Combustion System, a stratified charge engine concept, utilizes a coordinated arrangement of fuel injection, positive ignition and air swirl within the combustion chamber to yield "patch burning" of a combustible mixture. The resulting ability to burn unthrottled, overall lean fuel-air mixtures produces engines having excellent fuel economy with inherently low emissions of exhaust pollutants. Equally important, the unique coordinated arrangement prevents combustion knock without regard to fuel octane or cetane rating and permits the use of high compression ratios and/or inlet pressure charging. The basis of the concept, the general operating characteristics associated with the system and the development background over a period of many years are reviewed. The results of recent work on vehicle-installed TCCS engines, both in naturally aspirated and turbocharged configurations, are discussed.

Wall, J. C., and J. B. Heywood. The Influence of Operating Variables and Prechamber Size on Combustion in a Prechamber Stratified-Charge Engine. Presented at the International Fuels & Lubricants Meeting, Toronto, Ont., Nov. 13-16, 1978, SAE Technical Paper Series 780966, 21 pp.

This paper describes the results of experimental and computer simulation studies of the combustion process in the prechamber three-valve stratified-charge engine. Prechamber and main-chamber pressure data and matched computer simulation calculations are used to determine the effects of variations in overall air/fuel ratio, engine speed and load, and prechamber volume and orifice diameter on the parameters which define the combustion process (spark advance for optimum torque, ignition delay, combustion duration), on cylinder pressure diagrams (mean main-chamber pressure, mean pressure difference across the orifice, and cycle-by-cycle pressure fluctuations) and on exhaust emissions. General correlations are derived from the data for the shape of the combustion rate profile and the extent of the combustion duration.

Wood, C. D. Performance of a Stratified Charge Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790434, 10 pp.

An experimental study of a single-cylinder direct-injected stratified charge engine is described, with emphasis upon influence of configuration and injection system details upon performance and exhaust emissions.

B. Stirling Engine

Bjerklie, J. W., E. J. Cairns, C. W. Tobias, and D. G. Wilson. An Evaluation of Alternative Power Sources for Low-Emission Automobiles. Presented at the Automobile Eng. Meeting, Detroit, Mich., Oct. 13-17, 1975, SAE Preprint 750929, 20 pp.

Two successive surveys and round-robin interviews were conducted to determine if there might be in the offing for automobiles an alternative engine which would meet the most stringent emissions requirements. In comparing engines, overall acceptability was evaluated considering emissions, customer requirements and manufacturers' requirements for an engine, and engine efficiency and fuel varsatility. An attempt was made to establish a time scale as to R and D requirements and eventual production. Comparison of all engines was made with equivalent pre-control Otto cycle engines as the standard. Alternative engines were deemed to be any powerplant that was not based on spark ignition Otto cycle engines, or diesel engines. The remaining heat engines largely used continuous combustion as the heat source. Electrical powerplants considered were batteries and fuel cells. Hybrid engines and fuel-less stored energy powerplants were given some consideration.

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Miling Machinery. See IX.A.

Carlqvist, S. G., and G. S. K. Lundholm. Stirling Engines: Their Potential Use in Commercial Vehicles and Their Impact on Fuel Utilization. Power Plants and Future Fuels (A conference sponsored by the Combustion Engines Group and the Automobile Division of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 35-47.

Recent results and current development of double-acting Stirling engines are reviewed in this paper. Special emphasis is laid on the application of the Stirling engine to commercial vehicles for urban traffic. The paper presents the design features of experimental V4 engines, as well as the unique environmental characteristics and fuel versatility of Stirling engines in general.

Diesel and Gas Turbine Progress. RV Has Stirling TE System. December 1978, pp. 10-11.

A number of Winnebago recreational vehicles have been equipped with Stirling engines as a power source for electrical, heating, and air conditioning systems. Equipping these prototype models was a joint effort of Stirling Power Systems Corp., Ann Arbor, Mich., and Winnebago Industries, Forest City, Iowa. The new Stirling engine developed for this total energy system is called the V160 series. An external combustion engine, the 10.7 horsepower engine features low noise, low vibration, and clean, odorless exhaust emissions. The article details the engine's design and its operation.

Dowdy, M., and A. Burke. Automotive Technology Projections. See IX.A.

Fenton, J. E. An Air/Fuel Control System for the Stirling Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790328, 8 pp.

A repeatable air/fuel control system has been developed for the Stirling engine. This control system provides a wide range of metered fuel flows and adjustable air/fuel ratios, a requirement for mapping and optimization of Stirling engine components which placed limitations on conventional fuel metering systems.

Hallare, B. The Development of 40-150 kw Stirling Engines in Sweden and Their Application in Mining Equipment. Total Energy Systems and Road Vehicles. Proceedings of Fourth International Symposium on Automotive Propulsion Systems, Apr. 18-22, 1977. U.S. Dept. of Energy, Rept. No. CONF-770430/1, UC-96, v. 1, February 1978, pp. 248-268.

United Stirling is a Swedish corporation, owned by FFV, a government-owned industrial group, and Kockuma, a publicly owned company having its main business in shipbuilding and lumber industries. The corporate goal of United Stirling is to commercialize the Stirling engine. Special emphasis has been put on special market segments, but a considerable effort has also been made to further increase the specific performance of the Stirling engine, allowing the engine to be one of the most attractive candidates for the future volume engine markets. This paper describes the effort made in Sweden to: Develop Stirling engine components acceptable to the market; develop suitable engine configurations; and approach special market segments for the Stirling engine.

Hirschfield, F. The Resurrection of the Stirling Engine. Mech. Eng. v. 100, No. 10, October 1978, pp. 38-44.

The article is a feature interview with Dr. Beno Sternlicht, Board Chairman and Technical Director at Mechanical Technology, Incorporated, in which Dr. Sternlicht gives a detailed insight into the $100 million government-sponsored program for making the 150-year-old Stirling concept a viable commercial proposition in the late 20th century. Research objectives are stated. Early history of the Stirling engine and the role of various companies or individuals in its development are outlined. In comparing the Stirling engine with the spark ignition engine, the Stirling engine's advantages were listed as very high efficiency potential, multifuel capability, low emissions, very low noise, and the fact that much of the existing tooling and manufacturing service know-how can be used since it is a piston engine. Some of the problem areas were listed as high cost, high weight, and unproven reliability.

Jet Propulsion Laboratory. Should We Have a New Engine? An Automobile Power Systems Evaluation: v. II. Technical Reports. See IX.A.

Marshall, W. F. The Stirling Engine--An Option for Underground Mines. U.S. Dept. of Energy, BERC RI 78/3, March 1978, 5 pp.

The use of heat engines for powering mobile equipment in underground mines offers advantages over electric power in terms of mobility and electric shock hazards. However, exhaust is discharged into the working environment; thus there is a potential hazard associated with toxic combustion products. Although diesel engines are in use in underground mines, other heat engines might be considered for use because of potentially lower emission rates. The Stirling engine is a possible alternative to the diesel because it shows promise as a low emission, high power density engine. In order to assess the potential of the Stirling for mining applications, performance data are required. To fill this need, data on the composition of the exhaust from a Stirling engine were obtained. The results of this work indicate that the Stirling engine compares very favorably with "low emission" diesels with respect to emissions characteristics.

Martini, W. R. Stirling Engine Diesel Manual. Univ. of Wash., Contract No. NSG-3152, April 1978, 360 pp.; NTIS N78-23999.

