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**Proceedings of the Symposium
on the Use of Diesel-Powered Equipment
in Underground Mining,
Pittsburgh, Pa., January 30-31, 1973**

Compiled by Bruce F. Grant and Dorothy F. Friedman
Research Liaison—Technical Support, Washington, D.C.



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PROCEEDINGS OF THE SYMPOSIUM ON THE USE OF DIESEL-POWERED
EQUIPMENT IN UNDERGROUND MINING, PITTSBURGH, PA.,
JANUARY 30-31, 1973

Compiled by

Bruce F. Grant¹ and Dorothy F. Friedman²

INTRODUCTION

A symposium was held on January 30 and 31, 1973, at Pittsburgh, Pa., to review the state-of-the-art in designing and utilizing diesel-powered equipment in underground mining. The Health and Safety Activity of the Bureau of Mines sponsored the symposium with major assistance from the following four participating organizations:

The American Mining Congress
J. Allen Overton, President

The United Mine Workers of America
Arnold R. Miller, President

The National Independent Coal Operator's
Association
Cloyd D. McDowell, President

The Bituminous Coal Operators' Association, Inc.
Guy Farmer, President

Seventeen papers were presented during four half-day sessions devoted to the general subjects of the diesel engine, the place of the diesel in underground mining, health protection using diesels underground, and maintaining safety of diesels underground. Eleven of the speakers were from industrial organizations here and abroad; one represented the Provincial Government of Nova Scotia; two were with the Department of Health, Education, and Welfare; and three reported on Bureau of Mines work related to diesels.

The papers are reproduced in this volume in the order of their presentation. Questions from the audience and the replies from the authors also are included.

The Bureau wishes to thank each author and his organization for his contribution to the symposium.

¹Chairman of the symposium.

²Secretary.

WELCOMING REMARKS

by

Dr. Earl T. Hayes¹

It is my pleasure to welcome each of you to this symposium. We in the Bureau of Mines believe that the presentations made during the next 2 days are significant to the mining industry, to miners working underground, and to the Bureau. The common concern we share at this event is to examine the potential of diesel power in underground mining--both coal and noncoal. We have called upon experts from here and abroad to shed light on that subject through the four sessions, starting with the characteristics of the diesel engine itself and the advances that have been made in engine design and performance; then learning from case histories of actual mining operations using diesels; looking at the health effects related to diesel use, and at some of the protective measures taken to safeguard miners working with diesels; and finally, the experience of Sweden, Britain, and Canada with diesel use, particularly in their coal mines. We are fortunate to have Dr. Jorgensen, Mr. Gilbert, Mr. Zorychta, and Mr. Hews from these countries appearing on our program. We thought you would have heard enough about coal mine equipment and transportation for 1 day, so tonight we have scheduled an excellent speaker, Dr. Robert Kupperman of the Office of Emergency Preparedness, Executive Office of the President, to tell you about the country's options for dealing with the "energy crisis," and to give some ideas about the outlook for coal in helping to forestall an energy shortage.

It is the growing interest in the use of diesel-powered equipment in underground coal mining that brought about this symposium. U.S. coal operators, coal miners, and the Federal Bureau of Mines have not yet had an opportunity to gain practical experience with diesels. In carrying out the Bureau's responsibilities under the Federal Coal Mine Health and Safety Act of 1969, which requires us to investigate safer sources of power, we have started to develop new and revised standards under which diesel-powered equipment can be made permissible for, and used in, the Nation's coal mines.

In working with coal mine management, labor representatives, and manufacturers of coal mine equipment, it became apparent that we all needed more technical information on which to base our individual decisionmaking. Thus, this symposium was conceived as a means of broadening our information base.

To all who helped in developing the symposium program, and who helped in securing the panel of high-caliber speakers we are to hear, we extend our personal, as well as official, appreciation.

Proceedings of the next 2 days are to be published in time as a Bureau of Mines Information Circular for public distribution. We will include your

¹Chief scientist, Bureau of Mines, Washington, D.C.

comments and discussions of each paper. As you can see, we have 17 presentations in the 4 sessions, and floor discussion time will therefore be limited. Consequently, we will accept longer prepared discussions relevant to a paper for inclusion in the final publication. It is our hope that these proceedings will have lasting reference value, as well as assist all of us in our near-term decisionmaking about the safe role that we believe diesel power can play in underground coal mining.

The time frame in which we have arranged this program has placed extreme pressure on each of our speakers in preparing his presentation, and on the organizations that have allowed them time to participate. We of the Bureau are grateful for their efforts and for the fine cooperation we have received from their organizations.

At this point, I am going to ask the Bureau of Mines Deputy Director for Health and Safety, Mr. Donald Schlick, to give you some further indications of the kind of advances in safety and efficiency that we believe modern diesel technology represents for underground coal mines in this country. Recognizing that much remains to be done to transfer diesel technology on a wide scale to deep mining for coal, we nevertheless view this symposium as a valuable guide for all concerned as to where the state-of-the-art stands today. So, for a summary of our purpose and goals, here is Mr. Schlick.

PURPOSE AND GOALS

by

Donald P. Schlick¹

As Dr. Hayes told you, I do want to discuss with you why I am convinced--after years of working underground, coupled with the intensive analysis in my present job of the accidents involving electrical equipment--that there are applications where diesel equipment can be safer for the miner. I think the applications where diesels can improve coal mine safety most effectively are as powers for haulage equipment, locomotives, rubber-tired scoop trams, shuttle cars, men and equipment carriers, and cleanup equipment.

We in the Bureau of Mines are fully aware of the traditional opposition to the use of diesel-powered equipment in underground coal mines. However, we believe that advances in mining technology, with attendant stringent safety regulations and work procedures, have virtually negated the validity of opposition argument. We, therefore, feel that the next giant step to be taken toward providing the coal miner with the most healthy and safe working environment possible must be that of allowing and promoting the use of diesel equipment in underground coal mines.

The most immediate advantage, in terms of both short- and long-range benefits, to be gained is the potential for a significant reduction in underground fires caused by electrical malfunctions. The obvious approach here is simply the elimination of a large number of electrical cables and trolley wires. Diesel locomotives in Blacksville No. 1 coal mine, Monongalia County, W. Va., would have averted the tragedy that resulted in the death of nine men in 1972.

But what about the atmospheric contaminants inherent in the exhaust as byproducts of diesel combustion? The increased amount of air now required in the mines by Federal regulations and the new safety equipment requirements for diesels to reduce exhaust contaminants will eliminate the problem of diesel exhaust accumulation and regeneration; there is really no other valid reason for objection to the use of diesel equipment in underground coal mines.

We must not forget though that we are talking about a very basic change in the methodology of underground mining. Far more is involved than implementing a new haulage or roof control concept. A new way of thinking on everyone's part may be a necessity. Therefore, the Bureau feels that it must move forcefully, utilizing the power and resources of the Federal Government in order to lead the way in this activity. We have had meetings and consultations with the mining industry and the manufacturers of diesel equipment. We have produced what we believe is a set of regulations approaching our final needs in the area of mine safety with diesels, and we hope to promulgate these regulations, with modifications if necessary, in the near future.

¹Deputy Director--Health and Safety, Bureau of Mines, Washington, D.C.

It is the Bureau's strong desire that diesel power will eventually replace electric power in underground mining because, as I have previously stated, the inherent dangers involved in diesel-powered equipment can now be eliminated, thereby permitting its use underground with less danger than similarly operated electrical equipment. There were 31 fires occurring in underground coal mines in 1970, 11 in 1971, and 16 in 1972. In my judgment these fluctuating totals point very definitely to a need for basic changes in power sources because we can trace, in most of those instances, the initiating cause to electrical power.

Bureau investigations of fatalities, mine fires, and explosions have, in too many instances, led to the discovery of the electrical power distribution system as the problem source or at least an accomplice to negligence. Therefore, it is not inconceivable that future regulations and standards will be so prescribed as to more readily allow permissible diesels underground while practically eliminating the need for a large power distribution system throughout the mine.

To realize these advantages, we in the Bureau must do several things in order to give you in the coal industry an opportunity to make a choice--as mine operators or as labor representatives--between diesel and electric power.

As Dr. Hayes said, the Federal Coal Mine Health and Safety Act of 1969 does require the Secretary of the Interior to "develop new and improved underground equipment and other sources of power for such equipment which will provide greater safety." It instructs him to initiate studies and investigations to further upgrade present standards and to develop and promptly promulgate new and improved standards that will provide increased protection for the miners including improved underground equipment and other sources of power for such equipment.

However, at no point does the Act include any but electric power in its definition of permissible equipment, and our present standards for approving diesel engine assemblies for gassy mines (Schedules 31 and 36) specifically exclude coal mines.

So we in the Bureau have to rewrite our standards for approving new diesel equipment for permissibility in coal mines and develop and amend standards in Part 75 to set the conditions for their use in coal mines. This is not as simple as it might superficially appear. The Act requires us to expand our standards for permissibility to include for all underground coal mining equipment, not only the prevention of fires and explosions ("flameproofing" as our British counterparts so aptly term it), but also to prevent other accidents arising from the operation of the equipment. In other words, we must address ourselves to insuring that all equipment, whether diesel or electric, is as safely designed and engineered as present technology permits.

Consequently, we now have under development the following three "packages" of new or revised standards for approving new equipment:

1. General requirements for prevention of industrial-type hazards or mechanical safeguards for all types of equipment, electric or diesel,
2. revision of requirements for flameproofing and safety of diesel power systems (Schedules 31 and 36), and
3. revision of requirements for flameproofing and safety of electrical power systems (Schedule 2G).

Completion of the first two packages will give us a basis for approving diesels and permissible equipment for coal mines.

At the same time, the Bureau is working intensively to develop standards for safely using diesels underground. The most critical factors are the ventilation and maintenance requirements. Although a permissible diesel locomotive or shuttle car does not have the hazards associated with trolley wires, batteries, or electric cable reels, the diesel emissions are toxic unless diluted to safe levels. Particulates in smoke can affect the respirable dust concentrations. Diesel fuel is a potential hazard. These are controllable hazards as attested by the history of diesel use in underground mining.

This brings me to this symposium and the reason we are here today and tomorrow. We found in discussions of standards needed for diesel equipment, with those of you in the coal industry who will buy, use, and work with diesels and in internal Bureau discussions, that we all need a better understanding of the diesel, its place in underground mining, and the health protection, safety, and engineering aspects peculiar to diesel equipment.

When it was first suggested to us that a state-of-the-art technical symposium on diesels underground would be in order, we quickly agreed. In fact, we wish we had thought of it first.

I have gone over our plans and thinking on the development of standards at this time only for your information and as the background reason for this symposium at this time. Although we did distribute a tentative draft of standards last fall, that draft was intended only as a starting point for working with you to arrive at the kind of standards that will meet our goals of safety and health protection in a practical and realistic way. Those standards are not the subject of this symposium. Instead, we of the Bureau are here, as you are, to learn from this distinguished group of speakers.

Because I do not see it covered in the program, I want to briefly list the following "homework" and research projects bearing on our subject that the Bureau has carried out or has underway:

1. Extensive studies of diesel engine characteristics--particularly with respect to emissions and methods for reducing emissions--at the Approval and

Testing Diesel Laboratory and through research at the Bureau's Fuels Combustion Laboratory at the Bartlesville Energy Research Center.

2. Evaluation of portable detectors to measure concentrations of the toxic gases in diesel emissions.

3. Search for sensor and alarm systems to warn equipment operators of dangerous concentration of toxicants. The sensors must be rugged and reliable under mine conditions.

4. Development of surface-recording mine atmosphere monitoring and communication systems with a system installed for demonstration at the Bruceton Experimental Mine.

5. Studies of the ignition temperatures of coal dusts and the design of joints and arrestors to prevent flame propagation.

6. Ventilation and industrial hygiene surveys in mines using diesel equipment.

7. Cooperative research agreement with the Martin County Coal Corp. to measure duty cycles of haulage units and to test research-developed instruments or devices in an operating mine.

8. A research project using mathematical techniques to evaluate the relative hazard potentials of shuttle car power sources.

9. An industrial engineering hazard analysis of face equipment.

10. Research on control standardization for various types of underground equipment.

We have set a tight timetable for such a comprehensive program, and certainly its success will depend in great measure on a cooperative effort among the Bureau of Mines, State enforcement agencies, representatives of the workers, mine operators, and manufacturers of mining equipment.

Through open and thorough public meetings we will be able to concentrate all of the existing expertise and come to a mutual understanding among all those interested in the furtherance of mine health and safety concerning the use of diesel power.

I thank you all for coming to our symposium.

MR. GRANT: We would like to get started now with the technical program. At this time we want to turn the session over to William N. Poundstone, Consolidation Coal Co., and Benjamin L. Hunton, Bureau of Mines, who are co-chairmen for the session and their speakers.

MR. POUNDSTONE: The first paper on our program this morning is entitled "Diesel Engine Design, Performance, and Emission Characteristics." Our speaker is Dr. John H. Johnson, who is Associate Professor in the Department of Mechanical Engineering at Michigan Technological University.

Dr. Johnson was born in Wisconsin and received his B.S., M.S., and Ph.D. in Mechanical Engineering from the University of Wisconsin. His experience includes work at the U.S. Army Tank Automotive Center, Advanced Power Package Section, and 4 years with the International Harvester Company.

SESSION I--THE DIESEL ENGINE

DIESEL ENGINE DESIGN, PERFORMANCE, AND EMISSION CHARACTERISTICS

by

John H. Johnson¹

SUMMARY

The application of diesel engines to underground mines is reviewed from the aspect of clarifying the system (mine) under consideration in the overall symposium as contrasted to the system (diesel engine) under consideration in this paper. A schematic diagram illustrating the mine ventilation system, conveyor, and a diesel powered shuttle car is used to illustrate the various systems. A general review of the overall diesel engine design, performance, and emission characteristics as influenced by regulations and various market developments in the past 5 years and in the future is discussed. The paper is subdivided into the three areas of design, performance, and emission characteristics. The overall objective of the paper is to develop concepts and define terms relative to diesel engine characteristics.

In order to develop an understanding of the diesel design characteristics, a conventional spark-ignition engine is used as a means to contrast with the basic diesel combustion system. The concepts of the prechamber diesel and its combustion system subcomponents of injector, prechamber, main chamber, heat plug, and high pressure fuel pump are discussed. Later, it is compared and contrasted with direct-injection engine combustion systems. The concept of turbocharging is introduced in a general manner, and turbocharged engines are contrasted to naturally-aspirated engines. The addition of an aftercooler to turbocharged engines is illustrated in schematic form, and its advantages are briefly outlined. The concept of two-cycle and four-cycle engines is developed and outlined in schematic form. A cross sectional view of a two-cycle direct-injection engine is illustrated showing the roots blower which is necessary for proper scavenging of the engine. The difference between a water- and an air-cooled engine is shown by several cylinder and complete engine cross sectional views. Lastly, a summary table illustrating the various engineering performance factors is presented with the conclusion that these factors are used in the basic engineering process of developing engines for various diesel engine applications. These factors vary in relative importance between different applications.

In order to develop the diesel engine performance concepts, an engine schematic is used to illustrate the engine as a system that uses fuel and air and produces brake power output and various exhaust emissions. The concept of

¹Associate Professor, Department of Mechanical Engineering--Engineering Mechanics, Michigan Technological University, Houghton, Mich.

exhaust emissions measured in concentrations of ppm is introduced. The basic measurements required to define the emission concentration, fuel rate, air rate, and brake power-engine speed characteristics of the engine are developed.

The diesel engine emission characteristics are developed from the viewpoint of showing what exhaust emission products are produced when 15 pounds of air and 1 pound of fuel react in a combustion process. First, the products of perfect combustion are illustrated, that is, water (H_2O), carbon dioxide (CO_2), nitrogen (N_2), and oxygen (O_2). This is then followed by defining the additional exhaust emissions that result from imperfect fuel and combustion, that is, carbon monoxide (CO), hydrocarbons (HC's), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon (smoke). The method of quantitizing emissions in terms of rates (grams/hour) is developed. The use of a 13-mode cycle to quantitize the average HC, NO_2 , and CO emissions over the engine-speed and brake-power operating range of the engine is illustrated. The general range of diesel emissions in units of concentrations and grams/bhp-hr is shown along with the general range of both spark-ignition and diesel-engine emissions on the 13-mode cycle.

The basic method of measuring exhaust smoke by measuring the exhaust opacity is developed. The Federal Smoke Cycle is shown, and the results of several smoke cycle tests are illustrated.

The technical fact that sulfur dioxide emissions are a function of the percent of sulfur in the fuel is further illustrated by calculations showing the concentrations resulting from various levels of sulfur in the fuel.

The effect of injector sac volume of hydrocarbons is shown. Data illustrating the effect of injection timing on NO emissions are also shown. These data illustrate the effect of several basic design variables on diesel emissions.

INTRODUCTION

In 1892, Rudolf Diesel planned a new type of engine that was to be capable of burning coal dust. It was well known at that time that rapid compression of air to a high pressure raised its temperature to such a point that a fuel, if delivered into the combustion chamber, would spontaneously ignite without depending on a spark to initiate combustion. Diesel soon found that coal dust was an unsatisfactory fuel and liquid fuels were necessary. The diesel engine became over the past 80 years, the highly developed engine which is used extensively today in heavy-duty over-the-highway trucks, construction equipment, farm equipment, and railroad locomotives, as well as for underground and in surface mining operations. Because the diesel engine has been in an expanding competitive market from both a performance and cost standpoint, it has seen extensive development during the past 5 years. These factors will continue in the next 5 to 10 years and the additional factors of the 1973 and 1975 California Gaseous Emission Standards for new over-the-highway diesel-powered heavy-duty vehicles and the 1974 Federal smoke and gaseous emission

standards (5)² (same as 1973 California Standards) will tend to develop the technology to make the diesel more acceptable for mining applications. It is therefore appropriate that the state-of-the-art of diesel technology be examined since the diesel offers many advantages as a mobile vehicle powerplant.

What are some of the outstanding features of the diesel as a powerplant? First, since the vehicle carries the energy supply, the vehicle is completely mobile with its inherent capability to maneuver about. Second, the diesel engine offers the highest thermal efficiency of any powerplant that is presently technologically feasible for mobile vehicles. This factor provides for excellent utilization of energy in the context of the present so-called "energy crisis." In addition, it offers the potential for low concentrations of exhaust emissions by proper design of the engine, vehicle, and mine ventilation system. One might ask the question of whether the diesel has any problems. Traditionally, it has been considered smokey, noisy, and odorous. It is my opinion that these problems can be eliminated by careful development of the engine's noise and exhaust emission characteristics by the engine manufacturer and development of the engine installation by the vehicle builder.

The general approach to this paper will be to discuss the three elements of the diesel as outlined in the title. First, the various designs of engines are outlined so that a basic understanding of what a diesel engine is all about is developed. Second, engine performance is explained in terms of how brake power and speed characteristics of the engine are defined. Finally, the various emissions ejected by diesels are defined and characterized, and the emission levels from modern engines are presented. The main thrust of the paper is to develop and define terminology and concepts used in diesel design, performance, and emissions work. These characteristics will be related largely from data available in truck type applications. Studying the intensive technology development of trucking applications has helped make the diesel more acceptable for underground mining applications. Although most of the data are developed from this approach, the fundamentals are perfectly general and applicable to diesels used in all mining operations.

It is appropriate that a basic understanding of the data presented in this paper be developed so that no confusion will arise with levels of pollutants presented in other papers. Figure 1 shows in schematic form the mine system and environment under consideration in this symposium and the diesel engine characteristics which will be presented in this paper. It should be noted that the emissions levels from the engine will be undiluted engine exhaust levels with no external control devices on the engine.

²Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

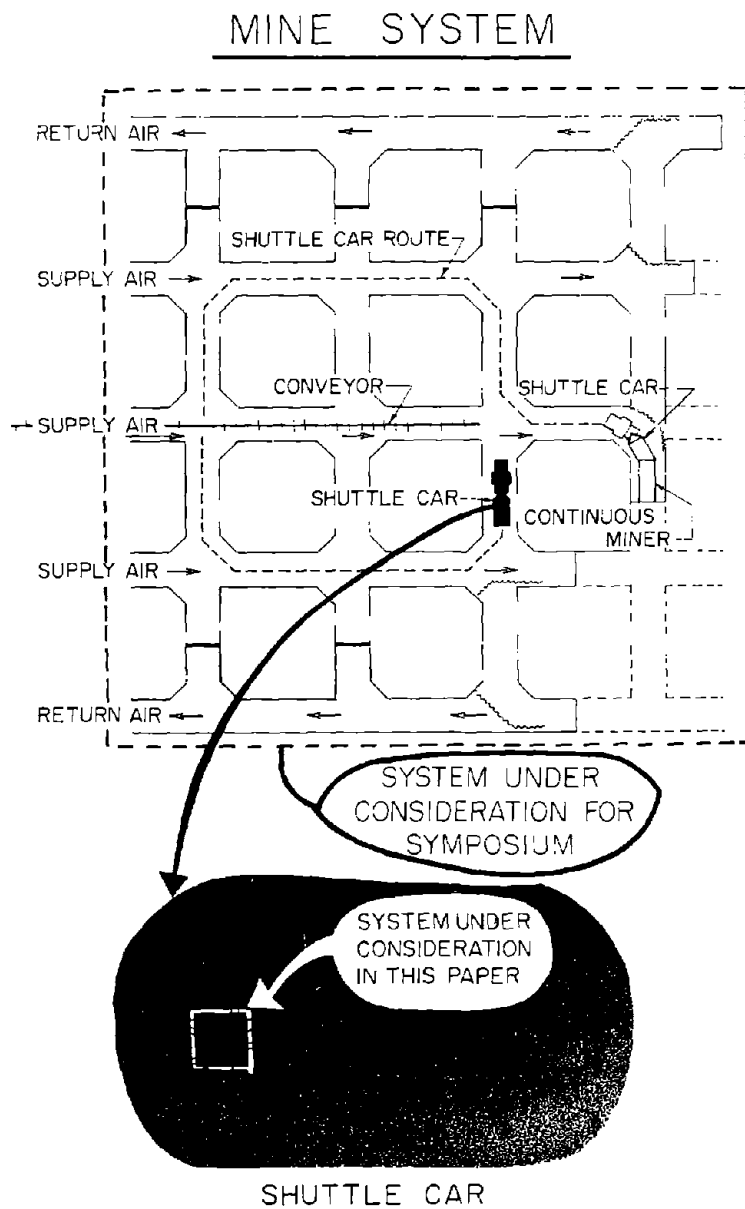


FIGURE 1. - Schematic of mine system and diesel engine-shuttle car system.

injected into the air, and combustion occurs by self-ignition of the fuel without the aid of any device. The output power of the diesel is controlled by the quantity of fuel injected into the cylinder.

Basic Combustion Systems

Two basic diesel engine combustion systems are used which are usually referred to as the prechamber and the direct-injection engines. Figure 2 shows in schematic form the prechamber combustion system. The high pressure

DESIGN CHARACTERISTICS

Spark-Ignition Engines Contrasted to Diesels

In order to understand the basic aspects of the diesel engine, it is useful to contrast its general operation with that of a conventional spark-ignition (SI) engine. The SI engine draws into the cylinder an air-fuel mixture. After compression of this mixture to higher pressures and temperatures, the mixture is ignited by a spark plug. The ratio of the air to fuel (A/F) in the SI engine must be approximately between 12 and 18 pound-mass (lbm) of air/lbm of fuel. A carburetor is the usual means for obtaining this A/F ratio. In order to control the output power of a gasoline engine, the carburetor contains a throttle plate which restricts the amount of mixture entering the cylinder.

The diesel engine is completely opposite in that it always inducts air alone and the air is not restricted by a throttle. After compression of the air in the cylinder to higher pressure and temperature, high-pressure fuel is

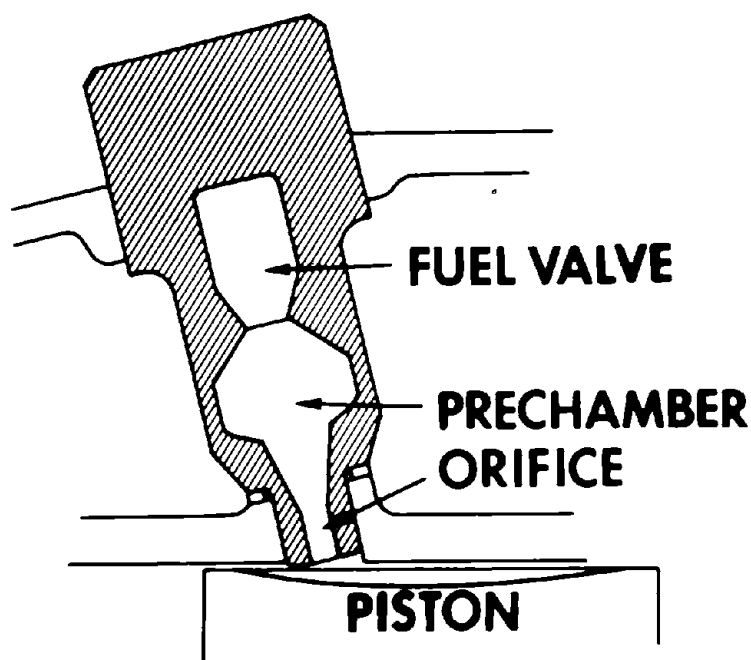


FIGURE 2. - Prechamber diesel combustion system.

fuel (4,000 to 8,000 pound-force per square inch (lbf/in^2) depending on the design and operating mode of the engine) is injected through one or two orifices directly into the prechamber (approximately 28 percent of the total volume when the piston is at the top of stroke). Self-ignition of the fuel takes place in the prechamber and expels the rich air-fuel mixture into the main chamber where further vaporization, mixing, and combustion of the fuel and air occurs. The piston usually contains a heat plug which is a special alloy that operates at a high temperature to assist in the vaporization and mixing process.

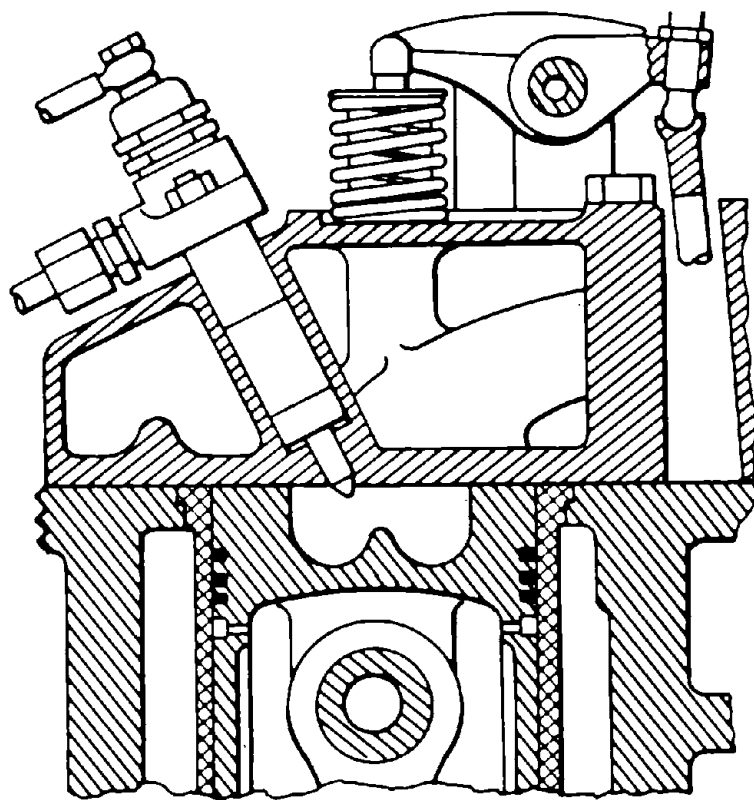


FIGURE 3. - Direct-injection diesel combustion system.

Figure 3 shows a cross section of a direct-injection combustion system. In the direct-injection engine, the fuel is injected directly into the main chamber through four to eight orifices that are in the range of 0.006 to 0.012 inch in diameter. The high-pressure fuel (5,000 to 20,000 lbf/in^2 depending on the design and operating mode of the engine) is injected into the cylinder and mixed with the air. Since the direct-injection engine does not basically use a portion of the chemical energy in the fuel to assist in the mixing and vaporization process (as does the prechamber), it is necessary to design the intake air ports so as to create a swirling air motion.

This air motion plus the higher fuel-injection pressures provides sufficient mixing and vaporization assist to make the direct-injection engine a feasible concept. Engineers also have found the need to develop a combustion chamber in the piston in order to provide a space to carry out these complex processes.

Engines of the prechamber and direct-injection type that draw ambient air into the cylinder of the engine are referred to as "naturally-aspirated" engines. In the next several paragraphs, several other design concepts will be described. These provide additional power output from a given engine displacement.

Turbocharging and Aftercooling

Diesel engines can be designed and developed to increased power out of the same displacement engines by the addition of a turbocharger (free-wheeling rotating turbine and compressor). This approach is shown schematically in figure 4. Air is drawn into the compressor at ambient conditions, and its temperature and pressure are increased across the compressor. This basically results in an air density increase across the compressor, and hence, each time the engine draws in a charge of air, additional mass is present over that of a naturally-aspirated engine. It is for this basic reason that additional fuel

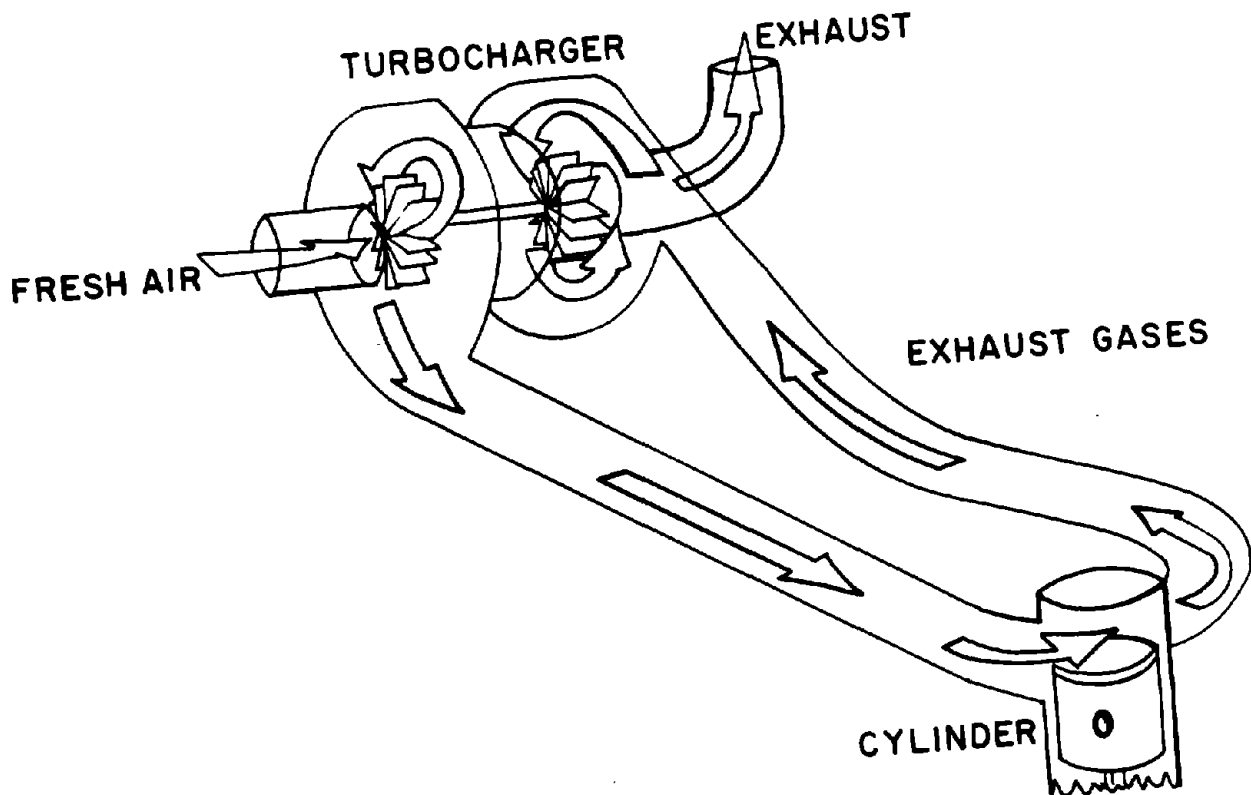


FIGURE 4. - Schematic diagram illustrating turbocharging concept.

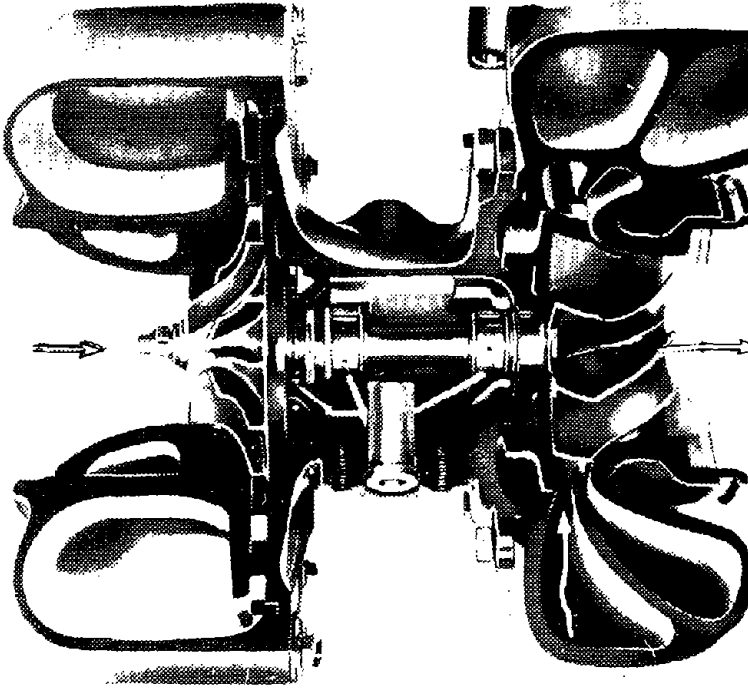


FIGURE 5. - Cross section of a turbocharger showing the rotating compressor (right side) and turbine (left side).

AFTERCOOLER

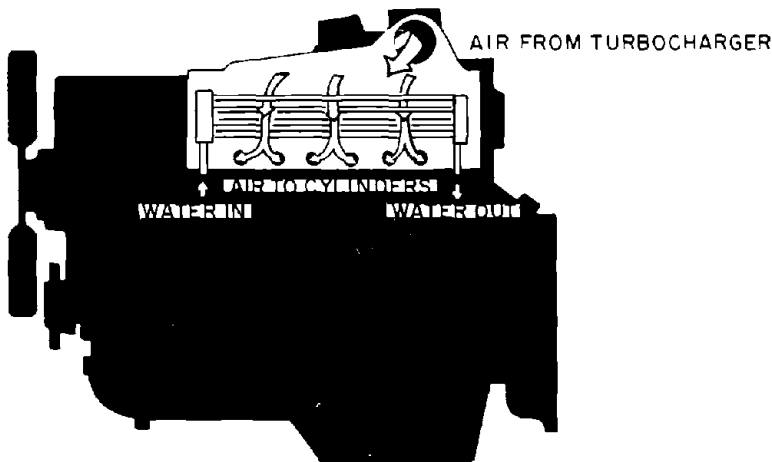


FIGURE 6. - Schematic diagram showing cross section of an aftercooler on a turbocharged-aftercooled diesel engine.

shown in schematic form in figure 6. The aftercooler is usually applied to engines when the inlet temperatures will be above approximately 275° F. The aftercooler generally keeps inlet temperatures below approximately 225° F.

can be added on each cycle of the engine which then results in increased output power. A cross section of a turbocharger is shown in figure 5. Note how the compressor and turbine are connected together with no connection whatever to the output crankshaft of the basic reciprocating engine. The exhaust gases pass out the engine valves and expand through the turbine to lower temperatures and pressures. The output work from the turbine serves as the input work to drive the compressor.

Turbocharging by itself provides the possibility of increasing the power output over that of a naturally aspirated engine by approximately 50 percent. It should be pointed out that to achieve this power increase considerable engineering effort is required to develop a turbocharged engine that is structurally sound, responsive to load demands, and that develops low transient smoke. As the fuel rate is increased, ultimately a thermal durability limit is reached where it is necessary to add an aftercooler between the compressor outlet and the inlet to the engine. Most aftercoolers use engine cooling water, and hence, the air passes over tubes that carry the water and during this process the air transfers heat to the water. This is

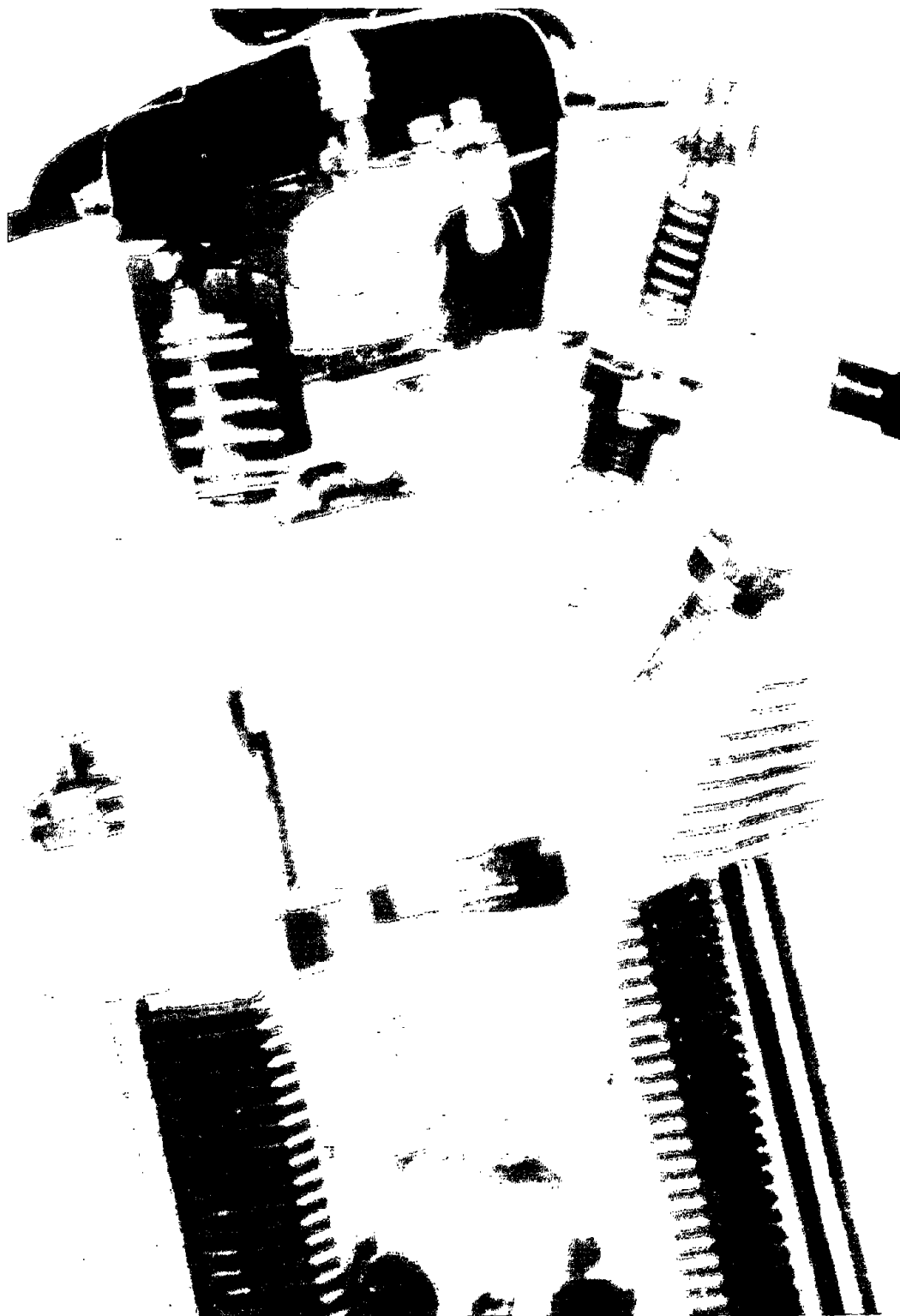


FIGURE 7. - Cross sectional view of an air-cooled prechamber diesel piston-cylinder head.

The application of the aftercooler lowers the local heat transfer to the valves, cylinder head, and the walls, thus holding the temperatures to levels where reasonable durability can be achieved. Turbocharged aftercooled engines can achieve an approximate 100-percent power increase over naturally-aspirated engines; but again considerable engineering design and development must be devoted to the engine to make it an acceptable performing engine.

Water and Air Cooling

The various surfaces in an engine's combustion chamber must be cooled below their metallurgical limit in order to have a workable and durable engine. The previous engines discussed in this paper have been basically of the water-cooled type. A lighter weight engine design can be achieved by utilizing air as the cooling medium and designing the cylinder with fins to assist in the engine cooling. The basic engine cross section of an air-cooled engine is shown in figure 7. In order to achieve sufficient cooling, a fan must also be used to increase the rate of heat transfer from the fins. The fan and an overall picture of a multicylinder air-cooled engine are shown in figure 8. Prechamber air-cooled engines are probably the most common diesel engines used

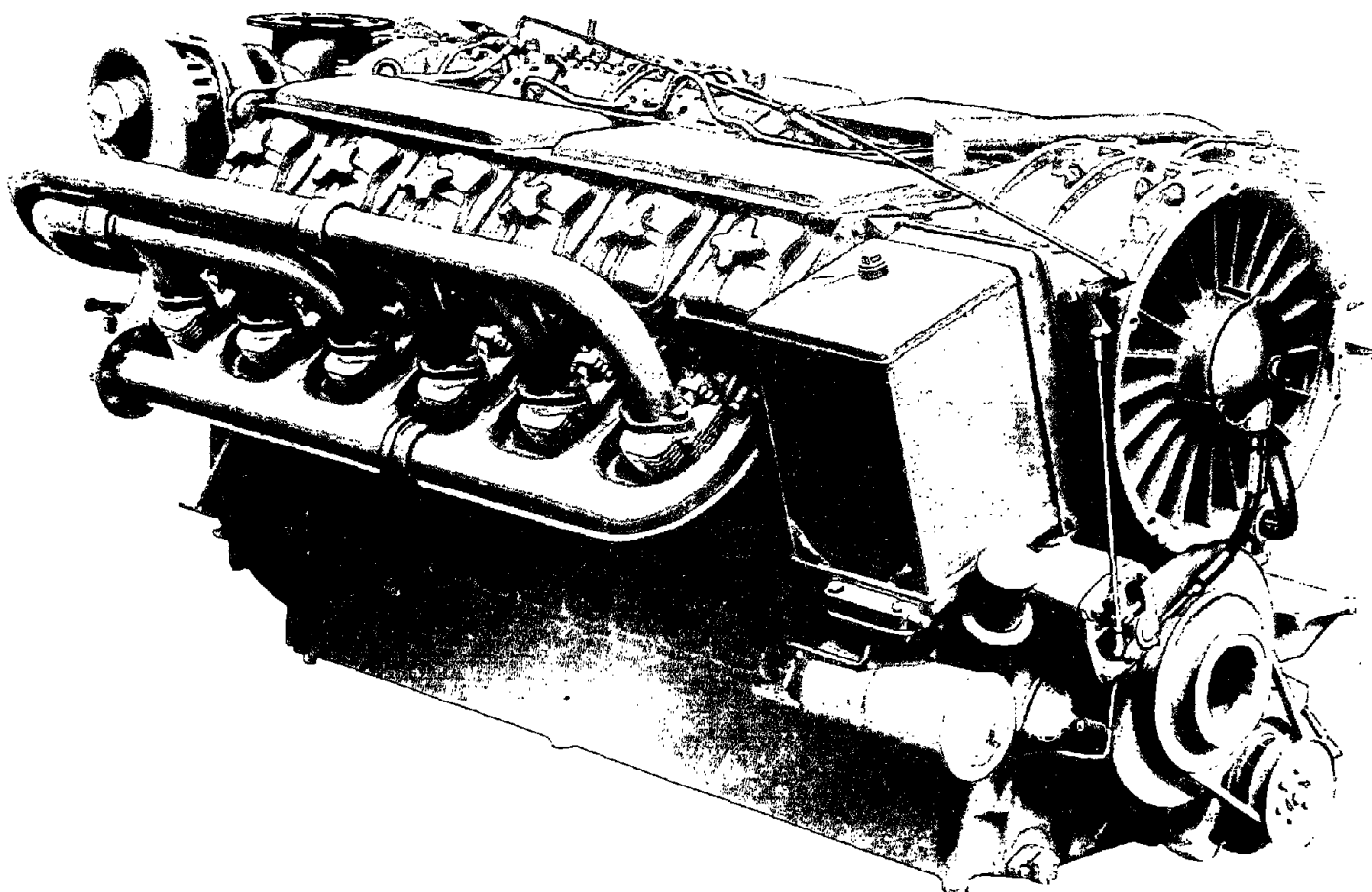


FIGURE 8. - A multicylinder air-cooled diesel engine.

COMPARISON OF TWO-CYCLE and FOUR-CYCLE ENGINES

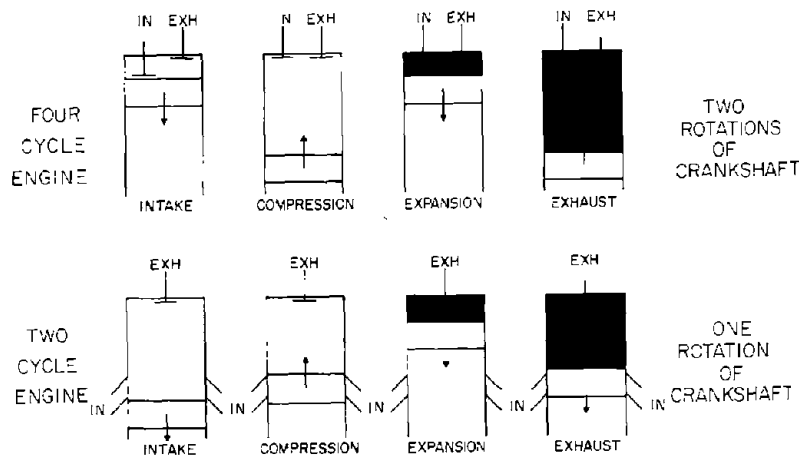


FIGURE 9.-Diagram illustrating the four basic processes in a two-cycle and four-cycle engine.

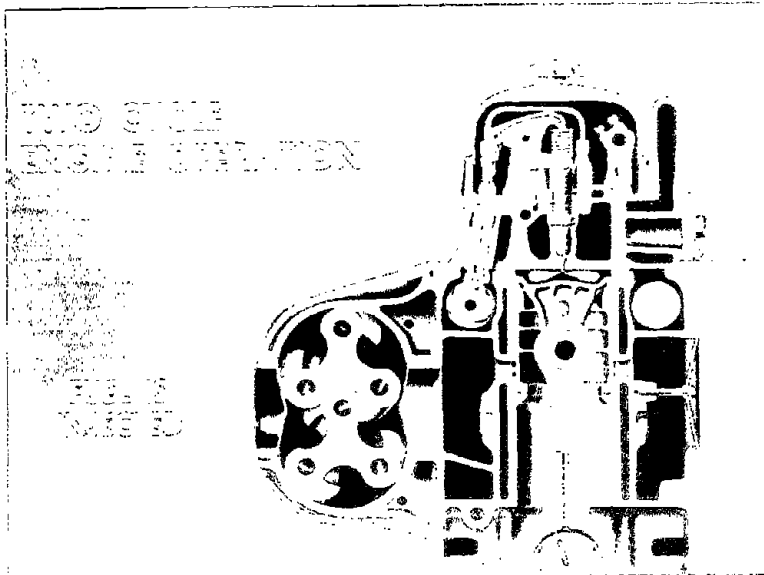


FIGURE 10.-Cross sectional view of a two-cycle, direct-injection engine showing the roots blower and piston-cylinder-port-valve design.

sufficiently high so that ignition of the fuel occurs in a reasonable time since combustion in the diesel is initiated by self-ignition of the fuel. Compression ratios (ratio of initial volume at bottom of stroke to volume at top of stroke) of approximately 17 to 1 are used in diesel engines to achieve temperatures sufficient for self-ignition of the fuel. This is contrasted to approximately 8.5 to 1 compression ratios used in SI gasoline engines.

presently in underground nongaseous mines today. Their surface temperatures run considerably higher (500° F) than water-cooled engines (180° F). In effect this will virtually eliminate them from consideration for gaseous mines since future surface temperature regulations will probably require temperatures near 300° F.

Two- and Four-Cycle Engines

Most of the previous engines shown have been of the four-cycle type. There are basically two different types of cycles used for diesel engines, that is, the four- and two-cycle types. Figure 9 shows the cycle of events in two-cycle and four-cycle engines. The four-cycle engine goes through four processes in two rotations of the crankshaft as follows:

1. An air intake stroke draws into the cylinder a charge of air on the downstroke of the piston during the time the intake valve is open.

2. A compression stroke with both valves closed on the upstroke of the piston raises the air to a high temperature (over 1,200° F), one which is

3. Injection of the fuel during the last portion of the compression stroke is followed by self-ignition of the air-fuel mixture. This liberation of chemical energy further raises the temperature and pressure of the gases in cylinder. The piston then descends downward on the expansion (power) stroke.

4. An exhaust stroke on the up-stroke of the piston with the exhaust valve open removes the exhaust products from the cylinder.

Diesel engines are also designed as shown in figure 9 to operate on the two-cycle basis, that is, accomplishment of the four basic processes in one rotation of the crankshaft. As shown in figure 9, it is usual to place intake ports in the walls of the engine and two or four poppet exhaust valves in the head. In order to accomplish the various processes and in particular the exhaust process in the one rotation of the crankshaft, it is necessary to use a roots blower. It is directly connected to the crankshaft, and air at pressures above ambient is delivered to the engine to help in the exhaust scavenging process. A cross section of a typical two-cycle direct-injection engine is shown in figure 10. The roots blower on the left side of the illustration should be noted. Two-cycle engines are of the direct-injection type combustion chamber only, while four-cycle engines are both direct-injection and prechamber types. Both two-cycle and four-cycle engines are turbocharged although four-cycle turbocharged engines are more common since they are generally easier to develop.

Performance Factors

One might well ask the question of why there are so many different design concepts used in diesel engines. The choice of a particular powerplant for a given vehicle is dependent upon a number of engineering factors. The following is a list of various engineering performance factors that are used in evaluating a powerplant's³ overall suitability for a particular application:

- Emissions (exhaust, evaporative, crankcase, noise).
- Cost (initial, operating, maintenance).
- Specific fuel consumption (lbm) of fuel/bhp-hr).
- Durability.
- Specific volume (bhp/ft³).
- Specific weight (lbm/bhp).
- Simplicity.
- Reliability.
- Type of fuel required.
- Customer preference.

³Including engine, radiator, heat exchangers, auxiliaries, and control systems.

The various diesel design features previously discussed have a significant effect on these engineering performance factors. Several of the performance factors become more important when comparing one type of powerplant to another of completely different basic design. The factors in the above tabulation are not listed in order of priority and they switch order from one application to another. The minimum (or maximum) levels of the performance factors, their relative order and weighting are determined mainly by the technical requirements of the particular application including government regulations imposed for health and safety reasons plus economics and competitive factors.

The diesel engine has as its most outstanding feature low "specific fuel consumption" (lbm/bhp-hr) throughout its load and speed operating range. There are other powerplants such as the gas turbine which can match or better its full load specific fuel consumption, but under an operating cycle which includes a significant amount of part-load operation (such as in mining operations) the diesel is superior to all other powerplants. Fuel consumption is important from the aspect of operating cost and from the broader aspect of conserving our natural resources.

"Emissions" are today an extremely important engineering performance factor to consider, and both exhaust emissions and noise emissions are included under this term. Failure to meet Federal standards can eliminate an engine from the particular market the engine was developed to serve.

The aspect of "cost" from both an initial operating and maintenance aspect is very important in the commercial market.

"Durability" in a sense represents the useful life of an engine or the life between certain maintenance procedures such as a major overhaul of the engine.

"Specific volume" is a parameter that is useful to use in rating powerplants where engine compartment volume is limited. This parameter becomes important in the design of mining vehicles of low heights, particularly when they are designed for operating in seam heights of less than 60 inches. For some mining vehicles, the height associated with this volume is also of engineering importance.

"Specific weight" is a parameter that rates the relative mass of a powerplant and is of some importance in commercial vehicles; however, it is probably not one of the most important parameters to consider.

"Simplicity" is important from the aspect that the simpler a device or the engine and its components are, the better the chance of having fewer mechanical problems. In every design there is some limit because, in going to the simplest design, one usually must trade off one or more of the other engineering performance factors. Simplicity is particularly important in the application of diesel engines to mines because of the type of environment, the need to keep machines operating 24 hours a day, and the type of operator involved.

"Reliability" represents the fact that ideally one would like the powerplant to have no mechanical failures owing to either faulty engineering design or faulty manufacturing. Since minimum cost does not occur at the point of 100 percent reliability, one must usually trade off some degree of reliability to achieve a reasonable engine cost.

"Fuel" requirements are probably of minor significance in commercial vehicles if there is no cost difference. This factor is to a degree important in mining applications from the aspect of safety and low-sulfur fuel requirements (under approximately 0.2 percent sulfur by mass to keep the sulfur dioxide emissions of low concentrations).

"Customer preference" is really not strictly an engineering performance factor, but it is extremely important when making engineering powerplant decisions for various vehicles. For example, the customer has a strong preference to have one common engine design because of spare parts stockage and training of mechanics on a single engine type.

Engine Maintenance

One additional aspect of diesel engine operation that cannot be completely designed into the engine is the need for regular and periodic maintenance. If the diesel engine is to see increased use in gaseous mines, the need for maintenance cannot be overemphasized. Maintenance for the diesel usually involves the fuel-injection or air-induction system. The condition of the fuel injection system has a definite effect on engine power output, smoke, and other exhaust emissions. The fuel injection system is probably abused and misused more than any other part of a diesel engine. The fuel system includes the tank, delivery and return lines, primary and secondary fuel filters, and transfer and injection pumps.

Injectors are often blamed for poor performance and excessive smoke when it is really the induction and exhaust systems of the engine that need attention. Maintaining these parts of the engine is generally straightforward and is easier than maintaining the injection systems. The general effect of increased intake and exhaust restriction is to decrease power and increase smoke.

In summary, the design of a diesel engine for mining operation takes careful engineering design and development by the engine manufacturer, which must be followed by additional sound engineering by the vehicle and equipment builders. In order that excessive design is not built into either the engine or vehicle, the Bureau of Mines must thoroughly develop performance standards that provide for the health and safety of the individual miners. In general, these standards should be related to performance levels to encourage design creativity in both the engine and the vehicle. Finally, whenever particular components are required in the engine-vehicle installation, their function and purpose should be well documented. Last and most important, the performance of these diesel powered vehicles and equipment will only be as good as the service and maintenance they receive. In turn, the health and safety of the miner will be directly related to this maintenance and service much in the

same manner as the original design of the engine and vehicle has a strong effect on performance.

PERFORMANCE CHARACTERISTICS

Before discussing the aspect of the diesel engine emission characteristics, it is of use to briefly outline its performance characteristics including terminology and the measurements that are carried out to define the engine's performance. Figure 11 shows an approximate schematic of the engine. An engine is basically designed to convert as much as possible of the chemical energy in the fuel into output shaft work. Because of limitations in the ability to extract all of the energy from the gases and because heat transfer from the hot combustion gases through the head and walls to either the cooling water or air takes place, this efficiency is of the order of 40 percent. About 30 percent of the energy goes out with the exhaust gas as sensible internal energy and approximately 30 percent is rejected to the cooling air or water depending on the type of engine design. It becomes important to develop engines that have high thermal efficiency throughout their speed and load range (operating range).

Engineers have found it useful to carry out this basic development and testing effort in a laboratory using a dynamometer to carefully load the engine to known loads. In the laboratory, one is also able to carefully measure fuel- and air-flow rates to the engine, heat rejection to the coolant, intake air temperatures and pressures, and exhaust temperatures and pressures. Figure 12 shows a typical engine dynamometer installation. Test procedures for measuring brake output power, engine speed, fuel-flow rate, and various other temperatures and pressures are described in other publications (15-16, 18).

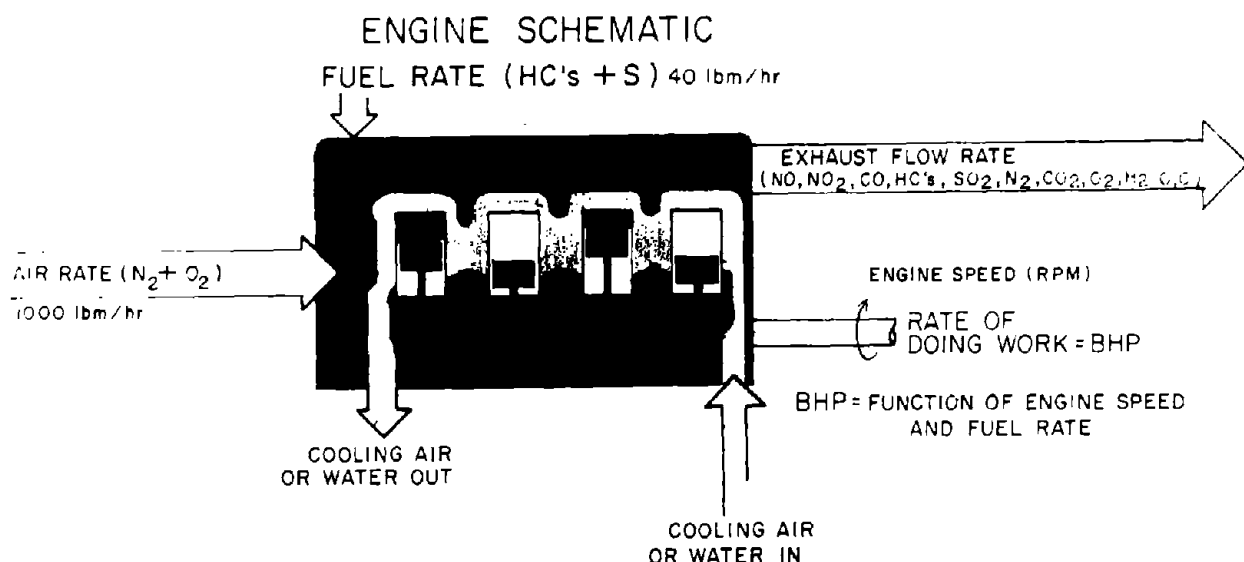


FIGURE 11. - Schematic of engine system illustrating air flow rate, fuel-flow rate as input variables with shaft power (BHP) and exhaust flow rate with various compounds as output variables.

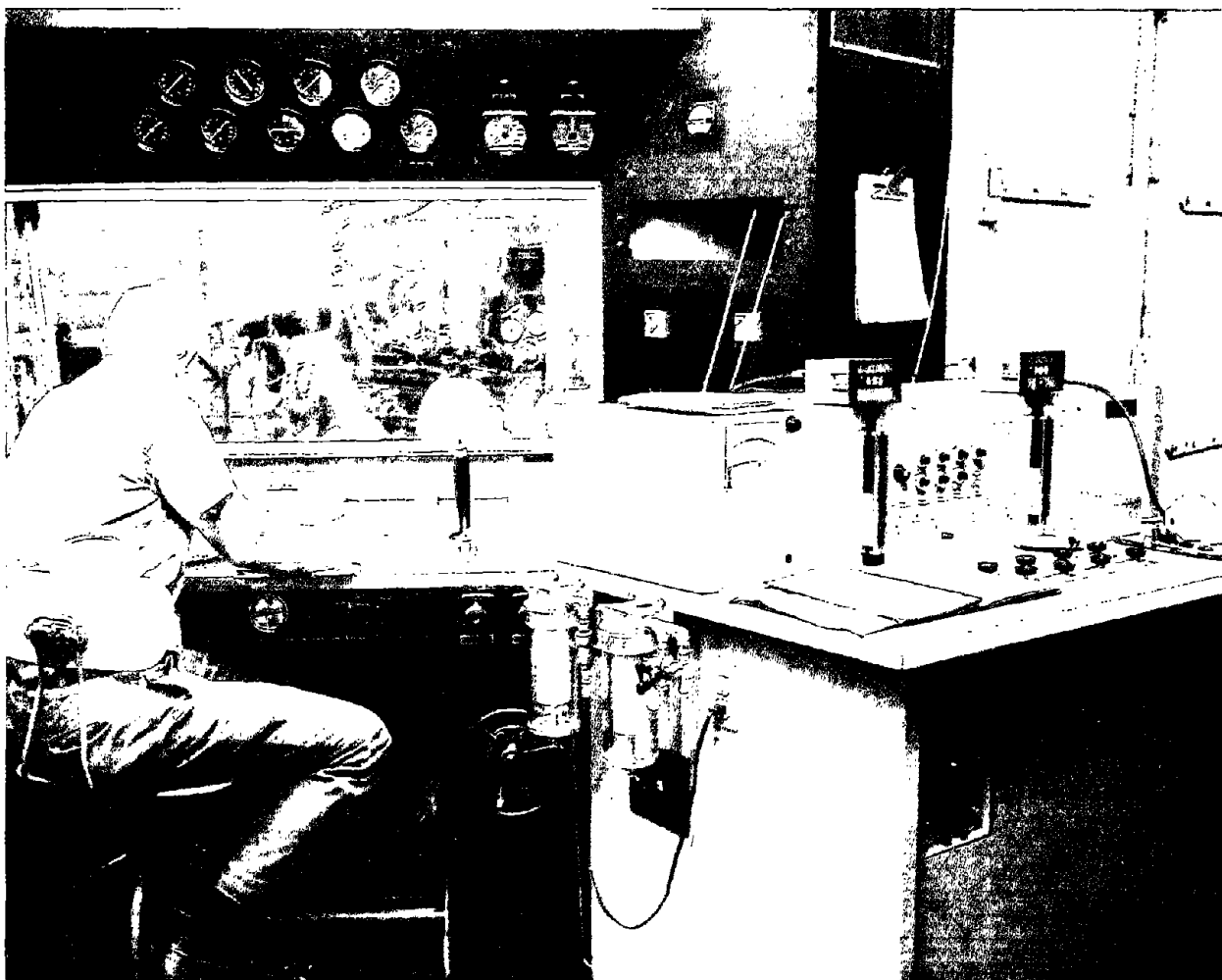


FIGURE 12. - Typical laboratory engine-dynamometer installation.

Figure 13 illustrates the brake-power versus engine-speed curves for a typical diesel engine as measured on an engine dynamometer. Two speeds are important to define. The first is the "rated speed" which is the maximum operating speed and is the speed where the engine produces its "rated power." The second speed is referred to as "peak torque speed" (or intermediate speed for emissions work) and is the engine speed where the engine produces maximum torque. An additional speed term is the "idle speed" and this is the speed where the engine operates in the unloaded condition. Additional part-load curves at 75, 50, 25, and 2 percent of full power are also illustrated in figure 13. The region between peak torque speed and rated speed and loads between 0 and 100 percent of full load is referred to as the operating range of the engine as applied to a vehicle. The 11 different load and speed points shown in figure 13 are an engineering means to define the power characteristics of an engine in its operating range and will be used in discussing and defining the average emissions characteristics of an engine in the next section.

TYPICAL DIESEL FULL AND PART LOAD POWER CURVES

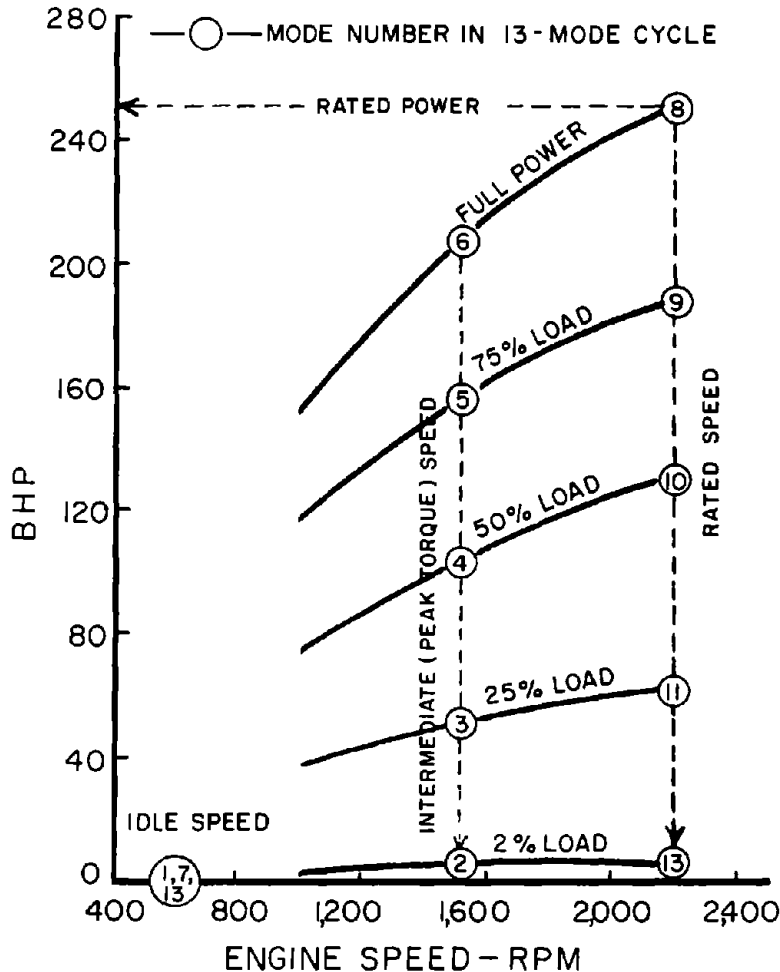


FIGURE 13. - Typical diesel full- and part-load power curves.

carbon fuel (slightly more than 1 pint) with 15 lb of air (this is the chemically correct ratio of air to fuel to completely oxidize all of the fuel to products of combustion) is carried out, it would produce approximately 225 ft³ of exhaust products. The exhaust products from a diesel engine under these "perfect" conditions would be of the composition and of the approximate percentages by volume shown in the following tabulation:

EMISSION CHARACTERISTICS

Now let us focus on the exhaust emissions coming from the engine as previously shown in schematic form in figure 11. First, a brief discussion of the type and quantity of emissions will be given followed by development of means to quantitize these emissions in terms that are useful from an engineering viewpoint. Secondly, the effect of various engine design variables on the emissions from diesel engines is developed.

Perfect and Imperfect Combustion

Before discussing methods of measuring exhaust emissions and showing data for their levels, it is appropriate to discuss what specific chemical compounds will be found in diesel exhaust first under "perfect" conditions and secondly under what might be referred to as "imperfect" or actual conditions.

If the combustion process of 1 lb of a hydro-

	<u>Percent</u>
<u>Perfect combustion products:</u>	
Nitrogen (N_2).....	73
Carbon dioxide (CO_2) plus oxygen (O_2)....	13
Water (H_2O).....	13
<u>Imperfect combustion products (pollutants):</u>	
Hydrocarbons (HC).....	<1
Carbon monoxide (CO).....	<1
Nitric oxide (NO) }	<1
Nitrogen dioxide (NO_2) }	
Carbon (C) or smoke.....	<1
Sulfur dioxide (SO_2).....	<1
Total.....	100

Because the combustion process in an actual engine is "imperfect," several toxic exhaust products are produced which are referred to as pollutants. For the mine air, primary concern will be for carbon monoxide (CO) and the nitrogen oxides (NO_x) but some concern for carbon dioxide (CO_2) must be given since large quantities are produced (as much as 13 percent by volume under full-load conditions) (7). It should be noted that all of the pollutants together resulting from imperfect combustion constitute less than 1 percent of the exhaust products by volume. Also, two other comments are in order. First, 95 to 99 percent of the NO_x produced in the diesel exhaust is NO, and because of the slow rate of conversion of the NO to NO_2 in the mine atmosphere very little NO_2 should be present (12). Second, the sulfur dioxide (SO_2) is a result of the presence of sulfur in the fuel rather than as a result of the imperfect combustion process in the engine. All of the other emissions present in the exhaust are a direct result of the imperfect combustion process which will be briefly described.

Hydrocarbons in diesel exhaust are generally considered to be mostly unburned fuel left from the combustion process. In addition, since the combustion process is carried out at high temperatures and pressures, a portion of the fuel's hydrocarbons has been changed by the engine. The concentration of hydrocarbons in the exhaust appears to be largely related to fuel injection system design and combustion chamber design (1). It would appear that hydrocarbons in the exhaust are from the following sources:

1. Impingement of fuel on the piston or the other combustion chamber walls which does not get vaporized, mixed, and burned prior to the exhaust process.
2. Fuel vapor that is in the fringes of the sprays and combustion zones and remains in regions that are greater than approximately 40 to 1 A/F ratio and hence, uncombustible.
3. Fuel that is left in the fuel injector tip and orifices at the end of the injection process and then is evaporated from the orifices later in the cycle (6).

The diesel engine also has an "odor" problem which is in a general manner related to the hydrocarbons in the exhaust. "Diesel odor" results from very small amounts of a large number of unburned and partially oxidized hydrocarbon compounds. The compounds associated with the diesel odor problem have strong odors at low concentrations. Two general types of odors have been characterized to date (19). One is an "oily-kerosene" odor which appears to be caused by certain classes of aromatic hydrocarbons and is related to fuel-type hydrocarbons. The second is a "smoky-burnt" odor which appears to be caused by partially oxidized material and is related to combustion-generated hydrocarbons. These two odor notes provide approximately equal odor contribution to the overall diesel exhaust odor. But, their concentrations were not the same and in fact "oily-kerosene" compounds were present in concentrations ten times higher than the "smoky-burnt" compounds. The "oily-kerosene" note was estimated to be approximately 3 ppm in one engine, with individual compounds ranging from 6 to 60 ppb (19).

Carbon monoxide is basically produced during combustion in local regions where there is insufficient oxygen present to fully oxidize the fuel to CO_2 . Since the diesel engine always operates with excess air, the carbon monoxide levels will be shown to be extremely low as compared to those of gasoline engines.

Nitric oxide is the major oxide of nitrogen formed in the diesel engine. Since it oxidizes to nitrogen dioxide in the atmosphere, it has become historical to express mass standards for NO_x in terms of NO_2 . The amount of NO formed in a diesel engine is a result of local temperature, oxygen concentration, and time available to complete the reactions since diesel combustion is extremely heterogeneous. The NO formation rate is slower than the combustion oxidation reactions; therefore, it is formed in the burned gases on the expansion stroke after combustion. Some nitrogen dioxide (NO_2) appears to be formed in diesel engines at low speeds and light loads where sufficient oxygen and time are available for the NO to convert to NO_2 .

Black smoke is primarily unburned carbon which is present in small particles from 0.4 to 1 micrometers in diameter. Smoke is formed when the local temperature is high enough to decompose the fuel in an area of the combustion chamber where there is insufficient oxygen to burn the resulting carbon. Carbon of visible quantities is left from the combustion process if there is (1) insufficient air, (2) insufficient mixing, or if (3) the carbon is formed late on the expansion stroke so that the temperature is below the temperature at which carbon reacts (7).

Sulfur dioxide in diesel exhaust emissions is not a result of imperfect combustion occurring as a result of the engine combustion system design, but is a direct result of the sulfur present in the fuel. Each 0.1 percent by mass of sulfur in the fuel when operating the engine at an A/F ratio of 20 to 1 results in 43 ppm of SO_2 being produced. The following equation provides a means to calculate the SO_2 concentration in the exhaust (assuming that all sulfur in fuel is converted to SO_2) given the A/F ratio and percent sulfur in the fuel:

$$(SO_2)_{conc} = \left(\frac{2}{1+A/F} \right) \left(\frac{\text{Percent sulfur}}{100} \right) \frac{M_{exh} \times 10^6}{M_{SO_2}} \quad (1)$$

where $(SO_2)_{conc}$ = SO_2 concentration, ppm,

Percent sulfur = percent sulfur by mass in the fuel, percent,

M_{exh} = molecular weight of exhaust products,
lbm/lb-mole ≈ 29 ,

and M_{SO_2} = molecular weight of SO_2 , lbm/lb-mole = 64.

The term $1/(1+A/F)$ represents the lbm of fuel/lbm of exhaust and the factor of 2 results from the fact that 2 lbm of SO_2 is produced for each lbm of sulfur in the fuel.

Measurement of Gaseous Emissions of HC's, CO, CO_2 , NO, and NO_2

Gaseous emissions are fairly routinely measured today. The references (2, 5, 13, 17-18) are sources of general and specific test procedures for measuring hydrocarbons, carbon monoxide, carbon dioxide, and nitric oxide in a laboratory engine dynamometer environment. The measurement of smoke will be discussed in a separate paragraph since the instruments, measurement techniques and cycle used to quantitize smoke are somewhat different than for the gaseous emissions. Figure 14 shows an exhaust gas analyzer system used for measuring these gases. Flame-ionization detector instruments are used for measuring total hydrocarbons (13), but it is most common to use nondispersive infrared instruments to measure CO, CO_2 , and NO (17). If both NO and NO_2 are desired to be measured, a chemiluminescence instrument (5) can be used. The emission data expressed in units of parts per million by volume along with, brake power, engine speed, fuel-flow rate, and air-flow rate are measured in the laboratory.

In quantitizing diesel engine emissions for determining their polluting effect on a mine environment, it is necessary to express the emissions in terms of flow rates so that one can distinguish between small and large engines. For example, two different engines ten times in size could both be operating at a load and speed point producing 1,000 ppm of NO but their flow rates of NO could be different by a factor of 10. The laboratory emission concentration data are converted to emission flow rates by the following equations (5):

$$(HC)_{mass} = 0.0132 \times (HC)_{conc} \times \dot{m}_{exh}, \quad (2)$$

$$(CO)_{mass} = 0.0263 (CO)_{conc} \times \dot{m}_{exh} \quad (3)$$

$$(NO_x)_{mass} = 0.0432 \times (NO)_{conc} \times \dot{m}_{exh}, \quad (4)$$

where $(HC)_{mass}$, $(CO)_{mass}$, $(NO_x)_{mass}$ = mass flow rates of HC's, CO, and NO_x (as NO_2) respectively in the exhaust, grams/hr;

$(\text{HC})_{\text{conc}}$, $(\text{CO})_{\text{conc}}$, $(\text{NO})_{\text{conc}}$ = concentration of HC's, CO, and NO respectively in the exhaust, ppm;

and $\dot{m}_{\text{exh}}$ = mass flow rate of the exhaust, lbm/min.

The exhaust mass flow rate is determined by measuring both the fuel- and air-flow rates (18) and calculating the exhaust flow rate by the following equation:

$$\dot{m}_{\text{exh}} = \dot{m}_{\text{air}} + \dot{m}_{\text{fuel}}, \quad (5)$$

where $\dot{m}_{\text{air}}$ = mass flow rate of the air to the engine, lbm/min,

and $\dot{m}_{\text{fuel}}$ = mass flow rate of the fuel to the engine, lb/min.

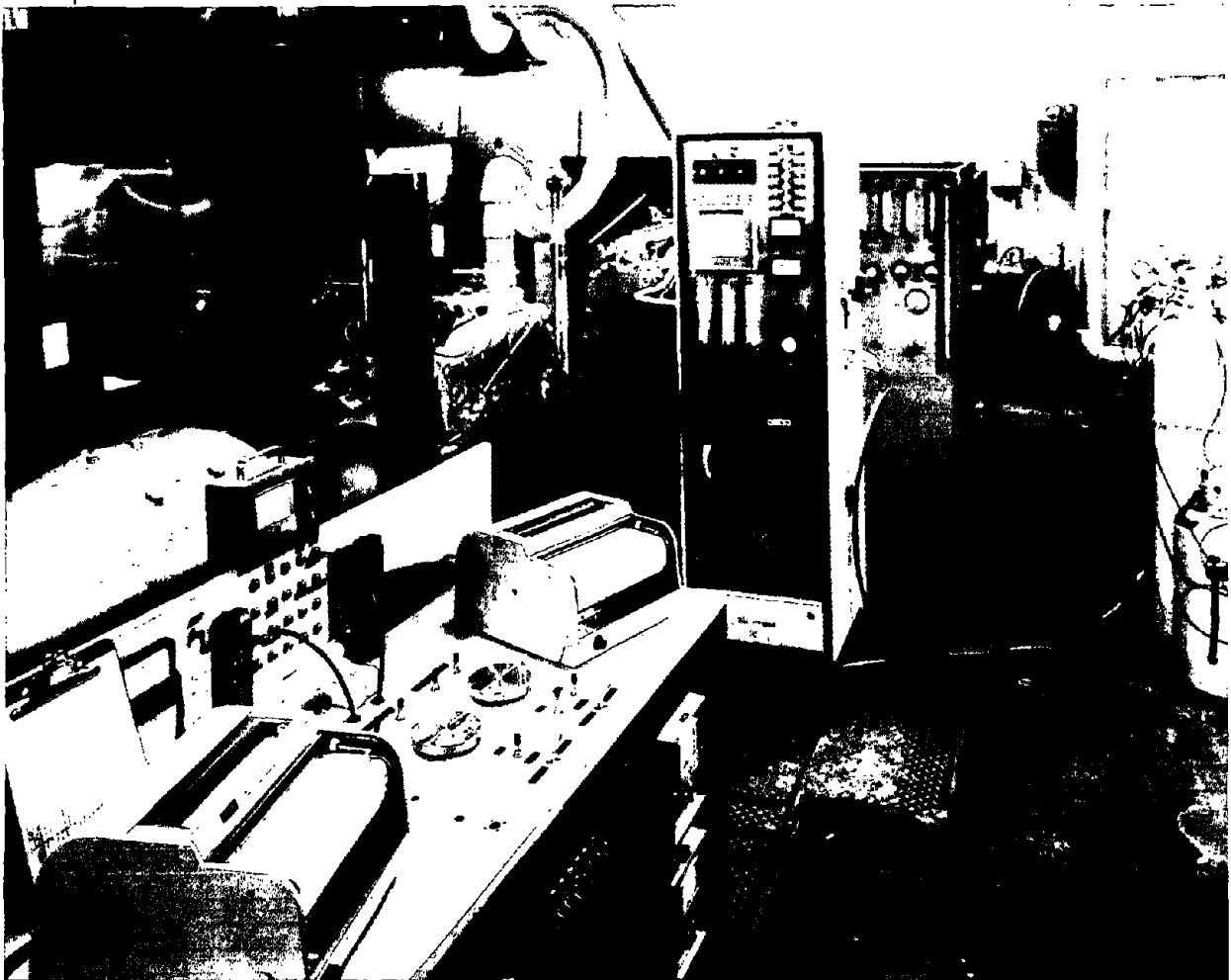


FIGURE 14. - Typical laboratory exhaust gas analyzer systems.

Figure 15 shows an emission map (constant emissions flow rates plotted versus engine speed and brake power) for NO emissions (3). It should be noted that the emission flow rates vary significantly throughout the operating range of the engine. The emission maps for the hydrocarbons and CO would be of different shape, but they would provide the same general pattern of wide variation depending on the engine speed and brake power being produced.

In order to develop an engineering parameter to make comparisons between different sizes and types of engines, the emission rate is divided by the brake power being produced at the output shaft. This quantity is referred to as the "brake specific emission rate" (BSHC) and is expressed as follows:

$$\text{BSHC} = \frac{\text{Rate of hydrocarbon emissions}}{\text{Rate of doing work}} = \frac{(\text{HC})_{\text{ssss}}}{\text{BHP}}, \quad (6)$$

where BSHC = brake specific HC emission rate, grams/bhp-hr,

and BHP = brake power output, bhp.

Similar equations can be developed for the other emissions by use of their respective emission rates. Since, from an engineering viewpoint at any operating point, it is desirable to maximize the brake power and minimize the emission rates, brake specific emissions should be minimized and made to approach zero.

Now that the emissions that come from diesel engines have been discussed in a general way including various means to measure and quantitize these emissions, it might be of general interest to illustrate their range of levels

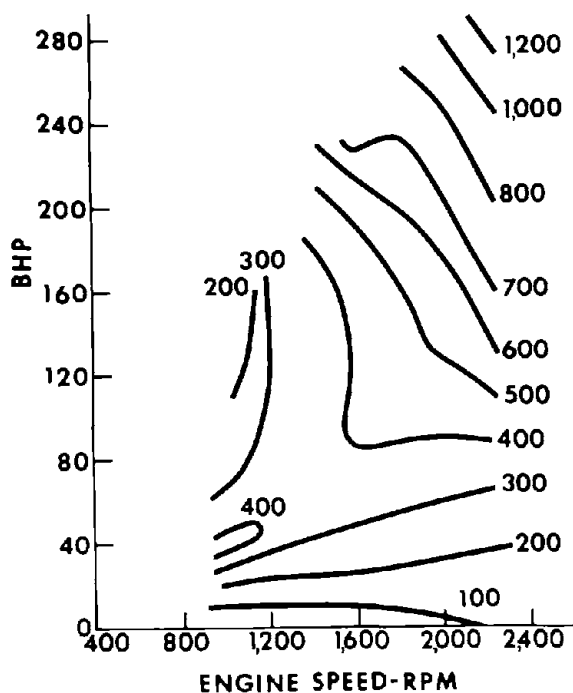


FIGURE 15. - Nitric oxide (NO) emission map with lines of constant NO flow rates in gm/hr (3).

across most engine design types and operating modes. Table 1 shows these data (1) expressed both in units of concentration and in terms of brake specific emission rates. Smoke is also shown since it is of interest to show its magnitude in comparison to the gaseous emissions. Smoke is insignificant on a mass basis, but it becomes highly visible above concentrations of approximately 5 mg/ft³. The development of the smoke measurements later in this paper will mainly be from the viewpoint of controlling its visibility to aesthetic levels.

TABLE 1. - Typical diesel emission levels

Emission	Concentration	Brake specific emission rates, g/bhp-hr
Smoke.....	1-10 mg/ft ³	0.05-0.3
Carbon monoxide (CO).....	50-5,000 ppm	2-10
Oxides of nitrogen (as NO ₂).....	200-3,000 ppm	4-20
Hydrocarbons.....	10-500 ppmC	0.2-3

13-Mode Gaseous Emissions Cycle

As shown in figure 15, the rates of emissions vary widely over the power and speed range (operating range) of the engine. In order to make it feasible for engineers to know which part of the emissions map to reduce and to arrive at a single number for each of the emissions, an average 13-mode cycle was

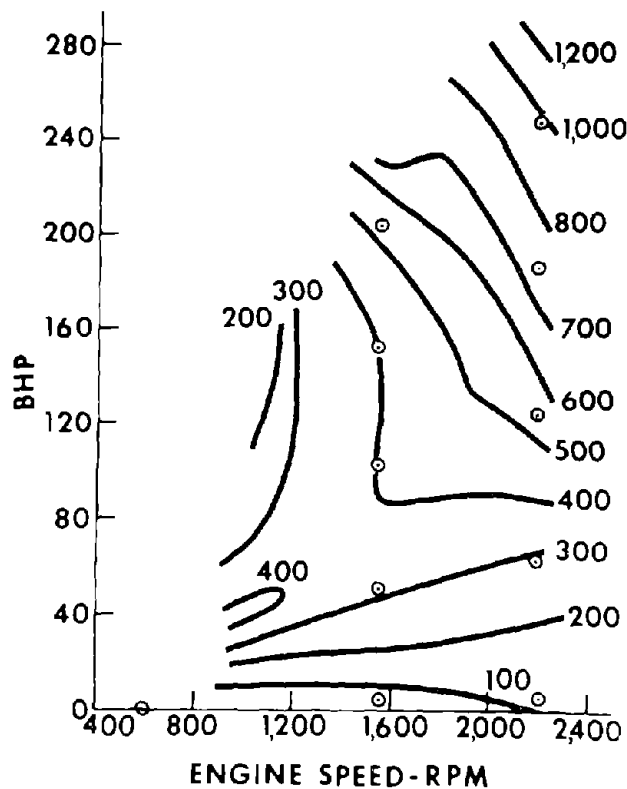


FIGURE 16. - Nitric oxide (NO) emission map with lines of constant NO flow rates in gm/hr with 13-mode cycle points superimposed (3).

developed for testing and certifying heavy-duty truck diesel engines. This cycle was first proposed for California (2) and has since been adopted by the Federal Government under the Environmental Protection Agency (EPA) for certifying 1974 heavy-duty diesel truck engines (5). The 13-mode cycle test is basically a steady-state, 10-minute in-mode cycle. The various modes in the cycle are shown in table 2. These are the same power and speed points illustrated on the Brake Power versus Engine Speed curves shown in figure 13. The average of the three idle modes are weighted 20 percent while each of the other ten modes are weighted 8 percent each. The weighting factors were based on approximate average times that a typical diesel-powered truck would operate in the field at these loads and speeds. Although this cycle does not precisely simulate all trucks or in fact all vehicles, it appears to be a fairly good overall average vehicle cycle for arriving at a single number to quantitize each of the gaseous emissions. Also, varying the weighting factors in the cycle does not drastically change the cycle average values computed. The cycle average brake power is approximately 35 percent of rated power and varies somewhat around this value depending on the torque rise of the engine and peak torque speed. Figure 16 illustrates the 13-mode points plotted on the NO emission map previously illustrated in figure 13. The various modal points cover the operating range of the engine and are sufficiently close together to simulate the approximate shape of the map. The actual 13-mode "Brake Specific Emission Rates" are calculated using the following equation:

$$\text{BSHC}_{13\text{-mode}} = \frac{\sum (\text{HC}_{\text{mode } i} \times \text{WF}_i)}{\sum (\text{BHP}_i \times \text{WF}_i)} \quad (7)$$

where $\text{BSHC}_{13\text{-mode}}$ = brake specific average emissions on
13-mode cycle, grams/bhp-hr,

BHP_i = measured brake power in each mode, bhp,

WF_i = weighting factor in each mode (0.2 for
average of idle modes, that is, modes 1,
7, and 13 and 0.08 for each of the
other modes).

Similar equations can be developed for the other emissions by the use of their respective emission rates. For other applications such as mining equipment and vehicles, the cycle weighting factors could be adjusted to better reflect operating modes and average time in each mode.

TABLE 2. - 13-Mode diesel emissions cycle

Mode	Engine speed	Percent load ¹	Mode	Engine speed	Percent load ¹
1.....	Idle.....	0	8.....	Rated.....	100
2.....	Intermediate ² .	2	9.....	do.....	75
3.....	do. ²	25	10.....	do.....	50
4.....	do. ²	50	11.....	do.....	25
5.....	do. ²	75	12.....	do.....	2
6.....	do. ²	100	13.....	Idle.....	0
7.....	Idle.....	0			

¹ Percent of maximum torque available at that speed.

² Peak torque or 60 percent of rated speed, whichever is higher.

Figure 17 shows the typical range of diesel and gasoline engine emissions when compared on the 13-mode cycle. It can be noted that diesel engines presently without any controls are as low as future automobile standards appear to be going for hydrocarbons and CO. The lowest engines for all three emissions appear in general at this point in time to be prechamber, turbo-charged, aftercooled engines with levels generally as follows:

BSHC = 0.2 - 0.3 gram/bhp-hr,

BSCO = 1 - 2 grams/bhp-hr,

and BSN₂ = 5.5 - 6.0 grams/bhp-hr.

Some direct-injection, turbocharged, aftercooled engines appear to be able to approach similar numbers although most engines other than prechambers that have emissions of NO₂ in this range have not been proven in field service. The most difficult engineering problem in achieving BSN₂ emissions in the 5 to 6 g/bhp-hr range is in maintaining low smoke and low brake-specific fuel consumption (0.43 to 0.45 lbm of fuel/bhp-hr on the 13-mode cycle) since engine design variables that tend to reduce BSN₂ generally tend to increase smoke and fuel consumption.

Exhaust Smoke Measurement

There are a number of different instruments used for measuring diesel exhaust smoke and these have been described in detail (14). The discussion in this paper will center around one general type of smokemeter which is referred to as a light-extinction smokemeter. The reason that the discussion will concentrate on this type is that it is the type of meter specified in the Federal Test Procedure for certifying new diesel engines for heavy-duty trucks (5) and because it offers the advantage that it can be used to measure transient smoke levels. Other types of meters generally do not have this capability. Figure 18 shows in schematic form the principle upon which the full-flow light-extinction meter operates. Light from a source passes through the full smoke plume, and a portion of the light is blocked by the smoke particles. The fraction of light blocked in passing from the light source through the plume to the light detector is expressed in percent and is referred to as the percent opacity. The percent opacity of diesel exhaust is dependent basically

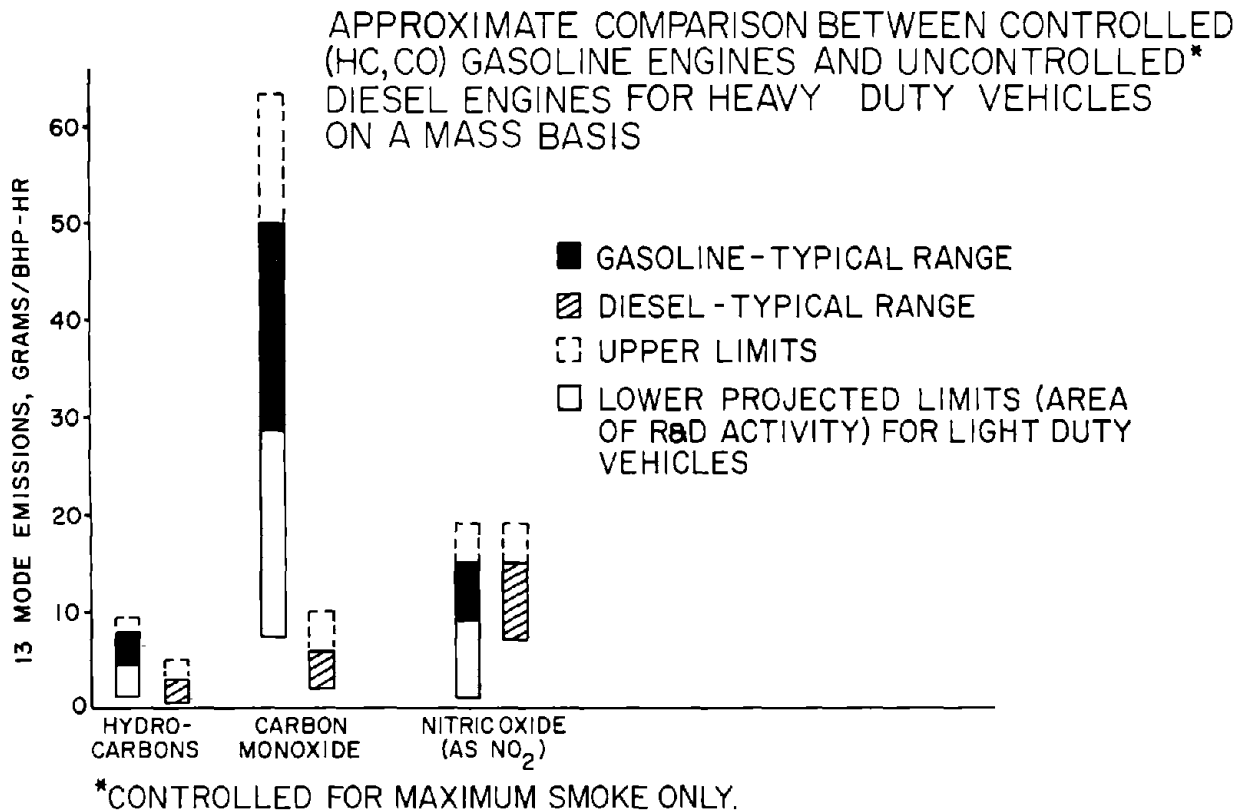


FIGURE 17. - Comparison of diesel and gasoline (spark-ignition) engine brake specific emission rates on 13-mode cycle.

on the concentration of carbon particles in the plume and in the light path length through the plume. Smokemeters of this type are calibrated at two points. First, percent opacity is when no smoke particles are present (air only) and 100 percent opacity is when no light penetrates the plume. Generally the 0 to 20 percent opacity is applicable for steady-state measurements, and the portion above 20 percent opacity is applicable for transient measurements.

Figures 19 through 21 show various types of light extinction meters presently available. Figure 19 shows the U.S. Public Health Service (PHS) Smokemeter (now sometimes referred to as the EPA Smokemeter) which is required for smoke certification in the laboratory tests for new diesel engines for heavy-duty trucks (5). Figure 20 shows a CELESCO Model 103 In-line Opacity Meter which is a development that followed the U.S. PHS (or EPA) full-flow meter and is a more suitable laboratory and production test cell smokemeter from an operational standpoint since it can be installed in the conventional closed exhaust system used in these two applications. Figure 21 shows a CELESCO Model 101 Full-Flow Portable Field Opacity Meter. Its portability,

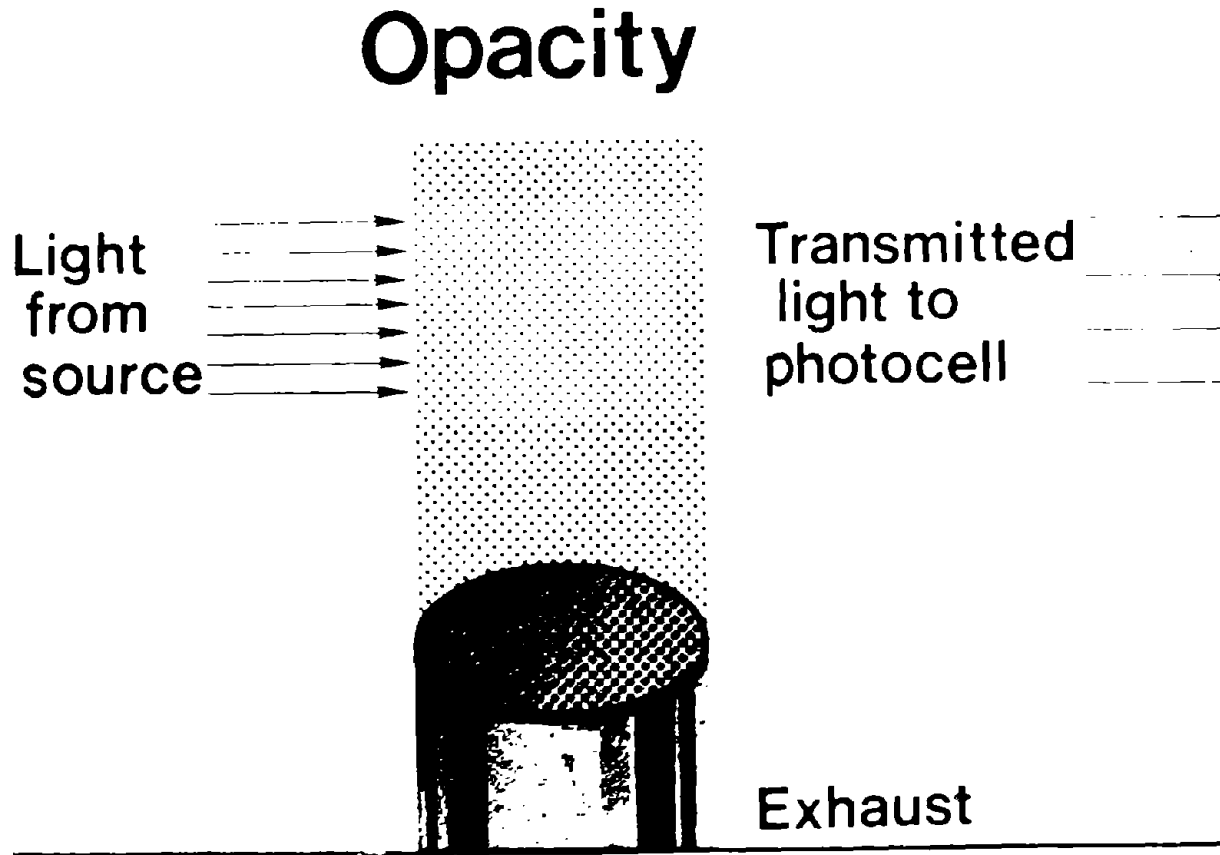


FIGURE 18. - Schematic illustrating principle of operation of light-extinction smoke-meters.

lightweightness, simplicity, and low cost relative to the other two smoke-meters becomes clear with a brief review of its performance characteristics.

Federal Smoke Cycle

The most widely accepted U.S. test procedure for measuring smoke under all types of conditions encountered with diesel engines in mobile vehicles is the EPA Federal Test Procedure (5, 11). The basic test cycle is carried out on an engine dynamometer and is illustrated in figure 22 (11). The test cycle simulates maximum smoke conditions encountered in highway operation, and separate smoke limits are set in both the acceleration and lugging modes. Although this cycle was originally developed for highway vehicles, it appears to be a useful laboratory test cycle for other applications, and it would appear to be a meaningful laboratory test to quantify the worst smoking conditions of diesel engines for mining vehicles although the correlation between the laboratory results and the worst in-service smoke levels would require additional study.

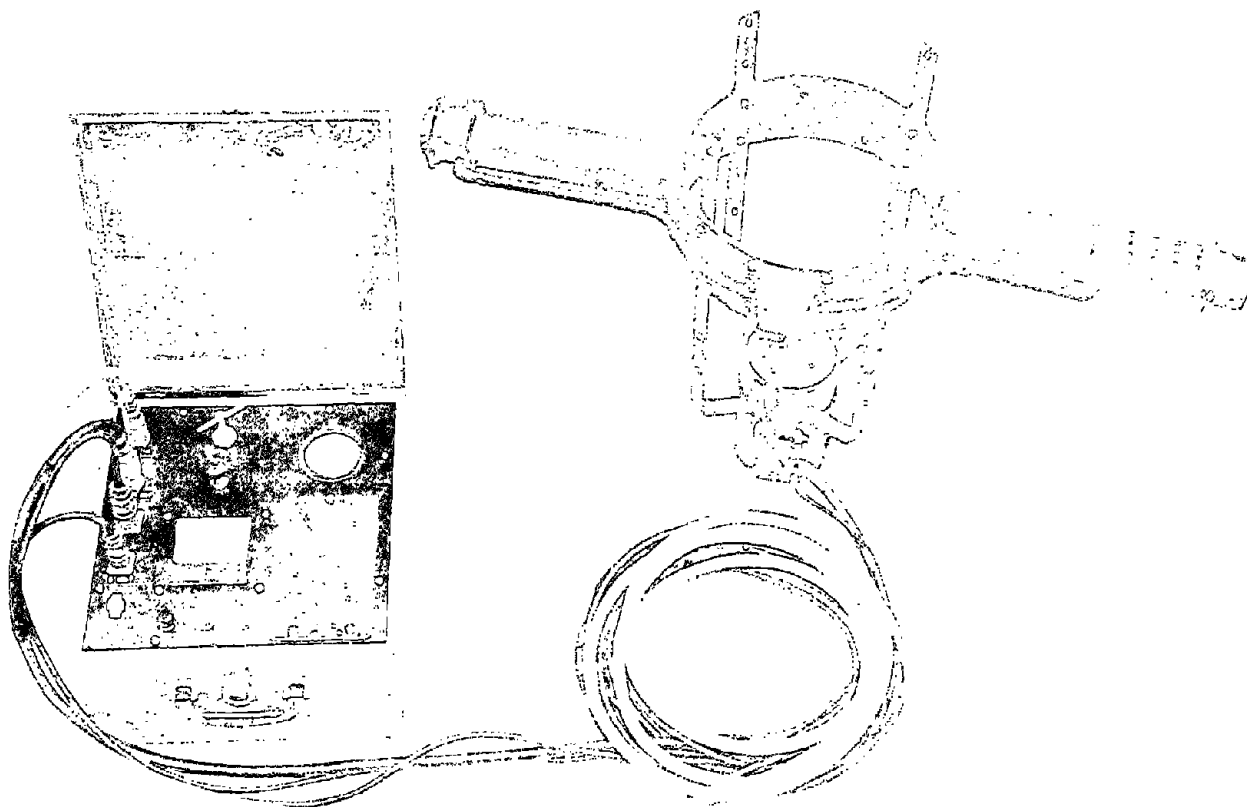


FIGURE 19. - U.S. Public Health Service (or Environmental Protection Agency) smokemeter.

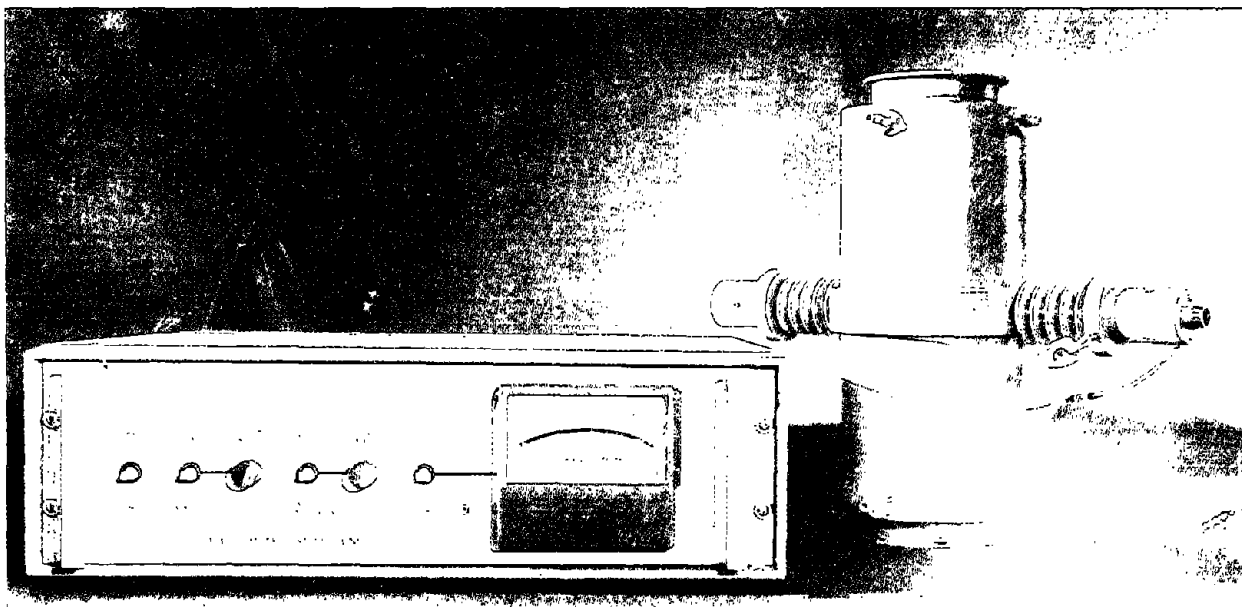


FIGURE 20. - CELESCO Model 103 in-line opacity smokemeter.



FIGURE 21. - CELESCO Model 101 full-flow portable field opacity smokemeter.

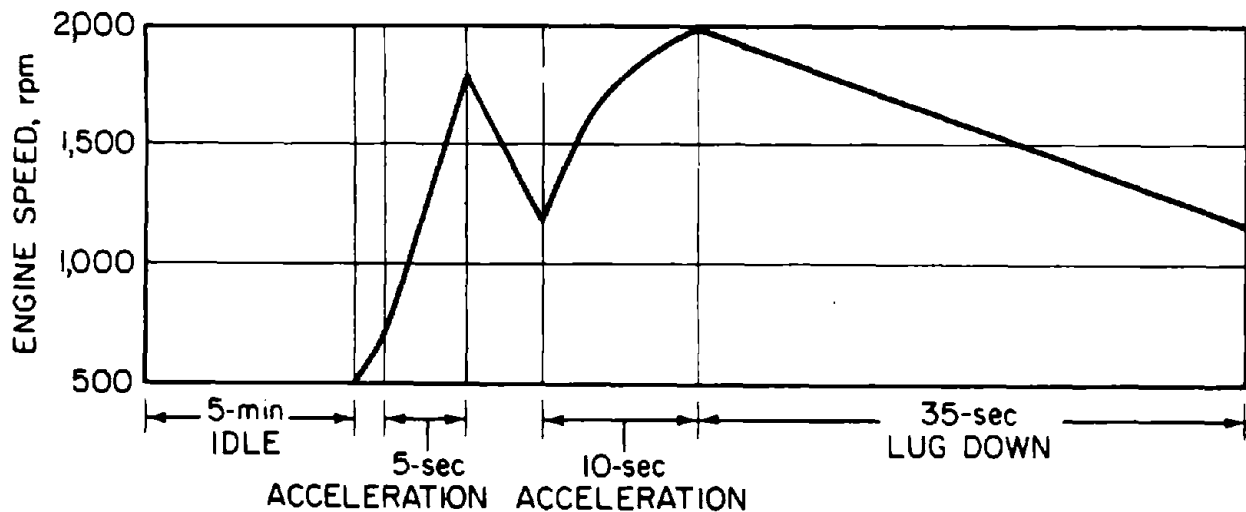


FIGURE 22. - Federal smoke test cycle (11).

The Federal Cycle (fig. 22) begins with 5 minutes at low idle followed by a part-throttle acceleration from idle to 200 ± 50 rpm above idle (within 3 seconds). On reaching a speed 200 rpm above idle, the throttle is fully opened and the engine accelerates against inertia to reach 85 to 90 percent of the rated speed in 5 ± 1.5 seconds. The throttle is now closed and a dynamometer load applied so that engine speed drops. This transitional deceleration is maintained until engine speed reaches that of peak torque or 60 percent of rated speed (whichever is higher). The cycle continues with a full-throttle acceleration to 95 to 100 percent of rated speed under dynamometer load. This acceleration must be accomplished in 10 ± 2 seconds. These two engine accelerations are considered to make up the "acceleration mode" of the cycle.

The engine is then stabilized very briefly at rated power and speed. Dynamometer load is then gradually increased lugging the engine from the rated speed to the speed of peak torque (or 60 percent of rated speed whichever is higher) in 35 ± 5 seconds. This portion of the test is referred to as the "lugging mode" of the cycle. During the complete test, smoke opacity and engine speed are recorded continuously on a strip chart recorder.

To obtain average opacity values, the mean smoke readings during each half-second interval are determined. The 15 highest half-second readings in the "acceleration mode" and the 5 highest in the "lugging mode" are selected. The average of these smoke readings in the respective modes are referred to as the "acceleration smoke value" and the "lugging smoke value." In the 1974 truck standards, the three highest half-second readings are also averaged to arrive at a "peak smoke value" (mainly to control peak smoke values on turbo-charged engines).

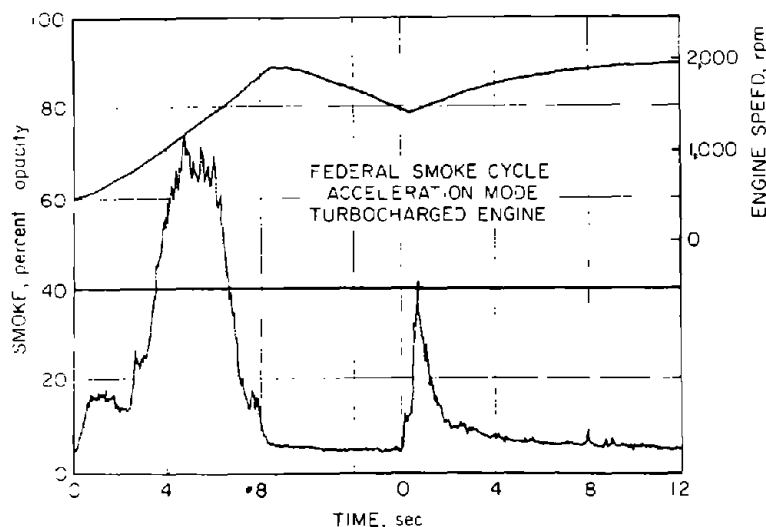


FIGURE 23. - Typical turbocharged engine smoke levels on acceleration mode of Federal smoke test cycle (11).

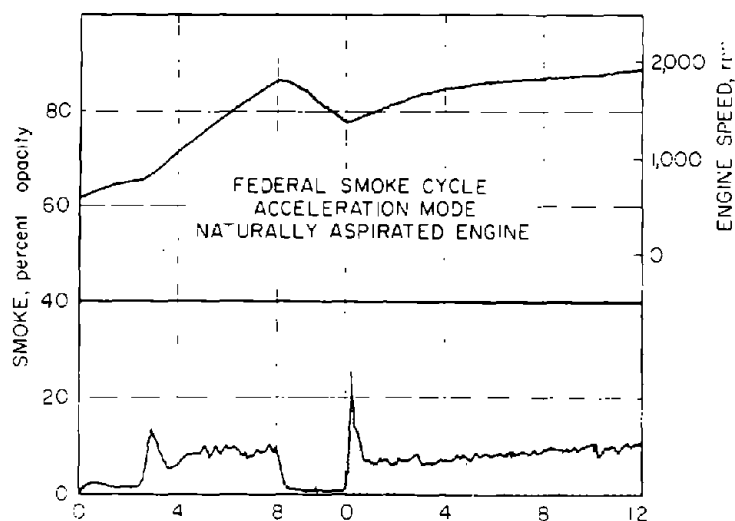


FIGURE 24. - Typical naturally aspirated smoke levels on acceleration mode of Federal smoke test cycle (11).

resulting from the higher air temperatures when the fuel is injected in the cylinder, and the higher full-load air-fuel ratios (25 to 1) in turbocharged engines as compared to naturally aspirated engines (20 to 1).

Figures 23 and 24 (11) show typical turbocharged and naturally aspirated, acceleration mode smoke traces. The shaded portions of the curves are the readings used to calculate the acceleration smoke value for the engine. Turbocharged engines generally show greater smoke under the acceleration mode since the turbocharger requires time to accelerate and provide sufficient air to the engine. These peaks have seen considerable reduction during the past 3 years with improved A/F ratio control devices and fuel-injection systems--turbocharger developments that provide improved transient characteristics and better matches to the engine. Hence, there appears to be no inherent problem in developing relatively clean and responsive turbocharged engines under transient conditions such as encountered in the Federal Test Cycle.