This manual is intended to serve both as an introduction to Stirling engine analysis methods and as a key to the open literature on Stirling engines. Over 800 references are listed and these are cross referenced by date of publication, author and subject. Engine analysis is treated starting from elementary principles and working through cycle analysis. Analysis methodologies are classified as first, second, or third order depending upon degree of complexity and probable application; first order for preliminary engine studies, second order for performance prediction and engine optimization, and third order for detailed hardware evaluation

and engine research. A few comparisons between theory and experiment are made. A second order design procedure is documented step by step with calculation sheets and a worked out example to follow. Current high power engines are briefly described and a directory of companies and individuals who are active in Stirling engine development is included.

Mortimer, J. Alternative Engines for Tomorrow's Car. See IX.A.

Renner, R. A. Alternate Engines State of the Art Study. See IX.C.

Renner, R., and H. M. Siegel. Fuel Economy of Alternative Automotive Engines--Learning Curves and Projections. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790022, 16 pp.

This paper describes a distinct approach in making technological forecasts. From historical data, fuel economy learning curves have been constructed for alternatives such as the diesel, gas turbine, Stirling, stratified charge, and rotary engines. Assuming that evolutionary development will take place, projections of these learning curves are extended to the 1990 era. The investigation found that no engine is likely to exceed the fuel economy of the diesel in the next 10-15 years. However, serious questions are being raised regarding the feasibility of controlling nitrogen oxides and unregulated emissions in future diesel engines.

Richardson, R. W. Automotive Engines for the 1980's: Eaton's Worldwide Analysis of Future Automotive Power Plants. See IX.A.

Rosenqvist, K., T. Lia, and B. Goldwater. The Stirling Engine for the Automotive Application. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790329, 16 pp.

Both kinematic and free-piston Stirling engine technology is currently under development and, although the fundamentals are the same, each configuration demands unique engineering that is applied to the specific application. This paper discusses the current technology as it applies to the automotive application being addressed at United Stirling of Sweden and Mechanical Technology Incorporated in their respective Stirling engine fields.

Smithsonian Science Information Exchange, Inc. Alternative Fuels for Ground Vehicles. See II.B.

Tew, R. C., Jr., L. G. Thieme, and D. Miao. Initial Comparison of Single Cylinder Stirling Engine Computer Model Predictions With Test Results. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790327, 20 pp.

A Stirling engine digital computer model developed at NASA Lewis Research Center has been configured to predict the performance of the GPU-3 single-cylincer rhombic drive engine. Revisions to the basic equations and assumptions previously reported on are discussed. Initial comparisons of the model predictions with the early results of the Lewis Research Center GPU-3 tests are made.

Thieme, L. G., and R. C. Tew, Jr. Baseline Performance of the GPU-3 Stirling Engine. Technical Paper presented at the Highway Vehicle Systems Contractors Coordination Mtg., Sponsored by the U.S. Dept. of Energy, Dearborn, Mich., Oct. 17-20, 1978, 8 pp.

The NASA Lewis Research Center has converted a 10 horsepower single-cylinder rhombic-drive Stirling engine to a research configuration to obtain data for validation of Stirling computer simulations. The engine was originally built by General Motors Research Laboratories for the U.S. Army in 1965 as part of a 3 kW engine-generator set, designated the GPU-3 (Ground Power Unit). This report presents test results for a range of heater gas temperatures, mean compression-space pressures, and engine speeds with both helium and hydrogen as the working fluids. Also shown are initial data comparisons with the NASA-Lewis computer simulation predictions.

van Beukering, H. C. J. Stirling Engines for Passenger Cars: Modern Developments and Potential Future Applications. Power Plants and Future Fuels (A conference sponsored by the Combustion Engines Group and the Automobile Division of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 159-169.

A review is given of research work performed at the Philips Research Laboratories in the field of Stirling engine development. Specific reference is made to the current work on the Stirling engine as designed for cars. This is a potentially interesting application of Stirling engines because of their high efficiency, their good environmental compatibility, and their ability to utilize a variety of heat sources.

van Beukering, H. C. J., and H. Fokker. Present State-of-the-Art of the Philips Stirling Engine. 14 pp.

This paper deals with the progress in research, development, and engineering of the Stirling engine at Philips, which has lead to the present state-of-the-art. After a review of the performance and features of some selected types of engines built and projected at Philips in the last two decades, a survey is given of typical characteristics of engines that can be realized now and which are envisaged for a variety of applications, including the automotive field.

C. Brayton Cycle (turbine) Engine

Bjerklie, J. W., E. J. Cairns, C. W. Tobias, and D. G. Wilson. An Evaluation of Alternative Power Sources for Low-Emission Automobiles. See IX.B.

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Mining Machinery. See IX.A.

Dowdy, M., and A. Burke. Automotive Technology Projections. See IX.A.

Flanigan, E. E., and D. N. Nigro. Field Experience With the Detroit Diesel Allison 404/505 Industrial Gas Turbine Engines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790129, 28 pp.

Detroit Diesel Allison Division of General Motors Corporation has been conducting a field evaluation program on the 300 hp GT-404-3 and the 390 hp GT-505-3 Industrial Gas Turbine Engines over the time period from late 1974 until late 1977. This paper describes the overall program plan which involved installations in trucks, coaches, marine and industrial applications and the field experience which has been accumulated to date. Emphasis is placed on operator reaction, environmental effects, performance, and field-revealed problems. Two particular applications are explored in considerable detail: bulk hauling trucks with self unloading capabilities and the Greyhound inter-city coach operation with gas turbine power and automatic transmissions.

Huebner, G. J., Jr. Energy and Pollution vs Alternative Piston and Gas Turbine Powerplants. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790020, 16 pp.

The over-riding social importance of automotive fuel economy and power plant exhaust emissions is discussed in relation to proposed alternatives to the spark-ignition passenger car engine. Some engineering and use criteria for the selection of alternatives are proposed, and several alternative power plants are explored in their framework. Three gas

turbine types are discussed as alternatives, and a brief history of two-shaft turbines is presented. The influence of various automatic transmissions on passenger-car fuel economy and driveability is summarized. This paper concludes that automatic, continuously variable transmission functions can be achieved with a three-shaft turbine power plant with excellent fuel economy and at lower cost.

Jet Propulsion Laboratory. Should We Have a New Engine? An Automobile Power Systems Evaluation: v. II. Technical Reports. See IX.A.

Mercure, R. A. Some Design Considerations of Automotive Gas Turbines. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 26-March 2, 1979, SAE Technical Paper Series 790128, 12 pp.

An examination of some design considerations of gas turbine automobile engines is made including an overview of the unsolved problems. Emphasis is placed on the design and manufacturing aspects. Performance penalties due to size effects are discussed. The gains in cycle thermal efficiency with increasing peak temperatures are examined in view of these penalties. A cursory investigation of thermal efficiency is performed on a 75 hp and a 150 hp gas turbine. This was done considering both current and advanced design and manufacturing technology with regard to rotor clearances and blade thicknesses. Design and manufacturing limits used in defining the penalties in engines with advanced technology are qualified.

Mortimer, J. Alternative Engines for Tomorrow's Car. See IX.A.

Renner, R. A. Alternate Engines State of the Art Study. South Coast Technol., Inc., Santa Barbara, Calif., Contract No. DOT-HS-7-01790, November 1978, 78 pp.; NTIS PB-293 940.

Eleven different advanced automobile engine types were examined as to the possibilities for introduction prior to 1990. An assessment was made based on extensive literature survey and extrapolation of learning curves toward future values of fuel economy and emissions. Gas turbines and external combustion engines are unlikely to be in general use prior to 1990. Stratified charge engine, the advanced diesel, and internal combustion engines with variable displacement features were considered to be likely candidates for use prior to 1990. These engines were analyzed and learning curves were determined for fuel economy predictions with exhaust emission constraints.

Renner, R., and H. M. Siegel. Fuel Economy of Alternative Automotive Engines--Learning Curves and Projections. See IX.B.

Richardson, R. W. Automotive Engines for the 1980's: Eaton's Worldwide Analysis of Future Automotive Power Plants. See IX.A.

Rosenbaum, B. B. Closed Cycle Brayton Turbomachinery Research. Final Report for Contract No. N00014-76-C-0554, Mod. P00002, Line Item 0001AB (AA, AB, AC), Sept. 30, 1977, 13 pp.

This report summarizes and appraises the technical and managerial aspects of the closed cycle Brayton turbomachinery (CCBT) research effort sponsored by the ONR Power Program. Specifically, it considers the first year's CCBT contractual efforts at: (a) Westinghouse Astronuclear Laboratory, Contract No. N00014-76-C-0706 entitled "Compact Closed Cycle Brayton System Feasibility Study; and (b) United Technologies Research Center, Contract No. N00014-76-C-0542, "Lightweight Propulsion Systems for Advanced Naval Ship Application--System Studies." The report also mentions several related research efforts.

Shih, T., G. Smith, and G. Springer. Gaseous, Particulate, and Smoke Emissions from a Heavy Duty Automotive Gas Turbine Engine. Environmental Science & Technology, v. 13, No. 7, July 1979, pp. 855-859.

Gaseous, particulate, and smoke emissions were studied in the exhaust of a heavy duty automotive gas turbine engine. The effects of brake horsepower (bhp), gasifier rotor angular speed, overall mass air-fuel ratio, and combustor exit temperature were evaluated at engine loads ranging from 136 to 542 N·m and at constant output shaft angular speeds ranging from 1500 to 2700 rpm. The results were compared to emissions previously reported for a heavy duty spark ignition engine and a heavy duty compression ignition engine, both of which had platinum oxidation catalysts and EGR. The hydrocarbon emissions from the gas turbine engine were lower, while the NO_x and CO emissions were comparable to the emissions from the spark and the compression ignition engines. Under all test conditions, the amount of particulate matter emitted was less than 0.001 $g \cdot bhp^{-1} \cdot h^{-1}$, and the smoke opacity of the exhaust gas was less than 0.3 Bosch unit. The brake specific fuel consumption of the gas turbine engine was also measured and was 40-50% higher than the consumption of a heavy duty spark and a heavy duty compression ignition engine operating at corresponding conditions.

D. Rankine Cycle (steam) Engine

Bjerklie, J. W., E. J. Cairns, C. W. Tobias, and D. G. Wilson. An Evaluation of Alternative Power Sources for Low-Emission Automobiles. See IX.B.

Bristow, N. Trackless Transport for Men and Materials. U.S. Dept. of Energy, Technical Investigation No. 1-3, Contract No. FE/DSFMP-2, May 1978, 19 pp.

This draft report discusses some important aspects of the use of free steered vehicles for manriding and materials transport in underground coal mines. It highlights some of the advantages to be gained by using trackless vehicles and their limitations, and describes briefly current research and development work aimed at increasing the use of these vehicles underground. The report is presented to indicate the stage reached in the investigation after initial study of the subject and no conclusions or recommendations are made.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Mining Machinery. See IX.A.

Dowdy, M., and A. Burke. Automotive Technology Projections. See IX.A.

Gunderman, R. J. Underground Trials of a Diesel-Powered Face Haulage Vehicle. Jeffrey Mining Machinery Division, Columbus, Ohio, Final Technical Report, November 1979, 82 pp.

Two four-wheel drive articulated face haulage vehicles designed and fabricated under a previous government-sponsored program were fitted with permissible diesel engines. The vehicles were originally designed for both increased productivity and as test vehicles for steam engine power. The vehicles, with diesel engines installed, were evaluated under operating conditions in an underground coal mine. Results were favorable and demonstrate capabilities in very harsh steeply pitching coal seams.

Jet Propulsion Laboratory. Should We Have a New Engine? An Automobile Power Systems Evaluation: v. II. Technical Reports. (also v. I--Summary). See IX.A.

Mortimer, J. Alternative Engines for Tomorrow's Car. See IX.A.

Renner, R. A. Alternate Engines State of the Art Study. See IX.C.

Renner, R., and H. M. Siegel. Fuel Economy of Alternative Automotive Engines--Learning Curves and Projections. See IX.B.

E. Energy Storage and Hybrid Engines

Atlendorf, J. P. Electric and Hybrid Vehicle Power Train Development. Proceedings of the Fourth International Symposium on Automotive Propulsion Systems, April 18-22, 1977, U.S. Dept. of Energy, Rept. No. CONF-770430/1, UC-96, v. 2, February 1978, pp. 803-822.

The paper discusses research work conducted by Volkswagen during the past few years toward the conception, construction, and testing of electric and hybrid drive systems. In spite of their short range, electric vehicles are even today capable of handling transport functions otherwise performed by vehicles powered by internal combustion engines wherever the use of the former is demanded by low noise and emission requirements and wherever it is made possible by special operating conditions, such as in short-distance traffic. This function can be performed by Volkswagen's Electric Delivery Truck System. This system is ideally supplemented by the use of hybrid-drive vehicles which can be operated free of emissions in urban agglomerations and will even contribute toward reducing the general level of harmful emissions when running outside those centers. The paper details test results.

Bjerklie, J. W., E. J. Cairns, C. W. Tobias, and D. G. Wilson. An Evaluation of Alternative Power Sources for Low-Emission Automobiles. See IX.B.

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Burris, L., and P. A. Nelson. Advanced Batteries for Vehicle Propulsion. Presented at the Earthmoving Industry Conference, Central Illinois Section, Peoria, Ill., Apr. 10-12, 1978, SAE Preprint 780458, 12 pp.

This paper discusses the development of batteries for electric vehicles, the performance goals for the batteries, and the strategy being followed in the U.S. to promote commercialization of electric vehicles. Supported by the government, intensive development of several near-term and advanced rechargeable batteries that are projected to meet performance and cost requirements for electric vehicles is underway. Of the potential near-term batteries, lead-acid, iron-nickel oxide, and zinc-nickel oxide are the most promising for use in vehicles with limited range applications. Much better performance is expected from second generation batteries, which include lithium-aluminum/metal sulfides, zinc/chlorine, and sodium/sulfur batteries. Successful development of electric vehicles will help conserve the world's resource of petroleum by shifting the energy source to coal and nuclear.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Mining Machinery. See IX.A.

Chalpin, E. S., R. E. Anderson, J. J. Shore, J. L. Smith, D. M. Jassowski, and R. A. Hewitt. Research in Advanced Power Systems for Mining Health and Safety. See I.F.

Collie, M. J. (ed. by). Electric and Hybrid Vehicles. Noyes Data Corp., Park Ridge, N. J., 1979, 633 pp.

This publication is an assessment of electric vehicles, summarizing data on characteristics, costs, maintenance, and energy consumption gleaned from actual tests and from literature and trade. It includes a survey of electric bus operations in 19 foreign and domestic locales and a survey of 11 different types of cars and delivery vans in the U.S. Energy storage devices and power systems were analyzed as alternatives to current automobile propulsion systems.

Countryman, D. L. Diesel and Electric Power Applications for Underground Equipment. Presented at the International Off-Highway Mtg. and Exposition, MECCA, Milwaukee, Wis., Sept. 8-11, 1980, SAE Technical Paper Series 801002, 12 pp.

This paper gives an overall view, and outlines the pros and cons of diesel power versus electric power as used in underground rubber tired mining equipment. Emphasis is placed on the specific problems associated with the underground mining environment. The visualization of advantages and disadvantages of both power sources emphasize the need for both diesel and electric power underground. A revolutionary development in mobile electric cable handling is disclosed. This paper concerns itself only with hard rock mining (metallic) versus non-hard rock (non-metallic coal mines).