Figures 25 and 26 (11) show the same turbocharged and naturally aspirated engine smoke traces from the lugging mode. Here it should be noted that the turbocharged engine does considerably better than the naturally aspirated engine. This is mainly a result of improved combustion

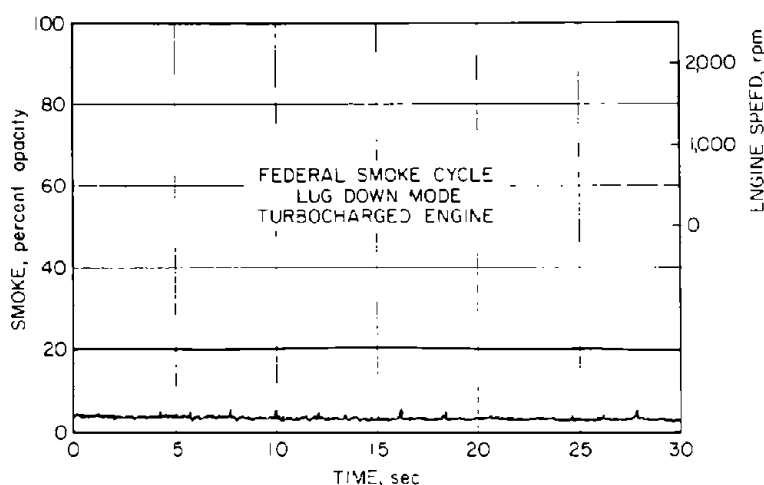


FIGURE 25. - Typical turbocharged engine smoke levels on lugging mode of Federal smoke test cycle (11).

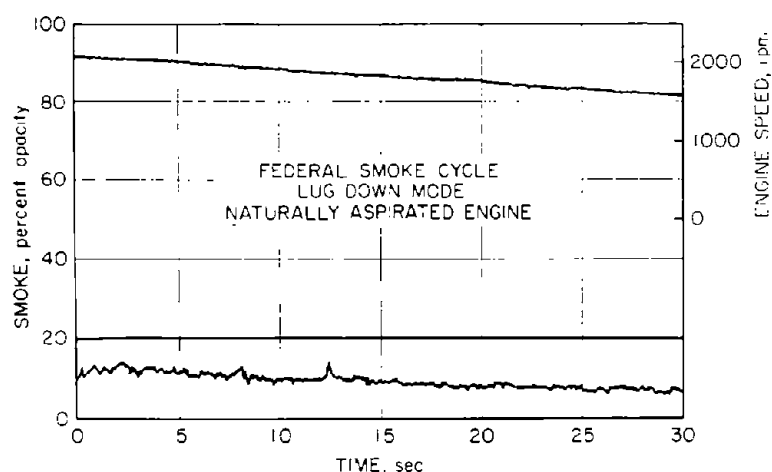


FIGURE 26. - Typical naturally aspirated engine smoke levels on lugging mode of Federal smoke test cycle (11).

Sulfur Dioxide Emissions

As previously stated, diesel sulfur dioxide emission levels are a direct function of the percent of sulfur in the fuel. Figure 27 (10) shows the effect of an A/F ratio (proportional to percent load with 20 to 1 and 125 to 1 representing approximately 100 percent and 0 percent load) for various typical levels of sulfur in diesel fuel. The fact that SO_2 is being generated in diesel exhaust does not appear to be a problem based on the latest Bureau of Mines survey of U.S. diesel fuel oils (20). Table 3 shows average sulfur levels in Diesel No. 1 and Diesel No. 2 Fuel. The average of Diesel No. 2 Fuel which is the most common diesel fuel used in diesel vehicles is 0.23 percent sulfur by mass. At this level of SO_2 , it would appear that this pollutant for even low emission engines would not be the limiting emission for dilution of diesel exhaust so that all pollutants are below the Threshold Limit Values (TLV).⁴ If the mass flow rate of SO_2 is desired in any mode of the engine,

it can be calculated with the following equation:

$$(\text{SO}_2)_{\text{mass}} = 0.06 \times (\text{SO}_2)_{\text{conc}} \times \dot{m}_{\text{exh}}, \quad (8)$$

where

$$(\text{SO}_2)_{\text{mass}} = \text{mass flow rate of } \text{SO}_2, \text{ grams/hr.}$$

⁴TLV of Airborne Contaminants and Intended Changes--Adopted by ACGIH for 1970, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio. Permissible 8-hr exposure values are: CO_2 , 0.5 percent; CO, 50 ppm; NO, 25 ppm; NO_2 , 5 ppm; and SO_2 , 5 ppm.

TABLE 3. - Sulfur levels in diesel fuel--1972 (17)

Fuel type	Sulfur content, percent by mass				
	Minimum average		Average	Maximum average	
	Actual	Minimum ¹		Actual	Maximum ¹
Diesel No. 1 ² (from type C-B fuels).....	0.0062	0.005	0.065	0.18	0.29
Diesel No. 2 ² (from type T-T fuels).....	.025	.005	.23	.61	1.10

¹ Both the average maximum and minimum throughout the five regions of the United States and the actual maximum and minimums found were reported to give a more accurate picture of these extremes.

² In accordance with the American Society for Testing and Materials Standard Classification of Diesel Fuels Oils (D975 in Annual Book of ASTM Standards: Part 17, Philadelphia, Pa., 1973, pp. 325-328).

Summary of Present Diesel Engine Gaseous and Smoke Emissions

It is useful to examine what future diesel engine emission standards will be since one of the original points of this paper was that these future standards will provide the technology for making the diesel more acceptable for mining applications. Table 4 illustrates presently known heavy-duty truck standards for new vehicles sold in California and nationwide. The 1975 California Standards will require low hydrocarbon and NO emission engines while some smoke reduction particularly the acceleration smoke from turbo-charged engines will be required nationwide in 1974. It should be noted that

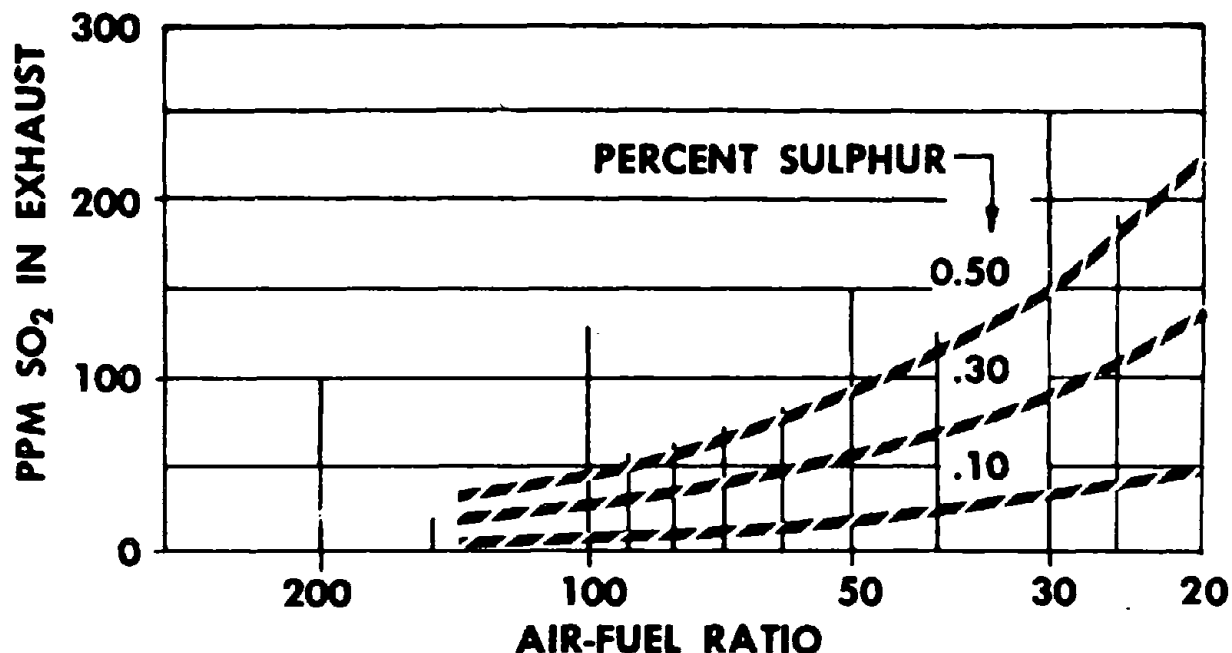


FIGURE 27. - Effect of percent sulfur in diesel fuel on sulfur dioxide emissions assuming all sulfur is converted to SO₂ (10).

the CO standards to date have been based on the technology available for gasoline engines, and diesel CO emissions are considerably lower than the standards.

TABLE 4. - California and Federal new diesel emission standards for heavy-duty trucks

Year	California		Federal				
	Gaseous emissions ¹		Gaseous emissions ¹		Smoke ³		
	² HC - NO _x , g/bhp-hr	CO, g/bhp-hr	² HC + NO _x , g/bhp-hr	CO, g/bhp-hr	Acceleration, percent opacity	Lugging, percent opacity	Peak, percent opacity
1973..	16	40	-	-	40	20	-
1974..	16	40	16	40	20	15	50
1975..	5	25	16	40	20	15	50

¹13-Mode Test Cycle (1).

²Hydrocarbon.

³Federal Smoke Test Cycle (1).

Table 5 illustrates the levels of hydrocarbons, CO, NO₂, particulates (smoke), and CO₂ on the 13-mode cycle for a number of different engine designs. The smoke emissions data on the Federal Smoke Cycle are also shown. In general, the prechamber turbocharged engine was lowest when considering all emissions, but turbocharged direct-injection engines of the design similar to Engine F would be very close to the emissions from Engine I.

TABLE 5. - Brake specific emission rates for diesel engines

Engine	Gaseous emissions, g/bhp-hr (18)					Smoke emissions (18)	
	Hydrocarbons	Carbon monoxide	Nitric oxide (as NO ₂)	Particulates	Carbon dioxide	Acceleration mode, percent opacity	Lug mode, percent opacity
4-STROKE CYCLE, NATURALLY ASPIRATED, DIRECT-INJECTION							
A.....	1.9	10.0	8.7	0.6	755	16.0	18.5
B.....	3.1	4.2	6.7	.6	595	10.0	12.5
C.....	3.0	5.8	19.8	.1	633	3.0	3.0
D.....	3.1	4.9	16.7	-	633	3.0	3.0
E.....	2.3	5.6	9.5	.2	570	25.0	12.4
F.....	.6	5.7	6.9	-	693	11.4	13.3
4-STROKE CYCLE, TURBOCHARGED, DIRECT-INJECTION							
G.....	3.1	3.9	17.8	.2	691	14.7	5.5
H.....	2.6	4.9	11.7	.3	677	14.7	5.5
4-STROKE CYCLE, TURBOCHARGED, PRECOMBUSTION CHAMBER							
I.....	0.3	2.3	6.1	0.4	694	19.7	2.2
2-STROKE CYCLE, DIRECT-INJECTION							
J.....	0.7	6.1	14.7	-	640	8.8	3.0

Therefore, to date, prechamber turbocharged aftercooled engines, in general, exhibit the lowest all around gaseous and smoke emissions while yielding high, specific output power. Direct-injection turbocharged aftercooled engines exhibit emissions characteristics in the laboratory only

slightly higher than that for all emissions. There appears to be little fuel economy difference between these two types of engines. One disadvantage of prechamber engines that will probably always exist throughout this development is the fact that its greater heat rejection to the coolant requires 30 to 50 percent larger radiators than equivalent horsepower direct-injection engine installations.

Effect of Engine Design Variables

This paragraph will briefly illustrate several design variables that

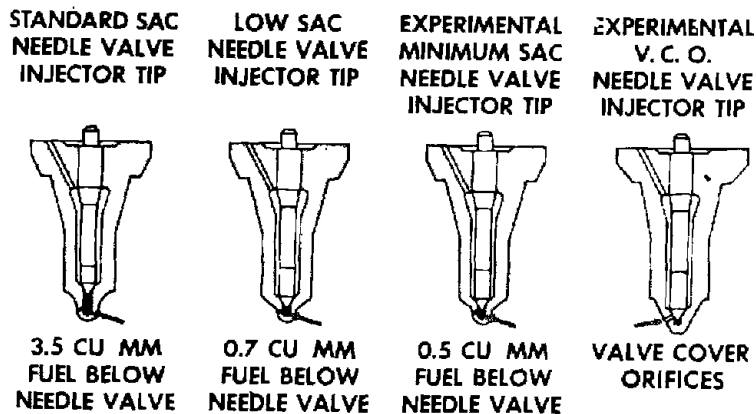


FIGURE 28. - Comparison of various needle valve injector tip sac volume designs (6).

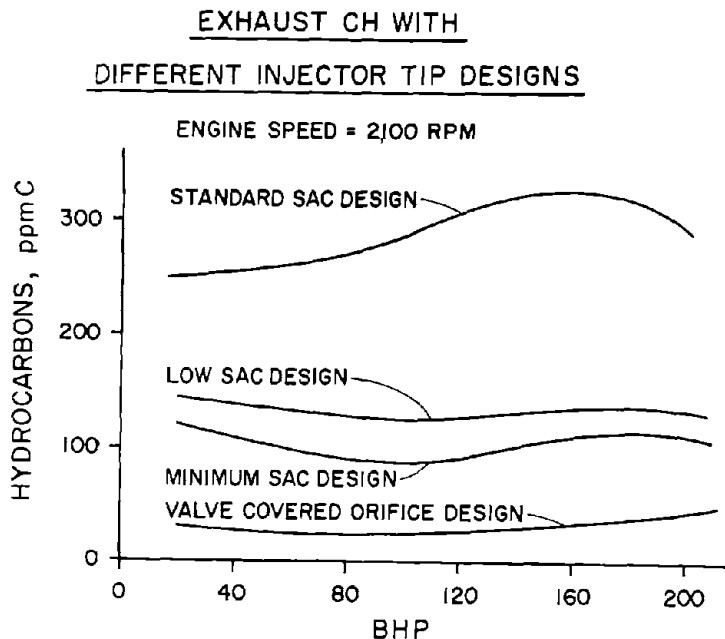


FIGURE 29. - Effect of injector tip sac volume on exhaust hydrocarbon (HC) emissions (6).

engineers can vary to optimize and reduce emissions. This is by no means a complete discussion and more complete papers on the effect of design and control system variables on gaseous emissions and smoke for different types of engines can be found in the references (1, 3, 6, 8-10, 12).

Figure 28 shows several design variations of the sac volume contained in the injector tip of a two-cycle direct-injection engine (6). The reduction of this volume reduces one of the three sources of hydrocarbons as previously discussed. Figure 29 shows the hydrocarbon concentration plotted versus the brake power output at the constant rated speed of 2,100 rpm (6).

An additional important variable is the time in the cycle that the fuel is injected into the cylinder. Figure 30 shows the effect of injection timing on nitric oxide emissions for various injection timings at standard, 3.4 CA° and 5.0 CA° retard for a two-cycle direct-injection engine (6) at rated speed of 2,100 rpm. As injector timing is retarded from optimum for maximum

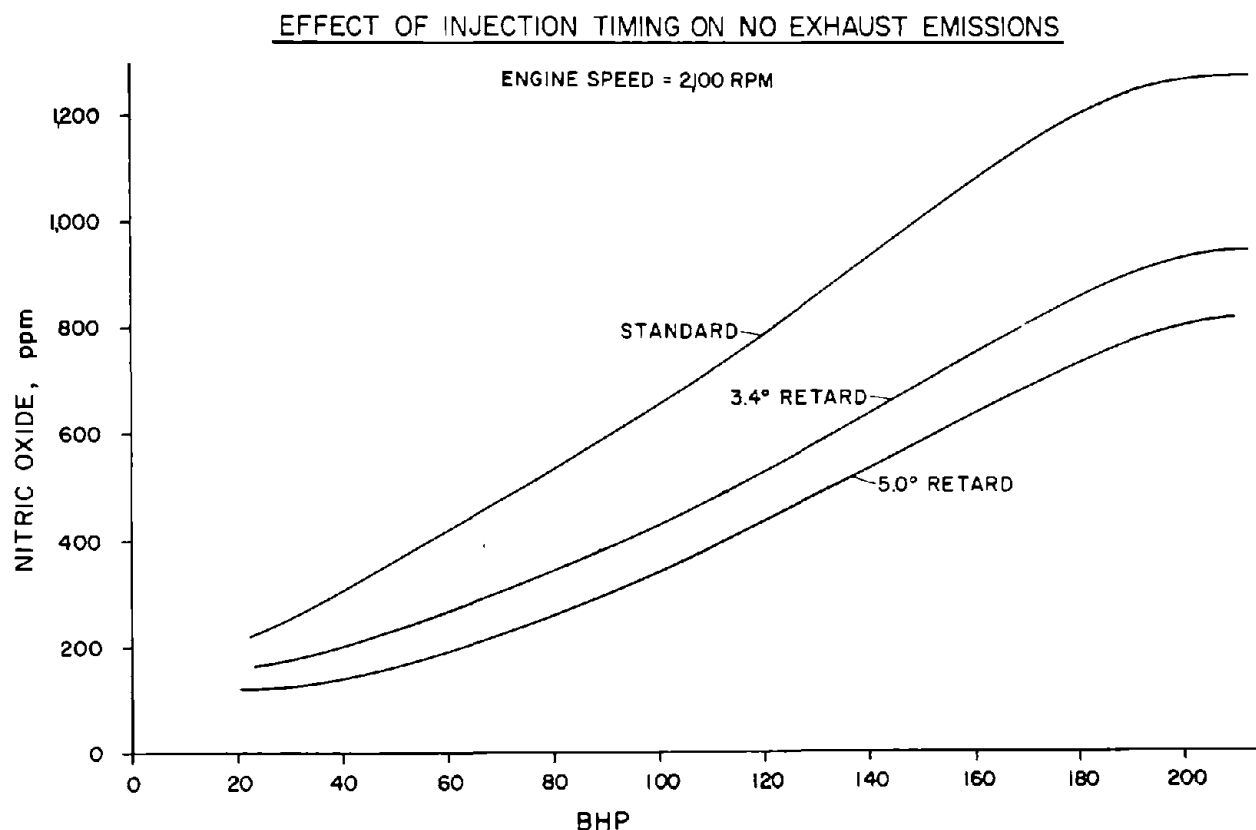


FIGURE 30. - Effect of injection timing on nitric oxide (NO) exhaust emissions (5).

performance, NO emission levels are decreased throughout the engine speed and load range. Peak temperatures and the time available for formation of NO are reduced as the injector timing is reduced.

These data briefly illustrate the effect of several design variables. One important fact that must be kept in mind is that some engine design variables tend to reduce one or two dependent variables but increase others. In the case of the injector timing retard, smoke and fuel consumption are increased. Hence, in developing an engine, careful attention must be given all the dependent variables of interest in producing an optimum engine. Briefly, these are the three gaseous emissions of hydrocarbons, CO, and NO, and smoke; from an engine performance standpoint, one is also interested in brake specific fuel consumption (lbm of fuel/bhp-hr), peak cylinder pressure and rate of pressure rise during the combustion process. The cylinder pressure and rate of cylinder pressure rise have a direct effect on the peak loads on the various mechanical components and hence, affect the durability of the engine. As stated early in the paper, the development of an optimum diesel engine for mine vehicles and equipment requires careful design consideration to a number of different and sometimes competing engineering performance factors.

CONCLUSIONS

Several general conclusions can be drawn from the material presented.

1. There has been during the past 5 years an intensive engineering effort directed toward developing test procedures for use in the development of diesel engines of low gaseous and smoke emissions.

2. This intensive development will continue during the next 5 to 10 years because of the need for further emissions reductions and because there is an ever-expanding diesel market. The diesel engine is the powerplant of the present and the future for mobile vehicles since it offers low emissions and high thermal efficiency which is important for overall minimizing the impact on fuel reserves and providing low ambient levels of pollutants.

3. The design of a diesel engine for mining operation takes careful engineering design and development by the engine manufacturer. This must be followed by additional sound engineering by the vehicle and equipment builders to provide an overall vehicle of low exhaust emissions and of low noise levels. In order that excessive design is not built into either the engine or vehicle, the Bureau of Mines must thoroughly develop performance standards that provide for the health and safety of the individual miners. In general, these standards should be related to performance levels to encourage design creativity in both the engine and the vehicle. Finally, whenever particular components are required in the engine-vehicle installation, their function and purpose should be well documented.

4. The performance of these diesel powered vehicles and equipment for the mine will be only as good as the service and maintenance they receive, and in turn, the health and safety of the miner will be directly related to this maintenance and service much in the same manner as the original design of the engine and vehicle. To insure that careful maintenance and service is carried out requires acceptance of this responsibility by the mine management and each individual worker. In addition, there are many technological aids such as the computer, engineering oil analysis techniques, and training schools to assist in this maintenance and service effort.

5. Diesel engines can be further developed for mine applications including lower seam height (under 80 inches) mines since considerable technology is available to improve their emission levels, noise, and specific volumes over present engines used in mining. It is also clear that the size of the market and the constraints of future regulations will determine the rate of application of this technology to the mine vehicle and equipment market. This last point is valid because considerable engineering design and testing is required by both the engine and vehicle builder, and if the market is small, little economic incentive will result because of the high engineering costs per engine and vehicle.

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DR. HUNTON: You heard Donald Schlick make mention of the work being done by the Bureau. This morning we have Richard W. Hurn, who is in charge of Fuels Combustion Research at the Bureau of Mines Bartlesville Energy Research Center, Bartlesville, Okla. He is currently responsible for research on engine and fuel technology for improved fuel economy with acceptable pollution characteristics.

Mr. Hurn joined the Bureau of Mines in 1948, after having been employed by Humble Oil and Refining Company for 8 years in various field engineering positions.

He holds degrees in mechanical engineering from Texas Technological College and the University of Wisconsin. He is a member of the Society of Automotive Engineers and the Air Pollution Control Association, and he is a registered professional engineer and member of that group's national and State societies.

DIESEL EMISSIONS MEASUREMENT AND CONTROL

by

R. W. Hurn¹

INTRODUCTION

Other papers prepared for presentation in this symposium will have described the diesel engine broadly. These other papers will have outlined the distinguishing features of the diesel engine as compared with a spark ignition engine and will have described the general characteristics of combustion products from the diesel family of engines. In contrast to the broad descriptions in other papers that address diesel engine characteristics, this paper is intended to focus upon one aspect of diesel engine use--control of its exhaust product.

To place the problems of diesel emission control in proper context, it would be well to attempt a correction of two widely held misconceptions about the characteristics of the diesel engine. Oddly, the two are diametric opposites, and as so often is the case, the truth lies between the two opposites. The first of the two misconceptions is that the diesel, by its inherent nature, produces a dirty exhaust--dirty in the sense of being heavily loaded with objectionable pollutants. The fact is that diesel exhaust is not inherently "dirty." In fact, in comparison with spark ignition engines typical of production only a few years ago, the diesel produces exhaust that is relatively "clean." A well-designed, well-adjusted, well-maintained diesel engine need not smoke excessively, need not produce malodorous exhaust, and typically will produce carbon monoxide only at very low concentrations compared with unmodified exhaust of the spark ignition engine.

The second of the misconceptions is that the diesel engine does not--even by some representations cannot--produce toxic exhaust. The fact is that a diesel engine typically does produce toxic gases, and it is indeed a very dangerous misconception to hold that the diesel generates no toxic material. The point of emphasis is the need to understand that diesel engines do in fact produce toxic combustion products but that the diesel family is not inherently "dirty" and that the toxic products are controllable at acceptable levels.

CHARACTERISTICS OF DIESEL EXHAUST

It is an axiom of control technology that in order to control, one first must measure; further, that to measure one must know the characteristics of the mixture upon which measurement is to be made. Above all, if measurements are to be made reliably, the influences that bear upon or affect the measurements must be known, and if possible, understood. Therefore, because it is

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well to understand the influences that bear upon diesel emission measurements, it would be well first to briefly review the nature of the diesel toxicity hazard. Knowing the nature of the hazard, one can then more effectively approach the all important preventative measures that involve anticipation and detection of potentially hazardous conditions.

The pollutants generated in the diesel combustion process are depicted graphically in figure 1. (In referring to this illustration, one should note the logarithmic scale and carefully avoid linear interpolation of the height representations.) In typical diesel combustion, 1 pound of fuel produces approximately 200 cu ft of exhaust gas. This 200 cu ft volume is made up of approximately 20 cu ft of CO_2 and roughly $1/3$ cu ft each of CO and NO_x , with the remainder being free nitrogen and water vapor. As will be addressed by papers of this conference, the pollutants of most concern in this inventory are CO and NO_x . However, in considering the problem of diesel exhaust, attention must be given to CO_2 because of the two following considerations:

1. CO_2 constitutes a large portion of the combustion product and represents a sizable volume of gas to be managed, and
2. it does have physiological effects such that it is not acceptable in breathing air at concentrations exceeding $1/2$ percent.

Insofar as the engine is concerned, the CO_2 and water of the combustion product if mixed back into the engine's air supply do, in effect, replace oxygen consumed from the air. This process leads to an oxygen starvation (of the engine) that will be discussed later.

It therefore follows that the combustion product, if not adequately disposed of, poses two problems, (1) toxicity and (2) oxygen deficiency for the engine. Essentially, in underground operations, the problem of diesel engine combustion product management is a problem of disposal. In this context the role of ventilation should be understood as serving to transport and to remove undesirable products as well as serving to supply fresh air. More precisely stated, the primary problem in connection with diesel operation underground is the problem of scavenging the toxic and oxygen deficient material from the occupied space; the controllable hazard from diesel exhaust becomes imminently dangerous only when the occupied working space is inadequately scavenged of the combustion products.

THE HAZARD FROM INADEQUATE VENTILATION

To better understand the hazard, one might examine what happens when adequate ventilation is denied an engine working in a confined space, and further, how one is to detect and protect against such a hazard. Figure 2 depicts an experimental rig in which the case of an engine operated in a confined space is experimentally reproduced by operating an engine outside a test chamber, but with both its exhaust and intake connected into the chamber. In this case, the chamber simulates the volume of a confined working space in which combustion product is mixed with the air that supplies both engine and operator.

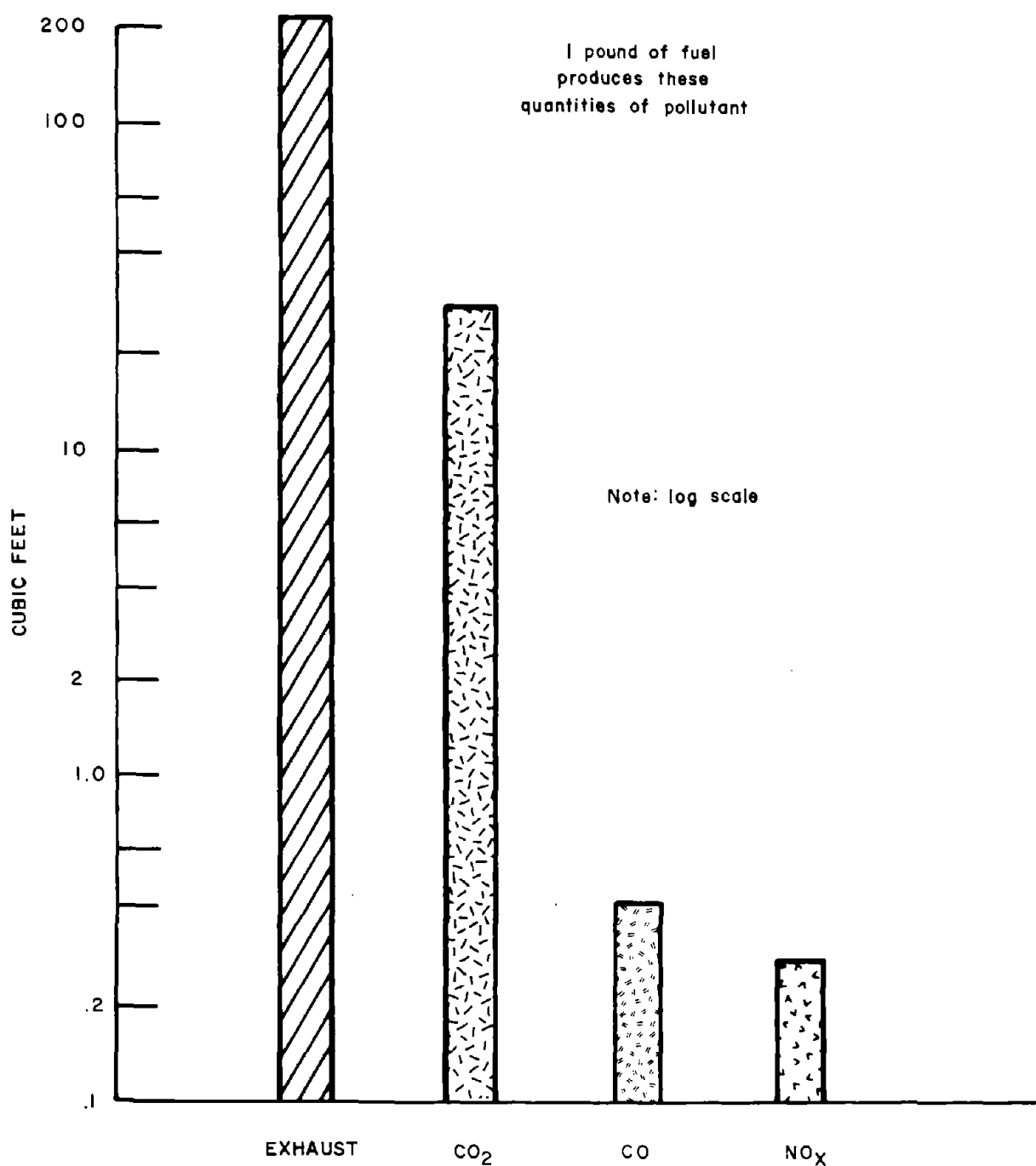


FIGURE 1. - Products of diesel combustion.

When an engine is operated in such fashion as to recycle a portion of its combustion product into the intake, as shown in figure 2, the resulting concentrations of combustion product and oxygen in the air mixture are shown in figure 3. Several changes occur simultaneously; obviously, the combustion process consumes oxygen from the available supply, and oxygen concentration decreases with time. Simultaneously, CO₂ concentration increases. The CO

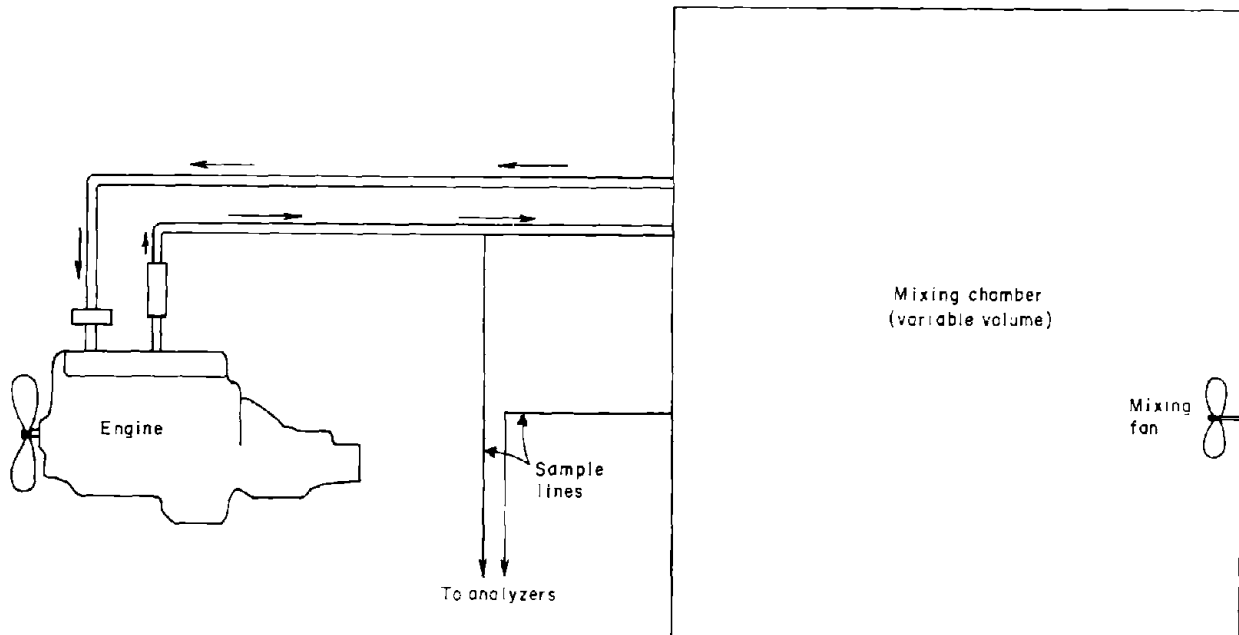


FIGURE 2. - Test arrangement simulating operation of an engine in closed environment.

concentration also increases; the increase initially represents a simple linear accumulation of the CO that is produced at the relatively low concentrations typical of diesel combustion. However, as oxygen is consumed from the intake air supply, the fuel-to-oxygen ratio in the combustion rises steadily, and production of CO begins to increase exponentially. The result is that at some point in time the concentration of CO in the exhaust increases rapidly with a parallel rapid increase in the CO content of the air/exhaust mixture. It is very important to understand the self-accelerating characteristic of the CO buildup.

The situation with respect to NO_x buildup in the confined space is shown in figure 4. In this case, the level of NO_x in the air initially increases with accumulation of the exhaust product. However, with increased concentrations of CO_2 in the engine's intake air and with the parallel decrease of oxygen available in the combustion process, the amount of NO_x produced by the engine decreases. The net result is that the level of NO_x concentration in the air-exhaust mixture first builds, and then declines. The overall result of the process of combustion product accumulation and the resulting exhaust rebreathing is that CO builds at an ever-accelerated rate while NO_x builds to a peak and then decays. The peak level of NO_x in such a case is far short of a critical level² and therefore in this type of exposure CO clearly presents the short-term critical hazard.

²Critical in the sense of posing threat of immediate danger or serious consequence of short-term exposure.

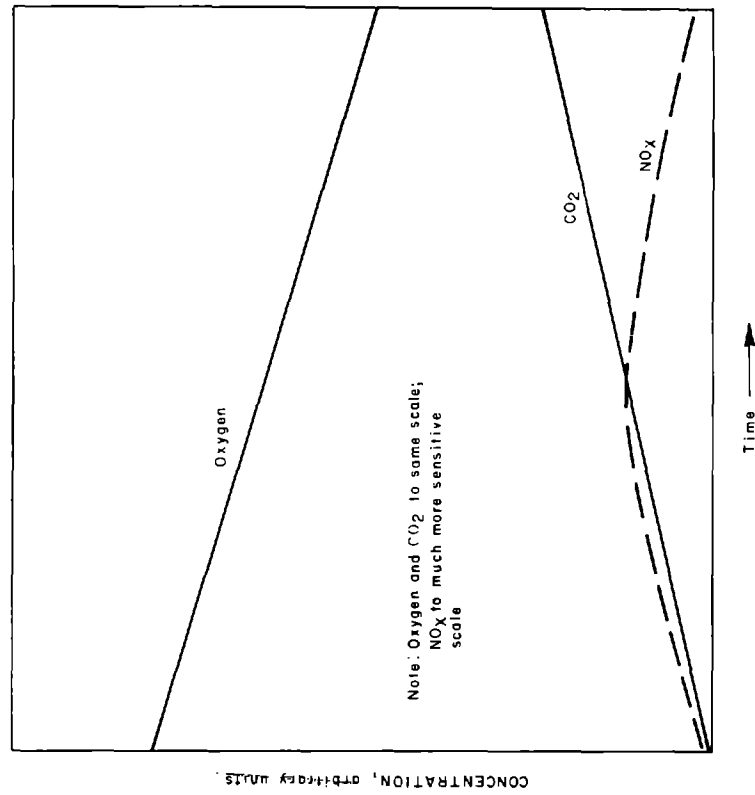


FIGURE 4. - Contamination and oxygen depletion accompanying diesel engine operation in closed system (trend for nitrogen oxide).

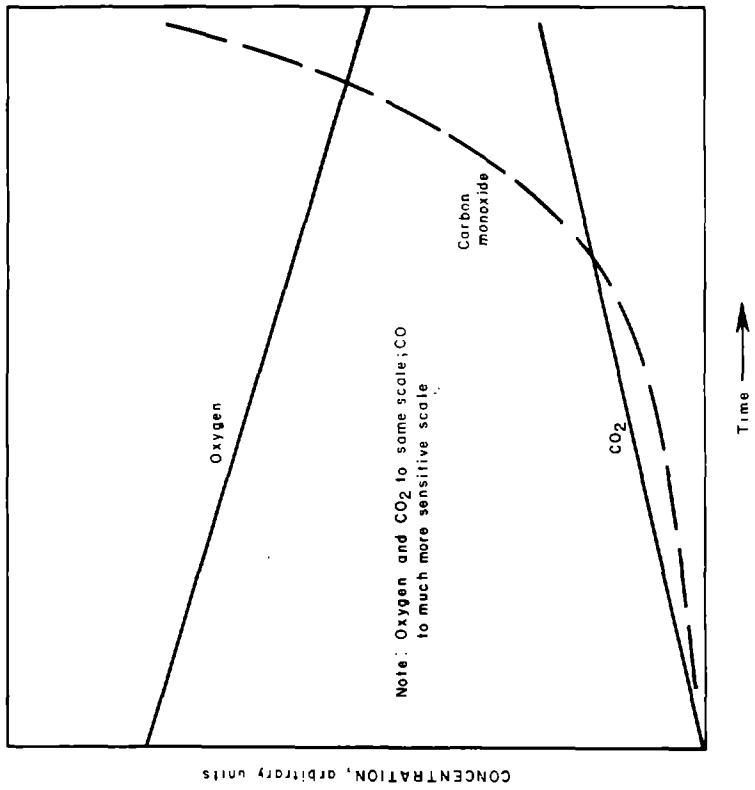


FIGURE 3. - Contamination and oxygen depletion accompanying diesel engine operation in closed system (carbon monoxide buildup).

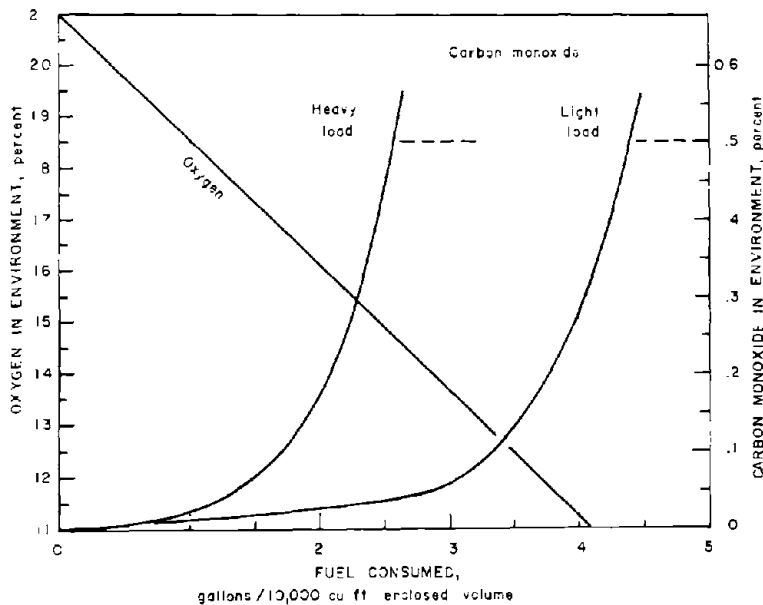


FIGURE 5. - Development of hazardous carbon monoxide concentration by an engine operated in closed environment.

The representations in figures 3 and 4 are stylized. Actual data from experimental work are shown in figure 5. In this graph the concentrations of CO and oxygen are shown as functions of the amount of fuel burned per unit volume of air with which the exhaust will be mixed. This, of course, also is the reservoir of air from which the engine oxygen supply is drawn. From figure 5, it may be noted that the relationship of CO concentration to the amount of fuel burned varies with the load upon the engine. The effect is readily explained in terms of the fuel-air metering characteristics of the diesel engine. As load

is increased in a diesel, the fuel-air ratio increases with load; in an oxygen deficient atmosphere, fuel-rich mixtures that result in high CO levels would be encountered at a lower power setting than would be the case with intake air of standard oxygen content. The point of the graph of figure 5 is that, in the case of an engine rebreathing its own exhaust, the CO hazard is markedly accentuated in the case of engines working under heavy load.

THE DETECTION OF POTENTIALLY HAZARDOUS EXHAUST CONDITIONS OF INADEQUATELY VENTILATED ENGINES

Without question, the most important aspect of safety protection is to guard against the existence of an unacceptably hazardous condition. The second most important aspect of safety protection is to detect and to correct a potentially hazardous condition. In the case of the diesel underground, this second aspect poses the question of how one best detects a problem of inadequate ventilation, or put more directly, how one detects the presence of a too high residue of the combustion product. The first reaction logically might be to suggest measurement of the toxicant of primary concern, which, in the case of the inadequately ventilated engine, is CO. However, a better choice may be the measurement of CO_2 as the indicator of inadequately scavenged combustion product. The reasons for such a choice are primarily as follows:

1. CO_2 is produced in quantity, that is, for practical purposes, directly and linearly dependent upon the amount of fuel burned. The concentration of CO_2 residual in the air is therefore probably the most valid indicator of the total level of combustion products present.

2. CO_2 is typically present in a concentration that is two orders of magnitude higher than the corresponding concentration of CO.

3. By instrumental techniques that are presently available, CO_2 is measured with greater reliability than any other of the combustion products.

These three considerations taken into account, a strong case is made for the measurement of CO_2 as the indicator of the amount of residual combustion product in the atmosphere. Moreover, the measurement of CO_2 does provide in effect an acceptably reliable indication of the probable level of CO. The justification of this is to be found in the data of figure 3 in which it can be seen that at low levels the concentrations of CO and CO_2 are in constant ratio. This relationship is depicted more clearly by showing data for only the low concentration range as in figure 6. In typical diesel combustion, CO will typically be present in the ratio of approximately 40 to 100 ppm CO per 1/2 percent of CO_2 . While this may appear to be a rather large range of CO values, for indication and for alarm purposes, the spread would appear to be, in fact, quite acceptable. Moreover, considering the much greater precision with which CO_2 can be measured, it would appear that the CO_2 measurement may provide a more reliable indication of the CO hazard than a measurement of CO directly. Therefore, in the Bureau of Mines development of mine monitoring instruments, emphasis to date has been placed upon the use of CO_2 as the indicator of residual exhaust contamination. Following this philosophy, development work has been underway for approximately 2 years toward an instrument that might be mounted on diesel equipment to monitor continuously its intake air. In such use, when the CO_2 concentration in the intake air reaches 1/2 percent, an appropriate alarm would be sounded. This condition would signal two occurrences--(1) the onset of a status in which CO concentrations probably were approaching or exceeding the Threshold Limit Value (TLV) and (2) a diminution of oxygen supply to the engine and possible development of a progressively deteriorating situation in which the generation of CO could accelerate and pose serious, or even critical, CO toxicity hazard. At this point in time, immediate corrective action would be indicated.

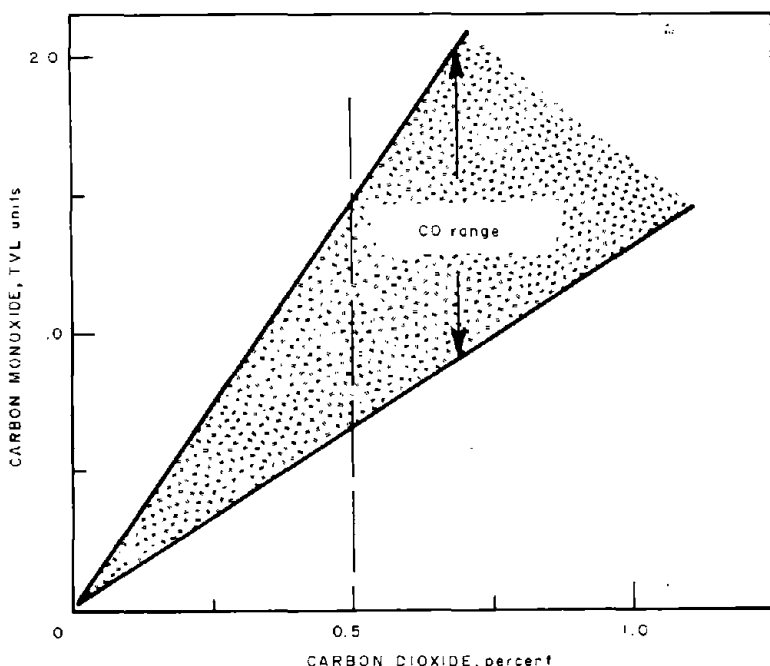


FIGURE 6. - Correspondence of carbon monoxide to carbon dioxide concentration in exhaust gas residue. (Note: 1 TLV unit equals 50 ppm carbon monoxide).

THE CONTROL OF DIESEL EMISSIONS

In controlling diesel pollutants in mine atmospheres, two approaches are possible--(1) accepting emissions from the engine at any level and providing ventilation air adequate to reduce the concentrations of

toxicants to acceptable levels, or (2) minimizing the amount of toxic material produced by the engine and thereby minimizing the amount of ventilation required. An argument using economic justifications can be made for the first case and, in fact, the proposition has merit. However, there is no question but that in the totality of the mine safety problem, the hazards from toxic substances are reduced by reducing the amount of toxic material that is introduced into the system. Therefore, it does appear appropriate to address the question of minimizing the amount of the toxic material discharged by an engine used underground.

In considering the reduction of diesel pollutants to the minimum level, one might assume that measures could be taken to reduce these pollutants virtually to the vanishing point. However, such is not the case within the limits of available technology. The data of figure 7 illustrate this fact. As earlier pointed out, in any process in which hydrocarbon is burned, CO_2 is produced in direct ratio to the amount of fuel that is burned. Typically, CO and NO_x accompany CO_2 as combustion products in the relationship shown in figure 7. To a degree, the production of CO and NO_x can be markedly suppressed, but for a given amount of fuel burned (or work to be done), the production of CO_2 cannot be reduced. The only way to avoid its discharge into a system such as the mine would be to remove it from the combustion product, and for the moment, there appears to be no near-term prospect of a feasible means by which this is accomplished. Therefore, inasmuch as the production of CO_2 is irreducible, it then follows that the minimum ventilation required for an engine is the amount of ventilation that is required to reduce CO_2 to its acceptable level. It further follows that if the minimum ventilation based on

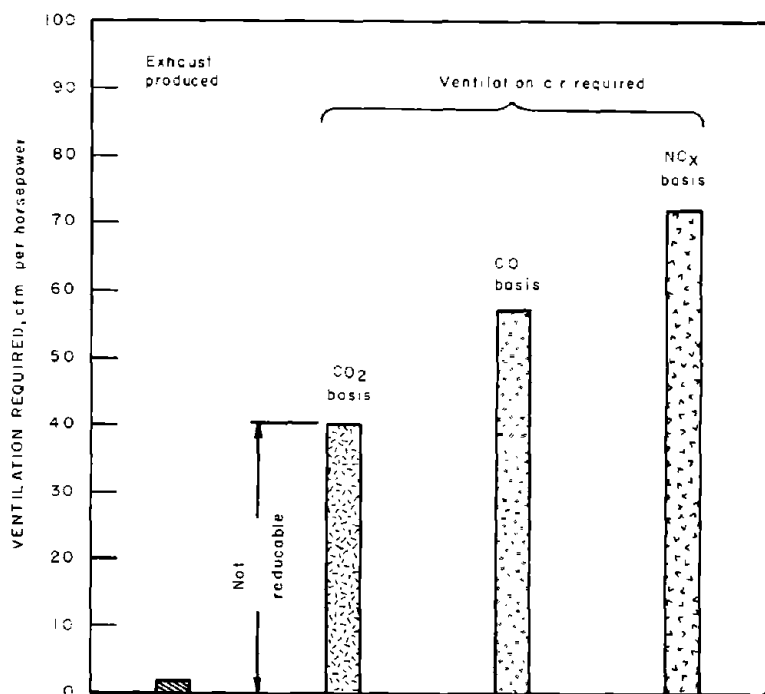


FIGURE 7. - Dependence of ventilation requirement upon toxicants.

CO_2 is to be acceptable, the TLV of CO and NO_x must be achieved with that ventilation. A current Bureau of Mines target in its study of low emission diesel engines has therefore been to achieve control of CO and NO_x at such emission levels that the CO_2 concentration controls ventilation requirements. Another way to express this is to say that for the ventilation requirements to be minimal the ratio of CO to CO_2 and similarly the ratio of NO_x to CO_2 in the engine exhaust must be equal to or less than the ratio of the respective TLV for these gases.

Several technical measures are available to control the objectionable

diesel emissions. The options in controlling NO_x are summarized as follows:

To control NO_x	}	Exhaust gas recirculation
		Fuel injection modifications:
		Timing retarded
		Rate increased
		Water injection

Oxides-of-nitrogen levels in the combustion process are markedly lowered by controlled recirculation of a portion of the exhaust gas into the intake air of the engine. Here we should note that controlled recirculation of exhaust can be a desirable thing, but that such controlled recirculation is to be clearly differentiated from uncontrolled recycle, or rebreathing, which can present a serious toxicity hazard. Oxides of nitrogen production can also be effectively suppressed by certain modifications to the fuel injection schedule and/or by the addition of water to the fuel-air mixture. Experimental data that illustrate the effectiveness of these control measures are shown in figures 8 and 9, which provide information on effects of exhaust recirculation and water injection, respectively. Inasmuch as it is not the purpose of this

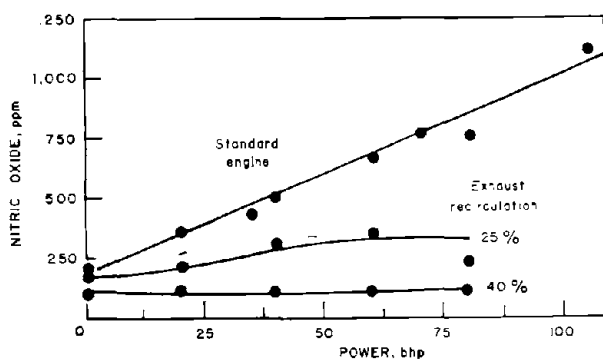


FIGURE 8. - Exhaust recirculation to control oxides of nitrogen.

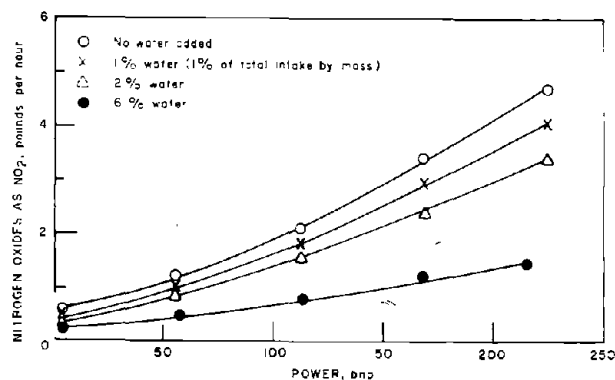


FIGURE 9. - Effectiveness of water injection in nitrogen oxide control.

paper to explore technical data in detail, these data are not discussed. Further details are readily available in reference material.

Methods to control CO, hydrocarbon, and odor are summarized as follows:

To control CO, HC, and odor

Catalytic conversion or
treatment of exhaust

Fuel injection refinements

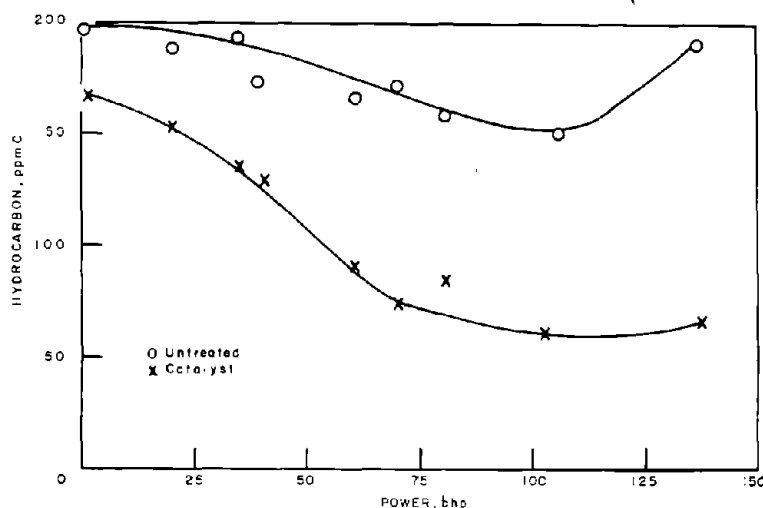


FIGURE 10. - Hydrocarbon reduction by catalytic conversion.

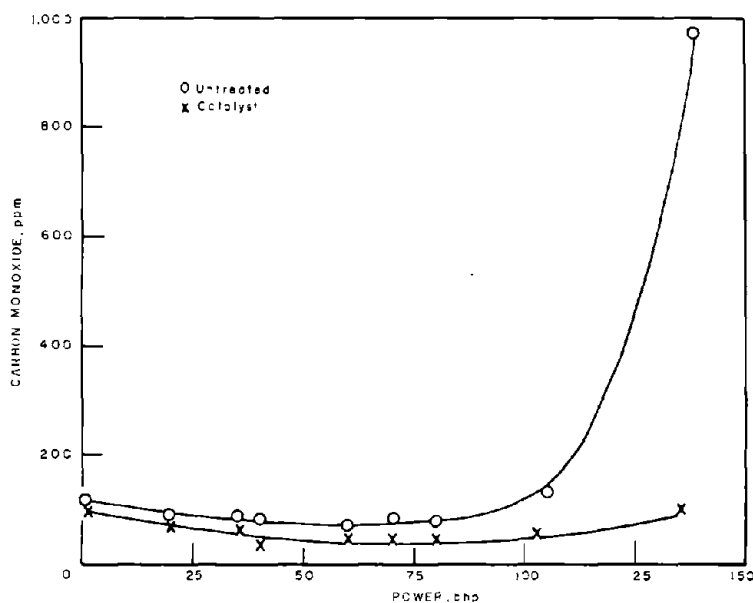


FIGURE 11. - Carbon monoxide emission control by catalytic conversion.

Of the two methods shown, catalytic conversion of the residual CO, unburned fuel, and odoriferous materials has for years been utilized in certain applications of engines in confined spaces. This method of exhaust product control unquestionably will find increased use and promises to be an important option in the control of emissions of diesels used underground.

Highly significant progress in decreasing the amount of unburned hydrocarbon and odoriferous material in the exhaust has been made also through refinement of the fuel-injection process. Still further improvement may be anticipated in some lines of equipment. Suffice it to say that, with emission control as a design criteria, one may expect further close and sustained attention to the fuel-injection process.

Experimental data showing the excellent effectiveness of catalysts in reducing CO and hydrocarbon are shown in figures 10 and 11. For the reasons indicated above, these data are not further discussed but there is a growing body of technical literature from which details may be obtained.

Although smoke has not been considered as a pollutant in the context of toxicity, the problem of diesel smoke is, without question, of interest in connection with the use of diesels underground. Heavy smoking from diesel equipment quite obviously would not be acceptable, but we need here only note that there are technical means by which diesel smoke may be controlled at acceptably low levels. The options, summarized below, are principally turbocharging and limitations upon maximum power withdrawn from the engine.

To control smoke	{	Turbocharging
	{	Power limitation

In connection with smoke control, it may be noted that maintenance of diesel engines, particularly maintenance of fuel injection equipment to give proper fuel distribution and fuel spray characteristics, is critically important. Operators might therefore anticipate the need for well-organized, tightly disciplined maintenance procedures. Such maintenance probably would be also consistent with the degree of maintenance required to assure acceptable levels of CO.

SUMMARY

In a recapitulation of the status of diesel emission control, the following summary is indicative of current status:

To control smoke	{	Turbocharging
	{	Power limitation
To control CO, HC, and odor	{	Catalytic conversion
	{	Fuel injection refinements
To control NO _x	{	Exhaust recirculation
	{	Water injection
	{	Modify fuel injection, timing, and rate

Of the options that are shown in this summary, turbocharging, power limitations, modifications of diesel injection schedules, use of catalytic converters, and refinement of the fuel injection process have been, or are being, incorporated in diesel equipment operating today. Exhaust recirculation and water injection have not seen use in production equipment and may not be used if the other measures prove to be adequate. However, both exhaust recirculation and water injection are viable options, if necessary, in the control of NO_x at acceptable levels.

DR. HUNTON: Ladies and gentlemen, we have time for two questions. Are there any curiosities to be resolved at this moment?

DR. HUNTON: There being none, Mr. Hurn, we thank you.

MR. POUNDSTONE: All right. After having heard from the academic community and from Government, for the third paper this morning, we will turn to an engine manufacturer and Mr. Don Henderson, who is the Emissions Control Manager--that is not mission control, but rather emission control--of Caterpillar Tractor Co. Mr. Henderson comes from Colorado. He holds a mechanical engineering degree from Colorado State University and has work experience in research with Caterpillar Tractor Co. and in various supervisory and staff positions.

DIESEL TECHNOLOGY

by

R. D. Henderson¹

INTRODUCTION

The diesel engine was brought to the United States in 1898 by Adolphus Busch who thought it would provide cheap power for factories, lighting plants, etc. The first engines were large and heavy, entirely unsuited for mobile or portable equipment. The development of lighter weight diesel engines in the United States started around 1919 with increasing impetus during the 1920's. Caterpillar Tractor Co. introduced diesel-powered track-type tractors in 1931.

During the last 40 years, the diesel has developed as a heavy-duty powerplant with high reliability, long life, and high efficiency. Modern truck diesels operate at high load factor and run from a third to a half million miles without overhaul. Diesels powering construction machinery run many thousands of hours before needing repair. Although more rugged, these engines are no more complicated than those in your automobile.

In addition to its record for high reliability and long life, the highly efficient diesel has made a major contribution in the conservation of our precious fuel reserves. In 1912, when Dr. Diesel was honored by the American Society of Mechanical Engineers, he said, "The diesel engine has doubled the resources of mankind as regards power production." Today, the diesel continues to do more work while using less fuel than other mobile powerplants.

It is unfortunate that the economic acceptability of the diesel has not been coupled with social acceptability. The reputation of the diesel has suffered because of smoke and odor from some early engines and from those which have not been adjusted and maintained according to the manufacturer's recommendations. Today, odor is not a necessary characteristic and engines are being built which are relatively smoke free.

The diesel engine is a relatively low emitter of the invisible emissions, carbon monoxide and nitrogen oxides, which are of concern to the health and safety of miners. Because of its low emission characteristic, the diesel engine has been used in underground mines and tunnels for many years. Later sessions during this symposium will report on the widespread use of the diesel engine in mines and the operating experience from the health and safety standpoint. Low emissions and the use of a nonvolatile fuel provide a solid basis for selecting the diesel for mining machinery power while protecting the health and safety of the people working in the mines.

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Diesel State-of-the-Art

A previous speaker has discussed the different types of diesel engines and their emission characteristics. The present state-of-the-art for available engines might best be presented to you by selecting a size which can be used in a piece of coal mining machinery such as a shuttle car and comparing performance. If we assume 135 horsepower and disregard temporarily the space required for the engine, Caterpillar has two naturally aspirated engines which can be considered. A smaller, turbocharged engine will not be considered because of surface temperature limitations which will be discussed later.

The first engine is a Model D333C precombustion chamber type, with six cylinders, a 4.75-inch bore by 6.0-inch stroke with a 638-cubic-inch displacement. Since it is rated at 2,000 rpm in some Caterpillar earthmoving machines, this speed was selected. Torque rise of 13 percent at a torque peak speed of 1,200 rpm was also selected as typical. The second engine is Model 3160, a direct-injection, open-chamber V8, with 4.5-inch bore and 5.0-inch stroke, and 636-cubic-inch displacement. This engine was designed for higher speed, but only medium duty service. Since it is rated at 2,200 rpm in the Caterpillar 613 Scraper, this speed was chosen. Again, 1,200 rpm is the torque peak speed and 13 percent torque rise was selected.

Information of interest for mine atmosphere control is shown in the following tables. It was decided to show performance at rated speed and load, at maximum torque, and at low idle. Since these points do not represent the average operation of the engine, the weighted averages obtained from the 13-mode test prescribed by California and the Environmental Protection Agency (EPA) for heavy-duty diesel truck engines are presented to indicate operation over a load and speed range. Since engine data were not available at the exact points shown, the comparisons presented are based on interpolation of actual results. This, plus the normal variation between engines and differences in measurements, suggests that a tolerance of ± 10 percent should be applied when using the emission data.

Mine ventilation must consider the amount of air an engine breathes for combustion. The comparison in table 1 reflects both the difference in rated speed and the breathing characteristics of the two engines which happened to be selected for test work. The 13-mode comparison suggests that the average air consumption of the Model D333C is approximately 18 lb/cycle hp-hr or about 195 cfm over the cycle. The Model 3160 average air consumption over the cycle is about 228 cfm or approximately 22 lb/cycle hp-hr.

TABLE 1. - Engine inlet air flow

Item	Model D333C		Model 3160	
	Lb/hr	Cfm	Lb/hr	Cfm
Rated load and speed.....	1,260	298	1,420	336
Peak torque.....	760	180	780	184
Low idle.....	412	97	420	99
13-mode (weighted average).....	827	195	964	228

When hydrocarbon fuel is burned with air as the oxidant, perfect combustion will result in end products of carbon dioxide, water, and nitrogen.

However, since perfect combustion is not possible, additional products such as carbon monoxide and nitrogen oxides also appear in the exhaust.

Since carbon dioxide can be of concern in mine ventilation, this type of information on the two engines is shown in table 2.

TABLE 2. - Carbon dioxide comparison

Item	Model D333C			Model 3160		
	Lb/hr	Percent	Lb/bhp-hr	Lb/hr	Percent	Lb/bhp-hr
Rated load and speed.....	175	9.8	1.29	155	7.5	1.15
Peak torque.....	110	10.2	1.2	92	8.1	1.1
Low idle.....	8.6	1.4	-	7.6	1.2	-
13-mode (weighted average)...	59	4.9	1.3	51	3.8	1.17

This comparison of carbon dioxide is shown because there is a Threshold Limit Value (TLV) of 5,000 ppm for the protection of health and because the Bureau of Mines has considered relating other pollutant limits to the carbon dioxide. At the maximum concentration shown--10.2 percent--the required exhaust dilution would be slightly over 20 to 1. Since the values shown in table 2 are for dry gas, actual concentrations of CO₂ and the dilution requirements would be slightly lower than calculated.

Carbon monoxide effects are well known and concentrations above the TLV must be avoided. Table 3 shows the comparison of the two engines.

TABLE 3. - Carbon monoxide comparison

Item	Model D333C			Model 3160		
	G/hr	Ppm	G/hp-hr	G/hr	Ppm	G/hp-hr
Rated load and speed.....	127	220	0.94	180	280	1.33
Peak torque.....	68	195	.74	95	268	1.14
Low idle.....	79	436	-	120	660	-
13-mode (weighted average)..	103	275	2.27	205	495	4.7

In this comparison, the precombustion-chamber engine has lower carbon monoxide values in all cases. Carbon monoxide results when fuel is burned without sufficient oxygen present. Since the turbulent mixing of the fuel and air in the precombustion chamber system provides a better opportunity for fuel atoms to find the necessary oxygen, this type of engine is a low emitter of carbon monoxide. In the case of the precombustion chamber, the exhaust gas needs dilution from approximately 4 to 1 to 9 to 1 to reach a TLV of 50 ppm or dilution from 6 to 12 to 1 if 35 ppm is adopted.

The final comparison of the engines is on the basis of the nitrogen oxides emitted. Nitrogen oxides result from the combination of the nitrogen and the oxygen in the combustion air. This occurs if combustion temperatures in the cylinder are high. Most of this material is in the form of nitric oxide as it leaves the exhaust pipe. It reacts with the oxygen in the surrounding air and becomes nitrogen dioxide. Since expected emission limits will probably be calculated as nitrogen dioxide, the comparison in table 4 is

on this basis. Corrections for humidity have been made according to the 1974 EPA procedure for certifying heavy-duty diesel truck engines.

TABLE 4. - Oxides of nitrogen comparison

Item	Model D333C			Model 3160		
	G/hr ¹	Ppm	G/hp-hr ¹	G/hr ¹	Ppm	G/hp-hr ¹
Rated load and speed.....	620	655	4.6	1,260	1,195	9.3
Peak torque.....	303	530	3.3	815	1,385	9.8
Low idle.....	13	44	-	18	45	-
13-mode (weighted average).....	247	329	5.4	450	552	10.3

¹Calculated as NO₂.

This comparison clearly shows the advantage of the precombustion chamber engine when nitrogen oxides are the determining factor. The direct-injection engine, without emission control modifications, will produce roughly twice as much nitrogen oxide as the precombustion-chamber engine doing the same job.

Mine ventilation requirements resulting from engine operation normally hinge on the oxides of nitrogen. The time factor required in the conversion of the nitric oxide in the exhaust to nitrogen dioxide allows some removal from the mine before the reaction is complete. The Bureau of Mines has proposed methods for calculating the required ventilating air flow. Based on one of these methods, a D333C-powered machine would require about 7,800 cfm at the 135-bhp rated point. A 3160-powered machine would require about 15,600 cfm, reflecting the approximately 2 to 1 difference in nitrogen oxide emissions previously pointed out.

Actually, the atmosphere in the mine can be maintained at a safe level without health hazard regardless of the engine selected by introducing sufficient ventilation air. Thus, engine selection becomes primarily an economic consideration. However, it is obvious from the comparison shown that more ventilating air would be required for some engines than others. It now appears that the Bureau of Mines will establish emission limits on the basic engine in addition to the ventilating requirement when the new Schedule 31 is published.

The comparisons also indicate that the ventilation air required for operation over a range of speed and load, as represented by the California and EPA 13-mode tests, is lower than if the machine were operating continuously at full load and speed. In the past, the Bureau of Mines has based ventilation requirements on the maximum rating with operation at levels below that providing an additional safety factor. In the future, when better air-monitoring instruments are available and when energy costs are higher, it would seem appropriate to modulate the ventilating air flow into the mine depending on the working rate of the machine and the number of machines working.

The engine comparison just made has been based on characteristics of engines being produced today. Because of California and EPA emission limits on diesel truck engines, the manufacturers are devoting considerable efforts

to develop engines with reduced emissions. Thus, in the future, it is likely that these control methods can be applied to engines used in mining equipment. These methods may include changes such as optimizing the combustion and fuel injection systems, retarding the injection timing, introducing inert and heat absorbing gases into the cylinder by recirculating some of the exhaust gas back into the inlet manifold, or by injecting water into the engine inlet manifold to reduce the peak combustion temperature. The practical limit of emission reduction has not yet been established. It is known that fuel consumption, smoke, power, reliability, durability, and cost may all be affected.

Provisions for Mine Safety and Health--Effect on Engines

So far, the discussion has concerned the basic engine as produced in quantity for a variety of applications. However, additional requirements to protect the health and safety of the miners preclude the use of standard engines and make alterations and add-on equipment necessary. Since the engine becomes part of a machine used in the mine, the major responsibility for compliance with regulations falls on the machine manufacturer. There is need for close cooperation between the engine manufacturer and the machinery builder.

Without presuming to speak for the manufacturers of equipment used in the mines, it may help your understanding to discuss the most important requirements from the engine builder's standpoint. Figure 1 is included to provide a schematic diagram of the minimum required equipment for a power system.

One of the most important expected specifications is that the surface temperature anywhere on the engine cannot exceed 300° F. This specification is made so that temperatures high enough to initiate an explosion can be avoided. Such a specification requires that the exhaust manifold and piping to the water scrubber be cooled in some manner. Water-cooled manifolds are

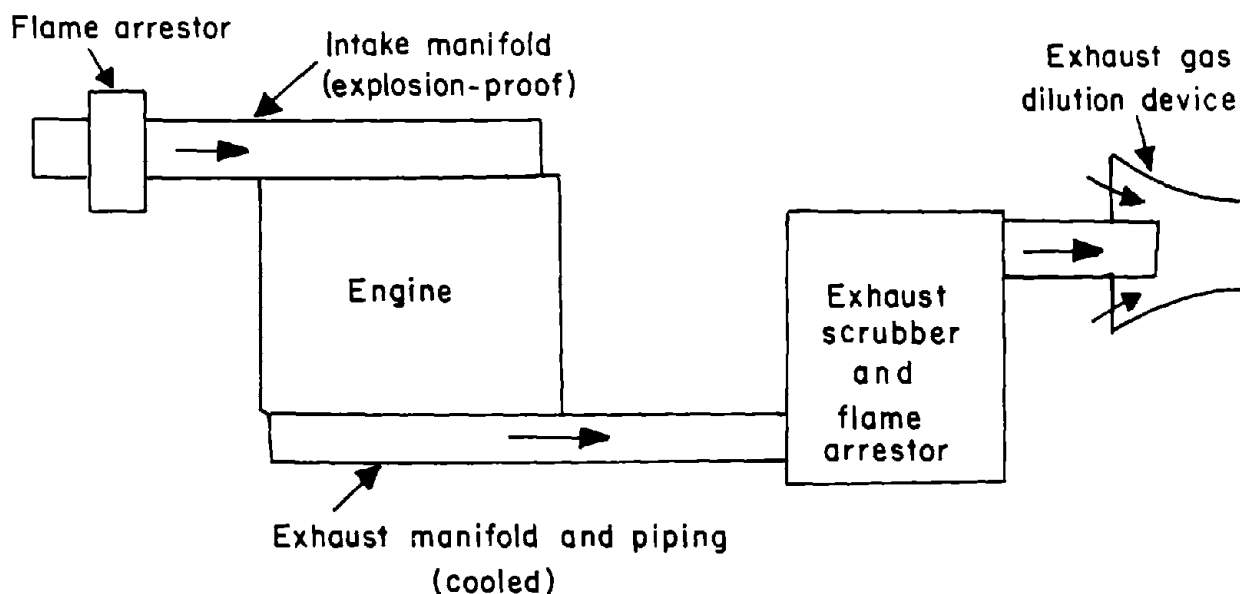


FIGURE 1. - Engine and exhaust system.

not usually commercially available unless the particular engine is offered in marine service. In the past, machinery builders have fabricated these manifolds when not available from the engine manufacturer.

If the temperature limit is established at 300° F, turbocharged engines probably cannot be used in the near future, since water-cooled turbocharger housings for that degree of control are not being developed. If turbocharged engines cannot be used, there is a serious limitation on the availability of small but powerful engines, since the use of a turbocharger can double the output of a given engine without much change to the space required. This points up the need to set the temperature limit as high as possible without compromising the safety of the miners.

If the present practice is continued, machinery builders will ordinarily supply flame arrestors and the water scrubber. The engine builder's principal concern is that intake restriction and exhaust back pressure are kept within recommended limits. Specifications for metal-clad cylinder head or manifold gaskets and length of flame path at hot gas joints could force the redesign of heads and manifolds or require the use of special gaskets. These adjustments can be made if the market can support the extra cost.

Exhaust gases as released from the exhaust system will require dilution in some manner to protect the machine operator. The schematic representation in figure 1 is intended only to show that some way is needed to mix the exhaust gas and air. This may be accomplished by proper positioning of the exhaust outlet, by discharging the exhaust gas into the engine cooling fan blast, or by pumping dilution air into the exhaust gas in some kind of mixing chamber. Although this final dilution step is the responsibility of the machinery builder, the engine manufacturer can help by supplying accurate emission data. Depending on the dilution device required, the engine manufacturer may want to participate in its installation.

Finally, other factors that are not emission related determine the availability of engines and the needed alterations. An example is the need for special engine arrangements to fit in low profile equipment. In some cases, it may be necessary to lay an engine on its side. Since engine models may not be offered for sale in a horizontal arrangement, alteration and special parts are necessary.

SUMMARY

The diesel engines powering mobile equipment have a historical background for providing reliable and economical service. You will be hearing more during this symposium concerning diesel success in underground applications. Its low emission characteristics make it a feasible powerplant for safe underground use.

Although many thousands of diesel engines are produced each year in the United States, they are not really a shelf item for mining equipment. Time is required to make the necessary changes that have been discussed, and economics

inevitably influences whether or not the engine manufacturer or the machinery builder can make these changes.

Introduction of the diesel into the coal mines in the United States will be watched with interest. There is every indication that such use will be of benefit to all concerned.

MR. POUNDSTONE: It is a good time for some questions now from anyone of the three speakers. Perhaps, first, we could just open it up for general questioning.

FROM THE FLOOR: My name is Dr. Von Miller. I am from Germany. I have a question concerning ventilation. May I show you two slides² to explain it?

Here is shown the exhaust emission of the most common diesel used in underground mining, and it is a true combustion system, so it is comparable to what you just showed before. The interesting thing is that you said it would be better for ventilation in underground mining to reduce load.

As you see, the carbon and the nitric oxides rise according to the power output of the diesel. So if you see these two compared in slide 1, both go down if you reduce the load. But if you look at the next slide, showing the hydrocarbons and the carbon monoxide, you see that both go up, especially for the motor with direct injection.

Now, I think it would be no solution to reduce load to get better results concerning ventilation in underground mining.

MR. POUNDSTONE: Now, did you ask a question?

DR. VON MILLER: I wanted to make a contribution, because I think it would be interesting to discuss the approach to be chosen in getting a good result concerning your ventilation in underground mining. In this respect, I think it is a dangerous thing to say that maximum output must be restricted and that we must accept a lower output to get better conditions. I think that is no solution, especially for a motor with injection.

MR. HURN: The point is well taken that reduction of power that is extractable from an engine is no immediate route to an acceptable emission. The question of the power operating point is one of balancing emissions at acceptable levels. In general, the production of oxides of nitrogen is dependent upon the power that is generated, or, that is to say, upon the number of gallons of fuel consumed--other things being equal. The limitation of power is brought into play in limiting carbon monoxide and in limiting smoke. After all is said and done, one modifies the engine as it must be modified to achieve a certain characteristic, and then limits power at that operating point at which the integration of these emissions is acceptable.

²Compiler's note: Unfortunately the slides could not be obtained for publication.

That is neither a simple answer nor is it a direct answer, but there is no simple and direct answer. Would you agree, Don?

MR. HENDERSON: The table on carbon monoxide which I showed supports, I think, what the gentleman said. If we take the precombustion-chamber engine at rated load and speed, we have 127 grams per hour of carbon monoxide and the concentration is 220 ppm. However, on the weighted average, which indicates working at lesser load over a speed range, the carbon monoxide would go to 103 grams per hour, but the average concentration is a little higher, 175 ppm.

On the other hand, the direct injection engine which I showed produced 180 grams per hour at the rate of speed and load, but on the 13-mode test, which indicates operation from idle, and these other points Dr. Johnson showed 205 grams per hour and the average concentration is higher, too.

DR. JOHNSON: I might make a couple of additional comments.

I think that some direct injection engines don't produce as much CO at part load. The second thing that comes into play is the weight of the engine and the cost. I suspect this might come in terms of talking about limits by derating before you reach the point where the emissions, particularly the CO, appeared to increase. So, I suspect these are a couple of other factors that enter in from an engineering standpoint in terms of talking about any given engine.

FROM THE FLOOR: Both gentlemen have spoken of catalysts, but they haven't mentioned what the catalysts were, how the catalysts would affect the emission, or what emission would be after the catalyst has worked on this original emission.

MR. HURN: I am sorry. Let me address that part of the question having to do with identification of the catalyst.

We have data from several different catalysts, but the only one that I can identify with assurance is a platinum catalyst distributed on a monolith. The platinum catalyst does very well if temperature is maintained fairly high.

There are others. Of course, as all of you must know, the field of catalyst development is very, very active at the present time, and I anticipate excellent materials to be available. Platinum certainly is one of them. Others, I cannot identify. I did not fully understand the second part of the question. I believe it had to do with concentrations of emissions before and after the catalyst. I did have one slide (fig. 11) that showed the concentration of carbon monoxide before and after catalytic treatment.

In general, I believe, the point is that catalysts can reduce carbon monoxide, can reduce hydrocarbons, and can provide an avenue to odor control. At the present time, catalysts are not effective for oxides of nitrogen control in diesel exhaust. There are catalysts for controlling oxides of nitrogen in automotive engine exhausts. But for the NO_x catalyst to be effective the engine's air-fuel ratio must be very carefully controlled. This is

something that has not yet been done with the diesel engine, and I don't think it would be a diesel engine if it were done.

FROM THE FLOOR: I note the drastic increase in ventilation requirements. Since the Federal Register calls for at least 3,000 feet over the miner, and we have extremely rotten roof, I would be interested in seeing 15,000 feet of air being passed over 200 feet of line. Does anybody have any idea how we can pin that canvass up? We have even tried board.

MR. POUNDSTONE: Maybe that question probably should come at a later point in the meeting when we get some of the ventilation people from the Bureau.

FROM THE FLOOR: I have three questions that I would like to ask.

The first one is, Mr. Hurn mentioned that the CO₂ monitor could be carried by equipment. Is this a production item? If so, how much does it cost? If it is not a production item, how much is it likely to cost when and if it is developed?

Second question is, Mr. Hurn also mentioned the possibility of water injection becoming a useful aid to reducing oxides of nitrogen. We have done a lot of research in this field, but I wonder how far the research has gone? I note from the graph showing results that obviously quite a bit is being done. Has Mr. Hurn done this research himself and with the Bureau, or are these figures from an engine manufacturer? If so, are there any results on the engine life? No doubt the engine life is reduced considerably.

The third question is to Mr. Henderson about the difference between the indirect injection and the direct injection. From the legends shown in Mr. Henderson's comparisons, we all note the D333C engine is a clean engine, but it is bulky and expensive and it would be very much more convenient to use the 3160.

Are there any plans to bring out indirect injection for the 3160 engine?

MR. HURN: Addressing the first of the questions, we have very little information to use as a basis for projecting the cost of a CO₂ monitor that might be mounted and carried with diesel power equipment. However, one might approach an estimate of the cost from looking at the present cost of the prototype. That instrument cost \$6,000 built as a research prototype. Similar type equipment that is coming from production lines for use in the laboratory is costing between \$2,000 and \$3,000.

I, myself, have expressed an opinion to instrument manufacturers that if this instrument is to be used--if it is to serve the need while being economically viable--the instrument must find its cost settling somewhere around \$1,000. Of course, all of us would wish that it would be under. That is about the best answer that I can give.

There was another part of the question having to do with the CO₂ monitor that I failed to get; would you repeat the second question about the CO₂ monitor?

FROM THE FLOOR: That was what I wanted to know--whether it was a production item or whether it was something being developed?

It is not a production instrument at the present time.

The gentleman asked about water injection--how far the development had been carried. We have done no work on the life of an engine with water injection. We who are in this game are all aware that there is serious concern for engine durability, and that there is concern for engine wear with water injection. Regrettably, however, we have no information on the wear problem--or if, in fact, it is a problem.

Another drawback to water injection, of course, is the nuisance of carrying it, the problem in insuring an adequate supply of water, water quality, and other such considerations. Water injection is not a practice that presently is with us; it is not even around the corner; it is an option that exists. There must be much more technological development if it is to be brought into play.

MR. HENDERSON: First, I would like to add a bit to the water injection discussion.

We published some data on a turbocharged precombustion chamber engine with water injection. I don't have the paper with me, so I am going to give you some numbers from memory. In this particular turbocharged engine, the induction of water on the basis of about 1 pound of water per pound of fuel, which is lots of water, reduced the nitric oxide to about a 4 to 1 ratio over that at full throttle operation. The effect, of course, is not as great at part throttle.

Now, there are several disadvantages to the water injection system, although it is attractive in some ways. In the first place, it must be used in nonfreezing temperatures only. So, perhaps, mines are the only place where it could be commercially considered acceptable.

In the second place, we think that it probably requires soft water, to avoid the deposits which might form in the engine.

The other is that introducing water into the turbocompressor wheel is a very good way to atomize the water, but it can be very hard on the wheel. So we are not afraid of using water in at least moderate amounts, as far as the overall effect on the engine is concerned, but there are these other problems.

In answer to the question on indirect versus direct injection system for the 3160 engine--I really have to leave that to the marketing people. However, I would say that we have to meet 1975 California emission standards, 5 grams/hp-hr HC + NO₂ with NO_x being predominant. We have to meet that with

the 1160, the truck engine version. With our technology for the precombustion chamber system, it is logical to look to that system to some degree. I am not in a position from the marketing standpoint to talk about availability or anything of that kind, but it is certainly a possibility.

FROM THE FLOOR: Mr. Hurn, you had a slide there on carbon dioxide and its relationship to carbon monoxide on the TLV scale. What does that stand for and what relationship, if any, does it have to parts per million?

MR. HURN: Would you find slide number six (fig. 6) from my presentation.

This is the slide to which reference was made. The CO concentration shown on the vertical coordinate is in terms of Threshold Limit Value (TLV)--1 unit being the equivalent of 50 ppm concentration. The slide indicates a general correspondence between carbon monoxide in terms of TLV units here (ranging from 1 to 5), and concentration of carbon dioxide ranging from zero to 1 percent. The range that is shown in the slide is the typical range of concentrations of carbon monoxide that would be associated with carbon dioxide in an occupied space.

The point of the slide is that if one monitors carbon dioxide, one has a handle upon the probable amount of carbon monoxide present in the occupied space. That really is the basis, of course, for the suggestion that we monitor carbon monoxide as the indicator of residual exhaust products.

I should add that certainly there will be mine air monitoring systems that will be operative at the same time as the CO₂ monitor is operative. But for control at the location, for control of the quality of air that is fed to the engine as well as to the people, this appears to be a reasonable technological principle.

FROM THE FLOOR: On the slide prior to that (fig. 5) showing the relative carbon monoxide in a confined area, would you explain where it showed the carbon dioxide rising rapidly and the carbon monoxide staying at the lower level? Does the slide show the amount of carbon dioxide proportionate to the carbon monoxide?

MR. HURN: No, no. In terms of scalar values, no. The two are drawn to vastly different scales. The point of this slide (fig. 5) is to show that as an engine is operated in a confined space with a portion of the exhaust gas recycled back into the intake of the engine, the oxygen is simultaneously depleted from the atmosphere. As oxygen is depleted, carbon dioxide builds up in the atmosphere and carbon monoxide also builds up in the atmosphere, first at a very low rate--a rate equal to the linear accumulation of adding small amounts of carbon monoxide--and then at an accelerated rate.

If there is a question about the relative amounts of carbon monoxide and carbon dioxide in this region (the lower left corner of figure 5), this is the region at which we would be controlling. Points much further upscale are disastrously high concentrations of carbon monoxide.

In this region (less than 100 ppm CO), the relationship between carbon monoxide and carbon dioxide concentrations is as shown in the next slide (fig. 6). This now is a magnified representation of the relative amounts of CO and CO₂ shown in the previous slide (fig. 4) near zero time when concentrations of CO and CO₂ were still at levels that would be acceptable. This then is the level of CO₂ and CO at which the monitor would be controlling.

FROM THE FLOOR: I would like to know generally what work the Bureau is doing at Bartlesville, Okla. What is the objective of that work?

I would also like to know where the industry is using their efforts in underground mining environment and how much money is being spent with a view toward underground mining application?

MR. HURN: An abbreviated answer as to what we are doing in Bartlesville, Okla., is that we are gathering the basic background engineering-type information that defines the problem of handling diesel emissions as they would be generated and dissipated in a confined space. We are obtaining information on typical emission characteristics from engines, and we are getting background information on the technology that is available to reduce emissions. This is all done with a view, as I earlier indicated, toward minimizing the hazard from the toxic components.

If the gentleman is interested in a more explicit definition of the precise work that is carried on at Bartlesville, we will, of course, be pleased to go into detail.

Now, with respect to the amounts of money that are spent and whether or not our efforts are coordinated with industry, I have no information on the total amounts of money spent on diesel emissions. With respect to coordination, I can say that in our thinking and in our program planning, the work that we do is very closely coordinated with industry. We know what industry is doing, we know what the diesel user is asking for, and much of our work is done to fill that need with a power unit that meets our safety objectives. Overall, I would say that there is a very good interchange of information between our operation and our industry contemporaries.

FROM THE FLOOR: I haven't heard anyone mention the decibels on the diesel engine when it is idling, and also under load.

Also, I would like to know if anyone of you would know whether the coal operators, the United Mine Workers, the State agencies, or the Federal agencies have done anything in training people for this diesel? Are we creating a monster--excuse my expression--before we are getting people trained? Are we getting into an environment of 1969? Can anyone of you people answer that?

DR. JOHNSON: I really can't speak specifically for noise, but I can say this: In terms of numbers, I think, it becomes quite difficult to talk about a decibel level from a particular engine, because what it involves is the overall vehicle in terms of its construction. In the automotive and the truck

application, there is a very intensive development relative to doing fundamental engine work and vehicle work to reduce noise on most construction-type equipment and also on over-the-highway vehicles. In talking about the closing on engines and doing vehicle designs and engine design to reduce noise, there is a tremendous technological development going on in this field. I was the one who originally raised this question, because I think it is appropriate to cars, and because there is a big difference between electric power and diesel power relative to the noise, but I cannot really give you any specific decibel numbers.

The suggestion of the chairman here is, I think, that maybe some of the people who are more familiar with measurements in terms of vehicles and who produce equipment ready for underground mines, might be able to give a more specific answer, because it does involve both the engine and the vehicle.

MR. HURN: The question on noise was very well put and certainly the miners who are involved are to be complimented for looking at this before it becomes a problem and before we are engaged in a direction that would commit us to an unsolvable or an unacceptable problem. Just a comment about noise.

I think, really, that any concern for inattention to this problem is not justified, because the problem is being given a lot of attention. We at Bartlesville are working on combustion-related noise and we are doing work on engine characteristics as influenced by the use of noise suppression devices on the engines. In industry, I see, as John indicated, a tremendous effort on noise. So I think that the problem is receiving adequate attention. I believe we will be ahead of this one before it is an unsolvable problem.

A final portion of the question dealt with the training prospectus. On the Federal level, we are in advance of the problem. The training standards which would be developed for strip mines, of course, very much apply here, because so much diesel equipment is used. When we have a better feel for the amount of this equipment which may go underground, and where it is going to be underground, it can be relatively simple for us to provide the same type of training which we are providing. So, I think, we will be able to cope with it.

FROM THE FLOOR: In the presentations by Dr. Johnson and Mr. Henderson, we have been given to understand that the best thing the prechamber diesel engine has is more favorable exhaust characteristics than the direct-injection engines. I take it that there must be something inherent in the two systems which causes this thing to come about, or be prevalent in the exhaust. Would we have any information here as to why this occurred within the combustion cycle of the two relative engines?

DR. JOHNSON: By and large, the main difference between the two types of engines is occurring in the NO_x , that is, the NO emissions. There are direct-injection engines that can achieve low levels of hydrocarbons, smoke, and CO emissions--that is, if you talk about turbocharged direct-injection engines as compared with the prechamber engine. So the discrepancy is, by and large, related to the temperatures and pressures and the local fuel-air ratios involved in the combustion process with the prechamber injection, and the fact

that the prechamber engine uses part of its energy to do this fuel-air mixing as I talked about in my presentation.

The prechamber can carry out this process later in the combustion cycle, and the amount of time that the nitrogen and oxygen is at those elevated temperatures is different. So, the net result is that generally the NO_x in terms of production engines today, is generally lower with prechamber engines.

Now, with this very intensive development, I really don't know. I really can't make a judgment today on whether the direct-injection engine will be competitive or not in the future. One of the reasons that it is still not competitive is that the prechamber engines reject more of their heat through the coolant. So for over-the-highway operations, larger radiators are required in terms of frontal area in vehicles. Even though the prechamber engine is very efficient for getting work out of the shaft because of the scrubbing action on the wall, there is more heat rejected to the coolant.

I think that the difference between fuel economy with the turbocharged prechamber engine and the turbocharged direct-injection engine is very small today. In the past development of the direct-injection engine, when there were more naturally-aspirated engines, the direct-injection engine was more widely used because of the radiator requirements and the fuel economy. So the naturally-aspirated direct-injection engine had an advantage over prechamber naturally-aspirated engines in terms of fuel economy and also in terms of this heat rejection. Thus, the situation is fairly complex.

I think that you are going to see the engines come closer together on these points. If you look in the literature of direct-injection development, you will see their emissions levels coming down. Whether they will both be in existence, I think will be answered in terms of whether both types can meet the 1975 California standards for trucks. I think this is one point in time when we will find out whether the direct-injection engine can still compete in this particular market with the prechamber.

MR. POUNDSTONE: Gentlemen, I think we have run out of time. If any of you have any other questions, I suggest that you try to contact the speakers.

We have one more announcement from Bruce Grant.

MR. GRANT: I won't keep you but for a minute, but I realize that one thing we intended to say this morning may not have been said. We are going to publish the proceedings. We will publish the discussion and comments and those of you who wish to expand on your discussion past the time we have, may send comments to us as soon as you can for inclusion.

COMMENTS

Submitted by

Walter Loevinsohn¹

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I would like to make the following comments with respect to the use of direct-injection type diesel engines in underground services:

As outlined in Mr. Henderson's paper, direct-injection diesel engines have a much higher ventilation requirement than prechamber-combustion engines, also referred to as two-stage combustion engines. Contrary to general belief, the exhaust gas quality does not improve under partial load conditions or at lower speeds, as shown in my figures 1 and 2.

These figures represent a comparison between two air-cooled diesel engines, one with direct injection and the other with the Deutz two-stage combustion system. The NO_x content is somewhat reduced under partial load conditions, but at the same time the more irritating hydrocarbon (HC) emission and the dangerous CO content increase considerably.

The use of a catalytic scrubber does not produce a satisfactory solution either, because exhaust gas temperatures drop under partial load, thus reducing the efficiency of the catalytic purifier, and the life expectancy of the latter is shortened tremendously. Catalytic scrubbers perform best at high exhaust gas temperatures. As partial load conditions and even protracted engine idling are inevitable, the reliance on catalytic scrubbers for improving the exhaust gas emissions of direct-injection engines seriously increases the danger of air pollution underground.

¹Vice-President, Deutz Diesel (Canada) Ltd., Montreal, Quebec, Canada.

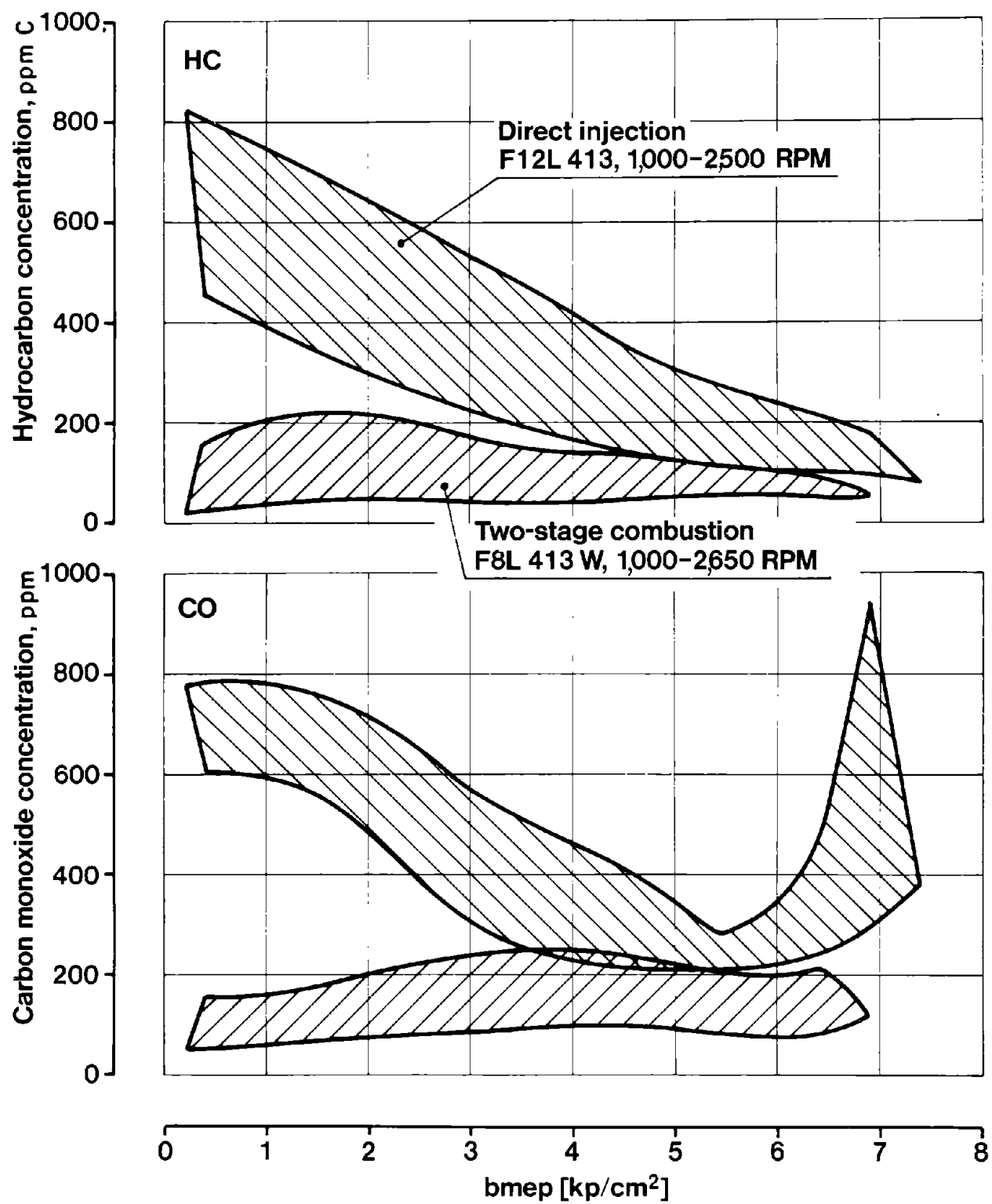


FIGURE 1. - Carbon monoxide and hydrocarbon emissions of two types of diesel engines.

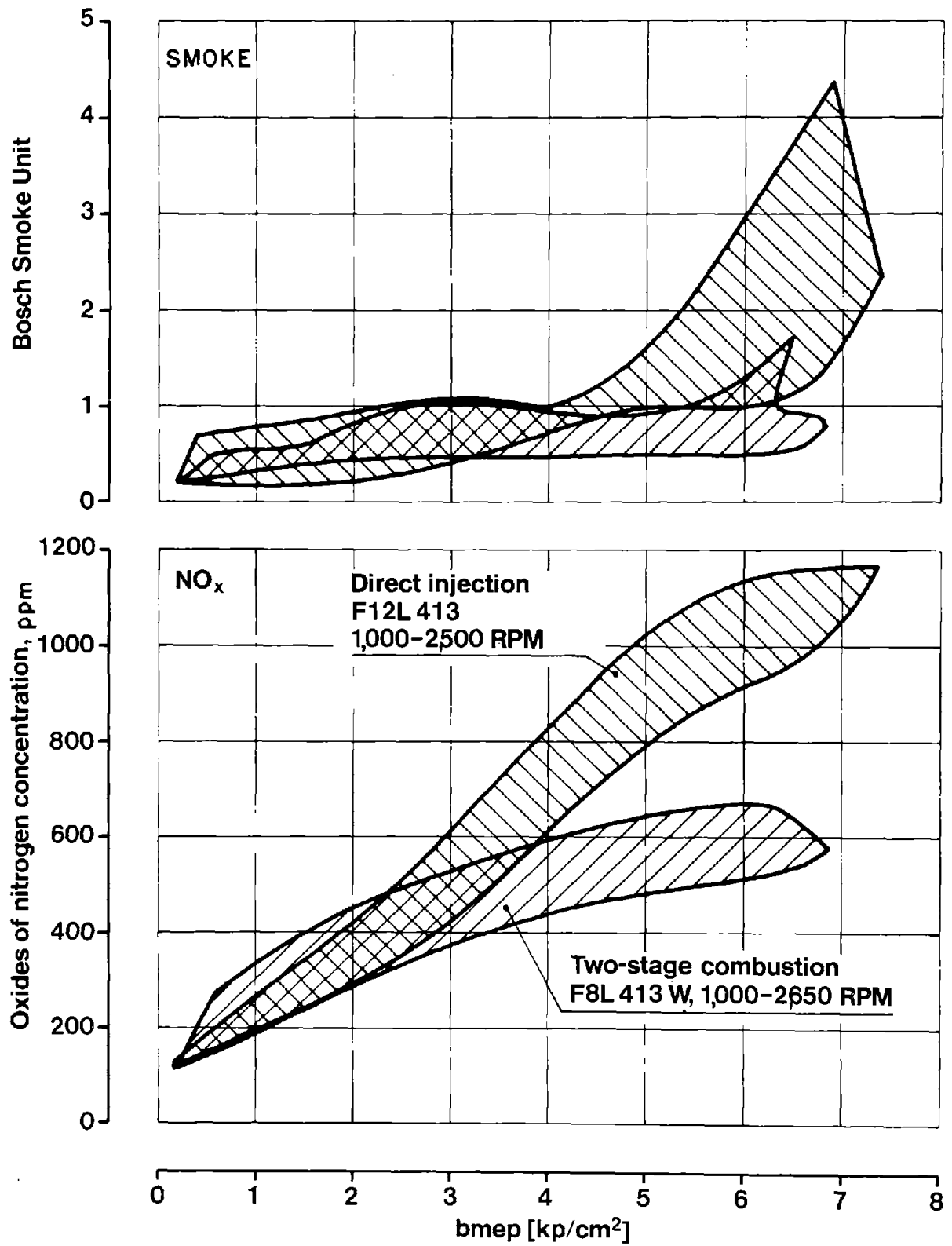


FIGURE 2. - Oxides of nitrogen and smoke emissions of two types of diesel engines.

MR. NELSON: I am Arthur Nelson, Acting Assistant Director of Metal and Nonmetal Mine Health and Safety of the Bureau of Mines from Washington, D.C.

This second session discusses the place of diesels in underground mining. We have five excellent papers to be presented between now and the time that the whistle blows at five o'clock.

We are fortunate to have as cochairman of this session, Mr. Otes Bennett, Jr., President, North American Coal Corporation and Chairman, American Mining Congress, Coal Mine Safety Committee. Mr. Bennett.

MR. BENNETT: Thank you, Art.

Our first speaker will discuss a case history using diesels in Green River Trona Mine, Wyoming.

Mr. William G. Fischer is a graduate of the Colorado School of Mines, and a Registered Professional Engineer. He is the chief mining engineer of the Inorganic Chemicals Division of the FMC Corp. He holds several patents and has several publications in connection with the Trona Mining and Rock Mechanics.

SESSION II--THE PLACE OF THE DIESEL IN UNDERGROUND MINING

CASE HISTORY OF DIESEL USE: FMC CORP.
GREEN RIVER TRONA MINE, WYOMING

by

William G. Fischer¹

The Industrial (Inorganic) Chemicals Division of FMC Corp. operates a 3MM TPY trackless trona² mine near Green River, Wyo. The flat-lying seam of trona being mined varies in thickness from 8 to 10 feet and occurs at a depth of approximately 1,600 feet. Access to the underground workings is provided by five vertical shafts ranging in diameter up to 24 feet. Ventilation is supplied by two main fans each capable of 500 MCFM at 12 inches of water, at the surface elevation of 6,400 feet. Underground workings extend 4 miles in one direction and 2 miles in the other and are connected by development entry systems consisting of 15-foot-wide openings. Roof hung conveyor is used throughout the mine since maintenance of rail system would be virtually impossible under the heaving floor conditions found in the mine. Conventional and continuous coal mine type equipment is used for ore production and logistic functions are provided by diesel powered vehicles of various breeds. The mine is designated by the State as gassy and falls under Section 57.21 of the Federal Metal and Nonmetallic Mine Safety Act. Workers belong to Local Union 13,214 United Steel Workers of America, AFL-CIO-CLC.

Underground mining of trona first began in December of 1947. Production levels remained low until 1952 when steady expansion began, leading ultimately to current levels and projections. Transportation and logistics were not critical factors in the early days of the mine but rapidly took on major proportion as the working areas receded and increased in number. In 1956 a diesel-powered haulage jeep was placed in service. Other diesel equipment rapidly began to appear in the supply handling, transportation and construction activities. Initial success with underground diesels was very encouraging, but little information was available from previous underground users. We felt it necessary to institute a formal program of exhaust fume measurement in an effort to define effectiveness of maintenance procedures, the degree of compliance with regulations, and special hazards associated with the use of diesels which may not have been readily apparent. Wide application of diesels, especially in face production, and the increased complexity of their use left little alternative but to continue surveillance of exhaust products. More than 8,200 samples have been taken in the past 10 years. A great deal has been learned from this program especially in the areas of engine selection, operation, maintenance, and safety requirements. At the present time there are 19 diesel units approved under the Federal Bureau of

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² $\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$.

Mines Schedule 31, and 46 diesel units approved under Federal Bureau of Mines Schedule 24 in service on a three-shift, 7-day-per-week basis. Some of these units could be rated excellent, others poor; but in general we have been satisfied with our overall application of diesels and are firmly convinced that the health and safety integrity of the mine has not been compromised through their use.

Sampling Techniques

Different types of exhaust measurement have been used in order to define both conditions of safe use and engine maintenance problems. An engineering technician was assigned to follow the diesel program and maintain biweekly, weekly, or daily measurement of exhaust gases as conditions dictated. He reported to the Chief Engineer who disseminated the information and took action to correct any unsafe condition found to exist. In the past 10 years this technician has recorded 3,342 samples of undiluted exhaust, 2,977 samples of carbon monoxide in the operator's position, 1,504 samples of nitrogen dioxide in the operator's position, and 409 detailed samples (several per shift on the same piece of equipment) for the purposes of defining ventilation techniques.

Carbon monoxide was measured with an MSA type 14670 portable hand operated carbon monoxide indicator. The only scale range on this device is zero to 1,500 ppm, expressed as percent, and therefore its primary application is in measuring undiluted exhaust. We found the MSA Model 1 Universal Testing Kit (part No. 83500) and the Drager Model 21/31 Multigas Detector most beneficial in determining concentrations of toxic fumes in the operator's position. Care is required in their use, especially in low concentrations. Initially, determinations of carbon monoxide, nitrogen dioxide, sulfur dioxide, and aldehydes were made. We very rapidly found that sulfur dioxide was not being produced in sufficient quantity from No. 2 diesel fuel to warrant continued sampling. Odor and visible smoke is a good indication of aldehydes and we began using this as an indicator rather than the redundant measurements. MSA Colorimetric carbon monoxide testers (part No. 47133) with scrubbers were also used. These devices read up to 1,000 ppm and are used by each diesel equipment operator to check his own equipment. A report card is made on these samples, which the maintenance foreman checks daily. We have reason to suspect their accuracy and have not used any of these data in the current analysis.

When the diesel equipment is running properly and ventilation is adequate we find that operators like their machines and tend to forget taking samples. When something is wrong they make themselves heard in a loud voice. This voice is heard and the production and maintenance foreman and the technician follow up on it. We have found, in practically every instance, that our equipment operators have acted in a prudent and fair manner. Generally, a judgment can be made as to the engine's maintainability and exhaust emission level after the first 60 days a diesel is in service and it then becomes unnecessary to monitor all units. Smoke and odor are by far the best indicator of trouble and a knowledgeable, prudent man can make the determination without an armful of instruments.

Undiluted Exhaust Samples

The carbon monoxide in undiluted exhaust is quantitatively related to the other noxious gases in the exhaust and is a key factor in engine performance. Each diesel unit is provided with a connection in the engine exhaust system permitting the temporary attachment of a gas sampling device. For Bureau testing, certain limits have been established beyond which approval is denied. The test covers the full rated power output range under all conditions of operation. In the case of Schedule 24, this limit is 0.25 percent carbon monoxide by volume. The established criterion used by the Bureau is of little value in the mine where a diesel test bench is unavailable. It is impossible to take a sample in a safe manner while mining equipment is moving under load. It usually becomes necessary to take the sample at the point of exhaust after passing through the scrubber, while the unit is parked and idling. This is preferable from an operator's standpoint in that noxious fumes enter the air stream here and one sample dictates the approximate condition of both engine and scrubber.

We have established criteria by which appraisal of the engine-scrubber system can be accomplished in the field. This is shown in table 1.

TABLE 1. - Field sample criterion

Ppm CO	Appraisal
Under 300.....	Excellent.
300-400.....	Good.
400-500.....	Fair.
500-1,000.....	Poor.
Over.....	Special ventilation consideration required.
Over 1,500.....	Take unit out of service.

After initial experience is gained using this criteria as a guide, and comparing the smoke and odor of the diesel with the sample readings, it becomes possible to make a competent judgment without the sample. This experience can generally be gained quickly.

Tables 2 and 3 compare the results of carbon monoxide measurements in undiluted exhaust by dividing the data into groups based on injection systems, cooling systems, and exhaust-conditioner type.

TABLE 2. - Engineer group designations

Designation	Injection system	Scrubber	Cooling	Mean ppm CO	Times shut down
A.....	Direct.....	Batch.....	Water.....	999	122
B.....	Swirl chamber.....	...do.....	...do.....	320	(¹)
C.....	Precombustion.....	...do.....	...do.....	410	5
D.....	...do.....	...do.....	Air.....	308	0
E.....	...do.....	Catalytic.....	Air.....	204	0
F.....	...do.....	Spray.....	Air.....	87	0

¹These engines were unsuccessful. They ran approximately 3 months.

TABLE 3. - Carbon monoxide released by engines at idle, ppm

(1963-73)

Schedule	Approximate air	Mean CO	Peak CO	Operator rating
A1-24.....	9,400	1,054	2,300	Bad.
A2-31.....	23,000	463	510	Poor.
A3-31.....	12,000	438	1,800	Poor.
B1-31.....	5,900	406	1,260	Bad ¹ .
B2-31.....	13,000	276	730	Poor ¹ .
C1-24.....	2,600	414	1,500	Fair.
C2-24.....	5,100	415	1,500	Fair.
C3-24.....	11,700	358	880	Good.
D1-24.....	1,000	235	570	Good ¹ .
D2-24.....	2,000	327	1,130	Good.
D3-24.....	3,900	274	1,110	Good ¹ .
D4-24.....	4,800	125	230	Excellent.
E1-24.....	3,900	218	440	Excellent.
E2-24.....	4,800	188	480	Excellent.
F1-24.....	3,900	87	360	Fair ¹ .

¹Operator ratings may differ from the criteria established since maintenance history influences their decision.

Maintainability

Tables 2 and 3 show that direct injected engines release substantially more fumes to the atmosphere than do precombustion engines. The swirl chamber is essentially a precombustion engine. The general impression derived from the data is that air-cooled engines are more efficient fuel burners than water-cooled engines. Water bath scrubbers appear to have little effect as fume eliminating devices. The spray-type scrubber appears to be quite efficient; however, it is relatively new and sample density could be misleading. We have had trouble with the spray pumps currently used and have found the reservoir tanks dry on occasion. Accountability for running these scrubbers properly on a three-shift, 7-day schedule has been found difficult since the operator is responsible for filling the tank and maintenance is responsible for the pump. Training can only accomplish so much in this area. The best scrubber found so far is the catalytic type which is highly efficient and maintenance free thus leaving the machine ready to run safely when a new operator comes on shift.

Another comparison can be made between Schedule 31 and Schedule 24 engines. The basic differences in the two schedules lie in the temperature limitations and flame arrestors required on the Schedule 31 engine unit. This does not show in the tables as being outstandingly bad from the standpoint of carbon monoxide, but, be assured from the operator's rating, that

it is indeed a problem. Air-cooled diesels run at about 400° F. The water cooled Schedule 31 engines are limited to a maximum surface temperature of 300° F. These differences sound slight until you consider that a diesel engine has no external source of spark ignition within the cylinder, and efficient burning of the low-volatile fuel is accomplished by compression heat alone. A precombustion chamber is one way of heating the fuel prior to entering the cylinder and it is obvious that there will be no fire unless a certain combustion temperature is reached. If the temperature is marginal, combustion will be incomplete which results in high carbon monoxide released to the atmosphere.

The injector tip must place fuel in the cylinder at exactly the right instant in order to obtain clean burning. The design of the combustion chamber must also be efficient, which is the primary difficulty in the engine shown as A1-24 in table 3. We have never known a diesel engine to backfire in either direction and suspect that it can only be done by deliberately setting the injector timing improperly. Even then, we doubt that it would be possible to run the engine under its own power. This discussion is obviously oriented toward the flame arrestors, primarily the intake arrestor. Much work must be done to develop an acceptable unit for the mines if backfiring through the intake is real.

The air filter outby the intake flame arrestor must have the capability of catching extremely fine particles and therefore plugs easily. Although they are changeable and some are recleanable, the process is expensive both in time and money. Dry type filters require changing every three shifts, if not more often, in our operation where water-soluble dust tends to cake on them.

Oil bath air cleaners release a mist which increases the tendency of soot particles to collect on the intake flame arrestor plates.³ The engine is therefore starved for air when either the air cleaner or flame arrestor becomes restricted and incomplete combustion with increased carbon monoxide and smoke results. This is a frequent occurrence with the Schedule 31 engine. A lot of fresh ventilating air might help, but remember that the diesel is constantly accelerating and decelerating during the day and this produces an over-fuel situation; compounded by a partially restricted intake system resulting from acceleration smoke, the situation can only get worse. We have found a partial solution to this problem on some of the engines by adjusting the governor to permit only slow acceleration of the engine itself. Another alternative is to limit the power taken from the engine. Everyone has seen a diesel truck smoke when lugging up a hill. We have blocked out high gear to prevent lugging the engine down in shuttle cars. All this combines to form a diesel unit that the men call "gutless wonders"--and for good reason.

Over control is another problem with the Schedule 31 engines. As mentioned earlier, temperature control restricts the engine to inefficient operation. Surface temperature of 300° F, water temperature of 212° F, exhaust temperature of 170° F, all combine to negate catalytic scrubbers and engine

³Oil is changed once per day and the flame arrestor is cleaned every other day.

efficiency. Most important, when combined with low-scrubber level shutoffs, intake air shutoffs, low brake-pressure shutoffs, methane and other monitors, the machine has only a 65 percent chance of pulling out of the barn if these devices are 95 percent reliable. It turns out even worse than this because the machines operate under constant vibration and in environments for which current devices were not designed. Provision for a very minimum of such shutdown devices required for safety is very important for successful application of diesels. This is especially true in the gassy, non-coal mines where possible methane is the primary hazard to be protected against. Here a monitor should be sufficient since the ignition temperature of methane is 1,200° F.