Davis, D. D. The Flywheel-Battery Hybrid Power System: A Concept to Improve Electric Vehicle Performance. Proceedings of the Fourth International Symposium on Automotive Propulsion Systems, Apr. 18-22, 1977. U.S. Dept. of Energy, Rept. No. CONF-770430/1, UC-96, v. 2, February 1978, pp. 864-876.

To make electric cars attractive to the driving public, their range must be maximized for urban driving and their performance improved. Both goals might be achieved by combining the lead-acid battery with a power booster--a fiber-composite flywheel replacing an equivalent weight of batteries. The possibility of this hybrid surfaced from a joint investigation of flywheel-battery power systems by Lawrence Livermore Laboratories and the AiResearch Manufacturing Company of California. Results of earlier investigations by these companies indicated that the flywheel addition has the

potential of extending the range of lead-acid powered electric vehicles by a factor of 1.8 and improving their acceleration, cruising speed, and hill-climbing ability to a point competitive with internal combustion vehicles. In this paper, they examine the benefits to be gained through the use of the flywheel in conjunction with improved and advanced batteries predicted for development over the next decade. In addition to the state-of-the-art lead-acid battery, the advanced lead-acid, nickel-zinc, and lithium-iron sulfide systems with 1980-85 development goals are examined as prime power sources for a flywheel-battery hybrid power system.

Dowdy, M., and A. Burke. Automotive Technology Projections. See IX.A.

Jet Propulsion Laboratory. Should We have a New Engine? An Automotive Power Systems Evaluation: v. II. Technical Reports (Also v. I--Summary). See IX.A.

Lund, T. J., and J. F. McCartney. Survey of Power Systems for Small Undersea Vehicles. Presented at the West Coast Meeting, Town and Country, San Diego, Calif., Aug. 7-10, 1978, SAE Preprint 780703, 11 pp.

The results of a survey of candidate power systems for small undersea vehicles are summarized. Power systems having capacity of 1 to 30 kW and endurance from 1 hour to 90 days are treated. Emphasis in this paper is given to electrical power systems. The performance of electrical power systems is compared in terms of overall weight and volume versus mission time with the performance of several candidate open cycle and closed cycle heat engines.

Mauri, G., G. P. Fetterman, Jr., and R. L. Ricci. Economic Comparison of Future Automotive Power Systems. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Technical Paper Series 780035, 8 pp.

This paper presents Exxon Enterprises Inc.'s approach to the economic evaluation of advanced automotive power systems. The paper derives and compares projected initial costs and operating costs for a subcompact car and a full size car powered by four different advanced power systems, i.e. an advanced spark ignition engine, a lightwieght diesel engine, a battery powered motor, and a diesel electric hybrid system. The operating economics are based on a detailed analysis of the power system energy consumption. A proprietary computer program was used to simulate vehicle operation on a specific driving cycle and thus provide suitable energy consumption estimates. The initial and operating costs of the vehicles also reflect the different size and weight of the power systems, as well as weight propagation effects on the rest of the vehicle. For a meaningful comparison basis, each vehicle power system is sized to achieve an equiva-

lent performance level (carrying capacity, acceleration capability, etc.), to the extent possible with motive components of vastly different characteristics.

Mortimer, J. Alternative Engines for Tomorrow's Car. See IX.A.

Murphy, J. N., and R. S. Fowkes. Advanced Power Systems for Underground Mining Vehicles. Presented at the Off-Highway Vehicle Meeting, Milwaukee, Wis., Sept. 13-16, 1976, SAE Preprint 760652, 8 pp.

A review of alternate power sources under consideration or development for underground vehicles is made, including (1) diesel (emission control and environmental monitoring), (2) steam engine, (3) flywheel, and (4) alternate battery supplies.

Renner, R. A. Alternate Engines State-of-the-Art Study. See IX.C.

Smithsonian Science Information Exchange, Inc. Alternative Fuels for Ground Vehicles. See II.B.

Sudworth, J. L., and G. W. J. Waldron. The Sodium/Sulphur Battery as a Power Source for Rail Traction. Power Plants and Future Fuels (A conference sponsored by the Combustion Engines Group and the Automobile Division of the Institution of Mechanical Engineers). The Inst. of Mech. Engrs., London, Jan. 21-22, 1975, pp. 143-149.

It is possible that a substantial proportion of British Railways main lines will become electrified over the next decade or two, and battery traction could be an important extension of this electrification policy. A new lightweight energy storage device, the sodium/sulphur cell, is being developed by British Railways specifically for traction purposes. The design of this cell, the battery configuration, and its use for specific applications are described.

Underhill, B. B. Performance Capability of Near-Term Electric and Hybrid Vehicles. Proceedings of the Fourth International Symposium on Automotive Propulsion Systems, Apr. 18-22, 1977. U.S. Dept. of Energy, Rept. No. CONF-770430/1, UC-96, v. 2, February 1978, pp. 969-977.

Analysis reveals the potential for energy conservation as electric vehicles (EV) encroach upon the internal combustion engine (ICE) vehicles market. The EV also offers the opportunity of shifting to an alternate source of

primary fuel (coal or nuclear) over the common vehicle fuel--petroleum. The article examines the advantages and disadvantages of the EV and the potential of a hybrid vehicle. Graphs comparing the economy and performance of the EV, ICE vehicle, and hybrid vehicle in terms of energy efficiency and economy, fuel costs, percent of total U.S. energy by use, acceleration characteristics, and range limits are included in the paper.

F. Hydrogen Engine

Adt, R. R. Jr., M. R. Swain, and J. M. Pappas. Hydrogen Engine Performance Analysis. Second Annual Report. Univ. of Miami, Miami, Fla., and Hawthorne Research and Testing, Inc., Coral Gables, Fla. Contract No. EC-77C03-1212, January 1980, 448 pp.

This document is the second annual report of the three-year projct dealing with the problems associated with the design and development of hydrogen-air breathing internal combustion engines for automotive applications. It commences with a review of operational performance and emissions characteristics of hydrogen-fueled engines, followed by a delineation of potential hydrogen engine configurations and evaluation of them. This review, delineation, and evaluation was conducted by the authors during the planning stages of the project. Following this background review is a reporting of the first and second years' project activities including descriptions of the test engine and its components, the test apparatus, experimental tcchniques, experiments performed, and the results obtained. Analyses of other hydrogen-engine project data are also presented and compared with the results of the present effort.

Billings, R. E. Survey of Hydrogen Energy Application Projects. See II.B.

Billings, R. E., and F. E. Lynch. History of Hydrogen-Fueled Internal Combustion Engines. Billings Energy Corp., 1973, Preprint 73001, 9 pp.

A survey of historical and current work with hydrogen fuel in internal combustion engines points the way to avoidance of the operating difficulties often encountered with this fuel. Hydrogen engines with proper carburetion and ignition systems are capable of remarkable efficiencies and negligible emissions without the use of complex auxiliary equipment but require more displacement than gasoline engines for equal power. Conventional engines may be converted to hydrogen fuel without significant loss of power through the use of water induction and near-stoiciometric mixtures for full throttle operation.

Billings, R. E., and F. E. Lynch. Performance and Nitric Oxide Control Parameters of the Hydrogen Engine. Billings Energy Corp., 1973, Preprint 73002, 10 pp.

The performance and nitric oxide emission characteristics of a 4-cycle engine at varying equivalence ratio are shown for hydrogen and for iso-octane under identical test conditions except for spark advance. Important results of earlier studies of hydrogen engines are discussed and the independent effects of exhaust recirculation, water induction and ignition timing on nitric oxide emission are reported for hydrogen operation at a fixed equivalence ratio.

Botha, W. J. Converting the Standard Internal Combustion Engine to Run on Hydrogen. National Inst. for Telecommunications Research. Report No. HC A02/MF A01, June 1979, 7 pp.

A 1,000 cc Mazda Bakkie was converted to run on bottled hydrogen using commercially available components. The engine was not modified but used in its standard form. The serious inlet manifold back-burn and back-firing problems were cured by recirculation of a portion of the inert exhaust gases. The result was a somewhat under powered, but driveable vehicle with a range of 30 km on one high pressure cylinder containing 0.52 kg of hydrogen. No attempt was made to solve the hydrogen storage problem or to determine engine wear, merely to "see if it will work."

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Buchner, H. Results of Hydride Research and Consequences for the Development of Hydride Vehicles. Proceedings of the Fourth International Symposium on Automotive Propulsion Systems, Apr. 18-22, 1977. U.S. Dept. of Energy, Rept. No. CONF-770430/1, UC-96, v. 2, February 1978, pp. 746-749.

From the results attained with the hydride-powered vehicles and hydride development at Daimler-Benz, it can be demonstrated that hydrogen storage in metal hydrides for virtually non-pollutive automotive propulsion systems has a number of system-specific advantages which, to some extent at least, make up for the relatively adverse weight proportions of the storage tank as compared to liquid hydrocarbons. Provided that suitable hydrides are chosen, the hydride tank assumes at least the following four functions at the same time: fuel supply, air-conditioning, water condensation, and storage of waste heat from the engine. The hydrogen powered vehicle equipped with an internal combustion engine and hydride storage system is thus extremely advantageous for the environment. Its range of operation varies between 200 km and 400 km. Although a hydrogen infrastructure comparable to the network of filling stations for liquid hydrocarbons does not exist, setting up a hydrogen supply system of any desired size, e.g. for municipal vehicle fleets, would be technically feasible within a very short time, using e.g. the steam reforming process of natural gas.

Cairelli, J. E., W. A. Tomazic, D. G. Evans, and J. L. Klann. Assessment of Alternative Power Sources for Mobile Mining Machinery. See IX.A.

Cole, R. B. The Performance of Hydrogen-Fueled Reciprocating Engines. Proceedings of the Fourth International Symposium on Automotive Propulsion Systems, Apr. 18-22, 1977. U.S. Dept. of Energy, Report No. CONF-770430/1, UC-96, v. 2, February 1978, pp. 739-740.

The thermodynamics and emissions performance of diverse experimental engines fueled with hydrogen are summarized and compared with theoretical (fuel/air cycle) analysis of such engines. Most of the experimental data

are from naturally-aspirated spark-ignition engines though several data sets are from fuel-injected engines. The data are found to be highly consistent with fuel/air-cycle analysis, and it is concluded that fuel/air-cycle analysis provides both: (i) an apt (if often neglected) baseline against which to compare both past and future engine performance data and also (ii) a suitable basis for describing the potential performance of hydrogen-fueled engines.

Cox, K. E., and K. D. Williamson, Jr. (ed.). Hydrogen: Its Technology and Implications. v. I. Production Technology. See II.B.

Cox, K. E., and K. D. Williamson, Jr. (ed.). Hydrogen: Its Technology and Implications. v. II. Transmission and Storage. See II.B.

Cox, K. E., and K. D. Williamson, Jr. (ed.). Hydrogen: Its Technology and Implications. v. IV. Utilization of Hydrogen. See II.B.

Cox, K. E., and K. D. Williamson, Jr. (ed.). Hydrogen: Its Technology and Implications. v. V. Implications of Hydrogen Energy. See II.B.

Diesel & Gas Turbine Progress. Hydrogen--A Fuel for Engines. See II.B.

Drexel, K. W., and M. Gutmann. Characteristics of a Single-Cylinder Hydrogen-Fueled I.C. Engine Using Various Mixture Formation Methods. Proceedings of the Fourth International Symposium on Automotive Propulsion Systems, Apr. 18-22, 1977. U.S. Dept. of Energy, Report No. CONF-770430/1, UC-96, v. 2, February 1978, pp. 741-745.

This paper surveys the research work on hydrogen engines at Daimler-Benz (Federal Republic of Germany). It is shown how the output of the engine depends on the mixture formation method used. Direct injection of hydrogen into the cylinder results in a gain in b.m.e.p. as compared with mixture formation in the intake pipe. The engine's operational parameters have been set to reach minimum fuel consumption and minimum emissions. This involves combined quality/quantity-control and a compression ratio of 7:1 to avoid knocking at stoichiometric air/fuel-ratios.

Escher, W. J. Hydrogen-Fueled Internal Combustion Engine, a Technical Survey of Contemporary U.S. Projects. Escher Technol. Assoc., St. Johns, Mich., September 1975, ETA Report PR-51, 110.

Under U.S. Energy Research & Development Administration sponsorship, as part of its continuing alternative automotive fuels program in the transportation energy conservation area, a special survey was carried out in 1974-75 of contemporary U.S. hydrogen-fueled internal combustion engine activities. Some 14 hydrogen engine research and demonstration project organizations were located and contacted in the course of this effort. In all, some 49 hydrogen engines of various types have been documented including fuels, research, small utility and automotive powerplants. Associated demonstration hydrogen-fueled vehicles numbered 15. The principal purpose of this report is to provide detailed technical information on hydrogen engine operational performance and emissions characteristics based on information gathered in the survey. Brief background and "overview" material is also included, as well as information to assist the reader desiring further follow-up.

Escher, W. J., and E. E. Ecklund. Recent Progress in the Hydrogen Engine. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760571, 16 pp.

Developments in the energy and environmental sectors have awakened interest in hydrogen-fueled internal combustion engines. Based on a 50-engine survey of recent U.S. research and demonstration activities, the technical status of hydrogen engines is summarized. A comparative hydrogen/conventional-fuel orientation is maintained in assessing basic fuel property, engine power and efficiency, emissions, and general operating characteristics. Key theoretical and experimental results, and correlations where evident, are noted. Engine problem areas and their solutions are discussed, accompanied by some thoughts toward future development possibilities and supporting research needs.

Foster, R. W., and W. J. Escher. Hydrogen-Fueled Railroad Motive Power Systems, a Feasibility Study. Escher Technol. Assoc., St. Johns, Mich., September 1976, ETA Report PR-70, 200 pp.

Under U.S. Energy Research & Development Administration sponsorship, and as part of its transportation energy conservation activity, a special assessment of prospects for railroad system use of hydrogen fuel was conducted in the summer of 1976. Based on contacts with railroad organizations and individuals in government, industry, and research organizations, the feasibility and desirability of converting conventional diesel-electric locomotives to hydrogen operation were evaluated. Such a step is shown to be technically feasible and would provide another alternative, in addition to hydrocarbon synthetic fuels and railway electrification, for moving U.S. railroad systems away from today's near total dependency on petroleum. Environmental benefits would also accrue. The study provides: (1) the overall rationale for developing hydrogen railroad motive power systems, (2) an assessment of technical feasibility, and (3) a nominal development and demonstration program plan.

Homan, H. S., P. C. T. deBoer, and W. J. McLean. The Effect of Fuel Injection on NO_x Emissions and Undesirable Combustion for Hydrogen-Fueled Piston Engines. Presented at the Internat. Fuels and Lubricants Meeting, Royal, Toronto, Nov. 13-16, 1978, SAE Technical Paper Series 780945, 20 pp.