Getting back to the reliable and well accepted Schedule 24 engines, we find that the effect of age is not as apparent as might be imagined. We found it difficult to locate among the engine exhaust samples true indication of increased fume hazard with advanced age. The best examples are shown in table 4, which includes the operator's rating for each individual unit of equipment selected.

TABLE 4. - Effect of age and maintenance

Year	Mean CO in exhaust for individual engines, ppm			
	Supply vehicle A1, bad	Mantrip D2, good	Powder monkey D2, good	Cleanup C2, fair
1964.....	724	-	281	556
1965.....	942	266	382	442
1966.....	1,119	293	475	610
1967.....	1,305	352	495	414
1968.....	1,294	¹ 295	379	¹ 293
1969.....	1,461	363	386	269
1970.....	1,460	490	370	355
1971.....	1,500	483	390	160
Mean.....	1,151	334	414	415

¹Engine replaced.

Figure 1 is a plot of mean carbon monoxide observations in undiluted exhaust as a function of time which shows the overall manufacturer's improvement in engines and the tendency toward more efficient scrubbing devices in the last couple of years.

A comparison between a Schedule 24 vehicle using precombustion batch scrubbing and air cooling and a direct-injected Schedule 31 engine with batch scrubbing and water cooling is shown in table 5. The two units performed identical functions in the mine.

TABLE 5. - CO in undiluted exhaust, ppm

	D2, Schedule 24	A3, Schedule 31	Percent increase
Mean.....	347	438	26.2
Peak.....	1,130	1,800	59.3
Air requirement.....	2,000	12,000	600

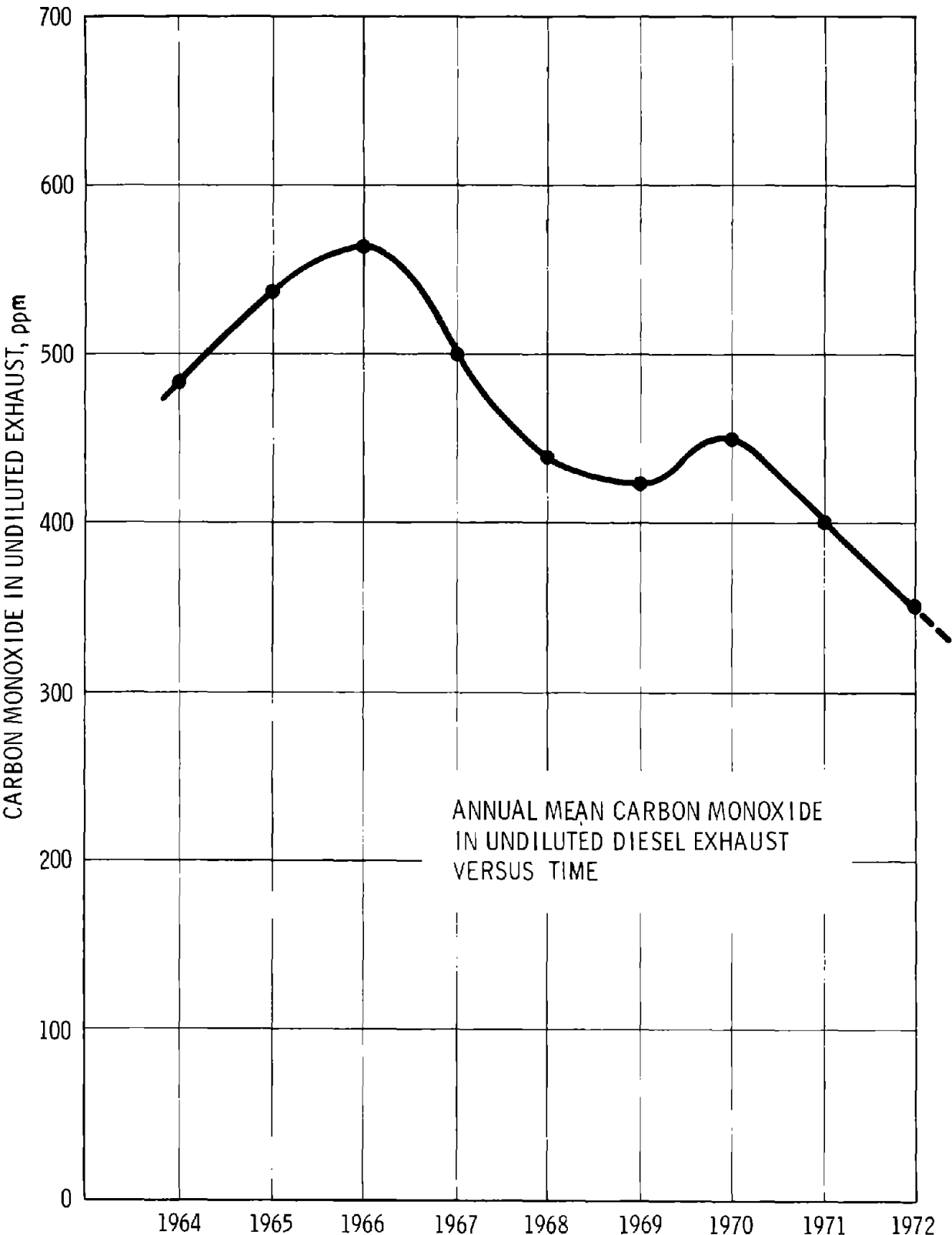


FIGURE 1. - Diesel improvement is taking place.

Health Hazards

A total of 4,890 samples were taken in the operator's position and/or downwind of the diesel units. The quantity of air was not measured except in a few cases. The mean average of 2,977 samples of carbon monoxide in the operator's position was 8.5 ppm. Five percent of the samples were in excess of 50 ppm, the current 8-hour threshold. The distribution of carbon monoxide for this 10-year study covering all types of diesel units is shown in figure 2. The mean average of 1,504 samples of nitrogen dioxide in the operator's position was 0.2 ppm. Three-quarters of one percent were in excess of 3 ppm and only one sample exceeded 5 ppm. The distribution of nitrogen dioxide samples is shown in figure 3. Practically all of the samples taken during the 10-year study were on Schedule 24 equipment used for transportation or maintenance. During the period of this study the diesels were being safely operated, with exceptions being very rare. Exhaust emission was well within limits and only

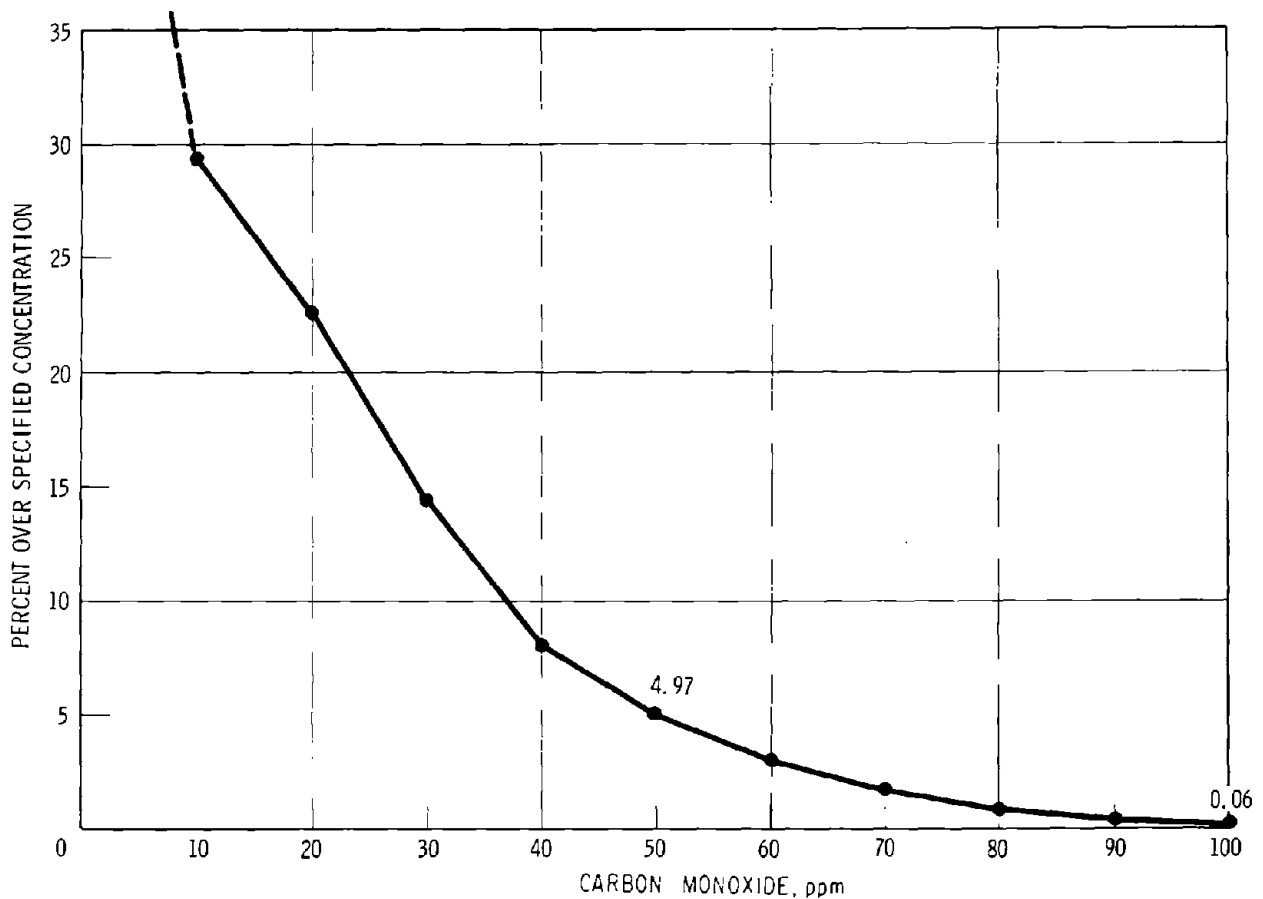


FIGURE 2. - Carbon monoxide-operator's position-1963 through 1972, 2,977 samples.
All diesels included. Mean, 8.5 ppm, regardless of application.

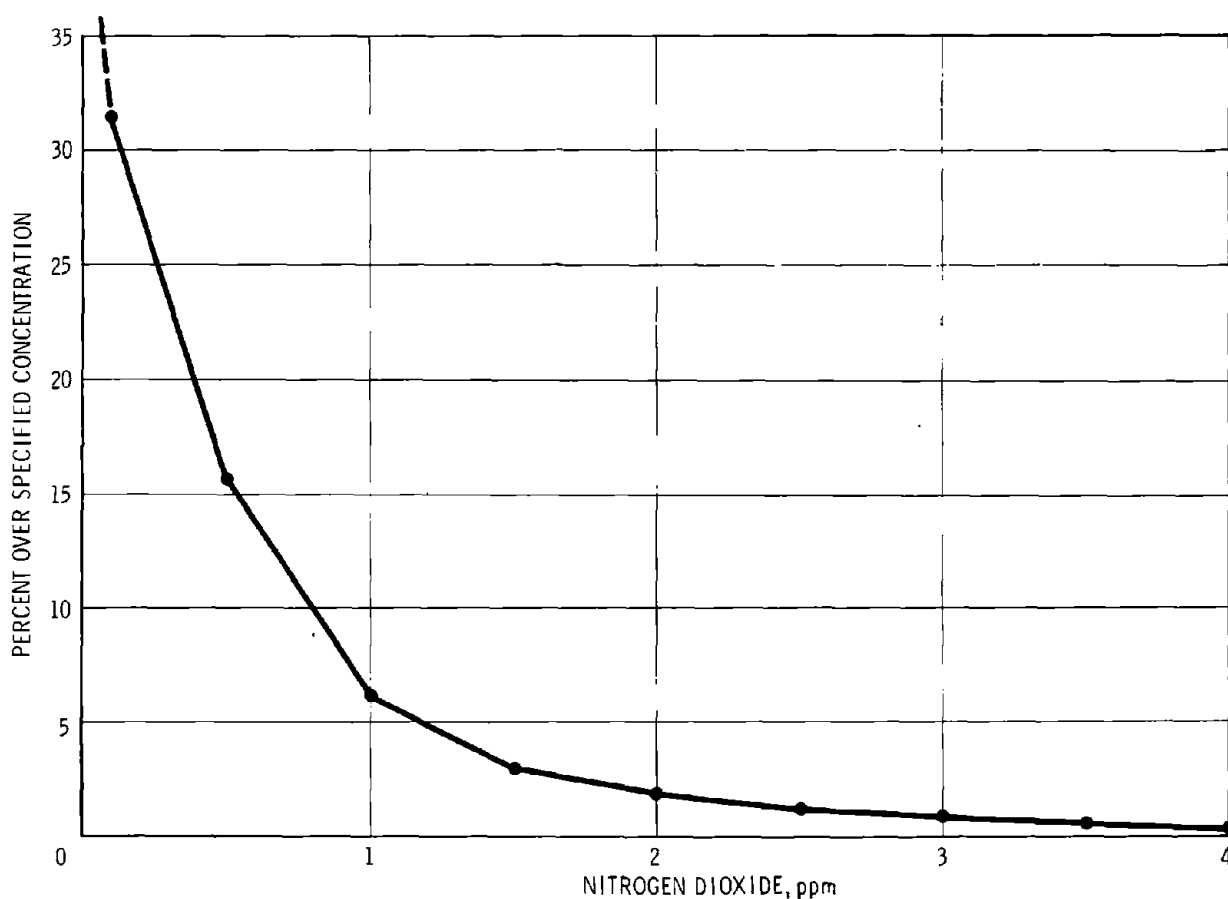


FIGURE 3. - Nitrogen dioxide—operator's position—1963 through 1972, 1,504 samples. All diesels included. Mean, 0.2 ppm, regardless of application.

one accident occurred where a man was physically hurt. He turned a corner too fast and ran into the rib, breaking his pelvis.

With the addition of Schedule 31 shuttle cars and powder monkeys in 1972, we concentrated on diesel operations in the production sections where ventilation is somewhat harder to control. The last open crosscut normally carries 40 to 50 Mcfm and goes as high as 65 Mcfm in some sections. Each of the seven entries has a blower fan capable of 5 Mcfm with tubing extending up near the face. Larger fans, up to about 8 Mcfm have been used but recirculation becomes a problem unless the air in the last open crosscut is above 60 Mcfm. The plate air requirements for the powder monkeys and shuttle cars are 12 and 23 Mcfm, respectively.

The data obtained during the detailed study of diesels in production sections are shown in figures 4 through 7. Figure 4 shows samples taken with Schedule 31 shuttle cars. Only 2 out of 111 samples read as high as 50 ppm CO including the peak samples at 80 ppm. The mean average concentration of carbon monoxide at the operator's position was 6.59 ppm and downwind of the car it was 14.24 ppm. Figure 5 shows the carbon monoxide samples for the

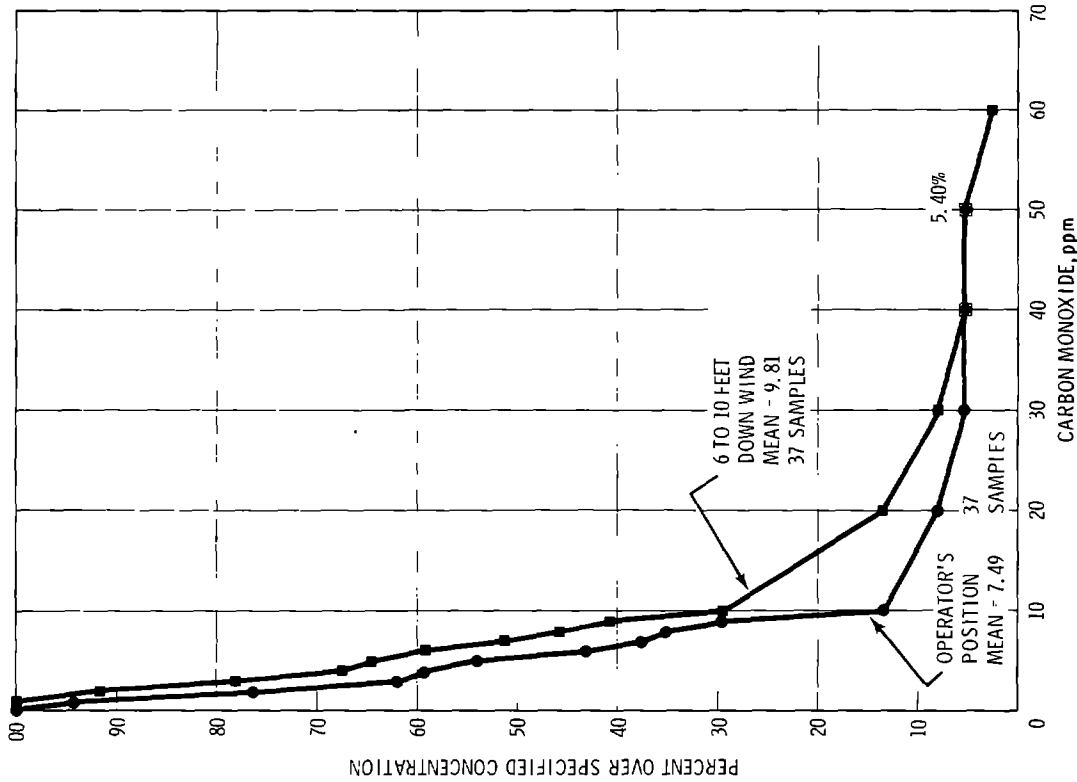


FIGURE 5. - Carbon monoxide samples-1972. Production sections using diesel Schedule 31 powder monkeys, Group A3 engines. 12 MCFM plate air. Air in entry being loaded-estimated at 5 to 8 MCFM. Auxiliary fan in each entry.

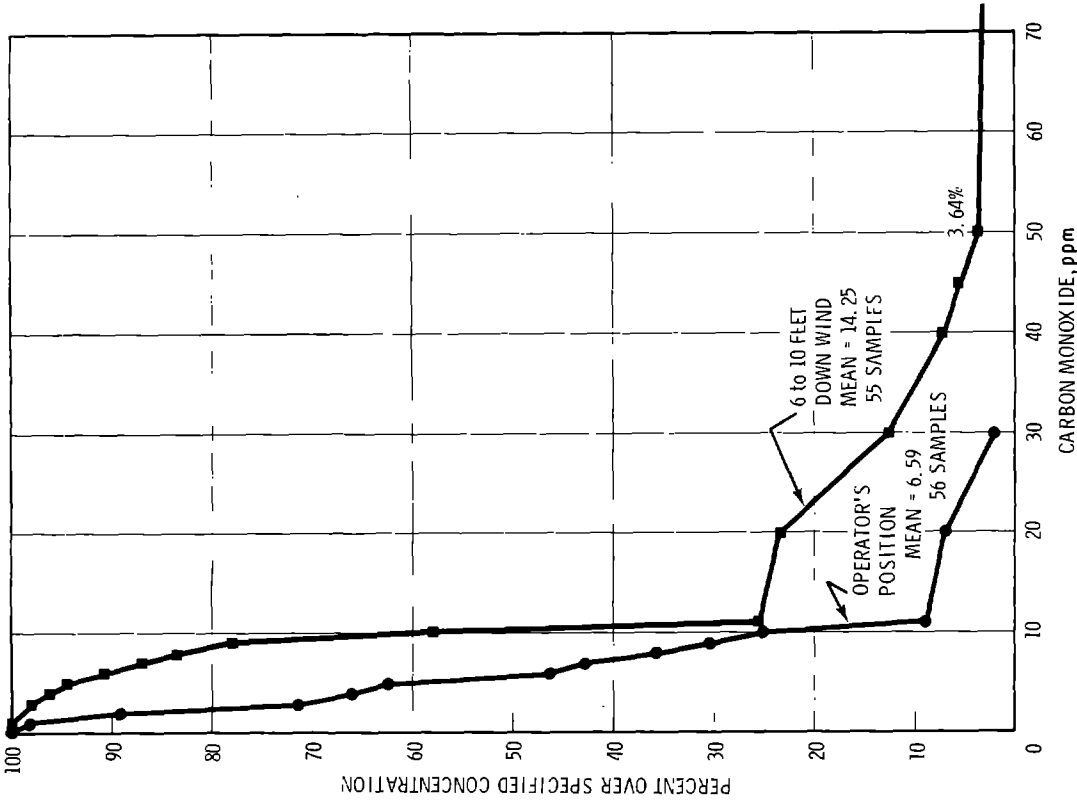


FIGURE 4. - Carbon monoxide samples-1972. Production sections using diesel Schedule 31 shuttle cars, Group A2 engines. 23 MCFM plate air. Air varies in last open crosscut-varies from 40 to 50 MCFM.

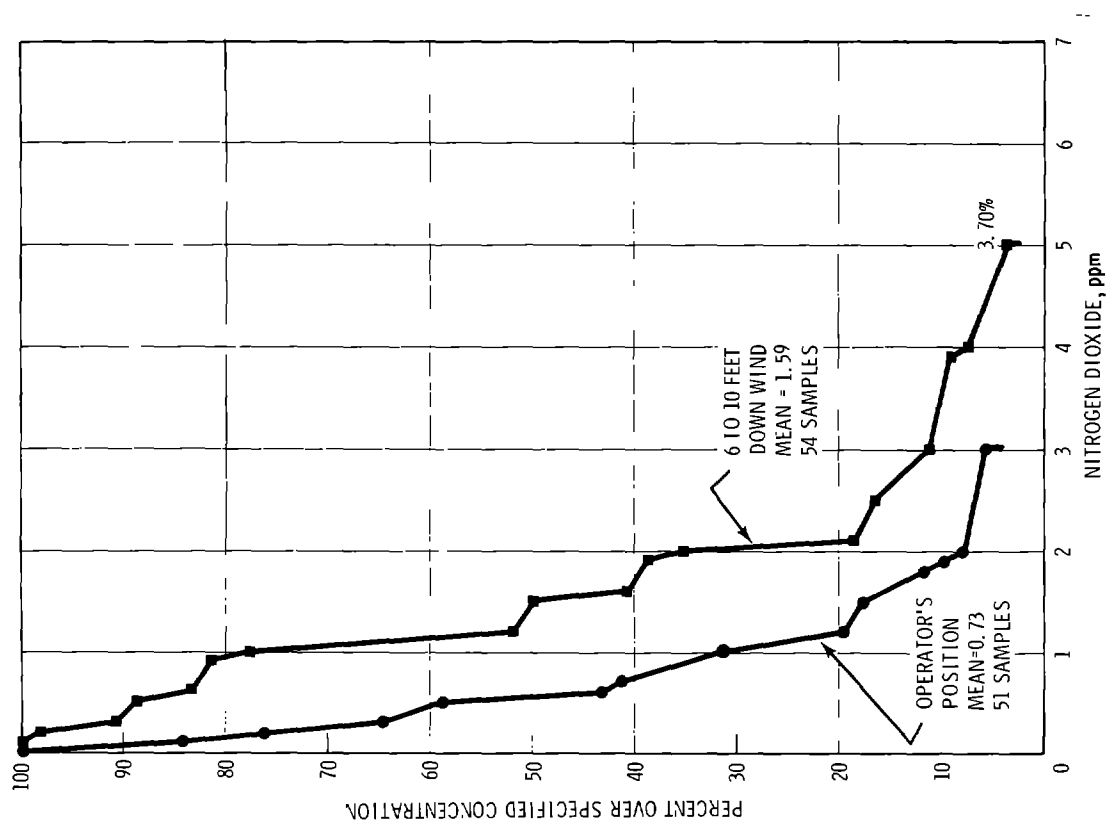


FIGURE 7. - Nitrogen dioxide samples -1972. Production sections using diesel Schedule 31 shuttle cars.

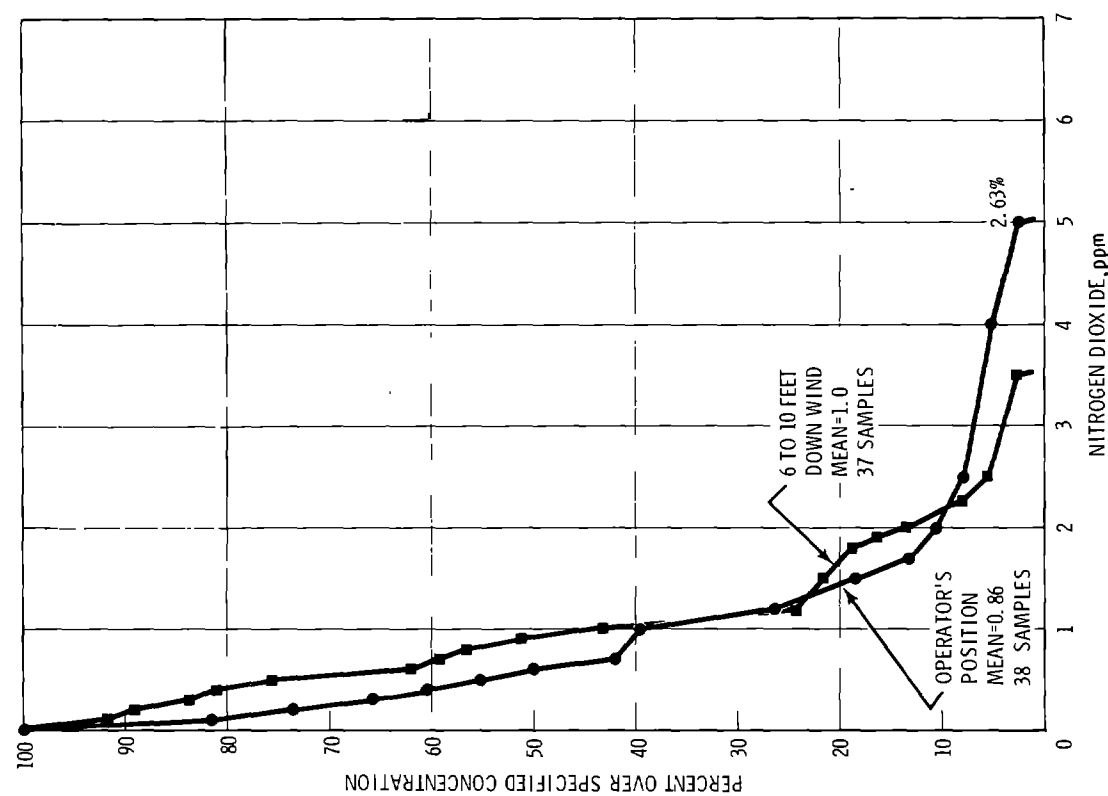


FIGURE 6. - Nitrogen dioxide samples -1972. Production sections using diesel Schedule 31 powder monkeys.

powder monkeys. In this case the peak sample was 60 ppm and three samples measured 50 ppm. The mean average at the operator's position was 7.49 ppm carbon monoxide and downwind of the powder monkey the average was 9.81 ppm.

Figures 6 and 7 present the results of nitrogen dioxide samples in a similar fashion. Note that the slope of the curves presented in this manner represents the distribution of samples which for the most part occurs below 3 ppm. The peak samples occurred at 5 ppm. The highest mean average was downwind of shuttle cars where 54 samples averaged 1.59 ppm. The highest concentrations occurred right at the face and behind the tailpiece. We began locating the belt tailpieces such that the diesel extended part way into a crosscut while dumping. This helped considerably since the flow of air is primarily in the crosscut at this location.

We were pleased that so few samples could be used to define the exhaust emission concentrations occurring in a working section. Compared to the 10-year mean concentrations measured throughout the mine we find a significant increase in nitrogen dioxide and small increases in carbon monoxide on the section. This results from several factors: direct injected engines, Schedule 31 controls, and perhaps less ventilation. Nonetheless the sample concentrations were within safe limits over substantial periods of time.

A few samples were taken on Schedule 24 diesels with catalytic scrubbers for comparison with the remainder of the study. This comparison is shown in table 6.

TABLE 6. - Comparison of operator exposure in ppm

	Carbon monoxide		Nitrogen dioxide	
	Operator's position	6 feet downwind	Operator's position	6 feet downwind
1963-1973 primarily S24 diesels:				
Samples.....	2,977	-	1,504	-
Mean.....	8.5	-	0.20	-
Detailed study S24 with catalytic scrubbers:				
Samples.....	11	12	10	11
Mean.....	1.73	1.58	0.22	0.18
Detailed study direct injected S31 shuttle cars:				
Samples.....	56	55	51	54
Mean.....	6.59	14.24	0.73	1.59
Detailed study direct injected S31 powder monkeys:				
Samples.....	37	37	38	37
Mean.....	7.49	9.81	0.86	0.95

In summary of the health hazards data presented here, we feel that health and safety has not been compromised through the use of diesels. On the other hand, caution is required, especially in the early stages of a diesel program. Assuming that the Bureau of Mines establishes their approval

criterion with sufficient latitude to permit the best possible diesel for a particular use underground, there should be nothing lost and a great deal gained through wide application of diesels.

CONCLUSIONS AND RECOMMENDATIONS

1. The criterion for approval is extremely important in giving the industry clean-burning diesel engines.

2. The criterion for operation should be different from that required for approval.

3. Approval of direct injected engines for underground service appears to be questionable unless the manufacturers are willing to do additional research and development.

4. Catalytic scrubbers are to be preferred over less efficient or higher maintenance types.

5. Measurement of sulfur dioxide and aldehydes are not necessary. Odor and smoke are excellent indicators, but all programs for diesels underground in the working section should incorporate a fume measuring program. Someone should be designated accountable for the measurements rather than leave it up to the equipment operator. Adequate density of samples can be obtained quickly.

6. Work must be done in the area of intake flame arrestors and/or air filters if the Schedule 31 engines are expected to be accepted by industry.

7. Overcontrol in the area of temperature requirements must be avoided. Acceleration rates and engine load limitations are only partial solutions.

8. Maintenance and operator training are important. We do not recommend mine site overhaul as opposed to sending the unit out. One diesel mechanic is required for every six or eight units in service.

9. A diesel should not be turned off every time the operator leaves the cab to couple a hitch or do other minor tasks. Cooling and starting diesels creates unnecessary fumes.

10. Gassy mines which do not contain flammable dust should use air-cooled precombustion-type engines with catalytic scrubbers. Methane monitor control along with fire bossing should be considered permissible in methane concentrations of less than 1 percent.

11. We wholeheartedly recommend cautious introduction of diesels into coal mines.

FROM THE FLOOR: Do you have any results of examinations of the men that have taken place during this same period of time?

MR. FISCHER: No, not specifically oriented toward the possible effect of diesel fumes. The concentrations we are measuring underground are generally less than those that occur every day in the city of Los Angeles.

FROM THE FLOOR: There have been cases of morbidities in Los Angeles attributed to fumes. This is what I am anxious to find out, what are your morbidity records as far as the men are concerned?

MR. FISCHER: We have no reported cases of any medical problem related to diesel fumes.

FROM THE FLOOR: Do you have any mechanism to pick them up if there had been?

MR. FISCHER: We have firmly established reporting channels on safety matters and we occasionally examine our people, but we have not made a specific effort to, for instance, periodically examine the same operator to determine whether or not he is progressively showing any symptoms. I have no data on that, whatsoever, medically. (Nurses are on duty, on day shift, 7 days per week and a local doctor makes random checks of the workers.)

FROM THE FLOOR: I would like to know the thickness of the seam.

MR. FISCHER: It is normally 8 to 10 feet thick. We leave some trona in the roof, so we mine an average thickness of about 7 to 8 feet. The pillar centers are very similar to coal, but the openings are narrow. They are normally running from 14 to 16 feet wide because of the roof problems.

FROM THE FLOOR: Did you take any temperature readings on the exhaust emission with the use of catalytic scrubbers?

MR. FISCHER: No, we have not.

FROM THE FLOOR: You said the mine was classified as gassy. Which gas?

MR. FISCHER: It is methane.

FROM THE FLOOR: Do you do your own diesel maintenance or do you send them back to the manufacturers?

MR. FISCHER: We do some minor maintenance of diesel equipment in our own shop. I, personally, prefer not to tear down the diesels at the mine site. You never order quite the parts you need to work on it. It is a lot quicker to send them out and get the job done right the first time.

MR. G. PERKUHN: (Chief engineer, Deutz Diesel Corp., Hicksville, N.Y.) I would like to comment on the question of surface temperature of diesel engines in gassy, non-coal mines. In addition to the critical statements of Mr. Fischer concerning the danger of explosion in gassy, non-coal mines, I would like to add the following.

With regard to the surface temperature limitation for diesel engines, I strongly suggest to clearly distinguish between coal and gassy, non-coal mines. In view of the fact that the ignition temperature of methane is 645° C (1,210° F), it certainly would be unreasonable to limit the engines surface temperature in non-coal mines at around 300° to 400° F, thus forcing the industry to purchase sophisticated and expensive equipment, which not only is unnecessary for safe operation of diesel engines in such mines, but which --as pointed out by Mr. Fischer--increases maintenance requirements and reduces engine reliability.

I would, therefore, like to suggest to limit the surface temperature at 600° C (1,140° F) for gassy, non-coal mines, which would also eliminate, for those applications, the use of specially insulated or even water-cooled exhaust manifolds.

MR. BENNETT: Our next speaker is Raymond A. Bradbury, Vice-president and general manager of the Martin County Coal Corp. Mr. Bradbury was born in England, and educated in Illinois. He graduated from Berea College, Ky., and received an engineering degree at West Virginia University. He served with U.S. Air Force as a navigator.

Mr. Bradbury's paper will deal with diesel haulage experience in the Martin County Coal Corp. with emphasis on health and safety aspects.

DIESEL HAULAGE EXPERIENCE IN THE MARTIN COUNTY COAL CORP.
WITH EMPHASIS ON HEALTH AND SAFETY ASPECTS

by

Raymond A. Bradbury¹

I consider it a privilege for our company to be a participant in this diesel symposium today. I will be talking about our experience with rubber-tired diesel haulage equipment in our underground coal mines.

A significant news item appearing in a coal mining journal in November 1969 stated simply that a Caterpillar D-333-CNA engine had received Bureau of Mines Schedule 31 approval. This item occurring at the time a new mining property in Martin County of East Kentucky was being prospected and prepared for mining, resulted in the management of Martin County Coal Corp. asking the question, "Why not use diesel equipment in our new operation?"

Martin County Coal Corp. is part of the A. T. Massey Coal Co., Inc. The property being developed is on a 17,500-acre leasehold obtained from Pocahontas Land Corp. and lies in the Wolf Creek area of Martin County. The Norfolk and Western Railway Co. built a 24-mile railroad into this undeveloped section of Kentucky to tap a huge reserve of steam coal. Duke Power Co. is the customer who will take all of the production which ultimately is projected to be 2 million tons annually, from Martin County Coal Corp. mines. Four coal seams, all above drainage, are included in the lease. The Middle Coalburg and Stockton are being deep mined now and it is in these mines that the diesel haulage equipment was introduced.

This paper will endeavor to trace the steps leading to the introduction of the first diesel-powered Wagner Mining Equipment Co. ScoopTram in a coal mine in the United States. It will further elaborate on the features which make this unit a very versatile and useful utility unit as well as the safety features which are incorporated in the machine. The success of this first unit led to the placing of orders for diesel powered TeleTrams which are telescopic trucks designed to haul from 10 to 20 tons of raw material from our continuous miners as well as from conventional coal loading equipment.

Mr. E. Morgan Massey, President of Martin County Coal Corp. is the individual who had the foresight and first suggested the use of the diesel equipment. As General manager, I have been responsible for pursuing through the necessary channels the approval and permits to operate, introduce, and implement the underground diesel equipment.

Lake Shore, Inc., the offices of which are located in Iron Mountain, Mich., is the exclusive sales agent for the Wagner Mining Equipment Co. of Portland, Oreg. Both of these firms were contacted for information and between them we were able to gain much knowledge of what was available. Lake Shore,

¹Vice President--General Manager, Martin County Coal Corp., Inez, Ky.

Inc., provided us with suggestions as well as quotations on various sized units. Schedule 24 units were virtually eliminated from consideration as a result of the 1969 Coal Mine Health and Safety Act. That schedule applies to non-gassy mines. Schedule 31 applies to gassy mines and following this route would permit us to go to the large 150 hp rated Caterpillar D-333-CNA engine and equipment which we could use in our thickest coal seam. It is also the seam of greatest acreage, and consequently, the greatest producer. We planned to penetrate it first.

Several meetings were held to help decide which size unit should be utilized to start the first mining. Lake Shore, Inc., worked very closely with Wagner as well as my company until the order for the first ST-5D(S) ScoopTram was placed. This was done June 12, 1970. The ScoopTram was a standard model made by Wagner and one to which the Cat D-333-C engine could be adapted. Since coal and shale would be handled rather than the rock and ore, normally loaded by such models, we decided to purchase a 7-cubic-yard Eject-O-Dump (EOD) bucket to go with the loader. Also, since our first mining would be done using a portable diesel generating set (in advance of the power contracted for from Kentucky Power Co.) and a cutter, coal drill, and roof drill, the front-end loader would best fit our requirements in advance of receiving the continuous miners. The use of this load-haul-dump vehicle would eliminate the need for a conventional loading machine. In our coal height, the ScoopTram functioned as a mucker does in hard rock mining and tunneling. This unit is well constructed and very rugged. You can imagine how it will stand up in coal and shale when normally used to "muck" ore and rock. The EOD bucket has proven particularly rugged with its extra heavy spade nose lip.

Delivery of the original unit was forecast for December of 1970. The manufacturer needed time to build the machine as well as get all the safety components approved by the Federal Bureau of Mines, first separately, and then as part of the assembled machine.

In the meantime we needed time to pursue the necessary approval and to obtain permits to operate the diesel unit in our proposed coal mine. This required meetings beginning as early as April 1970 and following on through that year. If we were to stake much of our future mining on diesel haulage equipment, then it would be important to pursue this matter through and with the cooperation of the inspection agencies with which we would be dealing. So the Kentucky Department of Mines and Minerals and the office of then District C of the Federal Bureau of Mines were contacted and visited. Their representatives would need to be fully acquainted with our plans and the machinery we intended to purchase. Both agencies, by which we would be governed, were receptive to our plans and were willing to cooperate in our efforts to secure permits to operate diesel equipment. In the State of Kentucky there had been previous attempts to use diesel shuttle cars but without a great deal of success.

An experimental permit, viable for 6-month periods, was obtained from the Bureau of Mines in December 1971. Meanwhile, delivery of the ScoopTram was delayed for at least 2 months. After January 1, 1971, the mine was licensed and approval to use the ScoopTram was granted by the Kentucky Department of

Mines and Minerals. Extensions of the original permit were applied for, and received, upon expiration of each 6-month period. We appreciate and acknowledge the cooperation we have recieved.

Both Lake Shore, Inc., and Wagner Mining Equipment Co. have assisted in making the equipment a success. Lake Shore provided a service man who lived with us for almost the first 3 months that the front-end loader was on the job. He was assigned to train the operators and also the maintenance personnel. A service man from Wagner Mining Equipment Co. was also on the property to assist in the familiarization program. My supervisory people had to learn as much as possible about the operation and maintenance of the machine, for they would be the people to "make the project go" if it were to succeed. Each time a new unit has arrived, the service people from Lake Shore have been present to check the machines out and to assist with the training of drivers. Parts manuals and instruction booklets have been provided by the manufacturer. Lake Shore, Inc., has since established a Sales Office and Warehouse in Louisville, Ky., from which we very readily obtain parts and service.

The ScoopTram is a 4-wheel drive, fully articulated vehicle. The driver sits "amidships" on the left hand side and is facing across the machine. This machine did an outstanding job of enabling us to develop the initial openings and entries of our l-C mine between March and December of 1971. This work was done on a single shift basis. The ScoopTram is now used largely as a supply unit and for roadway and face cleanup work. Mantrip and supply trailers are pulled by this vehicle. Air assists to start TeleTrams, which on occasion have lost their air pressure, are also rendered by this machine. We have even used it to load run-of-mine (ROM) coal out of the stockpile it built during our first mining. It has now become rather evident that another ScoopTram, perhaps of smaller capacity, will be needed for the second operating section.

Another most important application for the ScoopTram is cleaning the roadways of mud in wet areas and then depositing gravel in the chuckholes. This is a key item for rubber-tired haulage in coal mines and it is no less important in our Coalburg Seam mine. The bottom in this mine is a firm shale. It withstands the weight of our fully loaded TeleTrams without serious deterioration. When the bottom gets wet, the constant travel does cause the roadway to rut out. This is where the ScoopTram comes into use by performing road repair work.

The first TeleTram was delivered on December 8, 1971, and went into service 3 days later. This machine was specially built by Wagner for our coal mines. Nine of the Model MTT-F20-18(S) trucks were ordered and all have been delivered. Three of the smaller capacity MTT-F10-18(S) trucks were ordered for use in the 50-inch seam with our conventional loading equipment. These are also on our property, and it was one of these TeleTrams that was displayed last year by Lake Shore, Inc., and Wagner Mining Equipment Co. at the Coal Show in Cleveland, Ohio. For those of you who have not seen them, the TeleTram is simply an underground tractor-trailer with a telescopic box for the bed. The operator is located in a deck on a comfortable seat on the left hand side of the machine.

The large capacity TeleTram is fully articulated and has the same Caterpillar D-333-CNA engine that the ScoopTram has. These units have a Clark drive train and air-over hydraulic brakes. The brakes are actuated anytime the air pressure drops below 60 psi. Conversely, the brakes will not release until the air pressure builds up to greater than 120 psi. This is one of the outstanding safety features of these shuttle trucks. The brakes have given no trouble to date.

Safety features are incorporated in the haulage units which protect the operator from physical harm. The diesel equipment as presently constituted has no electrical components. An approved permissible alternator and lighting system is one electrical feature that we have incorporated. From the air-start feature through to the exhaust conditioner, commonly called a scrubber, there are no arc or spark potentials. By the same token there are temperature valves to shut the engine down at the engine exhaust manifold and the exhaust piping. An intake flame arrestor is designed to prevent flame as a result of "backfire" from getting into the mine atmosphere. Loss of air or water also results in shutdowns of the engine. The absence of a trailing cable and reel or storage batteries for energy to run the equipment eliminates the possibility of fires and electric shocks. This also adds to the flexibility of the shuttle trucks. We have encountered a 25-percent grade at one location which we think no other rubber-tired haulage equipment could have negotiated carrying the 15-ton load it pulled.

The management of Martin County Coal Corp. is convinced that diesel haulage equipment is safer than both cable-powered or battery-powered haulage equipment. The maintenance of the units has been no problem at all from the standpoint of faulty mechanical units or machine components. The fact that all of our present operators, who now number 18, are men who had never worked in a coal mine before and have had to be trained on the job has resulted in some abuse to the telescopic beds of the trucks. But these men have progressed rapidly and many have become extremely proficient in a very short time. Acceptance of the diesel equipment by all crew members in our mines plus the desire on the part of many of our employees, as well as job applicants, to learn to drive the trucks has been very heartening to management. This has resulted in our encouraging both the Wagner Mining Equipment Co. and Lake Shore, Inc., to develop trucks for even thinner coal seams. A 34-inch high model with a 4-wheel drive is being developed.

The telescopic trailers have a content of 440 cubic feet, level full with 12-inch sideboards. There is a hydraulically operated tailgate and bumper at the rear end of the trailer which helps to prevent spillage along the roadway. The telescopic "box" is advanced and discharged by means of hydraulic pistons and jacks. The overall length of the large TeleTram is 33 feet 8 inches and the wheel centers are 15 feet 9 inches. The overall width of the trailer is 10 feet 6 inches and the height and sideboards is 5 feet 8 inches. These measurements will provide some idea of the size of these machines. There is no problem about getting around corners with right angle breakthroughs. The trucks are very maneuverable.

There are other safety features which indicate that total emphasis is placed on operator safety. Most questions we are asked deal with the diesel engine exhaust and/or fumes. To put it quite simply, there are no fumes. The exhaust conditioner (wet scrubber) system, coupled with a clean burning engine, result in steam and condensation without fumes. Add to this the ventilation requirements established for use with these machines, and you have the gases and steam being diluted and swept away the moment they reach the mine atmosphere. As I have stated, the operator is situated near the front end of the tractor and he is in a deck on the opposite side from the scrubber discharge. It is virtually impossible for the operator to ever breathe any of the exhaust gases.

The scrubber tank is made of stainless steel, as is the exhaust piping and couplings leading from the engine exhaust water manifold to the scrubber tank. From the water jacket on the engine exhaust through the scrubber tank, the extremely hot gases are being cooled. This is done by immersing the hot gases in water and also injecting a jet of water into the piping before they reach the temperature control valves. The scrubber tank is designed in such a way that it not only cools the engine exhaust but also diffuses and disperses the gases. Carbon, oil, and other fine solid particles are deposited in the scrubber tank, and if allowed to build up, would render the scrubber ineffective. Therefore, at least once each day, and at times once per shift, the scrubber tanks are flushed out to remove the residue in the bottom. Water is added to the storage tank once each shift and more often, if necessary. The water level in the scrubber tank is maintained by means of a float valve in a small metal box beside the scrubber. The water pump and the cooling system are most important to the proper operation of the TeleTram engine. The primary purpose of the scrubber tank is to cool the exhaust gases and to serve as a flame arrestor. Soot and sparks are immersed in the water and deposited in the exhaust conditioner tank.

Two toxic gases are being diffused and dispersed by the scrubber and then diluted and carried away by the mine ventilation air current. There are carbon monoxide (CO) and oxides of nitrogen (NO₂). These gases have a toxic effect on individuals if breathed for any period of time. We have not had problems with either. By using indicator tubes with CO and NO₂ detectors we are able to detect any changes in the engine exhaust and make corrections. The allowable limits presently used by the Department of Mines and Minerals of the State of Kentucky and the Federal Bureau of Mines are 5 ppm of NO₂ and 50 ppm of CO. We are required by Kentucky regulations to take readings for each gas twice per shift. This is done once in the first half and again in the second half of each shift. These tests are made 6 feet from the exhaust outlet. If a high reading occurs the vehicle is immediately sent to the surface and the flushing out of the scrubber will usually clear up the problem.

Daily reports of the gas tests are completed by the truck operators and their foremen. The reports include the results of the tests, where they were made, and the time of the tests. Also recorded is the fact that fuel and water were added and that the scrubber was flushed. These reports are submitted each week to the Kentucky Department of Mines and Minerals.

Service records of our own design show when and what maintenance work is completed. Greasing; changing of oil and fuel filters; checking, cleaning, and replacement of air filters; cleaning the flame arrestor; recording the amount of fuel added and the hour meter reading is all part of the checklist. Service checks include checking the intake and exhaust systems for a free flow of air and tightness of joints. This means that once each month, the pressure drop through both the intake and exhaust systems is determined. The machines, and particularly the engines, are washed off daily to prevent coal dust deposits or oil leaks from accumulating in areas where any heat occurs. When so maintained, it is virtually impossible to create a fire on these units. Thus you have another one of the safety features of the use of diesel powered equipment in a coal mine. To have a fire, you would virtually have to build one. The flame potential that exists on electrical shuttle cars or electric locomotives through the use of trailing cables and trolley wires is eliminated.

The ventilation requirements for use of our diesel powered equipment are rather high. For one 150 hp rated engine, at least 17,000 cfm is required. An additional 75 percent is required for the second unit and 50 percent more to use a third one on a section. Thus, for the use of three 20-ton TeleTrams on a single section at least 38,250 cfm must be supplied to the section on which they are operating. This is in addition to the air required by State or Federal laws. We try to keep 50,000 cfm supplied to each producing section. This amount of air will carry away the condensation or steam that is emitted from the exhaust conditioner. This is soon dispersed in our 20-foot-wide by 7- to 8-foot-high headings. Good ventilation is the key to the dilution of the toxic gases. If the mine ventilation system should be interrupted, the engines should be shut off. The engines are not idled for excessively long periods and in fact, are shut off, rather than idled when not in use.

The use of diesel haulage equipment will eliminate belt panels in the State of Kentucky. That State's regulations permit diesel haulage up to distances of 3,000 feet. This in itself eliminates any and all of the potential hazards that exist with belt conveyor systems. Our plans are to use 42-inch and 48-inch belt conveyors under the ridges and to develop room entries and panels out to the crop lines by the use of the TeleTrams and continuous miners.

Additional operator protective features of the machine are a canopy over the driver's compartment, enough space in the deck to avoid arms and legs being exposed, a reversible seat and two steering wheels with hydraulic steering, a fire suppression system activated from the driver's deck, an independent fire extinguisher, and a loud air horn.

Martin County Coal Corp., after nearly 2 years of experience with the ScoopTram and close to 1 year of operation using the Wagner TeleTrams is well pleased with the performance of these haulage units. Maintenance has been minimal. The key to satisfactory operation is the servicing of the vehicles and preventive maintenance. We know we have a good, clean-burning engine. As long as we adhere to our present level of service, the trucks should provide us with maximum operating time. Flushing out the scrubber

tank, keeping the make-up water supply tank refilled, maintaining the flow of water through the exhaust system, monitoring the exhaust gases, and seeing that all air-operated valves and controls are functioning properly with the required air pressure available will assure mine management of reliable service and maximum usage of the haulage units.

Our company has entered into a cooperative research agreement with the Federal Bureau of Mines. Personnel from that organization have made several visits to our mines in conjunction with that program.

We take a certain measure of pride in having been pioneers in the introduction of one type of diesel equipment into coal mines in this country over the past 2 years. I see applications for both track and off-track haulage equipment. Coal haulage, supply, mantrip, cleanup, and utility vehicles can be adapted to diesel power.

MR. BENNETT: Are there any questions?

FROM THE FLOOR: I have one question. You mentioned that you measure two times per shift your exhaust emissions. Under which conditions and by which method?

MR. BRADBURY: Yes, we do measure that at full load.

FROM THE FLOOR: And full speed?

MR. BRADBURY: That's right, full engine speed and full loads.

FROM THE FLOOR: Have you monitored in any way the CO level in the ventilation air going out? Has there been any significant increase in the CO level? I will state my reason why if you answer the question.

MR. BRADBURY: The question was did we monitor the CO level in the mine atmosphere? I suppose you mean in the return air?

FROM THE FLOOR: Yes.

MR. BRADBURY: Yes, we definitely have done that. Part of our cooperative research agreement required us to make many tests for both CO and NO₂, and we get nothing but negative readings in our main return.

FROM THE FLOOR: Well, the reason why I am asking you is that CO detection in the ventilation air is being considered as a means of detecting a mine fire. If you had a sufficient number of diesels exhausting and there was a fluctuation in the CO level in return air, you might get a false reading, if such a detector was being used.

MR. BRADBURY: We also take the readings, part of our requirements are to take the readings directly from the return of the place where the equipment is being operated as well as in the main return.

FROM THE FLOOR: I would like to ask Mr. Bradbury, and mostly Mr. Fischer, what grade of fuel they are using.

MR. BRADBURY: No. 2-D, as it is specified. We happen to be using Gulf Oil fuel right now, and we were very particular that we got all the specifications from the Gulf industrial representatives in our area to be sure that we did meet all the necessary specifications as set up in the caution statement that accompanied each of these units that comes from the Bureau of Mines.

MR. BENNETT: To present our third paper we have Mr. Howard W. Williams. Mr. Williams is Assistant Product Manager, Power Systems, with the Aerojet Liquid Rocket Company, Sacramento, Calif.

Mr. Williams received his engineering degree from California State University. He has 17 years of experience in advanced power systems design and development in diesel and steam engines, turbine engines, and batteries. He is a co-holder of a closed-cycle diesel patent and he has participated in the Bureau of Mines study for advanced power systems for underground mining. In addition to that, Mr. Williams comes from a long line of coal miners, so he is well equipped to discuss diesels and coal mining. Mr. Williams.

HAZARDS AND SAFETY ANALYSIS OF VARIOUS POWER SYSTEMS FOR COAL MINE SHUTTLE CARS

by

Edward S. Chalpin, M. I. Rudnicki, and Howard W. Williams¹

SUMMARY

Three new analytical approaches bearing on the health and safety aspects of power systems for shuttle cars in underground mining operations discussed in this paper are as follows:

1. The "hazards analysis" which consists of a list of possible incidents that could occur when a shuttle car itself experiences various failure modes, as well as mine-associated incidents such as roof fall, face or rib cave-in, etc., that could affect the shuttle car and its power system. The four basic shuttle car power systems studied were the battery-powered, the electric cable-reel, the open-cycle diesel, and the closed-cycle diesel. An example of a hazards analysis for the open-cycle diesel powered shuttle car is given.

2. The "forced decisions analysis" is a method used to simplify a complex problem. The object of this technique is to arrive at a numerical value for each possible means of analyzing the complex problem. The method was applied to the four shuttle car power systems noted above. Numerical values and tables describing the analysis are given.

3. The "fault tree analysis" is an engineering tool which provides a systematic procedure by which a complex system can be studied from a safety viewpoint. The fault tree analysis of the open-cycle diesel-powered shuttle car is shown and numerical results of the number of incidents causing death or injury to miners during 1 million 8-hour shifts for the four power systems are given.

Also discussed is a diesel power system approach for a personnel carrier that can operate open-cycle for normal mining duties but can be switched immediately to operate in a closed-cycle mode and serve as an emergency survival car. The role of potassium superoxide in the closed-cycle system is explained.

DISCUSSION

Several methods of evaluating equipment used in aerospace programs have been proven of value. These methods could be applied to mining equipment as well, with equal success. Three of the methods most often used were applied to mine shuttle cars (1)² and are described below.

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²Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

The hazards analysis consists of listing possible incidents that could result when various failure modes occur within the shuttle car itself. Mine-associated incidents including roof fall, face or rib cave-in; shuttle car impact, accident or upset when struck by other equipment; ventilation deficiency, outage, or failure; and explosion and/or fire in the vicinity of the shuttle car are listed. Each incident is examined as to the failure mode causing the incident, its effect on the shuttle car and operator, and its effect on the mine environment, equipment, and miners in the vicinity. A hazard evaluation is then made for each condition. Remarks, where appropriate, are entered and usually recommend ways in which an incident can be prevented.

A typical hazards analysis as applied to an open-cycle diesel powered shuttle car is shown in table 1.

The second method used is called forced decisions analysis. To simplify a complex problem, it is broken down into simple choices from pairs of alternates and then the results are added up. The object of the forced decisions technique is to arrive at a numerical value for each possible means of analyzing the conditions or items. The highest value obtained, called the merit number, is the best choice; although in many instances the second- or even the third-place numbers can be close enough to the top to rate serious considerations. This method has been used for many years as a mathematical tool by value engineers in determining the best engineering design process, etc. (2).

The four basic shuttle car power systems, battery-power, electric cable-reel, open-cycle diesel, and closed-cycle diesel were evaluated, one against the other, relative to ten parameters or properties.

When one determines the value or safety of each power system mathematically, the emphasis placed on the significant properties is a numerical coefficient or "weight." This is then used to help make a value judgment. Of course, subjective judgment is still involved, because it is necessary to apply the numerical weighting. For a complex combination of parameters, subjective distribution of weights can be a serious obstacle to a realistic evaluation. One way to minimize subjective judgment is this "forced decision" technique. Instead of examining the ten properties and establishing their rank of importance in a single decision, each property is methodically compared with each of the others, making a large number of decisions (one for each comparison). Then the results are evaluated by conventional grouping and combination.

TABLE 1. - Hazards introduced to mine by presence of open-cycle diesel-powered shuttle car

Incident	Failure mode	Effect on machine and operator	Effect on mine environment, equipment and miners	Hazard evaluation	Remarks
1. Increased toxic exhaust gas emission.	1a Dirty air intake cleaner increases fuel-air ratio of diesel engine.	A. OPEN-CYCLE DIESEL-POWERED SHUTTLE CAR ASSOCIATED INCIDENT 1a Can result in sickness or death of operator. Machine will not operate at peak efficiency.	1a Can result in sickness or death of miners located in poorly ventilated areas. (Harmful gases are carbon monoxide, oxides of nitrogen, carbon dioxide, aldehydes, and smoke.)	1a Carbon monoxide poisoning can occur quite suddenly with no prior warning since gas is odorless and colorless. However, increase in smoke level should warn miners that incomplete burning is taking place and carbon monoxide levels are increasing.	1a Monitoring of pressure differential at engine intake during no-load, full throttle test should indicate air cleaner clogging.
	1b Badly worn or improperly functioning fuel-injection system.	1b Same as (1a) above.	1b Same as (1a) above.	1b Same as (1a) above.	1b Fuel should be kept free of dirt. Fuel injection system should be inspected on regular basis.
	1c Exhaust conditioner (scrubber) water level is low and is not replaced on schedule or system leaks.	1c Can result in sickness of operator owing to increased aldehyde emission, increased exhaust gas temperature.	1c Same as (1a) above.	1c A 10 percent aqueous solution of sodium sulfite, inhibited with 0.5 percent hydroquinone to prevent rapid oxidation of the sulfite will absorb satisfactorily all the aldehydes and reduce hazard.	1c Routine draining and cleaning of exhaust conditioner and refilling with clean water and/or collection should keep conditioner operating at its best performance point. However, CO, CO ₂ , and oxides of nitrogen will not be scrubbed. Catalytic scrubbers can reduce toxic gases but do not reduce exhaust temperature to permissible levels. They are not acceptable substitutes for exhaust cooling systems required for approved diesel machines in the United States.
	1d Operation of diesel at idle conditions for extended periods of time.	1d Increased CO, unburned hydrocarbons and smoke can result in sickness or death of operator.	1d Can result in sickness or death of miners in poorly ventilated areas.	1d Same as (1a) above.	1d Vehicle operator should be properly instructed as to potential hazardous operation.
2. Engine overheats.....	2. Loss of coolant, overtemperature shutdown and system malfunctions.	2. Overheating of engine can result in fire and explosion in presence of coal dust, oil, and methane.	2. Engine surfaces can become ignition source and initiate mine fire or explosion, subjecting miners to injury or death.	2. Over-temperature switch that automatically shuts engine down will minimize this hazard.	2. Preventive maintenance should be adhered to. Cool dust, oil, and grease should be removed from engine parts on routine basis.
3. Leakage or spill of diesel fuel.	3. Overfilling, cracks in fuel tank or lines.	3. Fire or explosion in presence of ignition source can result in injury or death of operator. Machine can become inoperative.	3. Diesel fuel can soak coal and coal dust, making them more susceptible to fire hazard.	3. In presence of ignition source, fire and explosion can become more severe than with coal or coal dust alone.	3. Inspection and preventive maintenance should be enforced.
4. Leakage or rupture of hydraulic system.	4a Leakage or rupture of hydraulic lines, fittings, cylinders, etc. Owing to wear, loose fittings, vibration, etc.	4a Dependent on degree of leakage, loss of hydraulic power can occur and leakage at 1,000-1,500 psig can be extensive.	4a Hydraulic fluid can soak coal and coal dust, making them more susceptible to fire hazard.	4a In presence of ignition source, fire and explosion can progress more readily than with coal alone. (With inert emulsions, water can evaporate leaving oil or glycol saturated coal.)	4a Use of straight synthetic and synthetic base hydraulic fluids should be used in lieu of water glycols and water-in-oil emulsions.

TABLE 1. - Hazards introduced to mine by presence of open-cycle diesel-powered shuttle car--Continued

Incident	Failure mode	Effect on machine and operator	Effect on mine environment, equipment and miners	Hazard evaluation	Remarks
A. OPEN-CYCLE DIESEL-POWERED SHUTTLE CAR ASSOCIATED INCIDENT--Continued					
4b	Failure of relief valves or improper adjustment of relief pressure.	4b Improper operation of hydraulic equipment, system leakage, or rupture. Damage to machine or injury to operator if steering mechanism fails during tramping.	4b Failure of steering mechanism during tramping can result in injury to miners or damage to mine and equipment.	Can result in injury or death dependent on circumstances at time of incident.	
5.	Failure of hydraulic pump.	5. Loss of all hydraulic controls.	5. Controls of machine can be lost and result in mine accident while tramping.	5. Can result in injury or death dependent on circumstances at time of incident.	5. Preventive maintenance could minimize this hazard.
6.	Transmission fluid leakage.	6. Dependent on degree of leakage, failure of gears and bearings could result. Leakage of transmission fluid can result in fire.	6. Erratic operation of shuttle car could result in mine accident. Production delays due to incapacitated shuttle car. Possible fire hazard.	6. Can result in injury or death if incident occurs during tramping. Fire from fluid leakage.	6. Inspection and preventive maintenance on a routine basis is required.
7.	Brake system leakage.	7. Loss of brakes can cause damage to machine while tramping and injury to operator. Leakage of brake fluid can result in fire.	7. Possible damage to mine ribs, equipment, or injury to miners in vicinity.	7. Can result in injury or death under certain conditions, fire with explosion can occur from fluid leakage.	7. Inspection and preventive maintenance should decrease the number of incidents. Brakes should be checked by operator prior to tramping.
8.	Tire blowout.	8. Possible injury or death of operator. Possible loss of control if incident occurs during tramping.	8. Possible damage to mine ribs and equipment. Injury or death to miners in vicinity.	8. Injury or death dependent on proximity of miners to tire blowout.	8. Inspection and preventive maintenance should be enforced.
B. MINE-ASSOCIATED INCIDENT					
1.	Roof fall, face or rib caving-in.	1. Rupture of hydraulic fluid lines and tanks, brake lines or tank, transmission fluid spills. Cracking or rupture of diesel engine components. Blowout of tires. Injury or death to operator from debris, fire, explosion, toxic gases, tire blowout.	1. Hot engine parts or exhaust gases can initiate fire or explosion. Hydraulic fluids, brake fluids, diesel fuel, transmission fluids, spills can propagate fire or explosion. Toxic exhaust gases can cause sickness or death.	1. Dependent on severity of mine associated incident, shuttle car can initiate a greater catastrophic mine and result in multiple injuries and deaths.	
2.	Shuttle car struck by other equipment in mine.	2. Same as (1) above.	2. Same as (1) above.	2. Same as (1) above.	2. Proper lighting, warning signals, traffic control should minimize this hazard.
3.	Ventilation deficiency, outage or failure.	3. Shuttle car cannot be used for egress except in a dire emergency since engine exhaust gases may be more toxic than mine air when ventilation fails.	3. Shuttle car cannot be used to remove miners except in a dire emergency.	3. Miner's ability to escape toxic gases is dependent only on his crawling, walking or running speed.	3. The use of the shuttle car to remove miners from the face or section will have to be decided at the time of the incident by the miners themselves.
4.	Explosion and/or fire.	4. Same as (1) above.	4. Spillage of hydraulic fluids, brake fluids, diesel fuel, transmission fluids can extend fire or explosion further than boundaries of initial fire or explosion.	4. Hazard posed by presence of shuttle car near source of fire or explosion can intensify or amplify the initial fire or explosion.	

Table 2 shows the weighting of 10 properties, one against the other. Only two choices are compared at a time, but all combinations are submitted to comparison. The decisions must be "yes" or "no" for each combination, one (1) being "yes" and zero (0) being "no." For instance, "shuttle car safety in event of mine associated incident" is considered more important than "shuttle car safety during operation." The reasoning is that a shuttle car which amplifies or increases the potential hazard as the result of a mine-associated incident (roof fall, fire, etc.) can cause a greater number of accidents or deaths than a situation where only the shuttle car itself is involved. It can be seen that 45 decisions must be made to evaluate 10 properties. As shown in table 2, the most important property is number 2, the second is property number 1, the third is number 5, and so forth.

Table 3 shows the weighting of the solutions (types of shuttle car) against each of the properties. Six decisions must be made for four types of cars in each property category. Here again, a value rating of 1 means that the power system is considered better than a value rating of zero. For instance, the battery-powered car was considered better than the electric cable reel car in the first decision of the first property (shuttle car safety during operation), mainly because the electric cable poses a greater electrical hazard than a battery.

Table 4 is a listing of the properties values from table 2 which are multiplied by the values obtained in table 3 for each of the shuttle car power systems. The results were then added vertically and the sums became the merit numbers for each car.

It was determined from these analyses that the open-cycle diesel with a merit number of 0.3743 was the most desirable power system. This was followed by the closed-cycle diesel with a merit number of 0.334. The electric-cable reel and the battery-powered systems were very close to each other with merit numbers of 0.1628 and 0.1297, respectively. Acceptability of the systems by the coal mine operators, the United Mine Workers, and the Bureau of Mines was not factored into the overall analyses. It is well known that the electric cable reel, the battery-powered systems and some open-cycle diesel systems are currently termed permissible by the Bureau of Mines in the coal mines of the United States. The United Mine Workers are not in favor of open-cycle diesels in union mines at this time, however. It appears that diesels, either closed-cycle or open-cycle, should be seriously considered from a health and safety standpoint for more extensive use in coal mines.

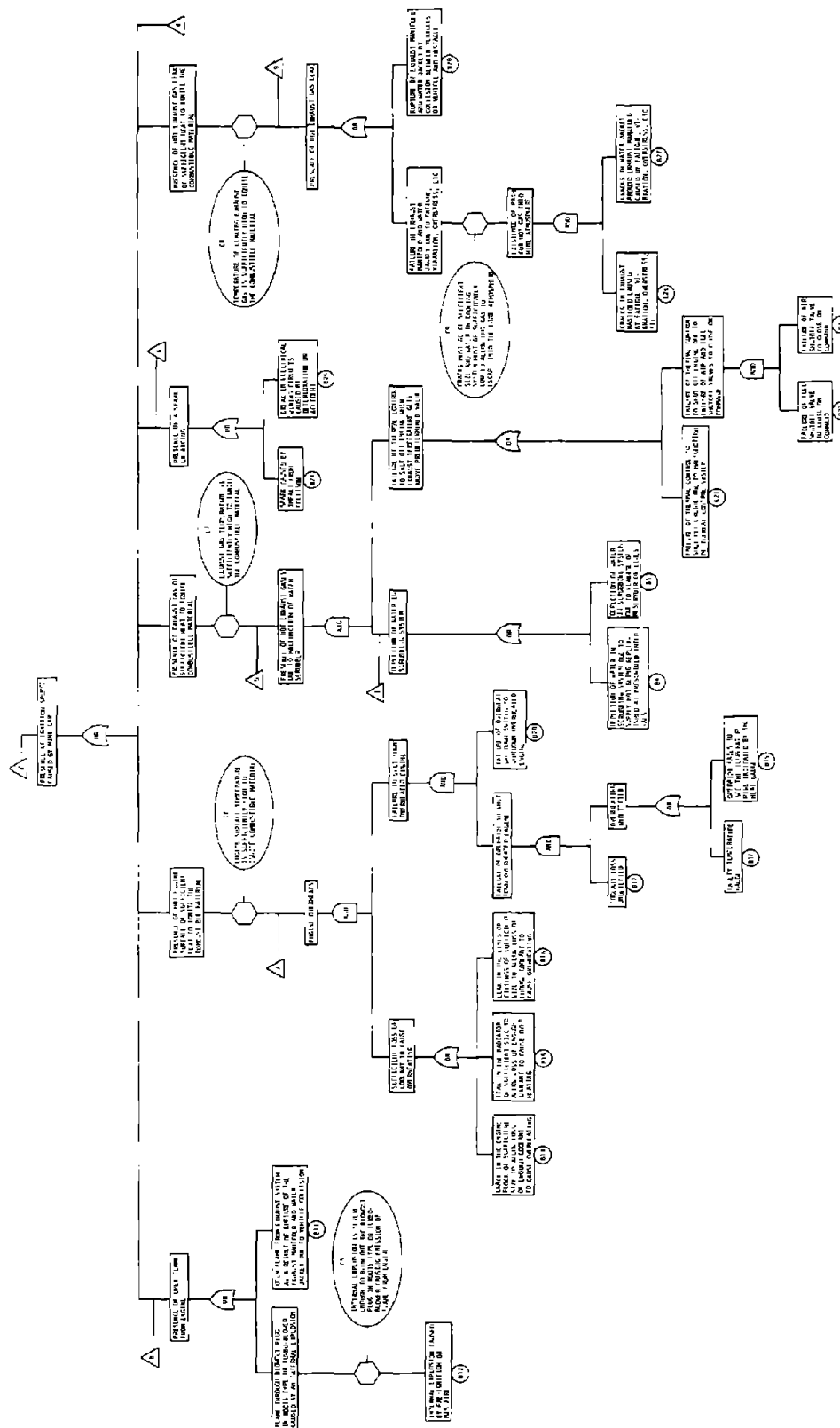


FIGURE 1. - Fault tree analysis for open-cycle diesel-powered (OCD) mine car.—Continued

1 million 8-hour shifts, it was estimated that there could be 10.89 incidents causing death or injury to miners when an open-cycle diesel-powered mine shuttle car is used. For a closed-cycle diesel-powered car, the number of incidents became 18.22. The number rose to 105.2 incidents for 1 million 8-hour shifts when the battery-powered car was analyzed and the highest number of incidents, 495.4, was attributed to the electric cable-reel mine shuttle car.

Based on the three methods of analyses, it can be reasoned that a diesel-powered system for a personnel carrier that could serve as an emergency survival car would be in order. However, under certain emergency conditions, notably when explosive methane atmospheres develop, the open-cycle diesel would not be the best powerplant to use. The closed-cycle diesel, on the other hand, would be an excellent choice. The system developed by the Aerojet Liquid Rocket Co. utilizes potassium superoxide (KO_2) for diesel engine exhaust (CO_2) absorption as well as oxygen liberation. In the fully closed system a portion of the engine exhaust products pass through a bed of KO_2 where a chemical reaction takes place between the carbon dioxide and the KO_2 , converting the KO_2 to a carbonate and releasing the oxygen gas on a continual basis. The resulting gas mixture of 20 percent oxygen and 80 percent carbon dioxide (that bypassed the KO_2 bed) becomes available to the engine intake and is mixed with the diesel fuel in the cylinders in the same manner as the normal open-cycle diesel. A system schematic is shown in figure 2.

When comparing a rechargeable battery/motor powerplant with the closed-cycle KO_2 system for an emergency survival car, the following advantages of the latter system become evident:

1. The closed-cycle diesel (CCD) will not require periodic maintenance during storage or non-use. The battery-powered system will require periodic trickle-charging to maintain its potential.

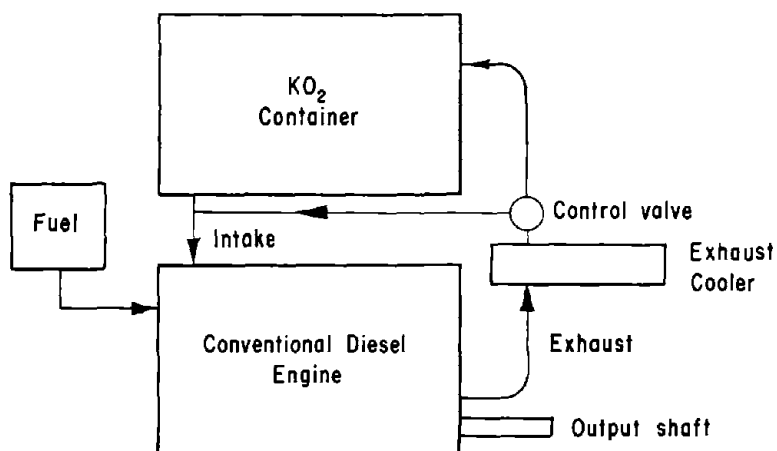


FIGURE 2. - Closed cycle diesel system schematic (KO_2 design).

2. The CCD can be designed to operate open-cycle when being used as a personnel carrier for normal mining duties but can be switched immediately to operate in a closed-cycle mode and serve as an emergency survival car. The KO_2 system will maintain its emergency potential even after long periods of operation in the open-cycle mode, thus giving mining personnel the assurance that the personnel carrier they are using can become their life-saving escape vehicle at a moment's notice.

3. The CCD will have no hazardous electric spark ignition source on board that could initiate a fire and/or explosion in the presence of combustible gases or dusts. All functions (power to wheels, steering, reversing, etc.) can be performed hydraulically by an engine-mounted hydraulic pump and hydraulic motors.

4. Potassium superoxide can be used for life support as well as for engine operation. Current emergency systems employ KO_2 for breathing. Thus the cost and handling of the chemical can be reduced, since two functions will be served, emergency power and life support.

CONCLUSIONS

The three methods of analyzing mine shuttle car systems were found to be of significant value in showing where hazards can exist and in making visual what the safety problems may be. As well, these methods are excellent for determining the relative merit of each system from a mining health and safety standpoint.

Two of the methods, hazards analysis and fault tree analysis, can serve as powerful tools for anticipating where potential hazards and incipient failure modes exist and can establish the means to effect corrective actions before an accident occurs for mobile equipment used in the mining industry, other than shuttle cars. Some of this equipment is listed in table 5.

TABLE 5. - Mobile equipment that can be investigated
by hazards and fault tree analyses

Track mobile mining equipment:
Trolley locomotives.
Electric cable-reel locomotives.
Battery-powered locomotives.
Diesel locomotives.
Mine cars.
Portal buses and personnel carriers.
Trackless mobile mining equipment:
Tractor scoop.
Continuous miner.
Loader.
Roof bolter.
Mine rescue vehicles.
Conveyor belt:
Coal transportation.
Man transportation.
Hoisting:
Vertical elevator hoists.
Sloped track hoists.

Based on the analyses conducted with mine shuttle car power systems it appears that diesels, either open-cycle or closed-cycle, should be seriously considered from a health and safety standpoint for more extensive use in coal mines.

Consideration should also be given to the versatility of a personnel carrier equipped with a closed-cycle diesel powerplant that can operate open-cycle for normal mining duties but can be switched immediately to operate in a closed-cycle mode and serve as an emergency survival car.

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MR. BENNETT: Are there any questions of Mr. Williams?

FROM THE FLOOR: Was your closed-cycle diesel cleaning chamber a packed bed scrubber or just a spraying chamber?

MR. WILLIAMS: It was a spray chamber in this instance.

FROM THE FLOOR: So the pressure drop was very low on it, I imagine?

MR. WILLIAMS: Yes, it was quite low.

FROM THE FLOOR: And that was able to take out most of the particulate matter just by spraying?

MR. WILLIAMS: We had no real indication of particulate matter, either in the exhaust or in the intake.

FROM THE FLOOR: Was it combined with a catalyst also?

MR. WILLIAMS: No.

DR. JOHNSON: This morning, I raised the question about noise with diesel-powered equipment. I didn't detect in your discussion whether you included the effect of noise in your analysis.

MR. WILLIAMS: The answer is that we did not. One of the reasons we did not was that after discussions with miners working underground with both diesel and electric equipment, we didn't really see that there was any significant difference.

FROM THE FLOOR: Did you use specific current state-of-the-art in all cases in all of your investigations?

MR. WILLIAMS: The answer is yes, with the exception of the closed-cycle diesel, in that it has no underground operating experience at this point, although I would say that it is certainly state-of-the-art as a power system. There is nothing used in the closed-cycle diesel system that is of the nature of advanced technology, that is, as far as any particular component is concerned.

FROM THE FLOOR: What was the battery system that you used in these studies?

MR. WILLIAMS: The battery system was the rechargeable lead acid battery system of the type that is most commonly used in mines now. That ties in with the previous question, too, in that there was no attempt to try to project to the future any systems that are under development, other than the closed-cycle diesel.

FROM THE FLOOR: I am wondering what this diesel system really looks like, what you are intending to accomplish with it with regard to particular underground mining use, and if it came in as second safety-wise, what in particular was it that caused it to take second place?

MR. WILLIAMS: Well, as far as the nature of the closed-cycle diesel, I don't think that I should get too involved here. There are published papers on it and the Bureau study gives quite a bit of detail on its construction and its application in mines.

Of course, the reason for the potential use in mines is primarily from the standpoint of allowing the productivity of diesel engines without the problems that you get with diesel exhaust products. In addition, it doesn't consume any oxygen from the air as it operates.

With regard to its coming in second, I think it should be borne in mind that the analysis can't predict that close between first or second in this case, as you saw, it was pretty much a "dead heat." We don't intend to imply that the analysis is precise to a two or three place accuracy. The main reason the closed-cycle diesel did not rank higher is our early concern over the hazard of carrying oxygen. It is difficult to evaluate and would require further tests and actual operation to see what those hazards really are.

FROM THE FLOOR: How were the carbon monoxide and carbon dioxide samples taken from the closed-cycle diesel, by bottle or other means?

MR. WILLIAMS: They were taken under a range of operating conditions by drawing off samples out of the loop and analyzing the samples through various different methods including mass spectrometry.

FROM THE FLOOR: With this closed-cycle diesel, are you carrying down liquid oxygen to supply the oxygen required for combustion?

MR. WILLIAMS: Yes.

FROM THE FLOOR: Can you tell us how the probability of accident or injury was determined for the closed-cycle diesel as opposed to the open-cycle diesel? There is very little background with closed-cycle diesels in coal mining.

MR. WILLIAMS: Primarily, it is based on determining what the potential causes are, and then looking into data which is available on that type of cause and also what the occurrence rates are for that type of cause.

For instance, with regard to valve malfunction or a radiator cracking, there are data available to give approximations for the frequency of that type of occurrence. There were also some places where data were not available and so engineering judgment was used and, to some extent, backed up by discussions with people in the field.

FROM THE FLOOR: Did you actually make these tests underground in coal mines or did you get this from reports to your office? Did you actually go in a mine to conduct the tests?

MR. WILLIAMS: No. There were no tests conducted in a mine. Although, within the scope of this study, we did some tests in a simulated mine where we allowed controlled spillage of materials including liquid oxygen under different conditions of air flow and measured the results.

FROM THE FLOOR: The closed-cycle diesel model you showed was a Detroit diesel two-cycle engine. Has that theory been tested on a four-cycle engine?

MR. WILLIAMS: There have been no tests on a four-cycle engine, only design studies that have indicated there would be no basic difference in the operation.

MR. BENNETT: May we have your attention, please. Our next speaker is Mr. Berl A. Trafton, General mine superintendent, International Minerals and Chemical Corp., Carlsbad, N. Mex.

Mr. Trafton was raised on a farm in Minnesota, has a degree in mine engineering from the University of Washington, is a World War II Navy veteran, had varying engineering assignments in underground, copper, lead, and zinc mines before his present position as General mine superintendent.

He will speak to us on diesel haulage equipment in an underground potash mine.

DIESEL HAULAGE EQUIPMENT IN AN UNDERGROUND POTASH MINE

by

B. A. Trafton¹

The International Minerals and Chemical (IMC) Corp. Carlsbad potash mine, located 26 miles east of Carlsbad, N. Mex., started operations in 1940, and has been in continuous operation since then. At present, there are six other companies operating in the area.

The beds of sylvinite and langbeinite ores are found in five different horizons over a vertical distance of about 200 feet in the upper part of the Delaware basin salt deposit, ranging from 1,200 to 2,500 feet in total thickness. The individual ore beds vary in thickness from 3 feet to over 12 feet, and many variations of mining methods have been employed by the different companies. Owing to the absence of methane or other combustible gases in these beds, all of the Carlsbad potash mines are classified as non-gassy.

To date, IMC has mined over 100 million tons of ore using conventional coal mine equipment. Nearly all of this was produced from areas that averaged over 6 feet in height. Because large tonnages of our reserves fall in the 4- to 6-foot-height category, continuous mining equipment and methods have been tested and are continually being investigated, but factors other than height have precluded their application. Low-grade ore and the unpredictable occurrence of salt horses necessitate selectivity in mining, and the presence of hard sulphate minerals which can't be cut with existing tools still require the flexibility of trackless conventional methods.

As far back as 1952--when main line haulage was done by rail--diesel equipment, in the form of Ford farm tractors and modified Jeeps and Power Wagons, was adopted for utility vehicle use in IMC's mine. The flexibility and versatility of diesel power had obvious advantages over battery, cable-reel or rail-mounted vehicles.

However, production equipment, particularly face haulage units, continued to be dominated by electric-powered cable-reel or trolley shuttle cars. Battery power at 96 volts was tried in the early 1950's, but results were unsatisfactory.

In an attempt to improve productivity and flexibility, a self-loading, diesel-powered Transloader was tested in 1962. No major problems were encountered with the diesel engine and drive train; but height restrictions and the expense of providing a bottom discharge hopper severely limited its application.

¹General mine superintendent, International Minerals and Chemical Corp., Carlsbad, N. Mex.

In 1965, the ram-plate type discharge was conceived for a low-profile, wide-bodied car of greater capacity. Partly to reduce the problems of operating with a cable reel on a car that could only load and discharge from one end, large, high-capacity batteries were developed for this unit. At the same time, special feeder-breakers had to be used in conjunction with the wider, fast discharge cars.

It was soon proved that the combination of the larger cars and feeders very favorably affected production rates and efficiencies. With the additional conversion in 1965 to larger loading machines, face efficiencies have increased from 120 to over 230 tons per face manshift, and loading and haulage costs have decreased by 15 percent. The flexibility of batteries over cable reels was a major advantage; but capacity limitations of batteries and high replacement and maintenance costs resulting from structural failure, and serious electrical fires in two different brands of batteries over a 5-year period prompted the study of alternate power sources. Silicon controlled rectifiers were tested on the batteries to reduce power loss, but with little success, because the equipment couldn't handle the high voltage and current involved.

By 1970, considerable experience in the operation of diesel production equipment in underground metal and nonmetal mines had been recorded and observed, and a wide range of engines and drive components was then in use. Comparisons were then made of all available power packages to convert our battery cars, namely diesel-electric, diesel-hydraulic, and direct-drive units, considering the factors of (1) performance, (2) operating height, (3) ventilation requirements, (4) maintenance, and (5) cost. The elimination of electrical shock hazards and fires experienced with both cable-reel and battery equipment was a major factor considered in the conversion to diesel power.

Engineering evaluations and estimates of the various power packages by different manufacturers all pointed toward a direct-drive diesel as most nearly meeting all of the above requirements. The diesel-electric required a larger engine, more height, and retained all of the existing electrical controls, motors, and gear cases. Excessive horsepower was indicated for the hydraulic-drive version and maintenance was a matter of concern.

Therefore, in December 1971 after comparing available bidders, a prototype vehicle was built and put in service, replacing a standard Ramcar battery tractor. Components consisted of a 401 CID naturally-aspirated diesel rated at 132 horsepower, a torque converter powershift transmission, and an industrial tractor type differential-axle assembly. Productivity and flexibility of the unit soon proved superior to either battery or cable power.

However, after a short time, axle failure and wheel mountings necessitated changing to a 50,000-pound planetary truck axle. Mine duty and the shock loads encountered soon found the weaknesses in this unit--spindle failure, inability to keep planetaries together, and inadequate brakes. We finally installed an 84,000-pound rated final drive with air brakes that has operated trouble free for nearly 3 months. Total weight on the tractor wheels

is not over 18,000-pounds, so it points out that the unsprung shock loads are difficult to design for by conventional standards and experience.

We now have five units in operation and are in the process of converting to the heavy duty axles as they are available. To date, only one engine has required overhaul. This was on the original unit, on which several types of air cleaners were used experimentally. When the engine was inspected at 3,000 hours, it was obvious from the amount of wear that dust and dirt had gotten by the filters. The fine, hygroscopic, salt dust inherent in potash mining rapidly clogs a single-stage paper filter, but isn't adequately reduced by an oil bath. A two-stage filter, with precleaner, is the most effective we have found to date, and an overhaul interval of 5,000 to 7,500 hours is now anticipated.

To meet exhaust gas requirements and minimize service and maintenance requirements on the exhaust system, Englehard PTX catalytic purifiers are used instead of water scrubbers. In order to control exhaust gas discharge temperature and hold back pressure to desirable levels, which should also extend service life on the purifiers, it was necessary to design an exhaust system with larger diameter piping and a heat diffuser at the end.

Although our experience is limited, and much experimental work has been necessary, availability and maintenance costs have been favorable. It appears now that operating and maintenance cost savings of diesel versus battery power should be \$0.025 per ton or \$100,000 per year at our present production level. This doesn't come free, though, since capital replacement costs will be about \$175,000.

Before concluding with some comments on safety, maintenance requirements and responsibilities, I would like to show you some pictures of the types of diesel equipment being used at IMC (figs. 1-5). They show the custom-made nature of most underground equipment in relation to mining height and the unrestricted mobility feature of diesels.

From our experience and the successful use of diesel equipment underground by operators worldwide, I feel confident that properly designed and constructed diesel vehicles in mine service can be safe, reliable, and productive.

In a nongassy, noncoal environment--such as most salt, potash and metal mines--safe, efficient diesel engine operation will result if (1) clean, good quality fuel is used; (2) the fuel-air ratio is correctly maintained; and (3) sufficient ventilating air is directed through the working area to dilute and remove exhaust gases.

Of course, to meet these basic requirements, it is essential to have a rigid maintenance schedule that insures regular inspection and service of air filters, fuel systems, exhaust systems and engine lubrication and cooling. Regarding these maintenance schedule requirements, I am somewhat concerned about the proposals for certifying individuals to perform specialized functions, such as maintenance and testing for emissions. Because decisionmaking



FIGURE 1. - The Sien Brute Ford-powered tractor operating with a Jeffrey Ramcar trailer.

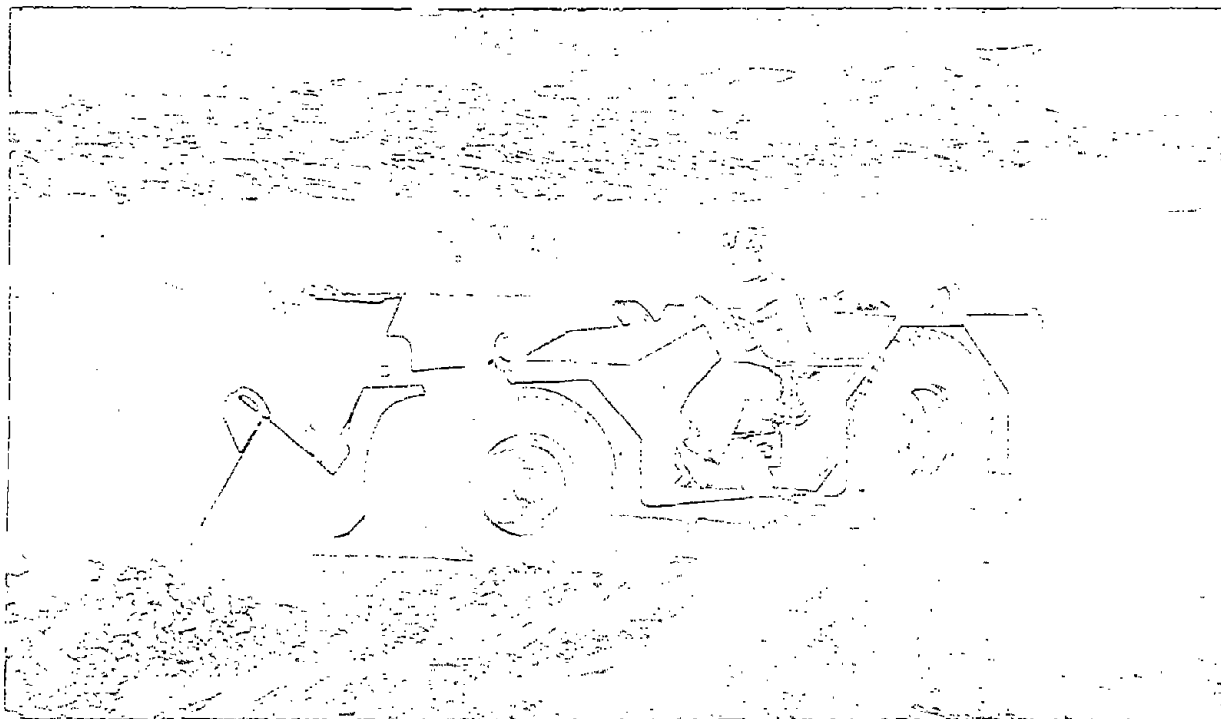


FIGURE 2. - Heavy duty mine tractor with a 1 cu yd bucket and weight boxes for moving heavy equipment.

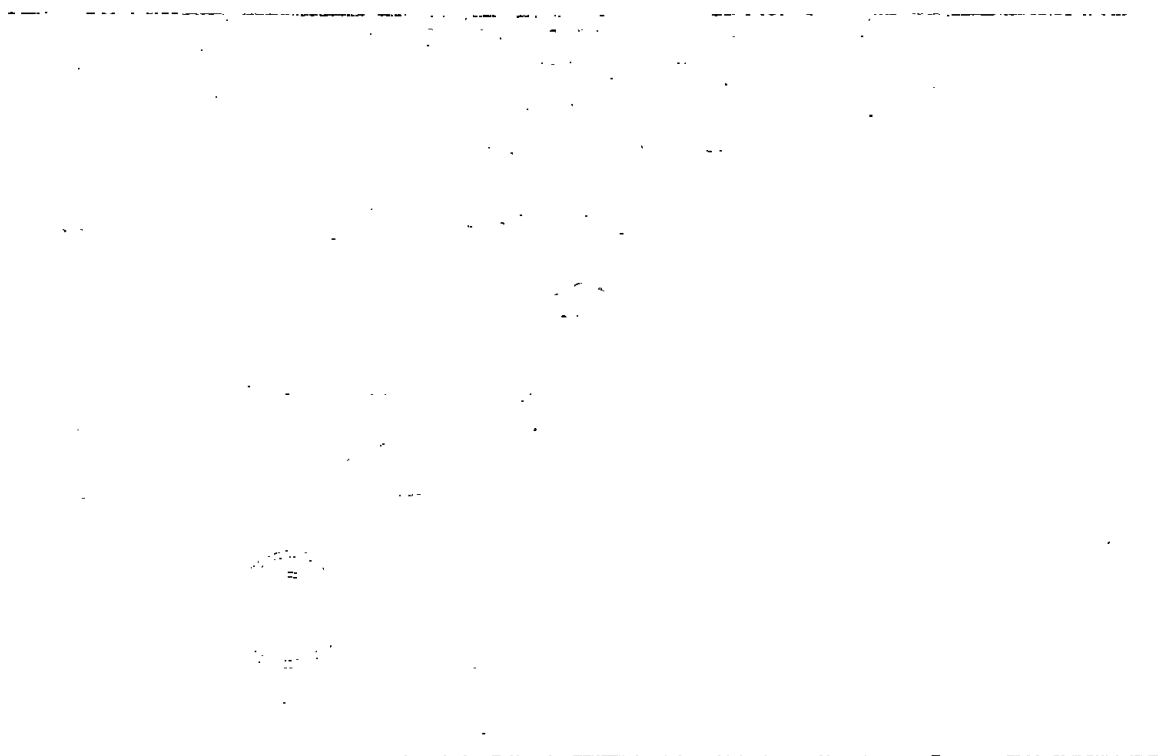


FIGURE 3. - Twelve-passenger utility vehicle for personnel transportation.



FIGURE 4. - Three-wheeled diesel unit for loading ammonium nitrate.



FIGURE 5. - Diesel-powered roof bolter.

or accountability is generally not delegated to or required by the hourly employees, certification doesn't provide assurance that the work will be performed properly. Thus work must still be assigned, inspected, and approved by a supervisor. It has always been management's responsibility to plan and direct all aspects of its business; and, in addition, the company is held liable for safety violations or errors in judgment caused by its employees. Therefore, in being responsible and accountable for the safe, profitable conduct of an operation, it follows that management must have the freedom of alternates and decisionmaking authority to function. As every operation's problems are unique to itself, we feel that the solutions to these problems in meeting the various standards and regulations are the responsibility of management, with assistance and cooperation from labor and Government.

It would seem that the important thing is not "how" a problem or safety regulation is met, but that the end result is in accord with good practice and is safe.

MR. BENNETT: Are there any questions?

FROM THE FLOOR: What does New Mexico allow for exhaust temperature?

MR. TRAFTON: 180-degrees.

FROM THE FLOOR: I think you ought to be commended on such a fine piece of equipment, but I notice the paint wasn't even worn off the inside of the bucket of the front-end loader.

MR. TRAFTON: I could try to say the paint is new, but actually the machine had just recently been put in service.

MR. G. PERKUHN: (Chief engineer, Deutz Diesel Corp., Hicksville, N.Y.) I would like to address myself to the question of direct-injection diesel engines with catalytic purifiers versus two-stage combustion type engines and wish to make the following comments with respect to the use of catalytic scrubbers:

1. In view of the desired optimum safety, diesel engines operating in an underground environment should be equipped as simply as possible for the prevailing conditions in the respective mines.

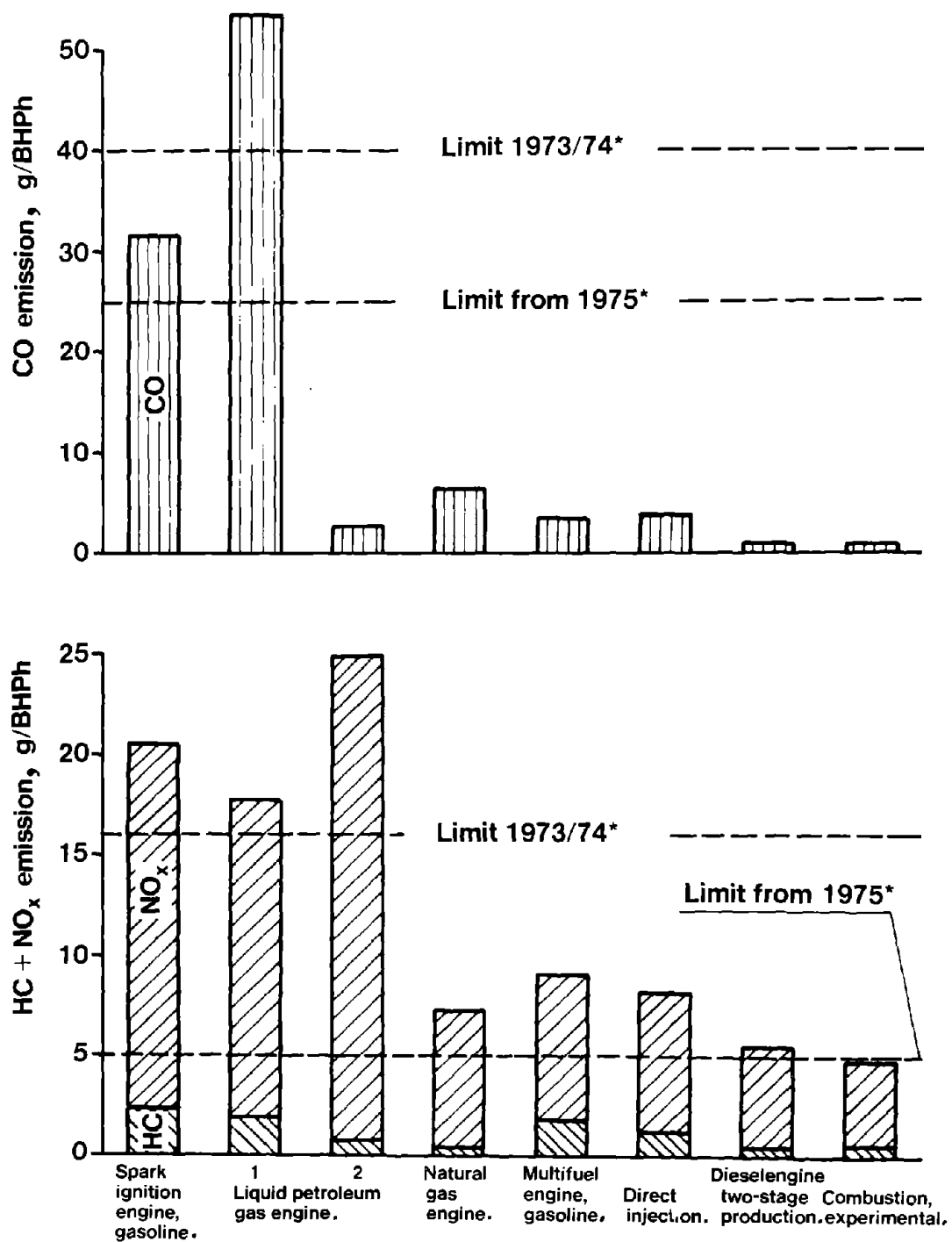
2. The use of direct-injection type diesel engines should not be permitted at all for underground mining applications, because an acceptable exhaust gas quality could only be reached with a catalytic scrubber which, as outlined in Mr. Loevinsohn's comments on "Diesel Technology" by R. D. Henderson is not reliable and efficient under all operating conditions.

The exhaust gas quality of a precombustion or two-stage combustion-type diesel engine (fig. 1) is at least equal to that of a direct-injection engine with a catalytic scrubber, working at the peak of its efficiency. It might be of interest to note that part of the NO oxidizes to the more poisonous NO₂ in the scrubber, which certainly is a most unwanted reaction and which occurs in particular at lower exhaust gas temperatures resulting from partial load operation.

MR. BENNETT: Gentlemen, our final paper is by Mr. Jerry Karlovsky, Jr.

Mr. Karlovsky has a mining engineering degree from the University of Illinois, worked in the coal mines in Illinois, worked as a design engineer with Goodman Manufacturing Co., and spent his last 14 years with National Mine Service Co., rising to his present position as vice-president of engineering.

He has spoken for the engineering effort and furnished the mining industry with continuous miners, feeders and diesel- and electric-powered shuttle cars and locomotives.



*Proposed in the USA for diesel powered vehicles (California 13-mode cycle)

FIGURE 1. - Emission levels for various types of engines compared to California proposed standards.

ENGINEERING CRITERIA FOR SELECTING DIESEL- OR ELECTRIC-POWERED
EQUIPMENT FOR UNDERGROUND MINING APPLICATION

by

Jerry Karlovsky, Jr.¹

For the purposes of engineering criteria for selecting equipment for underground mining applications it is best to consider the adaptability of diesel-powered underground mining equipment rather than permissibility. We should remember that a considerable number of studies are underway covering all facets of diesel engine and application technology. Engine manufacturers are studying ways to improve efficiency and produce cleaner burning engines. Work is also in progress to develop exhaust emission control equipment and instrumentation to monitor exhaust gases to insure that they meet the Federal regulations. Equipment manufacturers are attempting to stay abreast of these developments and to consider the place diesels have in underground mining.

In addition, Part 31, Title 30, Code of Federal Regulations remains in its preliminary draft form and undoubtedly will undergo numerous changes. What this all amounts to is that no one at this time can predict the ultimate outcome of diesel technology, Federal code changes, and exactly how all of this will affect the eventual use of diesel-powered equipment underground.

In preparation for this paper certain coal mine officials, Federal Bureau of Mines personnel, and representatives of firms presently manufacturing diesel engines and diesel-powered underground mining equipment were consulted. The general impressions gained from these discussions were that there is a definite place for diesels underground, but with some restrictions.

At this time it is fairly safe to rule out diesel-powered face equipment, that is, continuous miners, gathering-type loaders, and cutting machines. One might debate the merits of diesel-powered face and roof drills, but most face equipment is fairly compact and demands high torque. A diesel engine selected for its torque characteristics would be extremely large compared to an electric motor. Weight and space would likewise be important factors to consider. Since most people judge the relative merits of a piece of equipment by the horsepower of its prime mover, I think it is interesting to compare a typical water-cooled electric motor and water-cooled diesel engine both being rated approximately 150-hp. The electric motor would weigh approximately 1,200 pounds and be contained in a space of 3.4 cu ft. This calculates to approximately 45 hp per cu ft and 0.126 hp per pound of weight. Its diesel counterpart would weigh approximately 1,628 pounds and be contained in a space of 27 cu ft. By the same calculations we find that this package produces 5.6 hp per cu ft or 0.092 hp per pound of weight. It was previously mentioned that coal getting and cutting machines have high intermittent torque demands. To

¹Vice-president of engineering, National Mine Service Company, Mine Road, Nashville, Illinois 62263.

meet these demands with a diesel engine, one with a high horsepower rating would have to be considered.

These machines also operate for a large portion of their time in the last open crosscut, in generally confined space. Although ventilating air is readily available to control methane and dust, and in many mines this is sufficient to properly dilute the exhaust gases to the emission standards that are required by Federal regulations, heat could become a serious problem by affecting the efficiency of the men operating the machine and possible effects on the surrounding strata. A typical diesel engine has an efficiency factor of 30 percent which means that 70 percent of its fuel input is rejected in the form of heat. This translates to approximately 100,000 Btu per gallon of fuel burned. A shuttle car, for example, will have a 30- to 50-percent load factor and consume during a normal operating shift 15 to 20 gallons of fuel. In comparison, a loader would have a 75- to 80-percent load factor and consequently consume twice this amount of fuel and reject 3 to 4 million Btu per shift. Much of this heat is rejected through the exhaust system and can be tempered by means of a water-bath exhaust conditioner employing water sprays within the exhaust manifold. The water injected into the manifold causes adiabatic saturation to occur, which reduces the heat output so that the temperatures of the exhaust gases are reduced to 170° to 160° F. Dry-type exhaust conditioners do not normally contain this feature and under certain operating conditions may create environmental problems.

There is no question that wherever diesel-powered equipment may be employed to replace electric-driven equipment, adequate ventilation is essential. The proposed Part 31, Title 30, Code of Federal Regulations does allow for a reduction in the amount of air necessary to pass over a piece of equipment to dilute the exhaust gases to a safe level. At the present time the wording is such that this would be based on a 100 percent duty cycle. Since duty cycles for any piece of underground mining equipment, whether it be diesel-powered or electric-powered, are never 100 percent, we should expect some changes in this area which would allow diesel-powered equipment to now be used in many mines. The statutory provisions of the mandatory safety standards in underground coal mines, section 75.327, relates to air velocities in trolley-haulage entries. This will undoubtedly require amendments to provide such ventilating air to properly dilute the exhaust gases from diesel-powered equipment. Since the air traveling through a haulage road cannot then be used to ventilate the face area, many older mines would probably have difficulty in adjusting their ventilation plan to meet the requirements no matter what form they might take.

As can be detected from the previous remarks, many unknowns exist, but we cannot overlook the fact that diesel-powered equipment is being used successfully and safely in many noncoal mines and in the coal mines of foreign countries. They have been used in only a limited extent in the coal mines of the United States, but as far as known, these applications have been extremely successful.

The engineering criteria for the selection of diesel- or electric-powered equipment for underground mining application aside from the design

considerations can then be broken down into four essential elements. They are as follows:

- (1) Availability of diesel-powered equipment.
- (2) safety features,
- (3) operational advantages, and
- (4) servicing and maintenance.

Availability

The selection of diesel-powered equipment for coal mine service is rather limited at present but will increase rapidly with demand. There are presently four diesel engines certified under schedule 31 and currently in production, ranging from 45 to 150 hp. These are liquid-cooled engines; however, air-cooled engines may be available in the near future.

Haulage equipment approved under the Federal Bureau of Mines schedule 31 is available in heights from approximately 40 inches upward, in the conventional 4-wheel-drive shuttle car and articulated steering, self-unloading haulage units.

Locomotives are available in a variety of sizes; although 46-inch equipment is the lowest I have knowledge of, hardware is also available to build lower units in the 40-inch height.

Front-end wheel loaders are available from four manufacturers approved under schedule 31, and most of these units are low-profile, designed specifically for coal mine application.

There are a variety of utility vehicles now being used in the United States in noncoal mines. Much of this equipment can be modified or repowered for use in coal mines. Although some equipment of this type is available in the United States, diesel-powered support equipment is common in foreign countries where diesels are used in coal mines. Figures 1-15 show such equipment.

Safety Features

Diesel-powered utility and haulage vehicles have the following safety advantages when compared to their electric counterpart:

1. Electrical shock hazard to mine personnel is eliminated.
2. The trailing cable is eliminated, allowing the operator to pay full attention to driving without constant monitoring of the cable and reel.
3. Trailing cables are a potential source of gas and dust ignition and subsequent explosion; these are non-existent with diesels.
4. Flash burns and suffocation from burning cables are eliminated.
5. Tangled trailing cables and tripping injuries of personnel are minimized with diesel power.

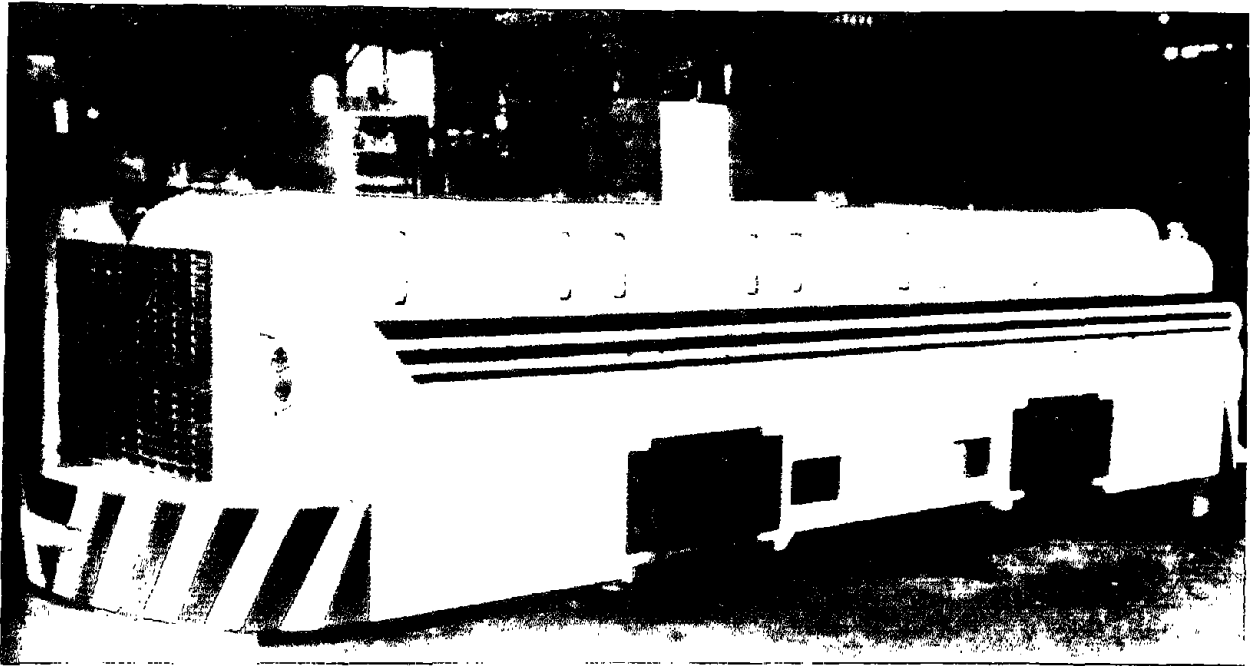


FIGURE 1. - N.M.S. 10-ton diesel-haulage locomotive, U.S.B.M. approval No. 2201, first approval issued to any manufacturer under Schedule 22 on May 8, 1951. Schedule 22 was first published on September 2, 1944.

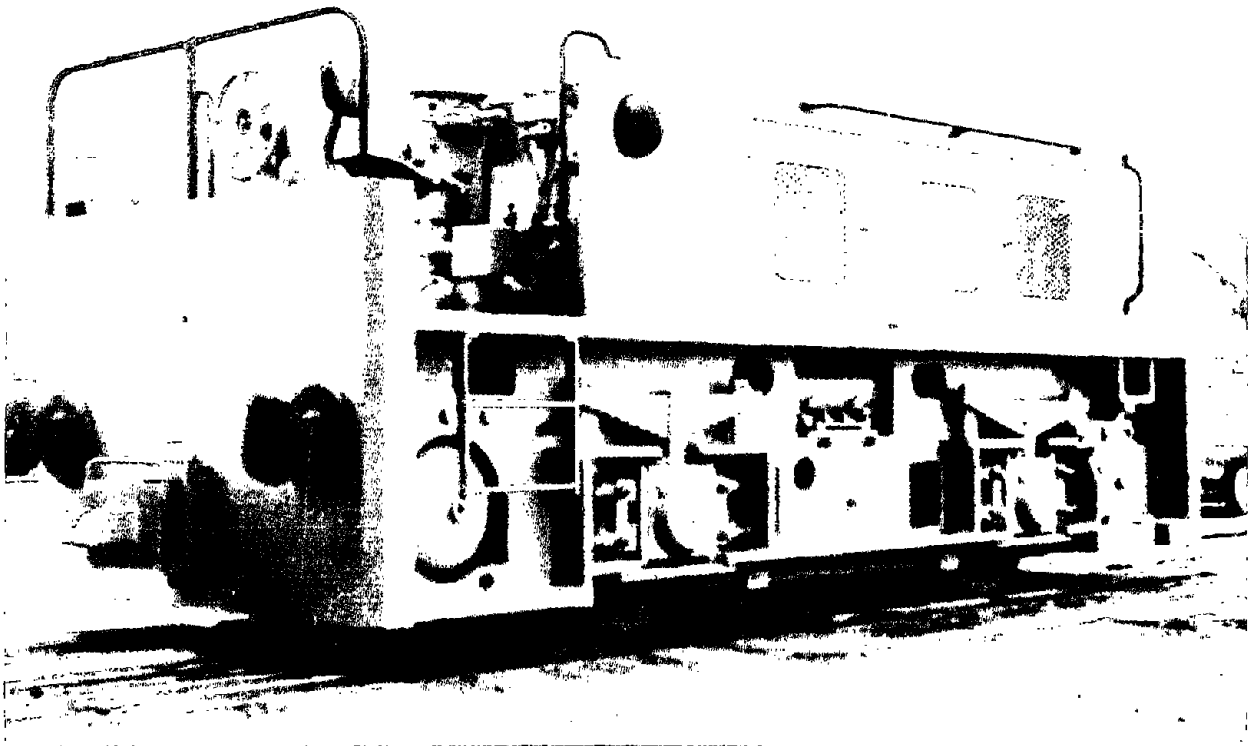


FIGURE 2. - Plymouth 15-ton diesel locomotive which has been manufactured both under Schedule 31 and Schedule 22.

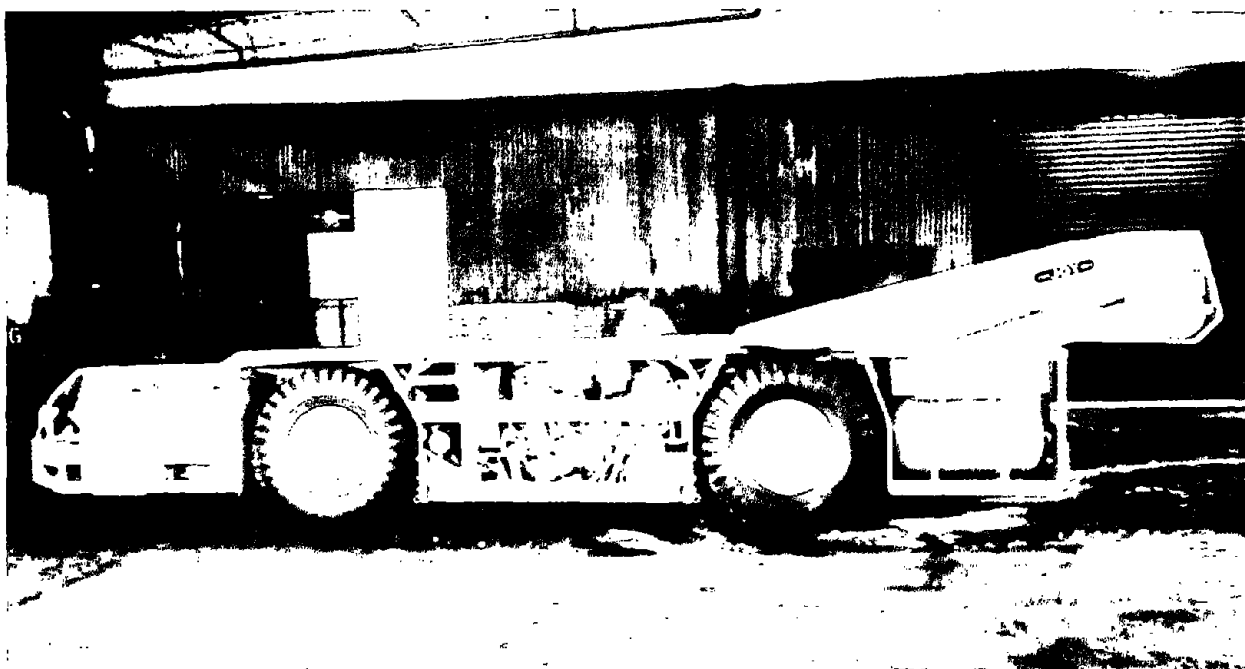


FIGURE 3. - Joy 10DSC utilizing two (2) engines mounted between the wheels, one on each side.

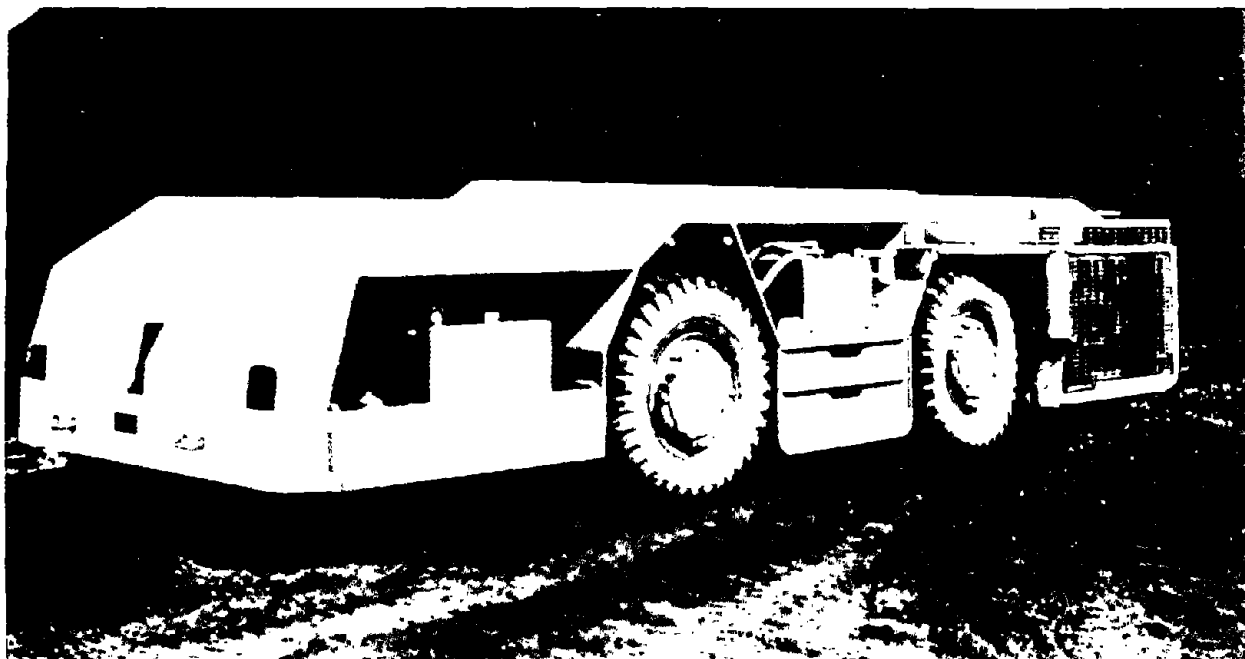


FIGURE 4. - N.M.S. CO. type 48-ED available in a variety of heights with Ford or Caterpillar engines and can be built to meet the requirements of either Schedule 24 or 31.

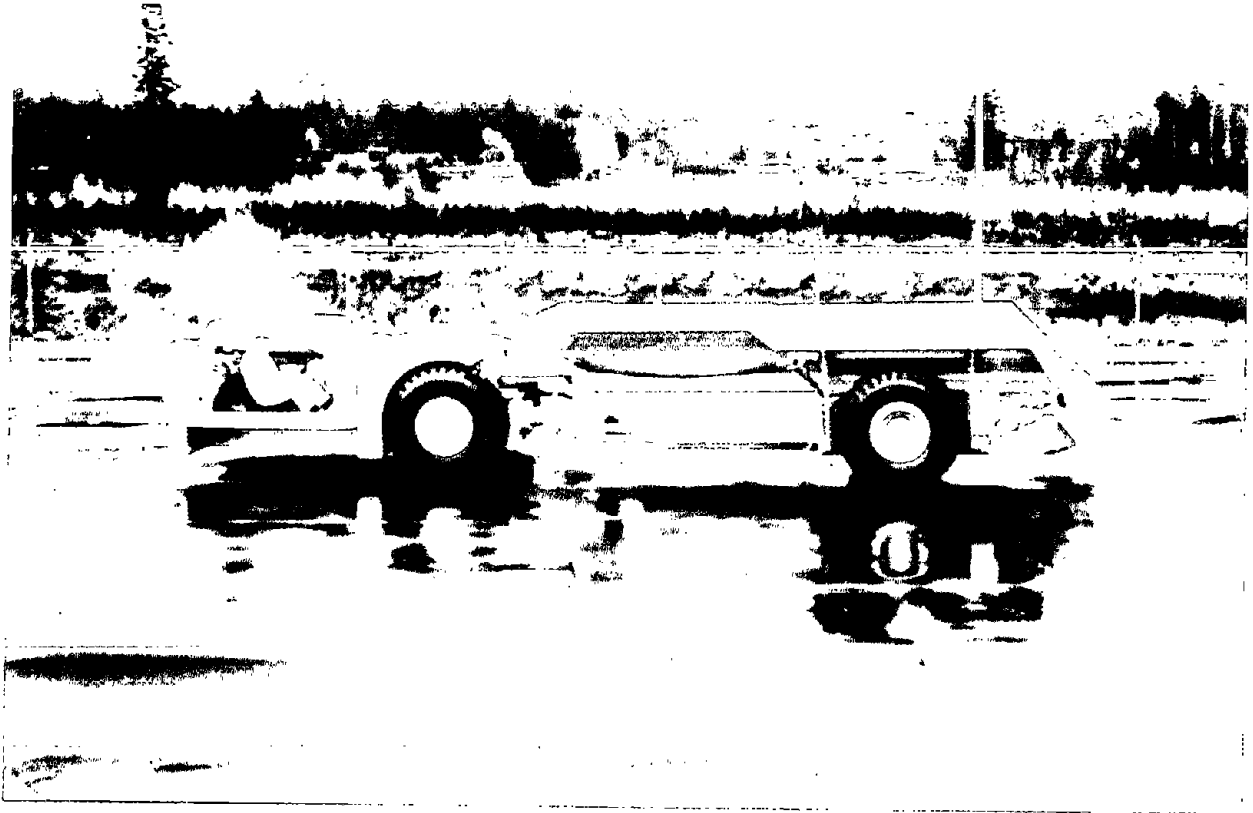


FIGURE 5. - Wagner mobile TeleTram.

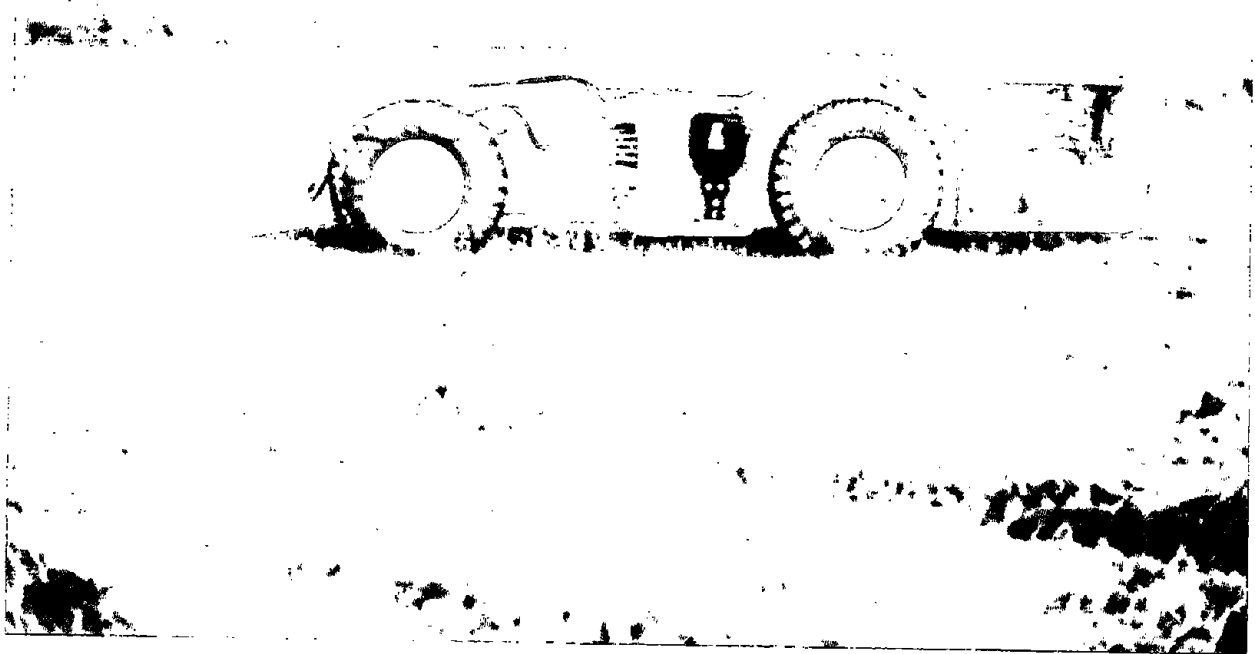


FIGURE 6. - Wagner scoop Tram.

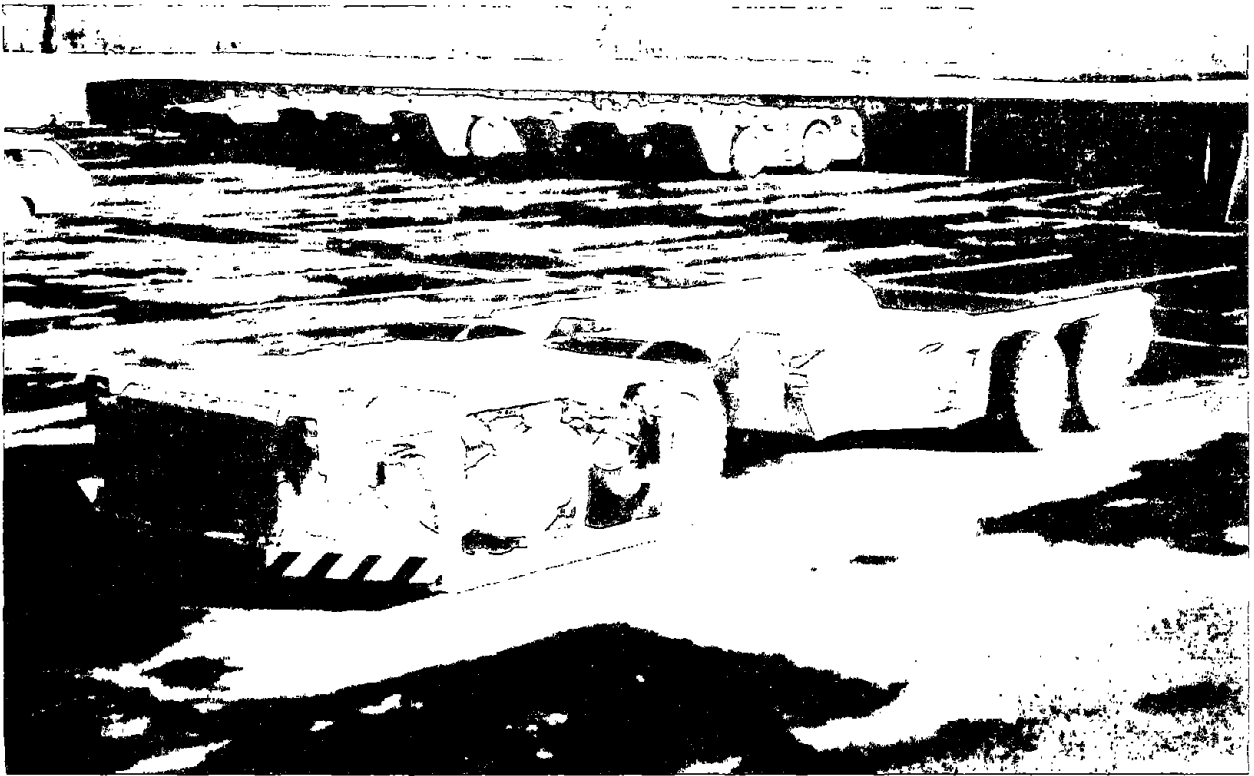


FIGURE 7. - Wagner mobile TeleTram.

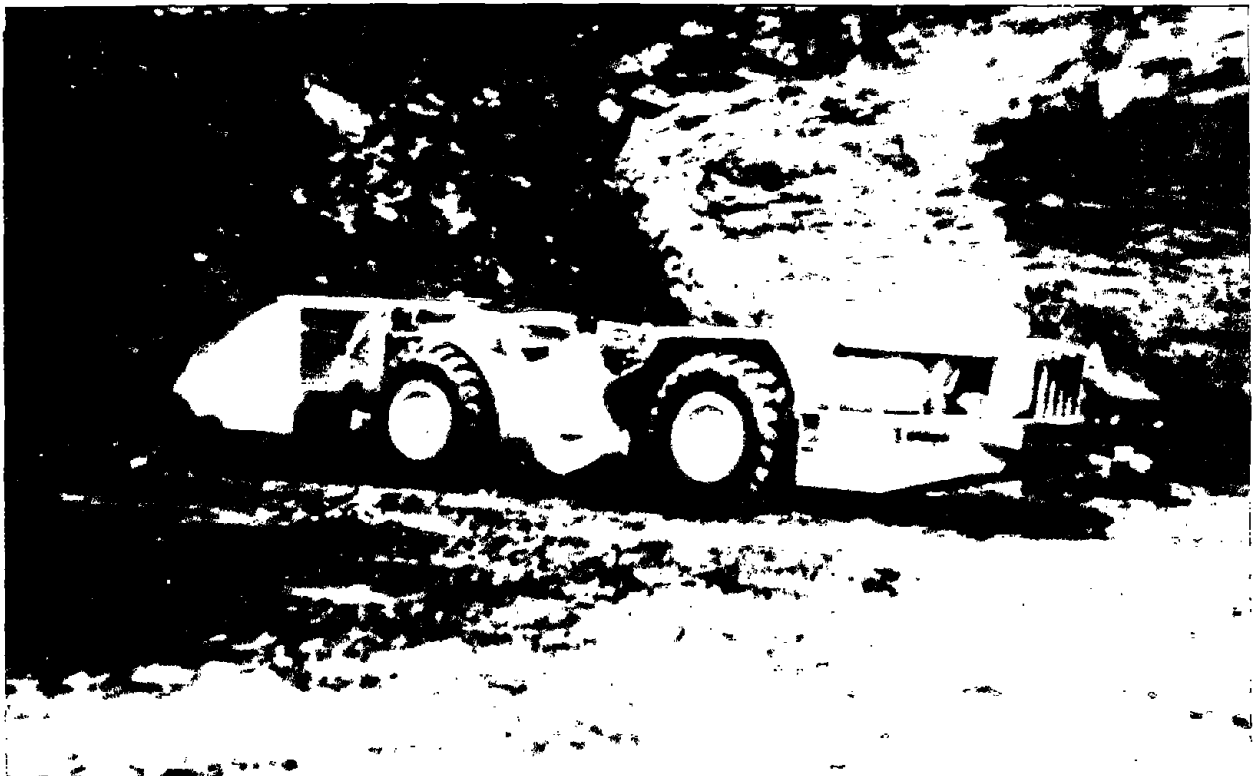


FIGURE 8. - EIMCO load-haul-dump unit.

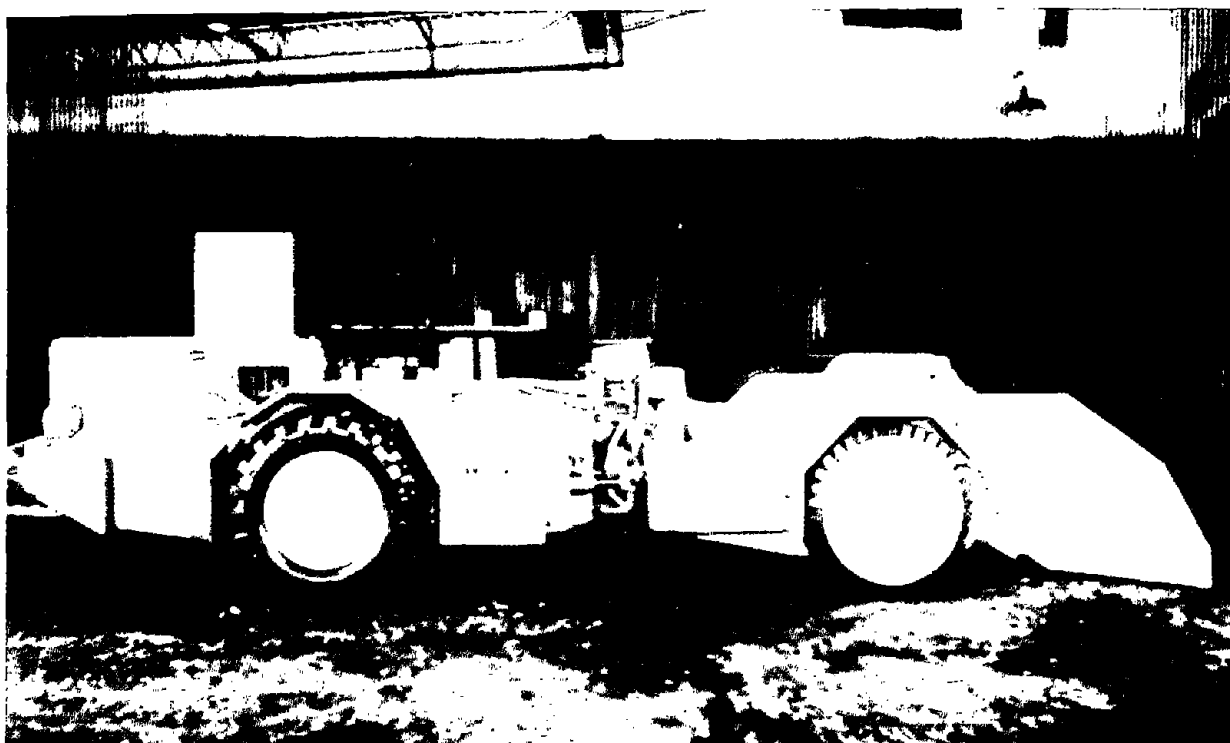


FIGURE 9. - Joy transloader.

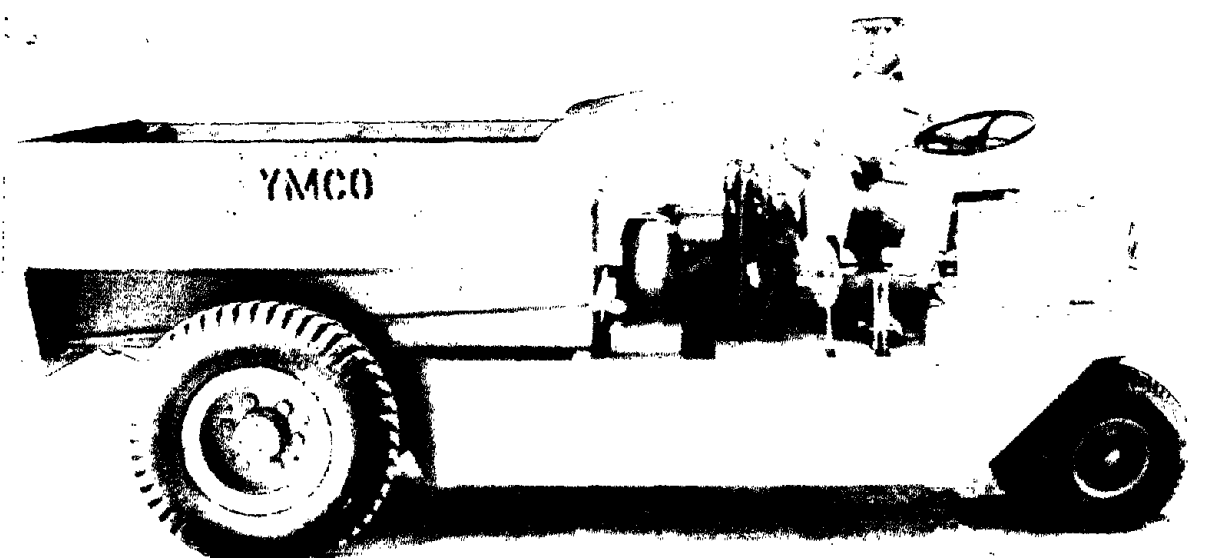


FIGURE 10. - Young buggy, dump type.

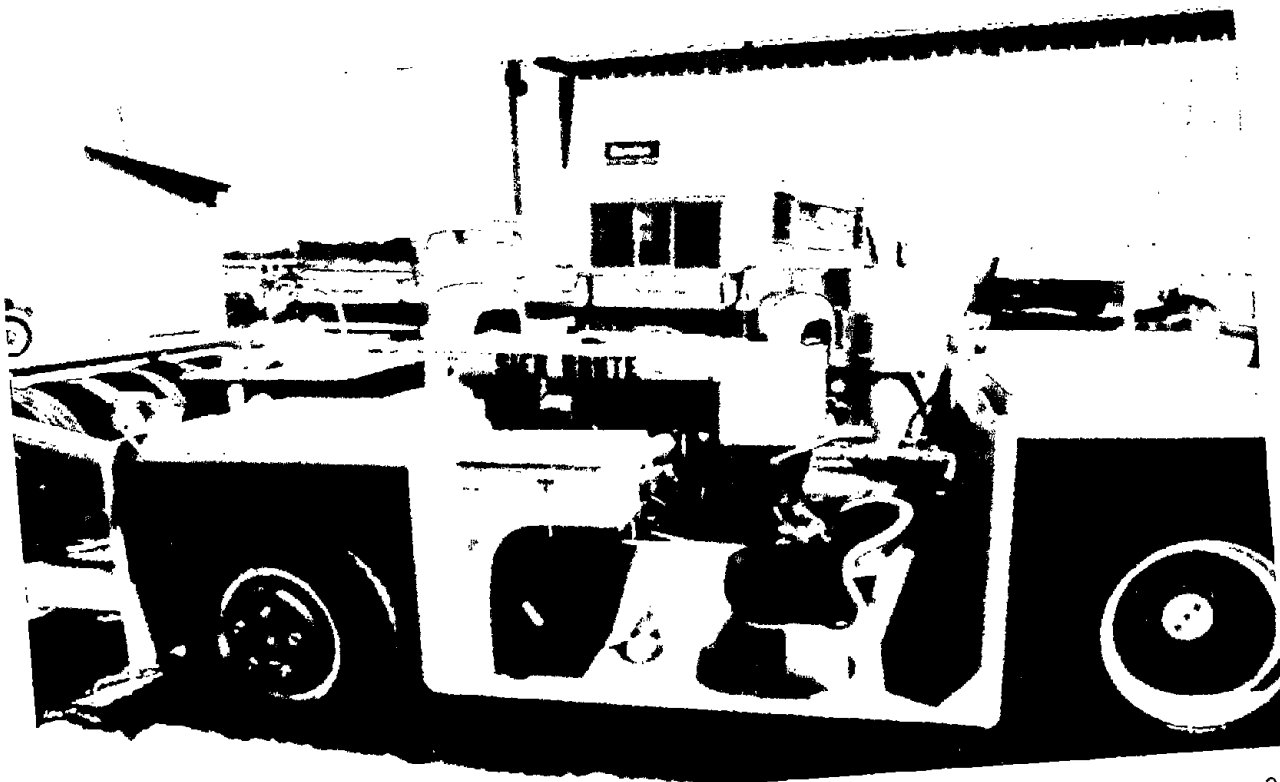


FIGURE 11. - SIEN lube truck—can be built to meet the requirements of either Schedule 24 or 31.

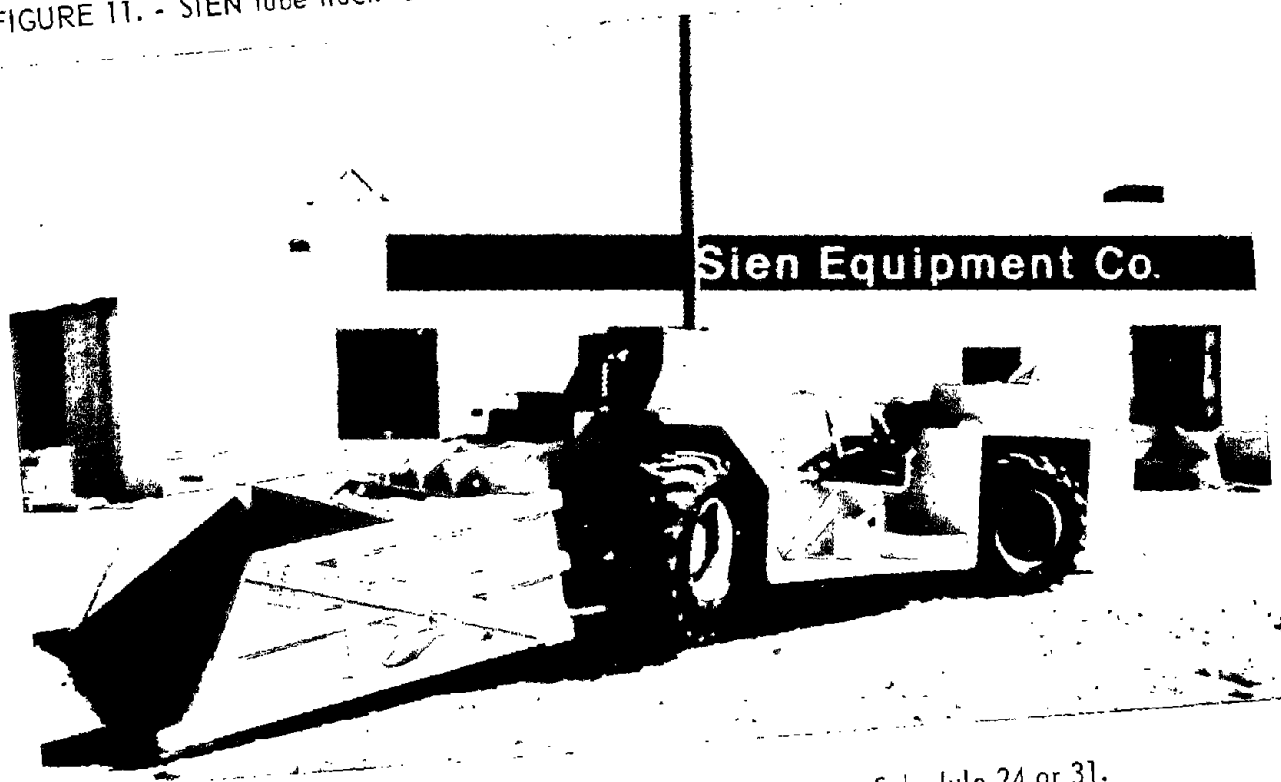


FIGURE 12. - SIEN brute load-haul-dump unit, Schedule 24 or 31.

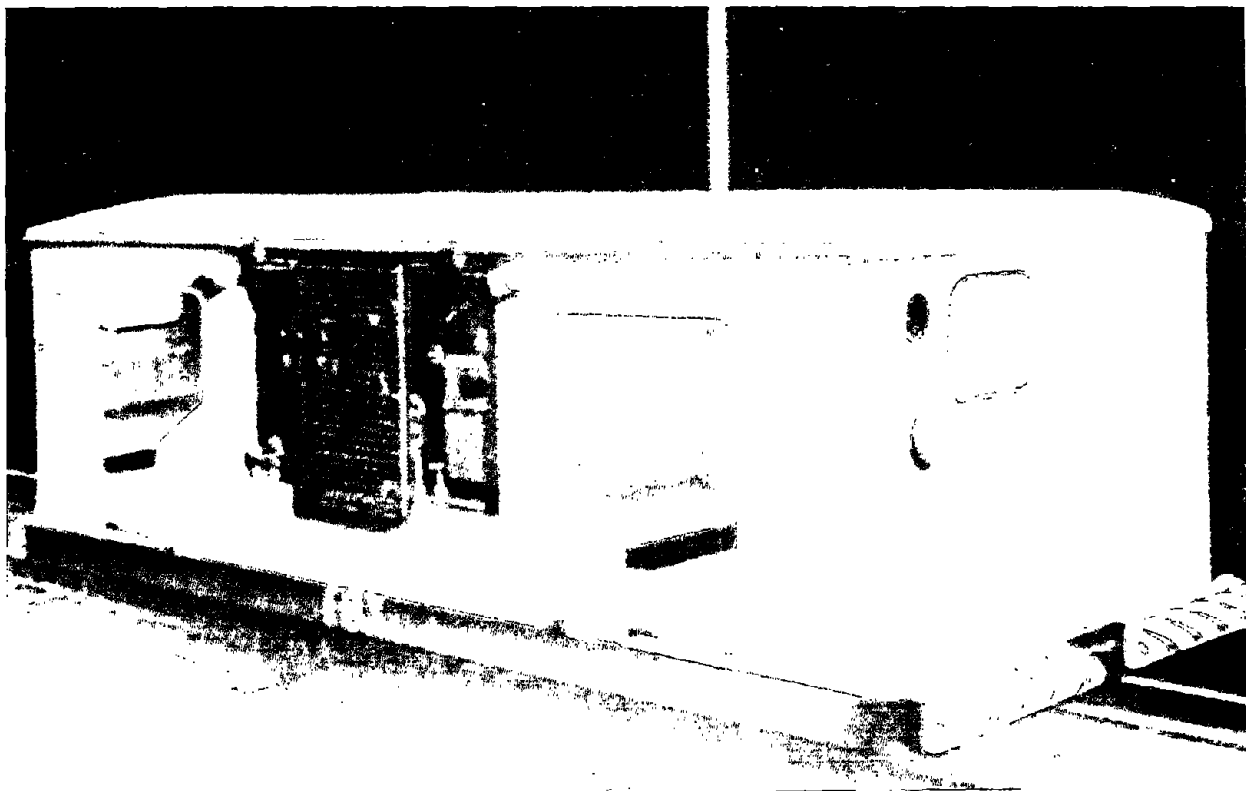


FIGURE 13. - Fox Manufacturing Co. diesel-powered personnel carrier.

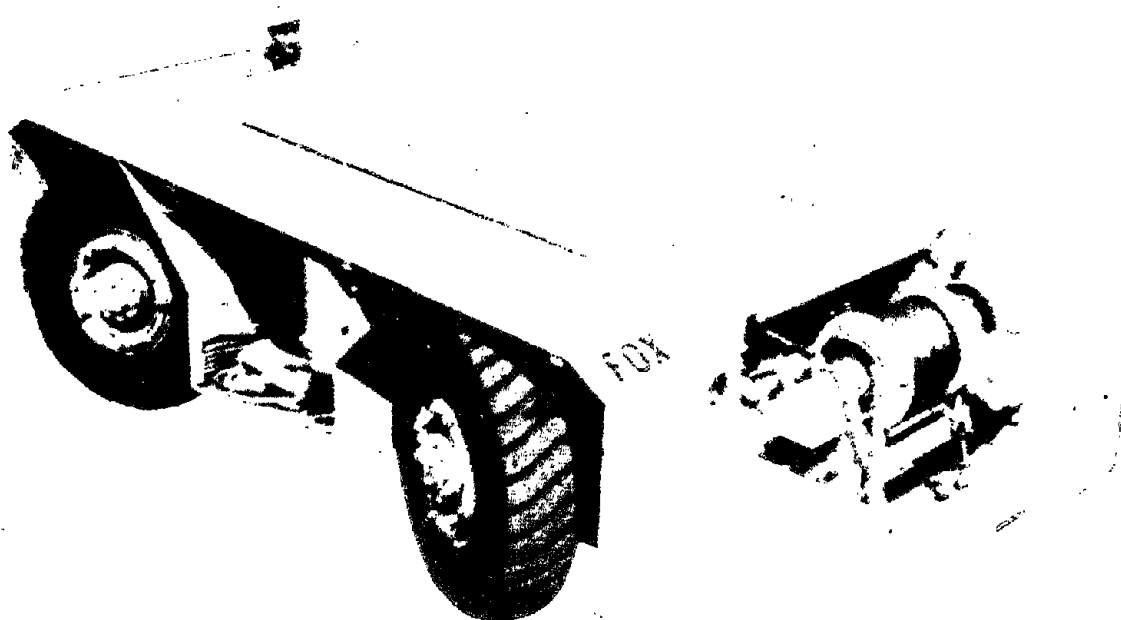


FIGURE 14. - Fox utility tractor available with numerous attachments.

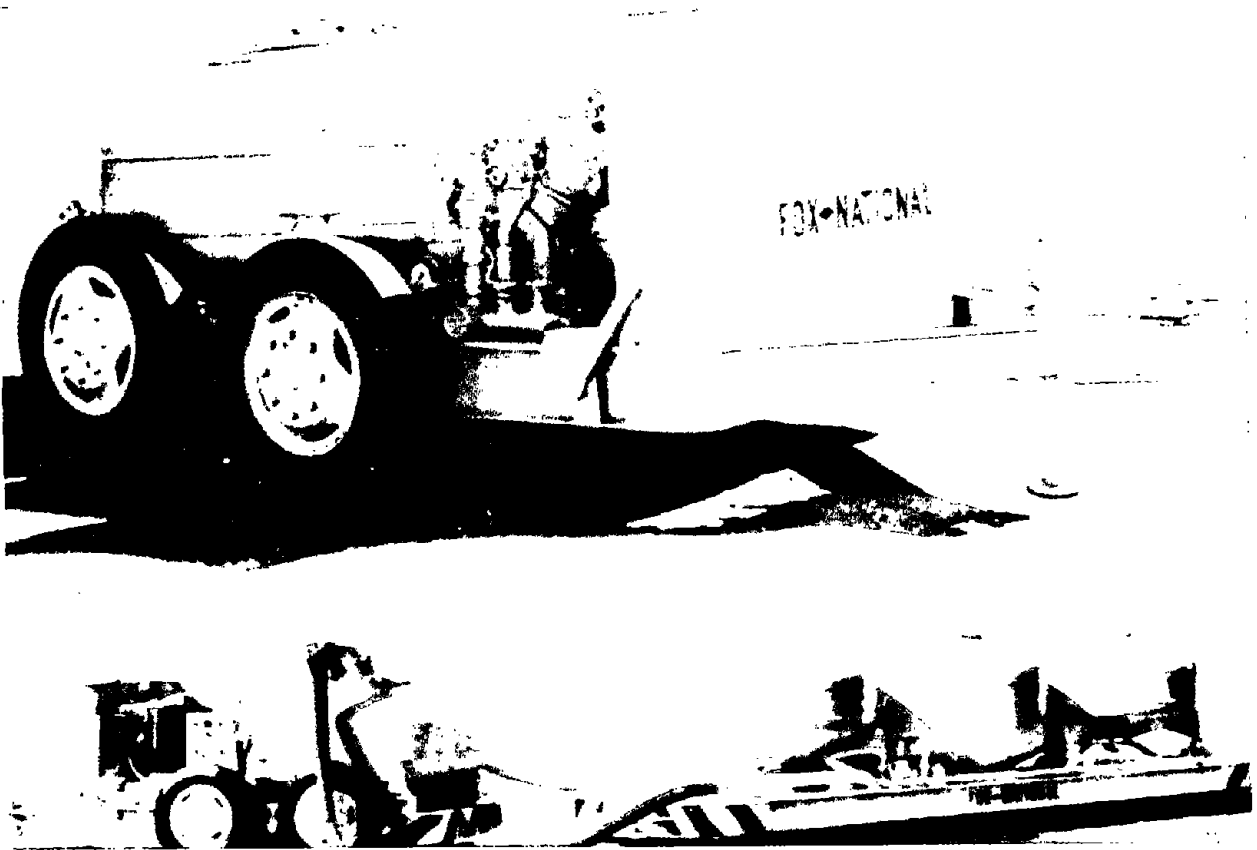


FIGURE 15. - Diesel-powered rockdusters manufactured by Fox Manufacturing.

6. The self-contained diesel-power system permits units to travel freely and quickly throughout the mine in case of emergency, even in areas void of power.
7. Passing through ventilation doors is simpler with diesel units and cables holding doors or curtains open are eliminated.
8. Diesel-powered locomotives would eliminate trolley-line shock and fire hazard, particularly in areas where men are working.
9. There is no trolley pole handling which would expose the operator to danger while passing through switches replacing on the wire or back polling.
10. Diesel locomotives would permit moving of equipment in areas void of trolley wire or simplify movement through areas with trolley wire, allowing the entire section to be de-energized during the equipment move.
11. Electric arcing between equipment coming into contact with each other is eliminated.

12. Battery equipment; normal current-type hazards, lost with encapsulated batteries; and shorting across terminals is eliminated.

Operating Advantages

Diesel shuttle cars and haulage units present the following advantages:

1. The length of the haul not critical; *diesels* can travel farther than units with conventional trailing cables.
2. More than two haulage units can haul from one face loader.
3. More than one entry can be used, virtually eliminating passing problems. This permits loaded hauling through one entry while returning empty to the face through an alternate entry.
4. Moving a shuttle car from one section to another is simple and fast, no cable-dragging is required.
5. Cable handling is reduced considerably along with the simplifying moving up of the distribution station.
6. *Diesel* shuttle cars are very good for supply vehicles, being able to go to several faces on one trip. They can also be used with power cutoff in a section.
7. Turn-around hauling in either direction is no problem with a *diesel* car and can be helpful during temporary stockpiling or as a supply vehicle.

Diesel-powered locomotives operate with the following advantages:

1. Need for the trolley wire is eliminated.
2. No rail bonding is required.
3. Sanding is more effective. The insulation of sand between rail and wheels is not detrimental as it is on electric-powered locomotives.
4. There are less wheel spinouts and more effective application of power having infinite speed control within the normal speed range.
5. Heavy loading of one unit has no effect on any other operating equipment, as is the case of electric power.
6. There is no loss of control or braking owing to the pole jumping the trolley wire. Some of these advantages also apply to battery locomotives.

Utility Vehicles

The main operating advantage is the freedom of movement due to elimination of the cable reel and trailing cable.

Servicing and Maintenance

Diesel-powered equipment requires servicing every shift. Although it may not require a lot of time, it must be performed regularly and thoroughly.

1. The fuel tank must not be allowed to become empty. When a diesel engine runs out of fuel it is necessary to bleed the injection lines before it will start and this can sometimes be a big problem. Fuel must be clean and free of contaminants. Fuel filters must be checked and serviced as required.

2. Frequency of cleaning or change of the intake-air filter will depend on the length of its operation and the amount of dust in the section. This is normally a daily operation. The intake flame arrestor must be inspected and serviced periodically. When the intake-air cleaner is serviced properly, once every 2 to 4 weeks is ample.

3. The engine lubricating oil must be kept to the indicated level. Oil filters must be changed according to the recommendation of the engine manufacturer.

4. The engine-cooling water supply must be checked and replenished if required, making sure that the radiator and cooling system are functioning properly.

5. The exhaust conditioner must be serviced and the supply tank refilled with clean water.

6. Timing and fuel-injection setting are important on underground diesel-powered equipment and must only be performed by authorized personnel when adjustments are necessary.

7. The emergency air-shutdown control must be checked once a week to assure its proper operation.

8. The mine air must be checked during each shift for toxic gases. Sampling details will be established in section 75.19 of the Code of Federal Regulations on this subject.

9. Storage and handling of diesel fuel underground will also be under strict regulations.

CONCLUSIONS

The first applications for diesel-powered equipment in the U.S. coal mines is for low to medium horsepower units. Most haulage and utility vehicles fall into this classification. They should be used in well-ventilated areas which meet the stated requirements established by the manufacturer and the Federal Bureau of Mines. Operational limitations or guidelines should be adhered to. Operating and maintenance personnel should be schooled in operation and service prior to the introduction of new equipment into the mine. Service and maintenance records should be kept on each piece of equipment.

Diesel-powered equipment generally requires more service than electric-powered equipment. This, however, must be weighed against the greater operating versatility and greater safety resulting from the use of diesel-powered equipment. Selection of diesel equipment for coal mine use is best made on an individual mine basis where all operational conditions are known and considered.

I would like to thank Leon H. Shoemaker, Chief Engineer-Locomotive and Diesel Products, National Mine Service Co., for his assistance in preparing this paper. I would also like to thank Plymouth Locomotive Works, Joy Manufacturing Company, Wagner Mining Equipment, Inc., Eimco, Young Machine Company, Sien Equipment Company, and the Fox Manufacturing Company of Australia for providing me with the visual aids.

Compilers' Note.--Dr. Robert H. Kupperman addressed the audience at the banquet held after session II on the options facing the United States in dealing with the "energy crisis."

Dr. Kupperman's experience spans a broad spectrum of academic, business, and Government activities. He received his B.A. and Ph.D degrees in mathematics from New York University, and has been associated with the Institute for Defense Analyses, Douglas Aircraft, and Cal Tech's Jet Propulsion Laboratory. He has served as a consultant to various Federal agencies, including the Civil Service Commission and the U.S. Army. Dr. Kupperman is the author of numerous studies in systems analysis, applied mathematics, strategic theory, and mathematical economics.

In the O.E.P., Dr. Kupperman conducted systems analysis activities and developed management information systems. He also provided analytical support for other agencies within the Executive Office of the President.

His address follows.

Address by Robert H. Kupperman¹

The United States has long enjoyed an abundance of oil, gas, and coal. These energy resources fueled the engine of our economic growth and enabled this country to achieve a standard of living unparalleled in the history of the world.

Today we have become a highly industrialized and technological society whose economic health and national security depend critically upon the reliable flow of vast amounts of energy. Our insatiable demand for this energy is projected to double within 20 years. Unfortunately, the finding and production of our domestic supplies of energy are not keeping pace with this rapidly growing demand, and we are becoming increasingly dependent on imports. National security concerns caution against undue dependence on foreign sources for our fuels. This dependence may reach 60 percent within the next 10 to 15 years. Our oil import bill alone could rise from about \$3 billion in 1971 to around \$25 billion in 1985 (in 1971 dollars), a development which would produce a major, adverse effect on our balance of payments.

The need to clean up our environment has exacerbated the energy crisis. Environmental concerns have led to a sharp increase in the demand for low-sulfur fuels. Unfortunately, the available supplies of these fuels are inadequate to meet potential demand.

Concerns for the environment and safety have also led to difficulties in getting new powerplants, refineries, and pipelines operational. For example, we are currently delaying the delivery of Alaskan oil which might provide

¹Assistant to the Director for Science and Technology, Office of Emergency Preparedness, Washington, D.C.

2 million barrels per day in 1980. At the same time, our air pollution standards for automobiles will increase consumption by about 2 million barrels per day by 1980.

Any reasonable approach to these national problems must take into account both the need to protect our environment and the necessity of having adequate energy supplies. We must find ways to produce and deliver needed energy in ways that are compatible with our environmental goals.

We also need to increase our domestic supplies of energy. We need to find more petroleum and more gas, and we need to develop new sources of energy such as breeder reactors and eventually fusion power. But it is also equally important that we do not use our energy supplies wastefully. All of us must begin a conscious, deliberate effort to conserve our energy resources and to use them more efficiently.

The Office of Emergency Preparedness recently undertook two studies on energy conservation. In the first, we examined a broad spectrum of conservation measures that could reduce overall consumption in the major sectors of the economy or increase the efficiency with which energy is consumed. In the second, we approached the issue of energy conservation by examining the potential for substituting our more abundant supplies of fuel such as coal for the limited supplies of oil and gas.

Neither of these studies is definitive. They do not represent policy statements of the Federal Government. Rather, they are intended primarily as food for thought--to generate interest in the energy crisis and to stimulate some serious thinking about the measures we as a nation can take to meet this problem.

I do not intend to discuss all the details of these two studies today. However, I should like to highlight some of their more significant findings.

In our first study, entitled "The Potential for Energy Conservation," we examined the potential for energy conservation in the four major sectors of the economy--transportation, residential/commercial, industry, and the utilities. If all the measures which our report considers were adopted, we estimated that energy demand by 1980 could be reduced by as much as the equivalent of 7.3 million barrels of oil per day. I emphasize the word "equivalent," because the energy savings would be spread across all types of fuels and only a portion would be applied to oil itself or to oil imports. This figure represents a considerable energy savings--about two-thirds of the projected imports for 1980. We recognize, of course, that only a limited number of the measures outlined in our study will be fully realized. Nevertheless, they all merit serious consideration.

In the transportation sector of the economy, which consumes 25 percent of our total energy, we looked at a number of conservation measures which could bring about substantial savings in energy consumption.

Although there have been improvements in the efficiency of individual propulsion systems, the overall energy efficiency of the transportation sector has in many cases decreased as a result of shifts among transportation modes toward less-energy-efficient systems. For example, the past importance of buses and railroads in intercity passenger traffic has been superseded by airplanes and automobiles. Similarly, mass transit, especially buses and trains, has been giving way to private automobiles for urban passenger traffic. In the area of intercity freight movement, the shift has been from railroads and waterways to pipelines and trucks.

To conserve energy in the transportation sector, we must begin to redress the balance between these transportation modes. The automobile industry has been, and no doubt will continue to be, a major source of our economic strength. But automobiles account for 55 percent of the energy consumed in the transportation sector, and much of this has been highly inefficient. The low average occupancy of commuter cars (1.4) and the short distances traveled combine with traffic congestion to lower drastically the energy efficiency of the automobile. By contrast, the development of well-organized, fast, safe, inexpensive, comfortable, and convenient mass transit systems will not only substantially decrease energy consumption but will also reduce pollution and contribute toward revitalizing our central cities.

In addition to promoting urban mass transit, we can stimulate the improvement of rail networks and related systems, encourage the consolidation of freight movement in urban areas, and revise regulations of the transportation industry to encourage an appropriate modal balance in terms of energy efficiency. In the long term, we can refurbish our cities and design new communities in ways which would reduce the need for transportation energy by encouraging clustering as opposed to uncontrolled conglomeration and by constructing attractive walkways and bicycle paths.

Transportation serves many national goals which must be balanced against the goal of fuel conservation. Nevertheless, energy conservation must play an important role in the design and development of our transportation systems. Given proper emphasis, the prospects for achieving large energy savings in the transportation sector without sacrificing other important goals seem highly probable.

In the residential/commercial sector, the most favorable prospects for conserving energy in the immediate future lie in the area of improved home insulation. According to experts, savings of up to 50 percent of the energy needed to heat and cool homes are possible with only a nominal additional cost for new construction, perhaps less than 5 percent of total cost. With the Federal Government involved either directly or indirectly in some 37 percent of all new construction, improved Federal insulation standards could result in substantial national energy savings. The Federal Housing Administration has already taken steps in this direction by revising its minimum standards for single family dwellings in 1971. Unfortunately, improved insulation of existing structures entails high initial costs. Here we need to begin an intensive R&D program to find inexpensive ways to install better insulation in existing homes.

Major home appliances are another area where the potential exists for substantial energy savings. Clearly, some minimum efficiency standards for appliances are needed, whether they be established voluntarily by trade associations or by the Federal Government. The need for such standards may be seen in the fact that some window air conditioning units differ by at least as much as one-third in their cooling capacity for the same amount of energy consumed in operating them.

Substantial energy savings are also possible in the industrial sector of the economy. Energy is a considerable cost factor for the major industries so that they use energy as economically as possible. Nevertheless, given a sufficient incentive, industry could reduce its energy consumption considerably within existing technology primarily by replacing old equipment, by using more energy-conscious design, and by increased maintenance on boilers, heat exchangers, etc.

More efficient plant equipment not only will conserve energy but also will help to reduce pollution and to make industry more competitive in world markets.

Industry can also reduce energy consumption through energy-conserving recycling or reusing. For example, in the case of nonferrous metals, the amount of energy required to recycle scrap is less than 20 percent of the energy required to refine the metal originally.

Some energy savings can also be obtained in the electric utility sector. Historically, electric utilities have attempted to improve the efficiency of fuel use, since fuel represents a major operating expense. It is not likely that any reasonable economic incentives could bring about efficiency improvements in the electric utility sector in the near future. Thus conservation measures must be directed toward the more effective use of existing facilities and accelerated replacement of outmoded equipment.

Effective measures would include smoothing out the daily demand cycle to reduce the use of inefficient generating equipment, facilitating new construction and reducing maintenance on new plants and equipment. And, of course, we need to continue development and refinement of safe and efficient nuclear plants and breeder reactors and to resolve the problems inherent in nuclear waste disposal.

In the electric utility industry, as in all sectors of the economy, we can take effective measures to conserve our energy and to use it more efficiently.

Nevertheless, even if all the measures outlined in our study were implemented, it can only postpone energy shortages unless we can increase supply. One way of enlarging the number of alternatives we have is to look at some of our more abundant supplies of energy. In our second, companion study, we attempted to do precisely that.

Proven reserves of coal in the Nation are estimated at the equivalent of about 400 years of supply at present rates of consumption. Considering the abundance of coal and the scarcity of oil and gas, it was only natural to consider the potential savings of scarcer fuels that might be achieved by using coal instead of oil and gas. Since the electric utility industry appears to offer the best prospects for coal substitution, we confined our examination to this sector. We considered three possible actions relating to coal consumption in this industry; these were (1) permitting present trends to continue, (2) updating and revitalizing existing coal-burning capability; and (3) in addition to (2), requiring all new fossil fuel equipment installed after 1977 to have a coal-burning capability. Both (2) and (3) also assume that coal-burning equipment is used at maximum possible loads.

Our analysis provided estimates of a theoretical maximum potential for coal substitution in each of these cases. I should point out that the "theoretical maximum" does not account for many specific operational problems such as power transmission constraints or the high costs of continuously operating some of the older and inefficient coal-fired units. Nevertheless, we felt that the "theoretical maximum" was sufficiently large to warrant broad public discussion of this important matter. This could in time stimulate a more thorough analysis, utilizing better data than are currently available.

According to current estimates, coal's share of fossil steam-generating capacity will remain stable at about 55 percent through 1980 and 1985. Coal-burning capacity could increase to as much as 68.2 percent of fossil steam-generating capacity in 1980 and to as much as 74.6 percent in 1985. This increase, however, will depend on the following conditions: (1) All multiple-fuel equipment burns coal, and all oil- or gas-burning equipment that was converted from coal is reconverted back to coal, (2) all new fossil steam equipment that becomes operational after 1977 burns coal, and (3) coal-burning equipment is operated at maximum possible loads.

If the schedule of nuclear power plant construction is delayed, coal use could increase even further. Recent estimates of projected nuclear capacity have been consistently adjusted downward, so that it is both reasonable and prudent to assume additional shortfalls in nuclear capacity. We assumed a shortfall of 30 percent in 1980 and of 24 percent in 1985, and we also assumed that some of this shortage would be met by coal rather than by oil or gas. Added on to the measures I discussed above, this could increase coal-burning capacity to as much as 70.6 percent of all fossil steam-generating capacity in 1980 and to as much as 74.6 percent in 1985.

Needless to say, if we substitute coal in the electric utilities to the maximum extent possible, the savings in oil or gas would be substantial. Savings in oil and gas could reach as much as the equivalent of 2.6 million BPD in 1980 and as much as 3.9 million BPD in 1985. Between 42 and 75 percent of these savings, however, would result solely from increased coal-burning capacity and would not require major changes in current generating practices, that is, increasing utilization so that plants will operate at maximum possible loads.

These maximum potential savings may not be realizable, however, due to various environmental and economic considerations.

Problems in meeting environmental standards are particularly severe in the mid-term, that is, to 1980. Studies have concluded that stack gas desulfurization will be cheaper for 80 to 90 percent of the powerplants in the northeastern United States than switching to clean fuels if clean fuel costs materialize as presently projected.

The low cost of delivered local high-sulfur coal plus stack gas cleanup costs appear to be less than the costs of acceptable alternatives, and according to a recent interagency study, sulfur oxide removal from stack gas is technologically feasible in commercial sized installations. However, pessimism abounds, in both industry and Government. Clearly, special efforts should be made to accelerate resolution of current engineering, environmental, and institutional problems.

We examined three different cases in order to arrive at some gross estimates of the potential for coal substitution under various environmental constraints.

In the first case, coal would be used to the maximum extent possible except during pollution emergencies. Inventories of low-sulfur fuels would be stockpiled for use in all coal-burning plants during these pollution emergencies.

This case would necessarily involve the application of pollution control requirements on short-term managed bases, much as automobile speed limits are often adjusted to meet prevailing weather and traffic conditions. Although this case would involve the setting aside of existing pollution control requirements, the intent in presenting this "extreme" case is not to suggest or advocate the removal of all environmental constraints for powerplants but rather to provide a gross estimate of the maximum potential for coal substitution and its attendant savings in scarcer fuels. In any application of this case, there certainly would be a detailed tailoring for individual localities.

In the second case, maximum use of coal would be made in all utilities to the extent possible consistent with the environmental requirements of the State Implementation Plans (SIP's).

In the third case, coal would be burned in compliance with primary environment standards, but selective secondary SIP standards would be relaxed.

If only minimal environmental controls were maintained, that is, attuning restrictions to those most needed during periods of inversion, potential savings in oil and gas would be reduced only by about 100,000 BPD from the maximum of 2.6 million BPD in 1980. While slight relaxation of secondary SIP standards will reduce savings to 2.2 million BPD, strict adherence to State Implementation Plans will reduce potential savings in 1980 to 1 million BPD. In addition, depending on whether there is a strict adherence to, or a slight

relaxation of, SIP standards, a capital investment of between \$8.7 billion and \$9.3 billion for pollution control equipment and other plant changes will have to be made by the utility industry between 1972 and 1985 to meet environmental standards. If "pollution emergency control only" standards are maintained, the utility industry will have to invest some \$1.7 billion in plant changes to maintain the necessary \$1.7 billion inventory of low-sulfur fuels through 1980.

Our intent in examining these cases was not to suggest or advocate the removal of pollution control standards. Rather, it was to illustrate the implications of various policies given the two laudable goals of pollution control and adequate energy supplies. It should be noted, however, that a selective and temporary relaxation of secondary SIP standards could result in savings in oil and gas almost as high as those under policies requiring no or minimal environmental controls.

Not all the limitations on the use of coal are confined to the requirements of the Clean Air Act, however. As you well know, the coal industry is facing severe problems. Mines are closing at an alarming rate, new mines are not being opened, and there is a growing problem of insufficient and inadequately trained manpower. Loss of sales and lowered investment in new coal mines have also had their effect on the transportation industries which haul coal, especially the railroads. Investment in railroad equipment, roadway, and structures has declined, as has profitability. Past problems with hopper car availability could arise again should coal shipments be suddenly increased.

In both the coal and railroad industries, large investments will be needed for expanded capacity. Advanced coal-mining systems will have to be developed to meet health and safety standards, to cut operating costs, and to increase production rates. In the railroad industry, substantial capital will be required to expand hopper car and locomotive capacity and to replace inventories of worn out rolling stock and inadequate track bed.

If there were no environmental constraints and coal were to be used to the maximum extent possible envisaged in our study, required investment could reach as much as \$14 billion for the coal industry and as much as \$39 billion for the rail industry during the period 1972 to 1985. In addition, the utilities may have to invest as much as \$6.2 billion through 1985 in order to attain the level of capacity necessary to use coal to the maximum extent possible. To make such investments attractive, however, the Federal Government will need to provide an energy policy giving these industries the long-term assurances justifying investment commitments to them.

Both fuel substitution and energy conservation will demand further analyses of all types in order to identify the costs and benefits of various measures and to determine their impact on the economy, the consumer, and our life style. Obviously, some hard choices will have to be made.

At the risk of being repetitious, I want to emphasize once again that neither energy conservation nor fuel substitution is a panacea for the energy problems which this Nation will face over the next several decades. We must

still increase our supplies of oil and gas. Together, all these measures will hopefully comprise a complete and successful response to the energy crisis.

Proceedings

MR. GRANT: I would like to introduce the cochairmen for the third session, Health Protection Factors of Diesel Use Underground. Dr. Lorin E. Kerr, Director of Department of Occupational Health, is representing the United Mine Workers of America; Bob Peluso is acting for the Assistant Director for Health and Safety--Technical Support, Bureau of Mines.

DR. KERR: Mr. Peluso and I will chair the joint direction of the session this morning. I will give the introductions and Bob will handle the question and answer period that will follow each speaker.

Our first speaker this morning is Dr. Stokinger who graduated from Harvard with a degree in Chemistry. In 1937 he received his Ph.D in biochemistry from Columbia University. He taught at New York City College, and for the next 4 years served as a research chemist at the medical school of the University of Rochester. He headed the Industrial Hygiene section for the Manhattan Project for 8 years where he directed research on health effects. In 1951, he became Chief Toxicologist of the Toxicology Branch, Laboratories and Criteria Development, Division of National Institute for Occupational Safety and Health in Cincinnati, Ohio, where he has served to the present date. In addition, Dr. Stokinger is chairman of the Threshold Limit Value Committee of the American Conference of Governmental Industrial Hygienists. He is the former chairman of the Committee on Toxicology of the National Research Council and also chairman of the Committee of the U.S. Public Health Service for Water Standards.

SESSION III-HEALTH PROTECTION USING DIESELS UNDERGROUND

TOXICOLOGY OF DIESEL EMISSIONS

by

H. E. Stokinger, M.D.¹

The almost unending complexity of diesel emissions with respect to their chemical constituents has been increasingly revealed, as evermore sensitive and specific procedures have been used for their analysis and identification. However, the character and amount of the complex exhaust mixture is drastically altered by changes in power output, motor speed, engine design and load, and fuel additives. Lack of proper engine maintenance further modifies the nature and amount of emissions. So, despite analytic advances, chemical characterization of diesel emissions is still far more complete, either as to type or amount of the various compounds. Analytic investigators often fail to agree on some classifications of emission components or fail to analyze for the same constituents, leaving comparison gaps. These uncertainties and unknowns, coupled with potential toxicologic interactions among the exhaust constituents, make it extremely difficult to make a definitive toxicologic evaluation, or to suggest anything but highly tentative air standards.

COMPOSITION OF DIESEL EMISSIONS

To provide an informed toxicologic evaluation of potential hazards to health and well-being, it is obviously essential to know the nature and amounts of the chemical constituents of the diesel emissions. Tables 1 and 2 list the major vapor and gaseous components as identified in a recent Bureau of Mines publication (10),² using a conventional kerosene fuel without additives. The carbon dioxide values originated from a study of diesel locomotive exhausts by the Pennsylvania Railroad in the 1950's (12). Table 2 lists the particulate composition of diesel exhaust as determined by Frey and Corn (4). The values for carbon smoke particulate are the combined data of McKee and coworkers (11), Linnell and Scott (9), and Frey and Corn (4).

¹Chief, Toxicology Branch, Division of Laboratories and Criteria Development, National Institute for Occupational Safety and Health, Cincinnati, Ohio.

²Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

TABLE 1. - Components of diesel exhausts--vapors and gases (10)

Vapors and gases	Proportionate amounts in exhaust (ppm)		TLV, ¹ ppm	Relative dilution to meet TLV ²
	Median	Range		
Carbon monoxide.....	400	100-3,600	50	8-75X
Carbon dioxide.....	125,000	90,000-138,000	5,000	25-30X
Hydrocarbons ("unburned").....	11,400	760-25,000	50 ³	230-500X
Lighter fraction (C ₁₋₁₂).....	4,000	260-9,000	1,000	4-9X
Nitrogen oxides (NO, NO ₂).....	735	70-3,280	C 5	150-700X
Aldehydes (total).....	30	3-97	-	15-50X
Formaldehyde and aliphatics....	Undetermined	Undetermined	C 2	-
Unsaturated (acrolein?).....	Undetermined	Undetermined	0.1	-
Aromatic?.....	Undetermined	Undetermined	-	-
Sulfur dioxide.....	Negligible	Negligible	5	-
Malodor.....	DI odor units ⁴ 3-4.5	DI odor units ⁴ 3-4.5	-	-

¹Threshold limit value for air at 1 atm. pressure and 25° C.²Based on median and maximum amounts.³TLV for hydrocarbon, cumene.⁴Diesel intensity odor units.

TABLE 2. - Components of diesel exhausts--particulates (4)

Particulates	Proportionate amounts ¹ in exhausts, mg/m ³	TLV, mg/m ³
Smoke.....	30-75	-
Carbon.....	20-45 (60 pct)	(3.5)
Ether extractables (total).....	10-13 (30 pct)	-
Paraffins.....	10-12	² 250
Paraffin acids.....	0.1-1	² 250
Nitroparaffins.....	Trace	³ 25 PPM
PAHC's ⁴ (carcinogens?).....	?	-
Water extractables (total).....	0.3-2 (3 pct)	-
Paraffinic acids.....	0.1-0.6	-
Nitroparaffins.....	0.03-0.1	-
Aldehydes.....	0.03-0.1	-
Nitrite.....	0.03-0.1	-
Sulfate ⁵	0.2-0.3	⁷ 1
Hydrocarbon "heavy" fraction.....	⁶ 69,000	² 250
Barium salts, soluble.....	-	0.5
Trimanganese tetroxide (Mn ₂ O ₄).....	-	?

¹As measured 4 inches from exhaust pipe.²TLV for cumene.³As nitropropanes.⁴Polycyclic aromatic hydrocarbons.⁵Sulfur content of fuel, 0.75 pct.⁶Calculated particulate as 65 pct of "unburned" hydrocarbon of average molecular weight of 226.⁷As sulfur trioxide.

POTENTIAL HAZARDS TO HEALTH AND WELL-BEING

The major items in diesel emissions posing potential threats to health, but more particularly to well-being, are commonly recognized to be smoke particulates with their adsorbed carbonaceous substances, which give rise to physical irritation of the eyes and mucous membranes of the nose and throat, as well as malodor, which causes subjective irritation. Unfortunately, for a definitive toxicologic evaluation, the precise chemical and physical structures responsible for either of these two responses are not known with the certainty we would like. On the other hand, there is abundant information on these constituents of diesel exhausts that have direct health effects, that is, all substances listed in table 1 and for most substances listed in table 2.

VAPORS AND GASES

Carbon Monoxide (CO)

This well-known gas, the product of incomplete combustion of diesel fuel, has insidious health effects because it has neither color nor odor, and, being of the same density as air, neither settles nor rises, but diffuses to all spaces with air. Its health effects consist of reducing the oxygen-carrying capacity of the blood by successfully competing with oxygen at a rate of 200 to 1 for hemoglobin, which, in so doing, reduces the availability of oxygen for cellular systems of the body and thus lessens their functional capacity. The resulting toxicologic effect is similar to, but, in some respects, more serious than a simple lack of oxygen caused by reduced oxygen intake.

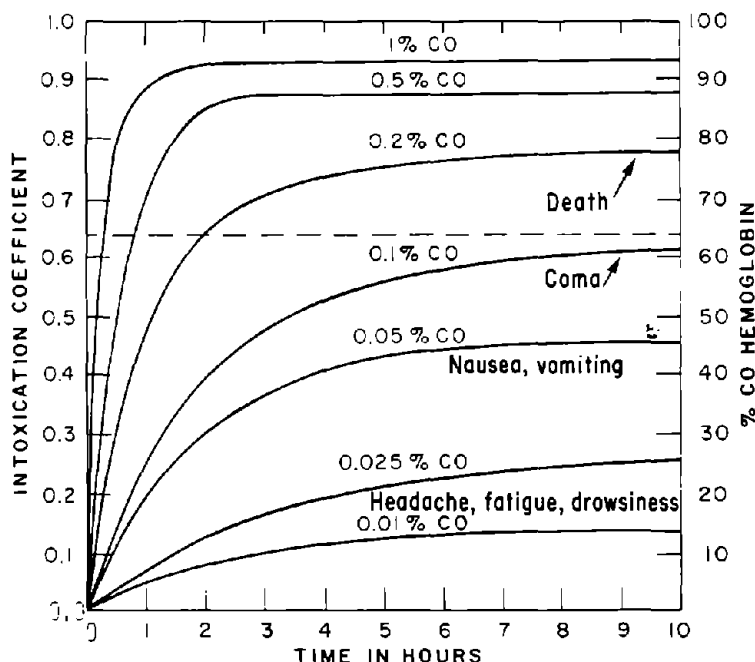


FIGURE 1. - Speed of saturation of hemoglobin with different concentrations of CO (Hanne, 1935).

Figure 1 shows a family of curves illustrating the different rates at which hemoglobin becomes saturated with CO at a given atmospheric level of CO and the corresponding intoxication coefficient (IE). Headache, fatigue, and drowsiness begin at an IE of 0.2; nausea and vomiting at 0.4 and above; coma above 0.5, and death above 0.65. The rate of CO uptake by hemoglobin increases from 3- to 6-fold between rest and heavy work because of the increased rate of breathing. The blood of tobacco smoke inhalers will contain from 2 to 8 percent CO hemoglobin, and nonexposed adults, a normal average background of 1 percent formed within the

body from disintegrating red blood cells. Variation in individual susceptibility is great; those with existing or potentially lowered oxygen-carrying capacity for whatever reason--anemia, alcoholism, thyroid disease, those with poor lung function, among others.

Relative Hazard

The relative role of CO as a potential health hazard from diesel exhausts is small owing to the nearly complete combustion of the fuel to carbon dioxide if the engine is well maintained. Table 1 shows that even at the maximal output of 3,600 ppm, a relative dilution factor of only 75 is required to meet the industrial air standard (under average operating conditions only 8-fold relative dilution is required). The exhaust gas emission standards for new, heavy-duty diesel engines for the 1974 model year, as promulgated by the Environmental Protection Agency (3), shall not exceed 40 g/bhp-hr. Tests made of the brake specific emission rates over a modified 13-mode, diesel-emission test cycle show that the CO emissions are well within the emission standards; CO values ranged between 2 and 10 g/bhp-hr (10) (table 3). The EPA standards are for aboveground operation. Separate standards will have to be set by the Bureau of Mines, upon the recommendation of the National Institute for Occupational Safety and Health.

TABLE 3. - Diesel exhaust output and standards
from Bureau of Mines
RI 7530, 1971 (10)

Exhaust component	Brake specific emission rate, g/bhp-hr ¹	Above ground diesel emission standard ³ g/bhp-hr ¹
Carbon monoxide.....	2-10	40
Hydrocarbons.....	0.3-3	} 16 ²
Nitrogen oxides.....	6-20	
Aldehydes.....	0.1-0.5	

¹Grams per brake horsepower-hour.

²Combined standard for hydrocarbons and nitrogen oxides assuming ultraviolet radiation effects.

³Environmental Protection Agency, Federal Register, v. 37, No. 221, Nov. 15, 1972, p. 24,309.

Carbon Dioxide (CO₂)

Carbon dioxide, a colorless gas resulting from the complete combustion (oxidation) of carbonaceous matter, has two principal physiologic actions: stimulation of the respiratory center resulting in an increased breathing rate, most pronounced at 5 percent (50,000 ppm); and at higher concentrations, around 100,000 ppm, asphyxiation and loss of consciousness. The gas is weakly narcotic at 30,000 ppm, producing decreased hearing acuity and increased blood pressure and pulse rate. Since CO₂ is about 1.5 times heavier than air, it tends to settle. Because no serious effects on health or well-being occur

at concentrations below which the oxygen content of the air becomes undesirably low, the main concern is to prevent the level of CO_2 from rising to a value where the oxygen content of the air does not fall below 18 percent by volume at normal atmospheric pressure (equivalent to 135 ml Hg).

Hydrocarbons

This group of substances, comprising literally hundreds of carbon and hydrogen combinations ranging from methane (one carbon atom) to combinations containing 19 or more carbon atoms, has not been well characterized in either kinds or amounts to allow more than a very general toxicologic evaluation of their potential effects on health and well-being.

Table 1 and 2 show that the conventional way of classifying this complex mixture of hydrocarbons is to divide the mixture into a "heavy" fraction and a "lighter" fraction. The heavy fraction is composed primarily of raw, unburned fuel components; the lighter fraction consists of lower molecular weight hydrocarbons that have been partially burned ("cracked") during combustion in the engine (and not present in the fuel), the kinds and amounts being dependent on the fuel-air ratio. The lighter fraction is largely olefinic (unsaturated) hydrocarbons, the heavy fraction is wholly paraffinic (hydrogen-saturated) hydrocarbons (10, 15).

Toxicologically, the paraffins are considered rather inert, noted more for their nuisance value, haze and fogging potential and surface contamination. The industrial air standard or threshold limit value (TLV) for mineral oil mists of 5 mg/m^3 has been set on its nuisance value. On the possibility that the heavy fraction may contain certain substituted aromatics, a TLV of 250 mg/m^3 for cumene has been suggested.

The lighter fraction, being more complex, is more difficult to evaluate. The lowest molecular weight constituents from methane, one carbon to five carbon constituents, pose more of a fire hazard than a health hazard, but their relatively low emission rate removes even this concern under ventilation rates necessitated to reduce levels of other exhaust components. The olefinic, unsaturated components which comprise the bulk of the lighter fraction also are not regarded as posing any specific health threat. What industrial air standards have been set for this type of hydrocarbon are in the category of "inert" gases and vapors, and have been assigned a TLV of 1,000 ppm.

Relation to Odor and Photochemical Smog

Although exhaust hydrocarbons pose little threat to health per se, they possess other characteristics that affect not only well-being but have a potential for affecting health, namely, odor and photochemical smog production. Research investigations by the Bureau of Mines (10, 13) have ascribed a role to hydrocarbons and possibly their partial oxidation products, phenols and carbonyls, in the productions of malodors in diesel exhausts. The correlation with this component was better than for any other component tested and multiple correlations did not prove informative. The precise components of hydrocarbons or their combinations with sulfur- or nitrogen-containing exhaust constituents has yet to be revealed.

Hydrocarbons have been given an important role in the production of so-called photochemical smog (5). Smog development occurs by photodissociation of hydrocarbons and/or nitrogen dioxide, leading to the production of highly reactive free radicals and recombinations to form minute particulate droplets, termed smog. Since this type of smog develops only under conditions of intense ultraviolet radiation, concern for this byproduct of diesel engines, when operating underground or in places sheltered from the sun, does not seem warranted. To cover sunlit situations, however, a standard of 16 g/bhp-hr for hydrocarbons plus oxides of nitrogen has been set (3) (table 3).

Nitrogen Oxides (NO_x)

Of all the constituents of diesel emissions, none would appear to offer a greater health hazard than oxides of nitrogen, both from the standpoint of toxicity and quantities emitted. Generated chiefly as nitric oxide (NO), it rapidly oxidizes to the more toxic nitrogen dioxide (NO_2). Nitrogen dioxide is noted for its insidious capacity to develop edema of the lungs if inhaled in sufficient quantities for a sufficient time. Pulmonary edema has resulted from workers inhaling 80 to 90 ppm NO_2 for half an hour, and mild irritation of the eyes, nose and upper respiratory tract occurred from exposures of from 10 to 20 ppm. Animals exposed 6 hours daily, 5 days each week for 18 months at 5 ppm NO_2 showed no permanent alterations in tissues or function, with the possible exception of enhancement of lung tumors in a lung-tumor susceptible strain of mice. For this reason the industrial air limit has been set as a ceiling limit of 5 ppm not to be exceeded; all concentrations should be controlled below this limit. The characteristic sweetly pungent odor, detectable slightly below this limit, can serve as a warning of approaching undesirable concentrations. The relative volume of oxides of nitrogen in the exhaust, coupled with the low industrial air standard, makes the ventilation requirement the largest of all exhaust components, with the possible exception of that for smoke and possible that for unsaturated aldehydes (tables 1 and 2).

Aldehydes

This category of diesel exhaust chemicals represents a broad group of partly oxidized hydrocarbons, currently very poorly characterized, but believed to comprise aldehydes of the saturated and unsaturated aliphatic series, as well as those of the aromatic series. Being only partly oxidized hydrocarbons, their concentrations in the exhaust are directly related to the unburned hydrocarbon fraction. Toxicologically, aldehydes are noted for their irritancy to the eyes and respiratory passages, particularly formaldehyde and certain unsaturated aliphatic ones, Acrolein and crotonaldehyde (methyl acrolein). (The latter two substances are responsible for the irritant fumes from overheated fats and oils in cooking.) Their irritant potency is reflected in the very low TLV of 0.1 ppm for acrolein (table 1). Which of these aldehyde types occurs in the exhaust or in what quantities is not known at this time, but their quantities vary widely according to engine type, the 2-cycle engine producing very small quantities, the 4-cycle, naturally aspirated, direct-injection type producing considerably greater quantities (10).

Sulfur Oxides

This chemical group comprises the dioxide (SO_2) and the trioxide (SO_3). Both are respiratory tract irritants, SO_2 affecting the upper respiratory tract only because of its high solubility in body fluids; SO_3 , the lower respiratory tract and lungs because its particulate, droplet nature carries it down into the deeper recesses of the respiratory tract.

The sulfur oxides are presently of little or no concern from the toxicologic standpoint; the sulfur content of diesel fuels has been so reduced because of the Federal and local environmental air standards as to result in no toxicologically significant amount of oxides.

Particulates

The constituents, comprising this component of diesel exhausts, are listed in table 2. The most prominent among them is smoke that arises when there is insufficient oxygen for complete fuel burning. Aside from its undesirable esthetic and obscuration qualities, smoke is an important factor contributing to malodor and adverse health effects. Table 2 indicates that smoke acts in these two ways, not per se, but through combined effects on body tissues from the adsorbed exhaust constituents, as shown by the listed extractables by ether and water. Pure carbon particles are noninjurious when inhaled, but when inhaled with appreciable amounts of adsorbed substances with toxic potential, they can enhance the inherent toxicity of adsorbed substances by carrying these substances to the more sensitive tissues of the respiratory tract where they would not ordinarily go by virtue of their solubility, volatility, or other property. At least 33 percent of the carbon smoke consists of adsorbed, potentially hazardous substances as shown by extraction procedures with two solvents (table 2). As these two solvents are typical of solvating agents in body tissues and fluids, the probability is good that the extracted substances could be desorbed from the carbon particles and deposited in the respiratory tract to be disseminated throughout the body. The fact that the particle size of the carbon smoke is of the order of $0.05 \mu\text{m}$ (10), lessens its toxic potential by a factor of four to fivefold; submicron particles of this size are deposited in the lung at about one-fifth that of particles 100 times this diameter, that is, 5 to 6 μm in diameter (6).

The important question of the presence of adsorbed carcinogenic polycyclic aromatic hydrocarbons cannot be answered until special examination of diesel smoke has been made under varying operation conditions.

In the light of the foregoing, the TLV of $3.5 \text{ mg}/\text{m}^3$ probably has little relevance to diesel carbon smoke; the value is set for pure carbon particles for esthetic reasons, and hence does not apply to carbon particles containing adsorbed potentially toxic substances. The TLV that is ultimately set for diesel smoke must be based on the toxic potential of the combined substances with the carbon. In any case, it is wholly possible that the effect of heavy cigarette smoking in underground diesel workers after 45 will have more serious effects, including cancer, than inhaling comparatively dilute diesel smoke.

The "heavy" fraction of unburned hydrocarbons also appears among the particulates as they occur as a fog of minute droplets upon condensation (table 2).

Sulfur trioxide is listed among the particulates, but is of toxicologic significance only for those fuels containing more than 0.5 percent or more of sulfur, a percentage not permitted in today's diesel fuels.

The inclusion of trimanganese tetroxide (Mn_3O_4), the combustion product of the smoke-reducing fuel additive, methyl manganese cyclopentadienyl tricarbonyl (MMCCT), is currently undergoing toxicity tests and hence its toxic hazard has yet to be determined. Although MMCT is highly toxic, it decomposes rapidly in air at ordinary humidities to Mn_3O_4 . Whether a hazard exists depends upon the amount of Mn_3O_4 emitted.

The listing of barium compounds (the sulfate, oxide, and nitrate is included as barium) may be used as a smoke reducer in old diesel engines. What forms of barium appear in the exhausts depend on the amounts of sulfur and nitrates (cetane improvers) or nitrogen oxides relative to amounts of the barium additive. Barium sulfate would constitute no health hazard, but more soluble forms would have to be controlled to around 0.5 mg/m³ of barium to prevent health effects.

INTERACTIONS AMONG EXHAUST GASEOUS CHEMICALS

In addition to the potentiation of effects from unburned hydrocarbons adsorbed on smoke noted above, there remains the question of potentiated toxicologic effects from interactions among exhaust products. The older toxicologic literature (14) contains numerous instances of the hypoxia-producing substances, or CO, showing enhanced effects when inhaled with other substances that act similarly, such as nitrogen dioxide, and carbon dioxide. These effects occurred, however, at several hundred parts per million of each substance. Whether potentiated effects would occur at the concentrations resulting from ventilation dilution is highly questionable. Failure of the ventilating system, however, would make potentiated effects highly probable. Potentiation might be of the order of two or threefold that of each substance singly, depending upon concentration.

INTERACTION OF PHYSICAL AGENTS WITH EXHAUSTS

The two physical agents causing potentially significant alteration in toxicologic responses are temperature and pressure. The graphs shown in figure 2, although derived from animal experimentation at altered temperatures, show that very significant enhancement, from two to seventeenfold of toxicity may be expected when chemicals are taken into the body at temperatures that deviate from normal by as little as 20° F (7). Interestingly enough for our present concern, the substance producing the greatest enhancement in toxicity at elevated temperatures was the paraffin, hexane, seventeenfold and kerosene, elevenfold. Note also, enhancement occurred also at temperatures below normal, though not to so great a degree.

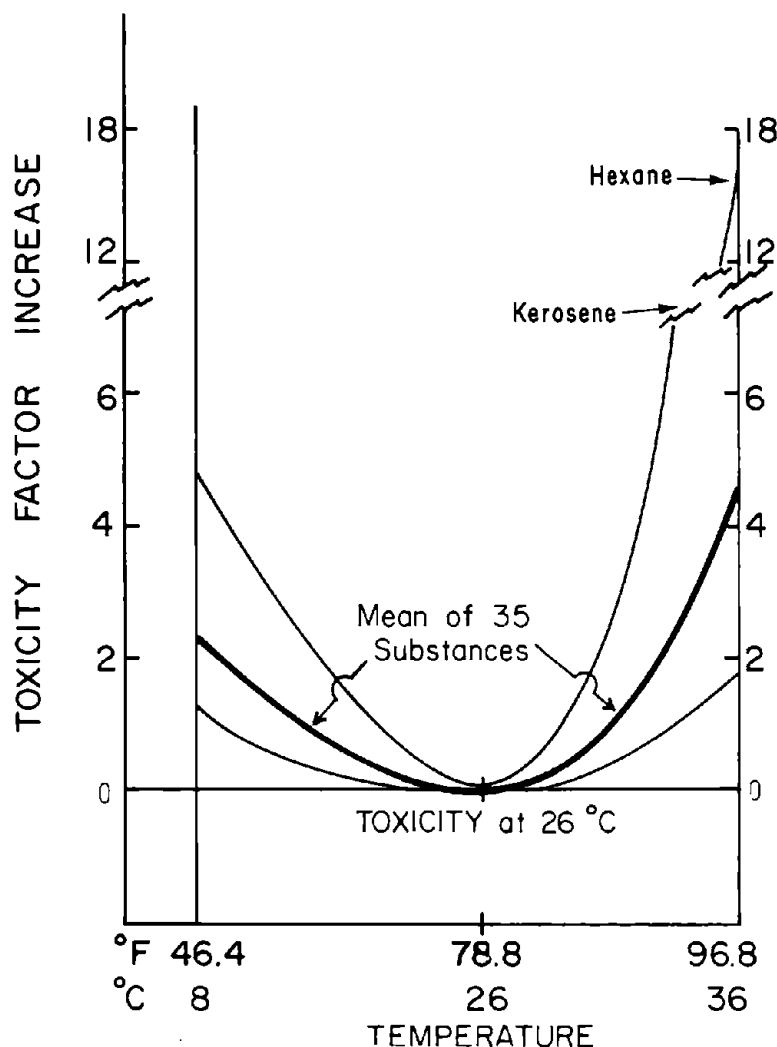


FIGURE 2. - Change in toxicity of CNS depressants with temperature (developed from data of Kephlinger and others, *Tox. Appl. Pharm.*, v. 1, 1959, p. 156).

Significantly increased pressure, two to three atmospheres, also is associated with increased toxicity of gases and vapors with concomitant need to reduce the TLV and increase ventilation rate. The "rule-of-thumb" reduction is halving the TLV at double the pressure, that is, the TLV is 50 ppm at two atmospheres for a gas that at one atmosphere has a TLV of 100 ppm.

Similarly, the toxicity of gaseous substances is increased at altitude. This generalization is based on studies with CO (1). CO at altitude combines with more hemoglobin at the same partial pressure because of a lower oxygen partial pressure at an altitude higher than sea level. For example, at 4,000 feet, 1 percent more carbon monoxide hemoglobin (COHb) forms than at sea level at 50 ppm CO. Moreover, performance is increasingly impaired at increasing altitudes; 3 percent COHb at 15,000 feet produces an effect equivalent to 20 percent COHb at sea level. Thus, TLV's for gaseous diesel emissions

must be reduced according to altitude at which work is being done.

A third physical agent with possible potential for enhancement of effects from toxic agents is noise. Although research into the combined effects of noise and toxic agents is very limited (2), enough has been done to indicate a combined effect. Exposure to selected agents resulted in more inner ear damage in the presence of noise than either alone at the same exposure levels. Whether the types of substances present in diesel exhaust are candidates for such effects cannot be said at present, but diesel engine noise is at such a level that if such substances are present, the possibilities for interaction are good.

THE QUESTION OF CARCINOGENICITY

Finally, the all-important question of the potential of diesel emissions to induce cancer. Older statements in the literature, circa the early 1950's, have generally concluded that one of the differences between automotive and diesel exhausts was the absence of polycyclic aromatic hydrocarbons with carcinogenic potential from diesel sources. Subsequently, however, Kotin, et al (8) demonstrated the presence of carcinogenic hydrocarbons in the particulate phase of diesel exhausts under conditions of inefficient operation; painting of the skin of a susceptible strain of mice with these particulates resulted in tumors. The most recent inventories of diesel emissions (8) failed to examine diesel emissions for the presence of carcinogenic polycyclic aromatics in the hydrocarbon fraction. Resolution of the conflicting evidence would appear to lie in the operating condition of the engine; when new or in proper maintenance, insignificant amounts of polycyclic aromatics would appear to be present, but this should be reinvestigated under present operating conditons.

SUMMARY AND CONCLUSIONS

Toxicologic evaluation of the numerous components of diesel exhausts and their probable interactions points to oxides of nitrogen and the oxides of carbon as substances posing the greatest threat to health. Smoke, with its adsorbed, partly oxidized, and nitrated hydrocarbons, chiefly aldehydes and nitroparaffins, although constituting an irritation and odor problem, actually can contribute to health effects by carrying the irritants to the deeper, more sensitive recesses of the lung, where they can act to initiate, promote, or accelerate emphysematous, fibrotic, or carcinogenic processes. Smoke-adsorbed oxides of nitrogen would be particularly notable in this respect.

Serious major gaps in analytic information still have to be filled before a firm toxicologic appraisal can be made, however. Information is needed, among other things, on the types and amounts of aldehydes, particularly unsaturated aldehydes, whether smoke-adsorbed or free, and whether, and under what conditions polycyclic aromatic hydrocarbons of the carcinogenic type are smoke-adsorbed.

From the toxicologic viewpoint, two things can be said with assurance: (1) Poorly maintained diesel engines will enhance to such proportions all of those constituents most hazardous to health and comfort as to require uneconomic amounts of ventilation to reduce their levels to acceptable concentrations, and (2) underground mine temperatures must be maintained below 80° F if greatly enhanced toxicity from unburned hydrocarbons is to be prevented; kerosene and certain of its individual components produced the greatest enhancement of toxicity at elevated temperatures of 35 substances tested.

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DR. KERR: Our next speaker is Dr. John Kibelstis. He received his M.D. degree from the University of Pennsylvania, and served internship and residency at U.S. Public Health Service Hospital, Baltimore, Md. After he did his residency, he had a Fellowship in Respiratory Diseases at John Hopkins University School of Medicine. He has been in the U.S. Public Health Service since 1965, and has served for the last 2-1/2 years with the Appalachian Laboratory for Occupational Respiratory Disease (ALFORD), paying particular attention to the problems of respiratory diseases involving coal miners.

MEDICAL EFFECTS OF DIESELS UNDERGROUND

by

John A. Kibelstis, M.D.¹

In order to reduce the hazards of electrical cables in mines, industry and Government have turned their attention to alternative sources of power. Diesel power is a logical and available alternative because of its proven usefulness in mine equipment and the low volatility of its fuel. Unlike electrically operated equipment, diesels consume a significant amount of the available oxygen and produce emissions which can have toxic effects in animals. To protect the miner, exposure limits have been defined for the various exhaust components. The scientific justification of these limits will be discussed in this paper.

Before discussing the effects of each of these compounds, a brief description of the anatomy and function of the respiratory organs is in order.

The respiratory system begins at the nose, mouth, and throat where the inspired air is filtered and humidified. The air then passes into the "wind-pipe" or trachea which subdivides into smaller air passages called bronchi and bronchioli (fig. 1). These tubes are lined with cells which have small hairlike appendages, called cilia, which move a surface film of mucous toward the head (fig. 2). Particles of dust or bacteria impinge upon this mucous layer and are passed toward and out of the trachea by this so called "ciliary escalator" (1).² Some of the cells in the walls of these air passages secrete mucous which flows over the cilia. Many of the air passages have muscles which can contract to reduce the diameter of the lumen of the tube and increase the resistance to airflow through that tube. At the level of the smallest tube division, the respiratory bronchiole, the air sac or alveolus is found (fig. 3). This structure contains air. Gases like oxygen, carbon monoxide, and carbon dioxide diffuse freely across its wall into the surrounding blood vessels. This wall is frequently referred to as the alveolar-capillary membrane since it separates the air in the alveolus from the blood in the capillary. The alveolus is policed by macrophages which ingest foreign material and clear it from the alveolus.

CARBON DIOXIDE (CO₂)

Carbon dioxide is an end product of oxidation in both living cells and diesels. As oxygen is consumed, carbon dioxide is produced. Unless ventilation is adequate to dissipate the CO₂ produced, its concentration increases and oxygen concentration falls. For this reason, miners who work in poorly

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²Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

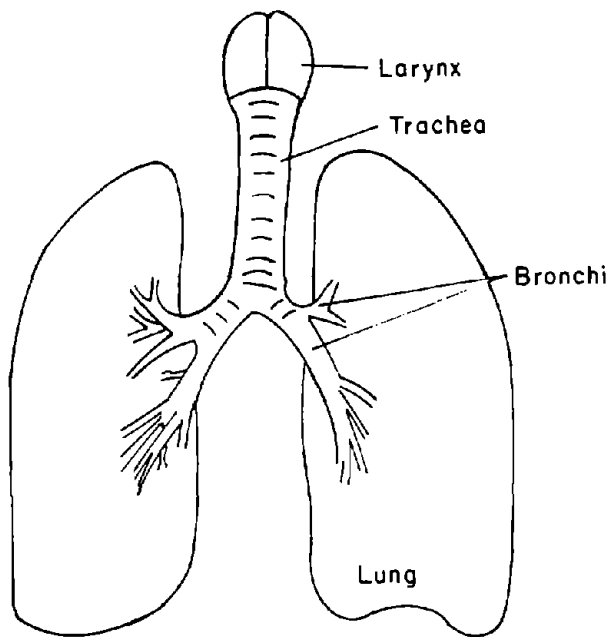


FIGURE 1. - Human respiratory system.

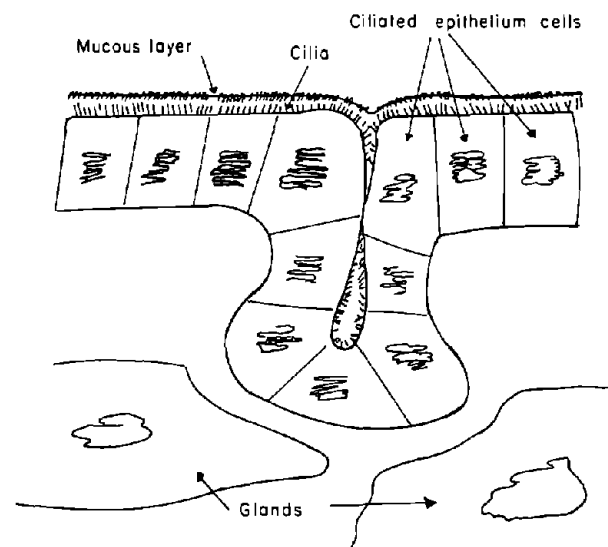


FIGURE 2. - Structure of bronchi and bronchioli.

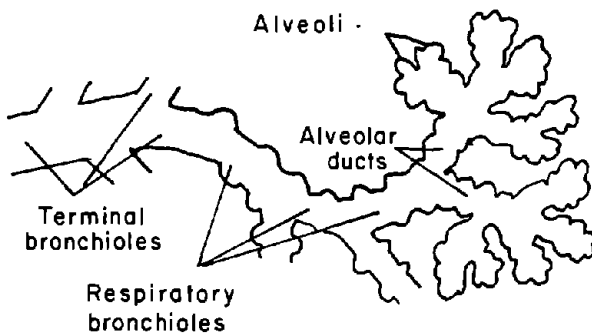


FIGURE 3. - Bronchioli and alveolar ducts.

ventilated areas would experience the effects of both elevated CO_2 and lowered oxygen. For simplicity, let's consider the effects of elevations of CO_2 (hypercarbia) apart from the effects of low oxygen (hypoxia).

Carbon dioxide, produced by cellular metabolism, diffuses through the cell wall into the blood. It combines with water to produce carbonic acid (H_2CO_3) which dissociates into hydrogen (H^+) and bicarbonate (HCO_3^-) ions. The hydrogen ion is buffered by blood bicarbonate, hemoglobin, and plasma proteins to keep the pH within certain limits. When the blood reaches the lungs, this process is reversed. The CO_2 then diffuses across the alveolar-capillary membrane and is ventilated into the surrounding atmosphere. Ordinarily, almost all the CO_2 produced in the body is excreted from it through the lungs.

If ventilation is inadequate, CO_2 concentrations rise and the pH of the blood drops when its buffering capacity is exceeded. The medullary respiratory centers of the brain sense these CO_2 accumulations and increase the rate and depth of respiration to return the CO_2 level to normal. This ventilatory response is almost linear when plotted against CO_2 concentrations. CO_2 accumulates in the blood when the ventilatory centers of the brain are suppressed or the ventilatory ability of the lungs is impaired by disease or injury. In such circumstances, the kidneys begin to conserve bicarbonate to buffer the resulting acidosis. However, this response is slow, taking 3 to 5 days before pH is returned to normal. See table 1.

TABLE 1. - Effects of carbon dioxide exposure

CO concentration, percent	Effect
0.5 (5,000 ppm).....	Recommended exposure limit.
1.5.....	Irritability, decreased ability to concentrate. Increased ventilation.
3.0.....	Apathy, mental dullness.
3.1-3.9.....	Decreased tolerance to exercise.
(3.6).....	Normal arterial blood CO_2 pressure.
6.0.....	Increased cardiac output.
7.7.....	No change in venous oxygen tension to this point.
10.0 (in air).....	Coma (Comroe).
10.0 (in 40 percent O_2)....	Increased blood flow to the brain, increased blood pressure, drowsiness, headache.
11.2.....	Depressed heart muscle function.
30.0 (in oxygen).....	Decreased renal blood flow and oliguria in dogs.

In the absence of acidosis, elevated carbon dioxide causes impaired muscle function. This may be manifested by decreased exercise tolerance at low concentrations (2). At higher concentrations, heart muscle function is depressed (3). Other vascular effects of increased carbon dioxide include increased cardiac output, increased blood pressure, increased blood flow to the brain, and the dilatation of cerebral and coronary vessels. Although the direct effect of elevated carbon dioxide is depressant to the heart muscle, the associated acidosis results in the release of adrenergic substances which increase heart rate, blood pressure, and cardiac output.

The earliest mental changes include irritability and decreased ability to concentrate. Headache and drowsiness develop as the level of arterial carbon dioxide increases. At high levels, this gas becomes anesthetic, causing coma and then death.

Ordinarily, elevations of CO_2 content have no direct effect upon kidney function. However, concentrations of 30 percent CO_2 in oxygen have been shown to cause decreased renal blood flow and oliguria (4).

In certain patients with severe obstructive airway disease, a tolerance to elevated CO_2 levels develops. Although certainly not functioning normally, these patients do not usually exhibit the acute cardiovascular or cerebral effects of CO_2 elevations. They do not feel particularly short of breath

because the level of CO_2 at which their respiratory center becomes stimulated has been adjusted upward. The body seems to decide that the extra breathing efforts necessary to maintain normal levels of carbon dioxide is intolerable. Some of these people have respiratory centers which are totally unresponsive to elevated CO_2 but trigger respiratory efforts only when low oxygen levels are detected by the carotid and aortic chemoreceptors.

The physical effects of CO_2 accumulations cause considerable discomfort at a concentration well below toxic levels. It has a relatively large span of concentrations that are tolerable in normal persons in the presence of sufficient oxygen. Since cardiac muscle depression occurs at relatively low levels, the combination of moderate CO_2 elevations and hypoxia can be dangerous, particularly among persons with heart disease.

OXYGEN (O_2)

Decreased oxygen levels can cause shortness of breath, mental obtundation, and death. Five minutes of oxygen lack results in loss of cortical function of the brain in normal persons. In people who are chronically hypoxic, brain cells may die after even shorter periods of complete oxygen lack. Other body tissues may be considerably more tolerant to anoxia.

Low levels of arterial oxygen are sensed by carotid and aortic chemoreceptors and respiration is increased. If hyperventilation continues, alveolar carbon dioxide levels drop allowing higher alveolar oxygen concentrations to develop. If alveolar carbon dioxide concentration is kept constant and within normal limits, alveolar oxygen concentrations below 40 mmHg may cause a seven to eightfold increase in the ventilatory rate.

Decreased levels of inspired oxygen or lung diseases which decrease blood uptake of oxygen from the alveolus result in low oxygen delivery to the tissues. This oxygen deficiency results in increased anaerobic metabolism. Instead of producing carbon dioxide and water, the end products of anaerobic metabolism are lactic and pyruvic acids. Significant accumulations of these acids cause the intracellular pH to drop resulting in inactivation of enzymes and death of the cells.

Maintaining inspired oxygen levels at or above the recommended minimum of 19.5 volume percent will prevent symptoms of hypoxemia in all but severely impaired persons.

CARBON MONOXIDE (CO)

Carbon monoxide impairs health by its effects upon the oxygen-carrying capacity of the blood. Both carbon monoxide and oxygen diffuse equally well across the alveolar capillary membrane and the red cell wall. Once in proximity to hemoglobin, carbon monoxide is more likely to be bound to the hemoglobin than is oxygen. Although this affinity for hemoglobin varies with different conditions, it has roughly 210 times the affinity of oxygen for hemoglobin. As a result, small but continuous exposures to this gas result in significant levels of carbon monoxide hemoglobin (COHb), thus reducing the

amount of hemoglobin available to carry oxygen. The amount of COHb formed will depend upon the carbon monoxide concentration which is inspired, the diffusing capacity of the lung, and the duration of exposure. Assuming a normal diffusing capacity, the quantity of COHb can be reasonably well estimated for persons with sedentary jobs. In humans, an exposure to 35 ppm carbon monoxide for 8 hours will result in a COHb level of 5 percent. Since the amount of lung involved in diffusion is increased with increased ventilation, the worker who is physically active will develop higher levels of COHb for the same CO exposure. See table 2.

TABLE 2. - Effects of carbon monoxide exposure

(Recommended limits 35 ppm or 38.5 gm/m³)

CO concentration, ppm × time	COHb, percent	Findings
Endogenous production.....	0.4	Blood levels in nonsmokers.
50 ppm × 4 hrs.....	3.0	Decreased exercise time before angina develops in patients with coronary disease (1).
Do.....	3.0-10.0	Average concentration in smokers (2).
35 ppm × 8 hrs.....	5.0	No symptoms in normal nonsmokers but increased oxygen debt is noted on exercise. Adverse behavioral effects.
Do.....	12.4-22	No effects on discriminatory tests.
180 ppm.....	16-18	35 percent neonatal mortality in rabbits (3).
200 ppm × 6 hrs.....	25	Headache, nausea, vomiting, dizziness, drowsiness, and collapse.
Do.....	50	Residual peripheral neuropathy after recovery from acute CO poisoning.

A small reduction in the oxygen carrying capacity of the blood generally results in no detectable symptoms or physical signs in most persons. The tissues extract what oxygen they need leaving lower levels of oxyhemoglobin in the venous blood. If the tissue has a high oxygen consumption, such as heart muscle does, it may not be able to extract enough oxygen in conditions with elevated COHb levels. This is a result of both a decreased oxygen-carrying capacity and a reduced ability of the oxyhemoglobin to release the oxygen it does carry to the tissues. The body attempts to compensate for this decreased oxygen delivery by increasing the blood flow. In most people, this compensatory mechanism adequately handles the situation and only a few physiologic changes can be detected. In fact, many normal people have been able to tolerate 20 percent COHb levels with little or no change in their physical or mental function.

Among those who have coronary artery narrowing due to arteriosclerosis, the delivery of more oxygen to the heart muscle cannot be accomplished because blood flow cannot be increased. Anginal chest pain thus occurs after a significantly shorter period of exercise in patients with 3 percent COHb than in the same patients with 1.32 percent COHb (5). Chest pain is a clear cut indication of inadequate tissue oxygenation. Less impressive and less specific indications of elevated COHb levels include easy fatiguability, shortness of breath, somnolence, headache, coma, and death.

Patients who have severe lung disease will also demonstrate effects of low oxygenation of tissues. In persons with low blood oxygen levels, carbon monoxide exposure will cause even further reduction in the oxygen delivery to tissues. If depression of ventilation has resulted in carbon dioxide accumulations, the resultant acidosis will help to deliver more oxygen to tissues (6).

Arterial disease which decreases blood flow to the brain, anemia, and thyrotoxicosis, which increase tissue oxygen demand in the fetal state, are other conditions in which elevated COHb levels would cause further physical impairment. The children born of mothers who smoked cigarettes regularly during their pregnancy have significantly lower birth weights than children of nonsmoking mothers. Since carbon monoxide freely crosses the placenta, it would be expected to have greater effects upon the relatively hypoxic fetus than it would upon the mother. There is some evidence to suggest that chronic exposure to low levels of carbon monoxide may predispose humans to arteriosclerosis (7). The effects of CO upon cytochrome oxidases which control intracellular oxidation are almost unknown. The effects of 5 to 20 percent COHb upon visual judgmental, and coordination functions of the nervous system are the subject of several conflicting reports.

Since coal miners who smoke cigarettes regularly carry 3 to 10 percent COHb, the logic behind the current exposure limits is twofold, to protect those miners with physical impairments and to avoid adding significantly to the COHb burden of the miner who smokes. The safety of this level is defensible on the basis of current knowledge of carbon monoxide effects.

NITROGEN DIOXIDE (NO₂)

Diesel emissions contain nitric oxide (NO) and nitrogen dioxide (NO₂). Nitric oxide has far less effect upon animals than nitrogen dioxide. Although there is oxidation of NO to NO₂ in the presence of oxidants, such as hydrocarbons and ozone, the physiologic effects of NO itself can be ignored at this point. See table 3.

In contrast to this, the effects of nitrogen dioxide are detectable at low exposure levels. At 1 ppm, oxidation of double bonds occurs in fatty acids (8). At 1.5 ppm, fatty acid methyl esters are oxidized at a significantly higher rate than in air (9). Between 2 and 5 ppm, minor changes occur around the terminal bronchiole and in the alveolus. The effects of NO₂ are found in the oxygen exchanging parts of the lung even at low exposure levels. In contrast, the effects of sulfur dioxide are found in the air passages until very high exposure levels are attained.

TABLE 3. - Effects of nitrogen dioxide exposure(Proposed limit 5 ppm, 9 mg/m³)

NO ₂ concentration, ppm	Effect	Animal
1.....	Oxidation of double bonds in fatty acids.....	Rat.
2.....	Slight collagen deposition around terminal bronchiole.	Rat.
3.....	Bleb formation in alveolar endothelium.....	Beagle.
5.....	Decreased lung compliance; mild congestion, focal septal thickening, and dilatation of air sacs.	Dog.
7.....	Intraalveolar edema.....	Beagle.
12.....	Increased connective tissue bundles; mild emphysematous changes.	Rat.
15.....	Altered surfactant properties; suppressed phagocytic activity.	Rat. Rabbit.
17.....	Thickened basement membrane and increased collagen deposition in terminal bronchioli increased cell replication.	Rat.
25.....	Death in respiratory failure in 20 to 22 weeks (pulmonary discomfort in humans).	Rat.
200+.....	Pulmonary edema + death (Silo-filler's disease).	Human.

Besides the deposition of collagen fibrils (10), mild dilatation of the alveoli and changes in the alveolar macrophage population, pulmonary capillaries become permeable to fluids upon exposure to 5 to 7 ppm in dogs (11). This allows some of the plasma fluids to leak into the alveoli. When this happens, the lungs become less distensible, presumably because of the tissue swelling and the dilution of pulmonary surfactant. Exposures to high nitrogen dioxide concentration in Silo-filler's disease causes so much fluid to extravasate that it causes death. This fluid prevents oxygen from diffusing into the blood in sufficient quantity to support life.

Chronic exposures to 12 to 17 ppm has been shown to cause increased connective tissue bundles, emphysema, and increased cell production in rats (12). Phagocytic activity in the alveoli of rabbits is suppressed at this level of exposure (13). Dust or bacteria reaching such alveoli would not be phagotized and eliminated from the alveoli as readily as in normal alveoli.

At a level of 25 ppm, humans are aware of difficulty in breathing (14). In the rat (12), continuous exposure for 20 to 22 weeks at this concentration results in death due to respiratory failure. Thickened ductal walls and emphysema were found to be similar to changes described by Auerback (15) in the lungs of cigarette smokers.

Deaths occur following acute exposure to high levels of NO₂. Silos have been found to have 200 to 4,000 ppm NO₂ and N₂O₄ within the first week after being filled (16). Farmers who breathe these fumes become acutely ill within hours. Even if such an exposed person survives, he shows increased collagen

deposition in the intralveolar septae and centrilobular emphysema. The edema is reversible but the scarring and alveolar destruction are not.

Much has yet to be studied about the effects of chronic exposure to low levels of NO_2 in man. Nevertheless, a limit of 5 ppm for industrial exposures is certainly justified from our present knowledge.

SULFUR DIOXIDE (SO_2)

The importance of sulfur dioxide in diesel emissions has decreased with the development of diesel fuel containing less than 0.25 percent sulfur by weight. Its effects in air breathing mammals are irritative. At low levels, the eyes, nose, and throat are swollen and inflamed. At exposures of 10 to 20 ppm SO_2 , mice become significantly more susceptible to viral infection and pneumonia (17). This is probably due to inactivation of cilia. With longer exposures, ciliated cells and goblet cells are replaced by squamous epithelium thus permanently destroying the ciliary escalator system. See table 4.

TABLE 4. - Effects of sulfur dioxide exposure

(Proposed limit 5 ppm, 13 mg/m³)

SO_2 level (ppm)	Effect	Animals
0.14-4.69.....	No change in lung diffusion or mechanical properties.	Monkeys.
5.72.....	No change in pulmonary function.....	Guinea pigs.
10.....	Edema and necrosis of turbinates.....	Mice.
10-20.....	Increased susceptibility to viral respiratory infection.	Mice.
16-46.....	Loss of cilia and goblet cells in trachea and bronchi.	Pigs.
26.....	25 percent increase in airway resistance.....	Monkeys.
40.....	Decreased O_2 consumption, food intake, and weight gain; thickened stratified squamous epithelium in trachea.	Mice
300.....	Bronchitis, reduced ciliary action, and increased acid phosphatase in alveolar macrophages.	Rats.

Resistance to airflow is increased owing to broncho-constriction of the major air passages (18). At concentrations of 40 ppm, mice demonstrate decreased oxygen consumption, decreased food intake and poor weight gain (19). At higher levels, involvement reaches the alveoli where alveolar macrophage acid phosphatase activity was increased (20). These effects can be accentuated by the concurrent exposure to organic dusts (21) or carbon black (22). This could be explained by the dust absorbing SO_2 , being deposited on the mucosal surface, then being leached of its SO_2 . The dust would act as a vehicle for the SO_2 . The effects of concurrent exposure to coal dust and sulfur dioxide has not been completely explored.

MISCELLANEOUS COMPOUNDS

Diesel emissions contain significant quantities of various aliphatic and aromatic hydrocarbons. Aliphatic hydrocarbons facilitate the oxidation of other compounds but even this reaction is medically unimportant. Some aromatic hydrocarbons, like benzene, have toxic potential but their concentrations never reach significant levels. Others, such as benzo(a)pyrenes (23), are known to induce or accelerate the growth of cancers. Aldehydes, besides being odoriferous, can cause irritation of the tracheobronchial wall and ciliary stasis.

Other compounds are found in diesel exhaust but their physiologic effects are not known.

CONCLUSIONS

From a review of the current medical literature, one can conclude that adherence to the recommended exposure limits for diesel operated mine equipment would prevent significant toxicity. Although a lot of research is still needed, it is unlikely to change these current standards appreciably.

In a sense, the conversion of electrical to diesel power is a swapping of one set of health hazards for another. It remains for the engineers to devise ways to limit these health hazards and for health researchers to better define these hazards.

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MR. PELUSO: Are there any questions?

MR. MARTONIK: My name is John Martonik from the Bureau of Mines. Have there been any reported injuries due to the workmen breathing diesel exhaust so far in underground mines?

MR. PELUSO: Have there been any reported injuries or accidents to miners who are working underground due to breathing diesel exhaust?

DR. KIBELSTIS: I have not read any medical literature. I have not heard of any.

MR. PELUSO: Dr. Kerr, would you like to comment on that?

DR. KERR: My only inclination would be to respond to that on the basis of the experience that we have had for about 25 years with the dust diseases. Even if there has been such a case, it is exceedingly doubtful that it would be reported as such, because it probably would not have been recognized by the physicians as being due to the inhalation of diesel gases or diesel emissions.

MR. PELUSO: We have time for another question.

FROM THE FLOOR: Dr. Stokinger, you had a slide that indicated the adjustments for temperature. I was wondering if you had a similar slide for altitude? We have mines that are 12,000 feet, at some depth, below sea level.

DR. STOKINGER: I did not say anything about pressure. Pressure in deep mines, the atmospheric pressure is reduced for the safe level of exposure. In other words, if you had an overall threshold limit value of 100 and you went down to 2 atmospheres of pressure, you would have that threshold, and if you went up to 2 altitudes, I think you probably would have to do the same thing. Every 10,000 feet, I think, you would want to reduce your TLV in the same way.

DR. KIBELSTIS: I think it depends on the compound that you were talking about. If you are working at 14,000 feet, you must have enough available oxygen that would give a blood oxygen level of 50 ml Hg. If you add to that a load of carbon monoxide, that is enough to bring the level of arterial oxygen further down. Thus the adverse effect of carbon monoxide is much more quickly reached at higher elevations. If you take a person with arteriosclerosis and put them in a high altitude situation, he may not be able to tolerate a similar level of CO he could tolerate at sea level.

MR. PELUSO: One more question?

MR. GIBBENS: John Gibbens of Westinghouse. Yesterday Bill Fisher mentioned that machinery operators could see smoke or smell any emissions when they work around diesel engines. Are these human sensitizing devices adequate to protect the human individual from the hazards that you have discussed this morning?

DR. KIBELSTIS: The human senses are trained to recognize different smells, but they are not trained to recognize the significance of them chemically in the body or physiologically. They may know they are breathing exhaust and note that the exhaust level increased or that they became "headachey." They may recognize it and attribute it to poor ventilation, but, in general, as time of exposure to the lung becomes conditioned to the smell, they do not notice the difference. If you talk to a man who has been a fisherman all his life, he does not notice the smell of the fish as much as the guy that is sitting beside him on the subway.

INDUSTRIAL HYGIENE SURVEYS OF U.S. MINES

by

Glen W. Sutton¹

This report summarizes the results of studies of mine air contaminants found in underground mines using diesel powered equipment. The studies were made in three underground coal mines and four underground noncoal mines. The investigations included systematic sampling of the mine atmosphere for the purpose of obtaining engineering information relative to air contamination originating from diesel exhaust in underground mines.

INTRODUCTION

The practice of industrial hygiene is concerned with the recognition, evaluation, and control of health hazards in the working environment. During a prior presentation of this symposium you heard Professor Johnson speak on the subject of emission characteristics of diesel engines, first from perfect combustion and then, more realistically, from imperfect combustion.