Direct cylinder injection for hydrogen-fueled piston engines was studied experimentally with an ASTM-CFR engine. An injection scheme was devised for which the combustion occurs during the period of hydrogen injection so that little unburned hydrogen accumulates in the cylinder. This scheme should preclude flashback and preignition, and lowers the rate of cylinder pressure rise to acceptable levels. The potential of hydrogen as a low pollution fuel was investigated by comparing the NO_x emissions from the same engine operated on hydrogen and hydrocarbon fuel. NO_x emissions for hydrogen are very low provided the equivalence ratio is less than 0.5, and provided the hydrogen and air are well mixed. For equivalence ratios greater than 0.5, NO_x emissions for hydrogen fuel were higher than for hydrocarbon fuel. With hydrogen injection, indicated mean effective pressure was varied between 0.07 MPa and 0.78 MPa without intake air throttling. Indicated efficiencies higher than 40% were achieved for part-load equivalence ratios, near 0.3. The timing of hydrogen injection has a significant effect on NO_x emissions.

Hord, J. Is Hydrogen Safe? See II.B.

Houseman, J. (assigned to the National Aeronautics and Space Administration). Combustion Engine. U.S. Pat. 4,041,910, Aug. 16, 1977.

An arrangement for an internal combustion engine is provided in which one or more of the cylinders of the engine are used for generating hydrogen rich gases from hydrocarbon fuels, which gases are then mixed with air and injected into the remaining cylinders to be used as fuel. When heavy load conditions are encountered, hydrocarbon fuel may be mixed with the hydrogen rich gases and air and the mixture is then injected into the remaining cylinders as fuel.

Imarisio, G. The R & D Programme of the European Communities in the Field of Hydrogen: Progress and Results. Internat. J. of Hydrogen Energy, v. 4, No. 5, 1979, pp. 371-375.

The status of the R & D program on hydrogen production and utilization, implemented under cost sharing contracts, is reviewed. The program, started in July 1975, was at mid-term when this paper was prepared. This program covers the following topics: Production of hydrogen by thermochemical decomposition of water; production of hydrogen by electrolysis; uses and safety. The funds allocated for this 4-year program amount to 13 million European Units of Account (roughly 16 million US$). Their distribution among subtasks is given. The more important achievements of the program are schematically listed, and the expected further developments up to the end of the program are outlined.

Levi, J., and D. B. Kittelson. Further Studies With a Hydrogen Engine. Presented at the Cong. and Exposition, Cobo Hall, Detroit, Mich., Feb. 27-March 3, 1978, SAE Preprint 780233, 12 pp.

This paper describes the performance and emissions of a hydrogen-fueled, spark-ignited engine. An electronic control device, designed to provide the engine with a timed injection of the fuel, is shown to give high mean effective pressures and high efficiencies. The oxides of nitrogen from the exhaust gases have been analyzed and the mechanism for their formation is reviewed. The paper further describes an experiment with traces of hydrocarbons added to the hydrogen in an attempt to explain any additional phenomena that may be taking place during the combustion, such as "prompt NO" which is known to occur in hydrocarbon flames only. As it turns out, such additions have a negligible effect on the NO_x formation in the region investigated.

Lynch, F. E. Backfire Control Techniques for Hydrogen Fuel Internal Combustion Engines. Billings Energy Corp., 1974, Preprint 74001, 10 pp.

The commonly cited causes of backfires, such as hot spots caused by preignition, are inadequate to explain backfires under many circumstances. A viable hypothesis is formed through consideration of high-temperature particulate matter in the residual cylinder gases. Various methods for controlling backfires are surveyed from the viewpoint of thermal explosion theory. Some novel engine constructions, which are effective in suppressing backfires, are offered in support of a residual gas quenching technique.

Mackay, D. B. Automotive Hydride Tank Design. Conference Proceedings: v. III. 1st World Hydrogen Energy Conference. Univ. Miami, Coral Gables, Fla., 1976, pp. 7C-13 - 7C-23.

Automotive hydride tanks must be designed as both pressure vessels and heat exchangers. Little data are available pertaining to hydride heat transfer properties. Thus, limited precedence has been set for tank designs. This paper includes heat exchange data and results obtained from theoretical investigations and prototype testing at Billings Energy Research Corporation. Discussion of promising designs and directions for future activity are included. Novel tabular designs which avoid many previously-encountered difficulties are analyzed.

McCarty, R. D. Hydrogen: Its Technology and Implications. v. III. Hydrogen Properties. See II.B.

Mechanical Engineering. Closed-Cycle Hydrogen-Fueled Engine. November 1977, p. 56.

The article describes the operation of a closed-cycle hydrogen-fueled diesel engine. The proposed powerplant is fueled by a gaseous mixture of hydrogen and oxygen and an inert diluent such as argon. Since the closed-cycle engine can provide high-efficiency energy conversion with zero pollutants (oxides of nitrogen), it may be an environmentally sound prime mover for a central-station powerplant which is dependant on an intermittent supply such as solar energy.

Pennings, P. Sicherheitstechnische Aspekte Der Wasserstofftechnologie (Safety Engineering Aspects of Hydrogen Technology). Gas-Wasserfach, Gas Erdgas, v. 118, No. 6, 1977, pp. 230-235, available for consultation at the Twin Cities Research Center, Minneapolis, Minn.

Discussions which have recently been stimulated on a broad international basis concerning the suitability of hydrogen as an energy source and the related goal of replacing the fossil energy basis may justify an attempt at an early evaluation of such a hydrogen technology from the standpoint of safety engineering. Starting from the physical properties of hydrogen as an energy source, on the basis of which the essential risk factors of this gas can already be deduced, the main aspects of handling hydrogen are discussed from the standpoint of the safety engineering criteria which are relevant here. Discussions of hydrogen technology are divided into the subareas of production, storage, distribution, and use.

Renner, R. A. Alternate Engines State of the Art Study. See IX.C.

Rohy, D. A., and J. F. Nachman. Development of Lightweight Hydrides (Proceedings of the U.S. Department of Energy Automotive Technol. Development Contractor Coordination Meeting, Dearborn, Mich., Oct. 23-25, 1979). Contract No. DE-AC03-78CS52059, 10 pp.

Hydrogen is a potential automotive fuel in mid- and far-term projections. The use of hydrogen as an energy carrier is dependent on the solution of two primary technical problems: inexpensive production of hydrogen and lightweight storage of hydrogen. This program addresses the storage problem. Metal hydrides can store more hydrogen per unit volume than normal high pressure or cryogenic techniques. Practical considerations of the cost, size, weight, fueling, and storage period of a hydride system are reviewed.

Saga, K., and S. Furuhama. Performance and Emission Control in Stratified Charge Hydrogen Fuelled Engines. See IX.A.

Salzano, F. J., A. Mezzina, M. Beller, G. Strickland, and S. Srinivasan. Hydrogen Technology: An Overview. See II.B.

Simpson, F. B., J. H. Lofthouse, D. R. Swope, and R. L. Woolley. Modification Techniques and Performance Characteristics of Hydrogen-Powered IC Engines--State of the Art, 1975, Conference Proceedings: v. III. 1st World Hydrogen Energy Conference. Univ. Miami, Coral Gables, Fla., 1976, pp. 6C-75 - 6C-95.

Over the past quarter of a century there has been a great deal of work on modification of internal combustion (IC) engines to operate on hydrogen. However, comparisons are difficult because of large variation in designs, engine parameters, and test conditions. This paper presents, under a unifying format, a comparative summary of the recent work on hydrogen-powered engines. This includes material extracted from published reports and obtained by private communication. It is intended that this survey be of value to those beginning work in the field, and will provide some guidance in determining the direction of future research. Included are the following: engine parameters, modifications, operating conditions, running characteristics, performance, and related comments. More detailed discussion is included on the manpower and material costs associated with the modification of one of the engines listed.