Mr. Hurn then discussed diesel emission control through engine design as well as the treatment of the exhaust gases with engine accessories. In actual practice emissions from diesel engine-powered equipment underground probably range somewhere between perfect and imperfect combustion and are most likely different than the results determined in the laboratory. This can occur as the result of several reasons including the level of service and maintenance performed by the mine operator. In addition, accessories such as scrubbers or catalytic mufflers, added to the engine by the mining equipment manufacturer to achieve acceptable levels of emissions, can cause a significant variation from theoretical or laboratory results.

In actively ventilated mine areas exhaust gases will always be diluted by the ventilating air current. For a health hazard evaluation to determine the impact on man, it is the diluted mixture that is of concern. Therefore, it may be the diluted concentration in the immediate vicinity of the equipment, the cumulative effect of multiple diesel units on the mine system, or the effect on a remote travel or work area that is of immediate concern in the hazard evaluation.

In this presentation I will summarize the results of studies in seven underground mines. The studies, conducted by Bureau of Mines personnel during the past several months, include three coal mines, one gassy noncoal mine and three additional noncoal mines. The mines included in the studies are as follows:

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1. CO-OP Mine, CO-OP Mining Co., Huntington Canyon, Emery County, Utah.
2. No. 1 Mine, Southern Utah Fuel Co., Salina, Sevier County, Utah.
3. Martin County Coal Corp., Inez, Martin County, Ky.
4. Big Island Trona Mine, Stauffer Chemical Co., Green River, Sweetwater County, Wyo.
5. White Pine Mine, White Pine Copper Co., White Pine, Ontonagon County, Mich.
6. Magmont Mine, Cominco American, Inc., Bixby, Iron County, Mo.
7. Bunker Hill Mine, Bunker Hill Mining Company, Kellogg, Shoshone County, Idaho.

The surveys varied in scope and magnitude depending on the size of the operation. However, the investigation included systematic sampling of the mine atmosphere, air quantity measurements, and other pertinent study information.

Although evermore sensitive and specific procedures are available and used in the laboratory for the analysis of diesel emissions, underground instrumentation is currently limited to portable, self-contained instruments which generally lack the sensitivity and precision of laboratory equipment. Sampling for gases underground is frequently accomplished with indicator tubes. These are glass tubes packed with a chemically active granular material which is sealed until use. Tubes are manufactured by several different companies for many different chemicals. In use the tips or ends of the tube are broken and a known volume of air is aspirated through the tube with a squeeze device or special pump. The chemically active material may change in overall color; or in other tubes the length of stain, or change in color, is proportionate to the concentration. The limitation of these tubes must be recognized. Their name, indicator tube, aptly describes them; they are not precise instruments. They indicate the approximate concentration of the sampled contaminant, and their accuracy, in the absence of information to indicate otherwise, should be considered as approximately plus or minus 25 percent.

Another technique is to collect air samples in previously evacuated bottles for subsequent laboratory analysis, generally by chromatographic techniques. The sample container is a sealed glass flask that has been air evacuated prior to sealing. In use the seal is broken, air enters the flask, it is resealed and transported to the laboratory.

Taking air samples by means of any indicator tube or an evacuated flask results in an instantaneous or near instantaneous sample of the atmosphere. Air samples taken in this manner represent the concentration at the precise time the sample was taken whether it be a peak value or during a period of inactivity. Exposure to any contaminant, unless it has a ceiling value, is evaluated primarily by a known exposure of the worker to the range of

contaminant concentration over a period of time, that is, to a time-weighted-average concentration.

To improve on the deficiencies of spot sampling, a technique was introduced whereby mine air was sampled by continuously pumping air at a low rate into a plastic bag for subsequent analysis. While the analysis limitations have not changed, the sample does represent conditions over a definite and longer period of time than spot sampling.

Since the introduction of gravimetric respirable dust sampling, the presence of diesel soot or smoke on filters has been noted. The presence of such carbon on a sample complicates the assessment of a worker's exposure to mineral dust and, conversely, the mineral and other organic particulate present complicates the assessment of a worker's exposure to the diesel emission particulate. To define exposure to diesel particulate, personal gravimetric samples were placed on operators of diesel equipment and samples collected in a normal manner.

Aldehydes were collected using collection flasks with bubblers. Aldehydes were determined by an isometric titration and reported as formaldehyde.

Samples for oxides of nitrogen were also collected utilizing collection flasks with bubblers and an appropriate reagent. Results of samples collected in evacuated flasks were reported as NO_x .

Ventilation measurements were made utilizing standard instruments and techniques for air velocity and air volume. In some cases wet and dry bulb temperatures were also measured and reported.

Noise measurements were made in some operations by either utilizing a noise dosimeter or a sound pressure level meter.

The sampling strategy varied somewhat from survey to survey as the studies progressed. Therefore, specific procedures are discussed under the individual surveys in the appendixes.

INTERPRETATION OF RESULTS

Threshold limit values (TLV's) refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effects. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the TLV; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness. TLV's refer to time-weighted-concentrations for a 7- or 8-hour workday and 40-hour workweek. They should be used as guides in the control of health hazards and should not be used as fine lines between safe and dangerous concentrations.

Time-weighted averages permit excursions below the limit during the workday. The degree of the permissible excursion is related to the magnitude of the TLV of the substance.

Exception to the time-weighted average concept are those substances designated as ceiling values. These values should not be exceeded during the workday, that is, all exposures should be below the ceiling value.

The following TLV's were reported for contaminants evaluated during the survey:

	Contaminant	Concentration ppm
	Carbon monoxide CO	50
	Carbon dioxide CO ₂	0.5 percent
C	Nitrogen dioxide NO ₂	5
	Nitrogen oxides NO _x	25
	Sulfur dioxide SO ₂	5
	Hydrogen sulfide H ₂ S	10
C	Aldehydes (as formaldehyde)	2
	Carbon	2-3.5 mg/m ³

NOTE.--"C" indicates ceiling value.

Many objections arise from irritation and odor. Since both of these are subjective in nature, instruments are not currently available to either confirm the presence or to quantitate the level of odor or irritation.

SUMMARY OF MINE RESULTS

A summary of the results obtained in the seven mines are shown. Detailed results on individual mines are included in the appendixes.

CO-OP Mine, CO-OP Mining Company, Utah

(See appendix A.)

The mine located at an elevation of approximately 7,400 feet is mining a coal seam ranging from 9 to 12 feet thick. Two mine constructed diesel-powered dump truck shuttle cars were used. They were powered by Detroit 453 diesel engines rated at 102 horsepower and equipped with mine built exhaust scrubbers. The total air reaching the point where the cars were loaded was approximately 17,000 cfm. The following time-weighted average concentrations were determined:

Carbon monoxide, CO.....	8 ppm
Carbon dioxide, CO ₂	1.1 percent
Nitrogen dioxide, NO ₂	0.1 ppm
Nitrogen oxides, NO _x	6 ppm
Hydrogen sulfide, H ₂ S.....	-
Methane.....	0
Sulfur dioxide, SO ₂	0
Aldehydes.....	0

No. 1 Mine, Southern Utah Fuel Co., Utah

(See appendix B.)

The mine located at an elevation of approximately 7,300 feet is mining coal utilizing two diesel load-haul-dump units. The Eimco units powered by Caterpillar 3160 engines were equipped with water scrubbers. Approximately 30,000 cfm of ventilating air was passing through the section. The duty cycle was calculated as 30 percent based on fuel consumption. Time-weighted averages ranged as follows:

Carbon monoxide, CO.....	10 ppm
Carbon dioxide, CO ₂	0.04 percent
Nitrogen dioxide, NO ₂	0.5 ppm
Nitrogen oxides, NO _x	3 ppm
Particulate.....	1.3 mg/m ³
Noise (dosimeter).....	¹ 2.7

¹Dosimeter measurement is the normalized percent of calculated fullshift allowable exposure level. Present standard based on a 90 dBA--8-hour exposure has a compliance level of 1.0.

Martin County Coal Corp., Kentucky

(See appendix C.)

A detailed description of this operation was presented by Mr. Bradbury during an earlier presentation. To summarize, the diesel equipment consists of a Wagner loader and nine diesel trucks. The duty cycle for the loader was approximately 20 percent and for the trucks 40 percent. In evaluating the mine environment no aldehydes were present; carbon monoxide ranged up to 10 ppm. Carbon monoxide ranged up to 0.35 percent and no oxides of nitrogen were encountered. Noise levels up to 100 dBA were measured while loading and other values over the standard were recorded in other operational cycles.

Big Island Trona Mine, Wyoming

(See appendix D.)

This is a large gassy noncoal mine; therefore, a representative panel (northwest) was surveyed. Equipment included two shuttle cars, a powder car, a welder, and a grease vehicle. All samples were below the appropriate TLV, as follows:

Carbon monoxide, CO.....	¹ 5-25 ppm
Carbon dioxide, CO ₂	0.04-0.1 percent
Sulfur dioxide, SO ₂	Trace
Aldehydes.....	0
Nitrogen dioxide, NO ₂	0.5-2 ppm

¹One sample was 50 ppm in return after blast.

Ventilation consisted of 28,000 cfm intake to the panel with auxiliary tubing carrying 3,000 cfm to each face.

White Pine Mine, Michigan

(See appendix E.)

White pine is a large noncoal underground mine utilizing over 300 diesel units. Because of the mine size and number of units, only a representative section was surveyed. Approximately 162,000 cfm was entering the study section. An average of 26 units were in the study section or on the intake air side of the section, with a total brake-horsepower of 3,300. All carbon monoxide samples were below the TLV, with the highest being 15 ppm. All other values were below the approximate TLV except the isolated instances shown in the detailed results in appendix E.

The duty cycle for the equipment averaged 20 to 30 percent.

Magmont Mine, Missouri

(See appendix F.)

Magmont is a large lead mine and had a total of 35 units of diesel equipment underground. Of these, 13 units were in the area of study. They included a loader, two trucks, three transloaders, four drill jumbos, one service truck, one scaler, and one personnel carrier. Total ventilation was 155,000 cfm. Only the particulate samples, including mineral dusts, exceeded the TLV ranging up to 12.9 mg/m³.

Bunker Hill, Idaho

(See appendix G.)

Bunker Hill is a noncoal mine and was utilizing a total of five units including four Eimco 912 loaders and one Young buggy. Several locations where work was performed were surveyed. A carbon dioxide sample over the TLV (0.63 percent) was measured. All other samples were below the TLV.

CONCLUSIONS

1. Although individual spot samples for carbon monoxide and carbon dioxide indicated elevated peak concentrations, the time-weighted averages were below the current TLV of 50 ppm and also the suggested lower value of 35 ppm.

2. Concentrations of nitrogen dioxide and aldehydes did not exceed their ceiling TLV's.

3. Samples for particulates in some mines ranged above the TLV. Samples were cumulative samples of all particulate including mineral dust which was present and do not reflect diesel soot concentrations.

4. Noise levels exceeded the standard applicable in coal mines.

5. Based on observation, calculations and best estimates, the duty cycle of equipment was in the range of 20 to 50 percent.

6. Study of operations indicates that with mobile diesel equipment, the effects of equipment travel speed, air velocity, travel distance, and duty cycle are as significant as size and type of engine in determining levels of contaminants at a given location and time.

7. Some samples for total nitrogen oxides were erratic. The variation in the results indicates that more reliable methods should be developed for mine use. In spite of the variation in the reported results, it is indicated that the TLV can be realized.

APPENDIX A.--CO-OP MINE, CO-OP MINING COMPANY, HUNTINGTON
CANYON, EMERY COUNTY, UTAH

General Information

The CO-OP Mine was operating about 7,400 feet above sea level in the Hiawatha coalbed which averaged 19 feet in thickness. Mining height ranged from 9 to 12 feet. The mine contained one coal producing unit equipped with a Lee-Norse continuous miner and two mine-constructed diesel-powered dump truck shuttle cars. A total of eight men, six underground and two on the surface, were employed on one coal-producing shift per day, 5 days per week.

Coal was being produced from a pillar line at a point approximately 2,800 feet from the outside via the shuttle car route. The mine roof was supported by breaker posts at the working place. Roof bolts were also used at a few locations where the condition of the roof required it. Intake and return entries observed were free of roof falls.

Ventilation

Mine ventilation was induced by a surface-installed, belt driven 4-ft-diameter axial flow fan, reportedly operated at a speed of 3,450 rpm by a 25-hp General Electric motor to exhaust 39,000 cfm of air at approximately 0.3 inches of water gage pressure. Air density decreased with air travel through the mine from 0.065 pcf at the mine intake to 0.060 pcf at the mine exhaust. Temperature and relative humidity of the mine exhausted air was 42° F and 92 percent, respectively, the mine intake air was 13° F and 82 percent.

The total air quantity reaching the point where shuttle cars were being loaded was approximately 17,000 cfm. The face area was ventilated by an exhaust type line brattice. The air quantity at the inby end of the line brattice was approximately 12,000 cfm.

PHYSICAL DESCRIPTION OF DIESEL POWERED SHUTTLE CARS

The two shuttle cars operating in this mine were dump truck-type mine-built equipment, powered by Detroit 453 diesel engines reportedly rated at 102 continuous horsepower having a brake specific fuel consumption at full load of 0.443 pounds of fuel per horsepower hour. The units, equipped with mine built exhaust scrubbers, had five forward speed gears but reportedly were used in the third gear for driving either empty or loaded. The average load was reportedly 7 tons of coal.

Sampling the Air Quality

Air quality was sampled at three strategically selected locations. One of the locations was moving and two were stationary as follows:

1. Station 1 was a moving location, representing the environment of miner operator and other workers in the face area. This location was chosen

because being the most downstream position occupied by workers, it was judged to be the high-risk area.

2. Station 2 was a stationary location in the return entry about 1,550 feet outby the face area via the airflow path. This location was selected to obtain information about the total amount of air contaminants leaving the face area. It was observed that, because the relative position of the diesel exhaust to the exhaust line brattice curtain, the exhaust gases from the shuttle car being loaded did not contaminate the breathing zone of miners in the face but traveled directly into the return airflow by line brattice leakage.

3. Station 3 was a stationary location in the intake entry at the last permanent stopping about 450 feet outby the face area. Since both empty and loaded shuttle cars traveled the single intake entry, this location was selected to represent the high-risk part of the shuttle car tramway.

Air quality was sampled at the above locations by four different techniques:

1. Systematic series of samples by chemical stain tubes at all three locations were collected.

2. A series of vacuum bottle air samples were collected at all three locations for laboratory analysis.

3. Large volume bubblers containing Griess-Saltzman reagent and acidified KMnO_4 oxidizer were operated at all three locations to obtain gross samples of NO_2 and NO for a longer time period (several hours).

4. Midget bubblers were operated at station 2 in the return air course to sample continuously for several minutes for the following contaminants: NO_2 , NO , acrolein, total aldehydes, SO_2 and SO_3 .

In addition to the above, the ventilating air was sampled for particulate matter at the three stations and in the environment of both shuttle car operators throughout the working hours by silver membrane filters equipped with a size selector ($-10 \mu\text{m}$ equivalent diameter) and constant volume pump. The results of all the tests are listed in tables A-1 through A-4.

TABLE A-1. - Station 1--face area

(Barometric pressure = 22.84-23.04 inches Hg, temperature = 360° F, elevation = 7,400 feet above sea level, and air quantity = 17,000 cfm)

Date 1972	Time at start of sam- pling	Stain tube (ST) or vacuum bottle (VB)	CO, ppm	CO ₂ , per- cent	NO ₂ , ppm	NO _x , ppm	H ₂ S, ppm	SO ₂ , ppm	Total alde- hydes, ppm	CH ₄ , per- cent	O ₂ , per- cent	N ₂ , per- cent	Time at end of sam- pling
Dec. 13	0820	ST	0	0	0	-	0	0	0	-	-	-	0844
	1042	ST	19	0.06	0.2	-	-	-	0	-	-	-	1111
	1112	VB	10	.05	-	4.4	-	-	-	0.00	20.89	79.06	1112
	1135	ST	13	.06	trace	-	-	-	-	-	-	-	1142
	1505	ST	16	.05	0	-	0	0	0	-	-	-	1553
	1554	VB	10	.06	-	10.3	-	-	-	.00	20.87	79.07	1554
	1605	ST	32	.05	0	-	-	-	-	-	-	-	1624
	1625	VB	-	-	-	2.3	-	-	-	-	-	-	1625
	1642	VB	-	-	-	10.1	-	-	-	-	-	-	1642
Dec. 14	0832	ST	13	.05	0	-	0	0	0	-	-	-	0844
	0845	VB	0	.05	-	8.4	-	-	-	.00	20.90	79.05	0845
	0900	VB	0	.04	-	6.5	-	-	-	.00	20.89	79.07	0900
	0937	ST	19	.05	.1	-	-	-	-	-	-	-	0946
	0947	VB	0	.06	-	15.8	-	-	-	.00	20.85	79.09	0947
	1038	ST	13	-	.1	-	-	-	-	-	-	-	1045
	1134	ST	19	.06	.1	-	0	0	0	-	-	-	1147
	1148	VB	10	.11	-	8.4	-	-	-	.00	20.85	79.04	1148
	1157	VB	10	.11	-	17.9	-	-	-	.00	20.81	79.08	1157
	1316	ST	13	.06	0	-	-	-	-	-	-	-	1324
	1325	VB	0	.06	-	8.5	-	-	-	.00	20.87	79.07	1325
	1345	ST	13	-	.1	-	-	-	-	-	-	-	1357
	1358	VB	10	.09	-	10.1	-	-	-	.00	20.83	79.08	1358
	1424	ST	19	.06	.1	-	0	0	0	-	-	-	1438
	1439	VB	10	.10	-	2.5	-	-	-	.00	20.82	79.08	1439
	1451	VB	10	.11	-	19.8	-	-	-	.00	20.82	79.07	1451
	1510	ST	13	.06	.1	-	0	0	0	-	-	-	1522
	1523	VB	10	.44	-	12.4	-	-	-	.00	20.42	79.14	1523

- NOTES.--1. All stain tube readings with the exception of CO₂ were corrected by a factor of 1.3 for elevation and in addition NO₂ tube readings were corrected by a factor of 1.15 for temperature.
2. Carbon dioxide stain tube readings were corrected as recommended by the manufacturer.
3. The results of laboratory analysis of vacuum bottle air samples were corrected for barometric pressure and temperature.
4. Large volume bubblers operated as follows:
 Dec. 13, 1972 1132-1152 and 1503-1657 indicated 0.07 ppm NO₂ and 0.09 ppm NO.
 Dec. 14, 1972 0923-1211 indicated 0.18 ppm NO₂ and 0.09 ppm NO.
5. The results obtained by the bubblers are barometric pressure and temperature corrected.

TABLE A-2. - Station 2--return entry

(Barometric pressure = 22.84-23.04 inches Hg, temperature = 46° F, elevation = 7,400 feet above sea level, air quantity = 23,000 cfm)

Date 1972	Time at start of sam- pling	Stain tube (ST) vacuum bottle (VB), or small volume bubbler (SVB)	CO, ppm	CO ₂ , per- cent	NO _x , ppm	H ₂ S, ppm	SO ₂ , ppm	Aldc- hydes	CH ₄ , per- cent	O ₂ , per- cent	N ₂ , per- cent	Acro- loin	Time at end of sam- pling
Dec. 13	1529	ST	5	<0.1	0	-	-	-	-	-	-	-	1545
	1540	VB			43.4	-	-	-	0.00	20.89	79.06	-	1541
	1545	ST	5	<0.1	0	-	-	-	-	-	-	-	1556
	1556	ST	9	<0.1	0	-	-	-	-	-	-	-	1608
	1604	VB			12.9	-	-	-	.00	20.90	79.05	-	1605
	1608	ST	16	<0.1	0	-	-	-	-	-	-	-	1623
	1625	ST	-	-	-	-	0	0	-	-	-	-	1631
Dec. 14	1003	VB	-	-	2.5	-	-	-	-	-	-	-	1003
	1145	VB	10	0.06	6.7	-	-	-	.00	20.86	79.08	-	1145
	1332	SVB	-	-	0.08	-	-	-	-	-	-	-	1351
	1336	SVB	-	-	-	-	-	-	-	-	-	(¹)	1425
	1347	SVB	-	-	-	-	(²)	-	-	-	-	-	1407
	1351	SVB	-	-	-	-	(²)	-	-	-	-	-	1414
	1413	SVB	-	-	-	-	-	-	-	-	-	-	1426
	1419	SVB	-	-	-	-	-	0.3	-	-	-	-	1455
	1421	VB	10	0.08	2.6	-	-	-	.00	20.84	79.08	-	1422
	1442	SVB	-	-	(³)	-	-	-	-	-	-	-	1459
	1448	VB	-	-	8.6	-	-	-	-	-	-	-	1448

¹Because the lack of appropriate chemical (4-hexylresorcinol) the test was not yet conducted on this sample.

²Since the absorbing reagent (iodine) penetrated the plastic container of the sample, reliable analysis could not be performed.

³Rockdusting interfered with reliability of sample which indicated NO₂ at 0.47 ppm and NO at 1.00 ppm.

NOTES.--1. All stain tube readings with the exception of CO₂ were corrected by a factor of 1.3 for elevation and in addition, NO₂ tube readings were corrected by a factor of 1.15 for temperature.

2. The results of laboratory analysis of vacuum bottle air samples were corrected for barometric pressure and temperature.

3. Large volume bubblers operated as follows:

Dec. 13, 1972 from 1529 to 1714 indicated 0.04 ppm NO₂ and 0.03 ppm NO.

Dec. 14, 1972 from 1001 to 1204 indicated 0.02 ppm NO₂ and 0.02 ppm NO.

4. The results obtained by the bubblers are barometric pressure and temperature corrected.

TABLE A-3. - Station 3--intake entry inby end of shuttle car tramway

(Barometric pressure = 22.84-23.04 inches Hg, temperature = 31° F, elevation = 7,400 feet above sea level, air quantity = 22,000 cfm)

Date 1972	Time at start of sam- pling	Stain tube or vacuum bottle	CO, ppm	CO ₂ , per- cent	NO ₂ , ppm	NO _x , ppm	H ₂ S ppm	SO ₂ , ppm	Alde- hydes	CH ₄ , per- cent	O ₂ , per- cent	N ₂ , per- cent	CHOH, ppm	Time at end of sam- pling
Dec. 13	1510	VB	-	-	-	4.4	-	-	-	-	-	-	-	1512
	1515	VB	-	-	-	4.4	-	-	-	-	-	-	-	1515
	1645	VB	-	-	-	-	-	-	-	-	-	-	-	1645
Dec. 14	0929	VB	-	0.05	-	-	-	-	-	0.00	20.90	79.05	-	0929
	1016	ST	13	.06	0	3	-	-	-	-	-	-	-	1038
	1038	ST	13	.07	0.4	6	-	-	-	-	-	-	-	1052
	1053	ST	13	.05	.4	4	-	-	-	.00	20.86	79.09	-	1105
	1103	VB	0	.05	-	-	-	-	-	-	-	-	-	1103
	1106	ST	9	.05	Trace	3	-	-	-	-	-	-	-	1120
	1121	ST	-	-	-	-	0	0	-	-	-	-	0	1135
	1201	VB	10	.07	-	-	-	-	-	.00	20.88	79.05	-	1201
	1203	VB	-	-	-	6.3	-	-	-	-	-	-	-	1203
	1511	VB	0	.16	-	2.5	-	-	-	.00	20.78	79.06	-	1512

NOTES.--1. All stain tube readings with the exception of CO₂ were corrected by a factor of 1.3 for elevation and in addition, NO₂ tube readings were corrected by a factor of 1.15 for temperature.

2. Carbon dioxide stain tubes readings were corrected as recommended by the manufacturer.

3. The results of the laboratory analysis of vacuum bottle air samples were corrected for barometric pressure and temperature.

4. Large volume bubblers operated as follows:

Dec. 13, 1972 from 1458 to 1705 indicated 0.12 ppm NO₂ and 0.04 ppm NO.

Dec. 14, 1972 from 1014 to 1204 indicated 0.21 ppm NO₂ and 0.05 ppm NO.

5. The results obtained by the bubblers are barometric pressure and temperature corrected.

TABLE A-4. - Sampling with silver membrane filters equipped
with size selector and constant volume pump
for air suspended particulates of minus 10
micrometers equivalent diameter

	Total particulates, mg/m ³	Benzene soluble, mg/m ³	Benzene insoluble, mg/m ³
Station 1-face area (miner operator environment):			
Dec. 13, 1972 from 0826 to 1655 indicated.....	1.39	0.56	0.83
Dec. 14, 1972 from 0840 to 1515 indicated.....	2.44	.52	1.92
Station 2-return entry:			
Dec. 13, 1972 from 0852 to 1714 indicated.....	.59	.15	.44
Dec. 14, 1972 from 0814 to 1503 indicated.....	1.59	.00	1.59
Station 3-intake entry (inby end of shuttle car tramway):			
Dec. 13, 1972 from 0837 to 1705 indicated.....	.00	.00	.00
Dec. 14, 1972 from 0834 to 1514 indicated.....	1.20	.17	1.03
Shuttle car No. 1 (operator's cab):			
Dec. 13, 1972 from 0903 to 1711 indicated.....	.14	.00	.14
Dec. 14, 1972 from 0759 to 1540 indicated.....	.89	.30	.59
Shuttle car No. 2 (operator's cab):			
Dec. 13, 1972 from 0829 to 1717 indicated.....	.39	.26	.13
Dec. 14, 1972 from 0803 to 1544 indicated.....	.30	.15	.15

- NOTES.--1. A further analysis on the composition of particulate matter would be desirable. It may be possible with fluorescent spectroscopy. At the present the DTSC was not equipped to conduct this analysis.
2. Concentration indicated in the tables are barometric pressure and temperature corrected.

A noise dosimeter was also used and located between the miner operator and the shuttle car being loaded. It indicated 15 percent of the allowable exposure on the first day and 27 percent of the allowable exposure on the second day. Methane concentration was indicated to be 0 percent at all locations when tested by a handheld methanometer. Irritating odor, eye discomfort, or other adverse physiological effects were neither apparent nor reported.

The average time-weighted concentration of contaminants, based on stain tube indications and the results of laboratory analysis of vacuum bottle air samples, are given, on the following page:

Contaminant	Average time-weighted concentration throughout the study.	TLV
STATION 1-MINER OPERATOR		
CO	7.4 ppm	50 ppm
CO ₂	<0.07 percent	0.5 percent
NO ₂	<0.1 ppm	5 ppm
NO	6.1 ppm	25 ppm
STATION 2-RETURN ENTRY		
CO	4.3 ppm	50 ppm
CO ₂	<0.1 percent	0.5 percent
NO ₂	<0.1 ppm	5 ppm
NO	4.9 ppm	25 ppm
STATION 3-INTAKE ENTRY		
CO	4.5 ppm	50 ppm
CO ₂	<0.06 percent	0.5 percent
NO ₂	<0.2 ppm	5 ppm
NO	2.4 ppm	25 ppm

During 37 percent of the total study (service equipment, lunch, move miner), air contaminants originating from diesel exhaust were not indicated. Air samples collected in the remaining 63 percent of total time indicated concentrations of contaminants as listed in tables A-1 through A-3.

APPENDIX B.--NO. 1 MINE, SOUTHERN UTAH FUEL COMPANY, SALINA,
SEVIER COUNTY, UTAH

General Information

The No. 1 mine is located approximately 30 miles northeast of Salina, Utah, and the mine portals are at an elevation of about 7,300 feet. Coal was being mined by the room and pillar method. Permissible powder was used as the blasting agent for primary coal breakage. Coal was trammed from the face areas to a crusher-feeder by two Eimco load-haul-dump (LHD) vehicles. Three portals service the mine. Portal 1 contains a belt conveyor, portal 2 is for the entrance and egress of men and equipment and the route of the intake air. The mine ventilating fan is situated at portal 3.

Ventilation

Mine ventilation was induced by a Joy axialvane fan, model L-14, driven by a 75-hp General Electric motor. The total quantity of return air measured at the fan was found to be 86,600 cfm. Intake air entered portal 2 and was coursed past the crusher-feeder to the first entry. Intake air was directed to faces 1, 2, and 3 by line brattices. Faces 4 and 5 were ventilated directly from air going through the last open crosscut. Air volumes across the faces were measured and found to be near 30,000 cfm. The air volume across face 3 measured 7,200 cfm.

Diesel Equipment

Two diesel-powered, LHD vehicles were used underground to tram the coal. These units were Eimco wheel loaders, Model 915D-LHD, powered by Caterpillar Model 3160 V-8 engines equipped with a water scrubber on each cylinder bank.

Each unit consumed approximately 24 gallons of fuel during the 9-hour-day shift. A similar consumption was reported for the night shift. A duty cycle of 30 percent was calculated from the maximum fuel consumption rate of 6,116 lb/hr and the actual average consumption rate of 18.4 lb/hr.

Excessive engine smoking was not observed and there was an absence of eye irritation during the survey. Engine maintenance is handled by an outside firm.

Survey Methods

A number of underground locations where the diesel equipment was in use were visited. Representative gas samples were taken in these locations by means of a Draeger Multigas Detector with detector tubes for carbon monoxide, carbon dioxide, oxides of nitrogen, nitrogen dioxide, sulfur dioxide, and formaldehyde. Air samples utilizing evacuated bottles were also taken and analyzed for oxides of nitrogen, carbon monoxide, carbon dioxide, oxygen, and methane in the Bureau of Mines, Mount Hope, W. Va., gas laboratory. Results of detector tube samples and gas bottle samples are listed in table B-1.

TABLE B-1.--Detector tube and gas bottle sample results

Location	Time	Vacuum bottle (VB) or detector tube (DT)	Gas concentrations					Remarks
			CO, ppm	CO ₂ , per-cent	NO ₂ , ppm	NO _x , ppm	O ₂ , per-cent	
Main intake 100 ft inby No. 4 entry.	0800	VB	0	0.03	-	43	20.93	-
Main return North No. 5 entry 100 ft inby fan.	0800	VB	10	.09	-	0	20.80	-
Crusher-feeder.....	0845	DT	0	-	-	-	-	-
Crusher-feeder.....	0850	DT	-	<.02	-	-	-	-
No. 4 face.....	0851	DT	12	-	-	-	-	-
Main return No. 13 cross-cut.	0855	VB	-	-	-	10	-	-
Split return No. 13 cross-cut.	0855	VB	10	.09	-	-	20.81	-
No. 4 face.....	0900	DT	-	.06	-	4	-	-
No. 4 face.....	0902	DT	-	.06	-	2	-	-
No. 4 face.....	0905	DT	-	-	-	4	-	-
Return No. 4 face..	0910	VB	20	.10	-	-	20.77	-
Return No. 4 face..	0915	DT	-	-	<0.5	-	-	-
Return No. 4 face..	0920	DT	-	-	-	3	-	-
Return No. 4 face..	0925	DT	-	<.05	0	-	-	-
Face No. 4 entry right cross-cut.	0940	VB	10	.11	-	19	20.76	-
Face No. 4 entry right cross-cut.	0950	VB	20	.13	-	32	20.74	Shot fired 0945.
Face No. 4 entry right cross-cut.	0957	DT	-	.05	<.5	4	-	-
Face No. 4 entry right cross-cut.	1000	DT	70	-	.5	-	-	-
Crusher-feeder.....	1010	DT	-	-	<.5	-	-	-
Face No. 4 return..	1015	DT	10-25	.06	-	-	-	-
Crusher-feeder.....	1025	DT	tr	-	-	-	-	-
Crusher-feeder.....	1030	DT	-	-	-	<.5	-	-
Return face No. 4..	1040	VB	30	.12	-	-	20.75	-
Return face No. 4..	1045	DT	-	-	.5	4	-	-
Crusher-feeder.....	1040	DT	-	<.02	-	-	-	-
Crusher-feeder.....	1045	DT	-	-	.5	-	-	-
Return face No. 4..	1045	DT	-	-	<.5	4	-	-
Crusher-feeder.....	1100	DT	0	-	<.5	-	-	-
Crusher-feeder.....	1135	DT	-	-	-	3	-	-
Face No. 3 return..	1147	DT	-	-	.5	4	-	-
Crusher-feeder.....	1200	DT	0	-	<.5	-	-	-
Crusher-feeder.....	1220	DT	<5	-	-	2	-	-
Face No. 3 return..	1225	DT	25	.06	-	-	-	-
Crusher-feeder.....	1230	DT	-	<.02	-	-	-	-

TABLE B-1. - Detector tube and gas bottle samples results--Continued

Location	Time	Vacuum bottle (VB) or detector tube (DT)	Gas concentrations					Remarks
			CO, ppm	CO ₂ , percent	NO ₂ , ppm	NO _x , ppm	O ₂ , percent	
Return face No. 3..	1240	DT	25	.06	-	-	-	-
Return face No. 3..	1250	DT	-	-	0	2	-	-
Return face No. 3..	1255	DT	10	.05	-	-	-	No vehicles, barring down.
No. 4 entry.....	1300	VB				16.		
	1300	DT	-	.02	<.5	-	-	-
Return face No. 3..	1330	DT	10	.08	-	-	-	-
Return face No. 2..	1415	DT	-	-	0	4	-	-
Entry No. 3.....	1420	DT	5	-	0	-	-	-
Entry No. 3.....	1425	DT	-	.02	-	-	-	-
Entry No. 3.....	1430	DT	-	-	-	4	-	-
Main return inby No. 1 fan.	1430	VB	10	.08	-	-	20.85	-
Return face No. 2..	1440	DT	30	.08	-	-	-	-
Return face No. 2..	1448	DT	20	.05	-	-	-	-
Return face No. 2..	1450	DT	-	-	.5	5	-	-
Entry No. 3.....	1450	DT	20	-	-	-	-	-
Return face No. 2..	1500	-	-	-	0	2	-	-

To improve upon the deficiencies of spot sampling, each shuttle car was outfitted with a plastic bag into which ambient air was continuously pumped. When the bag was nearly full, the bag was removed from the vehicle and the concentrations of the gases of interest were determined by detector tubes and evacuated gas bottles. This technique provides an assessment of the operator's average exposure and permits the sample to be taken safely near the operator's breathing zone. The results of plastic bag collected samples are listed in table B-2.

TABLE B-2. - Results of plastic bag samples collected, December 14, 1972

Diesel unit	Sampling time	CO, ppm	CO ₂ , percent ¹	NO ₂ , ppm	NO _x , ppm	Remarks
1.....	0825-0855	9(0)	0.06(-14)	<0.5	3	Five trips tramming from No. 1 face to feeder.
2.....	0820-0855	8	.04	<.5	2	Do.
1.....	0940-1010	10(10)	.04(.08)	.5	3(4.7)	Tramming from face No. 5 to feeder.
2.....	1020-1050	10(10)	.04(.08)	<.5	3(0)	Two trips tramming from face No. 4 to feeder.

¹Indicates gas bottle results.

In an attempt to define the exposure to diesel soot, personal gravimetric samplers were placed on operators of diesel equipment. Some gross and

respirable samplers were set out in areas where diesel equipment operated. These samplers were operated in the conventional gravimetric dust sampling technique. A silver membrane filter having a mean pore size of $0.8 \mu\text{m}$ was used.

The analysis of a sample containing mineral dust, carbon, and a multitude of organic compounds requires a lengthy analytical technique. The concentrations of total airborne material and the benzene soluble fractions are listed in table B-3.

TABLE B-3. - Results of samples for respirable particulate matter,
December 13, 1972

Location	Particulate matter concentration, mg/m^3	Benzene soluble fraction, mg/m^3
Worn by operator of diesel unit 1.....	1.3	0
Worn by operator of diesel unit 2.....	1.3	0.7
Section 5 return.....	1.0	0

In addition to the evaluation of airborne contaminants, the exposure of the diesel equipment operators to noise was also checked. A noise dosimeter was placed on each activity. Each noise dosimeter gave a reading of 2.7 times greater than the allowable noise exposure level. The dosimeter placed on the operator of car 1 indicated an exposure of undetermined length to greater than 115 db.

APPENDIX C.--MARTIN COUNTY COAL CORPORATION
INEZ, MARTIN COUNTY, KY.

Mining Aspect

The Martin County Coal Corporation is located 8 miles south of route 40 near Pilgrim, Martin County, Ky. The property contains three coal seams.

Present mining consists of a drift mine in the Coalburg seam, a drift mine in the Stockton seam and a strip mine in both seams.

A 6-ft, 30-hp Jeffrey Airdyne fan provides 85,000 cfm of air. Inside, the air is directed to the face area with the belt isolated, where plastic checks and two plastic line curtains, one blowing and one exhausting, are installed in the working place. The working place had 6,500 cfm and the section return had 55,600 cfm of air. Methane readings taken in the working place in the section return and at the fan were 0.0 percent.

The relative humidity was 97.5 percent approximately 300 ft from the face at the feeder and 100 percent at the face at inside temperatures of 67° and 66.5° F.

General Background Information of Diesel Equipment

The following diesel-powered equipment was used at the Inez Mine:

1. Wagner, Model ST-5D(S) diesel loader with Caterpillar Model D333C-NA diesel engine (1).
2. Wagner, Model MTT-F20-18(S), 20-ton diesel trucks with Caterpillar Model D333C-NA diesel engine (9).
3. Wagner, Model MTT-F10-18(S), 10-ton diesel trucks with Caterpillar Model D330C-NA, diesel engine (3).

The Schedule 31 ventilation requirement for the Caterpillar Model D333C-NA diesel engine is 17,000 cfm.

Maintenance

The diesel machines are maintained conscientiously. All machines except the Model ST-5D(S) Scooptram are relatively new and no major overhaul has been needed.

Duty Cycles

From data during period August 15, 1972, through August 21, 1972, the Scooptram is working at a duty cycle of about 22 percent.

The 20-ton trucks had an average duty cycle of 40 percent. This is a medium load condition.

The engine is rated 150-brake horsepower at 2,200 rpm, and used 70.0 lb (about 10 gal) per hour of diesel fuel at full load (1,000-ft altitude). This value was used in all duty cycle calculations.

Underground Information

Diesel information obtained underground included the following:

1. Sampling of ambient air and of diluted diesel exhaust gas,
2. Light (reflected) intensities of types of lights on the diesel machines, and
3. Sound level readings of the machines.

Underground data are summarized in table C-1.

Noise Levels

Results were greater in some cases than the standard.

TABLE C-1. - Summary of underground data at Martin County Coal Company, Inez, Ky., August 24, 1972

Location in mine	Time, a.m.	Sampling				Noise levels, dba	Reflected light intensities, candles/ft ²	
		CO ₂ , per- cent	O ₂ , per- cent	CO, ppm	NO ₂ , ppm		Cap lamp	Kersey lights
No. 5 entry, dumping point 1,500 ft, block, right side of belt truck 1 dumping.	0930	0		-	-	95 (at conveyor belt)	0.1	4.0
Truck 2 dumping.....	0933	Trace		0	-	99 (operator's ears)	-	-
Truck 3 dumping.....	0935	-		-	-	-	-	8.0
Truck 4 dumping.....	0950	0.35		-	0	-	.1	-
No. 4 heading intake, face area.	1000	-		-	0	88 (general area)	-	-
No. 4 heading, intake, face area, continuous miner, operating.	1010	-		-	0	100	-	-
Face area No. 4 intake air, operator's cab, truck, ventilation 45,000 cfm.	1010	Trace .05		-	-	-	-	-
Face area behind line curtain.	1015	-		-	-	95	-	-
Bottle samples, face area behind line curtain.	1015	.09	20.88	10	-	-	-	-
		.15	20.82	10	-	-	-	-
6 ft outward from conditioner outlet, truck exhaust gas, No. 5 entry.	1020	.25		0	0	-	-	-

NOTE.--Observed in mine--barometer 29.08 in Hg;

relative humidity--100 percent at 67° F.

Sampling (except for vacuum bottles) was done with well known squeeze bulb-type detectors as follows: Monoxer (CO), MSA (NO₂), and Draeger (CO₂).

APPENDIX D.--BIG ISLAND TRONA MINE, STAUFFER CHEMICAL COMPANY
GREEN RIVER, SWEETWATER COUNTY, WYO.

General Information

A survey was conducted at the Stauffer Chemical Company's Big Island Trona Mine located near Green River, Wyo., on September 29, 1972. This mine was chosen because it is classified as a gassy mine. Schedule 31 applies to the operation of diesel equipment in gassy noncoal mines.

Survey Methods

A number of underground locations where diesel units were in use were visited. Representative gas samples were taken in each location by means of a Draeger Multigas Detector with detector tubes for carbon monoxide, carbon dioxide, oxides of nitrogen, sulfur dioxide and formaldehyde. Results of detector tube samples are listed in table D-1.

TABLE D-1. - Big Island Trona mine, detector tube results
September 29, 1972

	Location	Gas concentration indicated					
		NO+NO ₂ , ppm	NO ₂ , ppm	CO, ppm	CO ₂ , per- cent	SO ₂ , ppm	Formalde- hyde, ppm
Time:							
A.M.:							
1015	North panel shot firer, loading holes.	4	1.5-2	25	0.1	N.D.	N.D.
1045	Room 13, loading cars at face.	2.5	.75	12	.1	N.D.	N.D.
1105	Return air ~ 10 min after shot.	10	1.0	50	.07	TR.	N.D.
1125	Crusher-feeder.....	2	.75	<5	.04	TR.	N.D.
P.M.:							
1415	Room 23, panel entry 3 return air.	3.5	.5	11	.08	-	-
1435	Crusher-feeder.....	3.5	.5	12	.08	-	N.D.
1500	Face area by shot firer.	3.5	1.5	8	0.1	TR.	-
1555	Haulageway.....	1.5	.5	<10	.06	TR.	-
Threshold limit value.		25(NO)	5 ceiling	50	0.5	5	2C

N.D.--Not detected.

TR.--Trace, some color change on tube but not positive.

Although diesel smoke or soot is recognized as a diesel exhaust contaminant and its presence has been used as a relative indicator of proper engine adjustment, studies to quantitate diesel soot exposure to underground workers have not been undertaken.

Since the introduction of gravimetric respirable dust sampling, health personnel have observed the presence of diesel soot on personal sample filters. The presence of diesel soot in a sample complicates the assessment of a worker's exposure to mineral dust and conversely the presence of mineral dust complicates the assessment of a worker's exposure to diesel soot.

In an attempt to define the exposure to diesel soot, personal gravimetric samplers were placed on operators of diesel equipment. Some gross and respirable samplers were set out in areas where diesel equipment operated. These samplers were operated in the conventional gravimetric dust sampling technique. A silver membrane filter having a mean pore size of $0.8 \mu\text{m}$ was used.

The analysis of a sample containing mineral dust, carbon and a multitude of organic compounds requires lengthy analytical techniques. The concentrations of total airborne material and the benzene soluble fractions are listed in table D-2.

TABLE D-2. - Big Island Trona Mine, filter sample results
September 29, 1972

Sample No.	Sampling time	Location/operator sampled	Airborne concentration, mg/m^3		
			Total airborne material	Benzene soluble	Benzene insoluble
1-14	0902 a.m.-1609 p.m.	North panel, E. Jones shot firer.	1.2	0.14	1.06
1-15	0906 a.m.-1605 p.m.	North panel, L. Ortega loader operator.	1.3	0.14	1.16
1-16	0906 a.m.-1606 p.m.	North panel, D. Birch shuttle car operator.	1.3	0.14	1.16
1-17	0913 a.m.-1533 p.m.	North panel, L. Beauchamp shuttle car operator.	0.9	(¹)	-
1-22	0955 a.m.-1611 p.m.	Gross. Area sample. Crusher-feeder.	9.5	2.9	6.6
1-18	0955 a.m.-1611 p.m.	Respirable. Area sample. Crusher-feeder.	0.9	(¹)	-
1-23	1000 a.m.-1613 p.m.	Gross. Area sample. Return air.	16.7	2.1	14.6
1-19	1000 a.m.-1613 p.m.	Respirable. Area sample. Return air.	1.6	(¹)	-

¹A weight gain was obtained after washing with benzene instead of a weight loss.

VENTILATION AND DIESEL UNITS

The total mine ventilation was measured and found to be 280,000 cfm. Twenty-eight thousand cfm was measured at the northwest panel where the survey was made. Auxiliary fans placed in fresh air provided 3,000 cfm through ventilation tubing to each working face.

Diesel equipment operating at the north panel includes two shuttle buggies and a powder monkey. A welding truck and a greasing truck were also present, but operated sporadically. The diesel equipment operating during the survey is listed in table D-3.

TABLE D-3. - Summary of diesel-powered units used underground in North panel September 29, 1972, during survey

No. units	Bureau of Mines approval No.	Name, manufacturer, and model	Engine	Brake hp	Air required, cfm
2	31-1-7	Torkar, National Mine Service, 60-66ED	-	-	16,000
1	31-D18	Powder Monkey, Sien Equip. Co., 531	-	-	12,000
1	24-30	Greaser, Getman, KD2	Deutz F2L812	22	2,000
1	24-39	Welder, Getman, D70	Deutz F2L712	11	1,000

APPENDIX E.--WHITE PINE MINE, WHITE PINE COPPER COMPANY
WHITE PINE, ONTONAGO COUNTY, MICH.

On December 5 through December 7, 1972, a survey was conducted of ventilation and diesel exhaust products found underground in one section of the White Pine Mine.

Description of the Survey

The area selected for the diesel exhaust products survey at the White Pine mine was one which would most nearly resemble that found in an underground coal mine. The area selected was in the southeast section of the mine consisting of Units 15, 41, and 37-1/2. Unit 41 was surveyed in detail.

Air volumes were measured throughout the area along with wet and dry bulb temperatures, airflow patterns, fan locations, brattice and door locations, equipment travel routes, sampling stations, and grades of haulageways and are recorded on the attached map. The number of pieces of each type of diesel-powered equipment along with approval numbers, fuel rates, horsepower rating, trips and total tonnage, and ventilation requirements are listed in Data Sheets 1 and 2.

DATA SHEET NO. 1.--Diesel Equipment Data by Units--Operating
in Area Sampled (December 6, 1972)

Unit 15 (in unit and through pocket area)

3 - Wagner, ScoopTrams: ST-5-DH; Approval No. 24-108; rated at 70 pounds of fuel/hr; 174 hp; 20,000 cfm ventilation.

1 - Wagner, Endloader, Scoopmobile: MS-2; Approval No. 24-67; rated at 52 pounds of fuel/hr; 130 hp; 15,000 cfm ventilation.

3 - Personnel Carriers: (for 1/2-hour - beginning and end of shift). (GMC Detroit Diesel No. 453); No approval number; 82 hp; no ventilation rate data.

6 - Jeeps (Three Types): (for total of 2 hours during shift)--

(1) Approval No. 24-79 (Willys-Jeep - Engine No. 4.192); rated at 60-hp; 22.6 pounds fuel/hr; 9,400 cfm ventilation.

(2) No approval (Willys-Jeep; Perkins Engine No. 4.107 and No. 4.108); 38-hp; no other data.

(3) No approval (CR-100 or Ensign Jeep) (Ford DD172 Engine) 59-hp; no other data.

2 - Wagner, Ore Trucks - (Road Rock): Wagner, MTT-23 and MTT-425 - (for 3 hours during shift); Approval No. 24-55; rated at 107 pounds of fuel/hr; 266 hp; 30,000 cfm ventilation.

1 - Welder (Utility Truck): (at Pocket for 2-1/2 hours); approval No. 24-125; (Mercedes-Benz Engine); rated at 18.3 pounds fuel/hr; 35 hp; 7,800 cfm ventilation.

1 - Grader: (for 3 hours during shift); (Cat. Grader 120); (Cat. D-333A) approval No. 24/D22; rated at 57 pounds of fuel/hr; 115 hp; 14,100 cfm ventilation.

1 - Explosives Truck: (for 1/2-hour during shift); approval No. 24-53 (same as utility vehicle); rated at 33 pounds of fuel/hr; 70 hp; 7,270 cfm ventilation.

1 - Powder Platform: (for 3 hours during shift); approval No. 24-67; rated at 52 pounds of fuel/hr; 130 hp; 15,000 cfm ventilation

1 - Wagner, Utility Vehicle: (for 1 hour during shift); approval No. 24-53; rated at 33 pounds of fuel/hr; 70 hp; 7,270 cfm ventilation.

Unit 41 (Miscellaneous vehicles not included under unit 15)

1 - Truck, Wagner: MTT-23; approval No. 24-55; rated at 107 pounds fuel/hr; 266 hp; 30,000 cfm ventilation.

1 - ScoopTram: ST-5A; approval No. 24-108; rated at 68 pounds fuel/hr; 154 hp; 20,000 cfm ventilation.

1 - Powder Platform: (for 1 hour during shift); approval No. 24-67; rated at 52 pounds of fuel/hr; 130 hp; 15,000 cfm ventilation.

2 - Jeeps (Two Types): (for 1 hour during shift); approval No. 24-79 (Willys-Jeep; Eng. No. 4.192) rated at 60 hp; 22.6 pounds fuel/hr; 9,400 cfm ventilation.

Unit 37-1/2 (Miscellaneous vehicles not included under unit 15)

2 - Trucks, Wagner: MTT-23 and MTT-425; approval No. 24-55; rated at 107 pounds of fuel/hr; 266 hp; 30,000 cfm ventilation.

1 - ScoopTram: ST-5-DH; approval No. 24-108; rated at 70 pounds of fuel/hr; 174 hp; 20,000 cfm ventilation.

1 - Powder Platform: (For 1 hour during shift); approval No. 24-67; rated at 52 pounds of fuel/hr; 130 hp; 15,000 cfm ventilation.

2 - Jeeps (Two Types): (for 1 hour during shift); approval No. 24-79 (Willys-Jeep; Engine No. 4.192) rated at 60 hp; 22.6 pounds of fuel/hr; 9,400 cfm ventilation.

DATA SHEET NO. 2.--Diesel Equipment Data by Units--Operating in Area Sampled (December 7, 1972)

Unit 15 (in unit and through pocket area)

3 - Wagner, ScoopTrams: ST-5-DH; approval No. 24-108; rated at 70 pounds fuel/hr; 174 hp; 20,000 cfm ventilation (one ST-5-DH operated to 1 p.m.).

- 1 - Wagner, Endloader, Scoopmobile: MS-2; approval No. 24-67, rated at 52 pounds of fuel/hr; 130 hp; 15,000 cfm ventilation.
- 3 - Personnel Carrier: (for 1/2-hour-beginning and end of shift). (GMC, Detroit Diesel No. 453); no approval No.; 82 hp; no ventilation data.
- 1 - Welder (Utility Truck): (for 1/2-hour during shift); approval No. 24-125) (Mercedes-Benz Engine); rated at 18.3 pounds of fuel/hr; 35 hp; 7,800 cfm ventilation.
- 1 - Utility Vehicle (Wagner): (for 1/2-hour during shift); approval No. 24-53; rated at 33 pounds of fuel/hr; 79 hp; 7,270 cfm ventilation.
- 4 - Jeeps (Two Types): (for total of 2 hours during shift)--
 (1) Approval No. 24-79 (Willys-Jeep Engine No. 4.192) rated at 22.6 pounds fuel/hr; 60 hp; 9,400 cfm ventilation.
 (2) No approval (Willys-Jeep Perkins Engine No. 4.107 and No. 4.108); 38 hp; no other data.
 (3) No approval (CR-100 or Ensign Jeep); (Ford DD172 Engine); 59 hp; no other data.
- 1 - Powder Platform: (for 2 hours during shift); approval No. 24-67; rated at 52 pounds fuel/hr; 130 hp; 15,000 cfm ventilation.
- 1 - Explosives Truck: (for 1/2-hour during shift); approval No. 24-53 (same as utility vehicle); rated at 33 pounds of fuel/hr; 70 hp; 7,270 cfm ventilation

Unit 41 (Miscellaneous vehicles not included under unit 15)

- 2 - Trucks, Wagner: MTT-23; approval No. 24-55; rated at 107 pounds fuel/hr; 266 hp; 30,000 cfm ventilation.
- 1 - Endloader: MS-2; approval No. 24-67; rated at 52 pounds fuel/hr; 130 hp; 15,000 cfm ventilation.
- 1 - ScoopTram: ST-5A (down 1-1/2 hours); approval No. 24-108; rated at 68 pounds of fuel/hr; 154 hp; 20,000 cfm ventilation.
- 1 - Powder Platform: (for 1 hour during shift); approval No. 24-67; rated at 52 pounds of fuel/hr; 130 hp; 15,000 cfm ventilation.
- 2 - Jeeps (Two Types): (for 1 hour during shift); approval No. 24-79; (Willys-Jeep Engine No. 4.192) rated at 60 hp; 22.6 pounds of fuel/hr; 9,400 cfm ventilation.

Unit 37-1/2 (Miscellaneous vehicles not included under unit 15)

- 1 - Truck, Wagner: MTT-23; approval No. 24-55; rated at 107 pounds of fuel/hr; 266 hp; 30,000 cfm ventilation.
- 1 - ScoopTram: ST-5-DH; approval No. 24-108; rated at 70 pounds of fuel/hr; 174 hp; 20,000 cfm ventilation.

1 - Powder Platform: (for 1 hour during shift); approval No. 24-67; rated at 52 pounds of fuel/hr; 130 hp; 15,000 cfm ventilation.

2 - Jeeps (Two Types): (for 1 hour during shift; approval No. 24-79; (Willys-Jeep Engine No. 4.192); rated at 60 hp; 22.6 pounds of fuel/hr; 9,400 cfm ventilation.

Fuel consumption of the production vehicles operating in the survey was measured and data on horsepower, maximum fuel rates, fuel used, actual fuel rates, percent of maximum fuel rate, maximum ventilation, and ventilation required based on actual fuel consumption are included in tables E-1 and E-2. (Data on diesel fuel specifications was used in calculations for these tables.) Sampling for CO, CO₂, NO₂, NO + NO₂, CH₄, SO₂, H₂S, O₂, and aldehydes was done by the survey team during two entire workshifts using the following sampling methods:

1. Draeger Indicator Tubes, Draeger Multigas Detector.
2. MSA Indicator Tubes, MSA Gas Detector.
3. Kitagawa Indicator Tubes, Kitagawa Gas Detector.
4. Evacuated bottle samples, which were analyzed in the Bureau of Mines Gas Laboratory at Mt. Hope, W. Va.
5. Wet sampling method using midget impinger flasks with fitted bubblers. (Aldehydes were determined by an iodometric titration and aldehyde concentrations are reported as formaldehyde.)

A variation in sampling procedures was utilized to secure a more efficient method for studies of diesel exhaust. This consisted of using a pump to collect gases in a plastic bag and subsequent sampling for the various gases contained in the bag.

Gas sampling results are summarized, by hourly periods, in table E-3. The evacuated gas bottle sample analyses are shown in table E-4.

In addition to the gas sampling phase of this study, samples for particulate matter were taken during December 6 and 7, 1972, by the wearing of gravimetric personal samplers by employees representing all occupations in Unit 41. The particulate matter samples were collected on silver membrane filters and represented a full-shift exposure of representative occupations.

A total of 12 gravimetric personal samples were collected over the 2-day survey period and the results are recorded in table E-5.

Discussion of Results

Examination of the information in table E-3 shows the following:

1. All oxygen concentrations were within the recommended limit except a sample taken at the exhaust of a Wagner ScoopTram in a heading where loading was in progress.

2. All carbon monoxide samples taken during the survey were below the TLV.

3. All carbon dioxide samples taken during the survey were below the TLV except a sample taken at the exhaust of a Wagner ScoopTram in a heading where loading was in progress.

4. All nitrogen dioxide samples taken during the survey were below the TLV.

5. The nitric oxide + nitrogen dioxide concentrations measured with indicator tubes and by the wet sampling method were below the TLV. Those samples taken with vacuum bottles and evaluated at the gas laboratory for NO_x indicated an erratic evaluation when compared to the indicator tube and wet sampling method. Those latter values were included in the averages. Sample locations of NO_x vacuum bottles which exceeded the TLV included the following:

(1) Bottle No. N-7073 taken when loading trucks.

(2) Bottle No. N-7089 taken near loading operation.

(3) Bottle No. N-7086 taken when loading trucks.

(4) Bottle No. N-7085 taken in the haulageway where haulage trucks operated.

(5) Bottle No. N-5417 taken at the pocket where tracks and scoops were dumping.

NOTE: The variation in results of these samples raise doubts concerning the reliability of the vacuum bottle sample results.

6. The only indication of methane found during the 2 days of the survey was bottle sample No. N-6569 taken at the pocket (0.01 percent) and bottle sample No. N-5892 taken in the haulageway (0.02 percent).

7. The only indication of sulfur dioxide detected during the survey was 1.0 ppm on December 7 and 1.0 ppm on December 6. Both were well below the TLV.

8. No indication of hydrogen sulfide was found in the area surveyed.

9. Aldehydes were detected by the indicator tubes and the wet sampling method in the following locations:

- (1) In SE-108/NE-85 heading when loading trucks.
- (2) In SE-113 haulageway.
- (3) In SE-112 haulageway.
- (4) Sample of truck exhaust, 3 feet from exhaust of Wagner ScoopTram.
- (5) In SE-113 haulageway.
- (6) In SE-112 haulageway.
- (7) In SE-113 haulageway.

The only sample which exceeded the TLV was that taken at the ScoopTram exhaust and was included in the average.

Peaks attained during the sampling are listed in the table under "Maximum" column in table E-3. These higher gas concentrations appear principally in the headings, during loading operations, and for samples taken 3 feet from the exhaust of vehicles.

Table E-5 lists the concentrations of airborne particulate matter collected during each of the full shifts operated in Unit 41.

The benzene insoluble fraction includes the carbon particles from soot and other insoluble particles such as rock dust. Organic materials such as unburned hydrocarbons and drill oil are found in the benzene soluble fraction of the samples.

On December 6 when haulage to the pocket and stockpile areas was being accomplished with one shuttle car, but with more diesel equipment operating in intake areas, the following percentage of benzene-insoluble fraction was found:

Workman	Percent	Remarks
Pocketman.....	67.5	Welder operating in the area.
ScoopTram operator.....	0.0	Moving about headings.
Shuttle car operator.....	50.0	Hauling.
Bolter operator.....	50.0	More dust expected.
Drill-jumbo operator.....	20.3	More oil mist expected.
ScoopTram operator.....	0.0	Moving about headings.

On December 7 when all ore was hauled to the pocket with two shuttle cars--a normal operation--the following percentage of benzene-insoluble fraction was found:

Workman	Percent	Remarks
Pocketman.....	0.0	Generally on fresh-air side.
Shuttle car operator.....	75.5	Hauling.
ScoopTram operator.....	50.0	At workfaces all shift.
Shuttle car operator.....	83.7	Hauling.
Bolter operator.....	62.4	More dust expected.
Drill-jumbo operator.....	0.0	More oil mist expected.

Recommendations

Recommendations to achieve the lowest levels of diesel contaminants are general and involve adequate ventilation and maintaining the diesel engine in good repair. Diesel exhaust contaminants can be minimized by adhering to the following recommendations:

1. Fresh air at the rate specified by the Federal Bureau of Mines diesel unit approval plate should be supplied to all sections where diesels operate.
2. Exhaust scrubbers should be adequately maintained and serviced.
3. Engine intake air filters should not be allowed to reach a resistance of greater than 10 inches of water.
4. Engines should be adjusted to factory specifications and not readjusted.
5. Raw exhaust should be checked frequently by maintenance personnel to confirm the adequacy of engine adjustment.

TABLE E-1. - Fuel consumption data of vehicles in area sampled, December 6, 1972, using 6.9 lb/gal
(Specific gravity of 40° A.P.I. = 0.8251)

	horse- power	Maximum rated fuel rate, lb/hr	Measured fuel used, gal	Actual fuel rate, lb/hr	Per- cent of maxi- mum rate	Maximum ventil- ation required, cfm	Ventil- ation required based on percent of maxi- mum, cfm	Remarks
UNIT 15: OPERATION TIME 6.5 HOURS								
05028 (Wagner, Scooptram: ST-5DH).....	174	70	24	25.5	36.4	20,000	7,300	Operated 6-1/2 hours.
05034 (Wagner, Scooptram: ST-5DH).....	174	70	No record	25.5	36.4	20,000	7,300	Operated 4-1/2 hours.
04454 (Wagner, Endloader: MS-2).....	130	52	17.2	18.3	35.2	15,000	5,300	Operated 6-1/2 hours.
05024 (Wagner, Scooptram: ST-5DH) (Not assigned)...	174	70	No record	25.5	36.4	20,000	7,300	Do.
UNIT 15: VEHICLES PAST THE POCKET								
3 Personnel Carriers: (Total 1/2 hour in day).....	82	No data	No record	-	-	No data	-	Operated 1/2 hour- total.
6 Jeeps: (Total of 2 hours in the day).....	60	22.6	No record	-	-	9,400	-	Operated 2 hours- total.
2 Wagner Ore Trucks: (Haul Road Rock) MTT-23 and MTT-425 (Operating total of 3 hours in the day).	266	107	Estimated 22.6	23.9	22.3	30,000	6,700	Operated 3 hours- total (hauling 8 loads).
1 Welder (Utility Truck) (Total 2-1/2 hours in day).	35	18.3	No record	-	-	7,800	-	Operated 2-1/2 hours.
1 Grader: (For 3 hours in the day).....	115	57	No record	-	-	14,100	-	Operated 3 hours.
1 Explosives Truck: (Total 1/2 hour in day).....	70	33	No record	-	-	7,270	-	Operated 1/2-hour.
1 Powder Platform: (Total 3 hours in day). (Use same data as for Wagner Endloader).	130	52	No record	18.3	35.2	15,000	5,300	Operated 3 hours.
1 Wagner Utility Vehicle: (Total 1 hour in day)....	70	33	No record	-	-	7,270	-	Operated 1 hour.
UNIT 41: OPERATION TIME 6.5 HOURS								
00097 (Wagner, Ore Truck: MTT-23).....	266	107	20.2	21.4	20.0	30,000	6,000	Operated 6-1/2 hours.
05001 (Wagner, Scooptram: ST-5A).....	154	68	13.8	14.6	21.5	20,000	4,300	Do.
1 Powder Platform: (Total 1 hour in day).....	130	52	No record	18.3	35.2	15,000	5,300	Operated 1 hour.
2 Jeeps: (Total of 1 hour in day) Total production 19 loads (285 tons).	60	22.6	No record	-	-	9,400	-	Operated 1 hour (total).
UNIT 37-1/2: OPERATION TIME 6.5 HOURS								
00087 (Wagner, Ore Truck: MTT-23).....	266	107	29	30.8	28.8	30,000	8,600	Operated 6-1/2 hours.
00088 (Wagner, Ore Truck: MTT-425).....	266	107	18.5	19.6	18.4	30,000	5,500	Do.
05035 (Wagner, Scooptram: ST-5DH).....	174	70	33.1	35.1	50.2	20,000	10,000	Do.
1 Powder Platform: (Total of 1 hour in day).....	130	52	No record	18.3	35.2	15,000	5,300	Operated 1 hour (total).
2 Jeeps: (Total of 1 hour in day).....	60	22.6	No record	-	-	9,400	-	Do.

TABLE F-2. - Fuel consumption data of vehicles in area sampled, December 7, 1972, using 6.9 lb/gal
(Specific gravity of 40° A.P.I. = 0.8251)

	Horse- power	Maximum rated fuel rate, lb/hr	Measured fuel used, gal	Actual fuel rate, lb/hr	Per- cent of maxi- mum rate	Maximum ventil- ation required, cfm	Ventil- tion required based on percent of maxi- mum, cfm	Remarks
UNIT 15: OPERATION TIME 6.5 HOURS								
05028 (Wagner, ScoopTram: ST-5DH).....	174	70	24.4	25.9	37.0	20,000	7,400	Operated 6-1/2 hours.
05034 (Wagner, ScoopTram: ST-5DH) (To shop early).	174	70	23.8	25.3	36.1	20,000	7,200	Do.
05030 (Wagner, ScoopTram: ST-5DH) (To shop early; 3-hour operation).	174	70	Estimated	25.6	36.5	20,000	7,300	Operated 3 hours.
04454 (Wagner, Endloader: MS-2).....	130	52	24.1	17.5	33.7	15,000	5,100	Operated 6-1/2 hours.
UNIT 15: VEHICLES PAST THE POCKET								
3 Personnel Carriers: (Total 1/2 hour in day).....	82	No data	No record	-	-	No data	-	Operated 1/2 hour (total).
1 Welder: (Utility Truck) (Total 1/2-hour in day).	35	18.3	No record	-	-	7,800	-	Operated 1/2 hour.
1 Wagner Utility Vehicle: (Total 1/2-hour in day).	70	33	No record	-	-	7,270	-	Do.
4 Jeeps: (Total of 2 hours in the day).....	60	22.6	No record	-	-	9,400	-	Operated 2 hours (total).
1 Powder Platform: (Total 2 hours in day). Use same data as for Wagner Endloader.	130	52	Estimated	17.5	33.7	15,000	5,100	Operated 2 hours.
1 Explosives Truck: (Total of 1/2-hour in day).....	70	33	No record	-	-	7,270	-	Operated 1/2 hour.
UNIT 41: OPERATION TIME 6.5 HOURS								
00068 (Wagner, Ore Truck: MTT-23).....	266	107	21.6	22.9	21.4	30,000	6,400	Operated 6-1/2 hours.
00097 (Wagner, Ore Truck: MTT-425).....	266	107	20.0	21.2	19.8	30,000	6,000	Do.
05001 (Wagner, ScoopTram: ST-5DH).....	174	70	15.5	16.5	23.5	20,000	4,700	Operated 5 hours.
04006 (Wagner, Endloader: MS-2).....	130	52	15.2	16.1	31.0	15,000	4,700	Operated 6-1/2 hours.
1 Powder Platform: (Total 1 hour in day) Use same data as for Wagner Endloader.	130	52	No record	17.5	33.7	15,000	5,100	Operated 1 hour.
2 Jeeps: (Total of 1 hour in day). Total produc- tion 36 loads (540 tons).	60	22.6	No record	-	-	9,400	-	Operated 1 hour (total).
UNIT 37-1/2: OPERATION TIME 6.5 HOURS								
00088 (Wagner, Ore Truck: MTT-23).....	266	107	27.6	29.3	27.4	30,000	8,200	Operated 6-1/2 hours.
05051 (Wagner, ScoopTram: ST-5DH).....	174	70	15.2	16.1	23.1	20,000	4,600	Do.
1 Powder Platform: (Total 1 hour in day) use same data as for Wagner Endloader.	130	52	No record	17.5	33.7	15,000	5,100	Operated 1 hour.
2 Jeeps: (Total of 1 hour in day).....	60	22.6	No record	-	-	9,400	-	Operated 1 hour (total).

TABLE E-3. - Summary of gas analyses recorded at the White Pine mine

Date	Location	Volume of air, measured or estimated	Volume required	O ₂ , pct	CO	CO ₂ , pct	N ₂ , ppm	NO _x , ppm	CH ₄	SO ₂ , ppm	IL ₂ S, ppm	Aldehydes, ppm	Remarks
AVERAGE READINGS													
Dec. 6	Travel: Shaft to unit 41 or return	Various	Various	-	9 ppm	0.15	0.5	3.2	ppm	-	-	-	Draeger indicator tube samples.
Dec. 7	do.....	Various	Various	-	6.5 ppm	0.095	0.75	1.7	ppm	-	-	-	Do.
Dec. 6	Intake to the three units (unit 15 first)	239,825 cfm	-	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken.
Dec. 7	do.....	239,825 cfm	-	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	Do.
Dec. 6	Return air from the three units.	230,000 cfm	-	20.77	0.0 pct	0.17	-	23.0	0.0 pct	-	-	-	Vacuum bottles N-7093 and N-6497.
Dec. 7	do.....	230,000 cfm	-	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken.
Dec. 6	Intake air for unit 41 (including pocket and stockpile).	8,000 cfm to 162,000 cfm	-	20.82	0.002 pct	0.12	0.57	11.0	0.0 pct	-	-	-	Draeger indicator tubes and vacuum bottles.
Dec. 7	do.....	8,000 cfm to 162,000 cfm	-	20.82	0.002 pct	0.11	0.42	8.7	0.003 pct	0	-	-	Do.
Dec. 6	Haulageways in unit 41.	30,000 cfm to 70,000 cfm	-	-	4.4 ppm	0.1015	0.452	5.49	-	-	-	-	Draeger indicator tubes and bubbler samples.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	-	4.4 ppm	0.12	0.44	5.63	-	-	-	-	Do.
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	20.55	0.001 pct	0.31	0.49	7.0	0.0 pct	0.20	0	-	MSA indicator tubes, Kitagawa indicator tubes, and vacuum bottles.
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	20.76	0.001 pct	0.11	0.27	32	0.0 pct	-	0	-	Do.
Dec. 6	Return air from unit 41.	140,800 cfm	-	20.73	0.0 pct	0.21	-	15	0.0 pct	-	-	-	Vacuum bottle samples (only).
Dec. 7	do.....	140,800 cfm	-	20.78	0.0 pct	0.15	-	16	0.0 pct	-	-	-	Do.
MINIMUM READINGS													
Dec. 6	Travel: Shaft to unit 41 or return.	Various	Various	-	9 ppm	0.1	Trace	1.0	-	-	-	-	Draeger indicator tube samples.
Dec. 7	do.....	Various	Various	-	5 ppm	0.09	0.5	1.0	-	-	-	-	Do.
Dec. 6	Intake to the three units (unit 15 first).	239,825 cfm	-	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken.
Dec. 7	do.....	239,825 cfm	-	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	Do.
Dec. 6	Return air from the three units.	230,000 cfm	-	20.77	0.0 pct	0.17	-	23	0	-	-	-	Vacuum bottles N-7093 and N-6497.
Dec. 7	do.....	230,000 cfm	-	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken	None taken.
Dec. 6	Intake air for unit 41 (including pocket and stockpile).	8,000 cfm to 162,000 cfm	-	20.69	0.0 pct	0.07	0.5	0	0	-	-	-	Draeger indicator tubes and vacuum bottles.
Dec. 7	do.....	8,000 cfm to 162,000 cfm	-	20.80	0.0 pct	0.07	0.10	0	0	0	-	-	Do.
Dec. 6	Haulageways in unit 41.	30,000 cfm to 70,000 cfm	-	-	9 ppm	0.001	0.03	0.05	-	-	-	-	Draeger indicator tubes and bubbler samples.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	-	3 ppm	0.11	0.03	0.09	-	-	-	-	Do.
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	19.66	0.0 pct	0.10	0.3	0	0	0	0	-	MSA indicator tubes, Kitagawa indicator tubes, and vacuum bottles.
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	20.67	0.0 pct	0.001	0.1	16	0	-	0	-	Do.
Dec. 6	Return air from unit 41.	140,800 cfm	-	20.73	0.0 pct	0.21	-	15	0	-	-	-	Vacuum bottle samples (only).
Dec. 7	do.....	140,800 cfm	-	20.78	0.0 pct	0.15	-	16	0	-	-	-	Do.

TABLE E-3. - Summary of gas analyses recorded at the White Pine mine--Continued

Date	Location	Volume of air, measured or estimated	Volume required	O ₂ , pct	CO	CO ₂ , pct	NO ₂ , ppm	NO _x , ppm	CH ₄	SO ₂ , ppm	IL ₂ S, ppm	Aldehydes, ppm	Remarks
MAXIMUM READINGS													
Dec. 6	Travel: Shaft to unit 41 or return.	Various	Various	-	9 ppm	<0.15	0.5	5.0	-	-	-	-	Drueger indicator tube samples.
Dec. 7	do.....	Various	Various	-	<8 ppm	.10	<1.0	2.5	-	-	-	-	Do.
Dec. 6	Intake to the three units (unit 15 first).	239,825 cfm	-	taken	taken	taken	taken	taken	None	None	None	None	None taken
Dec. 7	do.....	239,825 cfm	-	taken	taken	taken	taken	taken	None	None	None	None	Do.
Dec. 6	Return air from the three units.	230,000 cfm	-	20.77	0.0 pct	.17	-	23	0.0 pct	-	-	-	Vacuum bottles N-7433 and N-497.
Dec. 7	do.....	230,000 cfm	-	None	None	None	None	None	None	None	None	None	None taken
Dec. 6	Intake air for unit 41 (including pocket and stockpile).	8,000 cfm to 162,000 cfm	-	20.87	0.001 pct	.26	1.0	.46	.0 pct	-	-	-	Drueger indicator tubes and vacuum bottles.
Dec. 7	do.....	8,000 cfm to 162,000 cfm	-	20.85	0.0009 pct	.18	.7	32	.02 pct	0	-	-	Do.
Dec. 6	Haulageways in unit 41.	30,000 cfm to 70,000 cfm	-	-	<10 ppm	.18	<1.0	10	-	-	-	1.01	Drueger indicator tubes and bubbler samples.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	-	6 ppm	.15	.7	10	-	-	-	1.51	Do.
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	20.87	0.0015 pct	1.15	1.0	29	.0 pct	.1.0	0	5-10	MSA indicator tubes Kitagawa indicator tubes and vacuum bottles.
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	20.80	0.0015 pct	.24	.4	55	.0 pct	-	0	1.0	Do.
Dec. 6	Return air from unit 41.	140,800 cfm	-	20.73	0.0 pct	.21	-	15	.0 pct	-	-	-	Vacuum bottle samples (only).
Dec. 7	do.....	140,800 cfm	-	20.78	0.0 pct	.15	-	16	.0 pct	-	-	-	Do.
7:00 TO 8:00 A.M.													
Dec. 6	Travel: Shaft to unit 41 or return.	Various	Various	-	9 ppm estimated	<0.15	0.5	1.5	-	-	-	-	Drueger indicator tube samples.
Dec. 7	do.....	Various	Various	-	<8 ppm	.09	<.5	3.0	-	-	-	-	7:11 to 7:27 a.m.
Dec. 6	Intake to the three units (unit 15 first).	239,825 cfm	-	None	None	.10	<.5	1.5	-	-	-	-	Drueger indicator tube samples.
Dec. 7	do.....	239,825 cfm	-	taken	taken	taken	taken	taken	None	None	None	None	7:19 to 7:37 a.m.
Dec. 6	Return air from the three units.	230,000 cfm	-	taken	taken	taken	taken	taken	None	None	None	None	None taken.
Dec. 7	do.....	230,000 cfm	-	taken	taken	taken	taken	taken	None	None	None	None	Do.
Dec. 6	Intake air for unit 41 (including pocket and stockpile)	8,000 cfm to 162,000 cfm	-	20.85	0.0 pct	.08	-	-	0.0 pct	-	-	-	Do.
Dec. 7	do.....	8,000 cfm to 162,000 cfm	-	None	None	None	None	None	None	None	None	None	Vacuum bottle sample D-5012.
Dec. 6	Haulageways in unit 41.	30,000 cfm to 70,000 cfm	-	taken	taken	taken	taken	taken	None	None	None	None	None taken.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	None	None	None	None	None	None	None	None	None	Do.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	taken	taken	taken	taken	taken	None	None	None	None	Do.

TABLE E-3. - Summary of gas analyses recorded at the White Pine mine--Continued

Date	Location	Volume of air, measured or estimated	O ₂ , pct	CO	CO ₂ , pct	NO ₂ , ppm	NO _x , ppm	CH ₄	SO ₂ , ppm	H ₂ S, ppm	Aldehydes, ppm	Remarks
9:00 TO 10:00 A.M.--Continued												
Dec. 6	Haulageways in unit 41.	30,000 cfm to 70,000 cfm	-	<10 ppm	0.0001	<1.0	6	-	-	-	-	Draeger indicator tubes and bubbler sample.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	3 ppm	.13	.6	6	-	-	-	-	Do.
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	-	5 ppm	.12	.5	-	-	-	-	-
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	-	.03	0.09	0	-	-	-	-	-
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	20.61	0.001 pct	1.15	-	0.0 pct	-	-	-	Vacuum bottles, N-7077, N-6053, and N-6052.
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	20.79	0.001 pct	.14	-	0.0 pct	-	-	-	Vacuum bottles N-7088, N-6493, N-7089, and N-6576.
Dec. 6	Return air from unit 41.	140,800 cfm	-	20.77	0.001 pct	.16	-	0.0 pct	-	-	-	-
Dec. 7	do.....	140,800 cfm	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 6	Travel: Shaft to unit 41 or return.	Various	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 7	do.....	Various	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 6	Intake to the three units (unit 15 first).	239,825 cfm	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 7	do.....	239,825 cfm	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 6	Return air from the three units.	230,000 cfm	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 7	do.....	230,000 cfm	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 6	Intake air for unit 41 (including pocket and stockpile)	8,000 cfm to 162,000 cfm	-	20.83	0.0 pct	.11	18	0.0 pct	-	-	-	Vacuum bottles D-5015 and N-7075.
Dec. 7	do.....	8,000 cfm to 162,000 cfm	-	-	5 ppm	.1	.7	-	-	-	-	-
Dec. 6	Haulageways in unit 41	30,000 cfm to 70,000 cfm	-	20.85	0.0 pct	.10	-	0.0 pct	-	-	-	Draeger indicator tubes and vacuum bottles N-5893, N-5892, N-2072, and N-5998.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	20.80	0.0 pct	.15	-	0.07 pct	-	-	-	-
Dec. 6	Haulageways in unit 41	30,000 cfm to 70,000 cfm	-	-	<10 ppm	.001	.6	0.0 pct	-	-	-	Draeger indicator tubes and bubbler sample.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	-	5 ppm	.12	.5	-	-	-	-	Do.
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	-	4 ppm	.11	.7	-	-	-	-	-
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	-	-	.04	.8	-	-	-	-	-
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	NAP	10 ppm	.10	.5	-	1.0	-	-	NSA and Kitagawa tubes, and vacuum bottles N-7091 and N-6143.
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	NAP	10 ppm	-	.5	-	NAP	NAP	NAP	-
Dec. 6	Return air from unit 41.	140,800 cfm	-	20.73	0.001 pct	.22	0	0.0 pct	NAP	NAP	NAP	-
Dec. 7	do.....	140,800 cfm	-	20.77	0.001 pct	.15	53	0.0 pct	-	-	-	Vacuum bottles N-6577 and N-7086.
Dec. 6	Travel: Shaft to unit 41 or return.	Various	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 7	do.....	Various	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 6	Intake to the three units (unit 15 first).	239,825 cfm	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
Dec. 7	do.....	239,825 cfm	-	NAP	NAP	NAP	NAP	NAP	NAP	NAP	NAP	-
NAP--Not applicable.												

11:00 A.M. TO 12:00 NOON

TABLE E-3. - Summary of gas analyses recorded at the White Pine mine--Continued

Date	Location	Volume of air, measured or estimated	Volume required	O ₂ , pct	CO	CO ₂ , pct	NO ₂ , ppm	NO _x , ppm	CH ₄	SO ₂ , ppm	H ₂ S, ppm	Aldehydes, ppm	Remarks
Dec. 6	Traverse Shaft to unit 41 or return.	Various	Various	-	9 ppm, estimated	0.10	Trace	5	-	-	-	-	Draeger indicator tubes (2:07 to 2:17 p.m.).
Dec. 7	do.....	Various	Various	-	Nap	Nap	Nap	4	-	-	-	-	-
Dec. 6	Intake to the three units (unit 15 first).	239,825 cfm	-	Nap	Nap	Nap	Nap	3	Nap	Nap	Nap	Nap	-
Dec. 7	do.....	239,825 cfm	-	Nap	Nap	Nap	Nap	Nap	Nap	Nap	Nap	Nap	-
Dec. 6	Return air from the three units.	230,000 cfm	-	Nap	Nap	Nap	Nap	Nap	Nap	Nap	Nap	Nap	-
Dec. 7	do.....	230,000 cfm	-	Nap	Nap	Nap	Nap	Nap	Nap	Nap	Nap	Nap	-
Dec. 6	Intake air for unit 41 (including pocket and stockpile).	8,000 cfm to 162,000 cfm	-	Nap	2 ppm	.15	1.0	6	-	-	-	-	Draeger indicator tubes and vacuum bottles D-5006 and D-5013.
Dec. 7	do.....	8,000 cfm to 162,000 cfm	-	Nap	0.0 pct	.14	-	-	0.0 pct	-	-	-	Draeger indicator tubes and vacuum bottles N-6040, N-5409, T-6039, and N-6569.
Dec. 6	Haulageways in unit 41.	30,000 cfm to 70,000 cfm	-	-	0.001 pct	.07	.5	9	-	-	-	-	Draeger indicator tubes.
Dec. 7	do.....	30,000 cfm to 70,000 cfm	-	-	0.0 pct	.10	-	16	0.0 pct	-	-	-	Do.
Dec. 6	Loading in unit 41 at mining headings.	5,000 cfm to 62,000 cfm	-	-	<10 ppm	.13	.7	7	0.01 pct	-	-	-	Draeger indicator tubes and bubbler samples.
Dec. 7	do.....	5,000 cfm to 62,000 cfm	-	-	<10 ppm	.18	.5	8	-	-	-	-	MSA indicator tubes
Dec. 6	Return air from unit 41.	140,800 cfm	-	-	5 ppm	.12	.6	9	-	-	-	-	MSA indicator tubes and vacuum bottles N-5695, and N-6566.
Dec. 7	do.....	140,800 cfm	-	-	-	.21	.1	15	0.0 pct	-	-	-	Vacuum bottles N-6495, and N-5698.
Dec. 6	Return air from unit 41.	140,800 cfm	-	-	10 ppm	-	.3	-	-	-	-	-	Vacuum bottles N-6495, and N-5698.
Dec. 7	do.....	140,800 cfm	-	-	10 ppm	.15	.1	18	0.0 pct	-	-	-	MSA indicator tubes and vacuum bottles N-5695, and N-6566.
Dec. 6	Return air from unit 41.	140,800 cfm	-	-	0.0 pct	.21	-	15	0.0 pct	-	-	-	Vacuum bottles N-6495, and N-5698.
Dec. 7	do.....	140,800 cfm	-	-	0.0 pct	-	-	-	-	-	-	-	Vacuum bottles N-6495, and N-5698.

Nap -Not applicable.

TABLE E-4. - Analyses of air samples collected December 6 and 7, 1972,
White Pine mine, White Pine Copper Co.

Bottle number	Location in mine	Carbon dioxide, pct	Oxygen, pct	Methane, pct	Carbon monoxide, pct	NO _x , ¹ ppm	Cubic feet air per minute
N6496	Intake air U-41.....	0.20	20.76	0.00	0.000	-	40,000
N6497	Main return inby fan at bulkhead.....	.17	20.77	.00	.000	-	230,000
N6495	Unit return U-41 cross NE79-SE110.....	.21	20.73	.00	.000	-	140,800
N6575	Return U-41 station No. 8.....	.15	20.78	.00	.000	-	140,800
N6494	Intake U-41.....	.12	20.80	.00	.000	-	40,000
N6493	Intake U-41 station No. 4.....	.14	20.79	.00	.001	-	40,000
N6144	Face 111SE.....	.26	20.69	.00	.001	-	5,000
N6143	Crosscut 111SE/87SE.....	.22	20.73	.00	.001	-	5,000
N6052	Exhaust emission from tram unit 05-001...	1.15	19.66	.00	.001	-	5,000
N6053	Face of heading 115SE.....	.32	20.61	.00	.000	-	5,000
N6574	Face of heading 111SE.....	.28	20.67	.00	.000	-	5,000
D5011	Unit 41 lunchroom area 81NE-115SE.....	.07	20.86	.00	.000	-	35,000
N6565	110/87.....	.24	20.67	.00	.000	-	50,000
N6576	Crosscut outby gross air face 108/85.....	.16	20.77	.00	.001	-	50,000
N6577	Face 110/87.....	.15	20.77	.00	.001	-	62,000
N6566	110/87.....	.15	20.80	.00	.000	-	62,000
D5012	U15 pocket.....	.08	20.85	.00	.000	-	8,000
D5004	U15 pocket.....	.09	20.85	.00	.000	-	8,000
D5003	Haulageway SE113, NE72.....	.15	20.78	.00	.001	-	70,000
D5006	Haulageway SE113, NE72.....	.14	20.80	.00	.000	-	70,000
D5015	U15 pocket.....	.11	20.83	.00	.000	-	8,000
D5018	U15 pocket.....	.08	20.86	.00	.000	-	8,000
D5021	U15 stockpile SE113A, NE70.....	.07	20.86	.00	.000	-	8,000
D5005	U15 pocket.....	.08	20.84	.00	.001	-	8,000
D5013	U15 pocket.....	.07	20.87	.00	.001	-	8,000
N6596	U15 stockpile.....	.10	20.84	.00	.000	-	8,000
N6597	U15 pocket No. 38.....	.15	20.80	.00	.000	-	8,000
N6598	U15 pocket No. 38.....	.07	20.85	.00	.000	-	8,000
N6039	Intake SP-U15.....	.10	20.84	.00	.000	-	8,000
N2072	U15 pocket No. 38.....	.15	20.81	.00	.000	-	8,000
N5893	Pocket No. 38.....	.10	20.80	.00	.000	-	8,000
N6569	U15 pocket No. 38.....	.10	20.84	.01	.000	-	8,000
N5892	113A haulageway.....	.10	20.77	.02	.000	-	70,000
N6040	U15 pocket No. 38.....	.10	20.85	.00	.000	-	8,000

N5698	Unit return crosscut NE79-SE110.....	-	-	-	-	-	15	140,800
N7082	Intake air U-41.....	-	-	-	-	-	None	40,456
N7093	Main return inby fan at bulkhead.....	-	-	-	-	-	23	230,000
N5697	Return U-41 station No. 8.....	-	-	-	-	-	16	140,800
N7079	Intake U-41 station No. 4.....	-	-	-	-	-	9	40,000
N7088	Intake U-41 station No. 4.....	-	-	-	-	-	21	40,000
N7073	Face of heading 111SE.....	-	-	-	-	-	29	5,000
N7090	Face of heading 111SE.....	-	-	-	-	-	None	5,000
N7091	Crosscut 111SE/87NE.....	-	-	-	-	-	None	5,000
N7077	Face heading 115SE.....	-	-	-	-	-	None	5,000
N7076	Exhaust of tram 05-001 at face idling....	-	-	-	-	-	None	5,000
N5695	110/87.....	-	-	-	-	-	18	62,000
N5696	110/87.....	-	-	-	-	-	19	50,000
N7089	Crosscut outby face 108/85.....	-	-	-	-	-	55	50,000
N7086	Face 110/87.....	-	-	-	-	-	53	62,000
N7075	U15 pocket.....	-	-	-	-	-	18	8,000
N7085	Haulage way SE113, NE72.....	-	-	-	-	-	27	70,000
N7087	U15 pocket.....	-	-	-	-	-	13	8,000
N7078	U15 stockpile SE113A, NE70.....	-	-	-	-	-	None	8,000
N5417	U15 pocket No. 38.....	-	-	-	-	-	46	8,000
N5409	U15 stockpile.....	-	-	-	-	-	16	8,000
N5998	U15 pocket No. 38.....	-	-	-	-	-	None	8,000
N5999	U15 pocket No. 38.....	-	-	-	-	-	32	8,000

The percentage of nitrogen can be determined by subtracting the sum of the reported values from 100.00.

TABLE F-5. - Showing results of gravimetric personal samplers (using silver membrane filters)
Unit 41, White Pine mine, White Pine, Mich., shift exposure samples

Sample No.	Sampling time	Date	Location and job classification	Total airborne particulate matter (mg/N ³)	Benzene insoluble fraction (mg/M ³)	Benzene soluble fraction (mg/N ³)	Remarks
3-7	0701 to 1422	Dec. 6, 1972	Pocketman--at feed section; belt.	0.37	0.25	0.12	Station No. 10.
3-10	0711 to 1423	..do.....	Scoop operator--at work areas in unit 41.	.25	.00	.25	Loading cars and cleanup, stations No. 14 and 15.
3-14	0712 to 1421	..do.....	Shuttle car operator--at work areas; unit 41.	.26	.13	.13	Hauls ore to pocket, stations No. 14, 15, and 10.
3-18	0714 to 1421	..do.....	Bolter operator--at work areas; unit 41.	.52	.26	.26	Stations No. 14, and 15.
3-19	0715 to 1423	..do.....	Drill jumbo operator--at work areas; unit 41.	.64	.13	.51	Operates also as blaster, stations No. 15, -. ¹
3-20	0717 to 1423	..do.....	Scooptram operator--at work areas; unit 41.	.26	.00	.26	Loading cars and hauling to pocket, stations No. 14, 15, and 10.
3-22	0651 to 1420	Dec. 7, 1972	Pocketman--at feed section belt.	.12	.00	.12	Station No. 10.
3-24	0703 to 1420	..do.....	Shuttle car operator--at work areas; unit 41.	.49	.37	.12	Hauls ore to pocket, stations No. 16, 17, and 10.
3-26	0704 to 1420	..do.....	Scooptram operator--at work areas; unit 41.	.24	.12	.12	Loading cars and cleanup, stations No. 16, 17, and 10.
3-27	0706 to 1420	..do.....	Shuttle car operator--at work areas; unit 41.	.74	.62	.12	Loading cars and cleanup, stations No. 16 and 17, -. ¹
3-29	0707 to 1420	..do.....	Bolter operator--at work areas; unit 41.	1.73	1.08	.65	Stations No. 14, -. ¹
3-30	0707 to 1420	..do.....	Drill jumbo operator--at work areas; unit 41.	.62	.00	.62	Operates also as blaster, stations No. 15, -. ¹

¹Workplaces other than established sampling station.

NOTE.--Values corrected to standard pressure and temperature (25° C or 77° F from 71°) (30.55 inches barometric pressure). No TLV is included since the exact content of the benzene soluble fraction was not determined

APPENDIX F.--MAGMONT MINE, COMINCO AMERICAN, INC.,
BIXBY, IRON COUNTY, MO.

General Information

A survey was made at the Cominco American, Inc. Magmont mine located near Bixby, Mo., on October 3, 1972. This lead mine was selected because it has 35 diesel units underground and a high and uniform production rate. The mine is classified as nongassy.

Survey Methods

A number of underground locations where diesel units were in use were visited. Representative gas samples were taken in each location by means of a Draeger Multigas Detector with detector tubes for carbon monoxide, carbon dioxide, oxides of nitrogen, sulfur dioxide, and formaldehyde. Results of detector tube samples are listed in table F-1.

TABLE F-1. - Magmont mine detector tube results, October 3, 1972

Time	Location	Gas concentration indicated					
		NO+NO ₂ , ppm	NO ₂ , ppm	CO, ppm	CO ₂ , ppm by volume	SO ₂ , ppm	Formal- dehyde, ppm
1130	Dump point.....	3	0.5	5	0.08	Trace	N.D.
1407	A level, 493 by driller.....	2.5	-	10	.1	-	-
1415	Enroute from 493 area to No. 1 vent shaft.	-	-	10	.1	-	-
1428	No. 1 vent shaft.....	5	.75	10	.15	-	-
1450	534E, B level by driller....	6	1.0	8	.1	-	-
1500	539 area.....	6	.5	6	.12	-	-
	Threshold limit value (TLV).	25 (NO)	¹ 5	50	.5	5	2C

N.D.--Not determined.

¹Ceiling.

Although diesel smoke or soot is recognized as a diesel exhaust contaminant and its presence has been used as a relative indicator of proper engine adjustment, studies to quantitate diesel soot exposure to underground workers have not been undertaken. Since the introduction of gravimetric respirable dust sampling, health personnel have observed the presence of diesel soot on personal sample filters. The presence of diesel soot in a sample complicates the assessment of a worker's exposure to mineral dust and, conversely, the presence of mineral dust complicates the assessment of a worker's exposure to diesel soot.

In an attempt to define the exposure to diesel soot, personal gravimetric samplers were placed on operators of diesel equipment. Some gross respirable samplers were set out in areas where diesel equipment operated. These samplers were operated in the conventional gravimetric dust sampling technique. A silver membrane filter having a mean pore size of 0.8 μ m was used.

The analysis of a sample containing mineral dust, carbon, and a multitude of organic compounds requires lengthy analytical techniques. The concentrations of total airborne material and the benzene soluble fractions are listed in table F-2.

TABLE F-2. - Magmont mine filter sample results, October 3, 1972

Sample number	Sampling time	Location/operator sampled	Airborne concentration, mg/M ³		
			Total airborne material	Benzene soluble	Benzene insoluble
2-1	0925 a.m. to 1539 p.m.	Ken Mowray, foreman, travel all.	0.7	0.2	0.6
2-2	0929 a.m. to 1525 p.m.	Mike Conway, operator of diesel utility truck, service jumbo's.	2.2	1.5	.7
2-3	0940 a.m. to 1400 p.m.	Paul Hutson, operator of jumbo (start "A" level off 493).	7.7	7.7	.0
2-4	0946 a.m. to 1535 p.m.	Johnny Downs, operator of 110 truck (mucking out of 524E).	2.6	1.0	1.6
2-5	0950 a.m. to 1535 p.m.	Homer Bays, operator of 627 truck (start mucking 524E).	3.0	.7	2.4
2-6	0957 a.m. to 1425 p.m.	No. 1 vent shaft (size selected).	.9	.9	.0
2-7	1020 a.m. to 1450 p.m.	Joe Miner, operator of Gardner-Denver pneumatic drill, "B" level 534E.	7.1	5.9	1.2
2-8	1036 a.m. to 1505 p.m.	Bonnie Crocker, operator of front-end loader (until midshift in 534E).	12.9	2.4	10.5
1-21	1059 a.m. to 1534 p.m.	Ore dump, "B" level (size selected).	4.0	1.4	2.6
RAC	1057 a.m. to 1315 p.m.	Ore dump, "B" level.....	3.9	.5	3.4

Threshold Limit Value for Benzene Soluble Fraction of the Coal Tar Pitch Volatiles, American Conference of Governmental Industrial Hygienists, 1971.

Ventilation and Diesel Units

The total mine ventilation rate was measured and found to be 155,000 cfm. The ventilation was split, giving 100,000 cfm through the main haulageway with 55,000 cfm directed into the southerly mining areas. Ninety-five thousand cfm passed over the dump point where considerable diesel traffic occurred. Ventilation velocities at the working areas were minimal.

Of the 35 pieces of diesel equipment underground, 13 were observed in operation. The diesel units operating during the survey are listed in table F-3. All units except the drill jumbos operated continuously through the shift.

TABLE F-3. - Listing of diesel units used underground during survey, October 3, 1972,
Magmont mine, Cominco American, Inc., Bixby, Iron County, Mo.

Unit No.	Equipment manufacturer	Type of equipment and model No.	Engine		Exhaust gas conditioner	Certification or approval No.	Air required (estimated or actual)
			Manufacturer	Cylinders			
1	Caterpillar....	Loader 980.....	Caterpillar..	6	(¹) Catalytic..	-	-
2	Caterpillar....	Truck, 627.....	Caterpillar..	6	(²) Catalytic..	-	-
3	Caterpillar....	Truck, 627.....	Caterpillar..	6	(²) Catalytic..	-	-
4	Joy.....	Transloader TL-110	GMC 671.....	-	228 Water bath.	-	22,800
5	Joy.....	Transloader TL-70.	Deutz F8L714.	6	174 Water bath.	-	17,400
6	Joy.....	Transloader TL-70.	Deutz F8L714.	6	174 Water bath.	-	17,400
7	Warner & Swasey	Gradall scaler....	GMC 453.....	-	130 Water bath.	-	13,000
8	International..	Service truck.....	GMC 453.....	-	130 Water bath.	-	13,000
9	Gardner-Denver.	Drill jumbo.....	Deutz F4L812.	4	52 Water bath.	24-84	4,800
10	Gardner-Denver.	Drill jumbo.....	Deutz F4L812.	4	52 Water bath.	24-84	4,800
11	Gardner-Denver.	Drill jumbo.....	Deutz F4L812.	4	52 Water bath.	24-84	4,800
12	Gardner-Denver.	Drill jumbo.....	Deutz F4L812.	4	52 Water bath.	24-84	4,800
13	Getman.....	Personnel carrier.	Deutz F4L812.	4	52 Water bath.	24-84	5,200

¹Engine derated, Caterpillar dealer indicates 275 hp.

²Engine derated, Caterpillar dealer indicates 240 hp.

APPENDIX G.--BUNKER HILL MINE, BUNKER HILL MINING COMPANY,
KELLOGG, SHOSHONE COUNTY, IDAHO

General Information

On February 29 through March 2, 1972, a survey of diesel exhaust products found underground at the Bunker Hill mine was conducted. The purpose of the survey was to determine whether or not diesel equipment operating in underground workings presents a significant health hazard to diesel equipment operators and other workers.

Description of the Survey

A number of underground locations in the Bunker Hill mine where diesel equipment was in use were visited. The type and number of pieces of equipment in use, and the ventilation rates were noted and are listed in table G-1. Representative gas samples were taken in each location by means of a Draeger Multigas Detector for carbon monoxide, carbon dioxide, and nitrogen dioxide. Evacuated bottle samples were also taken and analyzed by gas chromatography. The results of gas bottle samples and indicator tube samples are listed in tables G-2 and G-3.

TABLE G-1. - Ventilation and diesel equipment inventory

Location	Diesel equipment in use ¹	Ventilation to work area, cfm	Federal Bureau of Mines recommended ventilation rate, cfm
Russell tunnel.....	Eimco 912, LHD 78 hp; Young buggy, 39-hp.	9,000 - 11,000	10,720
5 level, Stanley Newgard	Eimco 912, LHD 78-hp.	7,100	7,800
20 level Francis.....	do.....	10,000	Do.
22 level Francis.....	do.....	7,560	Do.

¹Load haul-dump (LHD).

TABLE G-2. - Gas bottle analysis

Sample time	Location and operation	Gas concentration (pct)				
		CO ₂	O ₂	CH ₄	N ₂	CO
0907	Russell tunnel, loading point.....	0.26	20.8	0	78.9	<0.003
0920	Russell tunnel, near powder magazine, hauling.	.19	20.8	0	79.0	<.003
1030	5 level, Stanley-Newgard hauling.....	.63	20.4	0	78.9	<.003
1803	22 Francis down ramp loading, hauling, dumping.	.40	20.5	0	79.1	.003
1815	do.....	.31	20.7	0	79.0	<.003
(approximate)						
1815	do.....	.40	20.6	0	79.0	<.003
(approximate)						
1845	20 Francis up ramp.....	.30	20.7	0	79.0	0
Threshold	-	.5	-	-	-	.005
limit values						

TABLE G-3. - Gas analysis by Draeger multigas indicator

Location and operation	Gas concentration (pct)		
	CO ₂	NO _x	CO
Russell tunnel, loading point.....	0.1	0.00005	Not detectable
5 level Stanley-Newgard.....	.6 - 0.7	.00002	0.001 - 0.0015
22 level Francis down ramp.....	.5	0	.0007
Threshold limit value.....	.5	.0005	.005
Russell tunnel, sampled at exhaust outlet on idling Eimco 912.	3.5	.0012	.01

In addition to gas samples, samples for aldehydes and particulate matter were taken during the swing shift in the Francis area. The particulate matter samples were collected on preweighed membrane filters. Two employees, one a driller and the other a load-haul-dump operator, each wore a filter sampler to collect a breathing zone sample. A filter sampler was also collected in the haulageway for a general area sample.

The filter samples were reweighed after sampling to give a total weight of airborne material collected. Benzene was later passed through the filters to extract the benzene soluble fraction of the collected soot. The filters were then reweighed after drying to determine the amount of benzene insoluble material remaining on the filter. The material on the filter after the benzene wash represents the carbon fraction of the soot.

Results of the filter samples collected in the Francis up and down ramp areas on the swing shift are listed in table G-4.

TABLE G-4. - Filter sample results

Sampling time (p.m.)	Location/operator	Total airborne particulate matter (mg/M ³)	Benzene insoluble fraction (mg/M ³)	Benzene soluble fraction (mg/M ³)
1800-1850	On rib, 22 down Francis area.....	8.7	4.2	4.5
1720-2000	LHD operator ¹	2.8	2.1	.7
1730-1855	Driller.....	4.6	3.9	.7
1830-1845	On rib, 20 up Francis area.....	1.6	1.1	.5

¹Load-haul-dump (LHD).

Aldehyde air samples were taken in a midjet impinger flask outfitted with a fritted bubbler. Aldehyde concentrations were determined as formaldehyde by an iodometric titration. Aldehyde sample results are listed in table G-5.

TABLE G-5. - Aldehyde sample results

Location	Aldehyde concentration (as formaldehyde), ppm
22 down Francis area.....	1.3
20 up Francis area.....	1.1
20 up Francis area.....	3.3
Threshold limit value.....	5.0

Discussion of Results

Examination of tables G-2 and G-3 shows that carbon monoxide and nitrogen dioxide were below the threshold limit values (TLV's) at all locations sampled. Oxygen concentrations likewise were acceptable, being quite close to the normal value of 20.95 percent. Carbon dioxide gas concentrations were also below the TLV except in the Stanley Newgard 5 level area. The gas bottle sample and the Draeger tube agree well with each other.

Table G-4 lists the concentrations of airborne particulate matter collected on the swing shift in the Francis area. The sample collected on the load-haul-dump operator was found to be 2.8 mg/M³ of air, and that of the driller 4.6 mg/M³ of air. Both samples were obtained over a short period of time, and they are representative of only a fraction of the men's work shift. In the case of the driller, his sample was observed to contain a considerable, but undetermined, amount of rock dust.

The amounts of benzene soluble and insoluble materials were determined. The benzene insoluble fraction includes the carbon particles from the soot and other insoluble particles such as rock dust. Organic materials such as unburned hydrocarbons and drill oil are found in the benzene soluble fraction of the sample. From 15 to 55 percent of the sample weights were attributable to benzene soluble materials.

The aldehyde sample results listed in table G-5 were below the TLV of 5 ppm for formaldehyde.

DR. KERR: Our next speaker is Dr. Jorgensen who comes from Sweden. We are indeed very fortunate to have been able to have Dr. Jorgensen with us. In preparing for this meeting, there was a tremendous literature search conducted, and we found that Dr. Jorgensen was one of the very few people who had written anything on the medical aspects of the diesel in underground mines.

Dr. Jorgensen graduated from medical school at the University of Copenhagen in 1949, and in 1959 did post-graduate studies at the London School of Hygiene, where he received both a degree in public health and a diploma in industrial hygiene. He has been associated with Loussavaara--Kiirunavaara AB (L.K.A.B.) in Sweden since 1961, and has been the medical director of this iron ore mining company since 1963. He has a number of publications to his credit on various phases of mining. In 1971, the Swedish Mining Association published a monograph of his entitled "Medical Viewpoints on Air Pollution in Mines," with particular reference to diesels.

MEDICAL VIEWPOINTS ON AIR POLLUTION IN MINES CAUSED
BY DIESEL EXHAUST GAS

by

Harold S. Jorgensen¹

INTRODUCTION

Our knowledge of the effects of diesel exhaust gas on the organism derives in principle from the two following sources: (1) Animal experiments and (2) studies of populations working in places where diesel driven vehicles are used.

In animal experiments we can study the single effect of the different components in diesel exhaust gas. It is also possible to study the effect of a combination of factors. In this way, for example, significant changes in the respiratory mucosa of mice have been found following exposure to 0.5 ppm nitrogen dioxide (NO₂) for 6 hours daily for 3 months as found by Ehrlich (1968), Henry (1969), and Blair (1970). The principal effects are as follows:

1. Emphysema, whereby the interstitial walls between lung bubbles are destroyed and the lung function deteriorates (1).²
2. Decreased ability of the mucous membrane to clean itself (4).
3. Decreased resistance to bacterial infection. The animals normal survival time was not influenced by these changes (2).

The weakness with animal experiments is quite obvious. We cannot with total assurance transfer the results directly to man since there are even variations in the way different animal species react. The results obtained from animal experiments can therefore only serve as a guide and the final judgment should be based on the results from studies on human populations as well.

The main air pollution factor in the general environment is sulphur dioxide (SO₂) which, in principle, has an effect on the respiratory mucosa similar to the effect of NO₂. Both are highly irritating gases, although SO₂ mainly attacks the upper part of the respiratory system and NO₂ mainly the lower part.

Experiences from the air pollution in the general environment is also valuable when considering the effects of diesel exhaust gas. Population studies in this field have established that it is predominantly persons already suffering from respiratory disease, and especially older people,

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²Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

who are affected. They develop increased respiratory symptoms when exposed to air pollution.

That smoking is of importance has been demonstrated also in this connection. It is likely that there is an interaction between smoking and air pollution. In the highly air-polluted St. Louis area there were four times as many people with severe emphysema of the lungs found among smokers, as compared to the frequency of emphysema among smokers in the principally non-air-polluted Winnipeg area. Between the nonsmokers there was no such difference.

The Problem

Air pollution in mines is generally caused by dust and blasting gases. The frequency of chronic bronchitis under such circumstances has previously been studied on many occasions.

The effect of air pollution caused by diesel exhaust gas has been studied in the iron ore mine in Kiruna, Sweden, which is probably the largest underground iron ore mine in the world. In 1958 and 1959, vehicles with diesel motors were introduced for transportation underground. Today approximately 75 trucks and 35 frontloaders are continuously in use underground. To these are added a certain number of smaller vehicles, also with diesel engines but with minor pollution effects. The daily consumption of diesel oil underground at present is about 7 to 8 metric tons.

The Environment

Attempts to keep air pollution at a low level are based primarily on a powerful and extensive ventilation system. The air is pressed down into the mine through 26 fresh air shafts. The engine function of all vehicles is checked at least once per month, and light diesel oil (S <0.1 percent) is used.

Water scrubbers and/or catalytic afterburners are used on all trucks and frontloaders.

The tendency is to further increase the amount of frontloaders at the expense of electric driven Joy loaders which, until now, have been used extensively.

The air pollution is sampled at regular intervals according to a predetermined plan, with fixed test points all over the mine. The concentration of nitrogen dioxide, nitrogen dioxide plus nitrogen oxide, carbon monoxide, and aldehydes is determined at regular intervals. A total of approximately 20,000 samples is taken per year. The concentration of 3.4 ppm benzopyrene is at present not examined regularly because of the great technical difficulties involved.

All the results are computerized and analysed according to the epidemiologic triad, that is, time, place, and substance. The type of work operation and climatic conditions are also taken into consideration. Frequency

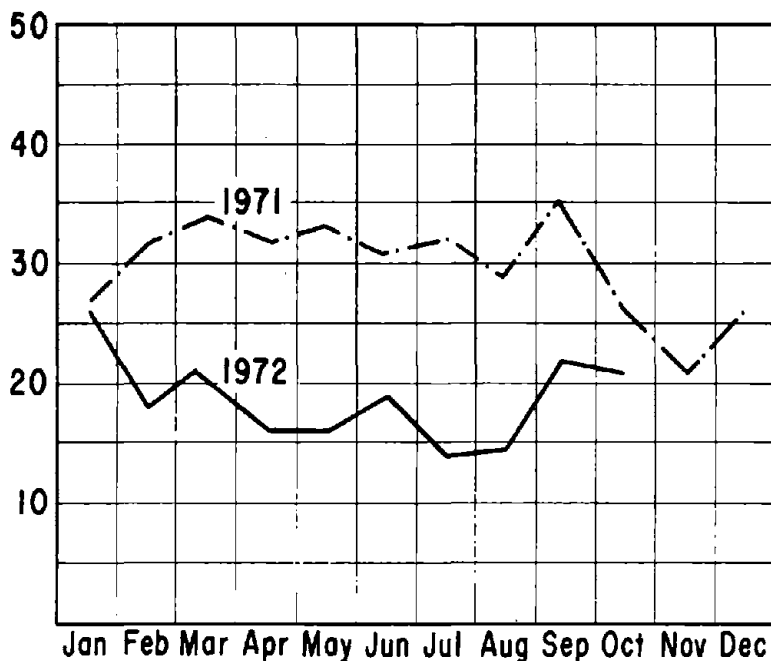
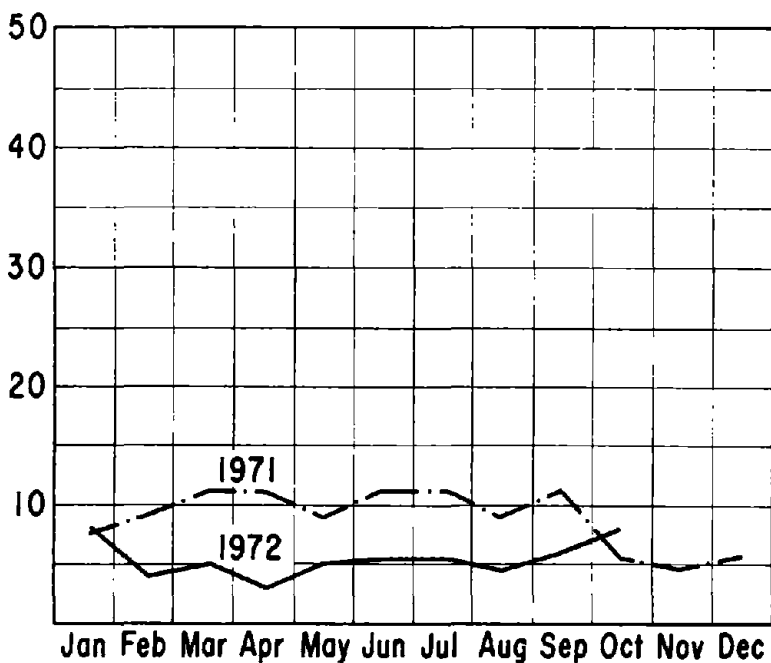
NO₂ in percent over 3 ppmNO₂ in percent over 5 ppm

FIGURE 1. - Concentrations of NO₂ in Kiirunavaara underground mine. A. NO₂ in percent over 3 ppm; B. NO₂ in percent over 5 ppm.

distributions of the excess of certain limits (for example, NO₂ in amounts greater than 3 and 5 ppm) and average values over 1-month periods are calculated routinely.

Although we now have a complete coverage of the air pollution situation in our mine, this has only been the case for a couple of years.

It may possibly be deduced from the present situation that the concentration of NO₂ was previously on the order of 2.5 to 3 ppm (median value). The limit, 3 ppm of NO₂, has probably been exceeded to the extent of 30 to 35 percent of all measurements, and the limit 5 ppm NO₂ to the extent of 10 to 15 percent (fig. 1). The level of SO₂ was not normally measured but, when it was, it proved to be very low. Aldehydes were nearly always low or unrecordable, although on isolated occasions, high levels of aldehydes were measured (10 to 20 ppm).

The concentration of carbon monoxide was determined in the blood before and after work. The concentration before work underground was within the limits of 0.5 to 1.5 ppm CO and after work between 1.5 to 2.5 ppm. These levels are of no significance to health.

The dust situation in the mine was well under control before 1966-67 when the natural ventilation deteriorated because of

increased depth. In 1968 gravimetric measurements showed that the concentration of particles (total dust) was between 3 and 9 mg/m² (20 to 30 percent particles <5 μ). Quartz concentration was 6 to 7 percent of the fraction below 5 μ . In connection with loading, the dust concentration has increased since 1968, and it is now up to between 10 to 15 mg/m³.

The Material

In order to determine whether the present exposure to gas and dust in the mine could have had any effect on the respiratory system, a group of 240 mine workers were selected at random for a study of the lung function and the frequency of respiratory symptoms. Half were underground workers and the other half, which served as a control group, were surface workers who had never worked underground. In both cases the groups were subdivided with regard to age and smoking habits (table 1).

TABLE 1. - Composition of the chosen groups with respect to average age, standard error, and range

Group	Smokers		Nonsmokers		Total
	Younger	Older	Younger	Older	
Underground workers:					
Average age.....	30	30	30	30	
Standard error.....	30.9 $\pm$ 0.90	53.6 $\pm$ 0.52	30.6 $\pm$ 0.55	53.8 $\pm$ 0.82	120
Range.....	(22 to 39 years)	(51 to 60 years)	(26 to 35 years)	(46 to 60 years)	
Surface workers:					
Average age.....	30	30	30	30	
Standard error.....	29.9 $\pm$ 0.69	55.6 $\pm$ 0.58	30.4 $\pm$ 0.65	55.6 $\pm$ 0.60	120
Range.....	(23 to 35 years)	(51 to 60 years)	(20 to 35 years)	(47 to 60 years)	
Total.....	60	60	60	60	240

The Method

An interview carried out by the mine nurse was designed to reveal symptoms from the respiratory system. The British Medical Research Council's bronchitis questionnaire was used, slightly modified to suit Swedish mining conditions.

Lung function studies were carried out by spirometry. These tests were performed immediately before starting work and again at the end of the shift. Half of the subjects carried out their first spirometry before starting work while the other half did so after finishing work. This was in order to exclude any training effect. Subsequent analysis showed that no such effect occurred. The investigations after work were carried out 1/2 to 1 hour following the end of the shift, when the subject had come up from the mine. Subjects with silicosis and those who had had tuberculosis were excluded from the investigation.

The Result

To start with, the subjects were asked about their opinion of the air in the mine. The result is shown in figures 2 through 4. The majority of smokers in the underground group said that the air was bad while the majority of non-smokers thought that it was good. Among the surface workers there was no such difference. The majority of the younger underground workers thought that the air was good, whereas the majority of older underground workers were of the opposite opinion. Among the surface workers there was no such difference. Pressure over the chest and difficulty in getting air were much more common problems among smokers than among the nonsmokers in the underground group, but there was no such difference among the surface group.

After this the subjects were interviewed according to the bronchitis questionnaire (British Medical Research Council). Figure 5 shows the incidence of "productive cough lasting at least 3 weeks during several winters." This was much more common among the smokers than among nonsmokers. The difference was significant among underground workers but not among surface workers. The incidence among nonsmokers working underground was the same as among smokers in the surface group; 7 to 8 percent. Among underground workers who smoked, the frequency was 28 percent, which suggests synergism and not merely summation of effects.

When analysed according to age there is no significant difference between the younger and the older group in the frequency of respiratory symptoms among underground workers (fig. 6). Figure 7 shows frequency of respiratory tract infection in relation to the number of years underground. From these illustrations it is apparent that symptoms are much more common among smokers after only 5 years of underground employment, which is the shortest period in our study.

Nonproductive chronic bronchitis occurs only among smokers. Whereas the effect of smoking is significant, there is no significant difference in the frequency of chronic bronchitis between the underground and the surface

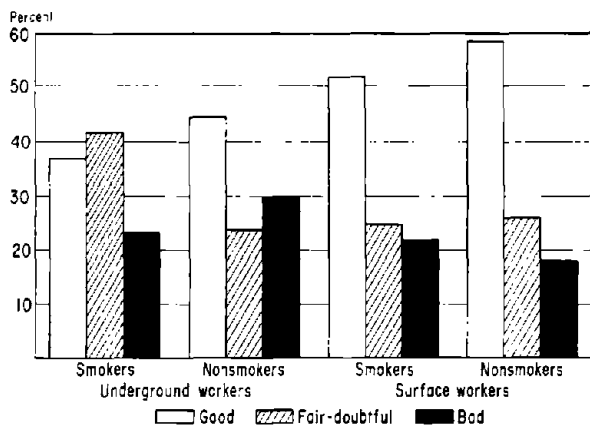


FIGURE 2. - Employees' impressions of air quality, smokers versus non-smokers.

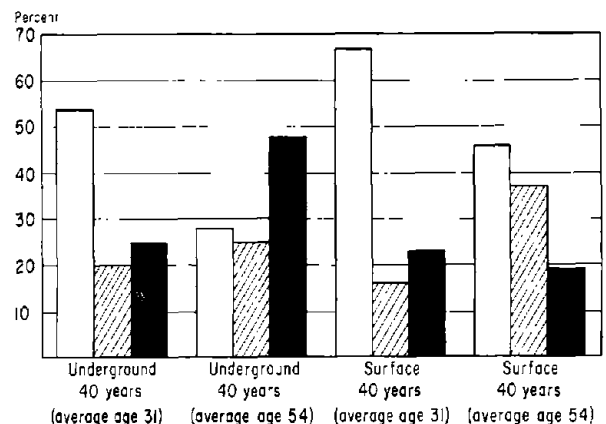


FIGURE 3. - Employees' impressions of air quality, according to age.

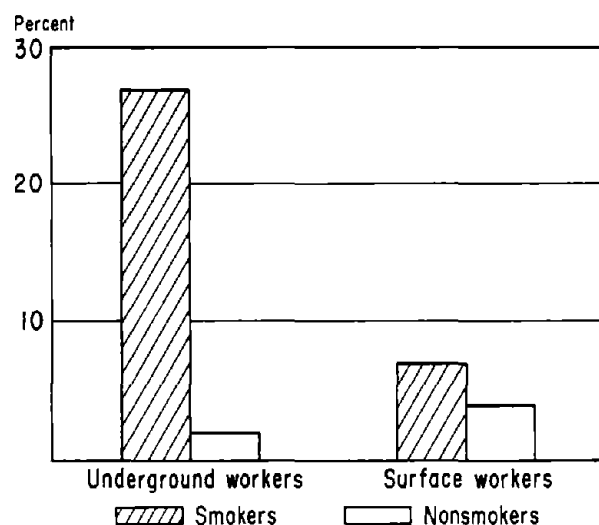


FIGURE 4. - Workers reporting pressure over the chest or feeling of difficulty in getting air.

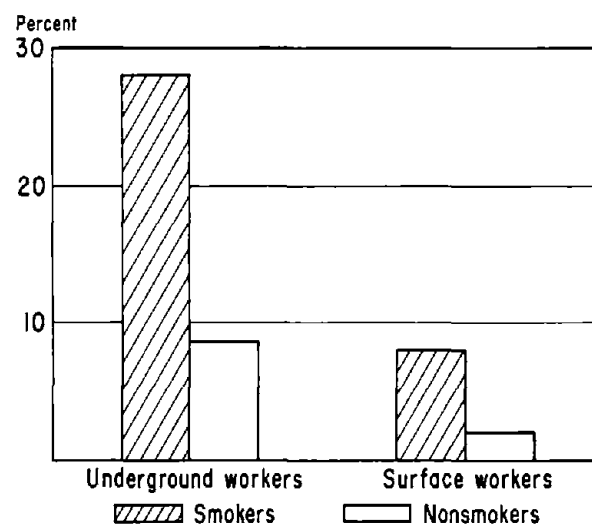


FIGURE 5. - Productive cough lasting 3 weeks during several winters, smokers versus nonsmokers.

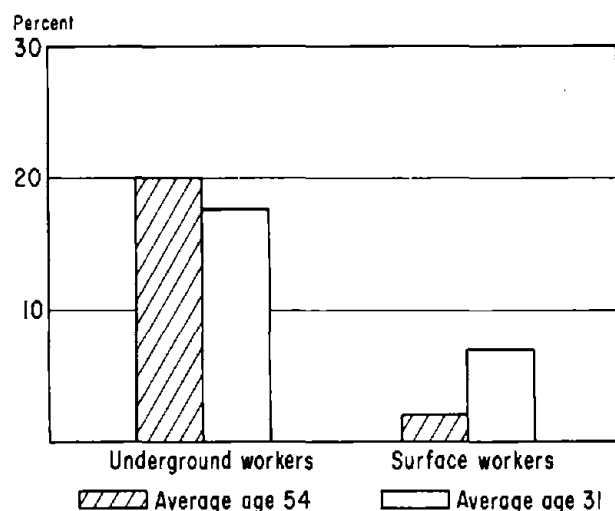


FIGURE 6. - Productive cough lasting 3 weeks during several winters, according to age.

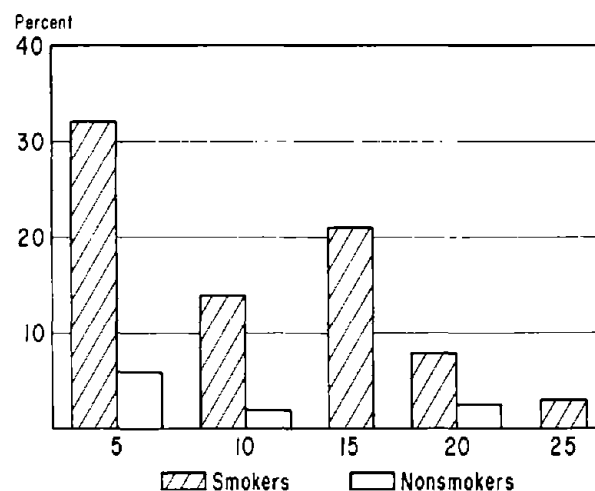


FIGURE 7. - The frequency of respiratory tract infections in relation to the number of years underground.

group. The frequency of bronchitis seems to be independent of the amount of tobacco smoked. The essential factor is that the subject smokes, not how much he smokes.

Lung function studies were carried out on all subjects before and after working 8 hours. These results showed no significant difference between underground and surface workers, nor did they show any difference before and

after working an 8-hour shift underground. That is to say that there was no apparent difference in the younger and older workers' reaction to work. The studies otherwise showed a somewhat better lung function among the younger groups but this is what one would normally expect.

To sum up, the study did not show any significant changes in the lung function studies other than those attributed to age. The interview by questionnaire, on the other hand, showed a significant difference in the frequency of respiratory symptoms between underground and surface workers and between smokers and nonsmokers.

This demonstrated, first, that lung function study in general is too coarse an instrument to show any changes caused by bronchitis, whereas interview by questionnaire is a more sensitive method. Second, it demonstrated that smoking among the surface workers seemed to have an effect equal to that of working underground without smoking. Smoking and working underground were interacting and were shown to have an effect that was double as high as expected. The subject's own impression of the quality of the atmosphere was largely dependent on whether he smoked or not. The most important observation is probably that there is a synergic effect of smoking plus another factor in the mines--irritating gases, dust particles, or a combination of the two.

Interaction Between Gases and Aerosols

When evaluating the effects of air pollution by diesel exhaust gas in mines, many considerations must be taken into account. The most important substance is probably nitrogen dioxide. The effect of NO_2 and other irritating gases is not easily defined when they are together with aerosols. Undoubtedly the effect is increased by interaction between the gas and the aerosol. To what extent depends not only upon the amount of gas particles but also upon the aerodynamic qualities (weight and size) of the particles.

The pollution by irritating gases and aerosol in a mine must therefore be considered as an entity. Efforts to decrease either of the two parts may benefit the total effects of the air pollution, but improvements may be accomplished only up to a certain point if one side of the problem alone is attacked.

Technical Preventive Aspects

The technical contributions aiming at eliminating the air pollution by diesel exhaust gas are as follows: Suitable choice of engine type, optimal engine function, driving discipline, choice of low sulphur fuel, regular checkup of engine function, use of scrubbers and catalytic afterburners, and strict discipline in connection with blasting. Lastly, but possibly most important is that of a ventilation system which allows optimal distribution of fresh air and sufficient air movement at all working places. A close coordination between management of ventilation and production is vital.

This has to be looked upon as a dynamic process, where new engine types, new power sources, new mining and loading techniques, etc., are constantly on trial and evaluation, and may supersede less efficient methods.

Medical Preventive Aspects

Smokers are at special risk in mine work since the effect of air pollution and smoking will interact. Considerable effort should therefore be put into encouraging underground workers to stop smoking. This may be done by regular health education. Underground workers should also, as far as possible, be recruited among nonsmokers and underground workers should have their health situation checked regularly. Air pollution is foremost a risk for persons who already suffer from respiratory disease. It is important to prevent those individuals from being employed underground.

Epidemiological Aspects

The main interest in the use of diesel engines in mines is attached to NO₂ levels. The threshold limit value (TLV), for NO₂ should of course not be exceeded but conditions of work in a mine make it difficult to avoid this completely. Anyway the important aspect is not so much the TLV as the long term exposure to levels below the TLV. In order to be able to observe the average daily pollution level and the time trend, it is necessary, and of greater interest, to observe the average median values of representative measurements. The air pollution should be continuously mapped out and sampling routines be based on epidemiologic principles. It is vital from the beginning to enforce strict rules not only as to the sampling technique, but also as to where the samples should be taken in relation to the process of work and the workers, and also as to when and how often sampling should be undertaken.

INTERPRETATION

The main problem from a medical point of view in a mine where diesels are used are gases of nitrogen of oxides especially nitrogen dioxide. This is not a question of an acute effect of exposure to high levels but the long term, chronic, effect of exposures to low levels (<5 ppm NO₂).

Carbon monoxide is usually no problem as long as ventilation is adequate and motor function optimal.

The effect of polycyclic hydrocarbons is minor compared with that of smoking. If they have any effect or not can only conclusively be determined by followup studies in 20 to 30 years.

Smoking is undoubtedly, from most points of view, more deleterious than anything else.

Lastly, it is probably worthwhile to underline that measurements of air pollution, especially in a mine, should be interpreted as technical aids which only allow a rough estimate of biological risks. The technical observation should not be an aim in themselves but should serve as a guide. They should always be considered against the background of the individual man with his special qualifications such as constitution, smoking habits, and sickness pattern.

SUMMARY

A long-term study of workers in a Swedish iron ore mine where diesel trucks have been used extensively underground for more than 10 years has been carried out. It demonstrated a significantly increased frequency of bronchitis among underground workers compared with surface workers, and more so among smokers. The findings indicated interaction between underground work and smoking. The workers' impression of the air was also influenced by smoking habits.

Lung function studies did not reveal any difference between the groups and subgroups other than those which could be accounted for by differences of age.

The air pollution problem in mines caused by diesel exhaust gas should be considered comprehensively.

The diesel problem is closely attached to the dust problem. To prevent any ill effects on health caused by diesels underground it is necessary to direct efforts toward the gas problem as well as the dust problem. The air pollution situation should be checked continuously by representative sampling. Lastly, the workers' health situation should be followed up by regular check-ups. Those with signs of bronchitis should not be employed underground, and smoking among underground workers should be discouraged.

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MR. PELUSO: Thank you. Are there any questions?

FROM THE FLOOR: Mr. Chairman, I have a couple of questions. Do you have a regular annual or regular examination of your miners? And secondly, do you do regular or occasional lung tests?

DR. JORGENSEN: We examine all the miners upon entrance with X-ray of the chest, with lung function tests, and physical examinations. Following that, we check them again after 5 years, and following that, every third year.

FROM THE FLOOR: You mentioned that a 20- or 30-year-long term effect would have to be studied. You mentioned another first introduction of the diesel in the mines in 1958. When did your study begin? Did it begin in 1958 also, with the control groups, the surface workers, and the underground workers?

DR. JORGENSEN: This study was made, when we had had diesel equipment for 10 years, and we wanted to see its effects. We, at that time, realized how unfortunate it was that we did not make a similar study when we started with the diesel comparison. I think this is a very common situation unfortunately. Your question is very important, and I am sorry that we did not do it. We did the best we could, and we are going to repeat the study in 10 years. Then we will have this background.

MR. PELUSO: Any more questions?

FROM THE FLOOR: Nick Salina, Department of Mines. Could you tell us what the total ventilating volume in the mine is and the total horsepower in the Kiruna Mine?

DR. JORGENSEN: I hesitate to tell you, because I could be wrong. If you are interested, of course, it would be very easy to give you the information later.

MR. PELUSO: Thank you, Dr. Jorgensen. Are there any questions?

DR. KERR: May I digress for a moment. There is a general saying, a rule of thumb, that has been developed among medical administrators since a few years ago, before we began to develop some of the finer techniques which are still inadequate, that we have today. The question that you ask of yourself, as a physician, is, "Is this the kind of medical care that I would want my family or myself to have?" If it isn't, as a rule of thumb, "Why do I feel that it is not a particularly good quality of medical care?" I think the same rule of thumb must be considered in this situation with diesels. Is this an environment in which I would want to work?

I would like to introduce our next speaker, John Murphy, who is an electrical engineer. He received his degree from the University of Pittsburgh in 1961, and has a M.S. in business administration from Duquesne University. He is a registered professional engineer in the State of Pennsylvania. He joined the Bureau of Mines in 1961. At present, his responsibility is for research and development in areas of illumination, instrument development, industrial safety, and mine communication systems.

EVALUATION OF PRESENT INSTRUMENTS AND NEW DEVELOPMENTS EXPECTED
IN MONITORING CONTAMINANTS IN MINE ATMOSPHERES

by

John N. Murphy¹

SUMMARY

The Bureau of Mines has an extensive and diversified program to evaluate and develop approved mine monitoring methods including personal devices to be worn by a miner, portable instruments that can be carried by a single miner, and stationary instrumentation that operates typically at fixed locations; the latter two categories in most cases would include instruments capable of monitoring several contaminants. Requirements of the proposed regulations on "Diesel Powered Equipment for Coal Mines and Gassy Metal and Nonmetallic Mines" include limitations on the concentrations of carbon dioxide (CO₂), carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and oxygen (O₂) and requirements on minimum ventilation in places where diesel engines are operated.

This paper covers an evaluation of available instruments and the development of instruments suitable for the monitoring of the above parameters. Operational mine monitoring systems which have been or are being installed in operating coal mines are reviewed. General approaches to the implementation of and requirements for area mine monitoring systems are discussed. Additionally, available or soon to be available hardware which can be used for personal as well as portable instrumentation is presented. Instrumentation for providing instantaneous indications of contaminant concentrations, small personal alarms which only indicate when certain threshold values have been exceeded, and dosimeters which measure the dosage (that is, summation of concentrations times the time) are reviewed.

Recommendations for calibration procedures and frequency of same are reviewed and performance requirements and test procedures for candidate instruments are proposed.

Area mine monitoring systems can be implemented where applicable. Some portable instrumentation is available and several interesting new developments in terms of personal monitoring and dosimetry techniques for contaminants are presented. It is anticipated that within 1 year suitable portable instrumentation for all of the airborne gaseous contaminants of concern will be available.

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INTRODUCTION

The Bureau of Mines has an extensive and diversified program to evaluate and develop improved mine-atmosphere monitoring techniques including personal devices to be worn by a miner, portable instrumentation that can be carried by a single miner, and stationary instrumentation that operates at typically fixed locations; the latter two categories in most cases would be a collection of two or more instruments to monitor multiple parameters. One area of interest that probably would be implemented by the portable instrument class, involves the use of monitors mounted on the diesel-powered equipment that would control fuel-air ratios to minimize undesirable effluent. If the contaminants became objectional, the engine would be shut off.

Also, the stationary and perhaps the portable instrumentation might be used with a simple but reliable telemetry system to transmit the pertinent intelligence from several stations to the surface or to a central point underground. Finally, the ultimate test of any mineworthy system is to evaluate the hardware underground; several such evaluations are underway and more are planned shortly.

In terms of the parameters to be monitored, the proposed rule making (5)² specifies the following:

1. In Section 31.61 (a), (d) and (e), the maximum allowable emissions of carbon monoxide (CO) or oxides of nitrogen from diesel engines.

2. In Subpart H--Ventilation Requirements--Diesel-Powered Equipment, proposed paragraph 31.75 specifies that "...The purpose of this requirement is to ensure that the mine atmosphere into which the diluted exhaust gas is discharged shall not exceed the percentage by volume, of carbon dioxide (CO₂), carbon monoxide (CO), nitric oxide (NO), and nitrogen dioxide (NO₂) prescribed by the threshold limit values (TLV) as specified and applied by the American Conference of Governmental Industrial Hygienists (ACGIH) (1)...and not less than 19.5 percent, by volume, of oxygen."

3. Paragraph 31.75 (c) specifies that "the minimum ventilation airflow for each unit of diesel-powered equipment shall be the sum of the minimum ventilation requirements of the diesel engines utilized in the unit and shall appear on the approval plate for the unit."

4. Additionally, in Subpart F--General Construction and Performance Requirements, paragraph 31.51 b(1)(i) specifies that "diesel-powered equipment shall be specifically designed to provide respiratory protection against oxides of sulfur."

5. Also, in part 31.51 b(1) reference is made to the control of particulate emissions. Although this type of emission is certainly a potential respiratory hazard, instrumentation for monitoring it will not be reviewed in this paper. Some field survey work has been done using respirable dust pumps, normally in underground coal mines.

² Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

Hence from the requirements of the preceding proposed rulemaking we can see the parameters that need to be controlled and monitored.

The TLV's specified by ACGIH refer to exposure to the particular contaminants for 8 hours; for example, exposures to somewhat higher concentrations for shorter periods of time are considered not to be hazardous. Hence, we have the concept of a dose, that is the sum effect of concentration times exposure time for each level and time of exposure. For some contaminants the dose is simply as described above, that is concentration times time; in other cases, higher concentration levels are allowable for a disproportionately less amount of time so that a non-linear exposure criteria is required. The exception is NO_2 which has a ceiling value of 5 ppm with no allowable excursion. In both cases, where a suitable detector is available, it is feasible to furnish the computing circuitry to compute the dose.

It is not the intent of this paper to discuss every instrument, but to give examples of hardware and systems that are available and some that are presently in use in mines, some which are obviously not optimum, for mine use, that is, but which employ detection principles suitable for underground applications and which could be miniaturized and/or repackaged. A comprehensive list of commercially available instruments, which are not necessarily Bureau of Mines approved, can be found in Instruments and Control Systems Buyers Guide (3).

MINE INSTRUMENTATION

Concepts and Hardware

After decisions have been made as to what parameters should be monitored, the techniques as to how and where the monitoring is to be implemented must be resolved. The primary concern is protection of personnel, both those who are operating the diesel-powered equipment as well as others in the mine. Hence the most desirable situation is to insure that each man is not overexposed to any contaminant. This, of course, means that a personal monitoring device must be worn by the miner. Provided that this monitor is small, lightweight, and does not jeopardize his safety or encumber his performance, this approach may be desirable. However, one must remember that the miner is presently loaded with a cap lamp, self-rescuer, and perhaps a respirable dust pump, flame safety lamp, etc., so that any device to be worn by the miner must be about the size of a pack or two of cigarettes. In some cases the monitor itself would be small enough to fulfill this requirement. However, because of excessive power requirements, the battery supply becomes excessive; in such circumstances either intermittent readings must be taken (perhaps automatically) or an alternative approach followed.

A second category is portable monitoring where the instrument(s) can be located in the working place, be self-contained, and either provide a local alarm and/or, via a simple telemetry system, notify a central location of a high concentration. The advantage of this approach is that when the larger package is tolerable either more parameters can be monitored, and/or a larger but more reliable detector can be used. The disadvantage is, of course, that

it is an area being monitored, rather than an individual(s). The one possible exception is when a portable-type instrument is mounted on, and perhaps powered by, a unit of diesel-powered equipment. While this instrumentation can always indicate the exposure of the operator depending on the direction of the air-flow relative to the travel of the vehicle, the instrumentation may not indicate the potential exposure of others. However, this approach does offer the opportunity to use larger, perhaps more reliable instrumentation to assess the operator's exposure without encumbering the operator with a device or devices attached to his body. An approach for on-board vehicle monitoring is that described by Hurn earlier in this symposium when he spoke about observing the contaminants from the engine and then controlling the total effluents introduced into the atmosphere whether they affect the operator or not.

Instruments and Sensors

Before discussing the instruments in use or under evaluation a very brief review of the available principles of detection and some general comments seem appropriate. This is not intended to be an intensive review of the techniques or their merits. Not all of the techniques mentioned below are presented in the hardware section that follows. The candidate methods are as follows:

1. Stain tubes

These are very common to the mining community. A sealed glass tube containing some chemical which can change color in response to a specific gas is broken and a known volume of air pumped through it. The length or intensity of the color change along the tube gives an approximate indication of the amount of gas present. Such tubes are available for detection of CO, CO₂, NO, NO_x, and O₂. The main disadvantage of this method is that it is not a continuous measurement process and thus is not available for alarm and monitoring devices. The reading of the stain tubes is subjective at best and thus subject to error.

2. Electrochemical Cells

The exact nature of this method varies with the gas to be detected. Essentially a solution of some sort containing some electrodes is exposed to the air. It responds by setting up electrical current or voltage which is related to the concentration of the gas in question. Each cell is designed to measure a specific gas, but in some cases they are not too selective. Precautions must be taken to insure that the response of the cells is due to the correct gas. This may require chemical scrubbers preceding the detector cell to eliminate the interfering gases. Nonetheless, O₂, CO, NO, and NO₂ can be detected by this method. The method requires very little associated electronics and very little power. (Units can typically be battery-operated.) They do, however (except for O₂ cells), require frequent (often daily) calibration to maintain accuracy. They will also require cell replacement or rejuvenation every 3 to 6 months. At this time, these devices may prove to be suitable for underground use. Efforts are being made to evaluate and encourage the development of these devices for underground use particularly for the detection of NO₂.

3. Solid State Gas Detectors

In these devices, a heated metal oxide, or organic semiconducting film changes its electrical resistance as a function of the concentration of a reducing gas at its surface. Proper choice of metal oxide, additional catalysts, and operating temperatures may yield devices which are specific to CO, NO, NO₂, or CH₄. At the present state-of-the-art, such devices are relatively nonspecific, but very inexpensive. More basic research is necessary to refine this method for qualitative and quantitative gas analysis. Presently these devices are finding use as the sensors in domestic fire and smoke alarms and as gas detectors in campers, trailers, etc. It is also being evaluated in a personal CO alarm.

4. Colorimetric/Electrical Conductivity

This method uses the color change of a specific solution to detect low concentrations of gases. Field units are available. The air sample is bubbled by various schemes through the solution whose color change or electrical conductivity change is measured. Some automated versions are available for detecting NO and NO₂ and CO but these are rather fragile and require periodic adding of reagents.

5. Catalytic Conversion

This method passes the air sample over a bed of heated chemical; for CO the catalyst is called Hopcolite.³ A reaction takes place with any CO present changing it to CO₂ and producing heat. The amount of temperature rise of the bed is related to the amount of CO present in the air, and it is this temperature rise that is used for the signal.

This method is commonly used for CO detection. The disadvantage of this method is that it consumes power, requires a water-free sample, and replacement of the catalyst at infrequent intervals; this principle is also commonly used for detection of methane.

6. Thermoconductivity

This method is based upon the fact that the heat conductivity of the air varies with composition; thus foreign gases alter the equilibrium temperatures of a heated wire. However, this method is not specific to gases and is relatively insensitive. It is not a suitable method for detecting low concentrations of CO and NO required for safety.

7. Optical Spectroscopy

This method is based upon the fact that gas molecules absorb light at specific colors or wavelengths. This absorption can be detected by various schemes and can be made specific to the gas. The state-of-the-art is rapidly

³Reference to specific products does not imply endorsement by the Bureau of Mines.

advancing in this area, and the present laboratory instruments could quite soon be ready for adaptation to the mine environment. This method has demonstrated its capability in the laboratory and with refinements will soon produce a rather compact instrument for monitoring CO, NO₂, NO, CO₂, and CH₄ contaminants, but not O₂. However, being an optical device, steps must be taken to insure that the sample air is relatively free from dust and water vapor, both of which cause problems when full-scale sensitivities are on the order of a few parts per million, as for NO₂ for example. Most gases absorb in the infrared spectrum but some have absorption spectra in the visible or ultraviolet regions.

8. Ionization

This method detects and measures trace contaminants in an air sample using the ionization principle. Typically a small radioactive source mounted in an ion-chamber ionizes gas entering the chamber. The resultant ion current is maintained at a steady-state condition until some form of particulate is introduced into the ion-chamber, at which time there will be a pronounced drop in ion current. A reagent converts the gas or vapor of interest into a particulate matter which is then introduced into the ion-chamber. The effect of the particles or aerosol on the conductivity of the ion-chamber is a measure of the concentration of the gas or vapor of interest. The amount of voltage drop, resulting from the change in conductivity, is converted into a signal to the meter. Formation of particles for a wide range of materials is accomplished by reacting the gas or vapor of interest with a chemical reagent.

9. Index of Refraction

This method is also not specific to gases and hence not suitable for our detection purposes. It is used, however, for methane detection.

10. Mass Spectrometers

This is a laboratory method based upon the fact that charged-gas-molecule trajectories are bent in a magnetic field by different amounts depending upon the mass of each. Such a system requires a vacuum and other complicated peripheral equipment. Compact units have been made for National Aeronautics and Space Administration (NASA) and for the Department of the Navy, but are not readily suitable for mine use. One serious drawback of this method is its inability to distinguish between molecules of different chemical composition but identical mass. For example, the mass of CO is the same as that of N₂ which is a major constituent of air. CO cannot easily be detected by mass spectroscopic methods.

11. Paramagnetic

This method is suitable for detecting gases which are attracted to magnets, namely O₂ and NO. It is used primarily to detect oxygen. Instruments using this method differ in size and complexity, but generally require a magnet which may be heavy. The disadvantage of this method, although it is very specific, is that there are other more attractive and easily implemented methods available for oxygen detection.

12. Gas Chromatography

This method is a batch-type method in which a slug of air is passed through a long tube by a carrier gas. The tube contains absorptive materials, the effect of which allows different gases contained in the sample to travel the length of the tube at different rates. The rate at which each gas passes through the tube identifies the gas. The quantity is measured by a suitable nonspecific detector such as a thermocouple. Automation of this method is difficult and other problems such as poisoning of the column make the method an unattractive one for in-mine use.

13. Chemiluminescence

This method is used in the laboratory to detect NO. NO will react with ozone to produce NO₂ and excited oxygen which then decays producing light. The amount of light produced is proportional to the NO concentration. At the present state-of-the-art, these instruments use high-voltage photodetectors and must produce ozone and then dispose of it in a safe manner since ozone is toxic. Use of this instrument in the mine seems impractical.

Hardware Development and Evaluation

Personal Instruments

Work has been completed at the Bureau's Bartlesville Energy Research Center (BERC) to assess the accuracy and precision of gas detectors (2).

The performance of commercially available portable instrumentation for the detection of carbon monoxide, carbon dioxide, oxygen and methane was evaluated at conditions simulating an industrial work atmosphere. Portable instruments included in the study were gas-detection tubes (length-of-stain and color intensity), catalytic oxidation detectors for carbon monoxide, liquid absorption detectors, paramagnetic oxygen detectors, galvanic detectors, and pellement or hot-wire methane detectors. Evaluation of the instruments was in atmospheres of 50 and 80 percent relative humidity at 75° F and containing test gas concentrations of 0.1, 0.25, 0.50, 1.0, 1.5, and 2.0 times the threshold limit value (TLV). Correlation of the results from the portable gas analyzer to the measurement by the standard instruments was made by calculating and plotting an estimated line of regression, prediction, and confidence limits and the correlation coefficient for each detector system. Relative humidity in the 50 to 80 percent range did not appear to contribute to instrumental uncertainties in either performance or operation. Considerable deviation in detection precision between the portable gas-detection systems and the standard systems was established, especially at the lower gas concentration levels.

Gas detection instruments were evaluated in simulated work atmospheres that contained the test gases at concentrations of 0.1, 0.25, 0.5, 1.0, 1.5, and 2.0 times the TLV or lower explosive limit (LEL) (10, 15, 20, and 25 percent for O₂). Two humidity levels of 50 and 80 percent at 75° F were used. Usually three or four detector systems were exposed concurrently in the



FIGURE 1. - Typical gas detecting tube and sample pump manufactured by Bacharach Instrument Co.

test chamber. During the evaluation in the test chamber, the instruments were operated as prescribed by the manufacturer.

Gas Detecting Tubes

Gas detection tubes are used by breaking the sealed ends of the tube and aspirating a controlled quantity of air plus contaminant through the tube with a pump as shown in figure 1. Depending upon the tube type, the concentration of the toxic gas is proportional to the length of the colored zone

or proportional to the color intensity. Scales furnished by the tube manufacturer as shown in figure 2 were used to determine the concentration of the gas. Each manufacturer has a method or calibration scale for use with their detector system. Some alternative methods include a tube as shown in figure 3 where the calibration is directly on the tube and in figure 4 where the concentration is indicated by the color of the indicating material as compared to the calibration chart.

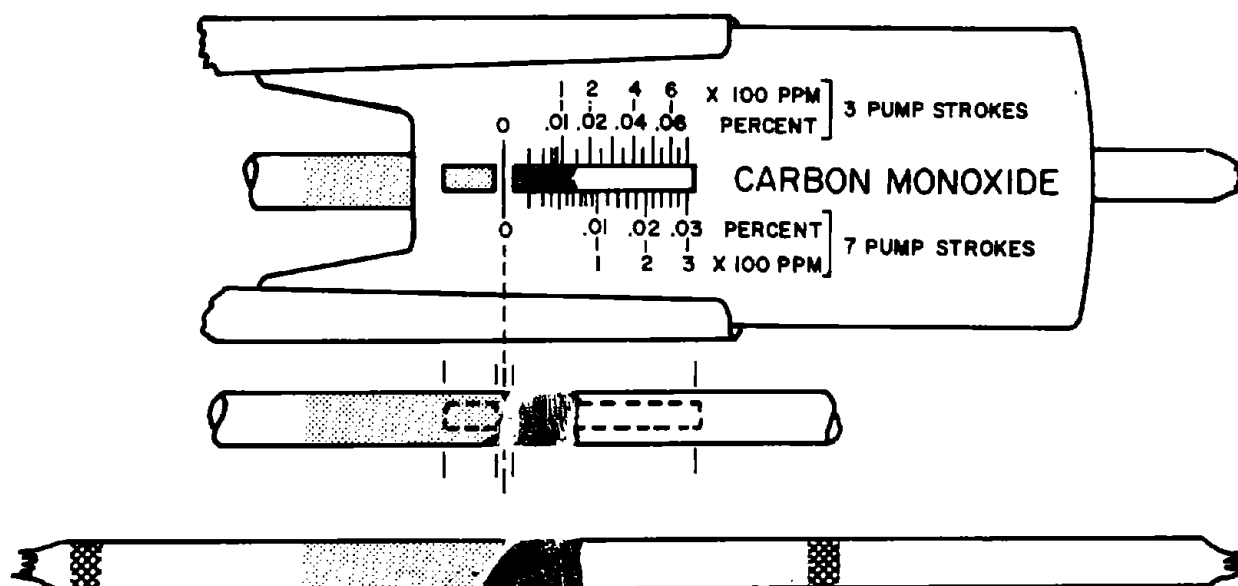


FIGURE 2. - Schematic of length of stain tube calibration scale as furnished by the manufacturer.

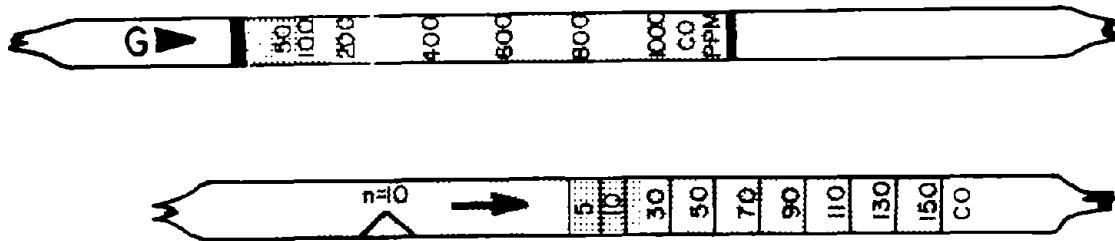


FIGURE 3. - Schematic of length of stain tube with calibration scale on tube.

CARBON MONOXIDE COLOR STANDARDS

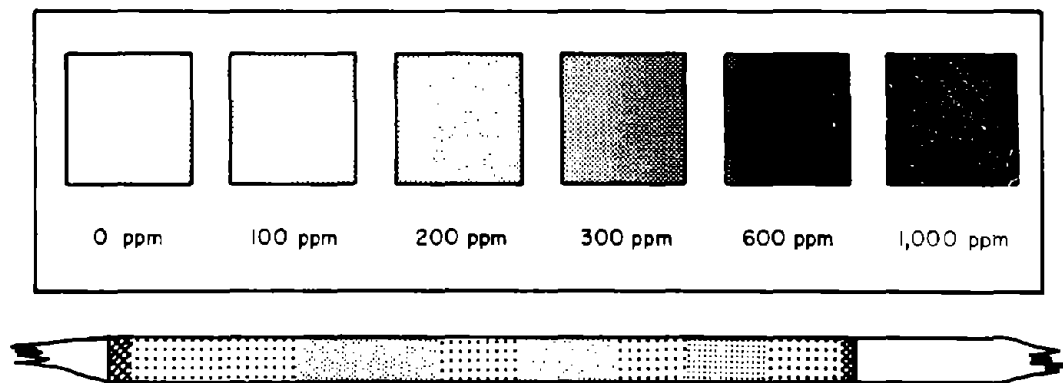


FIGURE 4. - Color indicating type of detector tube with calibration chart.

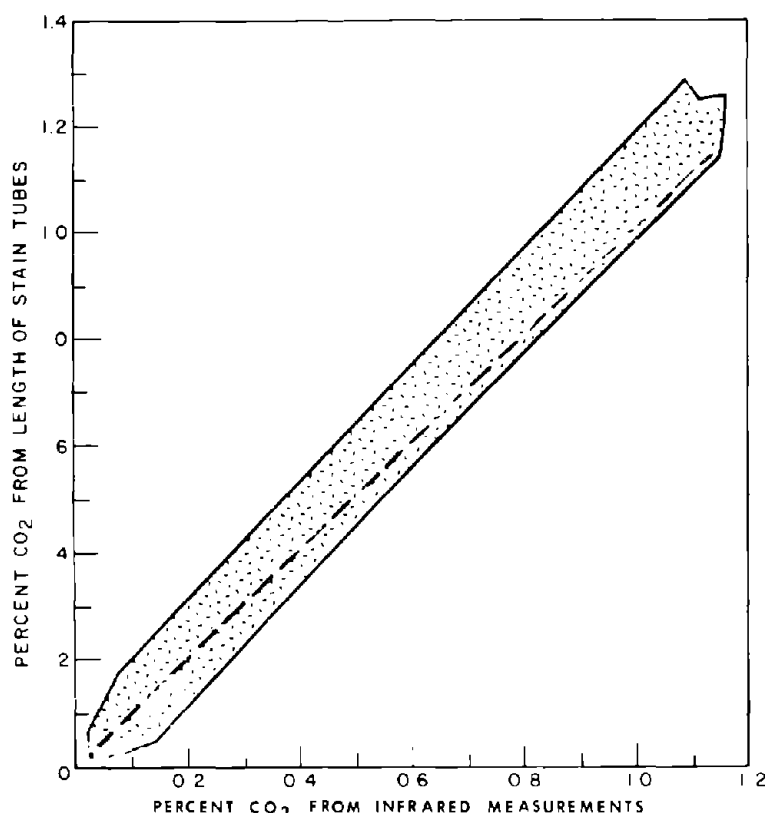


FIGURE 5. - Typical performance of an indicating tube where the observed concentration from the tube is plotted as a function of actual concentration.

A typical performance curve for the indicating tubes is shown in figure 5 where the concentration as indicated by observers is plotted against the true concentrations; typically, deviations were less than ± 25 percent. Other work has been reported in the literature on the evaluation of indicator tubes with a resultant accuracy of plus or minus 30 percent (4). This concludes the discussion of the Bartlesville Energy Research Center evaluation of indicating tubes.

Some length-of-stain tubes are available for detection of NO_2 ; however, there is an interest in the ability to detect total oxides as well as NO_2 (that is, $\text{NO} + \text{NO}_2$). Shown schematically in figure 6 is a NO_2 detector tube which has been modified with an

oxidizing material in the left end; hence, if the sample is aspirated from right to left, NO_2 will be indicated. If the sample is aspirated from left to right, the NO will be oxidized and so the reading will be total oxides (NO_x). Therefore, by using two tubes, one aspirated in each direction, all parameters of interest can be assessed. By using a sampling pump as shown in figure 7, samples can be aspirated through the tubes shown in figure 8. The tube at the top of the photograph has not been used and the indicating material is at the right, the oxidizing material at the left. In the second tube a sample



FIGURE 6. - Schematic of nitrogen oxides detection tube, by aspirating from right to left NO_2 is indicated, when aspirated from left to right the sample passes over the oxidizer and NO_x is indicated.



FIGURE 7. - Mine Safety Appliances Co., sample pump for determining nitrogen oxides with length of stain tubes.

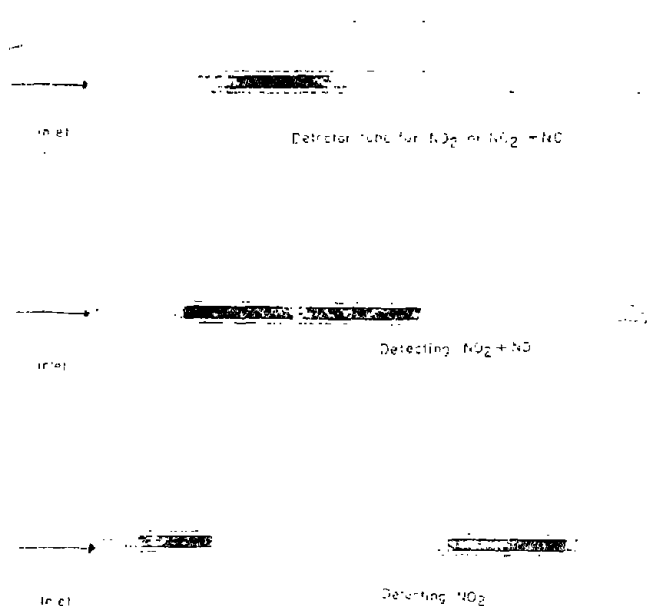


FIGURE 8. - Mine Safety Appliances Co., prototype nitrogen oxides indicator tubes; top-unused tube; center-10 ppm of NO_x ; bottom-6 ppm NO_2 .

has been aspirated through the indicating material first, and the indication is of 4 ppm NO_2 ; hence the NO concentration was 6 ppm.

In terms of the detection of oxygen there are numerous commercially available fuel cell or electrochemical oxygen detectors which are small, compact, and rugged, some of which have been approved by the Bureau of Mines for intrinsic safety. A typical miniature oxygen indicator is shown in figure 9. Laboratory tests on the polarographic type cells show their lifetime to be on the order of about 6 months. A replacement cell costs between \$10 and \$100, depending on the specific type and source of supply.

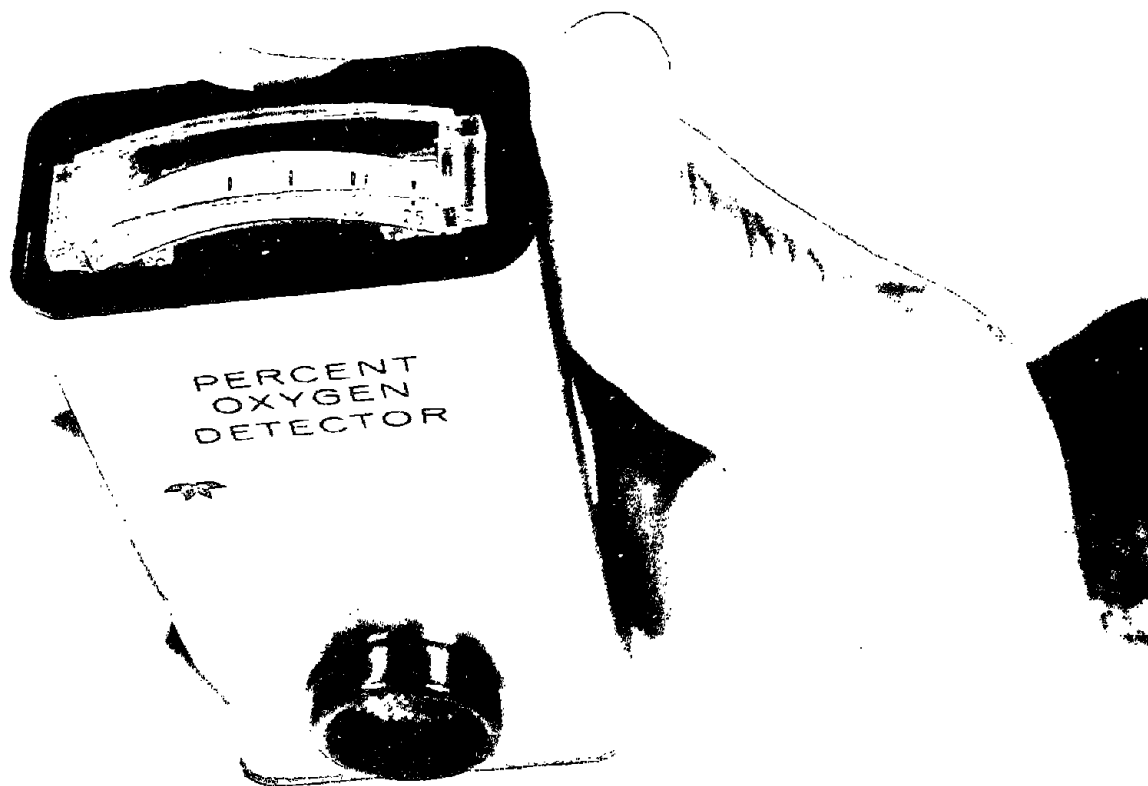


FIGURE 9. - Personal oxygen indicator manufactured by Teledyne Instrument Co.

Oxygen detectors using paramagnetic detection principles typically tend to be rather bulky and heavy owing to the magnet which is used in this detection method. Additionally, in many cases, the suspension system is rather frail; hence the device is not suitable for mine applications. The detection of oxygen by electrochemical methods poses little problem except for periodic replacement or reconditioning of the sensor, which in some cases can be done in the field. Another area of interest concerns that of CO detection. Shown in figure 10 is a personal CO alarm which has been developed by the Pittsburgh Mining and Safety Research Center (PMSRC) as a modification of a small portable device offered by ENMET Corp. The device shown in figure 10 is a self-contained alarm system using a metal oxide semiconductor detector; it can operate for 10 hours on self-contained rechargeable batteries. This particular system does not give a quantitative readout, but only activates an alarm in a predetermined set point, for example 100 ppm. As indicated above, while the metal oxide semiconductor detectors are not exactly specific to a given species, for example CO, they can be made reasonably specific as indicated by preliminary laboratory evaluations. Extensive investigation is presently underway to determine the explicit suitability of these devices as CO indicators. An alternative concept of the same general device is shown in figure 11 where the CO alarm is mounted on the cap lamp battery and operates from the excess energy in the cap lamp battery.

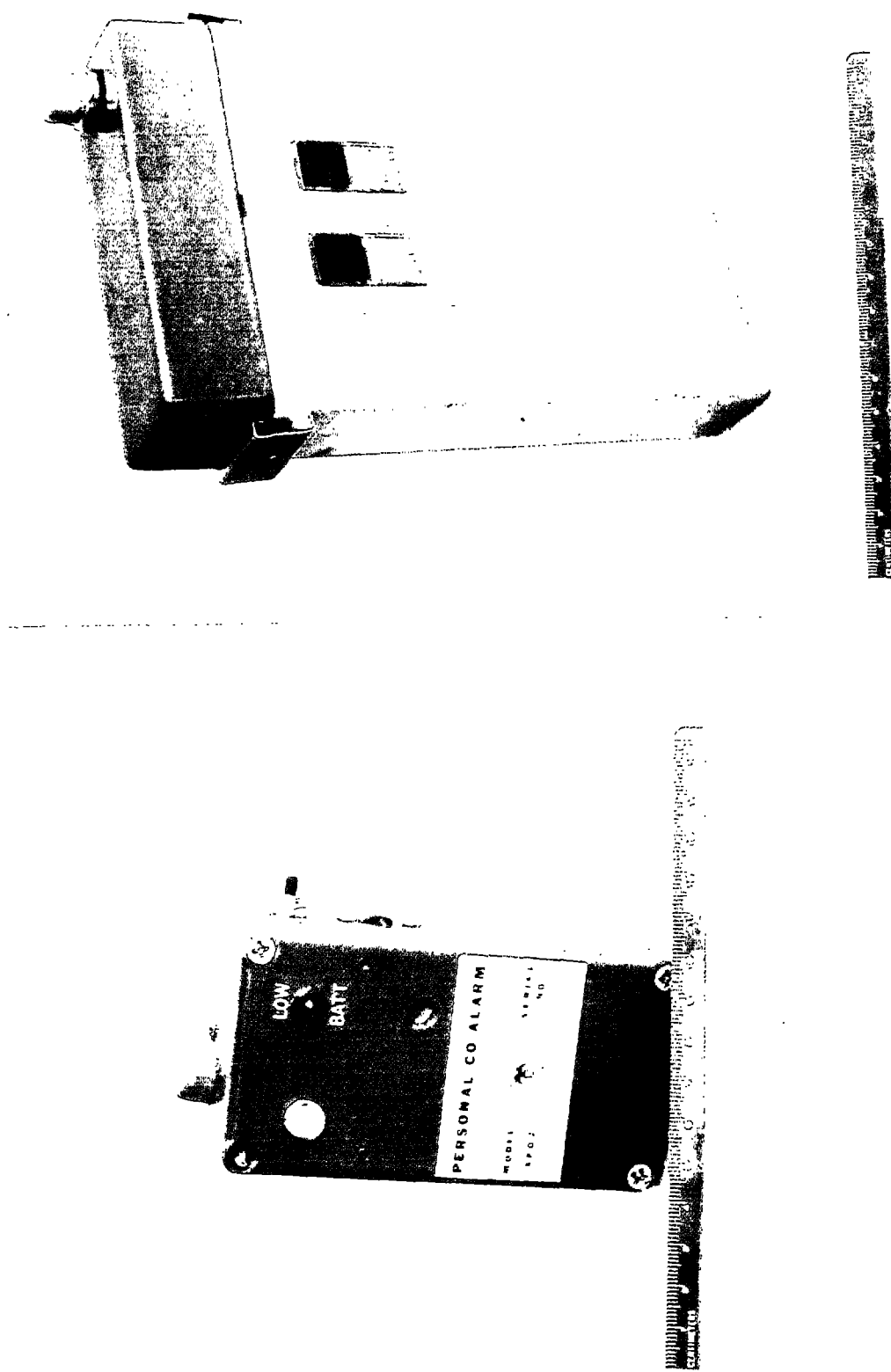


FIGURE 10. - Prototype self-contained CO alarm using a metal oxide semiconductor detector which operates for 10 hours developed by PMSRC.

FIGURE 11. - Prototype personal CO alarm developed by PMSRC, mounted on cap lamp battery.

Another promising candidate detection scheme for CO is that of electrochemical cells. There are some commercially available electrochemical detection systems which are discussed below in the portable class of instruments; however, some foreign-developed electrochemical CO alarms which are presently in the prototype stages are approximately the size of a pack of cigarettes. They have extremely low power consumption so that battery life is on the order of 1 year. The devices at the moment are not available for evaluation; thus additional details on this particular approach will have to be delayed.

The ultimate way to monitor personal exposure and determine doses rather than instantaneous exposures would be with a small personal passive dosimeter. Such a device would require no power underground, would be small enough to be attached to a miner's clothing, and could be an indication at the end of the shift of the types of concentrations that are anticipated. Some exposure badges for carbon monoxide are available, such as the one shown in figure 12. On the left, the badge has not been exposed, whereas the badge on the right has been exposed to carbon monoxide as indicated by the change in color of the circular tab; the calibration chart is at the bottom of the photograph. From preliminary evaluations the reproducibility of this type of device may

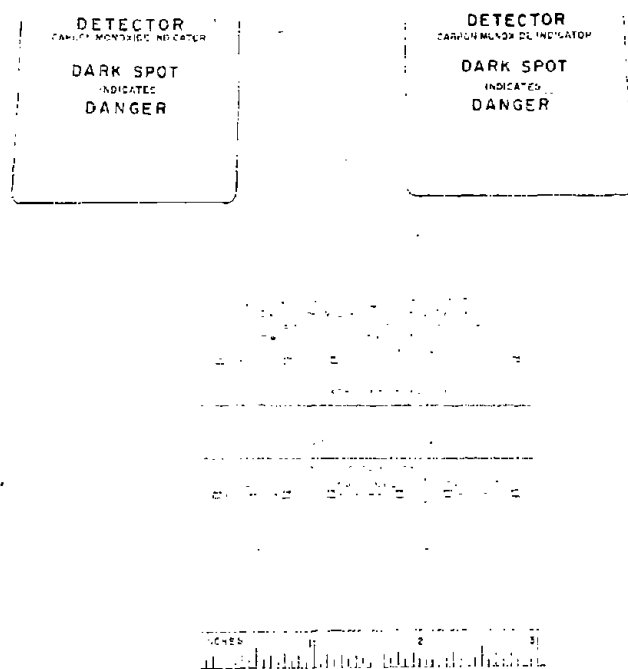


FIGURE 12. - Exposure badge for carbon monoxide; badge on the left is unexposed, on the right circular dot changes color after carbon-monoxide exposure. The calibration chart is at the bottom of the photograph.

not be adequate. Such a device may be possible with a concept orally presented by Dr. Palmes at the AIHA meeting in San Francisco in May 1972, where a small vial such as shown in figure 13 has a carefully selected orifice and can be used to indicate doses; the specific selection of the length-to-diameter ratio of the orifices determines the rate of diffusion into the integrating device. Additionally, the reagent as shown in the figure must be a specific absorber of the contaminant of interest and not be affected by other contaminants that may be in the atmosphere. While the concept appears interesting, there perhaps are two basic problems in terms of use underground: (1) the vial will not necessarily be maintained in the upright as indicated, and, therefore, the reagent contained therein could be spilled, and

Contaminant

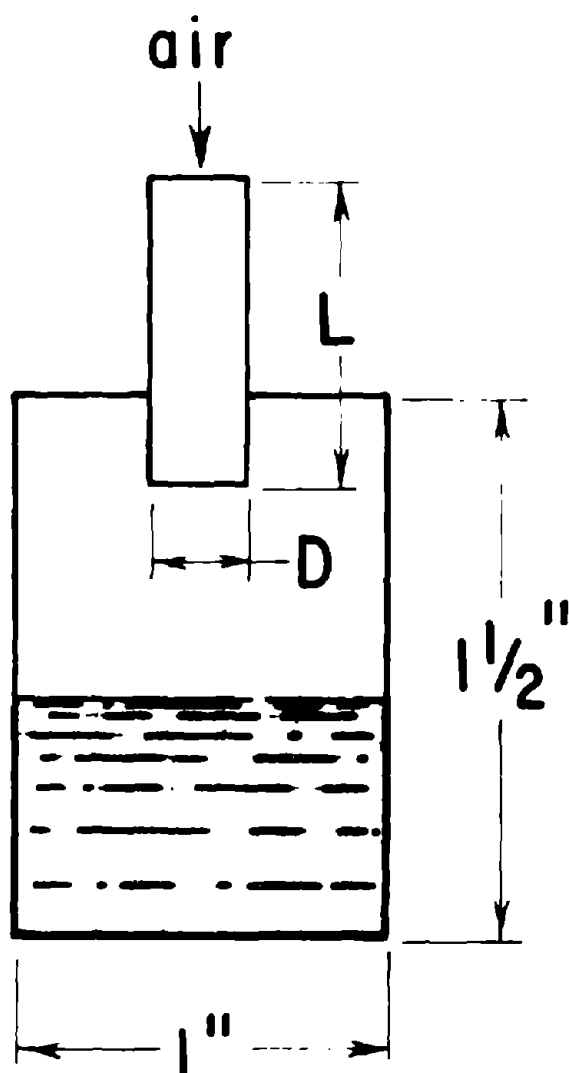


FIGURE 13. - Schematic of personal passive dosimeter as proposed by Dr. Palmes.

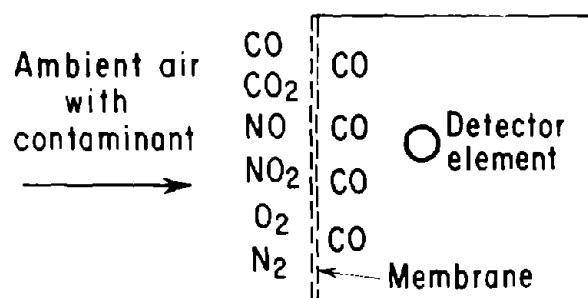


FIGURE 14. - Schematic of permeable membrane to improve the specificity of a detector.

(2) it may be difficult to provide reagents absolutely specific to the contaminants of concern.

Figure 14 illustrates how a permeable membrane may be used to improve the specificity of a detector for a contaminant of interest. The permeable membrane plus a small-diameter porous metal filter to contain the reagent may be used to eliminate the problems of spillage and to increase the specificity of the particular dosimeter, as shown in figure 15. In principle, the dosimeter could contain several vials and be used to monitor multiple parameters. The readout would be implemented on the surface where the exposed reagent would be analyzed via standard analytical techniques, perhaps ion-specific electrodes, or colorimetric or other appropriate techniques.

Portable Instruments

The problem of portable instruments in underground mining application is primarily one of portability. The miners and the inspectors are already burdened by numerous monitoring and safety devices, hence the need to minimize the size and inconvenience involved in the use of portable instruments in underground mining applications.

Perhaps some of the most common devices presently used underground are the liquid absorption type which can be used for CO_2 and oxygen, a typical one of which is shown in figure 16. However the accuracy of such devices is

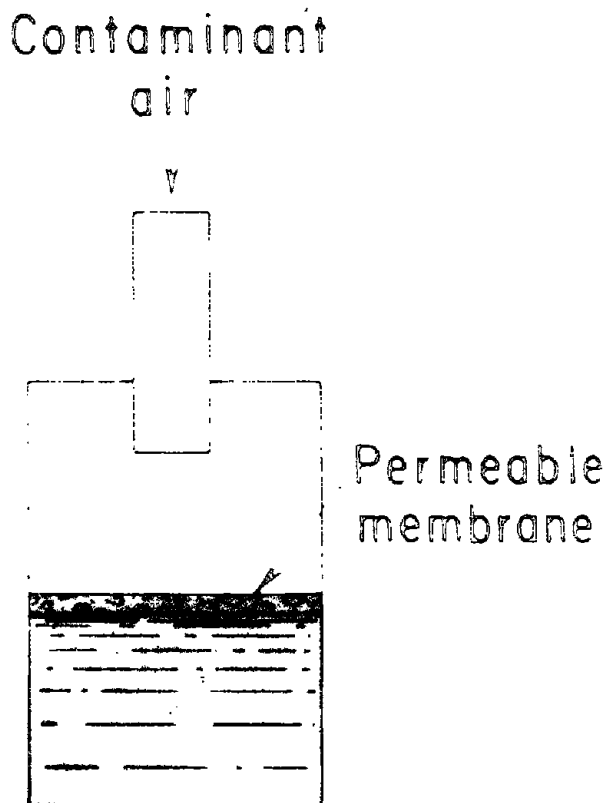


FIGURE 15. - Schematic of personal dosimeter with permeable membrane that with the appropriate reagent could be used to monitor CO or NO_x .



FIGURE 17. - Portable CO meter which uses a Hopcalite detector, manufactured by Mine Safety Appliances Co.

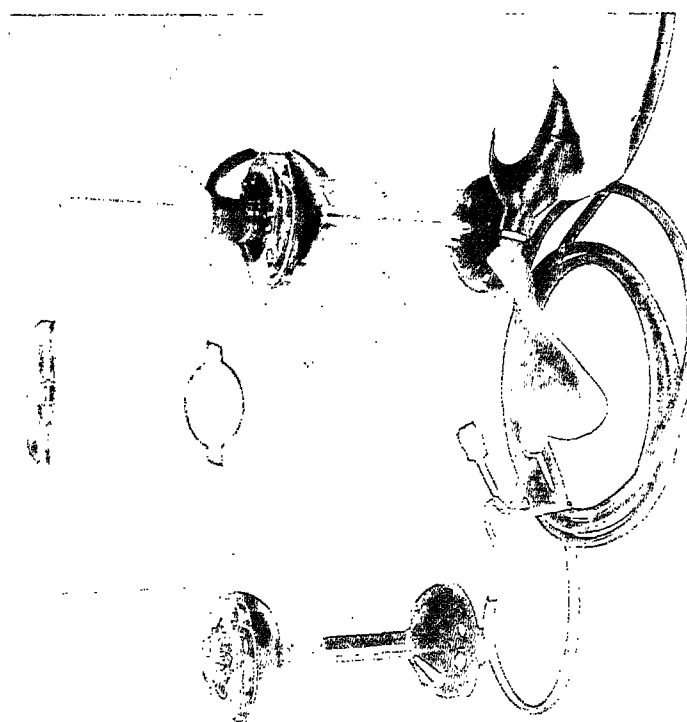


FIGURE 16. - Typical liquid absorption type instrument for the detection of CO_2 and O_2 manufactured by Bacharach Instrument Co.

on the order of ± 25 percent and hence the devices are not entirely suitable for underground applications.

Another type of device in the portable class for the indication of CO is shown in figure 17 and uses a Hopcolite bed as the detection principle.

The following is a series of laboratory-type instruments which, in their

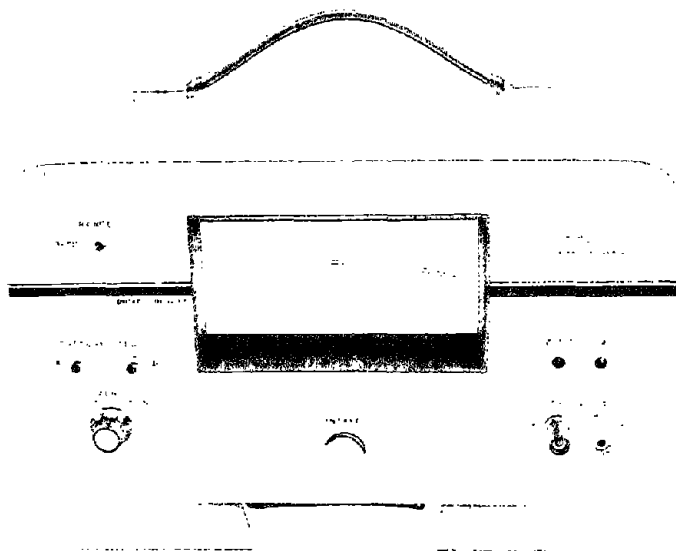


FIGURE 18. - Electrochemical carbon monoxide detector, manufactured by Energetics Science, Inc.

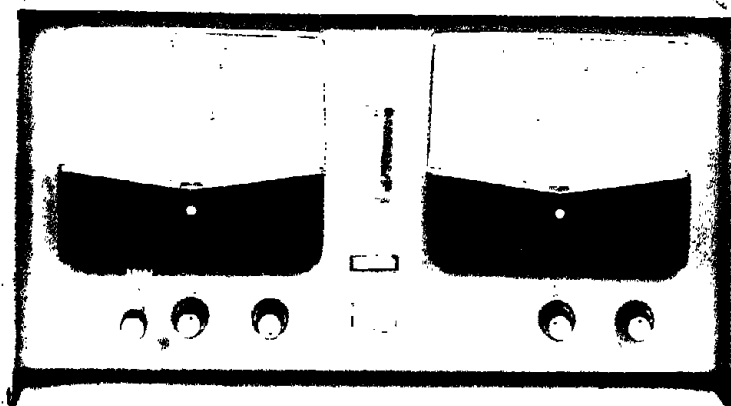


FIGURE 19. - Mine Safety Appliances, garage-type CO and hydrocarbon monitor.

existing packages, are obviously unsuitable for mine use; however, because of the basic detection principles employed, they are considered suitable for modification and programs are underway presently to implement these particular modifications. The CO detector shown in figure 18 is the Ecolyzer manufactured by Energetics Science Inc., which uses an electrochemical or fuel cell principle for detecting CO down to 1 ppm. It is small and lightweight and is completely battery powered. It has an internal zero calibration feature but requires mid-scale (50 ppm) span calibration at least once a day to maintain ± 1 ppm accuracy. Water vapor and dust have virtually no effect on its operation. A ruggedized version of this unit, 4 by 4 by 7 inches, would be suitable for area monitoring, for surveillance, or for local alarm at the working face; such a unit is being fabricated by Energetics Science Inc. for the Bureau of Mines and will be made available in 2 to 3 months. Battery life is in excess of 100 hours and rechargeable batteries could be used. The electrochemical cell does wear out and the replacement rate is anticipated to be about one every 3 to 6 months of continuous use at a cost of about \$50.

Another general class of instruments that may have some applicability for underground mine monitoring applications is that of the infrared analyzers being used for gas station exhaust monitoring applications. Such analyzers for CO and total hydrocarbons could be readily adapted to CO and CO₂ for in-mine use. The principle of detection is infrared (IR) absorption and employs a single beam IR detection and IR source. The commercially available device is shown in figure 19. This type of instrument can provide continuous monitoring and have alarms at predetermined set points.

Another laboratory instrument (fig. 20) which employs electrochemical detection for NO and SO₂ is also under evaluation by the Bureau of Mines for repackaging as an in-mine instrument. The CO analyzer shown in figure 21 is perhaps one of the most stable instruments available that is suited for underground use, that is, a normally polluted atmosphere.

The ANDROS Model 7000 carbon monoxide analyzer uses a novel method of nondispersive infrared spectroscopy to detect CO with a quoted root mean square (RMS) noise and sensitivity of 0.2 ppm. In its present form it is an extremely rugged laboratory-type instrument; but it requires 117 volts of ac power and would have to be enclosed in a permissible enclosure for inside mine use as an area monitor. It contains its own Hopcolite scrubber for internal zero calibration. This unit's maximum range is 200 ppm, but a new model designed for auto emission analysis is range-suitable from 20 ppm to 10 percent CO.

Either model as it stands is ideally suited for continuous monitoring of the ventilation exhaust at the surface primarily for the early detection of fire or spontaneous coal heatings. Although most of the unit uses intrinsically safe components and voltages, some engineering would be required to render the unit permissible; the major culprits are the power interfacing transformers, fan and chopper motors, sample pump, and the infrared source.

Figure 22 shows a "billionaire" analyzer that is usable for the detection of NO₂; however, because of the small low-powered radioactive source in this particular device an Atomic Energy Commission license is required for its use. The detection of NO₂ in Titan missile silos has been successfully accomplished for many years using a similar type of detection scheme.

Present hardware development efforts that are underway by Texas Instruments Co. on a Bureau of Mines-sponsored contract include the development of a mine air monitor which is shown schematically in figure 23. This particular instrument will be capable of detecting oxygen, CO, and NO₂, all by electrochemical means. The major package dimension will be on the order of 12 inches. The device will be self-contained and will have a digital readout to indicate the concentration of the parameter of interest.

The Bureau and the National Aeronautics and Space Administration (NASA) have jointly contracted Perkin-Elmer Corp. to develop a small portable carbon monoxide detector using their method of nondispersive infrared spectroscopy. The ultimate goal of this contract is to build a production prototype of a small, battery-powered hand-carryable carbon monoxide detector capable of

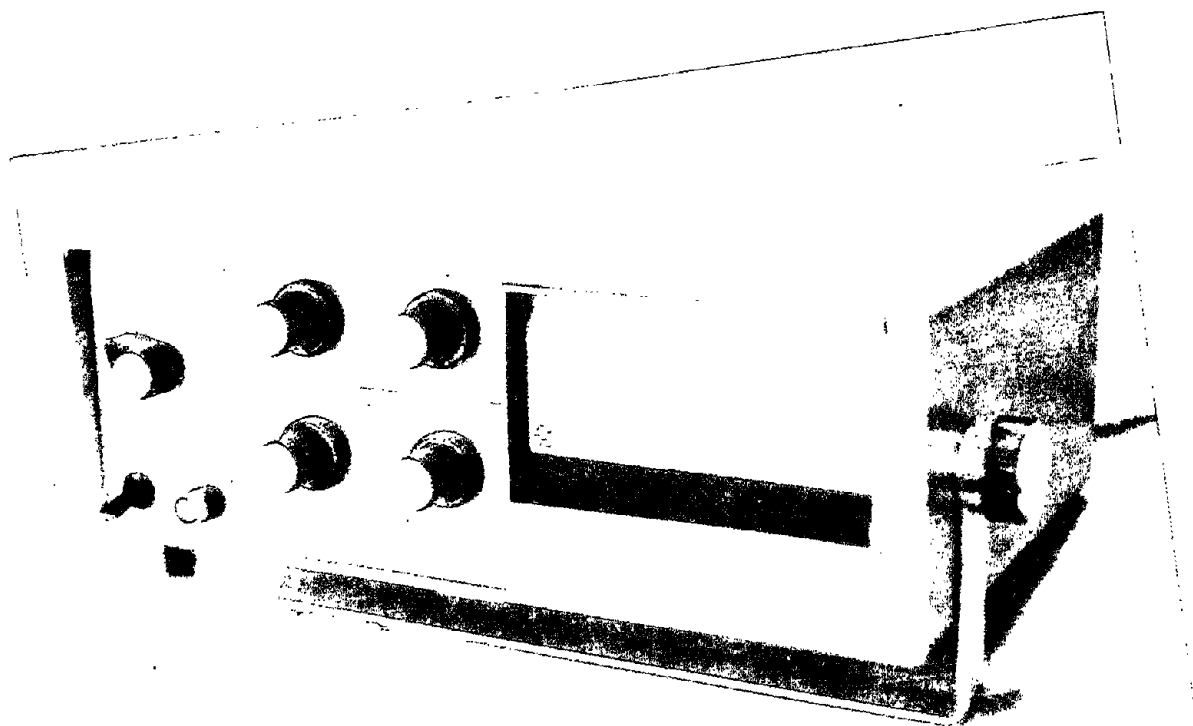


FIGURE 20. - Electrochemical SO_2 and NO detector manufactured by Enviro Metrics.

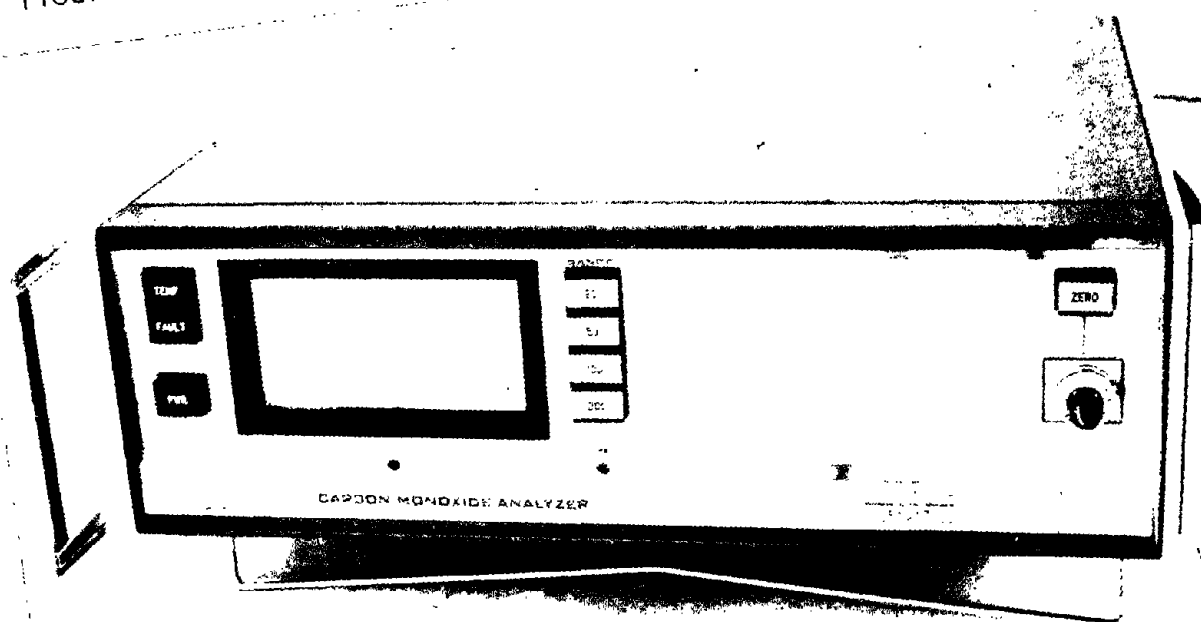


FIGURE 21. - Nondispersive infrared CO detector manufactured by Andros, Inc.



FIGURE 22. - Alpha ionization detector for NO_2 manufactured by Mine Safety Appliances Company.

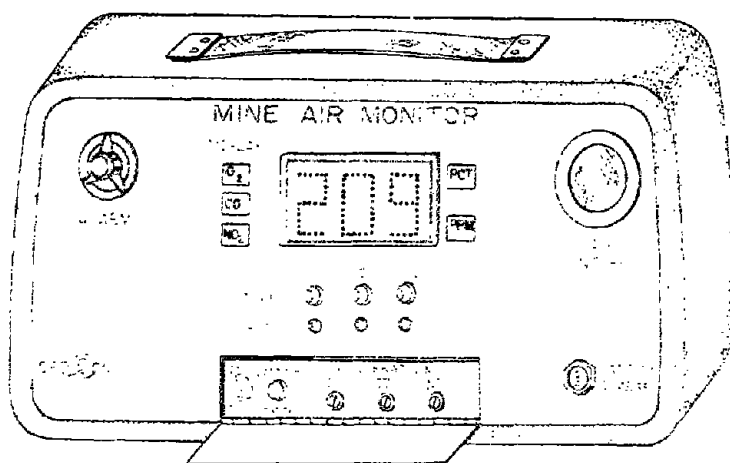


FIGURE 23. - Sketch of mine air monitor for CO , O_2 , and NO_2 under development by Texas Instruments for the Bureau of Mines.

detecting and resolving 5 ppm carbon monoxide. A breadboard model is being evaluated at this time. The final production prototype unit will be rugged, small (shoe-box size), and suitable for area monitoring or for rescue work. The unit price may be high, and because it is an optical device, contamination of the optical cavity by dust and water vapor must be minimized. This instrument could quite conceivably be on the market within this calendar year. A sketch of the instrument is shown in figure 24. As an indication of package size for multiple detection instruments, shown in figure 25, a four-channel detection system is being fabricated for Bureau rescue operations which will be capable of detecting CO , CO_2 , CH_4 , and O_2 . The device is self-contained, intrinsically safe, and will operate from internal batteries.

Stationary Instruments

Finally the concept of stationary monitoring should not be dismissed because of size since the state-of-the-art, in some cases, does not permit micro miniature detectors for some parameters. Since increased reliability can sometimes be obtained from a larger instrument, the suitability of this approach needs further consideration. In some cases it may be desirable to have a monitor not obstructed by

the actions of the men and machines. Also, if the instrumentation is too large to be carried by a miner, if suitable locations, such as an air split,

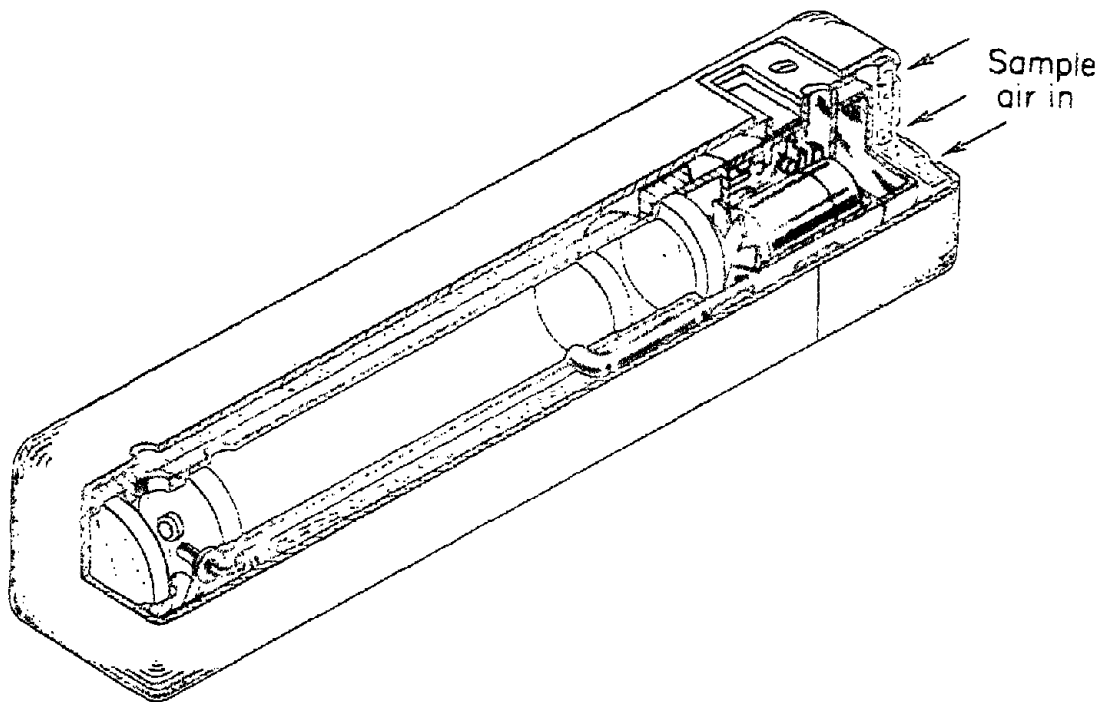


FIGURE 24. - Sketch of portable infrared CO detector being developed by Perkin-Elmer Inc. for the Bureau of Mines and NASA.

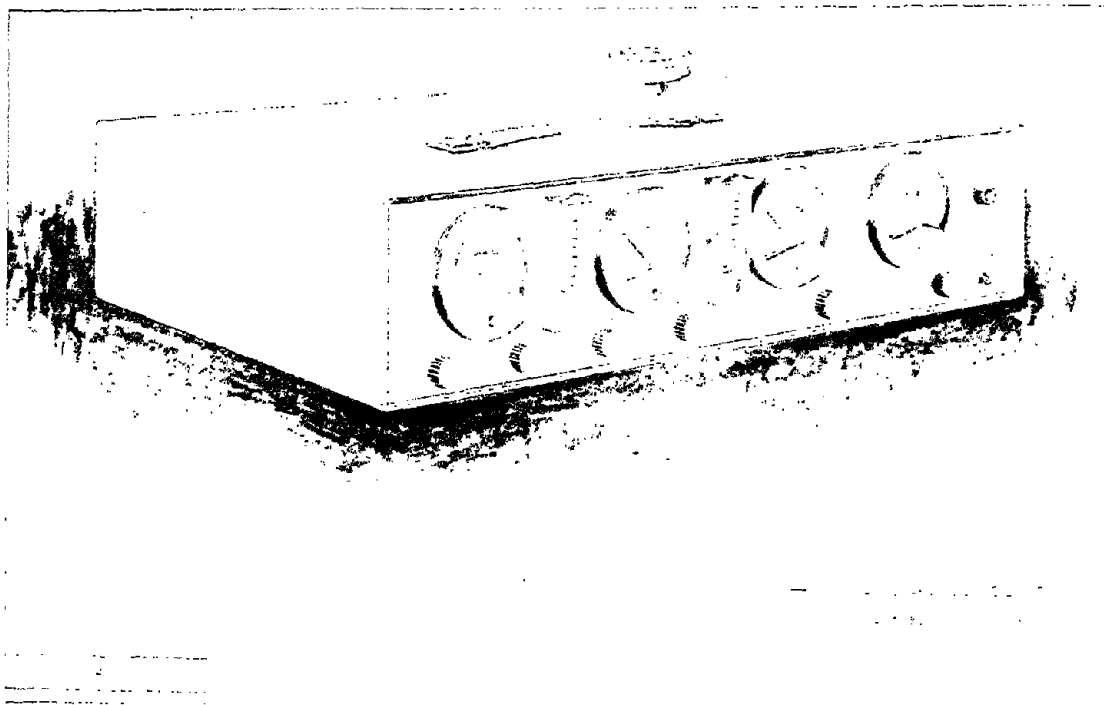


FIGURE 25. - Portable four-channel detection system for CH_4 , CO, CO_2 , and O_2 being manufactured by Mine Safety Appliances Co. for the Bureau of Mines.

can be instrumented and provided with power mains, this approach can be used to monitor contaminants. This approach may be preferable to carrying a battery-powered device that would be more vulnerable to accidental damage. Monitoring at appropriate points with provisions to alarm workers may be better than taking incremental samples at large time intervals.

The following projects are presently underway to implement the concepts discussed above. While some of these programs are presently not directed toward the monitoring of contaminants from diesel exhaust, the monitoring system (with different sensors) is directly applicable.

The University of West Virginia is developing, under contract to the Bureau of Mines, an integrated monitoring system for use in operating coal mines. Surveillance of a designated mine area is achieved by placing several sensor packages at major air splits; a typical sensor system, installed in the Federal No. 2 mine, is shown in figure 26. The sensor outputs are fed to a nearby telemetry transmitter and, in turn, transmitted to a central data processor. The sensor package with cover removed is shown in figure 27. The system has been operating in the Federal No. 2 mine, monitoring the developing six left entries off the 1 East mains. Four intrinsically safe sensor packages, each located in independent airways, are connected to a telemetry transmitter in fresh air by multiconductor cable. Telemetry signals are carried on standard twisted pair telephone wires to outside the mine and then by commercial telephone lines to the data processing center at the University. The entire system is computer controlled. A teletype at the mine permits data readout on demand and automatic warning of abnormal mine conditions.

The parameters monitored and method of detection are as follows:

1. Methane concentration using catalytic combustion detector.
2. Carbon monoxide presence using chemical color tabs.
3. Oxygen concentration using fuel cells.
4. Air temperature using linearized thermistors.
5. Humidity using linearized thermistors (wet bulb-dry bulb method).
6. Air velocity using hot wire.
7. Differential pressure using the force balance method.

The telemetry station (24 inches by 36 inches by 18 inches) and four sensor packages (each 8 inches by 12 inches by 15 inches) require about 200 watts at 110 volts ac.



FIGURE 26. - Mine monitor station installed in Federal No. 2 mine by West Virginia University on Bureau sponsored grant.

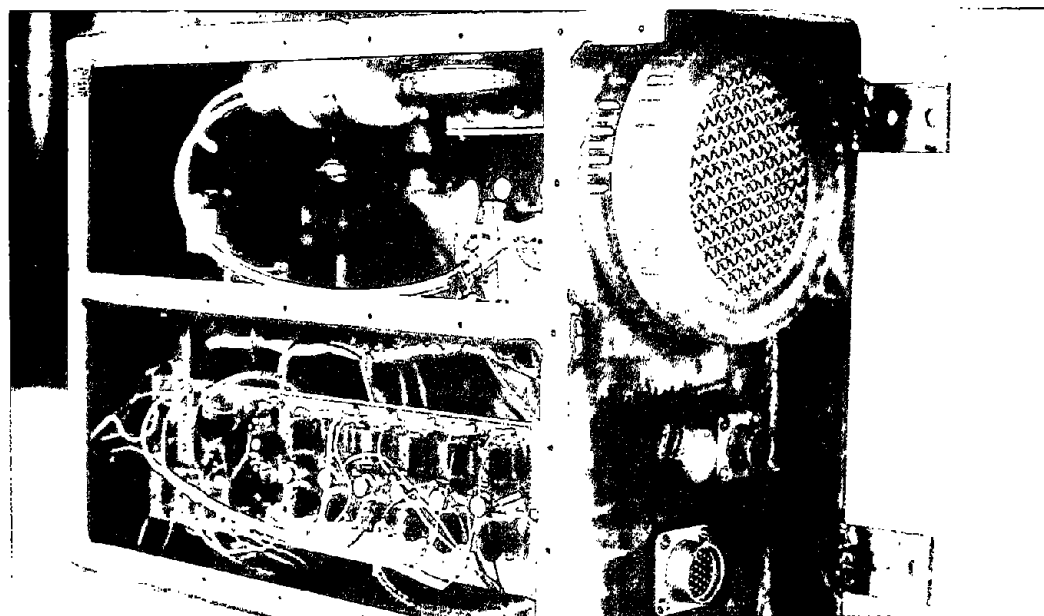


FIGURE 27. - West Virginia University mine monitor station with cover removed.

This system is capable of providing the following information:

1. When parameters exceed given limits;
2. The occurrence and approximate location of (1) major roof falls, (2) fire, (3) abnormal methane liberation, (4) blackdamp, (5) air regulator changes, and (6) reversal of air flow; and
3. Ready analysis of daily and weekly changes in ventilation resistance and methane liberation to aid the mining engineer in planning future ventilation needs.

While such monitoring systems are normally stationary, flexibility can be achieved in some cases via the use of sample tube bundles as shown in figure 28. This concept has been used previously in European mines to aspirate samples for many miles, for fire detection (CO) and methane control purposes. The technique may be applicable for environmental monitoring of diesel contaminants subject to problems of absorption of some contaminants on the tube walls.

A monitoring system has been designed and installed in the Bureau's Safety Research Coal Mine at Bruceton, Pa., which was developed by Mine Safety Appliances (MSA) on a competitively awarded contract to assess the utility and problems of mine area monitoring. The system has numerous detection and display options available; in a given commercial mine installation all of the features would not be used but have been included in this system for evaluation of the respective merits and to demonstrate the various ways of implementing mine monitoring techniques. One of the mine monitor stations is shown in figure 29. For example, one area of concern is fire detection and one or more of the following systems could fulfill this requirement: Smoke, carbon monoxide, hydrogen, temperature, and temperature rate of rise.

The parameters selected for monitoring and the principles of detection are as follows:

1. Methane concentration using catalytic combustion sensors.
2. Carbon monoxide concentration using catalytic combustion (Hopcolite).
3. Hydrogen concentration using catalytic combustion.
4. Air velocity using a hot wire anemometer.
5. Smoke density using an ionization detector.
6. Air temperature using a resistance wire probe.
7. Rate of change of air temperature derived from the temperature sensor.
8. Noise exposure using a modified sound-level meter.

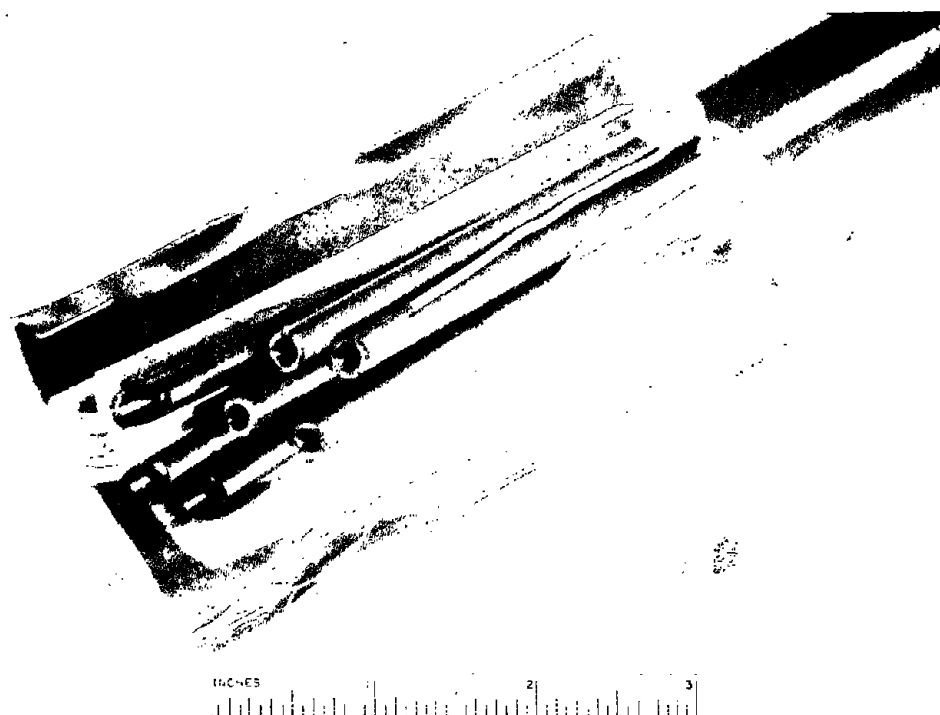


FIGURE 28. - Sample tube bundles that could be used for mine monitoring.

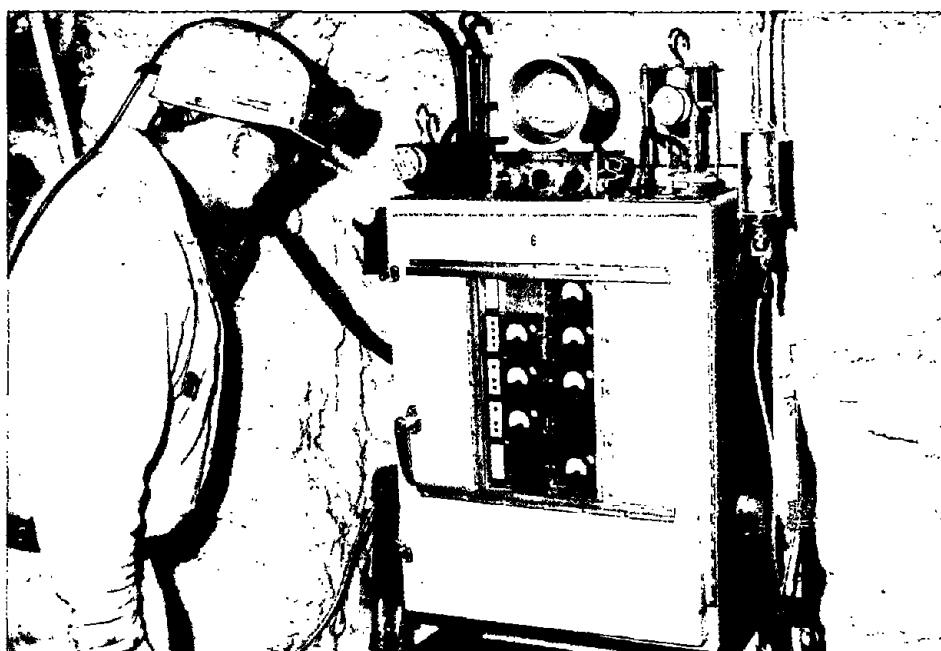


FIGURE 29. - Mine monitor station installed in Bureau's Safety Research Coal Mine.

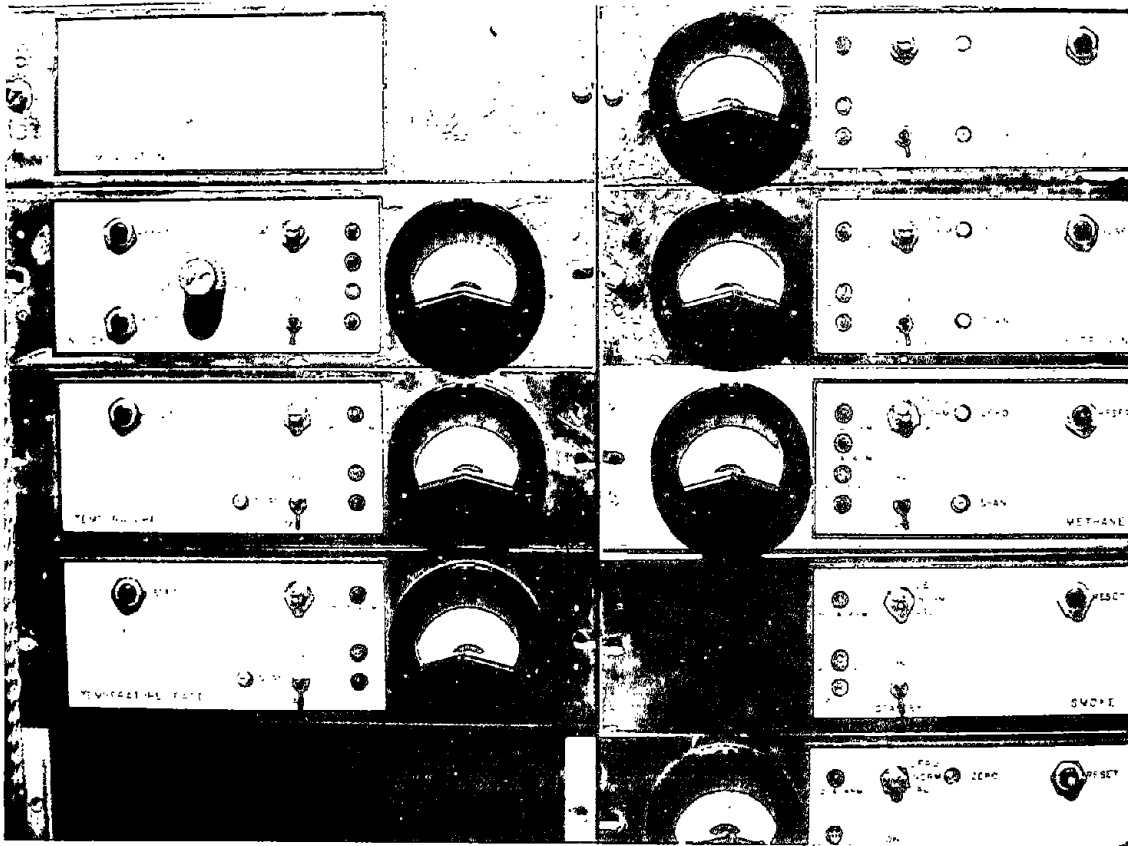


FIGURE 30. - Modular instrument trays of the mine monitor station.

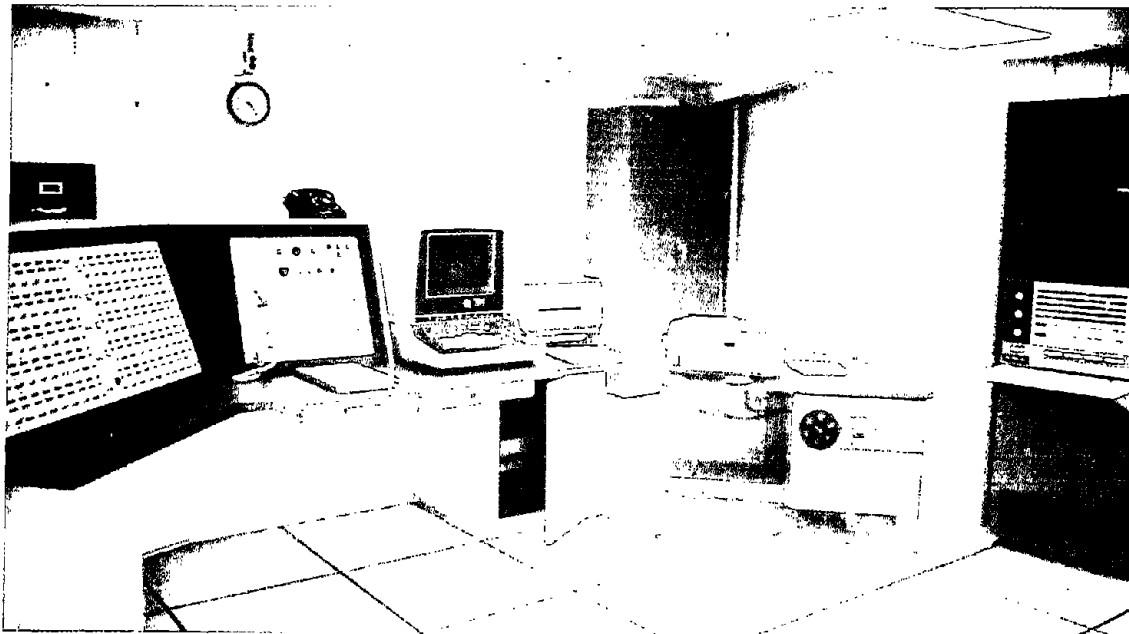


FIGURE 31. - Surface station for Bruceton mine monitor system.

A closeup of the modular instrument trays is shown in figure 30.

The surface station shown in figure 31 provides a variety of options for display and presentation of data, including a light panel (fig. 32), which gives the status of each sensor and indicates alarms if present; alternatively

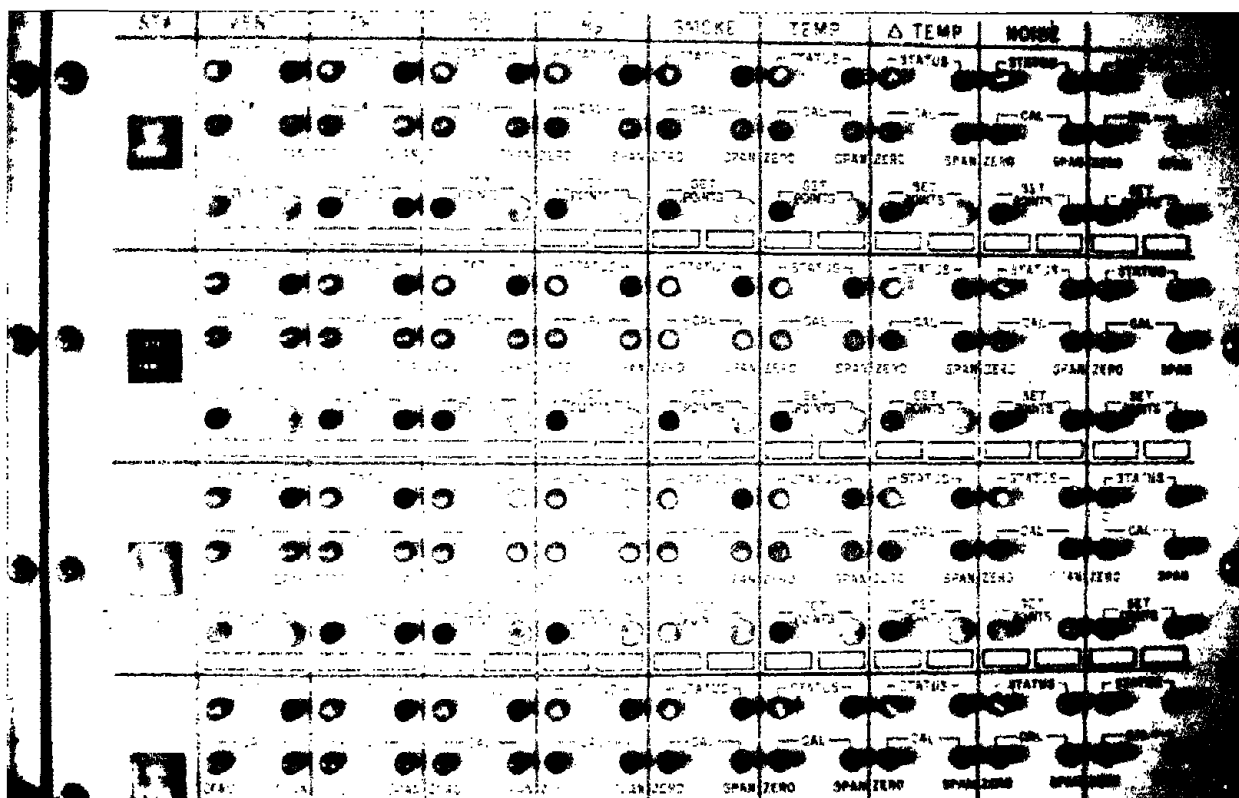


FIGURE 32. - Closeup of light indicator panel of surface monitor station installed at Bruceton.

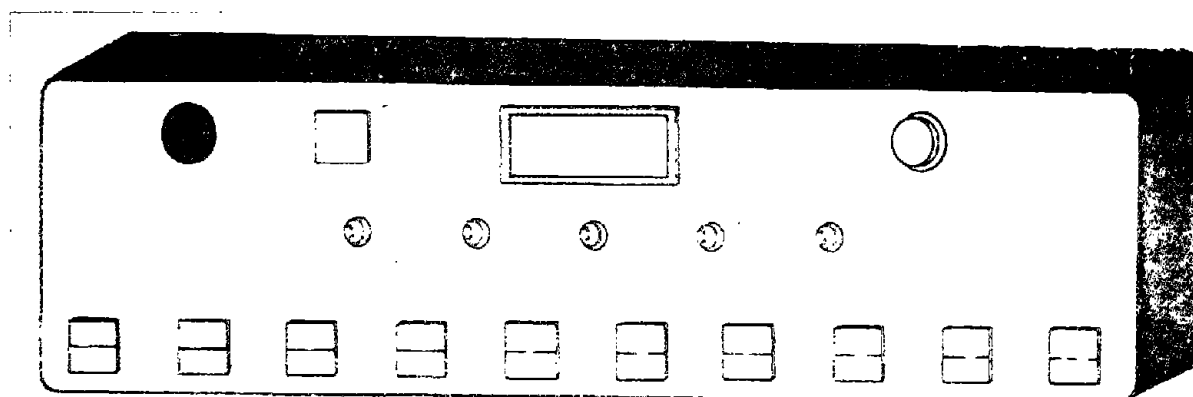


FIGURE 33. - Surface monitor station of miniaturized system under development by PMSRC.

a cathode-ray display or a printer are available as output devices. One of these display devices should be adequate for an operating mine.

The system is controlled by a minicomputer and has the capability of storing data on magnetic tape. (One tape will store data acquired over 1 month at the rate of one complete scan of the system, 80 sensors per minute.) It will recall selected data in either tabular or graphic form as well as tabulating data from selected sensors in real time. This is valuable as a research tool to assess the stability and performance of sensors, etc. All control signals and data are transmitted over two-conductor voice-grade cable.

This system approach has the advantage of being able to display simultaneously a large number of parameters on a real-time basis and to store and recall data.

Based on the experience and techniques developed above, PMSRC is assembling a prime monitoring system that will continuously monitor five selected areas of a mine and warn of potentially dangerous levels of five selected parameters. Alarm conditions will be transmitted via a single two-conductor cable to a surface station (fig. 33) where readouts from any sensor can be obtained on demand.

The parameters selected for monitoring and the method of detection are as follows:

1. Methane concentration using catalytic combustion detectors.
2. Carbon monoxide concentration using an electrochemical cell.
3. Air velocity using a vane-type anemometer with electrical analog output.
4. Air temperature using linearized thermistors.
5. Rate of change of air temperature derived in an electrical circuit from the air temperature sensor.

Equipment is presently being assembled and should be ready for installation about mid-May 1973.

Each underground station will be contained in two environmental-proof metal boxes about 12 by 12 by 6 inches (fig. 34), one box to contain the sensors and associated electronics and the second (remote) box, to house the power supply. The sensor package will be intrinsically safe and can be located in return airways, etc.

This system will provide area monitoring within a mine with minimum hardware requirements and utilizing existing telephone lines or relatively inexpensive two-conductor cable. The potential exists also for utilizing the power ground-check circuit for signal transmission with an inexpensive voice-grade carrier.

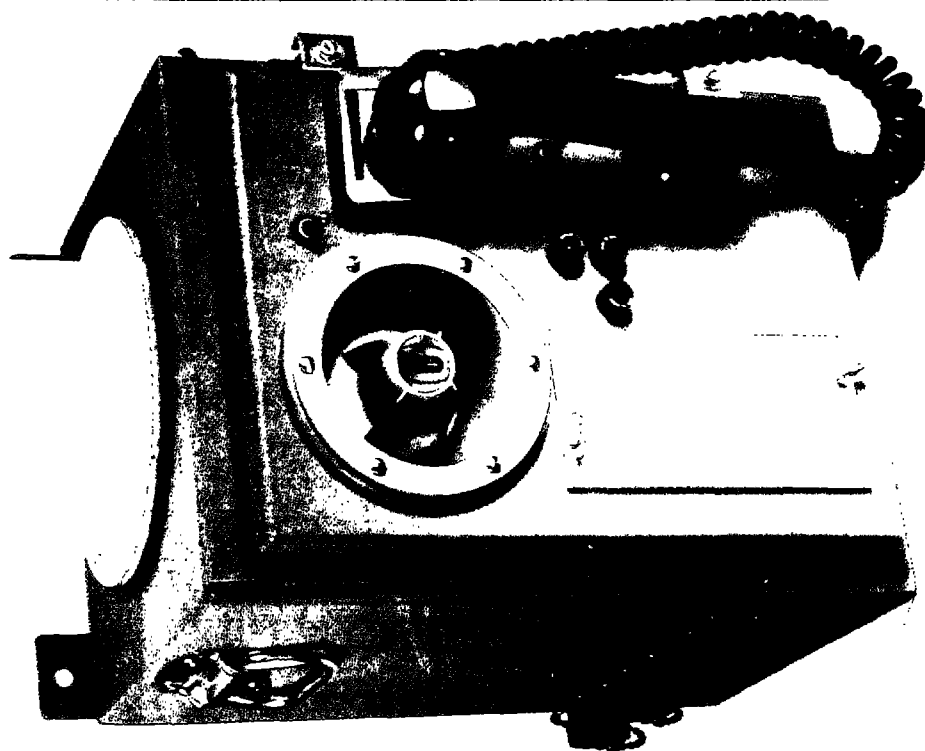


FIGURE 35. - Call box for in-mine use to provide monitoring and communications developed by Westinghouse Research for the Bureau of Mines.

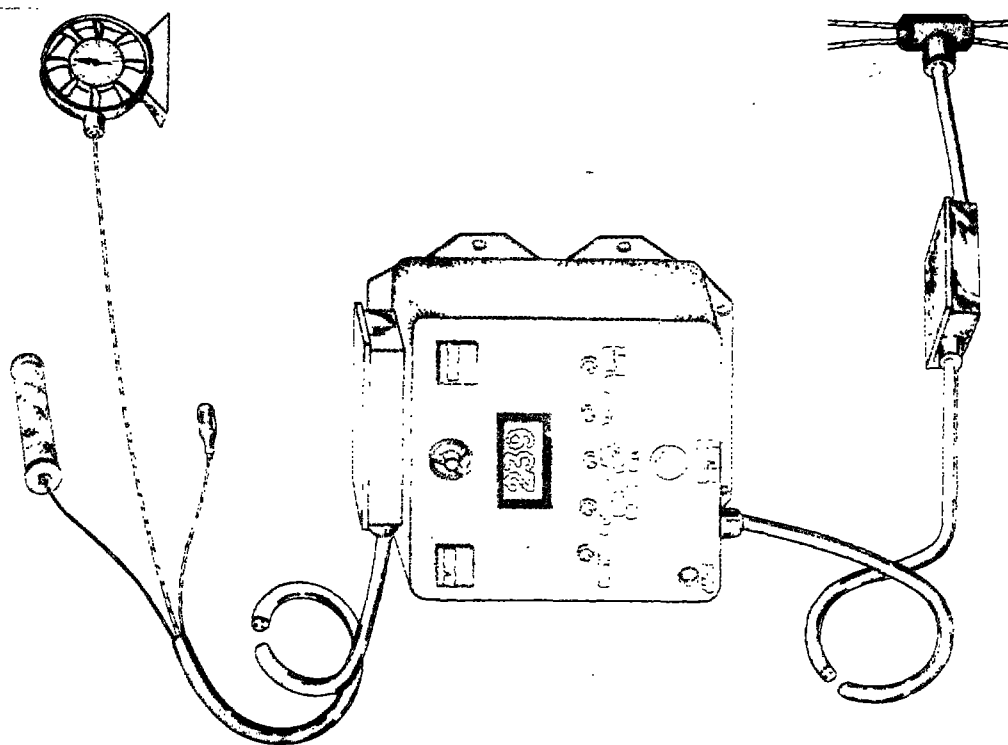


FIGURE 34. - Underground station to monitor CO , CH_4 , ventilation, and temperature.

A monitoring, locating, and communications system for normal mine operating and for postdisaster rescue operation has been fabricated by Westinghouse Research for the Bureau of Mines. The system will permit the following:

1. Single parameter monitoring per subsurface station.
2. Identification of the locator subsystem being operated.
3. Signaling from substation to surface station.
4. Two-way voice communication to the surface station.

The system uses transmission over mine phone lines and/or through earth-rock overburden. Each subsurface station (fig. 35) operates from a 400-volt ac float-charge battery and transmits the status of a single parameter in one of three discrete levels: normal, above normal, below normal. The surface station (fig. 36) monitors, accumulates, and compiles data from all substations. Above-normal signals from any subsurface station will trigger audible and visual alarms with the visual alarm identifying the substation.

A system consisting of one surface station and three subsurface stations has been installed at the Bureau of Mines Safety Research Coal Mine in Bruceton, Pa. The system offers numerous operational and emergency advantages in that it provides an alternative path for communications and the monitoring function desired.