Smithsonian Science Information Exchange, Inc. Hydrogen as a Source of Energy for Fuel Cells. See II.B.

Watson, H. C., and E. E. Milins. Some Problems and Benefits From the Hydrogen Fueled Spark Ignition Engine. SAE Preprint 789212, 7 pp.

Induction ignition or back-flashing associated with H_2 engines is shown to be caused by deposit ignition or residual gas ignition. Results from single cylinder engine tests show that operation free of induction ignition is possible at all mixtures and compression ratios up to knock and beyond. Test with a typical automotive engine gave thermal efficiencies on average nearly twice that for gasoline. Specific NO_x emissions were always less than with gasoline (1/200 to 1/3), but the maximum torque range could not be explored because pyrolised carbon from the lubricant caused induction which could not be eliminated.

Woolley, R. L., and G. J. Germane. Dynamic Tests of Hydrogen-Power IC Engines. Billings Energy Corp., Provo, Utah, 1976, Preprint 76002, 16 pp.

Two Analyses are performed to investigate the dynamic effect on hydrogen engine efficiency. A speed-governed, sawtooth, torque time cycle is proposed for use in checkout and calibration of computer controlled engine test cells. This cycle makes possible comparison of integrated steady-

state data with dynamic test results. Integration of available data indicates that a factor of 1.5 (50% improvement) is a valid number for estimation of hydrogen engine efficiency from a knowledge of gasoline efficiency. Vehicle driving dynamics for a transit vehicle are simulated for a simplified road cycle. An example calculation indicates that the efficiency penalty resulting from the addition of a 4,000 lb metal hydride tank is more than offset by efficiency benefits in the hydrogen engine. In this example, the energy savings with a heavier, hydrogen-powered transit vehicle was predicted to be nearly 30%.

Woolley, R. L., and D. L. Hendriksen. Water Induction in Hydrogen Powered IC Engines. Billings Energy Corp., Provo, Utah, 1976, Preprint 76004, 22 pp.

Addition of water to the hydrogen-air mixture in the intake manifold is an effective means of both suppressing the tendency to backflash and reducing the production of oxides of nitrogen. Tests are run on a Dodge 440 CID V8 engine having a compression ratio of 12 to 1. Dramatic reduction in oxides of nitrogen is observed as the water flow is increased, yet essentially no change is observed in either power or efficiency. Exhaust temperature, NO_x, and equivalence ratio is measured at each exhaust valve. It is found that a large cylinder to cylinder variation in NO_x production is caused by slight non-uniformity in mixing of the hydrogen-air streams. It is further shown that NO_x production is an exponential function of equivalence ratio, water to hydrogen mass ratio, and engine speed.

Woolley, R. L., and H. M. Simons. Hydrogen Storage in Vehicles--An Operational Comparison of Alternative Prototypes. Presented at the Fuels and Lubricants Meeting, St. Louis, Mo., June 7-10, 1976, SAE Preprint 760570, 9 pp.

Performance and operational characteristics of several prototype containers for storing hydrogen are described. A cryogenic vessel and three metal hydride containers of similar design but different size have been used in automotive service. Hydrogen release rates were controlled to match with engine demand. All prototypes were able to sustain a steady state flow rate sufficient for vehicle operation at a normal cruise speed. In order to illustrate the principle of hydride operation, a pressure-temperature history for recharge of a small portable hydride tank is given along with several discharge curves with and without heating.

X. DIESEL ENGINE RESEARCH

A. Industry

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Escher, W. J. Hydrogen-Fueled Internal Combustion Engine, a Technical Survey of Contemporary U.S. Projects. See IX.F.

French, C. C. J. Diesel Research and Development Techniques. Presented at the Diesel & Gas Engine Power Conference and Exhibit, Toronto, Ontario, Canada, Apr. 18-22, 1971, ASME Preprint 71-DGP-13, 10 pp.

With the very considerable increase in the use of turbocharging in recent years have come corresponding increases in the thermal and mechanical loads in diesel engines. Recently we have also been moving into an era of environmental control with a need to limit engine emissions--both gaseous and noise. The result has been a need for much closer study of engine operation and the paper describes a number of experimental techniques which have been developed at the Ricardo Laboratories and gives examples of their use.

French, C. C. J., and D. A. Pike. Diesel Engined, Light Duty Vehicles for an Emission Controlled Environment. See II.C.

Gunderman, R. J. Underground Trials of a Diesel-Powered Face Haulage Vehicle. See IX.D.

Hill, S. H., and J. L. Dodd. A Low NO_x Lightweight Car Diesel Engine. See IV.H.

The Institution of Mechanical Engineers. Power Plants and Future Fuels: M.A.N. Activities in Power Plants for the Future. See I.F.

Marzouk, M., and N. Watson. Some Problems in Diesel Engine Research With Special Reference to Computer Control and Data Acquisition. Proc. Inst. Mech. Engrs., v. 190 23/76, 1976, pp. 137-151.

A versatile computer-based testing and data acquisition facility developed to improve the speed and accuracy of engine research work is described.

The role of computer-aided technology is illustrated through the discussion of two quite separate problems. Fuel burning rates (heat release diagrams) are the most basic measurement of combustion, yet highly sophisticated equipment and techniques are required to obtain accurate rate diagrams. The problem is illustrated through the pressure diagrams from naturally aspirated and turbocharged diesel engines. Techniques developed for transducer mounting, choice of sampling interval, data-logging, processing, smoothing, etc. are presented. During transient conditions (e.g. sudden load changes) a turbocharged diesel engine moves through operating regimes not normally encountered in steady state operation. Although empirical models have been used to predict the transient response of these engines, only high-speed data-logging of many engine parameters during a transient will permit the development of more basic models. A fully instrumented turbocharged diesel engine has been run through a series of dynamic tests comprising load and speed demand changes, plus combinations of the two. The high-speed data logging system enabled basic data, such as fuel burning rates, to be obtained for each cycle during the transient.

Mining Magazine. Load Haul and Dump Vehicles--Moving into New Markets. March 1981, pp. 226-239.

For more than two decades, laud-haul-dump (LHD) machines have successfully carried out the arduous task of loading, carrying and dumping ore and rock in underground mines, especially in mines employing caving, stoping from ramp roads, open stoping, cut-and-fill, or room and pillar methods. LHD's have also achieved low operating costs and high productivity when loading from development ends or draw points and hauling to nearby ore and waste passes. In recent years LHD's have found new applications in types of mining where their use was at first difficult or even impossible. These include workings which are very narrow in width or height, in coal and gassy mines, and in places where ventilation quantities are limited. Features and standard ranges of the various types of electric and narrow width LHD's are provided.

Roessler, W. U. Diesel Engine Research and Development Status (Proceedings of the U.S. Dept. of Energy Automotive Technol. Development Contractor Coordination Meeting, Dearborn, Mich., Oct. 23-25, 1979). Contract No. EM-78-C=03-2184, 28 pp.

This paper presents a review and brief summarization of the fuel economy and exhaust emission characteristics of both production and experimental light-duty diesel engines and vehicles. In addition, the effects of emission control systems on fuel economy and emissions of currently regulated and unregulated species are briefly examined with particular emphasis on exhaust gas recirculation, water injection, trap oxidizers, and direct fuel injection. Other important parameters affecting fuel economy and emissions are combustion chamber and injection system design and operation, and modifications in fuel composition.