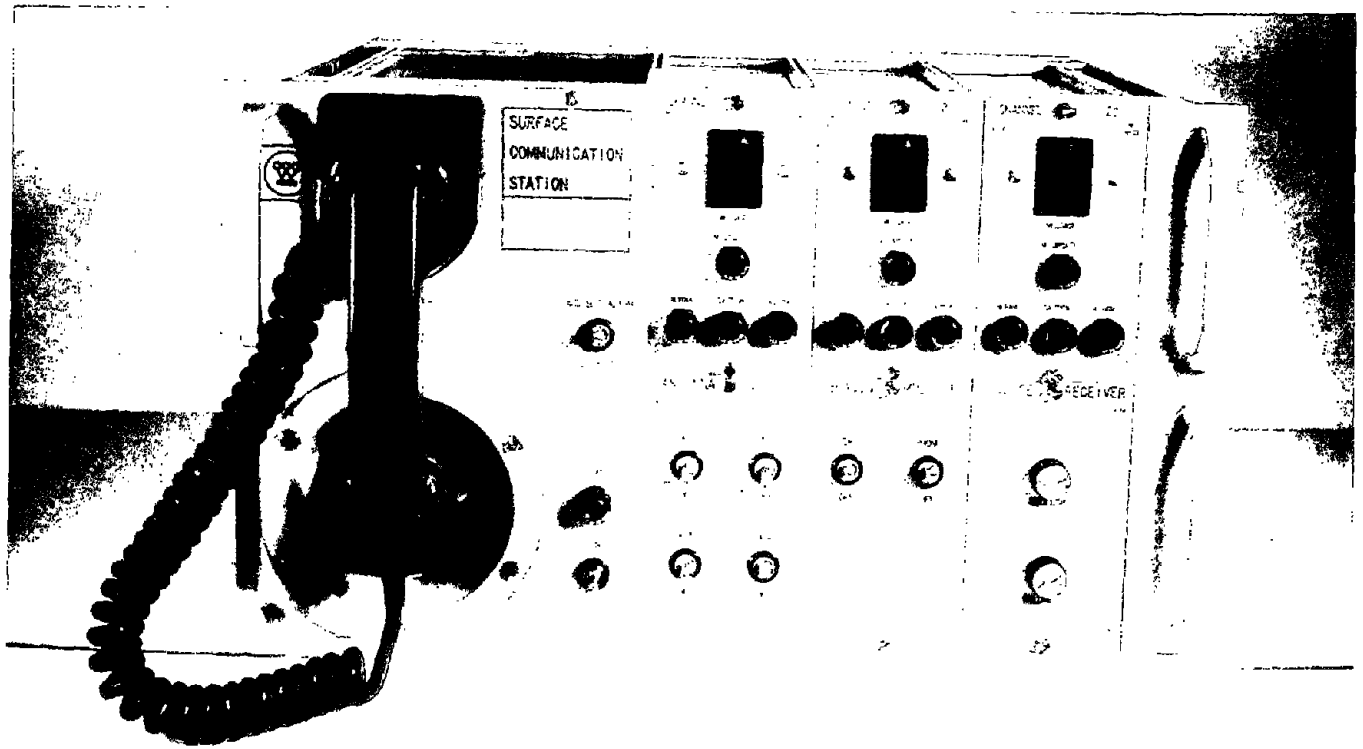


FIGURE 36. - Surface station for mine communications and monitoring system.

SHORT-TERM PROJECTIONS

As new instruments are developed and become available for in-mine use, it would be advantageous both to the equipment manufacturer and to the mine operator to be able to have instruments that have passed performance specifications, both in terms of their suitability for the environment anticipated as well as their reliability to monitor contaminants under the environmental conditions in which the instruments will be exposed. The use of pertinent sections of Military Specifications, which can include the important environmental parameters but not significantly increase the cost of the instruments, can be used to the best advantage of the mining community.

Electronic instrumentation for underground use should conform to the general provisions of MIL-STD-454C (7) insofar as the specifications set forth therein do not conflict with Bureau of Mines Schedule 2G or other Bureau of Mines documentation which will take precedence over MIL-STD-454C.

In addition, all instrumentation, be it electronic or otherwise, the proper function of which is to warn of or indicate the presence of harmful airborne contaminants and the failure of which to do so would endanger the health and safety of mine personnel, should be subjected to environmental tests of such severity and content that if the instrument continues to operate in a satisfactory manner a high degree of confidence will have been established that the item can perform in a reliable and accurate manner in the field environment.

Environmental tests should include the variables--temperature, relative humidity, shock, and vibration--over ranges exceeding those actually occurring in the field. Suggested environmental tests can be found in MIL-STD-810B (6).

In terms of range of the instruments, a recommended range would be 4 to 5 times the TLV, with an accuracy of ± 10 percent of the TLV at 2 times the TLV on the instrument as shown in table 1. In terms of short term projections and conclusions, the indicating tubes are commercially available, give resolutions of approximately ± 25 percent, and this reliability should be assured in terms of the recently proposed standards by the Secretary of Health, Education and Welfare (8) for quality control of indicating tubes. Other agencies are also sponsoring research and development efforts that could be applicable to the underground problems (9). Although the length-of-stain tube is used rather extensively in underground operations, the variations are on the order of ± 25 to 30 percent and they cost approximately \$1 per tube (that is, \$1 per reading). Hence the need for reliable, portable instrumentation is apparent. Some of the personal indicating devices, for example that for oxygen, are commercially available and quite suitable. Other alarms and dosimeters should be available in 1 to 2 years, principally electrochemical and low-power, nondispersive infrared instruments with accuracies on the order of ± 2 to 5 percent. Portable instruments are generally available at the moment with accuracies of ± 1 to 2 percent full scale. Efforts in this area will have to be directed toward the reduction of the size of the devices and modification of packaging for suitability in the mine environment. In terms of stationary instruments, existing devices have typically an accuracy of ± 1 percent as

discussed above. A survey of the types of detectors and accuracies is provided in table 2. Stationary monitoring primarily consists of (1) the detection instruments and (2) the telemetry and display. Telemetry and display techniques have been demonstrated in operating mines with additional hardware, which is more compact and more reasonably priced, to follow shortly. The majority of detection instrumentation has or will be in underground mines shortly, with the anticipation that in approximately 18 months engineering prototypes will be available and will have been demonstrated in operating mines.

TABLE 1. - Recommended portable gas analysis instrument specifications

Gas	TLV ¹	Range	Accuracy	Availability	
				Hand	Portable
CO..	35 ppm	0-250 ppm	0-100 ppm $\pm$ 5 ppm	1-2 years	Electro-chemical, presently
NO..	25 ppm	0-100 ppm	0-50 ppm $\pm$ 2.5 ppm	1-2 years	Electro-chemical, 6 months-1 year.
NO ₂ .	Ceiling 5 ppm	0-25 ppm	0-10 ppm $\pm$ 0.5 ppm 10-25 ppm $\pm$ 5 percent full scale	1-2 years	Electro-chemical, 6 months-1 year.
CO ₂ .	0.5 percent	0-2.5 percent	0-1.0 percent $\pm$ 0.05 percent 1-2.5 percent $\pm$ 0.1 percent CO ₂	?	NDIR, 1-2 years
O ₂ ..	16 percent	0-25 percent $\pm$ 0.5 percent O ₂		Presently	Presently

¹TLV or discussed modifications in TLV's.

TABLE 2. - Gas detection state-of-the-art (for underground use)

Gas	TLV	Detector tubes range accuracy at TLV	Hand-held portable	Portable	Stationary laboratory
CO...	50 or 35 ppm	10-3,000 ppm ±25 percent TLV.	None commercially available (electro- chemical prototype).	~0-500 ppm ±1 percent full scale (Hopcolite). ~0-100/500 ±1 percent full scale (electro- chemical).	NDIR ¹ 0-200 ppm ±1 percent
CO ₂ ..	5,000 ppm or 0.5 percent	0.1-10 percent ±10 to 20 percent.	None.	NDIR prototype 0.1-5 ±5 percent.	NDIR 0.03 to 10 ±1 percent full scale (range selectable).
NO...	25 ppm	±25 percent TLV.	None.	0-20 ppm ±2 percent full scale electro- chemical laboratory instrument.	0.01-5,000 ppm (chemilumin- escent).
NO ₂ ..	5 ppm	0.1-50 ppm ±25 percent TLV.	None.	0-5 ppm ±2 percent full scale (electro- chemical).	Do.
O ₂ ...	16 percent	2-30 ±0.2 percent full scale at TLV.	0-25 ±2 percent (electro- chemical).	0-25 ±1 percent full scale (paramagnetic, delicate).	Paramagnetic.

¹Not permissible.

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DR. KERR: I am going to pull a nasty trick now. In your crystal ball, how far down the road do you see continuous monitoring of the mine environment for carbon monoxide and NO₂?

MR. MURPHY: Well, let me answer that in two parts. I will arbitrarily divide the continuous monitoring systems into the sensor and the electronics, including the telemetry and so forth. The system, aside from the transducer, is what is used today. Carbon monoxide monitoring has been demonstrated in one operating mine. We have some improved hardware that we expect to demonstrate in additional operating mines within the year. The real problem, if you please, is the reliability and suitability of the transducer used to monitor these parameters. I feel confident that the CO monitoring from an area viewpoint is here. We have instruments that are either underground or will go underground shortly that can be used for reliable area monitoring of CO. NO₂ is a little bit behind us, but it is justified to make a prediction in terms of whether a complete system could be operational and available for every mine. It looks to us as though it will be, say, 12 to 18 months before an engineering prototype will be available for tests.

DR. KERR: One other point. Is there any arrangement built in the mechanism to shut off the sources of any harmful contaminants?

MR. MURPHY: Do you want me to put the trailing cable back on the diesel shuttle car? I should not really stand on that point because we are actively involved in some communication to mobile equipment. This is something that is available and which we can demonstrate at Bruceton. I guess, in a general way, I could say that the communication technology is in the same category as the telemetry technology, and it is a matter of integrating these systems. I have to be careful that I haven't addressed in detail the cost effectiveness of this or the absolute economies that it would cost to do this, but technically, I think it is as feasible as the rest of the recommendations I discussed.

MR. PELUSO: Thank you. That ends our regularly scheduled session, and I would like to thank each of the speakers for an excellent presentation. We are now going to go to our added speakers.

DR. KERR: There has been an arrangement made whereby there now will be a presentation by the miners--the men who are actually working in the environment that we have been talking about. I would like to have those four men come to the platform.

Mr. McAteer, who is the special consultant to Mr. Arnold R. Miller, President of the United Mine Workers of America on matters of safety, will introduce each of these men for their presentation. Mr. McAteer.

MR. McATEER: Thank you, Dr. Kerr. We would like to thank the Bureau of Mines for making this additional segment in the symposium available. I, as representative of the new administration of the United Mine Workers, will simply say very briefly that in the past, the Mine Workers have neither

received, been given, nor have they taken it upon themselves to represent most directly, most emphatically, the interest of the miners. That has changed. We intend to represent the interest of the miners. For that reason, we are here. For that reason, we would like to emphasize, generally, that while opposition to the diesel equipment has traditionally been the position of the mine workers, we will take a good hard look at it. But in doing so, what we intend to do is shift the burden away from the coal miners to the companies and the Bureau of Mines. If in fact, you companies want to put diesels in the coal mines, then you must prove to us beyond a shadow of a doubt that there will not be harmful effects in the mines, and to the men who will operate the machines. In keeping with that tradition, and in keeping with that idea, what we would like to do now is introduce individuals who will be running the machinery and people who will be directly involved with diesel equipment. It is very easy to make a decision on diesels in the corporate boardroom, where it will not affect your own health and safety. The more important factor will be the miners. They are the individuals with whom we must be concerned.

The first gentleman I would like to introduce is Mr. Thomas Hutchinson, Chairman of the Mine Health and Safety Committee at his mine. He has been a miner for 32 years, and he has some thoughts on just exactly how he would feel if the diesels were brought in.

Thank you.

MR. HUTCHINSON: I made some notes here. After hearing all these introductions, I feel like the weasel in the henhouse.

Nevertheless, I have been a miner for 32 years, and I also own, operate, and maintain two Massey Ferguson diesel farm tractors. I am familiar to some extent with the maintenance of diesel engines. To back up some of the statements I am going to make, you all have this blue folder. If you will please turn to paper 8, in about the center, not page 8, but paper 8, about the center of the folder, on the reverse side, page 2, Services and Maintenance. A definite check list for servicing the diesel engine must be provided and used regularly and thoroughly. Diesel-powered equipment, generally requires more service than electric-powered equipment. This, however, must be weighed against the greater operating versatility and greater safety. Overall, downtime will probably be increased because of the need of regular service and a maintenance program.

Now, let us keep in mind that when servicing a diesel engine, we are speaking of emptying and replacing the fuel, the first and second stage fuel filters, and we will probably find it necessary to bleed the air from the entire fuel system, all the way from the primary pump to the injector nozzles, each time the operation is completed. Now, if we want to bleed all the air out of the system, we must recycle the operation. While performing this operation, we can visualize the amount of fuel that will be spilled in and around the engine. Keeping in mind that the diesel engine operates most efficiently at a high temperature, this fuel will vaporize and give off toxic fumes, detrimental to the coal miner. Understand, we have not considered servicing the crank case. It is practically impossible to keep an operating diesel engine free from oil spillage on and around the engine. The Bureau of Mines, both

Federal and State, employ a small army of inspectors to insure the working miner that the coal operators keep their electrical equipment in compliance with the law. Therefore, taking into consideration the maintenance necessary on the diesel engine, how could we possibly believe that the coal operator would maintain this diesel equipment in a permissible and efficient working condition that would not be detrimental to the health of the working miner, even without considering the type of device to neutralize the exhaust fumes from the engine. Based on these and other facts, we, the working miners, object to the use of diesel equipment underground.

We also object to the manner in which this symposium is being conducted. The working miner, who has to be concerned with these conditions, has been completely ignored. These experts on the various panels know nothing at all about practical coal mining problems. I assure you, that when the coal companies try to introduce diesel equipment underground, they are going to be in for the battle of their lives. The mining of the coal depends on the willingness of the miner to perform the work not on a decision of a handful of supposed experts.

MR. McATEER: Thank you, Mr. Hutchinson. Next, we would like to introduce Mr. Marion Ladisic. He is an assistant to the vice-president, Michael Trobovich. He is chairman of the Mine, Health and Safety Committee. He has been president of the Local Union, 1197. Mr. Ladisic.

MR. LADISIC: Thank you, Mr. Chairman.

Ladies and gentlemen, what position can a working miner take? I ran a continuous mining machine for a number of years in a mine, and I also have 29 years of experience in the coal mine. Now, we are contemplating putting a diesel shuttle car line in the mines. Consider the problems that we have had with the coal dust in the air--now we are going to put another atmospheric hazard in the mines. A number of times, while operating a machine, I did not have ample air, nor was I protected from coal dust. It resulted in pneumoconiosis. Twenty years ago, no one had ever heard of pneumoconiosis. Now, it is prevalent in the mining industry. What are we going to call the new disease 10 years from now, "dieselosis?" They are putting bigger tires on the machines, on the buggies. How much more dust will this put into the atmosphere going up over the miner? You are also putting carbon monoxide in the air at this time with these diesel shuttle cars. The monitoring system on the proposed diesel shuttle car is not adequate. I feel slighted as a miner operator. You are putting no monitor to protect the operator. Why don't you put the monitoring system on the miner, where the carbon monoxide fumes are going to go, before they go into the returns?

There are serious maintenance problems with these diesel shuttle cars. Companies bring a machine in the mine, yet they did not give the people that maintain them ample schooling to service them. Monitors, such as methane monitors that are on the mining machines now are not adequate. The monitoring system that they are going to put on these diesels will probably be the same way. There has not been enough research done on the monitoring system to guarantee at this time that my lungs will be free of "dieselosis." What

chance are we taking by putting these diesels in the mines, pertaining to the explosives, the explosive factor in the mine?

And lastly, we have a Union in this organization, and if this system is not adequate, we are going to take the steps to see that it is made right.

I thank you, ladies and gentlemen.

MR. McATEER: Thank you, Mr. Ladisic. Finally, we would like to present Mr. George Resick, Pennsylvania State mine inspector, and the chairman of the Pennsylvania Committee to study diesel equipment for Pennsylvania coal mines. He has been a miner for quite some time, and he will begin his presentation from the standpoint of what effect it will have on the individual miner.

MR. RESICK: Thank you, Davitt.

Dr. Kerr, ladies and gentlemen, I am George Resick, Pennsylvania State mine inspector from Arnold, Pa. I finished the eighth grade, and then went straight into the school of hard knocks, where I graduated "Magna Cum Loaded." In fact, I was a fifth above most of the class all through the course, and my professor gave me a crash course because my exhaust emissions were always near the low explosive range. As a matter of fact, my lungs are full of the dust too.

You know, I am here with mixed emotions. Just this morning, I was told that I would be on the program, and I honestly wonder what is going on. I picked up the paper last week, and I see where our President tells us about an energy crisis. In another portion of our paper, I read that our Governor says to lower the temperature on the thermostats, and for girls to get those dresses down a little further. And here we are for 2 days selling diesel fuel like crazy! I suppose we found a new source of diesel fuel, otherwise, why are we selling it?

In talking to one of the local university professors in December, I told him that we were conducting some studies about the exhaust emission gases that come from diesel engines, and he started to giggle! I mean this! He said that we are talking about making extensive studies on quality air improvement--on diesel engines, on our streets, in our tunnels, and on our highways, and there isn't a good answer, and he said we are out in the wide open spaces. What the hell are you guys trying to do in the coal mines? I tried to tell him that we are trying to make a study based on our concern that we are going to do something for the workmen and to try to keep them in good health. He was very cooperative, as were a number of other people. I would like to name the people who have helped us in our study. We have gone to the Federal Bureau of Mines, both to their office and to Bruceton, Pa., to see not only their bulletins, but to actually see the shuttle car and the locomotive in operation. We have received from them a number of papers on diesel engines. We received their code of regulations entitled 30, Part 75. We have read papers on catalytic muffler control diesel fumes from a Canadian rock salt company. We have read about the theory in operation of the diesel engines from Cummings Diesel Electric. We have been prepped by the Diesel Committee

of the Department of Environmental Resources. We have a paper on diesel catalytic muffler purifiers through the courtesy of some people at Pennsylvania State University. We have papers on muffler purifiers from International Nickel Company. We have the diesel locomotive circular from the National Mine Service, and a discussion with one of the outstanding men, to me, Mr. Shoemaker of the National Mine Service on diesel engines. We have a paper called Clean Air and the Diesel. We have a circular on design factors that affect diesel emissions. With all this reading--and while I am down here, I probably will be invited to make a study of the salt mines after today's visit--well, I will be a little better prepared. Thus, it will only take me a short time to understand this new approach to mining.

This diesel engine thing is going to get big, and it is going to become a controversy. In the opening statements yesterday, one of the people mentioned that diesel equipment would eliminate the fire hazard from electricity, and possibly such occurrences as that in the mine in West Virginia, where some men died. In reading the proposed regulations, I noticed that there are no regulations that would require the removal or eliminate the use of electricity in our mines. If diesel power equipment is promoted, we are, in my opinion, creating some additional hazard with the proposed use of diesel-powered equipment, and the handling of the fuel, the transportation, and storage of same. The Bureau of Mines proposed regulations and other speakers used 50 ppm of pollutant as a criteria, yet we learn that the Environmental Protection Agency proposes 8 ppm in atmosphere for our city streets. The State of Pennsylvania has appointed a committee, namely, Frank Shoaf, Ed Shoemaker, and myself, to make a study and to learn everything that we can about diesel engines. At the present time, our study is inconclusive, and if I must use the term, there are a hell of a lot of questions that are unanswered!

My first concern in the State of Pennsylvania is for the health and safety of all the men working in the mines, and we are not going to use them for experiments. I have worked up some questions that I thought I might get a chance to ask. I did this last week, and the rest of my talk is going to be about some of the information that I learned during these past several months. I don't mean to be all derogatory, because there were some brilliant and learned men on the podium yesterday and today, and yet I would not be afraid to bet a shiny dime that their total combined time inside the coal mines in the last 2 years would hardly amount to 20 days. We have got to get some people who are on the practical side of coal mining in this type of program. These people, I enjoyed immensely. They knew their business, they knew how to present their papers and their views, and they were a good item in this meeting, but we have got to have practical men, people who can talk the coal miner's language. They have got to be in on these meetings as well as others. You surely don't want us to honor the greatness of the diesel engine in the ore, limestone, clay, and salt mines, which may have seam heights of 10 feet, 20 feet, or maybe 30 feet, and compare them with a coal seam that is under 48 inches, where our man is working on his knees with his nose right directly in the fumes.

Did you plan to give us another snow job, like the methane monitor? In other words, "We give you 1 month, they told the operators, to get them on all the machines," whether they work or not, get them on there. I tested 14 methane monitors and found 2 working in the first set of tests that I made on these pieces of equipment. If these fumes from emission systems don't harm anyone, who do diesel repair shops have a special corrugated hose from every repairman's location, so that fumes can be directed to the atmosphere? As a matter of fact, I talked with one of those fellows, and he said, "Do you think I am nuts that I would stand here and breathe these fumes?" He said, "I want them out the window." They put a hole in the window and the tubing went outside. With the intake air filter partially hidden by brackets and two hoses on one piece of equipment, how will they be readily accessible for cleaning in the dusty coal mines, possibly two or three times per shift? Or with your standard of 1 percent methane in work places that will burn approximately 1,100° F and 1,300° F and fine coal dust that will glow at 380° F? All the diesel fuel in the combustion chamber will not burn completely and the result will be in the mine air as carbon monoxide, nitrogen, nitrogen dioxide, aldehydes, or other possible harmful gases. In my opinion, fumes and emission control will be our greatest problems, if and when diesel engines are used in the mines of Pennsylvania.

Another person in the room told me this morning that there are methods of controlling the air-injection and the fuel-injection systems to cover the gases that might be present and the fine coal dust that might enter into the intake manifold. How do you plan to keep the fuel-injection system free of being tampered with, unless you provide some means of locking it? In other words, we heard yesterday a person who mentioned a grade, I believe, of up to 25 percent. If shuttle cars will not haul that grade, and our mechanics start messing around with that injection system other than the way it was originally set up, results from the exhaust emissions system will not be the best. We are going to be into some problems.

How will you suggest to maintenance and inspection people, mechanics, bosses, and inspectors to test compartment manifolds and so forth, when you expect to have 300° F on the outside of the engine as the temperature, and we know that 210° F to 212° F is the boiling point? How do you use a feeler gage around these compartments? Even if you can use a feeler gage, how can you get it around the hardware that is put next to the compartments when you can't even get your fingers in to use the feeler gage?

Do you expect the monitoring system on a unit in Bruceton, placed on a shuttle car at the operator cab, to be a guide for our study, when it is nowhere near the exhaust emission system? In other words, the sensor head and the monitor for carbon monoxide is not near the exhaust system of the shuttle car. It is on the outby side of the ventilation of the exhaust emission system and is near the right front wheel. If we are going to put these monitors where they are going to be of some good, then we better put them on the machine that is in front of the machine that is operating on diesel fuel, or in other words, on a loading machine in front of it. That is where that monitor ought to be. If it is a continuous miner, then it should be on the continuous miner, not on a shuttle car, where nothing but fresh air passes over the sensing device.

I have seen one unit of a national manufacturer that has been capable of testing exhaust emission gases in a showroom. However, where we visited, two units were not testing equipment available at that time. The equipment is probably available now, and I am glad to learn that it is.

We also have to consider the type of diesel fuel. And yet, I see no regulation that will differentiate distillate number 1, 2, or 3 diesel fuel. In talking with one of the diesel manufacturers, he told me, "George, you better make certain that they never go below number 2 grade."

You mentioned eliminating the hazards of electricity. Where are you going to safely store enough diesel fuel for six shifts in a section of a coal mine? Let us say you have two shuttle cars in the section, a supply tractor, a clean-up scooper, and a small personnel carrier. You are going to have 300 to 500 gallons of diesel fuel in that section. If I am any judge of anything, a fire with this amount of fuel around would not exactly be a boy scout bonfire when it gets started.

You mentioned that the storage depot should be ventilated at six changes per hour. You know, I have done a little searching. Where do you find this medieval term, six air changes per hour? We had better have a continuous flow of air, not just six air changes. We are dealing with men, not cattle. For instance, if we have a storage of 10 by 10 by 6, we would have 600 cubic feet times six changes, which would mean 3,600 cubic feet of air. I do not know if we can even measure that with a smoke tube.

You make no mention of possible turbulence due to the blowing from the cooling system fan and the emission scrubber, but there will be a retardation to normal mine air flows to the work face, from these two sources. They will tend to throw fine dust in suspension, and crack this smoke tube near the radiator or cooling system. If it was 5 or 6 feet from the coal rib, in less than 2 seconds, the smoke would expand against that coal rib.

You mentioned making tests of emission gases every 4 hours. Do you realize that that only means once per shift while the machinery is in operation? For instance, the men go in the mine and they land in their section at 8:20 a.m. The boss makes all the necessary tests. Four hours later, he must make a test, that is, at 12:20 p.m. In 4 hours, it is 4:20 p.m. and the miners are outside. Hence, during the working shift that this crew is in the mine and those engines are in use, you are requiring only one test for the exhaust emission gases.

You mentioned that if the diesel engine is idled for 5 minutes, it should be stopped. This is fine, but if we can create a fume or gas hazard in 5 minutes, then we better consider some tests be made before this piece of equipment is restarted, particularly in deadends or crosscuts, or in a crosscut near a stopping. We must be certain that we have automatic features on diesel engines when they are overheated, when lubricant is overheated, when excessive dangerous gases are emitted from the engine, when we have engine malfunctions, and that the engine will be stopped and not run again until repaired. We must regulate, where, when, and how the batteries on each diesel unit will be safely installed and safely recharged. We must regulate the air that is ventilated

when charging is conducted. On a test shuttle car and locomotive we saw asbestos gaskets and rubberized gaskets on manifolds; we must make certain that we have metal-to-metal points--in fact, we should have step-flange arrangements. We also may need to use a brush and soapsuds to find leaks when testing. We must avoid suggestions as to "color and/or odor" of exhaust fumes, as this is not certain criteria for our guidance, because we have people who are slightly color blind even though they will never admit it. We have people whose nostrils are not as sensitive to picking up odor as other people's are, and there will be arguments.

I might add, that the quantity of air that is going to pass over a diesel unit will need to be greater than the quantity specified on the name plate. I am going to tell you pencil boys that you should not tell practical coal mining men how much air they need. As a matter of fact, if the regulations are carried out, the 11,500 cubic feet of air per minute for the first piece of equipment and 75 additional percent for the second, 50 additional percent for the third. If you have four pieces of equipment, another 50 percent, you are talking like one of the men mentioned yesterday--the intake is 28,000 cubic feet per minute of air per split, and you automatically will eliminate 95 percent of the bituminous coal mines in Pennsylvania from using diesel engines.

Your regulations state that repairs should be made by a qualified person. From what I heard yesterday and today, and the information I accumulated on my assignment, we have very few people in our industry who are prepared. Thus, we are a hell of a long way from being ready for this movement in coal mining. I am certain our Director of Deep Mines, Bureau of Pennsylvania, the Department of Environmental Resources, and our mining inspectors will have a few words to say on this subject before any diesel engines will go into a coal mine in Pennsylvania. Mr. Vicinelly is prepared to go on record against the use of diesel-powered equipment in Pennsylvania coal mines at the present date.

I really appreciate that someone was nice enough to allow us to participate in the program. I deeply appreciate the opportunity to be permitted to present my personal views on diesel-powered engines to this meeting, and I ask that you please not hold it against our department. You can hold it against me, because I don't intend to stay very long anyway. You have been a very kind audience, and I might tell you that I refuse to answer any questions on the grounds that I need more study on the subject at hand.

Thank you.

MR. McATEER: Thank you, Mr. Resick. I want to thank all the speakers. I think what we are trying to say to you gentlemen is that there is a reluctance in everyone to make changes. All of us in some parts of our minds are reluctant to change, and the miners are no exception. As evidenced in the changing of the administration in the United Mine Workers, it was in our best interest that we made changes. But you have not shown us that it is in the best interests of the miners to make the change to diesel. We are asking that a second symposium be conducted in several months to specially deal with the questions of health and safety. At that symposium, we do not look for the

simple prototype as to the health and safety aspect of diesel, but actually working models that may be experimented with extensively. We want to see models just like the ones on which this symposium on the aspect of production is based--ones that will work effectively and that we can be sure of, so that the health and safety of the United Mine Workers' members are protected.

Thank you very much.

MR. PELUSO: That is the end of our morning session.

MR. GRANT: Before convening the symposium for our final session, I would like to express the Bureau's appreciation for the panel discussion presented this morning by Mr. McAteer of our participating organization, the United Mine Workers of America. I assure all of you that we in the Bureau completely agree that the introduction of diesels in the coal mines must be under conditions that will assure health and safety for miners. We are fully prepared to shoulder our responsibility for accomplishing this goal. I now turn the symposium over to our cochairman, Mr. Cloyd McDowell, president of National Independent Coal Operator's Association, and Mr. John W. Crawford, assistant director-Coal Mine Health and Safety of the Bureau of Mines.

MR. McDOWELL: Thank you, sir.

Our specific topic this afternoon is The Use of the Diesel Engines Underground; and the experience gained with the diesel engine underground in the United Kingdom. The paper will be presented by Sid Gilbert who is head of the Haulage and Transport Section of the National Coal Board, United Kingdom. He was drafted into the mining industry in 1942 and became a qualified mechanic in 1949. During this period he attended voluntary evening classes and obtained a Higher National Certificate in Mechanical Engineering and the London University Inter B.Sc. (External). In 1950 he was awarded a National Coal Board Scholarship for full time University study and obtained a B.Sc. (Hons.) degree in 1953.

He re-entered the National Coal Board on a 3-year management training scheme and since 1956 has held posts of assistant colliery engineer, unit colliery engineer, group mechanical engineer, conveying engineer at national headquarters, and his present post is head of the Haulage and Transport Section. Mr. Gilbert.

SESSION IV—MAINTAINING SAFETY OF DIESELS UNDERGROUND

USE OF DIESEL ENGINES UNDERGROUND IN BRITISH COAL MINES

by

N. Higginson¹Presented by Sid Gilbert²

SUMMARY

The paper outlines the introduction and growth of the diesel-powered vehicles operating underground in British coal mines and describes our general experience over the last 3 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.

GENERAL EXPERIENCE OF DIESEL UTILIZATION UNDERGROUND

History of the Introduction of Diesel Locomotives

In 1939 the first diesel-powered locomotive was introduced underground at Rossington Colliery near Doncaster in the Yorkshire coalfield. It was a 25 hp unit made by Hunslet Limited and was used for hauling manriding cars. It was finally retired after travelling three-quarters of a million miles. As a result of this introduction, the advantages and the flexibility of the locomotive over rope haulage became evident and diesel-powered locomotives began to be used for coal, men, and materials duties in the privately owned mines, but on a limited scale.

Since nationalization in January 1947, the trends in transport underground have been largely influenced by the Report of the Technical Advisory Committee 1945 (Reid Report), which recognized the need for improvement in this field. A pertinent extract from this report is as follows:

"We are satisfied that no single operation associated with coal production in Britain offers more scope for improved efficiency than that of underground transport."

¹A.M.I.Min.E., M.A.M.E.M.E., Chief mechanical engineer, National Coal Board, United Kingdom.

²Head of Haulage and Transport Section, National Coal Board.

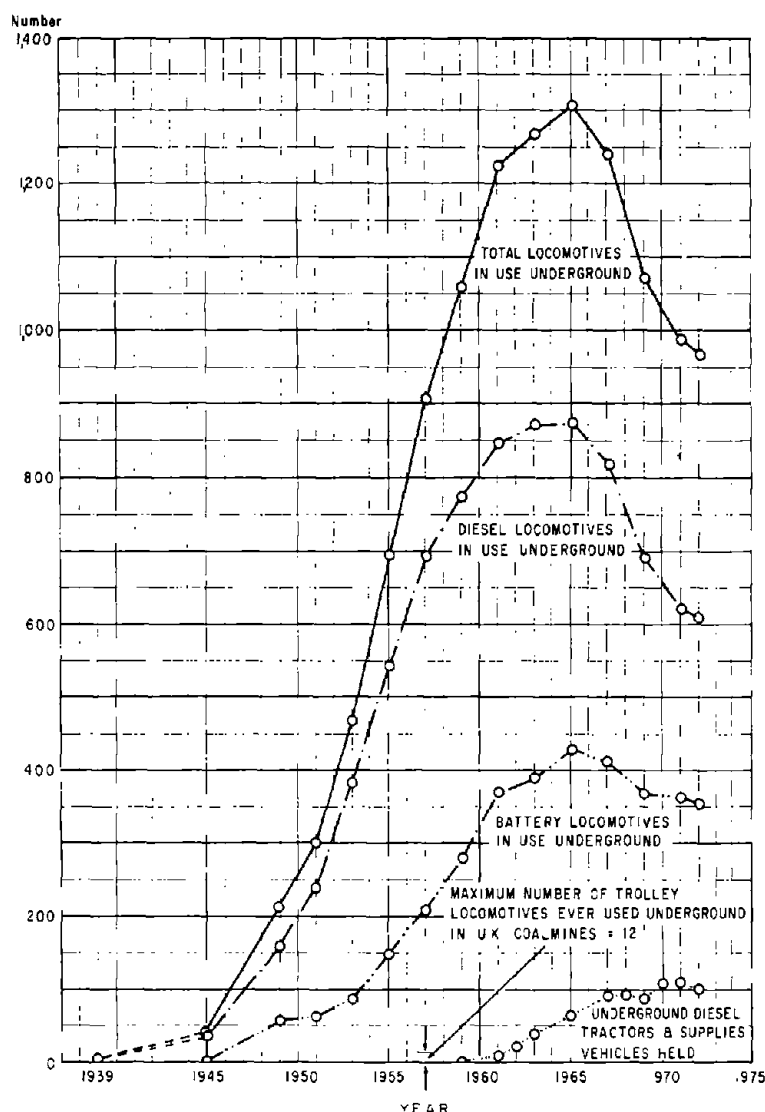


FIGURE 1. - Diesel used underground in United Kingdom mines.

It is interesting to note that at that time only about 1 percent of our output was power loaded.

The report recommended that subsidiary rope haulage from the face to the main haulage system should be replaced by conveyors, and that locomotive haulage or conveyors should be introduced as the main system of transport in new or reconstructed mines. Progress since has been generally along these lines as is indicated in table 1; figure 1 illustrates the progress graphically. From this graph it can be seen that there was a general increase in the usage of locomotives from their initial introduction until 1965. Since 1965 there has been a reduction in numbers which has been caused by the following:

1. the concentration of total output from fewer collieries, and a reduction in the number of coal faces, resulting from substantial increases in the bulk output per shift from mechanized faces;

2. improvements in conveyor belting using a carcass of synthetic fibers have been such that 700 hp can now be transmitted to a 42-inch-wide belt travelling at 500 feet per minute. Belt conveying is now an efficient and economic means of transporting coal. The progression of the belt conveyor from the gate to the main trunk situation for the transport of mineral is gradually changing the duty to be performed by the diesel locomotive and is limiting its use to the transport of men and materials.

The schedule in table 2 illustrates on an hp weight basis the various models and range of diesel locomotives currently operating in British coal mines. The photographs in appendix A show the different applications and vehicles in which the diesel engine has been fitted as the prime mover.

TABLE 1. - Progress in the use of locomotives underground

Locomotives in use underground	1939	1945	1949	1951	1953	1955	1957	1959	1961	1963	1965	1967	1969	1971	1972
Diesel.....	2	37	157	238	381	544	693	772	847	871	874	819	691	620	608
Electric battery.....	2	3	56	62	86	146	209	278	369	388	426	411	368	362	352
Electric trolley.....	-	-	-	-	-	4	4	10	11	11	11	12	12	7	7
Total.....	4	40	213	300	467	694	906	1,060	1,227	1,270	1,311	1,242	1,071	989	967
DIESEL TRACTORS AND UNDERGROUND SUPPLIES HELD BELOW GROUND															
Total.....	-	-	-	-	-	-	-	-	9	39	62	91	88	112	101

TABLE 2. - Sizes of diesel locomotive in use underground, 1972

Weight, tons (adhesive and total)	hp	Number in use	Weight, tons (adhesive and total)	hp	Number in use
3	22	3	7	44	25
3	23	5	8	50	9
Captive rail	23	2	9	50	3
3.5	18	4	10	65	60
Captive rail	25	18	10	¹ 68	75
4.5	27.5	4	10	70	24
5	28	3	10	75	7
5	40	2	11	¹ 66	18
Captive rail	40	11	11	76	4
6	36	1	15	² 100	310
6.5	25	4	16	² 100	16
Total.....					608

¹Nominal horsepower; actual fuel rack setting is 65 hp.

²Nominal horsepower; actual fuel rack setting is 98 hp.

NOTE: Captive rail weights are not given because adhesion is induced artificially and elastomer tires are used.

There is currently available a wide range of standard equipment from which a machine can be selected to suit the various conditions which exist in coal mines. Because of the ever-increasing distances that men and materials have to be transported in order to maintain a reasonable face operation time and a high speed, a diesel-powered locomotive is being developed. The following are brief details of the specifications:

Type.....	B - B.
Rail gage.....	2 ft 0 in to 3 ft 0 in.
Weight.....	21 tons.
Maximum speed.....	Variable, 17 - 30 mph.
Prime mover.....	Two "Gardiner" 6LW flameproof diesel engines.
Horsepower.....	200
Transmission.....	Torque converters using phosphate ester as the hydraulic fluid
Inlet and exhaust.....	Each diesel engine fitted with an entirely separate inlet and exhaust system.
Controls.....	Engine speed; brake lever; emergency brake lever; handbrake lever; forward and reverse lever; sanding; horn button; deadmans pedal.
Electrics.....	Flameproof generator, providing a supply to three flameproof headlights at each end of the locomotive.
Brakes.....	Bogies equipped with fail-safe, spring applied, air pressure released, Bretby designed, brake gear, fitted with automatic takeup.

HEALTH ASPECTS

To insure that the proportion of noxious gases contained in the mine air does not exceed acceptable limits, regular sampling and analysis of both the diesel exhaust and the ventilation air is carried out. The upper limits for carbon monoxide and oxides of nitrogen are fixed by the Mines and Quarries Act (1954), in the law relating to safety and health, under the locomotive regulations. The following are extracts from these regulations which illustrate the upper limits for noxious gases that are allowed where diesel engines are in operation:

1. "The manager of every mine in which any diesel locomotive runs shall insure that no such locomotive runs therein if gas emitted from its exhaust contains more than 0.2 percent by volume of carbon monoxide or 0.1 percent by volume of oxides of nitrogen."

Thus, this regulation sets limits for the products of combustion and insures that the condition of the engine is maintained to a reasonably high standard. The analysis of samples approaching the limits generally indicates one or more of the following defects:

- (1) Inefficient fuel injectors,
- (2) inaccurate timing of the fuel pump,
- (3) excessive clearance between the cylinders and pistons resulting in burning of the lubrication oil,
- (4) inadequate specification of the fuel oil, and
- (5) inadequate exhaust gas dilution.

2. "If at any place in a mine in which a diesel locomotive runs, there is found in the general body of the air an amount of carbon monoxide exceeding 0.005 percent by volume, the manager shall forthwith take such steps as are necessary so to improve the ventilation at that place that that percentage of carbon monoxide is not exceeded."

3. "If at any place in a mine in which a diesel locomotive runs, there is found in the general body of the air an amount of carbon monoxide exceeding 0.01 percent by volume, the manager shall insure that no engine of a diesel locomotive is run at that place or at any other place at which such running could affect the ventilation at the first mentioned place until it has been determined that the amount of carbon monoxide in the general body of the air at the first mentioned place does not exceed 0.005 percent by volume."

As well as specifying the maximum allowable quantities of carbon monoxide and oxides of nitrogen in the exhaust gas, the frequency of sampling, and the operation of the diesel engine during the sampling period, are also stipulated by law.

4. "At intervals not exceeding 90 days separate samples of the gas emitted from the exhaust of every diesel locomotive in use in the mine shall be taken when the engine of the locomotive is--

- (1) developing maximum power; and
- (2) idling with the locomotive stationary."

The personnel taking the exhaust gas samples have to be appointed by the manager. They are usually members of the colliery ventilation staff and either carry out the sampling themselves or supervise the diesel maintenance personnel during the sampling operation.

To obtain a representative sample, the exhaust gases are sampled by bolting onto the flame trap a cowl as shown in the figure 2. This cowl is made from 1/16-in mild steel sheet and has a tubulure to which is attached a length of rubber tubing. An adjustable slide can be closed until a stream of exhaust gas issues from the rubber tubing. It is desirable to confirm that a steady stream is being obtained by placing the outlet end of the tubing below the surface of the water in a container. The open end is then attached to a gas sampling bottle of approximately 220-ml capacity. Adequate time must be allowed for the air in the bottle to be displaced completely by the exhaust gases. Experience has shown that samples should be collected over periods of approximately 1 to 1-1/2 minutes.

If the flame trap is not fitted to the exhaust outlet, the sample is taken from the open end of the exhaust pipe. To facilitate this a wood plug fitted with a 3/8-in-diameter pipe is provided; this is illustrated in figure 3.

The sample is then taken from the colliery to the area laboratory where it is analyzed by the area scientific staff. The colliery manager receives on preprinted sheets the results of the analysis within 4 days of the sample being taken, as required by law. The results of the exhaust gas analysis are then recorded in the statutory book provided by the National Coal Board specifically for that purpose. A sheet from such a book is illustrated as appendix B and is known as the Mines and Quarries Form No. 274 Part 1. If a series of collieries all using several diesel engines are to be serviced by one analyzing center, as is the case within the National Coal Board, then an efficient collection and delivery service is essential if compliance with the law is to be maintained.

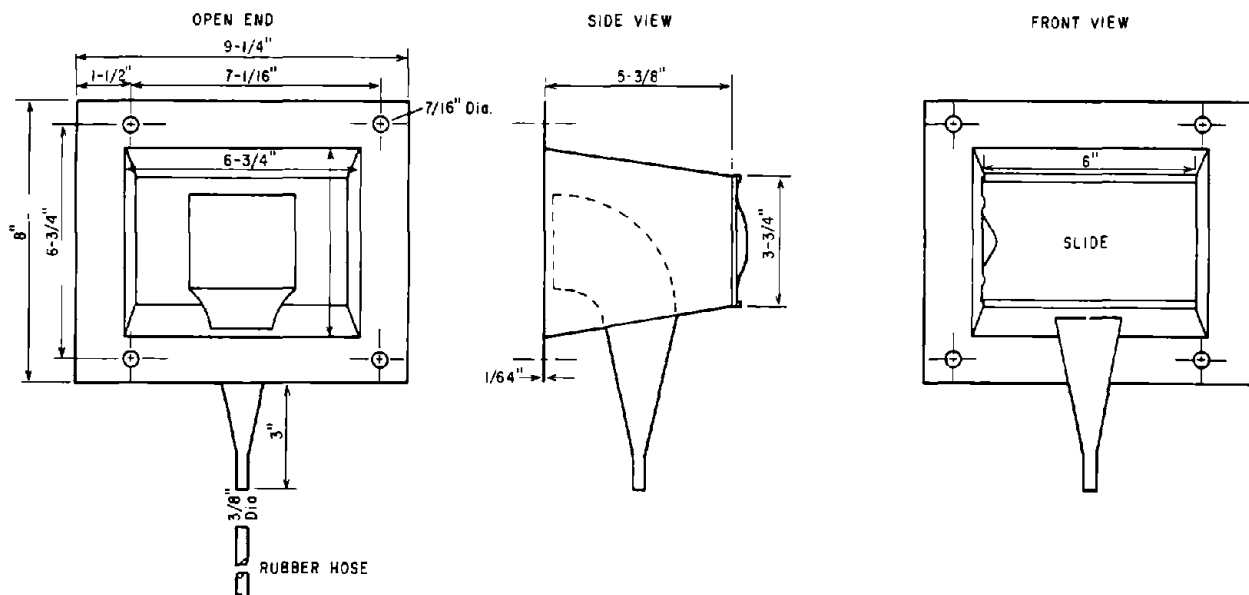


FIGURE 2. - Diesel exhaust mask for sampling 50 hp Hunslet locomotive.

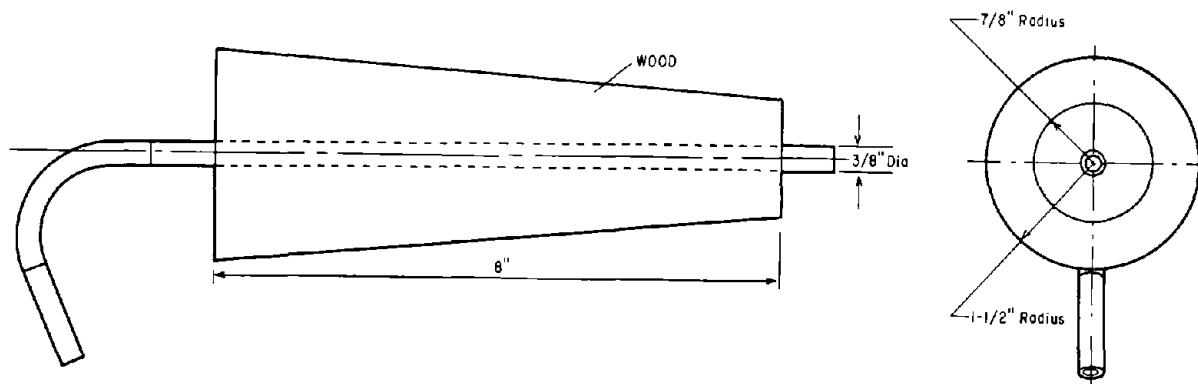


FIGURE 3. - Exhaust-tube plug for Ruston Hornsby diesel.

Methods Now Used To Determine the Percentages by Volume of Carbon Monoxide and Oxides of Nitrogen in Diesel Exhaust Gas

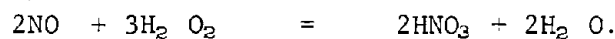
Determination of Oxides of Nitrogen

Principle of Method

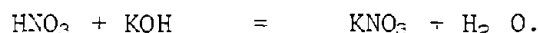
Oxides of nitrogen are converted to nitric acid by the action of an acid solution of hydrogen peroxide as follows:



and



The nitric acid is then converted to potassium nitrate by the addition of a slight excess of potassium hydroxide:



Method

Five milliliters of 0.1 N sulphuric acid and hydrogen peroxide solution are added to the 220-ml sample bottle and the contents periodically shaken for a period of 2 hours. The contents of the bottle are then washed into a beaker containing 2.5 ml of potassium hydroxide and the volume made up to 25 ml with distilled or nitrate-free water. A precipitate occasionally appears at this stage owing to carry over from the exhaust during sampling. In such cases the solution should be adjusted to pH of 2 to 3 using 0.1 N sulphuric acid before the solution is made up to volume.

The potential of the solution is now measured in millivolts against a reference electrode, allowing 30 sec for stabilization. The nitrate concentration is then interpolated from a predetermined logarithmic-linear graph, the millivolt readings being on the linear scale and the nitrate concentrations on the logarithmic scale.

A typical graph is illustrated in appendix C.

Chromatographic System for Assessing the Carbon Monoxide Content of Diesel Exhaust Gases

The sample of diesel exhaust gas to be analyzed is fed into a chromatographic system as shown in figure 4:

This system consists of the following:

1. Two 5-port midget poppet valves linked together to allow the introduction of a fixed volume of sample into a stream of carrier gas passing through an adsorbent (chromatographic) column.
2. A chromatographic column which consists of a tube about 6 in long and 3/16 in internal diameter packed with 60/72 mesh size activated carbon particles. The gases in the sample being analyzed are absorbed on the carbon, some more strongly than others, and are eluted through the column by a constant flow of 50 percent hydrogen, 50 percent nitrogen mixture (the carrier gas). The order of elution is air, carbon monoxide, and then methane, followed by a succession of hydrocarbons. The degree of activation of the carbon is optimized to provide a complete separation of these gases in the shortest possible time.
3. A furnace at about 300° C contains nickel to act as a catalyst in effecting the reduction of carbon monoxide to methane before it passes into a flame ionization detector.

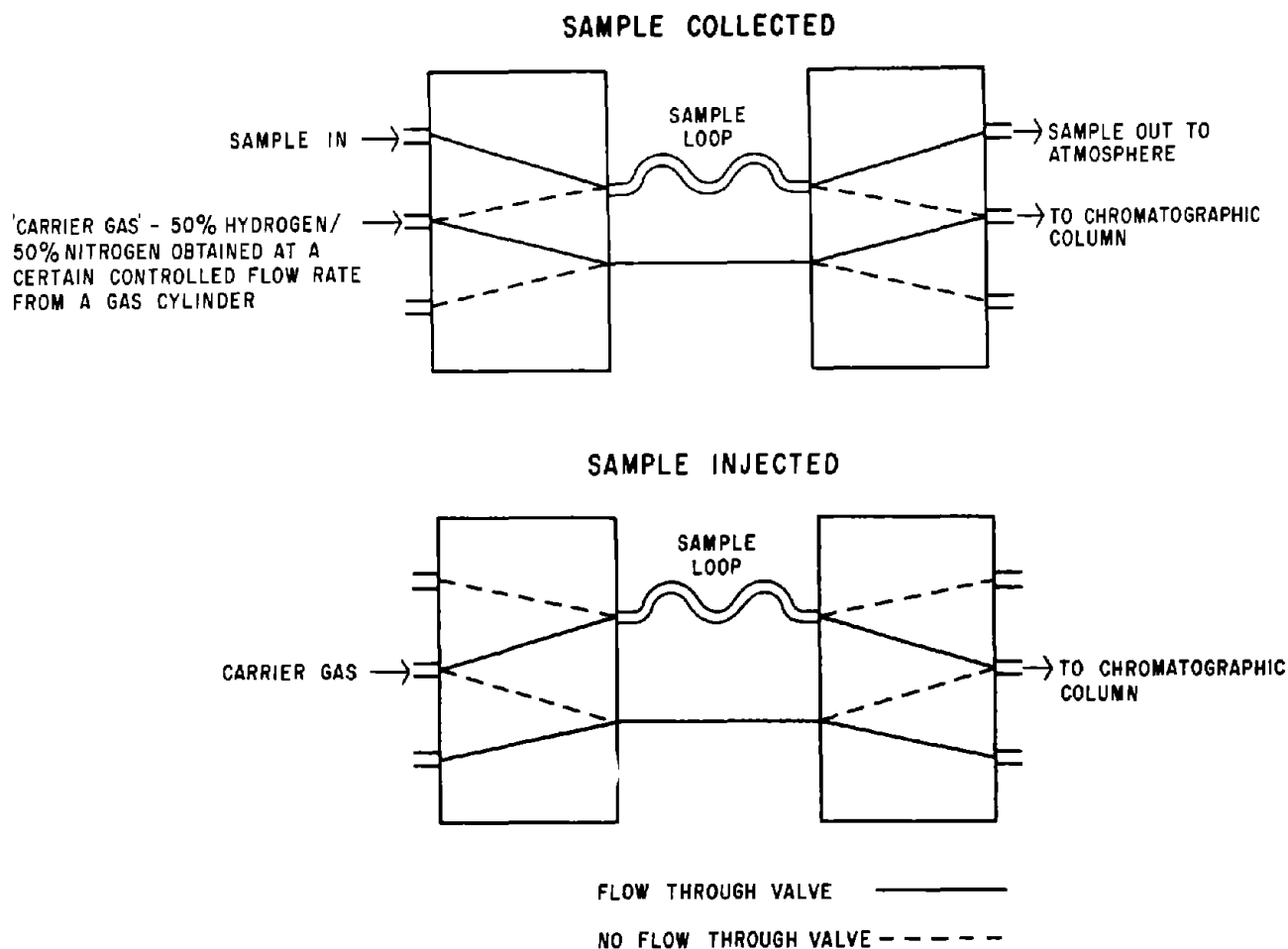


FIGURE 4. - Chromatographic system for assessing the carbon monoxide content of diesel exhaust gases.

4. The detection unit consists of a flame ionization detector (fig. 5) which gives a quantitative electrical signal, specifically for any hydrocarbon present in the eluted gas stream.

This signal is presented in a suitable form to a potentiometric recorder. An analysis is consequently recorded for the carbon monoxide content in the diesel exhaust sample.

The signal obtained from the flame ionization detector is due to the ionization of hydrocarbons in the hydrogen flame which alters the resistance between the two electrodes. The equipment is calibrated with standard gases of known CO concentration.

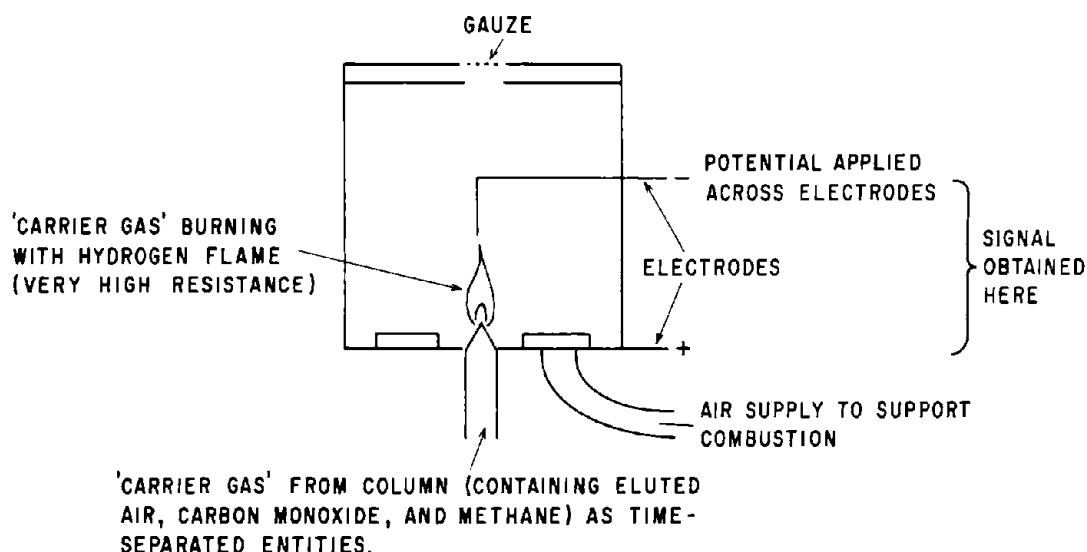


FIGURE 5. - Flame ionization detector for analyzing hydrocarbon in the eluted gas stream.

VENTILATION

The firedamp content of the general body of the air in roadways where diesel engines operate is also limited by the locomotives regulations. The following are extracts from those regulations:

..... where a locomotive runs in any length of road, the manager shall make and insure the efficient carrying out of arrangements whereby determinations of the percentage of inflammable gas present in the general body of the air are made in that length of road in accordance with the provisions of the three next following regulations:

.....

12. Methods for Determination

Determinations of the firedamp content shall be made--

- (a) by means of apparatus of a type approved for the purpose by the Minister, by a competent person appointed for that purpose by the manager of the mine; or
- (b) by means of samples of air taken by a competent person so appointed and analyzed within 4 days (without taking into account any Saturday, Sunday, or day of general holiday) of the taking thereof.

Places for Determination

13.(1) Determinations of the firedamp content shall be made--

- (a) at a point at each end of every length of road in which any locomotive runs;
- (b) at such other suitable points as may be fixed by the manager.

.....

(2) An inspector may, if he is of opinion that any point fixed in pursuance of sub-paragraph (b) of paragraph (1) is unsuitable, serve on the manager a notice requiring him to fix some other point in substitution thereof and may serve on the manager a notice requiring determinations to be made at any other point specified in the notice in addition to those required by the preceding paragraph.

Times for Determinations

14.(1) Determinations of the firedamp content shall be made at every point required by or under the last preceding regulation once in every week at the time when the firedamp content is likely to be greatest:

Provided that--

- (a) if any determination at any such point shows a firedamp content exceeding 0.8 percent by volume determinations shall be made at that point at intervals not exceeding 24 hours so long as the content is shown to exceed or to have exceeded that percentage and for the 7 next following working days;
- (b) if every determination made during a period of 30 days at any such point showed a firedamp content not exceeding--
 - (i) in the case of a point in a length of road not ventilated by air which has ventilated a working face, 0.2 percent by volume;
 - (ii) in the case of a point in any other length of road 0.6 percent by volume;

it shall be sufficient to make determinations at that point at intervals not exceeding 30 days for so long as the firedamp content shown thereby does not exceed that percentage.

The limit of firedamp content in the general body of air at which locomotives are allowed to operate is 1-1/4 percent by volume; this is a statutory requirement as shown by the following extracts from the locomotive regulations:

16(1) If any determination of firedamp content made in any length of road (not being a determination made by analysis of a sample of air) shows a firedamp content exceeding 1-1/4 percent by volume, or any indication of inflammable gas is seen on the lowered flame of a safety lamp in the general body of the air, the person making that determination or the person using the lamp (as the case may be) shall forthwith inform the person in charge of the part of the mine which includes that length of road and that latter person shall after forthwith verifying the accuracy of the information so given to him forthwith discontinue the running of any locomotive in that length of road.

(2) After such discontinuance no locomotive shall be run in that length of road until the manager of the mine, being satisfied that the firedamp content therein does not exceed 1-1/4 percent by volume, so directs.

(3) If any determination of firedamp content made in any length of road by analysis of a sample of air shows a firedamp content exceeding 1-1/4 percent by volume, the manager of the mine shall forthwith upon receipt of that information insure that no locomotive runs in that length of road until he is satisfied that the firedamp content therein does not exceed 1-1/4 percent by volume.

A sheet from the official book for recording the firedamp content in roads where locomotives are used is illustrated in appendix B; it is known as Mines and Quarries Form No. 270.

To fulfill these requirements it is essential that the samples taken are representative of the mine air and that the men taking them have received adequate training to carry out the sampling procedure, since the reason for taking regular samples and air measurements is to give information not only for controlling but also for future planning of the general ventilation along systematic lines. Methane is a light gas, density 0.559 relative to air. It occurs primarily under pressure in the coal seam and is released by any process which breaks the coal. When the coal is removed from the face, evolution of methane continues at a gradually decreasing rate for a considerable time and the volume released varies with the tonnage mined and with the barometric pressure. Sampling is therefore an important function when determining the firedamp content and is only carried out by personnel trained for the purpose.

The following methods are available for sampling mine air:

(1) Aspiration through a bottle, (2) water bottle, and (3) double acting hand pump and steel container.

Of the three methods, the third is currently the most popular, since the steel container can be pressurized; this not only increases the volume sampled but also facilitates the injection of the sample into the equipment used for analysis. The pump can be fitted with a rubber tube to assist when traversing

the roadway to establish a mean sample, and the steel container is equipped with a Schrader valve to prevent sample emission until required in the laboratory.

Figure 6 illustrates a gas sampling pump and figure 7 a gas sampling cylinder.

Method of Analysis of Mine Air To Determine the Firedamp Content
and Carbon Monoxide Content by the Infrared Gas Analyzer

Figure 8 is a diagram of the infrared gas analyzer. The infrared radiation from the radiation lamp (1) is divided by the rotating chopper (3) driven by the synchronous motor (2) into two equally intense portions modulated in phase reversal, which alternately pass through the analysis vessel (4) and the reference vessel (5) of the twin-vessel tube (6). After passing through the diffuser (7), which is arranged in the radiation path behind the twin-vessel tube, both radiation portions enter the receiver (8), which contains the gas constituent to be measured, for example carbon monoxide (CO). The reference vessel (5) is filled with a gas not absorbing infrared rays, for example nitrogen. The gas mixture to be analyzed flows through the analysis vessel (4). The two chambers (9) and (10) of the receiver block (8) are arranged in series, one after the other, in the ray path and are connected

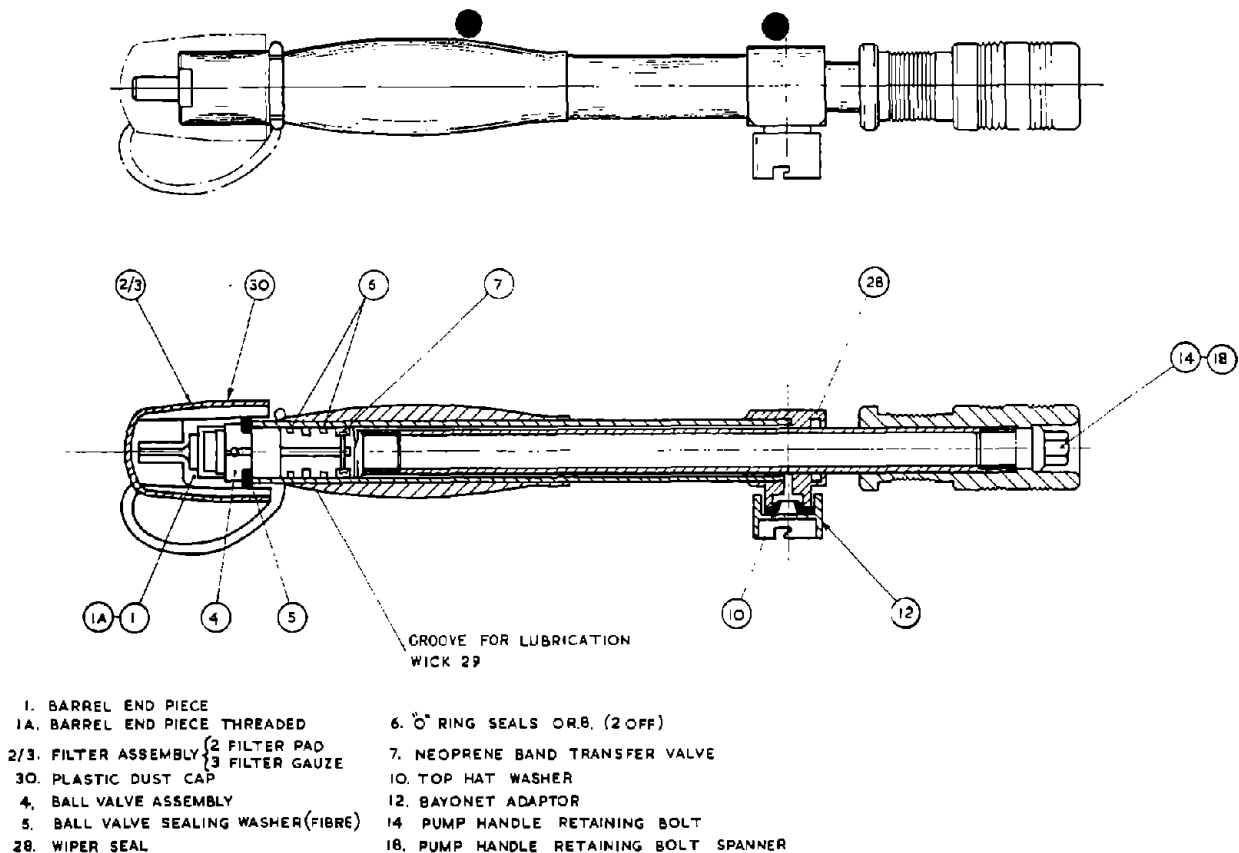
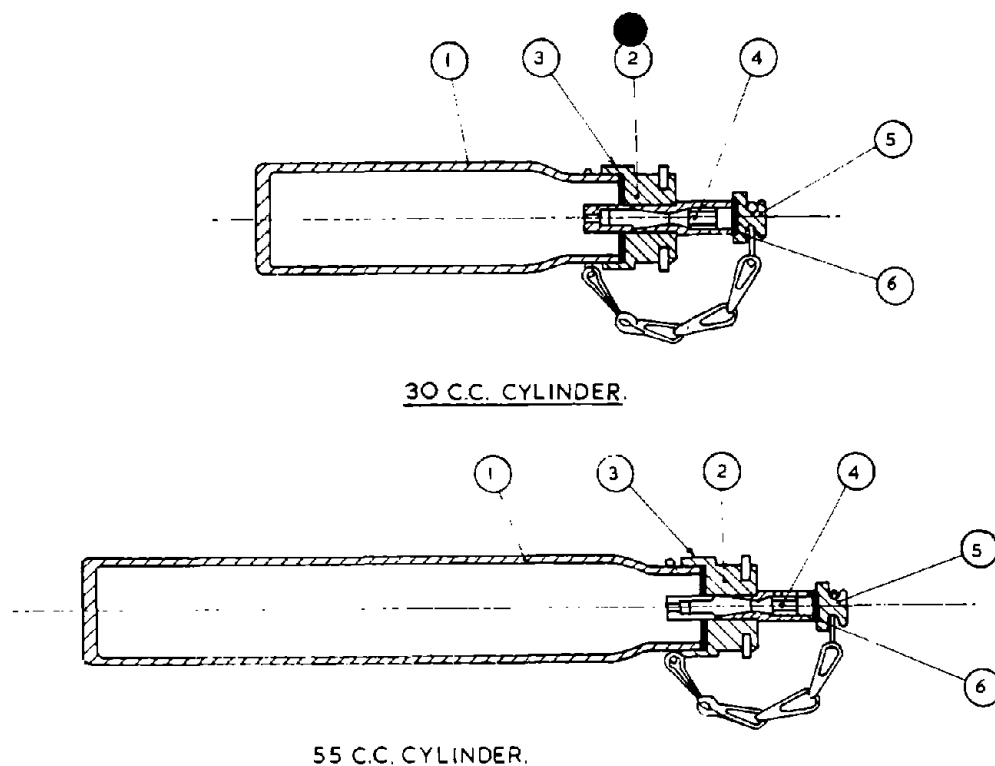


FIGURE 6. - Gas sampling pump.



1. BODY - 30 CC. OR 55 CC
2. CYLINDER HEAD ASSY.
3. SEALING WASHER
4. SCHRADER CORE.
5. DUST CAP & CHAIN
6. DUST CAP SEALING WASHER

FIGURE 7. - Gas sampling cylinder.

through channels (11) and (12) with the diaphragm (13) of the measuring capacitor. The measuring capacitor converts pressure pulses from the receiver chamber into proportional changes in capacitance.

The spectra of absorption gases comprise a number of lines, the total of which is also called bands. In the shorter front measuring chamber (9) of the receiver, absorption of the rays takes place preferably in the center of the bands, in the longer, rear measuring chamber (10) the radiation of the flanks of these bands is absorbed. The absorbed energies heat the gas in these chambers so that the pressures of the gas in the chambers rise. The gas concentration in the two measuring chambers and the geometry of these chambers are so dimensioned that, if there is none of the constituent to be measured in the analysis vessel (4), the pressures in the receiver (8) are equal on both sides of the diaphragm-type capacitor. If, however, the radiation in the analysis vessel passes through a gas mixture containing the constituent to be measured, for example carbon monoxide, some of the specific radiation energy is absorbed already in this vessel. Since this reduction of radiation intensity takes place mainly in the line centers, it affects primarily the

- 1 RADIATION LAMP
- 2 SYNCHRONOUS MOTOR
- 3 ROTATING CHOPPER
- 4 ANALYSIS VESSEL
- 5 REFERENCE VESSEL
- 6 TWIN-VESSEL TUBE
- 7 BEAM COMBINER
- 8 RECEIVER
- 9 FRONT MEASURING CHAMBER
- 10 REAR MEASURING CHAMBER
- 11 CONNECTING CHAMBER
- 12 CONNECTING CHAMBER
- 13 DIAPHRAGM OF CAPACITOR
- 14 MEASURING AMPLIFIER
- 15 CHECK INSTRUMENT
- 16 RECORDER
- 17 GAS PUMP
- 18 AUTOMATIC INTERFERENCE INDICATOR
- 19 SAFETY FILTER IN THE GAS INLET
- 20 SAFETY FILTER IN THE GAS OUTLET

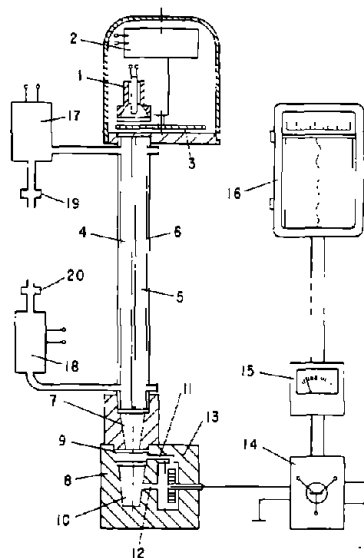


FIGURE 8. - Arrangement of infrared gas analyzer.

maintained in continuous vibration according to the rate of the radiation modulation (6.25 cycles/sec). The amplitude of this vibration is a measure for the gas concentration to be determined. The changes in capacitance are converted by the measuring amplifier (14) into a proportional dc signal which is measured in the instrument (15) and recorded on a recorder (16).

front measuring chamber (9) of the receiver block (8). The equilibrium of pressure previously existing between the front and the rear measuring chambers is thus eliminated. This differential of gas pressure in the two measuring chambers causes a pressure-proportional deflection of the diaphragm, that is, the capacitance of the measuring capacitor is changed accordingly.

Owing to the modulation of the rays, these phenomena are not static. The diaphragm of the capacitor is

Design Criteria for the Diesel Engine and Accessories When Used Underground

Fuel Oil

To control the products of combustion emitted from an underground diesel engine it is essential that the fuel oil quality be specified. The relevant statutory requirement is as follows:

27. The manager of every mine in which any diesel locomotive runs shall make and secure the efficient carrying out of arrangements whereby--

- (a) no fuel oil is used for the generation of energy in that locomotive other than oil of a specification approved by the Minister.

To insure that all suppliers of fuel oil deliver the correct, approved quality, National Coal Board Specification No. P.157/1958 was produced. This specification requires that the fuel oil shall be to the following design parameters:

Viscosity at 100° F.....	1.6 centistokes, minimum (30 Redwood No. 1 seconds). 7.5 centistokes, maximum (45 Redwood No. 1 seconds).
Cetane Number.....	47 minimum.
Carbon residue Conradson (on 10 percent bottoms).	0.15 percent maximum by weight.
Distillation recovery at 357° C.	90 percent minimum by volume.
Flashpoint closed.....	150° F minimum.
Water content.....	0.05 percent maximum by volume.
Sediment by extraction.....	0.01 percent maximum by weight.
Ash.....	0.01 percent maximum by weight.
Sulphur content.....	1.0 percent maximum by weight.
Sulphur corrosive (copper strip test).	Not more than slight tarnish.
Pour point.....	Suitable for the service conditions but not to exceed 20° F.

Engine and Ancillary Equipment

To comply with the regulations, specific design criteria have to be met, particularly by the ancillary equipment of the diesel engine. The relevant regulations are as follows:

3.(2) In the case of every locomotive in which the motive power is generated by an internal combustion engine, that locomotive shall be so constructed that--

- (a) no air enters the engine without first being cleaned;
- (b) no exhaust gases are expelled from the locomotive without first being cooled and diluted; and
- (c) no flames or sparks are emitted from the locomotive.

Figure 9 shows a typical, flameproof, water cooled, exhaust system with air dilution. The intake air for the engine flows through air cleaners and a flame trap which is fitted to prevent the transmission of flame and the ignition of an external inflammable atmosphere in the event of a backfire or other defect. The exhaust gases pass into a conditioner which absorbs some proportion of the soluble, noxious constituents and cools the gas before it passes through the flame trap. Air which is drawn through the radiator for water-cooling purposes is mixed with the cooled exhaust gases before being emitted to the atmosphere.

The flame traps generally used consist of an assembly of 2-in by 2-1/2-in preformed plates set at the required clearances. A typical plate is shown in figure 10. As the products of combustion flow through the narrow spaces between the plates, deposits build up and increase the resistance to the flow. When the frequency of cleaning both the intake and exhaust flame traps is

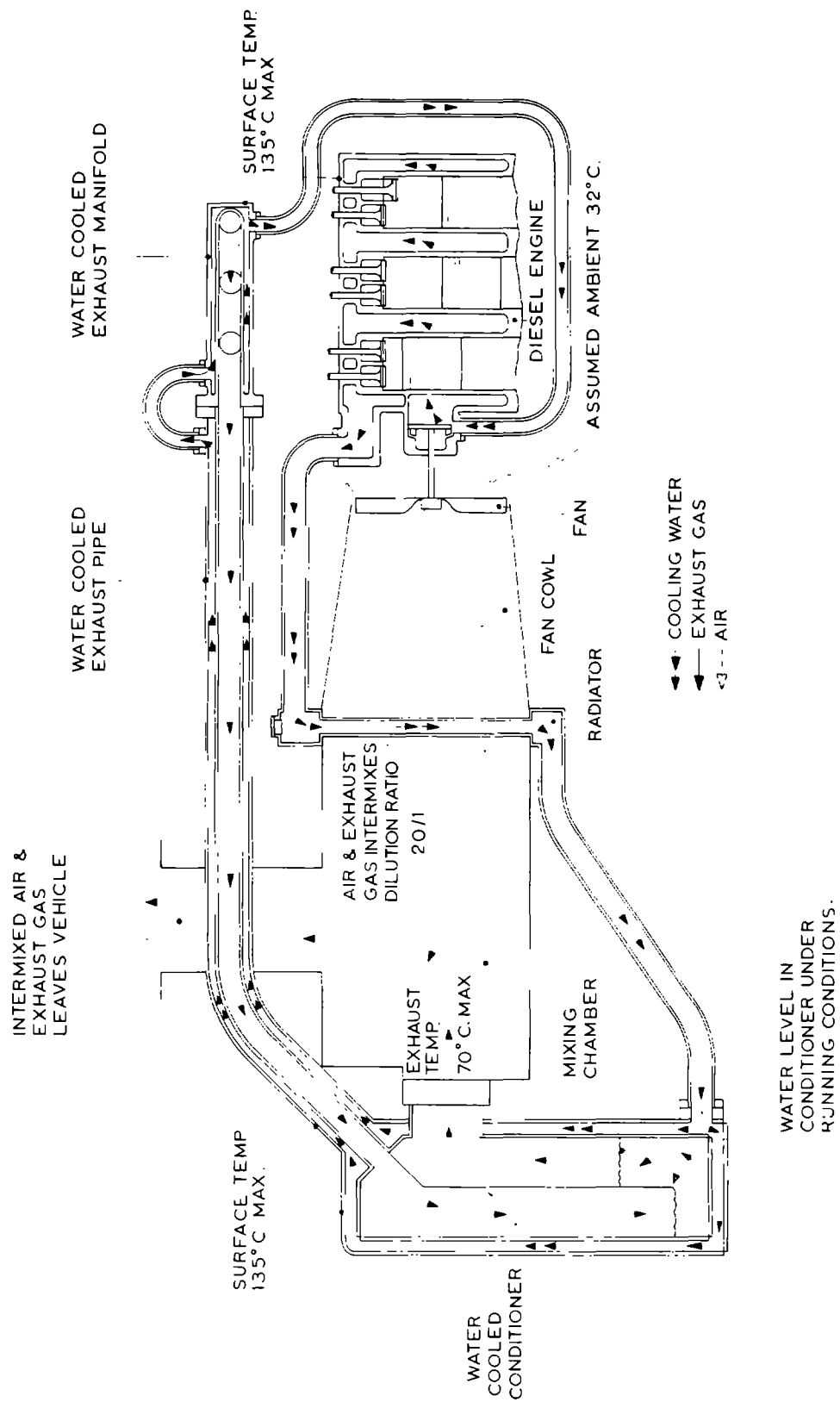


FIGURE 9. Diagrammatic arrangement of a typical, flameproof, water-cooled, exhaust system with air dilution. (Adapted from Hunslet Engine Co. drawing.)

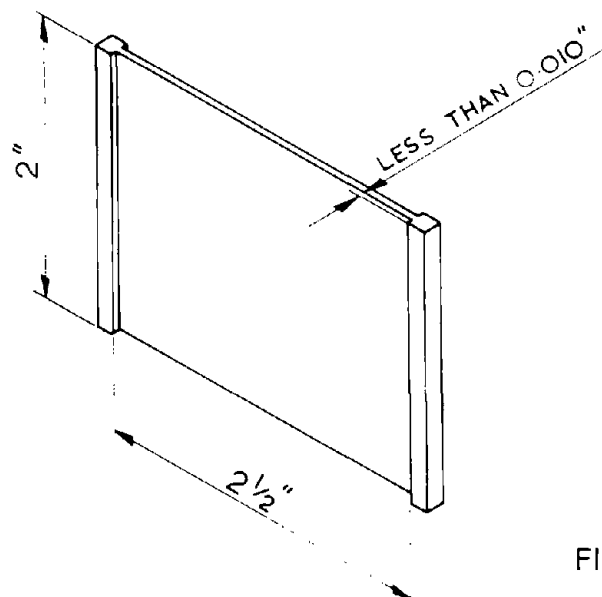
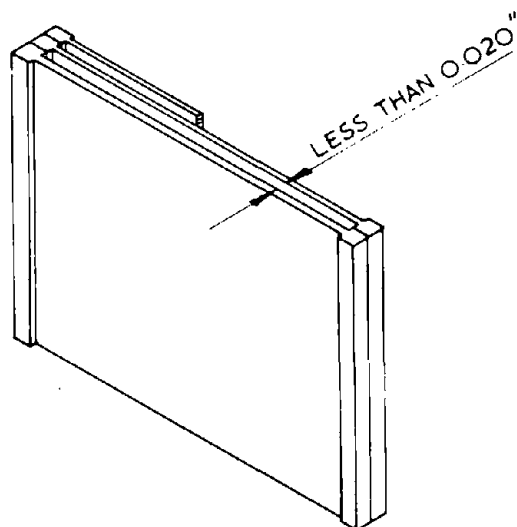


FIGURE 10. - Flametrap grill plates and resultant gaps. (Adapted from National Coal Board headquarters-mining department Doncaster drawing.)



chosen, due consideration is given to the working conditions and to the condition of the engine. The valves, fuel pump, etc., should insure that the weight of air taken in by the engine gives a fuel-air ratio not exceeding the maximum for which the engine was designed, so keeping the noxious gases and deposits to a minimum. In practice, it has been shown that these plates require cleaning after approximately 8 hours operation of the diesel engine.

The exhaust pipes and manifold are water jacketed and the design of the water-cooling system, radiator, etc., have to be such that the external temperature of the engine or exhaust system never exceeds 135° C. The conditioner box has to provide the following:

1. Adequate capacity for water to cool the exhaust gas below the allowable maximum of 70° C;
2. adequate capacity of water so that the replenishment or topping up of water is required only once a working shift; and
3. resistance to attack by the acidic contents of the exhaust gases. This is deemed desirable although alkaline solutions are added to the water. Usually, the box is made from stainless steel.

The diesel engines on underground machines all use the four-stroke cycle. In some, the fuel is delivered by direct injection into the cylinder while others have an auxiliary combustion chamber communicating with the space between the piston and the cylinder head, and the fuel is injected into that chamber where combustion takes place. The fuel-air ratios by weight at maximum speed and brake-horsepower lie in the range of 0.033 to 0.042 and have an average value of 0.04 as compared to the ideally correct fuel-air ratio of 0.07. Consumption of fuel is of the order of 0.4 lb/bhp/hr. The engines therefore are designed to take in about 25 lb of air for each pound of fuel and produce exhaust gas at about 2-1/4 cu ft/min/bhp at maximum speed. Consequently the required ventilation air quantities can be calculated as follows:

Maximum allowable CO in exhaust gas = 0.2 percent.

Maximum allowable CO in general body of air = 0.005 percent.

Therefore, the theoretical exhaust gas dilution = $\frac{0.2}{0.005} = 40$.

Hence it follows that ventilation at a rate of 40 times 2-1/4 = 90 cu ft/min/bhp is the theoretical minimum required. However, since a margin of safety is required, the practical ventilation should be greater than 90 cu ft/min/bhp and 150 cu ft/min/bhp is recommended.

To assist dispersion and dilution of the exhaust gases the dilution prior to emission to the atmosphere is about 20 to 1.

In the design, construction, and equipment of locomotives, additional criteria have to be considered so that the locomotive complies with statutory requirements. Even though some diesel-powered locomotives are thermally actuated cylinders of carbon dioxide, which completely flood the engine fitted with compartment with carbon dioxide should the cylinders be triggered off, the law requires that every vehicle must be provided with a suitable, portable fire extinguisher. Also, the controls must be so positioned relative to the driver's seat that he can simultaneously operate them and see ahead without leaning out of the locomotive.

SAFETY RECORDS

Although it is accepted that there are potential hazards arising from the emission of noxious gases in the exhaust gases of diesel engines, the degree

to which these are controlled in British coal mines has proved to be very effective. An examination of all safety records has revealed that no person has suffered any harmful effects either temporarily or permanently as a direct result of breathing any toxic gas emitted from any vehicle powered by a diesel engine. It can therefore be concluded that, if the ventilation, exhaust gas, sampling and analysis control, and procedures are fixed at the levels given in this paper, then the potential hazard from exhaust gas emission is reduced to zero.

The only other danger to consider when contemplating the use of a diesel engine as compared to other means of powering vehicles is that of fire. This hazard has been controlled to such an extent that there has been in the past only a very limited number of small fires associated with diesel-powered vehicles. On no occasion has there been an ignition of flammable gas in the general body of the air or an initiation of a coal dust explosion. The fires that were experienced have been of a localized nature within the confines of the locomotive and have been the result of a reduction in maintenance and cleanliness standards.

The quality of the fuel oil is controlled by specification, but the quantity and methods of handling and storage are also defined. The prime purpose of these controls is to limit the fire hazard to an absolute minimum. Experience has shown that these safety precautions have been effective since no fire has been reported as a result of the ignition of fuel oil outside the confines of the locomotive.

To provide conditions of safety, and precautions against fire, certain parameters have been laid down and enforced by law. Brief descriptions of these requirements follow:

27. The manager of every mine in which any diesel locomotive runs shall make and secure the efficient carrying out of arrangements whereby--

- (b) no fuel oil for use as aforesaid is taken below ground otherwise than in a suitable container which does not leak; and
- (c) any such oil at any time stored below ground (otherwise than in the tanks of a locomotive)--
 - (i) is kept in a filling station in a suitable container which does not leak; and
 - (ii) does not exceed in quantity, such quantity as, together with any oil then in the tanks of the locomotives for which it has been brought below ground, is likely to be consumed by those locomotives (having regard to their normal user) within the period of 48 hours next following.

In housing stations and filling stations, precautions against fire are taken both in the construction and services provided there. The stations have--

(1) to be constructed of non-inflammable material; (2) have a floor of smooth concrete surrounded by a sill; and (3) be provided with suitable and sufficient apparatus for combating outbreaks of fire.

Also, no person is allowed to take any oil from any container in a filling station while any internal combustion engine in the filling station is running.

Since adequate maintenance and cleanliness are essential for the safe operation of diesel-powered locomotives, and in order to assist the manager to produce a scheme for the systematic examination of the equipment, operation and maintenance check lists are provided. Samples of these check lists are included as appendix D. However, in spite of the precautions taken, there have been a small number of fires associated with locomotives and tractors. These fires, however, have not been predominantly associated directly with the diesel engine. Table 3 indicates the total number of fires associated with all locomotives and tractors and those fires in which diesel-powered vehicles have been involved. If the fires caused by overheated axle boxes, V-belt drives, and lack of cleanliness could be isolated and deducted from the number of fires, the conclusion reached would be that the diesel engine, properly maintained in a controlled environment, is a safe piece of equipment.

TABLE 3. - Fires associated with underground locomotives and tractors

Year.....	1947	1952	1957	1962	1967	1971	Total number 1947 to 1971	Average number fires per year
Locomotives and tractors all kind:								
Number in use...	185	450	910	1,230	1,242	989	-	-
Number of fires.	None	1	1	3	1	5	64	2.6
Diesel locomotives and diesel tractors:								
Number in use...	170	381	650	820	920	720	-	-
Number of fires.	None	1	1	1	1	3	40	1.6

To illustrate this conclusion the following are details of locomotive fires over the past 4 years:

Date	Colliery	Detail of cause of fire
1968 (6 fires):		
May 8.....	Wolstanton.....	Battery locomotive (failed resistance unit).
August 13.....	Newstead.....	Diesel locomotive (overheated bearing in rear axle box).
August 8.....	Seafield.....	Battery locomotive (short circuit owing to failure of insulation).
September 9...	Calverton.....	Diesel locomotive ("ran away" and oil from fluid coupling ignited).
November 11...	Barnburgh Main.	Diesel locomotive (lack of lubricating oil at axle bearing).
December 18...	Calverton.....	Diesel locomotive (exhaust gases impinging on coal dust behind locomotive radiator).
1969 (2 fires):		
June 10.....	Linby.....	Diesel locomotive (glowing dust on underside of chassis bedplate--no apparent cause).
July 24.....	Fishburn.....	Diesel locomotive (frictional heating owing to oil starvation at axle bearing).
1970 (2 fires):		
February 27...	Westoe.....	Battery locomotive (short circuit owing to failure of cable insulation).
November 23...	Murton.....	Battery locomotive (frictional heating of collapsed double roller bearings in axle box).
1971 (5 fires):		
May 20.....	Calverton.....	Diesel locomotive (collapsed clutch bearing).
August 16.....	Bilston Glen...	Battery locomotive (short circuit owing to failure of cable insulation).
August 9.....	Barony.....	Battery locomotive (disintegrated roller bearings in axle box).
September 17..	Mardy.....	Diesel locomotive (overheated engine owing to pin lost from throttle/governor control linkage).
November 20...	Kilnhurst.....	Diesel locomotive (ignition of oil deposits in vicinity of incorrectly fitted and dirty exhaust flame traps).
1972 (2 fires):		
March 29.....	Linby.....	Diesel locomotive (fractured fuel pipe).
May 4.....	Murton.....	Battery locomotive (axle-box bearing).

COST ASPECTS

Maintenance Costs of Diesel Locomotives

A sample has been taken of the maintenance cost of operating diesel locomotives of the conventional type on mixed duties of manriding and of hauling coal, stone, and material. Table 4 indicates the mean maintenance costs (labor, spare parts, and periodic overhauls) applying to the sample areas of the National Coal Board.

TABLE 4. - Lives of locomotives, of various components, and overall maintenance costs

Sample designation.....	NN	SY1	SY2	SY3	SY4	SY5	NW	NLD	NLD	NLD	S1	B
Locomotive life.. Years	25	Indef- inite	Indef- inite	Indef- inite	Indef- inite	Indef- inite	20	20	19	-	25	-
Engine life between over- hauls and/or replacement.	6	4	10	5	3	15	2	3	2	-	7	-
Life of condi- tioner box.	13	10	6	15	15	20	18	18	16	-	10	-
Life of flametrap	10	4	7	12	12	15	55	55	55	55	8	-
Spares/overhauls, maintenance cost per year per locomotive.	3,720	1,330	2,000	1,520	1,500	1,700	4,350	1,560	1,550	2,535	4,420	2,200
Number of loco- motives in sample, (hp).	26 (50/75) 50 (100)	6 (100)	11 (100)	5 (70)	6 (100)	15 (100)	-	8 (100)	5 (100)	4 (100)	5 (65) 2 (100)	-

1plate renewals are necessary at the end of the number of years specified.

From table 4, the mean maintenance cost per locomotive per year for 143 locomotives is $\frac{£416,110}{143} = £2,900$ approximately.

In many cases it has been possible to retain the original diesel unit over a period of some 20 years, provided complete overhauls or reconditioning replacements are made at 2- to 7-year intervals. Whether reconditioning of the original engine is carried out depends upon the availability of other locomotives to take over the duty. For conditioner boxes, the life will greatly depend on the use of the correct chemical treatment to allay corrosion. Such treatment in the United Kingdom has been developed very successfully.

Flame traps in stainless steel have an almost indefinite life; only damage has to be provided for, together with the occasional renewal of odd plates in the replaceable plate type of component.

In a special statistical analysis covering all diesel locomotives in the United Kingdom and based upon spares and services brought out, together with colliery labor, the maintenance costs per year per diesel locomotive amounted to £2,052, compared with £2,900 given in the table. The latter figure includes provision for lubricating oils and greases and reflects the use of many locomotives now over 20 years old.

It is estimated that the maintenance cost per ton-mile laden is approximately 2.34 new United Kingdom pence or 5.61 U.S. cents. If the higher figure of £2,900 per year cost is taken this would raise the upper figure to 7.85 cents per ton-mile laden on a mean annual laden haul mileage of 1,250 miles.

Maintenance Cost of Battery Locomotives

Figures for battery locomotives are in the range of £2,292 to £3,520 for the total cost of maintenance per year per locomotive, including a proportion for battery replacement at periods ranging from 3-1/2 to 5 years, including colliery maintenance labor and spares.

The merits of the diesel and the battery must be set down so as to include current capital cost and must take account of the performance criteria. The maintenance costs are less easy to estimate. Thus, this paper has concentrated on current cost experience since other criteria are available and must be applied to the duty proposed for given installations.

For a heavy, sustained, high-speed coal duty of 10 to 12 mph on gradients steeper than 1 in 80 and hauls of 1 mile or over, the frequency of battery charging either reduces the speed of the locomotive and thus coal-hauling capacity, or increased costs are incurred for operating more locomotives. In the United Kingdom, the diesel operates economically in a well defined field with some flexibility. The battery locomotive performs with equal satisfaction provided that any application for mineral haulage is well chosen. For manriding and service duties, a battery locomotive is often ideal. The

capital cost difference between battery locomotives and diesel is now changing so as to bring the former into the same price range as the latter. The gap may close still further.

One great difficulty with operating diesels in the United Kingdom is the engaging and holding of diesel craftsmen, particularly in close proximity to large towns and cities, since men prefer to work in factories rather than mines. This may not apply in the United States.

Rubber-Tired Underground Tractors and Vehicles

In many situations certain collieries avoid the cost of laying track by using diesel rubber-tired vehicles as follows:

25 hp tractors.....	88 in use.
40 hp tractors.....	6 in use.
Sundry carrying vehicles.....	7 in use.

Conditions are exceedingly rough, and the mean life between overhauls (usually carried out at the National Coal Board specialist workshops) is about 6 months. The total maintenance costs including these overhauls is therefore high, amounting to about £280,000 per year, or about £2,800 per tractor. No serious difficulties with fire or exhaust emission have been experienced.

Captive Rail Diesel Locomotives

Included in the total of 608 diesel underground locomotives, shown elsewhere, are 31 locomotives running on special forms of track to which they are captive, that is, unable in the absence of component breakage to overturn or become derailed. The track (of which there are two different proprietary makes) consists generally of 4-in by 2-in channel sections and the vehicles have, in addition to load-carrying wheels running on the top flange, guiding and trapping wheels running within the channel. On the locomotives, the driving wheels have polyurethane tires which are urged against the track not merely by weight but also by hydraulic cylinders. In this way large tractive efforts can be exerted by relatively light locomotives. Whereas conventional underground locomotives are limited by law to gradients of 1 in 15, captive rail locomotives can negotiate gradients of 1 in 7.

However these locomotives have not been entirely trouble-free. The polyurethane tires have a short and somewhat unpredictable life, failing sometimes because of heat generated by internal hysteresis, sometimes because of skiving (when wheelspin has occurred at rail joints) and sometimes by fatigue failures in shear or tension. Other items have called for heavy and costly maintenance, owing partly to the rough inby environment. However from the aspects of fire and exhaust emission these locomotives have given no trouble.

CONCLUSION

The paper has been written to give an overall impression of the experience gained and the precautions used in the operation of diesels below ground. In general their use, although declining because of coal transport by conveyor belt, has been attended by some success and without undue hazard.

APPENDIX A.--APPLICATIONS AND VEHICLES EMPLOYING THE DIESEL ENGINE

The schedule in table 2 illustrates on a hp weight basis the various models and range of diesel locomotives currently operating in British coal mines. These photographs show the different applications and vehicles to which the diesel engine has been fitted as the prime mover.

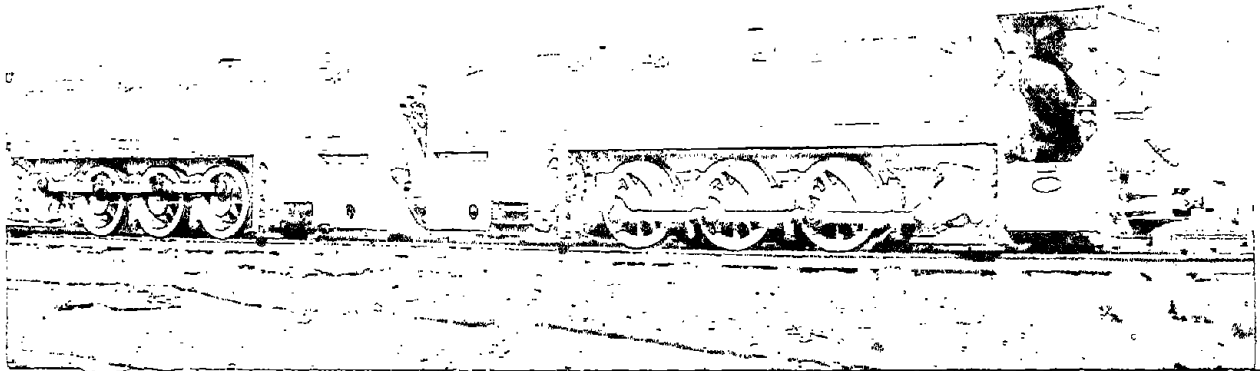


FIGURE A-1. - Tandem diesel locomotives (2 by 100 hp) Hudswell Badger. (3-ft 0-in gage, 28 tons weight, 20 mph maximum speed.)

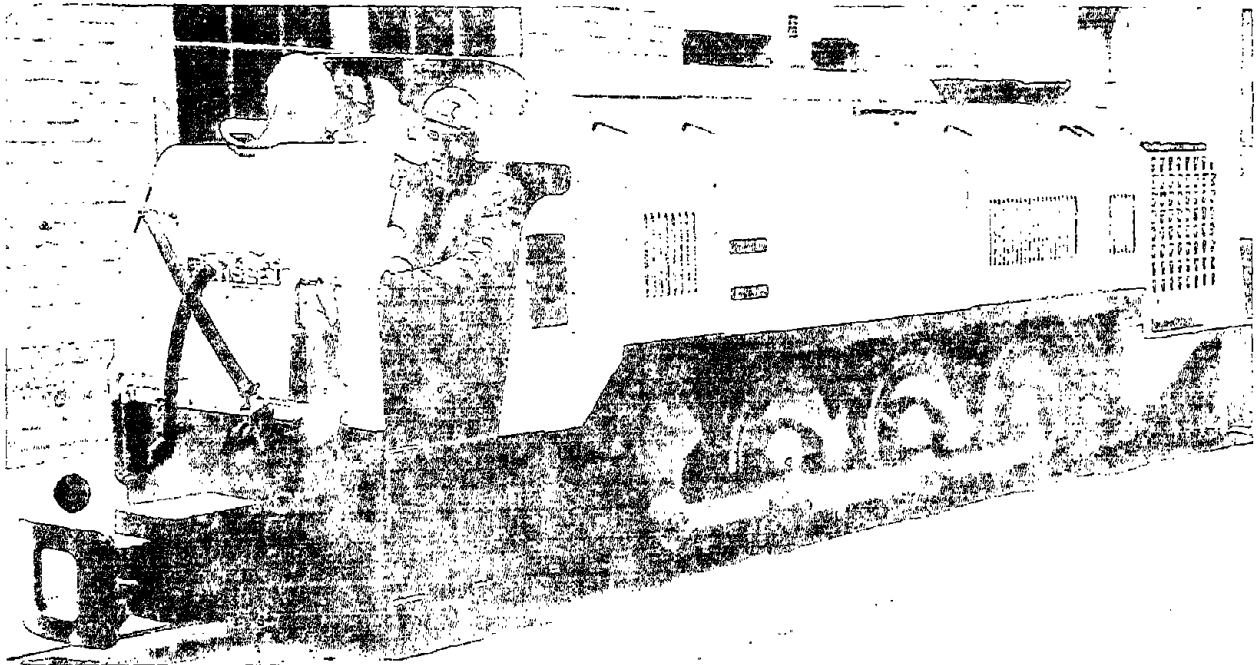


FIGURE A-2. - Double-end-control, 100-hp Hunslet diesel locomotive.

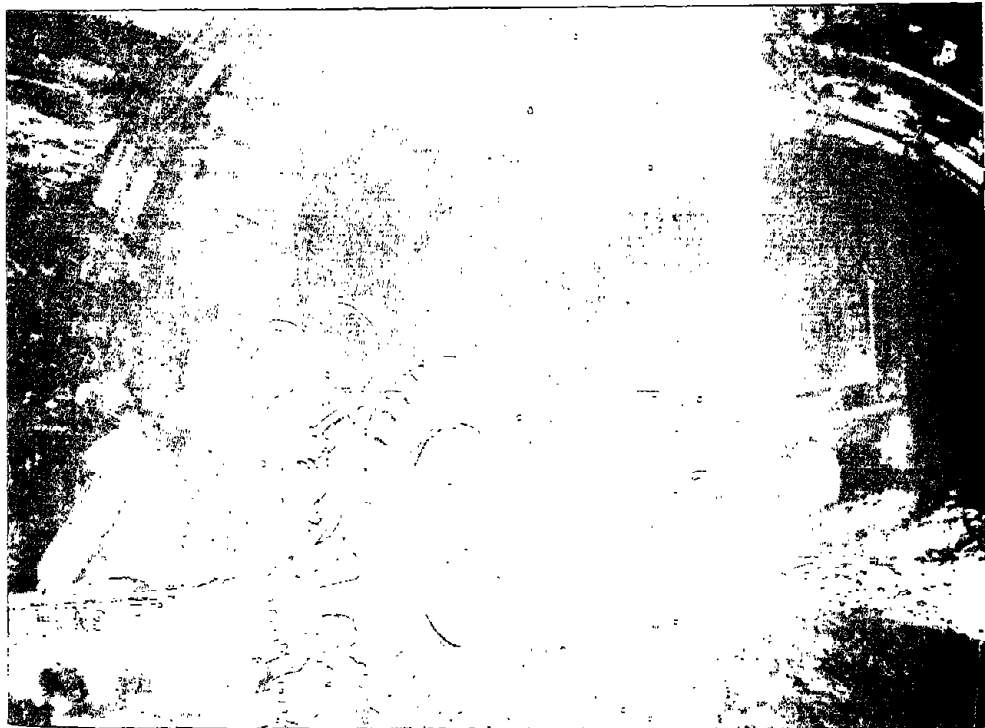


FIGURE A-3. - MT 25 Hunslet tractor.

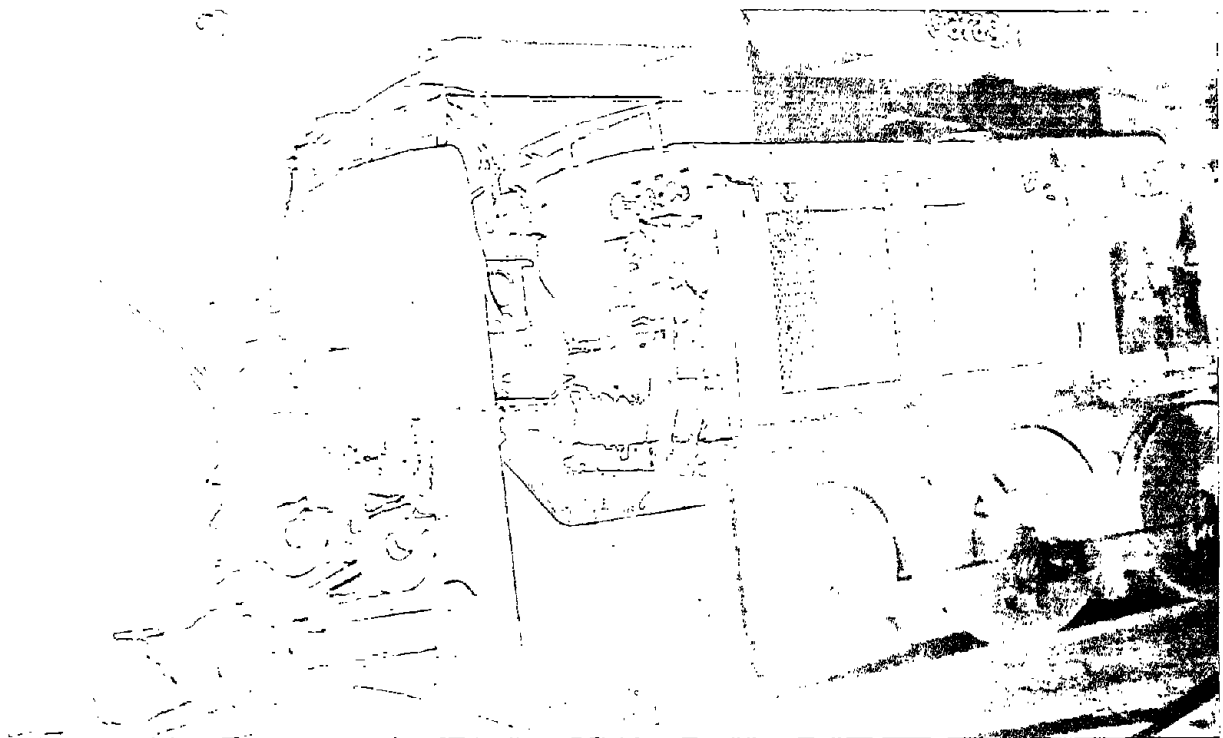


FIGURE A-4. - Leading cab of tandem diesel locomotives underground, Easington Colliery (maximum gradient 1 in 15).

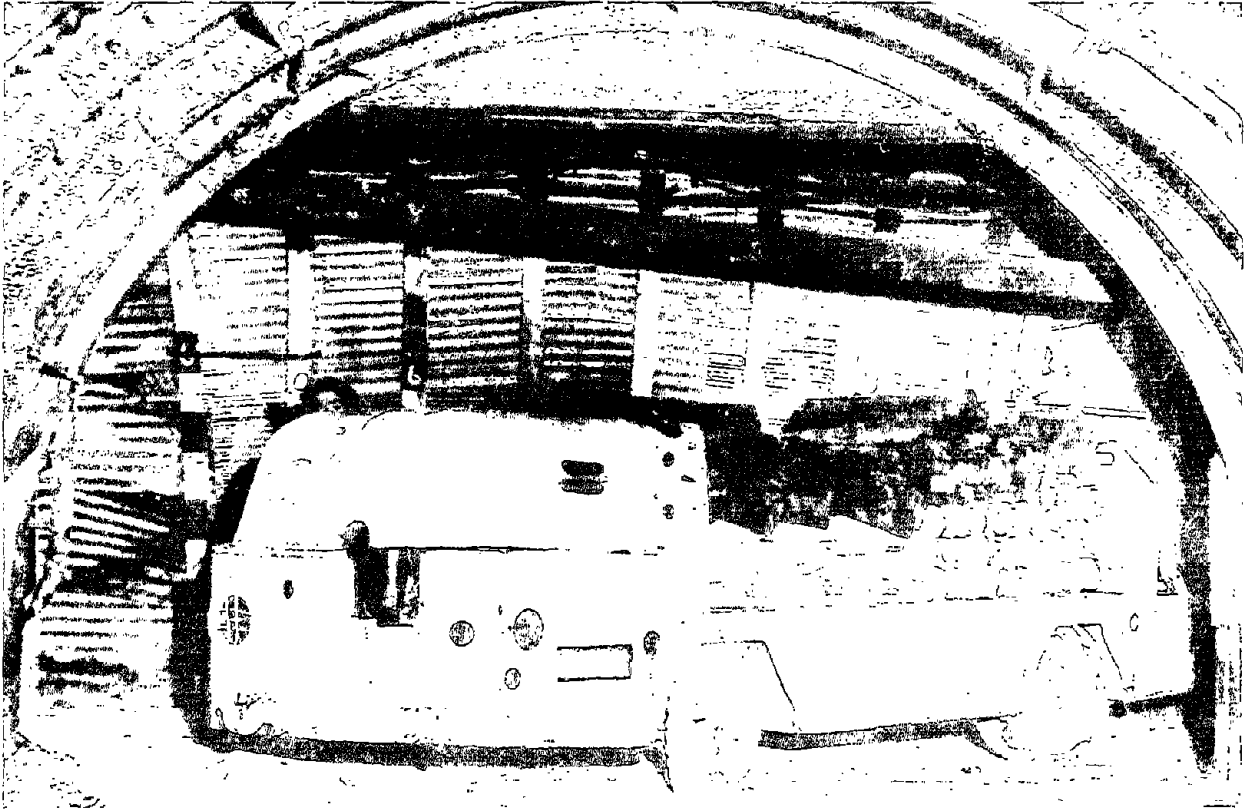


FIGURE A-5. - Hunslet MT 30 underground supplies vehicle, diesel/hydraulic operated.

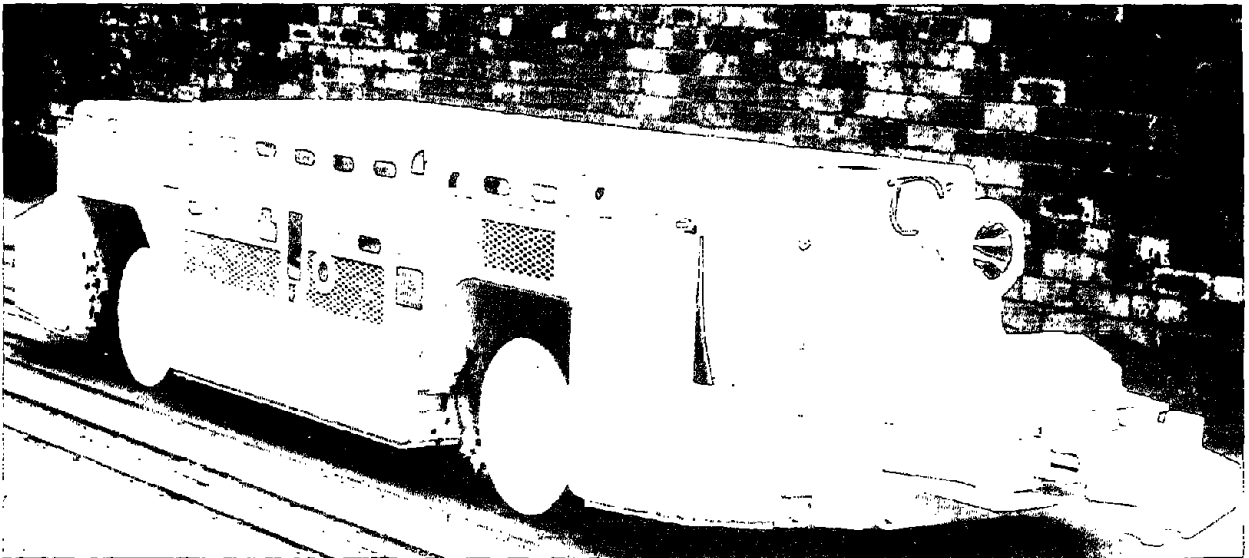


FIGURE A-6. - MT 40 underground supplies vehicle (diesel/hydraulic operated, conventional track mounted).



FIGURE A-7. - Becorit RL 40-hp diesel/hydraulic captive rail locomotive underground, Dawdon Colliery.

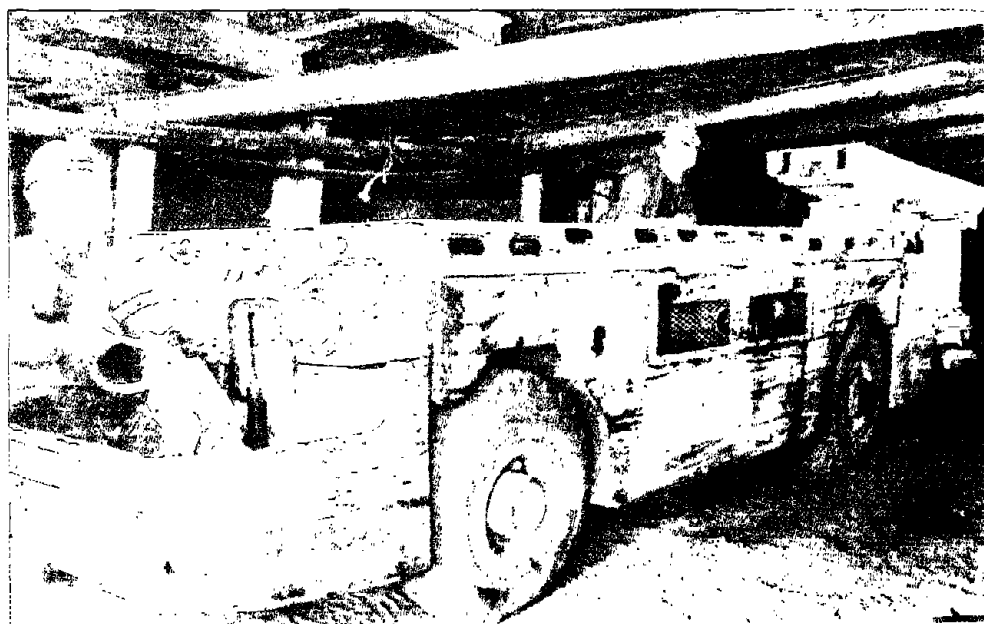


FIGURE A-8. - Hunslet MT 40, 40-hp underground diesel/hydraulic tractor, Dawdon Colliery.

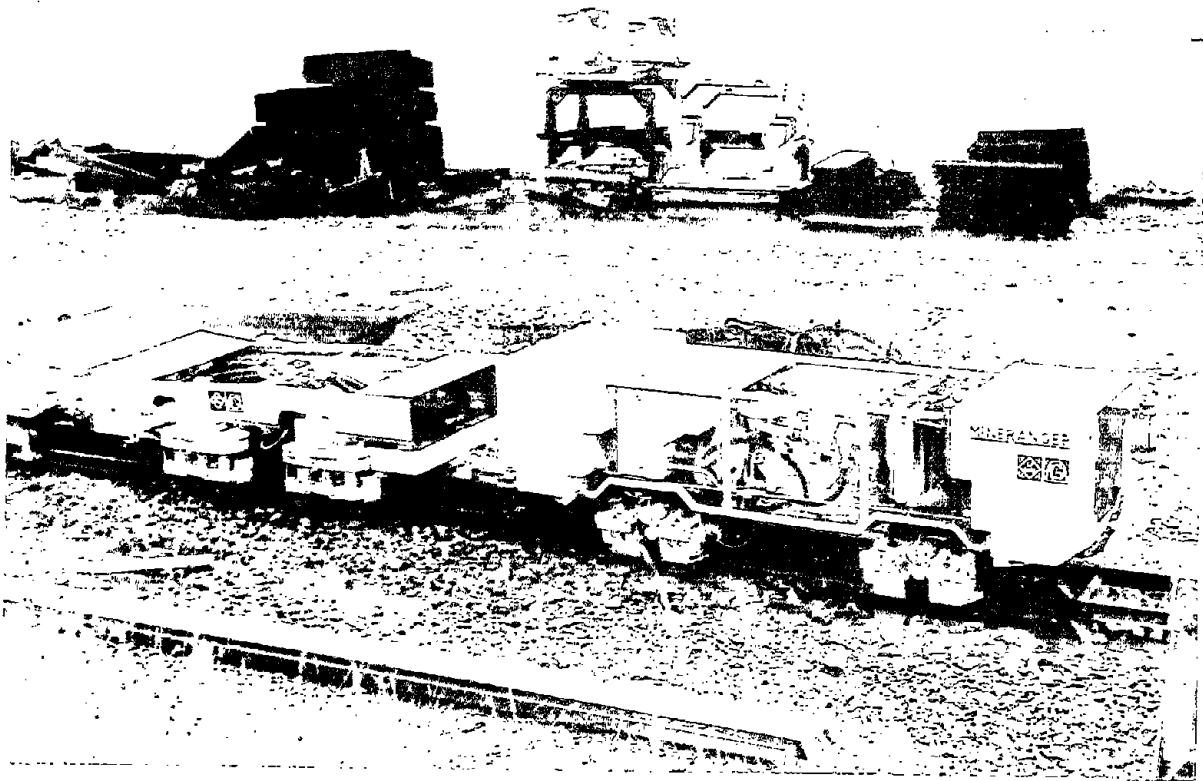


FIGURE A-9. - The U.M.M. Ltd. 40-hp diesel/hydraulic captive rail locomotive.