Savery, C. W., R. A. Matula, and T. Asmus. Progress in Diesel Odor Research. See III.A.4.

Smithsonian Science Information Exchange, Inc. Catalytic Converters. August 1977. See X.B.

Smithsonian Science Information Exchange, Inc. Catalytic Converters. August 1979. See X.B.

Smithsonian Science Information Exchange, Inc. Reduction of Pollution by Internal Combustion Engines. Washington, D.C., August 1977, SSIE Preprint GA04, 90 pp.

The report consists of a collection of individual research descriptions relating to reduction of pollution by internal combustion engines. Provides project title, names of the organization performing the research and the supporting organization, time period of the project, and a brief description of the project.

Smithsonian Science Information Exchange, Inc. Mine Atmosphere Conditions. Washington, D.C., August 1977, SSIE Preprint LA46, 200 pp.

The report consists of a collection of individual research descriptions relating to mine atmosphere conditions. Provides project title, names of the organization performing the research and the supporting organization, time period of the project, and a brief description of the project.

Smithsonian Science Information Exchange, Inc. Engine Exhaust in Mines. See VII.A.

Society of Automotive Engineers, Inc. Energy and the Automobile. July 1973, SAE Special Publications 383, 75 pp.

The report is a collection of 10 papers presented May 15, 1973, at a forum held in Detroit, Mich., as part of the 1973 National Automobile Engineering meeting. Papers relate to the direct and indirect factors affecting the supply and demand for energy to fuel automobiles.

Stang, J. H. Designing Adiabatic Engine Components. See I.B.3.

Trolinger, J. D., H. T. Bentley, A. E. Lennert, and R. E. Sowls. Application of Electro-Optical Techniques in Diesel Engine Research. Presented at the Automotive Eng. Cong., Detroit, Mich., Feb. 25-March 1, 1974, SAE Preprint 740125, 12 pp.

This paper presents preliminary results of studies of the feasibility of applying electro-optical diagnostic techniques to diesel engine research. A 2-cycle, 3-cyl, diesel engine was modified by installing quartz windows in the combustion chamber to provide optical access. Techniques investigated include photography, holography, laser resonance absorption spectroscopy, and laser velocimetry. Droplet formation, breakup, and combustion can be observed in the combustion chamber in three dimensions using holography. The same hologram can be used for particle sizing and flow visualization studies. Formation of certain hydrocarbons can be observed in real time with resonance absorption, using a tunable He-Ne laser. It has been established that laser velocimetry can give components of air velocity in the combustion chamber of a motored diesel engine. The techniques described are currently being developed for application to diesel engine research and to evaluation of a stratified charge spark ignition engine.

U. S. Dept. of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

Willis, E. A., and W. T. Wintucky. Diesel Emissions Control Technology Project Update. See X.B.

B. Government

Bristow, N. Trackless Transport for Men and Materials. See IX.D.

Elliott, M. A. Review of Bureau of Mines Work on Use of Diesel Engines Underground. BuMines RI 4381, September 1948, 28 pp.

The Bureau's work on the use of diesel engines underground was begun in 1937, soon after the development of high-speed automotive-type engines had reached an advanced stage in the United States. This investigation has continued since that time and has included studies both in the testing station and in the field. The results of work in the testing station up to the date of this report are summarized.

Escher, W. J. Hydrogen-Fueled Internal Combustion Engine, a Technical Survey of Contemporary U.S. Projects. See IX.F.

Gunderman, R. J. Underground Trials of a Diesel-Powered Face Haulage Vehicle. See IX.D.

Roessler, W. U. Diesel Engine Research and Development Status. See X.A.

Smithsonian Science Information Exchange, Inc. Catalytic Converters. Washington, D.C., August 1977, SSIE Preprint FB13, 80 pp.

The report consists of a collection of individual descriptions relating to catalytic converters research. Provides project title, names of the organization performing the research and the supporting organization, time period of the project and a brief description of the project.

Smithsonian Science Information Exchange, Inc. Catalytic Converters. Washington, D.C., August 1979, SSIE Preprint FB13-006, 200 pp.

The report consists of a collection of individual descriptions relating to catalytic converters research. Provides project title, names of the organization performing the research and the supporting organization, time period of the project, and a brief description of the project.

Smithsonian Science Information Exchange, Inc. Engines. Washington, D.C., June 1980, SSIE Preprint EQ05-316, 178 pp.

The report consists of a collection of individual research descriptions relating to various types of engines. Provides project title, names of the organization performing the research and the supporting organization, time period of the project, and a brief description of the project.

Smithsonian Science Information Exchange, Inc. Engine Exhaust in Mines. See VII.A.

Smithsonian Science Information Exchange, Inc. Mine Atmosphere Conditions. See X.A.

Smithsonian Science Information Exchange, Inc. Reduction of Pollution by Internal Combustion Engines. See X.A.

U.S. Dept. of Energy. Diesel Engine Research and Development Status and Needs. See III.A.2.

U.S. Environmental Protection Agency. Research Highlights 1978. EPA Preprint EPA 600/9-78-040, December 1978, pp. 54-57.

In view of the projected increase in diesels on American roadways, EPA embarked on a program in 1971 to evaluate the potential public health problems posed by diesel automobile exhaust products. This article describes some of EPA's research in this area, providing statements on preliminary results of completed studies and highlighting research underway during 1978.

U.S. Dept. of Health, Education, and Welfare. Program of the National Institute for Occupational Safety and Health. Program Plans by Program Area for FY-79. October 1978, DHEW (NIOSH) Pub. No. 79-103, 110 pp.

The responsibilities of the National Institute for Occupational Safety and Health (NIOSH) were established by the Federal Mine Safety and Health Act of 1977, the Occupational Safety and Health Act of 1970, and the Toxic Substances Control Act. One of NIOSH's major responsibilities under these Acts is the conduct of research programs necessary to ensure, insofar as possible, that no worker will suffer diminished health, reduced functional capacity, or decreased life expectancy as a result of his or her work experience. The Institute conducts its programs through in-house projects, grants, contracts, agreements with other Federal agencies, and through

special foreign currency arrangements with other countries. This document outlines NIOSH's in-house and extramural programs in a fashion convenient for internal planning and control by NIOSH management. It describes NIOSH research, manpower development, and technical service program plans as conceived at the beginning of FY 1979.

Willis, E. A., and W. T. Wintucky. Diesel Emissions Control Technology Project Update (Proceedings of the U.S. Dept. of Energy Automotive Technol. Development Contractor Coordination Meeting, Dearborn, Mich., Oct. 23-25, 1979). Interagency Agreement No. ED-77-A-31-1040, 10 pp.

For several years, the NASA Lewis Research Center (LeRC) has been working in support of ERDA and DOE funded automotive heat engine research programs. These support efforts have primarily been related to Stirling and Gas Turbine engines. With the increasing usage of diesel engines in automobiles and concern for environmental aspects of their unregulated emissions, the DOE has recently established a support project on diesel emission control at LeRC. The objectives of this effort are to: (1) contribute to a technology base for an independent DOE assessment of LDV diesel environmental acceptability, (2) to provide particulate filter samples for chemical characterization by others, and (3) to contribute technology and data to enhance industry development of advanced LDV diesels meeting 1983 and potential future standards. This paper presents the status and results to date of one of three tasks (namely in-house) in the LeRC diesel engine project. To date, a highly instrumented single-cylinder diesel engine research test facility is operational. Baseline performance and emissions testing have been completed on an AVL 521 single cylinder engine. Tests were performed for a number of injection timings, inlet air temperatures, and simulated turbocharged inlet pressure conditions over a wide range of engine operation conditions. Particulate emissions were calculated on the basis of smoke using a smoke correlation.