RECORD OF ANALYSES OF EXHAUST GASES

[illegible]

FIGURE B-1. - Mines and quarries Form No. 274, Part 1.

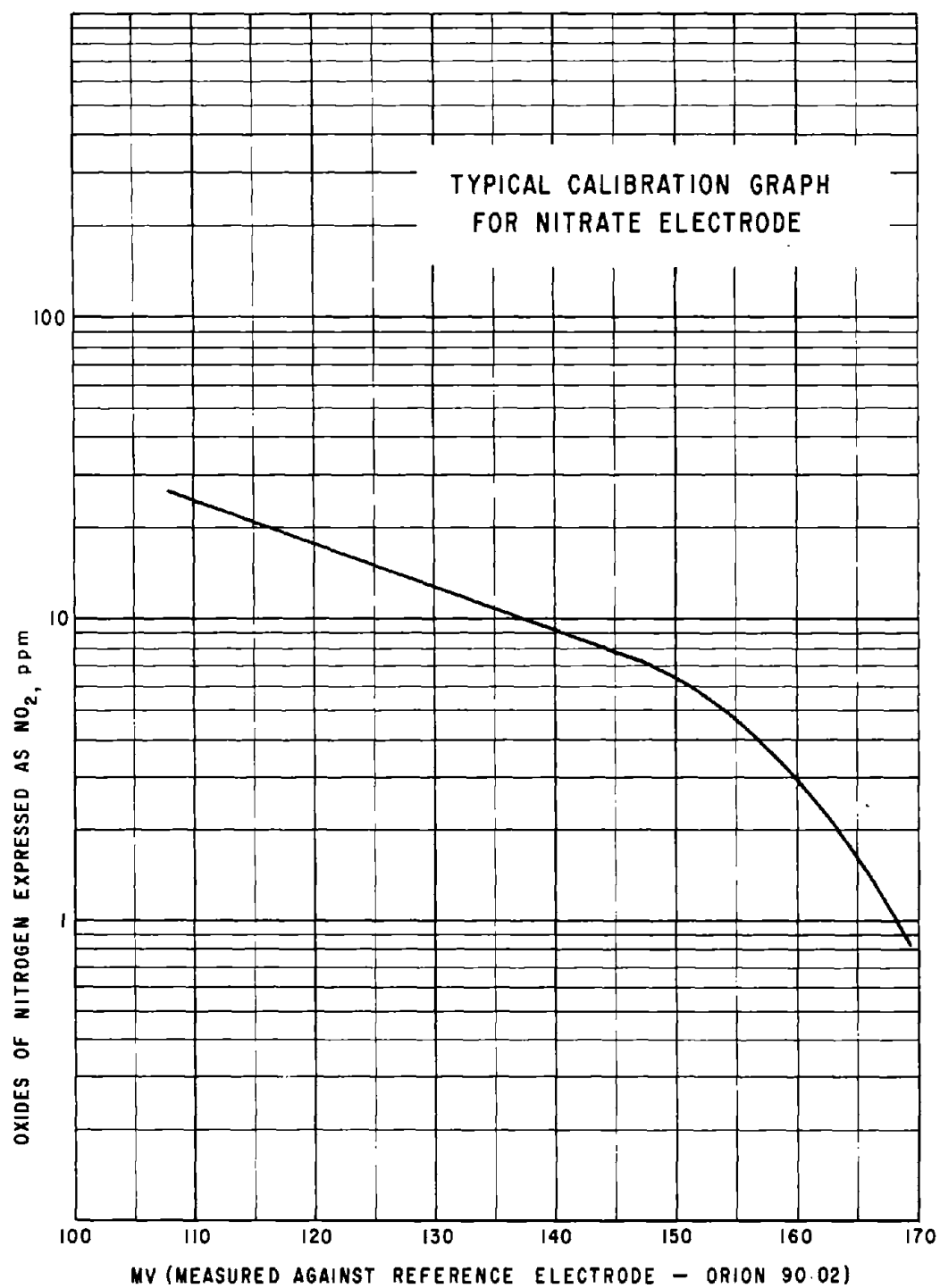
Record of Determinations of Firedamp Content in Roads where Locomotives are used

[illegible]

Insert sample number or type of apparatus used for determination

FIGURE B-2. - Mines and quarries Form No. 270.

APPENDIX C.--TYPICAL CALIBRATION GRAPH FOR NITRATE ELECTRODE



APPENDIX D.--CHECK LIST SAMPLES

CHECK LIST NO. MB.34/1

Diesel and Battery Locomotives (Underground)Oils and GreasesExamination 'A'--Daily StatutoryCheck Where Applicable and Leave in Safe Working Order

1. Check locomotive brakes for correct operation and adjustment.
2. Check belt drives. Adjust and renew as required.
3. Lubricate drawgear and uncoupler gear, if necessary.
4. Check oil level in the air compressor and top up as required. Record the quantity of oil used.
5. Check that the compressor unloading valve is operating at the correct pressure.
6. Drain water from the air reservoirs.
7. Check the operation of the sanders and the supply of sand.
8. Check all fuel, oil, and air pipes for leaks (including hose to manriding train).
9. Test the audible warning device.
10. Inspect the fire extinguisher.
11. Lubricate the axle boxes as required, horn blocks, side rods, jackshaft bearings and brake mechanism. Check that oil feed pipes are properly secured.
12. Check the oil levels in the engine sump and gearbox and top up as required.
13. Adjust and lubricate chains where fitted.
14. Make readings of the lubricating oil and air pressure gages, and check that the instrument glasses are clean and unbroken.
15. Check fuel tanks and refill as required.
16. Check radiator conditioner boxes and sprayer supply tank where fitted and top up as required.
17. Make sure that exhaust flametraps are changed at least once in every 24 hours during which the engine has run.
18. Check that the headlights are securely attached to the frame of the locomotive, and that the lamp glasses are clean and unbroken.
19. Check the operation of the lights.
20. Clean all surfaces of the exhaust system particularly the conditioner.
21. Check the engine for smooth running without excessive exhaust emission.
22. Check all drivers' controls for operational correctness.
23. Check clutch adjustment and lubrication of clutch yoke where applicable.
24. Check all guards for security.

Examination 'B'--Weekly StatutoryCheck Where Applicable and Leave in Safe Working OrderAs Examination 'A' Plus:--

1. Examine and test the locomotive brakes as per National Coal Board Codes and Rules at least once in every week, and immediately after any repairs or adjustments to the braking system.
2. Check the locomotive undercarriage for defects.
3. Check the power transmission equipment.
4. Check the side rods and axle boxes.
5. Check the scoop coupling and control gear.
6. Check the auto gear selection for correct operation.
7. Check the compressor air intake filter--clean or replace as required.
8. Check the inlet flametraps. Clean as found necessary.
9. Check the gap of inlet and exhaust flametraps (not to exceed 0.020 in).
10. Check the oil filters and clean or replace as required.
11. Check the linkage between the governor and the fuel pump.
12. Drain and hose out the conditioner box and inspect for corrosion.

Examination 'C'--MonthlyCheck Where Applicable and Leave in Safe Working OrderAs Examination 'A' and 'B' Plus:

1. Check the lubricating oil for contamination by fuel oil.
2. Check the engine valve clearances and adjust as required.

Examination 'D'--To Be Carried out at 5,000 MilesCheck Where Applicable and Leave in Safe Working OrderAs Examination 'A', 'B', and 'C' Plus:

1. Examine all belt drives, chains and pulleys and renew any defective parts.
2. Drain and refill the compressor sump.
3. Examine axle boxes for wear.
4. Examine linkages and pins in the braking system for wear and security of pins and fastenings. Adjust and renew as required.
5. Decarbonize the compressor, if necessary.
6. Weigh the fire extinguisher, and if necessary, renew the charge.
7. Decarbonize the engine and examine the gaskets.
8. Examine and if necessary, regrind the valve, renew defective springs, and check clearance.
9. Check the tension of the timing chain.
10. Remove and test the injectors and replace with service units, if required.
11. Drain and refill the sump with lubricating oil.
12. Examine and test the thermostat safety devices.
13. Examine joint between exhaust and conditioner box and insure that joint is properly made and the nuts tight.

Examination 'E'--To Be Carried out at 10,000 MilesCheck Where Applicable and Leave in Safe Working OrderAs Examinations 'A', 'B', 'C', and 'D' Plus:

1. Test sanders and nozzles and renew defective parts, and test pressure gages.
2. Withdraw the pistons. If the rings are worn, renew both pistons and rings. New rings must not be fitted in worn piston grooves.
3. Examine and adjust the starter motor and controls and renew worn or defective parts.
4. Examine and adjust the starter valves, and renew worn or defective parts.
5. Check all joints in the fuel tank.
6. Flush out all fuel pipes internally with fuel, and blow out with compressed air.
7. Examine and adjust all parts of the transmission system including compressed air.
8. Examine and adjust the cooling-water pump, and renew worn or defective parts.
9. Clean the water pipes internally.
10. Renew worn or defective parts in the cooling-system controls.
11. Fit new or works-reconditioned injectors.
12. Send the injection pump to the makers or service agents for calibration and service.

Examination 'F'--To Be Carried Out at 20,000 MilesCheck Where Applicable and Leave in Safe Working OrderAs Examinations 'A', 'B', 'C', 'D', and 'E' Plus:

1. Renew the compressor pistons and rings if required.
2. Examine and adjust all compressed-air equipment and renew worn or defective parts.
3. Examine the main frame for cracks.
4. Examine and adjust wheel and axle bearings (roller and journal) and renew worn or defective parts.
5. Examine tires, wheels and springs, and check for roundness and alinement.
6. Disconnect hand and airbrakes, examine, adjust, and renew worn or defective parts.
7. Check the couplings and hose of the braking system for defects and renew if necessary.
8. Test the speed and mileage indicators and cables.
9. Examine and adjust the connecting-rod bearings and renew the bolts.
10. Examine and adjust the main bearings and renew worn or defective parts.
11. Thoroughly clean the fuel-oil containers.
12. Examine lubricating-oil filter and renew worn or defective parts.
13. Overhaul the water tank and radiator, and renew work or defective parts of the cooling-system controls.

14. Examine and adjust all parts of the transmission system including fluid couplings, bearings, clutch and covers, torque converter, gearbox, coupling rods and bearings, and renew worn or defective parts.-

Examination 'G' (Every 26 months for receivers of fabricated construction, and periodically¹ for receivers of solid drawn construction)

Check and Leave in Safe Working Order

1. Thoroughly clean air receivers externally and internally.
2. If the construction of the receiver permits, thoroughly examine internally and externally for defects and corrosion.

If the construction of the receiver makes internal examination impracticable, thoroughly examine externally for defects and corrosion, and apply a hydraulic test as instructed.

Note to Areas:--

Since it is not compulsory for the receivers to be insured, the examinations and hydraulic tests may be carried out by National Coal Board personnel.

CHECK LIST NO. MB.36

HUNSLET DIESEL MINES TRACTOR

Oils and Greases

Examination 'A'

Check and Leave in Safe Working Order

Duties of the engine driver.

At the beginning of every shift the driver shall--

1. Insure that the parking brake is 'on' and that the directional control lever is in neutral.
2. Examine the external parts of the tractor and insure that they are free from any excess oil and from any inflammable material. Special care must be taken to insure that the utmost cleanliness of all potentially hot surfaces is maintained.
3. Clean out driving compartments.
4. Check that the fire extinguisher is present and not already discharged.
5. Check the horn.

¹The intervals between examinations for receivers of solid drawn construction shall not exceed 26 months, or at the discretion of the area chief engineer or area mechanical engineer, a longer interval not exceeding 4 years.

6. Check the draw-gear for secure fixing.
7. Check the tires for severe damage.
8. Drain, wash out, and refill conditioner box.
9. Check the fuel level, top up as necessary.
10. Start engine, count strokes on hand pump to reach pressure.
11. Bleed air from water system at pet cocks on conditioner box and exhaust pipe (engine end). Top up water system; correct water level must be maintained, however frequently topping up is required.
12. Check that headlamps are in working order and securely fixed to tractor frame and that glasses are clean, not broken, or cracked. If defective notify electrician immediately.
13. Check for obvious leaks of fuel, oil, or water.
14. Drive tractor. Check for any abnormal noise or abnormal operation of controls and response. Check readings of gages.
15. Check that all covers and guards are secure.

Examination 'A'

Check and Leave in Safe Working Order

1. Change exhaust flametrap. After refitting trap, check accessible joint with 6 thousand feeler.
2. Check the bolts securing inlet and exhaust manifolds to engine.
3. Check the fan belt for tension and damage.
4. Start engine and with direction control lever in neutral; check torque converter oil level; top up if necessary.
5. Check all fuel, oil, and water connections for leakage.
6. Check hydraulic oil level. Top up if necessary.
7. Check the engine oil level. Top up if necessary.
8. Check that all guards and covers are secure.

Examination 'B'

Check and Leave in Safe Working Order

As Examination 'A' Plus

1. Remove inlet flame arrestor and clean, after refitting flame arrestor check seating joint with 6 thousand feeler.
2. Check that air filter is clean; remove bowl and gauze and wash with diesel fuel, and refill bowl to mark with clean engine oil.
3. Check and adjust tires for pressure to 45 psi.
4. Check and examine steering clutch and adjust if necessary.
5. Check the oil levels in the transfer and reduction gearboxes.
6. Check the oil level in Bryce-Berger oil tank.
7. Remove filter tray from Bryce-Berger oil tank and clean with starter oil.
8. Check and carry out statutory brake test.
9. Check the security of nuts and bolts generally throughout tractor.
10. Check the fuel water trap.

Examination 'C'Check and Leave in Safe Working OrderAs Examinations 'A' and 'B' Plus

1. Remove wheels. Check tires and bearings.
2. Check the oil level in final drive gearboxes.
3. Check the bolts securing final drive gearboxes and in transmission shafts.
4. Check the oil level in generator drive gearboxes.

Examination 'D'Check and Leave in Safe Working OrderAs Examinations 'A', 'B, and 'C' Plus

1. Check the tappet clearance.
2. Check and remove and clean atomizers.
3. Test fuel injection with Injectester.
4. Change engine oil.
5. Carry out statutory gas test.
6. If CO high, retest, taking no less than three samples. If still high, remove cylinder head and grind in valves.
7. If oxide and nitrogen are high, refer to engineer; do not carry out any mechanical work to attempt to improve this figure.

MR. GILBERT: Thank you, gentlemen.

MR. CRAWFORD: Are there any questions from the floor?

FROM THE FLOOR: How many of these locomotives and tractors are working in the intake roadways?

MR. GILBERT: I am afraid that I do not know the exact numbers. However, the diesel locomotives utilized on mineral haulage are working in the intake roadways. The tractors since they are used for transport of men and materials will predominantly be working in the return gates.

FROM THE FLOOR: Despite the obvious difference between maintenance conditions in the various collieries, what would you estimate to be the average number of operating hours between major overhauls of your diesel engines?

MR. GILBERT: If the locomotive was working on a three shift system for 20 hours per day 5 days per week I would estimate an operating life of 5 years which is equivalent to 26,000 hours.

Therefore the diesel engine would require a major overhaul after working for 5 years.

MR. CRAWFORD: Are there any other questions?

MR. McDOWELL: Our next speaker is Mr. Zorychta, Director of Mining Engineering and Inspection of Mines, Nova Scotia. Mr. Zorychta was a member of the Royal Canadian Air Force from 1942 to 1945, after which he attended St. Francis University, where he received his B.S. degree in 1948. He received his B.S. degree in 1958, for Engineering. He had the position of Mining Engineer in the Nova Scotia Research Foundation and in the Mining Branch Department of the Environment and Resources from 1951 to 1972. He joined the Nova Scotia Department of Mines, and he has been a member of the Mine Society of the Nova Scotia and Canadian Institute of Mining and Metallurgy. His paper will be Canadian Experience Using Diesels in Underground Coal Mines.

CANADIAN EXPERIENCE USING DIESELS IN UNDERGROUND COAL MINES

by

H. Zorychta¹

INTRODUCTION

Diesels have been successfully used in Canadian mines for over 20 years. The first diesel powered equipment, a 100-hp diesel locomotive for underground haulage, North British Locomotive Company, Ltd., Glasgow, was introduced in Nova Scotia coal mines in 1949. This locomotive is shown in figure 1. Diesel

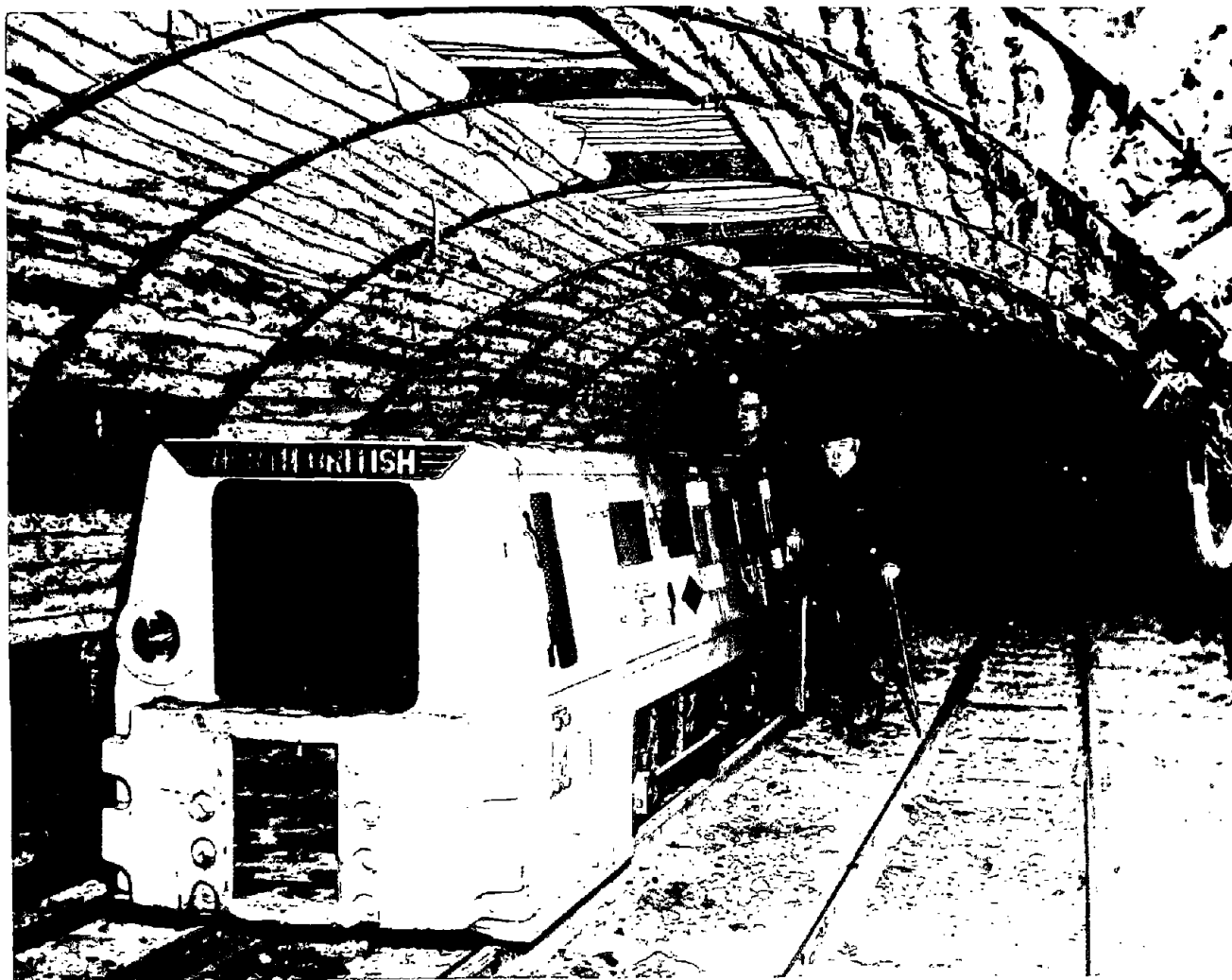


FIGURE 1. - North British locomotive-100 hp.

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locomotives were also first used in Alberta and British Columbia in the late 1940's. In Nova Scotia about 50 million tons of coal have been transported on level haulages ranging from several hundreds of feet to 1-1/2 miles in length.

In 1957, diesel locomotives were first used in metalliferous mines in Nova Scotia. In 1960, trackless diesel equipment was introduced into a salt mine and to date about 5 million tons of salt have been mined and transported underground in this mine. Diesel equipment was extensively used in the underground mining and transport of about 150 million tons of coal and ore mined in Canada in 1972.

DIESEL ENGINES USED UNDERGROUND

Simply stated, a diesel engine is a compressor fitted with a fuel injector. It has a surplus of oxygen for the combustion process resulting in almost complete combustion, and minimal CO and oxides of nitrogen. Other harmful exhaust emissions can be reduced by limiting the percent sulphur in the fuel and prohibiting fuels with a heavy asphalt base.

Diesel fuel is far safer than gasoline, with a flashpoint between 120° to 230° F whereas the gasoline flashpoint is around 100° F.

Diesel engines for coal mines are of an approved type and are equipped with the following ancilliary equipment: Intake filters, intake and exhaust flametraps, exhaust conditioner boxes, and exhaust dilution by air. Flame-traps consist of a large number of stainless steel blades contained in a housing with a gap of 0.016 inches between plates through which the intake air and exhaust gases pass. These traps prevent any flame from reaching the outside air. Exhaust traps are cleaned daily. Water is sprayed into the conditioner box cooling the exhaust gases and scrubbing them of carbon particles. If water supply becomes exhausted or pump fails and temperature in the conditioner reaches 200° F, a safety circuit is actuated to close off fuel supply to the engine. The exhaust gases are diluted and dispersed by air currents generated by the radiator fan.

DIESEL EQUIPMENT USED UNDERGROUND

Diesel locomotives were selected in 1949 by the Dominion Coal Company, Ltd., to replace main and tail-rope haulage system used on level haulages serving longwall faces. The company had 54 15-ton 100-hp North British diesel locomotives in operation in 1960. The successor company, the Cape Breton Development Corp., is currently using 43 of these diesel locomotives. The locomotives originally carried Buxton certification, but since the original Crossley engines, oval 5-cylinder 100-hp, are no longer available, new engine replacements must be approved by the certification officer, Mines Branch, if these units are to be kept in service.

Diesel locomotives are also used in Alberta and British Columbia coal mines.

Hunslet trackless, rubber-tired diesel tractors are used in Alberta and British Columbia to transport materials and men along level haulage roads to the working faces. These units are not allowed to go up to or along working coal faces.

Diesel power is applied to a wide variety of mining equipment in metal-liferous mines in Canada. Table 1 shows the number of units, make, and model of the various types of diesel powered equipment currently used in a salt mine in Nova Scotia.

TABLE 1. - Summary of diesel horsepower underground at Pugwash, Nova Scotia

No. of units	Make and model	Engine horsepower per unit	Total horsepower	Horsepower used for tramming only (intermittent)	Horsepower used for working (continuous)
3	Terex 13 UOT haulers.	160	480	-	480
2	Caterpillar 966C front-end loaders.	170	340	-	340
1	Euclid L-20 front-end loader.	152	152	-	152
1	Rogers drill.....	80	80	80	-
1	Joy drill.....	107	107	107	-
1	Giraffe 45-ft platform on Chevrolet truck with auxiliary engine.	{ 97 22 }	{ 119 }	97	22
1	Giraffe 40-ft platform on dumptor with auxiliary engine.	{ 107 25 }	{ 132 }	107	25
1	Wabco 2500 under-cutter with auxiliary engine.	81	81	81	-
1	Joy 15RU undercutter with auxiliary engine.	107	107	107	-
1	Ford 5000 tractor....	72	72	-	72
1	Champ 350 HLD tractor	140	140	-	140
1	Giraffe 70-ft platform on Chevrolet truck with auxiliary engine.	{ 195 25 }	{ 220 }	195	25
3	Massey Ferguson 135 tractors.	39	117	-	117
1	Caterpillar D336.....	300	300	-	-
Total: 19	-	-	2,447	774	1,673

It is very important that mine operators not only select the most suitable diesel equipment for their particular requirements, but also a well thought out maintenance program should be established before diesel powered machines are introduced into the mine. This is necessary to maintain safe and trouble-free operation of the equipment.

REGULATIONS

The Regulations of the Provinces of Canada covering the operations of diesels in underground mines vary to a certain degree but they have one aim in mind--"to maintain a very high standard of safety and at the same time enable the mine operator to obtain the benefits of diesel power."

In general, all regulations cover the following:

1. Operator must apply for a permit before diesels can be used underground.

2. Diesel equipment must be "of an approved type." In the case of coal mines "of an approved type" means that equipment certified as safe for use in coal mines by Buxton, U.S. Bureau of Mines, or the certification officer, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada. In the case of metalliferous mines, certification by the above testing laboratories is not a prerequisite to obtaining approval for use underground.

After approval all parts of the equipment and its accessories shall be properly maintained in their designed condition.

3. Ventilation--The amounts of ventilating air per horsepower of diesel power varies, but regulations are in keeping with known health and safety requirements, a minimum of 75 cfm/bhp in noncoal mines; in gaseous mines, coal or metalliferous, the volume of ventilating air per minute required is usually governed by the amount of fresh air required to keep the methane content below certain limits. In Nova Scotia all electrical and diesel equipment must be shut off if the methane content reaches 1.25 percent in the area where such equipment is operated. Special precautions must be taken when the methane content reaches 0.75 percent.

The regular analyses of diesel exhaust for carbon monoxide, nitrogen dioxide, aldehyde content, etc., is carried out and if percentages exceed specified limits, the diesel cannot be operated underground. In Nova Scotia maximum permissible amounts are as follows:

- (1) CO content of undiluted exhaust 0.20 percent coal; 0.25 percent other,
- (2) CO content of the atmosphere adjacent to engine 0.01 percent,
- (3) CO content of the general atmosphere 0.002 percent,
- and (4) nitrogen dioxide of atmosphere adjacent to engine 0.0005 percent.

4. Rules governing the type of garages, refueling stations, type of fuel (British Standard Specification No. 209 with a flashpoint not less than 150° F, Nova Scotia coal mines), refueling procedures, fire fighting, etc. Only 1 day's fuel supply is allowed underground.

5. Rules governing the diesel operation, authorization of operators, maximum speed limits, maximum loads, inspections, maintenance, etc.

The greatest problems facing the mine inspectors and operators are as follows:

1. Insuring that the diesels and their accessory equipment are "at all times" maintained in "approved condition,"
- and 2. insuring that the diesels are operated in approved locations underground and in a safe manner as laid down by regulations.

The inspectors and engineers of the Department of Mines in Nova Scotia are unanimous in their opinion that regulations requiring all mine operators to apply for a permit to use specified types of diesels operating under specified conditions in specified locations gives them, the inspectors, a reasonable degree of control. The inspector must be satisfied that all conditions in the regulations are adequately fulfilled before issuing such a permit and this permit limits the district or section of a mine where the diesels can be operated. A new permit must be applied for and approved before the mine operator can modify existing diesel equipment, introduce new and additional diesel equipment underground, or extend the use of diesels in other sections of the mine.

The inspector knows beforehand the type, and how and where the mine operator intends to use diesels underground; he approves the permit and if conditions deteriorate he can suspend or rescind all or parts of permits.

ACCIDENTS REPORT

Although inspections invariably uncover a number of minor deficiencies, particularly with the intake and exhaust systems, there has never been any serious incident directly related to the flameproof aspect or exhaust emissions of diesel locomotives used in Canadian coal mines. In general, the most serious incidents in Nova Scotia coal mines are categorized as follows:

Going too fast for conditions, overloaded trips, faulty brakes, inadequate clearances (roof and sides of roadways), pushing loads, poor tracks, and unauthorized or unskilled persons driving.

Several minor incidents of fires in diesel underground refueling stations have been reported but were quickly extinguished without damage. However, there have been cases where intake fires have been started by the use of "starter bombs" (aerosol cans filled with highly volatile liquids), fortunately with only relatively minor damage. Cases of refueling in other than refueling stations have been reported. It is imperative that mine inspectors

make sure that these unsafe and unauthorized practices be eliminated by strictly enforcing the regulations.

The metal mines also have had no serious incidents directly related to the diesel engines.

ADVANTAGES OF DIESEL POWERED EQUIPMENT

1. Diesel locomotives in coal mines:

- (1) Diesel locomotive is more flexible than electric locomotive or rope haulage.
- (2) Diesel can operate in either intake or return air.
- (3) Accident rate on diesel haulage levels one-quarter that on rope haulageways. (We cannot compare the diesel with shuttle cars, etc., since no trailing equipment of this nature has been used in Nova Scotia coal mines.)
- (4) Diesel costs 15 to 20 percent less than rope haulages in levels up to 1 mile in length and are more economical as length increases.
- (5) For main line haulage the diesel approaches the electric trolley locomotive in costs.

2. Diesel equipment in metal mines:

Trackless equipment provides additional mobility, increased gradient operation, increased productivity and lower mining costs coupled with increased safety. In addition, all the advantages listed for coal mines are applicable here as well.

CONCLUSIONS

1. Wherever possible, certification agencies should consider the inclusion of "idiot-proof" features as well as "fail-safe" features in permissible units. Fail-safe features, in too many cases, are tampered with and shorted out by underground personnel; for example, diesels have been operated without sufficient water, and the safety circuits in the exhaust water conditioners have been tampered with to prevent the automatic fuel shut off when the exhaust temperature reaches 200° F.

The exhaust flametrap is the backup safety feature and no serious incidents occurred in Nova Scotia coal mines that can be related to the flame-proof aspects of the diesels. If the exhaust flametraps had been eliminated, the above statement, in all probability, would not be true.

2. A sealed fuel injection system that would prevent mechanics from making unauthorized adjustments underground would be a decided safety asset.

3. Canadian experience indicates that the proper application of diesel powered equipment to mining systems underground can lead to added safety and increased productivity. These benefits can only be obtained if "approved" equipment is maintained in the "approved condition" and is operated in a safe manner as governed by regulations.

4. Canadian experience also indicates that mines inspectors must "strictly" enforce the regulations governing the use of diesels underground.

ACKNOWLEDGMENTS

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MR. McDOWELL: Thank you. Are there any questions?

(No questions were asked.)

MR. McDOWELL: The next paper is coauthored by Dr. Stefanko and Dr. Ramani. Dr. Stefanko presently is Assistant Dean of the College of Earth and Mineral Sciences, and has been on the faculty of Pennsylvania State University since 1955. Prior to assuming his present position in 1969, he was head of the Department of Mining Engineering from 1964 to 1969. He is a certified first grade mine foreman in Pennsylvania, having worked for the Westmoreland Mining Co. from 1948 to 1954, as a mining engineer, assistant mine foreman, and purchasing agent. He is active in the American Institute of Mining, Metallurgical, and Petroleum Engineers, and in the American Society for Engineering Education and holds important offices. In 1970, he received the AIME-SME award for outstanding contributions to the coal industry in the field of education and training and rock mechanics research. His most recent research has been in mine safety, mine power, and mining methods, subjects in which he recently published many papers. Dr. R. V. Ramani is assistant professor of Mining Engineering, and has been on the faculty of Pennsylvania State University since August of 1970. He has taught courses in mine systems engineering, mineral engineering management, and mining systems simulations. He has been involved, more recently, in the supervised research and operations research of mechanical modeling and computer simulation of various mining problems. In 1968, while working for his Ph.D., he won the AIME student prize paper award. He received his B.S. in Mining, with first class honors, at the Indian School of Mines in 1962. He worked for Bengal Coal Ltd. with intensive mechanization of deep mining operations where he earned a first class certificate of competency. He is a registered engineer. Dr. Stefanko will make the presentation.

EFFECT OF DIESEL EQUIPMENT ON MINE VENTILATION SYSTEMS

by

R. Stefanko¹ and R. V. Ramani⁻

INTRODUCTION

Diesel mining equipment is common in noncoal mining, both underground and in surface operations. However, because of a combination of circumstances, some of which are based at least partly on misunderstanding, the number of applications in coal mining has been limited. Nevertheless, the use of diesels in coal mines is a continually discussed subject and requires constant reassessment with changing technology, safety concerns, and economic conditions.

The application of diesels to haulage could provide certain safety and production advantages. Trolley rail haulage has always posed a hazard, probably the primary cause of mine fires; in fact, it is considered so hazardous that most countries have outlawed the use of trolley haulage in underground coal mines while frequently permitting diesels. The elimination of a trolley wire from rail haulage could be one of the significant safety factors in a change to diesel locomotives.

It is in the face area that diesel haulage could make a considerable impact. Presently, cable reel electric shuttle cars are the primary mode of face transportation, but they place tremendous restrictions on the mining method. Since reels are usually limited to a cable capacity of 500 feet, reach is severely limited from the loading point to the face whether the former be a belt or a rail sidetrack. In addition, separate travelways must be designated for each shuttle car to prevent cable entanglement or run over by other equipment. The result is normally that only two shuttle cars can be used per loading unit and each setup is limited to approximately 500 feet. When development consists of a large number of multiple entries, it is difficult to devise a workable plan that is efficient. Finally, the cable is a potential hazard, suffering terrible abuse even under normal usage. Cable blowouts can contribute to mine fires and explosions and serious burns to personnel.

The straight substitution of diesel for electric shuttle cars with panel intermediate haulage is the most obvious solution. By the use of more than two shuttle cars per unit, there is no real limitation on the length of a setup. In fact, it is possible to eliminate panel haulage entirely. Using a circular loop system, shuttle cars can haul to the panel intersection placing the coal on the main transportation unit, either belt or rail. However, it is the flexibility that one can achieve within the mining system that should appear most enticing to mining engineers and production supervisors alike.

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With a little imagination a whole host of possible corollary benefits with diesel haulage can be realized including use as emergency escape vehicles. When loading units also become dieselized, maintenance of airways will be much easier, since the equipment can be more easily diverted into the more remote areas of a mine for cleanup purposes.

With any equipment there are certain disadvantages and diesel engines are no exception. Although they may be constructed for efficient operation and minimum exhaust gas contamination, the design can be negated by improper maintenance. The authors view electrical equipment maintenance as one of the great weaknesses in today's underground coal mining. Yet, the skill required to maintain electrical equipment is probably much less than that required to maintain diesel equipment properly. Thus any introduction of diesel equipment into coal mines must be accompanied by effective maintenance education and training programs.

DIESEL ENGINE EXHAUST

The proper design and maintenance of diesel engines are paramount requirements and will be treated elsewhere. There is, however, an irreducible limit for the exhaust gases from diesel equipment no matter how well designed and maintained; but safety dictates that these be kept under established threshold limit values (TLV's). Therefore these contaminants must be diluted immediately upon release into the mine atmosphere to minimize local concentrations. Furthermore, since multiple units usually will be operating in the same air stream, there is a cumulative contaminant effect. Thus not only must local concentrations around diesel mine equipment be maintained below TLV's, but it is also necessary to determine the cumulative effect of diesel equipment on the mining system and then insure that TLV's are not exceeded anywhere, since men can be expected to work or travel in almost any part of a given mine, even though such activity may be temporary and of a brief nature.

Contamination of underground air by the exhaust of diesel haulage equipment is related to air velocity, equipment speed, the number of trips during an air change in the haulageways, and engine load and adjustment. Modern scrubbers do an effective job of dissolving aldehydes and reducing exhaust gas temperatures before discharge into the mine atmosphere. Other gases such as CO₂, CO, and NO are virtually unaffected and are discharged from the exhaust at noxious or toxic levels. Therefore, the mine ventilation system must be capable of immediate dilution of each below certain ceiling levels for the short term and below time-weighted TLV's for the long term.

There is considerable misunderstanding concerning air requirements with diesel equipment. Each approved diesel unit has a recommended quantity of air indicated on the approval sticker. This quantity had been determined by doubling the quantity of air calculated to be needed to reduce exhaust contaminants below TLV's when the engine is operating at full-rated continuous duty. Many studies have revealed that mining equipment has a load factor of only 30 to 35 percent and therefore the sticker number is exceptionally conservative, especially when one considers that a safety factor of two had been employed. The Bureau no longer uses a factor of two.

When determining working section air allotments, frequently the dilution volume of diesel exhaust gases is considered to be an addition to legal air requirements for methane and coal dust. One author (1)² implied that the superpositioning of the two requirements probably precludes the use of diesels in underground coal mines. In another instance (3), the diesel approval plate quantity has been used for calculating working section requirements to which has been added the minimum volume of air legally designated for the dilution of gas and dust by that State. The authors see no logical additive effect of diesel exhaust gases and methane gas. Because of the large quantities of air already required for gas and dust dilution, it is more likely that diesel exhaust dilution can be met with existing ventilation systems and should be explored.

The most practical approach to evaluating ventilation systems is to take a typical mine production system, determine diesel haulage requirements, calculate contamination per unit, and then accumulate the contaminants to obtain the most critical condition. If the ventilation system is capable of handling this most critical situation, other subcritical conditions will result in higher mine-air quality.

Hypothetical Mine Design

General

The Pittsburgh Block Slicing System is quite popular in southwestern Pennsylvania and northern West Virginia and one such mine reported on in a recent paper (2) was chosen as a modified illustrative example (fig. 1). It is assumed that seam thickness is 6 ft and all entries are driven 16 to 17 ft for an area of 100 ft² per entry. Nine entries are employed for the mains with entries on 80-ft centers, the five interior ones on intake and the two outside ones as returns. The runaround for main development is located 10,000 ft from the portal. A set of six entries on 70-ft centers are driven the length of panels. In the scheme shown, a milling head continuous miner is used in each panel entry, 10L being retreated on a pillar line, 11L just completed on development and 12L in the early stages of development. In 10L rail haulage is employed with two diesel shuttle cars, in 11L three diesel shuttle cars are used to haul to the sidetrack on the mains and in 12L a belt is used with two diesel shuttle cars. A loop sidetrack is used in the mains for development with two miner units being employed and two diesel shuttle cars assigned to each. With a production of 500 tons per shift unit, production on a two-shift basis is 5,000 tons. Ten-ton cars with 5-ton tare weight and 20-ft length are employed. Panel sidetracks are designed to hold 15 empties and 15 loads at any time so that train makeup is not required with a minimum of switching.

Diesel Equipment Deployment in the Mine Ventilation System

Ten-ton locomotives were selected for main haulage for which the emission characteristics are available (6) in table 1. Ten-ton shuttle cars are employed with representative emission characteristics as shown in table 2. Maximum speed for the locomotive is 10 mph (900 ft/min) and the shuttle cars

²Underlined numbers in parentheses refer to items in the list of references at the end of this chapter.

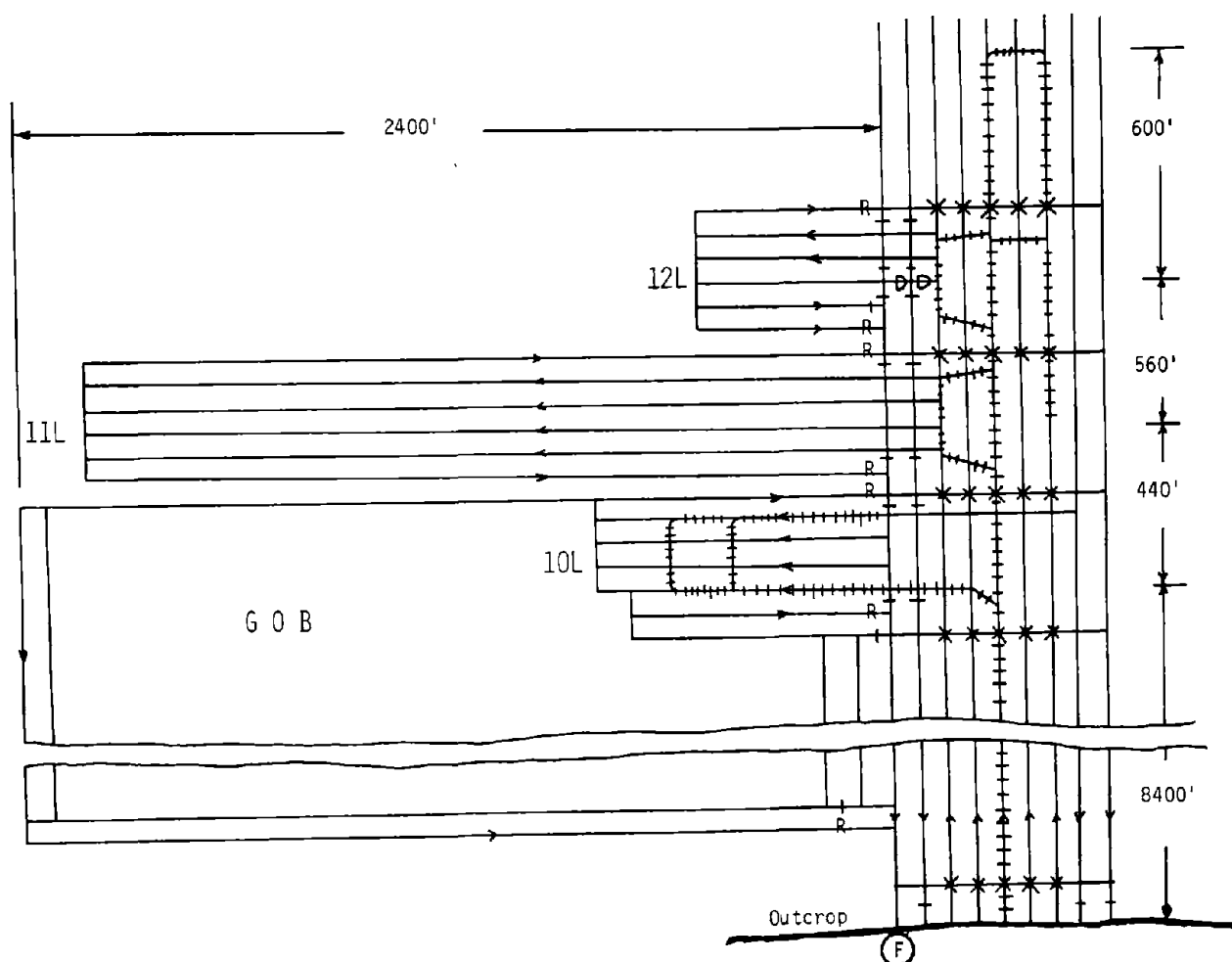


FIGURE 1. - Illustrative mine example.

can travel at a maximum speed of 5 mph (450 ft/min). If two 10-ton locomotives are used in a push-pull arrangement, tractive effort is more than adequate for a trip of 15 cars. Thus a total of 17 trips (2,500/150) must be made in a given shift. With a maximum haul distance of 10,000 feet and locomotives traveling at 900 ft/min, it will require just under 12 minutes for a one-way trip or 24 minutes for a round trip. Adding shifting time at each end, perhaps 10 to 20 minutes, a complete round trip will require only 34 to 44 minutes. Two locomotive units (four locomotives) in push-pull arrangement can handle the haulage requirements easily.

TABLE 1. - Quantity of exhaust gases (cfm)
from 10-ton locomotive

Contaminant	Loaded	Empty	Idling
CO ₂	20.50	12.00	1.50
CO.....	0.17	0.19	0.04
NO ¹	0.18	0.09	0.005

¹Total nitrous oxides.

TABLE 2. - Quantity of exhaust gases (cfm)
from 10-ton shuttle car

Contaminant	Loaded	Empty	Idling
CO ₂	16.40	9.60	1.20
CO.....	0.136	0.152	0.032
NO.....	0.144	0.072	0.004

To calculate gas dilution, information is needed about the ventilation system. It is assumed that a total of 40,000 cfm is to be employed in a two-split system for each working unit, 20,000 cfm at the open crosscut on each side. The two-split system is a premium arrangement exceeding legal requirements but allowing the miner and bolter each to remain on a separate split, and no shuttle car haulage is required through line brattice. Assume 8,000 cfm in fugitive air losses in the panels and another 12,000 cfm in the mains. Thus the fan must supply 60,000 for each working unit or 300,000 cfm total. With five intakes, the velocity on the main haulage entry will be 600 ft/min.

Dilution of exhaust gases depends on effective ventilation, a term that has been coined by the Bureau of Mines for the product of the difference in velocity between the air and haulage equipment and the entry area. For our example on main haulage, effective ventilation will be $(900-600)100 = 30,000$ cfm for empties in, $(900+600)100 = 150,000$ cfm for loads out, and $(0-600)100 = 60,000$ cfm for the locomotive idling. Notice the very conservative approach utilized in the calculation. Only one entry area (haulage entry) is employed for dilution purposes, although there are four other adjacent intake airways. It is highly improbable that no mixing will occur, further diluting the contaminants as they travel along the entry. Table 3 indicates the contamination contributed by each locomotive under the three load conditions specified. For each gas, the results in table 3 are obtained by taking the quantity exhausted under each load condition as specified in table 1 and dividing it by its effective ventilation. For example, 20.5 cfm of CO₂ will be exhausted by the single 10-ton locomotive under loaded conditions (from table 1). Dividing this quantity by the effective ventilation (150,000 cfm) indicates that the haulage air has a CO₂ content of 0.0137 percent under loaded conditions. Dividing 0.17 CO by 150,000 gives 1.13 ppm and so on.

TABLE 3. - Exhaust gas dilution for single 10-ton
locomotive on main haulage

Contaminants	Loaded, $Q_e = 0.15 \times 10^6$	Empty, $Q_e = 0.03 \times 10^6$	Idling, $Q_e = 0.06 \times 10^6$	Comments
CO ₂	0.0137	0.04	0.0025	Percent
CO.....	1.13	6.33	0.67	ppm
NO.....	1.20	3.00	0.08	ppm

To determine the worst possible air contamination on main haulage, it is necessary to consider the maximum number of contaminations that a given air volume will undergo as a result of the cumulative effects of locomotive

haulage units. It is impossible to expect cycling of the two locomotive units to be perfect at all times and therefore the worst abnormal situation must be considered. A normal situation that could be expected regularly would be a loaded trip nearly emerging from the mine while the other would be going in with empties. Thus initial contamination near the entrance of the mine is by loaded unit No. 1, to which will be added the exhaust effect of empty unit No. 2, since at a locomotive speed of 900 ft/min it will soon overtake the contaminated air traveling at 600 ft/min. However, because of the long run (10,000 ft), unit 2 will be able to deposit its empties in a sidetrack, couple to the loads, and start out adding this further contamination. Therefore, for an inby distance along the main haulage, there will be superposed contamination from two loaded units (No. 1 and No. 2) and the empty condition (No. 2).

Utilizing similar reasoning, it is possible also to accumulate two empty trips on top of a loaded unit on occasion. Finally, a remotely possible condition is having two empty units added to two loaded units. This might again occur at the furthest inby point of the mains if both locomotive units follow each other (with empties) into the mine (for example the preparation plant has been down for a time) and each immediately pulls a trip from a sidetrack and more or less follows the other outside. In table 4, exhaust gas contamination on the mains is calculated for each tandem locomotive unit (twice single values in table 3) and the three cumulative conditions that can occur if no mixing of air takes place between the haulage entry and other intake airways.

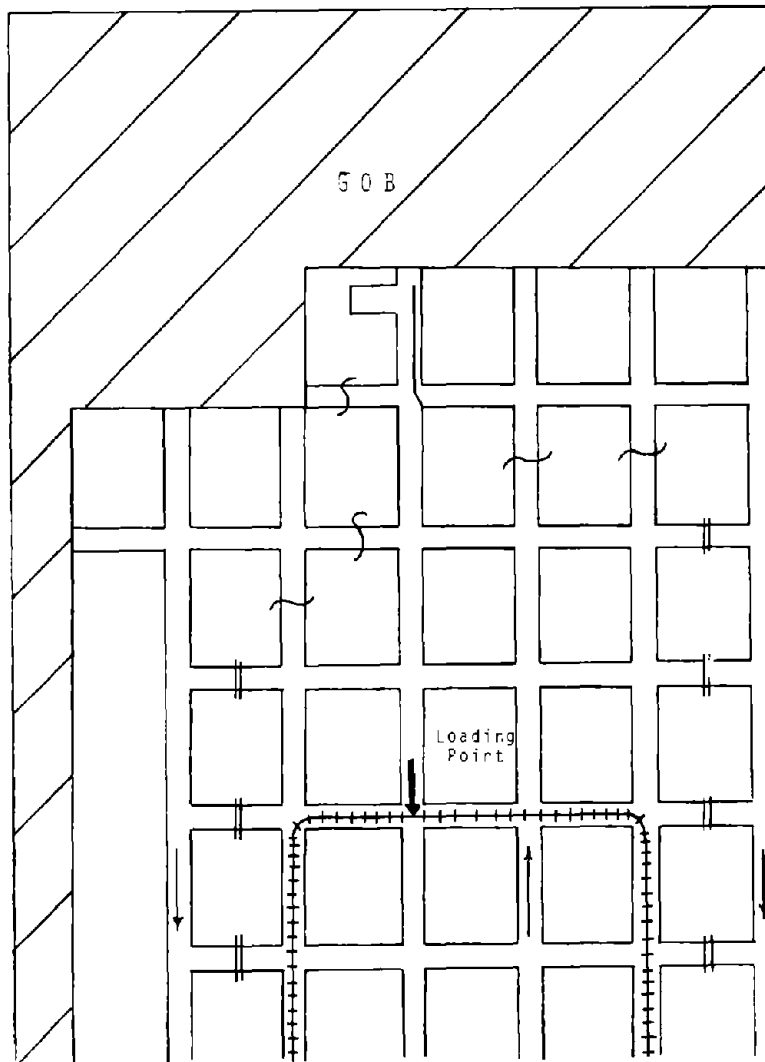
TABLE 4. - Cumulative effect of locomotive on main haulage

Contaminant	Loaded tandem	Empty tandem	Cumulative, two loads + one empty	Cumulative, two empties - one load	Cumulative, two loads + two empties	Time-weighted TLV's
CO ₂ ¹	0.0274	0.08	0.1348	0.1874	0.2148	5 pct
CO.....	2.26	12.66	17.18	27.58	29.84	35 ppm
NO.....	2.4	6.0	10.8	14.4	16.8	25 ppm

¹CO₂ values do not include 0.03 pct found in normal air.

It is necessary to determine what will be the contamination of the panel intake air from locomotive main haulage. A look at figure 1 reveals that considerable panel air mixing must occur from the haulage entry air and the other intake airways, about four parts of uncontaminated intake air to one part of contaminated air. However, since complete mixing cannot be assured, we will assume conservatively that the contaminated haulage entry air will be diluted one-third by the other intakes before reaching the neck of the panel, allowing a considerable safety factor. Thus main haulage values in table 4 should be divided by three to determine panel intake air contamination levels.

Assuming a six-entry system for each panel with a total quantity of air equal to 48,000 cfm, air velocities will be as follows: 10L, 120 ft/min; 11L, 120 ft/min; and 12L, 240 ft/min. The difference noted for 12L is due to the necessity of placing the belt on a neutral split and the addition of a second return on the left side to provide greater haulage symmetry during development.



Panel 10L

For panel 10L intake air, quality for each gas will be one-third the values shown in table 4, as it will be for any panel. To this must be added the contamination of locomotive haulage on the panel as well as the diesel shuttle car haulage (fig. 2). Considering that locomotives will probably average only one-half speed in the panel (5 mph or 450 ft/min), effective velocity for empties will be 330 and for loads 570 for effective ventilation of 33,000 cfm and 57,000 cfm, respectively ($V_A = 120$ ft/min). The worst condition at the sidetrack loading point would be the cumulative effect of main haulage air plus the contamination contributed by the tandem locomotive operating in the panel. The worst main haulage condition leading to maximum panel contamination would be the cumulative effect of two loaded trips. The locomotive unit

FIGURE 2. - Panel 10L working section.

operating in the panel at worst could subsequently further contaminate this air, once when going in with empties and again when returning with loads. Therefore, the cumulative effect at the sidetrack as shown in the last column of table 5 will be determined by doubling the loaded unit in column 1 of table 4, dividing by three for panel dilution, and adding this value to the accumulated panel empty plus the load value in column 3. For example, the CO_2 value for a tandem unit is 0.0274, doubling gives 0.0548 which divided by three gives 0.0183, which added to diluted 0.072 (by two for 4 entries) gives 0.0903 percent.

TABLE 5. - Cumulative effect of locomotives in 10L at loading point

Contaminant	Panel loaded, $Q_e = 0.057 \times 10^6$	Panel empty, $Q_e = 0.033 \times 10^6$	Panel cumulative empty + load	Total cumulative at sidetrack
CO ₂	0.072	0.072	0.072	0.0903
CO.....	5.96	11.50	8.73	10.24
NO.....	6.32	5.45	5.89	7.49

To the sidetrack figure must be added the contamination of the two shuttle cars at the face. With a speed of 450 ft/min and air velocity of 120, effective velocity will be 330 ft/min empty, 570 ft/min loaded or effective ventilations will be 33,000 and 57,000 cfm, respectively. The cumulative effect on the miner operator of both diesel shuttle cars operating in the same entry will be considered. Using the emission characteristics of the shuttle car shown in table 2, it is possible to construct table 6 which reveals the additional effects of the section shuttle cars as well as the cumulative effects of all diesel equipment at the face. The worst condition that can prevail under the relatively short hauls in this section is the superpositioning of two loaded shuttle cars upon an empty one as shown in column 4 in table 6. However, this figure could not be legitimately added to the sidetrack figure for two reasons. First, haulage would not be in a single entry but would encompass at least two at any given time. Secondly, whereas effective ventilation is considered for one entry, there are three additional ones. Therefore column 4 values in table 6 for shuttle cars have been reduced conservatively by one-half because of dilution prior to adding to the sidetrack factors in the last column in table 5. The last column in table 6 reflects total face (or return) contamination by all diesel equipment in the air stream outby the section.

Table 6. - Shuttle car cumulation in panel 10L with accumulative face effects

Contam- inant	Loaded, $Q_e = 0.057 \times 10^6$	Empty, $Q_e = 0.033 \times 10^6$	Idle, $Q_e = 0.012 \times 10^6$	Shuttle car, two loads + one empty	Total face accumu- lation
CO ₂	0.0288	0.029	0.01	0.087	0.134
CO.....	2.4	4.58	2.67	9.33	14.90
NO.....	2.54	2.18	0.33	7.26	11.12

11L Panel

Considering the maximum length of haul of 2,500 ft at an average maximum speed of 450 ft/min, it will require 11.1 minutes actual running time for a roundtrip for a diesel shuttle car. Allowing for switching delays, dumping and loading, three 10-ton diesel shuttle cars should easily handle the 500 tons per shift from the working section. Since the same effective velocity is employed in panel 11L and 10L, because of the similar geometric configuration, the exhaust quantities per shuttle cars are the same as shown in table 6 in the first three columns. The cumulative effect will differ however. A loop system or one-way travel system will be employed for empties

and another for loads. The worst possible condition that can occur (at the face) is the accumulation of four loaded trips, two empty trips, and an idling shuttle car (table 7, column 1). However, considering the configuration, a dilution factor of two can be expected from four entries, thus the values shown were reduced by one-half. This value was then added to panel intake values to give face contaminations in the last column.

TABLE 7. - Shuttle car exhaust accumulation in panel 11L

Contaminant	Shuttle car cumulative, four loads, two empties, one idle	Dilution, 2 X	Panel intake	Total contamination at face or return
CO ₂	0.184	0.092	0.071	0.163
CO.....	21.43	10.71	9.97	20.68
NO.....	14.85	7.43	5.6	13.03

12L Panel

For panel 12L since there are only two intakes, velocities will be double that of previous panels, 240 ft/min. Considering a shuttle car speed of 450 ft/min, effective ventilations are 69,000 cfm, 21,000 cfm, and 24,000 cfm for loads, empties, and idle, respectively. Contamination per unit under these three conditions are tabulated in the first three columns of table 8. The worst possible condition that could occur would be a superpositioning of one load, an empty, and an idling shuttle car. Tabulated on the basis of a single entry, accumulation effects would be as shown in column 4. Again, a dilution factor should be added to these values for multiple entries, but, since only entries are utilized and a conservation approach has been practiced throughout, no dilution factor is added. When added to the panel intake air contamination from the mains, face values will be as shown in the last column of table 8.

TABLE 8. - Shuttle car exhaust accumulation in panel 12L

Contaminant	Loaded out, $Q_e = 0.069 \times 10^6$	Empty in, $Q_e = 0.021 \times 10^6$	Idling, $Q_e = 0.024 \times 10^6$	Cumulative, one load, one empty, one idling	Total face accumulation
CO ₂	0.0238	0.0456	0.005	0.074	0.146
CO.....	1.94	7.25	1.33	10.52	20.47
NO.....	2.08	3.33	0.0167	5.43	11.03

Mains Development

To the contaminants at the sidetrack from the main locomotive haulage must be added the diesel shuttle car haulage to determine face TLV's. In this situation there is only one split per mining unit or approximately 48,000 cfm available. On the basis of five intakes, average intake velocity will be $48,000 \div 500 = 96$ ft/min. For an air velocity of 96 ft/min and shuttle car speed of 450 ft/min there will be effective ventilation values of 54,600,

35,400, and 9,600 cfm respectively for loaded, empty, and idling conditions. The first three columns in table 9 reveal exhaust contaminants for these conditions. For each side, the worst condition that can exist is the cumulative effect of two loads, an empty and an idling shuttle car, this over 2-1/2 entries. However, no dilution factor has been applied for multiple entries to obtain the face accumulations shown in the last column.

TABLE 9. - Shuttle car exhaust accumulation in main development area

Contam- inant	Loaded, $Q_o = 0.0546 \times 10^6$	Empty, $Q_e = 0.0354 \times 10^6$	Idling, $Q_i = 0.0096 \times 10^6$	Shuttle car accumulation, two loads, one empty, one idling	Total face accumu- lation
CO ₂	0.03	0.027	0.0125	0.100	0.171
CO.....	2.49	4.3	3.34	12.62	22.57
NO.....	2.63	2.03	0.417	7.71	13.30

Discussion and Analysis of Results

The effect of operating diesel locomotives and shuttle cars on a mine system was explored. Although representative emission characteristics were employed for the diesel equipment and a specific mine system was discussed, the example illustrates how a first approximation can be made for any combination of diesel equipment and mine ventilation systems. All one needs is the emission data for the equipment under various load conditions, an understanding of mining cycles, and a ventilation scheme.

Mining is a dynamic operation with operating load factors no more than 30 to 35 percent. Therefore, throughout the shift, load conditions are continually varying. But it is necessary to determine the cumulative effect of all engine exhaust gases on every segment of the ventilation system. Obviously, this requires the development of a digital computer simulator after which engineering data on the equipment, mining system, and ventilation network are imposed upon it. However, as a first approximation on a relatively simple system, one can take the most critical condition as was done in the illustrative example and determine the most acute contamination effect, all other operations therefore being subcritical.

In any multiple opening situation, it is necessary to determine the dilution effect of parallel openings on the entry where contamination is taking place. Since multiple openings are usually interconnected every 100 feet or less, there is turbulent flow, and splitting is predominant, hence, one would expect a great deal of mixing. Thus, calculated values on a single-entry basis could legitimately be diluted by the total number of interconnected airways. However, in an attempt to be conservative, this was never done in the illustrative example with only partial dilution having ever been considered.

Even with this most conservative approach to determining exhaust gas contaminations at the face or return, nowhere did instantaneous static contamination levels exceed the far more liberal time-weighted TLV's, the worst panel condition being in 11L where the ratios of the two values were 59 pct for CO and 52 pct for NO. A comparison of face values is not really valid, because different dilution factors were assigned. In 10L and 11L only a dilution factor of two was employed for four intakes, while for 12L and the mains no dilution factor was used even though there were 2 and 2-1/2 intakes, respectively.

The most significant conclusion to be drawn from the analysis is that the quantities of air presently employed in existing mine ventilation systems for methane gas and coal dust appear adequate to dilute, render harmless, and carry away the exhaust gases from diesel engines. It must be pointed out that leakage, which would have reduced effective ventilation on the inby end of each segment analyzed, was not considered. However, this was counteracted by the beneficial effect that the leakage would have on the diffusion and mixing of gases. In any event, the development of a suitable simulation model is a sizeable task and could not be attempted here. However, since somewhat similar haulage and ventilation simulators have been developed at Pennsylvania State University in the past, an outline of a suitable approach will be given.

Simulation by Digital Computers

According to Holtz (5) safe diesel machine ventilation can be determined by suitable tests of each engine but mine ventilation cannot be predicted safely, accurately, and economically from any general empirical relationship. Holtz and Dalzell (6) have analyzed the diesel exhaust contamination of tunnel air, but conclude that the calculations must anticipate the changing conditions that will develop during the life of the project. In this paper the previous approach (6) was used to evaluate ventilation requirements for a typical coal mine with various diesel equipment combinations in the working sections and mains, but the calculations were limited to the most critical static condition at any time in the cycle. A different approach is necessary to consider the dynamically changing diesel exhaust characteristics on a time-weighted basis.

Underground experiments to study the effect of diesels can be designed but only for small mines in view of the timeconsuming and cost-prohibitive time study data and air quality and quantity information that have to be collected for analyses. Also, because of the many interdependent activities and because of the probabilistic nature of mine equipment operation, one cannot be too careful about correlating the above data in analyses and subsequent inferences. At best, the latter is fraught with difficulties and has been discussed in greater detail by Holtz (5). Again, diesels are no panacea for the ills of the mining industry, and the chances are that they will selectively and gradually replace older conventional equipment. Therefore, there is a need to develop a tool on which the effects of incremental dieselization can be studied.

Technological forecasts or objective facts are necessary for scientific decisionmaking. Technological forecasting should consist of a systematic analysis which, when applied to specific data, will yield consistent, quantitative, technological conclusions, no matter which competent persons perform the analysis. Since the advent of computers about 2 decades ago, the number of scientific applications has increased tremendously and their application to the study of the effect of using diesels underground on mine ventilation systems can be attempted. In the opinion of the authors, digital simulation of this process is not only feasible but highly desirable. Management science techniques, particularly simulation, can be effectively used to determine the effect of dieselizing various mining equipment on air quality and,

consequently, the ventilation requirements. The research approach proposed here will consist of a threefold simulation model as follows:

1. Emission Model: In this model, at any given time, the emission of contaminants into the mine atmosphere will be generated using diesel engine emission characteristics and the duty cycle for the equipment. Duty cycles can be generated for any equipment (shuttle cars, locomotives, etc.) from the engineering and environmental characteristics of the equipment and deterministic simulation concepts. In fact computer-oriented simulation models that will generate duty cycles for underground mining equipment are available (7, 9). These duty cycles in conjunction with the diesel engine emission characteristics for a range of loads and speeds (which are available under the approval investigation of mobile diesel-powered equipment under Bureau of Mines Schedule 24 or from equipment manufacturers) should provide adequate information to generate the volume and analysis of the contaminant emission. As an example of the type of input data that is available for diesel engines, figures 3, 4, and 5 are presented from which the horsepower output, the volume of exhaust, and the constituent analysis of the exhaust can be interrogated for an engine operating at a given speed and fuel-air ratio. An example of the type of computer programs that are available to generate the duty cycle are given in figures 6 and 7. The locomotive performances (tonnage per shift, power consumption) can be accurately simulated using the equations of motion. Although figures 6 and 7 present a summary over a long period of operation,

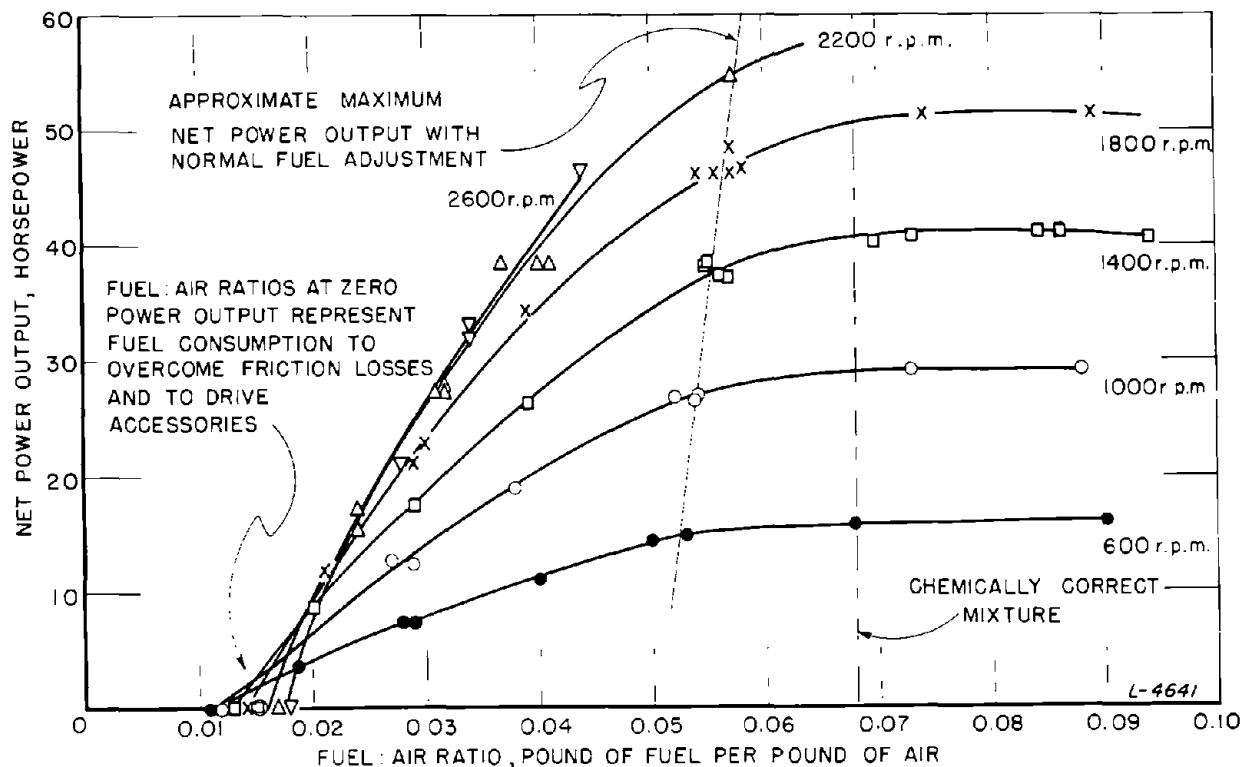


FIGURE 3. - Relation of net power output in tests with diesel engine B and fuel:air ratio (Holtz, 1960).

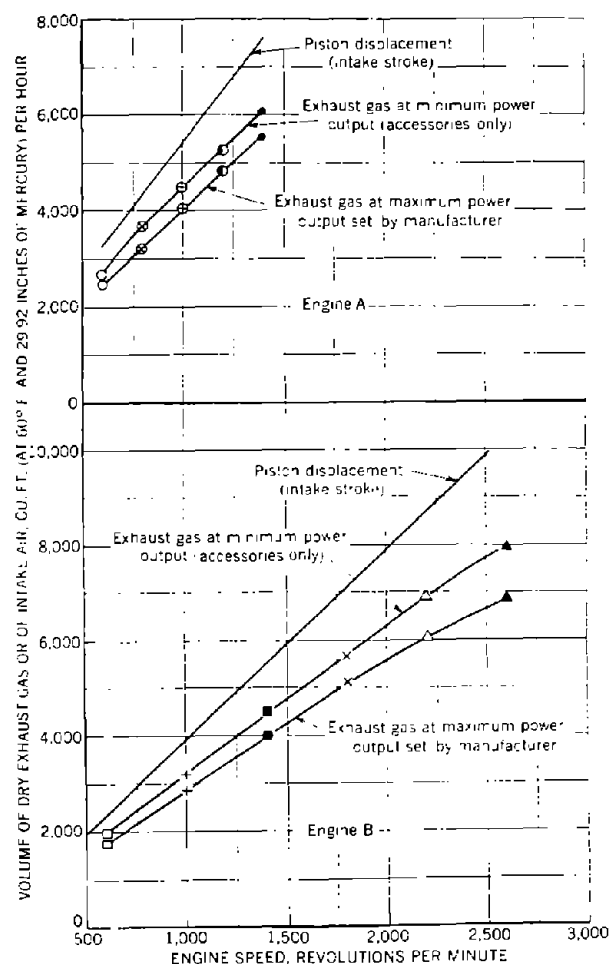


FIGURE 4. - Relation of volume of diesel exhaust gas to engine speed at minimum and maximum power outputs (5).

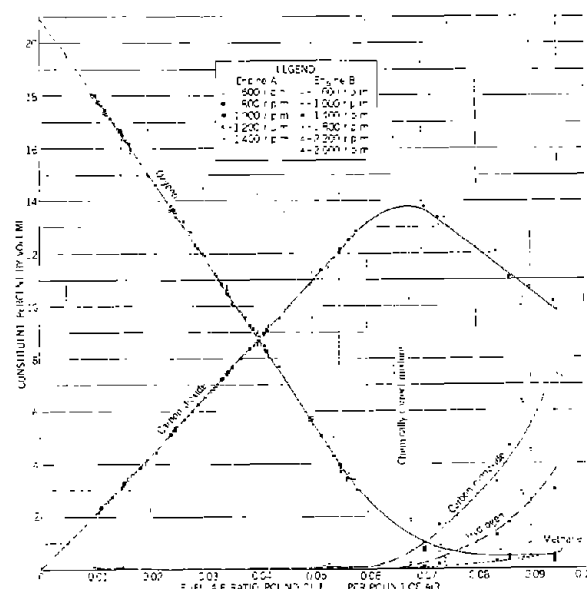


FIGURE 5. - Relation of composition of diesel exhaust gas to fuel:air ratio (5).

the statistics from the simulation could have been derived for every conceivable time interval. In short, using this concept, figures 3 through 7 can be used to calculate and accumulate the exhaust emissions for each condition (load, empty, idling) as they occur during a shift. Figure 8 is the macroflow model of a computer-oriented simulation model which includes individual sub-models for miners, belts, shuttle cars, and trains, and is dynamic and deterministic. Using the concept of this model as a basis, it can be seen that the exhaust emissions at various locations in the mine can be dynamically generated.

2. Dilution Model: In this submodel, the effects of air volume and velocity around the diesel equipment will be used to calculate the rate of dilution at any given time. Obviously, the dilution rate will be a function of the emission rate and the effective velocity. Computer programs to determine the initial air quantities (and therefore, velocities) in the various roadways are also available (10, 12).

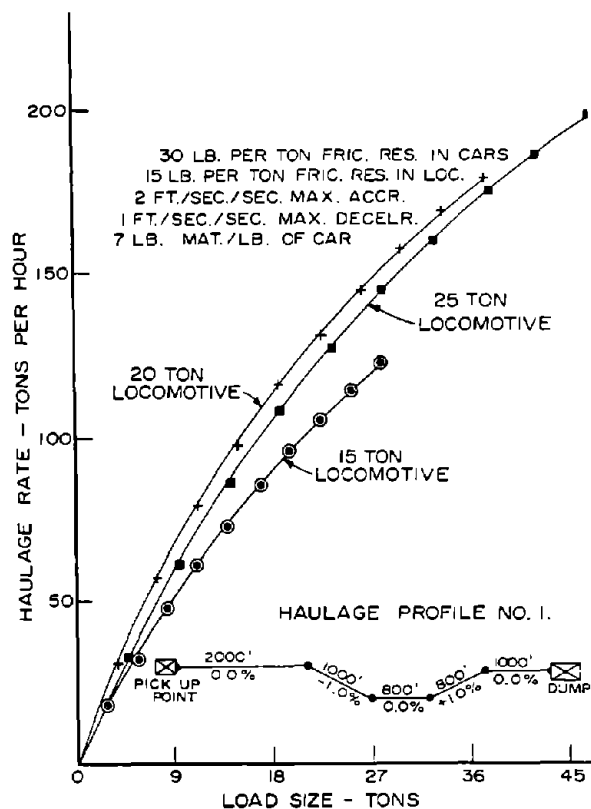


FIGURE 6. - Computed haulage performance for profile 1 (9).

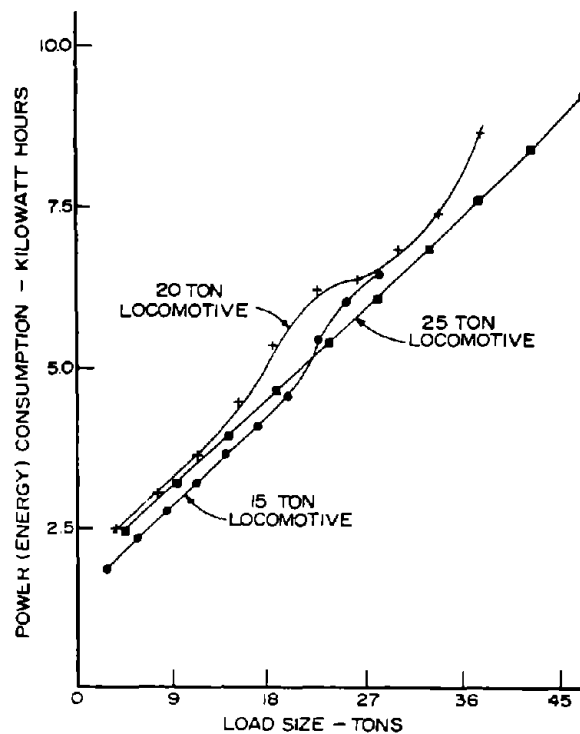


FIGURE 7. - Computed power consumption for profile 1 (9).

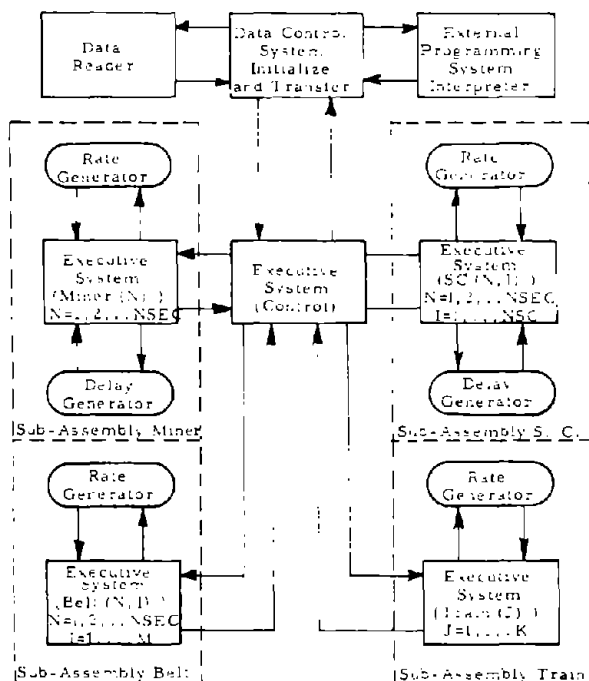


FIGURE 8. - Macroflow model (UGMHS) (Manula and Sanford, 1969) (7).

3. Distribution Model: The combined effects from models 1 and 2 above for various equipment will be interrogated in this submodel to arrive at the instantaneous concentrations at any location in the mining system. Because the simulation approach proposed here will be on a time increment basis, it will permit a calculation of not only the average contamination concentration over the exposure period but also identify peak concentrations and their time of occurrence. By suitably incorporating a print option, a check on equipment status can be made for detailed analyses of peak concentration periods or for that matter, at any desired time.

There exists a need for research along the proposed lines; for this tool, once developed fully, will be a management laboratory where the dieselization alternatives can be analyzed with respect to impact on ventilation requirements, and the best selected as guidelines for decisionmaking and for setting up demonstration projects in existing mines.

CONCLUSIONS

Since the illustrative example chosen was typical of a mine in the highly gaseous Pittsburgh coal seam, working section and fan quantities may be higher than in the average mine. Nevertheless, even when imposing the most critical diesel operating conditions on the mine ventilation system without allowing for complete dilution, instantaneous gas contamination readings in no section approached the time-weighted TLV's for the contaminant gases (0.5 pct CO₂, 35 ppm CO, and 25 ppm NO).

A full appreciation of the ultraconservative approach employed in the example may be had by recalculating the most critical panel, 11L, using full dilution factors; that is, main entry contamination is fully diluted by five intake airways and shuttle car contamination is diluted by a factor of four for the intake airways. Under such dilution conditions, instantaneous values for the contaminants will be 0.089 pct for CO₂, 11.33 ppm for CO, and 7.07 ppm for NO. If one considers typical load factors as 30 to 35 percent, then on a shift time-weighted basis, the above values could be further divided by three to give 0.039 pct for CO₂, 3.74 ppm for CO, and 2.39 ppm for NO.

A recalculation of the mains might be even more revealing because it is the only working section where one split is employed for a mining unit. Many mines use such an arrangement, and although the 20,000 cfm is slightly more than twice the federal minimum requirement in the last open crosscut (9,000 cfm), it is representative of average mines. Using a dilution of 5 for intakes and 2-1/2 in the working section, contaminant concentrations will be 0.083 pct for CO₂, 11.02 ppm for CO, and 6.67 ppm for NO. Using the same logic for load factors and dividing by three gives 0.024 pct for CO₂, 3.64 ppm for CO, and 2.23 ppm for NO on an approximate time-weighted shift basis.

The use of the illustrative example revealed how a simple approximate calculation can be made for any given mine and equipment combinations. The instantaneous contaminant concentrations calculated are for the most critical operating conditions and therefore must be considered an absolute upper limit with durations measured in seconds, or a few minutes at the very most. The

results would indicate that an air quantity of one-half that which was used probably would have sufficed for diesel exhaust dilution. Since the engines of each of the 11 shuttle cars were 80 horsepower each and each of the four locomotives was 100 horsepower, total diesel connected horsepower was 1,280. Dividing 1,280 into 150,000 cfm would indicate a need for 117 cfm per horsepower, certainly within the rule-of-thumb range of 100 to 200 cfm per engine horsepower frequently quoted.

The approximate approach in the example is simple enough to be practical for a manual calculation, at least for a relatively small mine. Unfortunately a number of assumptions were necessary concerning dilution and load factors, and the very laborious, almost hopeless accumulation of the contaminants requires a manual charting of each equipment move throughout the shift. Thus from a pure scientific or engineering standpoint, the manipulation leaves much to be desired. A much more attractive approach is digital computer simulation.

A sophisticated mathematical model can be constructed for the ventilation network and the operating characteristics of the diesel engines imposed upon it as explained earlier. Thus the charging of equipment, the dynamic effect of engine performance on the ventilation system, and the accumulation of contaminants in all segments of the mine are left to high-speed computers with tremendous memory capacities. Many equipment combinations could be tried out on paper for various mine configurations and ventilation systems. Additionally, however, initial diesel installations should be considered as demonstration projects with the gathering of data. The results from any digital simulator is only as good as the input and this must be gathered by empirical methods. Finally, the simulator model must be tested against a real situation to determine its validity.

Dieselization of coal mines offers too much potential to be approached in a haphazard manner. It is not good engineering to assign such excessive safety factors to air requirements that the proposed application becomes economically infeasible. The alternatives are much more attractive--the use of simulation models that reflect known engineering factors followed by documented demonstration projects. Only with such an approach will this great potential of dieselization of underground coal mining equipment be realized.

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FROM THE FLOOR: I wish to ask you if you care to introduce any diffusion effects in your calculations?

DR. STEFANKO: This is strictly an analytical study, based on the characteristics that I was able to obtain for locomotives and shuttle cars. This is not an application in a given mine where we have tested the accumulation of the gases. It is strictly an analytical approach, based on emission rates, and calculations take into account the mining characteristics and the duty cycles of the equipment.

FROM THE FLOOR: I enjoyed your paper, but I would like to ask you if you have had an opportunity to sit down and figure out the worst possible source of contamination in a section in a mine. I am not fearful of the locomotives, and your figures are fine, but when the continuous miner has turned to making a crosscut, which would be possibly 90 or 100 feet from the last open breakthrough, and he is at full length, or possibly a little further, and then the shuttle car comes up there, would you please estimate the contamination at that point. I will have a chance to talk with you later.

DR. STEFANKO: I would like to remark on this last question. When I was doing this calculation, I was worried about that. Actually, where they deposit the exhaust is important--I noticed that they were depositing exhaust on the curtain side, which is really desirable in an exhausting configuration. I think this is not an insurmountable problem. By proper design of your exhaust in relation to the line brattice, we can resolve this problem with the amount of air that we are bringing up, 3,000 cfm, and by the additional leakage through the curtain. I think this can be handled with the emission characteristics that I have seen. I will be happy to work on these things with you or anyone else.

MR. CRAWFORD: The next paper is Environmental Control of Underground Diesel Operations by Charles F. Hews and James G. Rutherford.

Mr. Hews is manager of mines maintenance of the International Nickel Company of Canada. He graduated as a mining engineer from Queen's University in 1950. He served during World War II with the Royal Canadian Air Force. He has over 22 years of mining experience, 20 of which have been with International Nickel. He worked up through the various mine supervisory positions, and was appointed to superintendent of safety, Ontario Division, in 1967, appointed assistant manager of mines in 1970, and then appointed manager of mines maintenance. He is the immediate past president of the Mine Accident Prevention Association of Ontario. Mr. Rutherford, the company's ventilation engineer, graduated from Queen's University in 1937. He has 35 years of mining experience with International Nickel.

The paper will be presented by Mr. Hews.

ENVIRONMENTAL CONTROL AT UNDERGROUND DIESEL OPERATIONS

by

C. F. Hews¹ and J. G. Rutherford²

INTRODUCTION

The mining operations of the Ontario Division of the International Nickel Company are centered at Sudbury, a city of 160,000 population, located 200 miles north of Toronto, Ontario. The company currently operates 11 underground mines and one open pit within 30 miles of Sudbury; the mines are located around the rim of the geological formation known as the Sudbury Basin. There are also three standby mines and one developing mine in the Sudbury area and one operating mine at Shebandowan near the city of Thunder Bay, Ontario.

In 1972 the mines produced 16,400,000 tons of ore, 14,700,000 tons from underground and the balance from the open pit.

The main facilities to extract and refine the metals contained in the ore are also located in the Sudbury area. A nickel refinery is located at Port Colborne on Lake Erie. Fifteen elements are recovered from the Sudbury ores: nickel, copper, iron, sulphur, gold, silver, cobalt, selenium, tellurium, platinum, palladium, iridium, rhodium, ruthenium, and osmium.

UNDERGROUND DIESEL EQUIPMENT

The first diesel-powered machine used in underground mining operations at INCO was a 145-hp ScoopTram. This load-haul-dump (LHD) unit was put in service in March 1966 in a block of cut-and-fill stopes at Frood Mine.

At present, there are 375 diesel-powered machines in use underground at 13 INCO mines in Ontario; the engines have a total rating of 38,000 brake horsepower. The diesel equipment includes the following: 192 load-haul-dump machines, 74 locomotives, 35 unimog service vehicles, 34 drill jumbos, 26 secondary drill and service tractors, and 14 Teletram trucks.

LHD Machines

Five sizes of these rubber-tired LHD units are being used as follows:

13 machines	1.3 cu yd	52 bhp	4 cylinder engine.
47 machines	2.0 cu yd	78 bhp	6 cylinder (in line) engine.
95 machines	4.0 cu yd	145 bhp	V-6 cylinder engine.
17 machines	5.0 cu yd	195 bhp	V-8 cylinder engine.
20 machines	8.0 cu yd	222 bhp	V-10 cylinder engine.

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All of the LHD machines are powered by Deutz air-cooled indirect-injection engines with precombustion swirl chamber. These are very clean-burning engines; they operate at higher temperatures than water-cooled engines and better suit the use of oxycatalytic exhaust scrubbers.

The intake air to the engine is drawn through a dry-type filter; there are two of these air cleaners on the 145-hp and larger engines. On the 52-hp engines, a cyclone-type precleaner and an oil-bath air cleaner are used.

The exhaust gases from all engines are passed through oxycatalytic scrubbers. A Dieseler III type, Model 51 is used on all of the LHD machines, except the 222-hp units which are equipped with Model 52 scrubbers. There is one scrubber on the 52- and 78-hp units, and two parallel scrubbers on the larger engines, one on each side. These scrubbers are cylindrical, made of stainless steel, and mounted vertically with a special connection at the top to permit inspection and addition of pellets when necessary. The engine exhaust is connected to the top of the scrubber; the exhaust gases are directed into a central chamber surrounded by an annular bed of pellets held within slotted walls which allow the gases to pass through the bed to an outer chamber from which the gases exhaust down toward the floor; a heavy steel plate located in the discharge stream spreads the gases horizontally above floor level. The Model 51 scrubber contains 12 lb of pellets; the Model 52 contains 16 lb.

In 1972 the LHD machines in our mines handled 11-1/4 million tons of ore and rock; the total handled since 1966 is 50-1/2 million tons.

Locomotives

Each of the first 35 locomotives put into service is powered by a Dorman 4DA 4-cylinder air-cooled diesel engine rated at 48 bhp; each is equipped with an oil-bath intake air cleaner and an Oxy-France catalytic exhaust purifier type DH. This scrubber is mounted horizontally.

Each of the other 39 locomotives is powered by a 48-hp Deutz air-cooled engine with hydrostatic drive and is equipped with a Dieseler III Model 49 exhaust scrubber mounted vertically.

Unimog Service Vehicles

There are 23 smaller Unimogs that are used as service vehicles and/or graders. Each is powered by a 38-hp Mercedes-Benz 4-cylinder water-cooled engine and is equipped with an oil-bath air cleaner and a Dieseler III Model 49 exhaust scrubber.

The other 12 Unimogs are used as personnel carriers. Each is powered by a 100-hp Mercedes-Benz 6-cylinder water-cooled engine, with similar intake air cleaner and scrubber.

Drill Jumbos

Each of the 34 drill jumbos is powered by a Deutz air-cooled engine in three sizes, 66, 78, and 100 hp; the engine is used only for transport. Each is equipped with an oil-bath air cleaner and a Dieseler III scrubber.

Tractors

Nineteen of the secondary drill and service tractors are powered by 42-hp Perkins 3-cylinder water-cooled engines and seven with 90-hp Mercedes-Benz 6-cylinder water-cooled engines. Each is equipped with an oil-bath air cleaner and an oxycatalytic exhaust scrubber.

Two of the larger tractors are equipped as mobile secondary muck conditioners, with a 3-1/8-inch piston diameter drill on a 6- or 8-ft drill shell attached to a swing boom on the front. The truck carries a 210-cfm compressor powered by the truck motor and two 30-gal water tanks, making the unit independent of air and water service lines.

Teletram Trucks

Twelve of the Teletrams are 20-ton units; each is powered by a 195-hp Deutz V-8 cylinder air-cooled engine and equipped with two dry-type intake air filters and two Dieseler III Model 51 oxycatalytic scrubbers. Two are 10-ton trucks, each with a 78-hp Deutz 6-cylinder air-cooled engine with one intake air filter and one scrubber.

OXYCATALYTIC EXHAUST PURIFIERS

The oxycatalytic scrubbers on the exhausts of the diesel engines eliminate most of the toxic gases in the engine exhaust, changing them into nontoxic gases by means of catalytic oxidation.

The three following factors are essential:

1. A suitable catalytic agent--platinum--is required to accelerate the chemical oxidizing reaction at relatively low temperatures, with no deterioration of the catalyst and without producing any other dangerous or objectionable chemicals.
2. A high temperature in the scrubber, from 500° to 800° F, is required for efficient oxidation.
3. Sufficient surface area of the catalyst and even distribution of the exhaust gases through the bed of pellets is necessary to insure adequate time of contact between the gases and the catalytic surface for complete reaction, without creating excessive back pressure on the engine.

The main toxic gas in the exhaust, carbon monoxide, combines with oxygen to form carbon dioxide. The catalyst enables this reaction to take place at normal exhaust temperatures, on the order of 650° F, rather than at flame

temperatures. Tests have shown that up to 90 pct of the carbon monoxide can be eliminated. Similarly, hydrogen is converted to water vapor; aldehydes are almost completely removed; solid carbon, tars, and unburned oil are burned to form carbon dioxide and water vapor. Thus the odors and most of the smoke normally associated with diesel engines are eliminated by the oxycatalytic scrubbers.

One toxic product of diesel combustion, nitrogen dioxide, is not affected by the oxidation process in the scrubber. Although there is a slight decrease in volume of the oxides of nitrogen as the exhaust gases pass through the oxycatalytic scrubber, it is necessary to keep in mind that the nitrogen dioxide content is not reduced. Adequate ventilation is still required to dilute and remove this toxic gas, along with the remnants of the other toxic gases and the carbon dioxide produced.

Using oxycatalytic scrubbers, it is important not to allow the diesel engine to run at idling speed except for very short periods (5 min), as the temperature of the exhaust gases drops appreciably. Pyrometer readings taken at the scrubber inlet of both LHD machines and the diesel locomotives show that the temperature of the exhaust gases under normal working conditions ranges from 500° to 800° F. When the engine is allowed to idle, the exhaust temperature drops quickly to 250° or 300° F. At relatively low exhaust temperatures, unburned oil and carbon particles are deposited in the bed and coat the pellets, thus impeding the flow of gases and reducing the effective surface area of the catalyst. Our experience with these scrubbers on the haulage units indicates that the scrubbers remain relatively clean; the exhaust temperatures under normal working conditions are high enough to burn off any oil or carbon deposited during brief idling periods.

A type A-316 catalytic pellet is used in all exhaust scrubbers. These are roughly spherical in shape, average 3/16 inch in diameter and are made of alumina with a thin coating of finely divided platinum (0.15 pct platinum by weight). There is some disintegration of the pellets, owing partly to the thermal cycling and also to attrition. Some of the fines from the broken pellets pass through the grid holding the pellets in place and are blown out with the exhaust gases. In the past year a total of 1,800 lb of pellets were used, an average of less than 4 lb per oxycatalytic scrubber.

From our experience with the oxycatalytic scrubbers on our diesels over the past 7 years and from some knowledge of the water scrubbers used on diesels at other metal mines, it is our opinion that the oxycatalytic scrubber is a more efficient exhaust purifier, is much easier to install on mobile equipment, and requires considerably less maintenance. The high temperature of the exhaust gases from the catalytic scrubber is not a problem in our mines.

MAINTENANCE OF DIESEL EQUIPMENT

The successful use of diesel-powered equipment in underground mining operations requires a rigid adherence to a well-planned inspection and maintenance program. Close cooperation and communication between operating and maintenance departments is necessary for the success of such a program.

The first line of maintenance is the vehicle operator. At the beginning of each shift the operator makes an initial check of his vehicle using a checklist that is completed, signed, and submitted to supervision. Particular attention is paid to the brakes, engine and machine condition, and appearance of exhaust gases. Any irregularities are reported immediately.

The maintenance department schedules each piece of diesel-powered equipment for inspection and service once every 2 weeks. This schedule must be rigidly maintained to insure that the equipment is available on the day it is scheduled and for sufficient time to permit a thorough inspection and the carrying out of any repairs required. Appendix A is the form used for the inspection and service of ST4A and ST5A ScoopTrams once every 2 weeks. Appendix B is the form used for the 18-week and the annual inspection and service of ST4A and ST5A ScoopTrams.

The servicing intervals have been established and revised, based on detailed investigations which have resulted in revisions involving intake air cleaning, lube and fuel oil filters, and fueling arrangements. The forms cover the inspection of the complete machine and include the following components that control the emission of fumes: (1) Air intake system, (2) exhaust system, (3) engine, and (4) fuel system.

Air Intake System

Each inline engine is equipped with a single intake air cleaner and each V-type engine is equipped with two cleaners, one for each bank of cylinders. Until recently, all air cleaners were the oil-bath type.

An important factor in maintaining the proper fuel to air ratio, and thus a clean-burning engine, is the regular maintenance of the intake air cleaners. The following schedule is used for the underground diesels at INCO:

1. The oil in each oil-bath air cleaner is changed on site every 2 weeks.
2. The entire air cleaner is exchanged on site every 2 months and the old cleaner is brought to surface where it is completely cleaned and serviced.

A decision was made to convert the air cleaner from the oil-bath type to the dry-type filter. The dry type is more efficient, reduces air cleaner maintenance and extends the engine oil-change interval. To date a total of 337 dry-type air filters have been installed on the engines of all of the Teletrams and all of the LHD machines except the smallest.

A 2-week period was initially established for changing the paper filter element, but atmospheric conditions and operating hours determine the change frequency. A "slack-tube" manometer is used at every scheduled inspection to determine the filter resistance. The manometer is connected to the intake manifold and the reading is recorded. A new element has a 6-inch water pressure drop; after 2 weeks of operation, if the reading is 13-inches or less, the element is scheduled to be changed at the next inspection; if the reading

is greater than 13 inches, the element is replaced. Filter elements that are removed because of contamination are cleaned and returned to stock for reuse.

Exhaust System

At every scheduled inspection the complete exhaust system is checked for leaks, cracks, holes, and loose connections. Special attention is paid to the scrubber for signs of any physical damage. The level of catalytic pellets is checked and more pellets are added if necessary to fill the compartment.

Each complete scrubber is removed and replaced by a reconditioned unit at least once per year. The repair and regeneration of all scrubbers is done at one central location on surface. The pellets are removed from the scrubber, any necessary mechanical repairs are made, and the scrubber is thoroughly washed out and cleaned. The scrubber is then refilled with previously regenerated pellets.

The used pellets are sifted on a No. 8 mesh screen to remove chaff and undersize pieces. They are then placed in a horizontal perforated tray on the regenerating unit where the carbon and tar are burned off at a temperature of 1,200° F; this takes from 40 to 60 min depending on the amount of contamination. The regenerated pellets are added to stock for reuse.

Engine

The main features of the 6-week inspection concerning emission control are:

- (1) Valve clearance.
- (2) Stall speed rpm. The maximum allowable for the ST4A engine is 1,850 rpm at full throttle. A tachometer reading of more than 1,850 rpm indicates too high a fuel setting.
- (3) Full speed no-load rpm. The maximum allowable for the ST4A engine is 2,300 rpm. A tachometer reading other than 2,300 rpm indicates a faulty governor setting.
- (4) Fuel injectors are changed every 18 weeks.
- (5) With the introduction of a fleet-wide engine oil analysis program, the oil change period has been extended to 6 weeks.

Fuel System

It is important that only perfectly clean fuel be supplied to the fuel injection pumps and fuel injectors. The fuel precleaner is cleaned and the primary and secondary fuel filters are changed every 6 weeks.

The specifications of the diesel fuel presently in use are as follows:

Sulphur.....	wt-pct..	0.18
Viscosity.....	centistokes at 100° F..	1.66
Cloud point.....	° F..	-38
Pour point.....	° F..	-35
Final boiling point.....	° F..	565

OPERATOR AND MECHANIC TRAINING

Thorough operator and mechanic training is essential to the safe and efficient operation of trackless equipment.

Prospective miners pass through the two following phases of training:

1. Initial training for 1 week is conducted at an introduction center and introduces the man to the underground environment.

2. A course of instruction for a specific work classification is carried out at the mine to which the miner is allocated.

In both phases the new miner must pass proficiency tests. In the case of a diesel loaderman, an applicant is given a 2-week training course. The trainee is under the guidance of and instructed by a designated instructor. His progress is followed and checked by the supervisor in charge. At the end of the training period, the successful applicant must pass a qualification test for diesel loaderman.

The company provides a 3-year garage mechanic apprentice program as part of the overall trades training program. Successful applicants are graduates of Ontario secondary school grade 12 or equivalent and must pass an aptitude test. The apprentice program includes formal classroom training as well as practical experience. The company also hires certified Class-A motor vehicle repairers as garage mechanics.

A continuous followup is carried out for both operators and mechanics through our safety program. In addition, an extensive yearlong upgrading program is currently being conducted for LHD operators, mechanics, and supervisors on the complete scope of operation and maintenance of trackless equipment.

UNDILUTED ENGINE EXHAUST TESTS

The Mines Branch of the Ontario Ministry of Natural Resources requires a weekly test for carbon monoxide in the undiluted exhaust for the scrubber(s) of each diesel-powered engine. These tests are made by the ventilation staff using Drager detector tubes, with the machine in neutral and the engine at three-fourths to full speed. At the engines with dual exhausts, each exhaust is tested weekly.

Because of the high temperature of the gases exhausting from the oxycatalytic scrubber under this condition, 300° to 600° F, it is necessary to use about 10 feet of copper tubing, or a special exhaust probe, to cool the gases ahead of the detector tube. There is an induced flow of engine exhaust gases through the tubing, but we use an aspirator bulb to change the air in the tubing several times before testing.

The readings obtained from the 4,500 tests for carbon monoxide taken in the undiluted engine exhaust during the latter part of 1972 have been summarized as follows:

LHD machines and teletrams.	88 pct are below 200 ppm;	96 pct are below 300 ppm.
Locomotives.....	82 pct are below 500 ppm;	94 pct are below 800 ppm.
Drills, tractors, etc..	85 pct are below 750 ppm;	98 pct are below 1,000 ppm.

NOTE:--The maximum allowable CO content of the undiluted exhaust (Mines Branch) is 1,500 ppm.

In the event that an abnormally high reading for CO in the engine exhaust is obtained, on the order of 800 to 1,400 ppm depending on the type of engine, the engine is turned off and the foreman is contacted. The engine, air filter, and exhaust scrubber are checked by a mechanic. The exhaust is tested for CO again before the machine is put back into service.

Normally we do not check the undiluted exhaust for NO₂, but a few special tests made with detector tubes indicated a range of 25 to 50 ppm. Laboratory analyses for NO₂ made by a chemist from the Ontario Department of Health, on samples of the undiluted exhaust taken by an engineer from the Mines Branch at 20 diesel engines in our mines, including all types in use, showed from 24 to 39 ppm of NO₂.

VENTILATION AT DIESEL OPERATIONS

The Mines Branch requires a minimum of 75 cfm of ventilating air per maximum brake-horsepower in all areas of diesel operations. The ventilation installations for diesel engines in our mines are designed to supply 100 cfm/bhp in order to guarantee that ventilation exceeds the minimum requirement.

During the last 6 years the total volume of fresh air supplied to our mines has been increased from 3.3 to 5.5 MM cu ft per minute. The average volume of air supplied per ton of ore hoisted per day has been raised from 50 to 80 cfm, which has the additional benefit of faster smoke clearance and improved dust control.

Mechanical ventilation systems are provided for all diesel-powered development operations. Supplementary systems are provided at all diesel ore extraction operations except those ventilated directly by the main fans. Electrically-driven fans are used, except in short headings where it is more feasible to use compressed air fans and when ventilation is required before the electric power system can be extended.

Development

For development with diesel equipment, 170 electric auxiliary fans are in use, totalling 4,500 hp and handling a total of 2,400,000 cfm. In addition there are 42 compressed air fans in auxiliary ventilation service.

In development headings using a 145-hp LHD machine, the standard ventilation system includes a 30-hp axivane fan supplying 15,000 cfm to the face through 28-inch-diameter steel ventilation pipe; the fan will handle 1,100 ft of pipe; there are 79 of these fans in service. In short headings, two 20-inch-diameter compressed-air fans are mounted in parallel to supply 15,000 cfm to the face through steel vent pipe or flexible tubing.

For development with a 78-hp LHD machine, a 15-hp fan is used to supply 8,000 cfm through 24-inch steel vent pipe. In development headings using a 48-hp diesel locomotive, 10-hp fans are installed with 24-inch pipe, or 15-hp fans with 20-inch pipe, to supply 5,000 cfm to the face of the heading.

The development of mining areas through main ramps requires auxiliary systems handling higher volumes. The largest system to date is comprised of two 40-inch-diameter steel vent pipes in parallel with two 60-hp axivane fans, at 1,500-ft intervals, supplying 30,000 cfm per pipe or 60,000 cfm total, to ventilate three 195-hp diesel units.

Ore Extraction

For ore extraction with diesel equipment, 85 electric booster fans have been installed underground, totalling 1,160 hp and handling 1,900,000 cfm. There are also 16 compressed air fans in use.

1. Cut-and-fill stoping:--LHD machines from 52 to 222 hp are being used in cut-and-fill stoping operations. Boreholes from 3 to 6 ft in diameter are drilled to provide air raises from the stopes to the level above; electric fans are installed at the tops of these raises to insure that the required volume of air is circulated through the stopes.

2. Drawpoint loading:--In most ScoopTram drawpoint loading areas, where the crosscuts off the main haulage drifts are less than 60 ft long, an adequate volume of air flowing through the main drifts provides good ventilation. Even a minor flow of air up through the broken ore at the drawpoints, along with the movement of the LHD machine in and out of the short crosscuts, is sufficient to keep the drawpoint crosscuts adequately ventilated.

Sublevel caving mining with ScoopTram loading is being used in a number of ore zones below areas mined through to surface. In one area there are 16 crosscuts up to 400 ft long developed from a footwall tram drift; the ore is recovered by retreating from a hangingwall slot. Two booster fans supply 140,000 cfm of fresh air directly to the area. Ventilation control doors are used to regulate the volume of air to each sublevel; the air flows through the footwall drift and the crosscuts, and up through the broken ore to surface. An adequate volume of air is supplied to each crosscut in which an LHD machine

is operating by using the auxiliary ventilation systems installed for the development of these crosscuts.

GAS TESTS AND VENTILATION MEASUREMENTS

Weekly Tests

The ventilation staff is responsible for making the weekly gas tests and volume survey at each diesel-powered machine, as required by the Mines Branch. In addition to the tests for CO in the undiluted exhausts outlined previously, the results of the other weekly gas tests taken at each diesel during the latter part of 1972 are as follows:

1. Adjacent to the engine (at the operator or just downstream)--
 - (1) Carbon monoxide--95 pct are from trace to 5 ppm; 99 pct are below 10 ppm (maximum allowable is 50 ppm).
 - (2) Nitrogen dioxide--95 pct are from trace to 1 ppm; 99 pct are below 2 ppm (maximum allowable is 5 ppm).
 - (3) Aldehydes¹--95 pct are from nil to trace; 99 pct are below 1 ppm (maximum allowable is 2 ppm).
2. In the general atmosphere--
 - (1) Carbon monoxide--86 pct are from trace to 2 ppm; 98 pct are below 5 ppm (maximum allowable is 20 ppm).
 - (2) Carbon dioxide¹--96 pct are from 400 to 1,000 ppm; 99 pct are below 1,500 ppm (maximum allowable is 5,000 ppm).

Most of the ventilation volumes measured at the diesels are on the order of 100 cfm/bhp, compared to the minimum of 75 cfm required by the Mines Branch.

The results of all weekly tests at each mine are recorded in a special logbook kept in the foreman's office off the collarhouse. These are inspected by the mining engineers of the Mines Branch.

Daily Tests

In addition, all mine foremen carry a Drager or Auer gas detector and carbon monoxide tubes. On the 8 a.m. to 4 p.m. shift, the foremen take one test at the operator of each diesel haulage unit during each shift. In the event of any abnormal occurrence, or if a high reading is obtained, approaching 50 ppm, the diesel engine is turned off until the ventilation system is

¹Weekly testing for aldehydes and carbon dioxide was discontinued in January 1972, because of the very low concentrations obtained. Weekly tests of these gases are not required by the Mines Branch.

checked and/or the engine is inspected by mechanics. The supervisors record the results of all tests in a special logbook also kept in the foreman's office.

Gravimetric Dust Sampling

For the past 2 years, test work with personal gravimetric dust samplers (Casella), collecting the respirable portion of the airborne dust on silver membrane filters, has been carried out at all operations in a number of Ontario mines. This work was financed by the McIntyre Research Foundation with direct assistance from the Federal Mines Branch at Elliot Lake and the Mines Accident Prevention Association of Ontario.

During the last 6 months an engineer on our ventilation staff has been using two sets of this equipment to take gravimetric dust samples on LHD operators in our mines. Direct supervision was maintained during the time the operators wore the samplers, and the flow rate was checked during the sampling period as well as before and after. The weight of the sample and its weight after heating to 1,050° F, to remove combustibles, was measured. Results to date are as follows:

1. Using 25 mm-diam filters, a total of 20 samples was obtained; average sampling period was 3 hours (all working time). Average results include total respirable dust = 2.9 mg/m³; 56 pct combustible dust = 1.6 mg/m³; rock dust = 1.3 mg/m³.

2. Using 37 mm-diam filters, a total of 15 samples was obtained, all 8-hour samples, from collar to collar. Average results included total respirable dust = 2.0 mg/m³; 75 pct combustible dust = 1.5 mg/m³; rock dust = 0.5 mg/m³.

3. Using 37 mm filters, nine 8-hour samples were taken on slushermen in nondiesel areas to obtain figures on the background combustibles. Average results included total respirable dust = 0.9 mg/m³; 50 pct combustible dust = 0.45 mg/m³; rock dust = 0.45 mg/m³.

Thus the indications are that the respirable portion of the carbon particles in the air from our LHD engine exhausts are in the range of 1 to 1.5 mg/m³.

ANNUAL MINERS CHEST X-RAY

All miners in Ontario are given an annual chest X-ray by the Workman's Compensation Board of Ontario. There has been no indication among our miners of a health problem resulting from the use of diesels underground.

CONCLUSION

From the experience gained over the last 7 years, it is our opinion that the successful use of diesel-powered equipment in underground mining

operations depends to a large extent on a program that includes all of the following factors:

1. The choice of clean-burning diesel engines using premium grade fuel, to minimize the toxic fumes produced.
2. The use of oxycatalytic exhaust scrubbers to eliminate most of the toxic gases in the engine exhaust and the odors normally associated with diesel engines.
3. Proper maintenance of engines, air intake filters, and exhaust scrubbers.
4. Adequate ventilation throughout all sections of the diesel operating areas.
5. Daily checks on atmospheric conditions at each diesel haulage unit, in addition to the complete weekly tests required by the Mines Branch at all diesels.

With this program of environmental control at our diesel-powered equipment in effect, it has been feasible to expand the use of this equipment to further mechanize our underground mining operations and to provide safe working conditions in the ore extraction areas.

APPENDIX A.--FORM USED FOR INSPECTION AND SERVICE OF ST4A AND
ST5A SCOOPTRAMS ONCE EVERY 2 WEEKS

Tag and Block Vehicle Record Inspection In Log Book		PM-527	inco		Equipment Location
Use Standard Check Off Code ☒ Checked OK ☒ Need Repairs		SCOOPTRAM SERVICE CHECK LIST - ALL UNITS		Hour Meter	
				Service	2wk 4wk 6wk

Item	Description	Code	Item	Description	Code	
ENGINE			HYDRAULIC SYSTEM			
1	Clean engine & entire unit		1	Check for leaks & oil level (running)		
2	Check valve clearance .010"		2	Check for oxidation colour & cuttings		
3	Check compressor & Alternator belts		3	Check tank filter & O-rings		
4	Check oil air fuel leaks (running)		4	Check hoses & cylinders for leaks		
5	Change oil in fuel pump HD30		5	Check dump & hoist controls		
6	Take crankcase oil sample (600 Hr.)		6	Check steering controls		
7	Change crankcase oil HD 30 (200 Hr)		7	Check for tank & filter damage		
8	Change air cleaner elements		AXLES & DRIVELINES			
9	Check engine mounts		1	Check all drivelines & U Joints		
10	Check cooling blower & belt		2	Check tie bolts		
11	Check engine Shut off rod		3	Check oscillating axle		
12	Check exhaust system (top scrubber)		4	Grease oscillating axle		
13	Check cowlings		5	Check differentials & planetaries		
14	Check engine warning system		6	Adjust air brakes to 1" travel		
15	Check air starter & grease		7	Adjust hydraulic brake 020" - 025"		
16	Fill air starter oiler		8	Exhaust tube type clearance (no gasses)		
17	Clean air starter filter & screen		9	Check brake fluid container fr. & rr.		
18	Test - engine over temp. switches		10	Check disc brake		
19	Check fuel pump seals		11	Check wheel nuts & studs		
20	Change all filters according to INCO Diesel service tag		12	Record tire number & % wear -		
TORQUE CONVERTER & TRANSMISSION			LF		RF	
1	Check oil level and for leaks		RR		LR	
2	Check for oxidation & colour		BOOM & BUCKET			
3	Check all transmission hoses (run)		1	Check pins bushings & locks		
4	Check mountings		2	Check for cracks		
5	Check controls (running)		MISCELLANEOUS			
6	Check neutral switch		1	Check all gauges (running)		
MECHANIC'S TEST			2	Top battery water & clean terminals		
1	Test drive unit		3	Remove compressor discharge hose		
2	Brake test unit on grade		3	Remove check valve		
3	Stop distance service brake	Ft.	4	Drain water from air tanks		
4	Stop distance emergency brake	Ft.	5	Test idle, no load, & stall speed		
5	Disc brake test		R.P.M.			
			6	Lubricate complete unit		

REMARKS:

I HEREBY CERTIFY TO THE ABOVE SERVICE & INSPECTION. DATE: _____

EMP. SIGNATURE _____ # _____

SERVICE INSPECTIONS ARE BOTH MANDATORY AND A LEGAL REQUIREMENT.	MTCE. F'MAN.	GENERAL F'MAN.	PM DEPT.

APPENDIX B.--FORM USED FOR 18-WEEK AND ANNUAL INSPECTION
OF ST4A AND ST4A SCOOPTRAMS

PM-178

STANDARD PROCEDURE FORM SM-2232-B-3
WAGNER ST 4A - 5A SCOOPTRAM 600, 1800 & 5400 HOUR INSPECTION

REVISED 7/1/70

MINE: _____ MACHINE NO: _____ DATE: _____ HOUR METER: _____

PERFORMED BY: EMP. NO: _____ NAME: _____

AT EACH 600 HOUR INTERVAL or every 6 weeks do 200 Hour Inspection as per form SM-2232-A3 and attend to the following additional items reporting in appropriate column.

O.K.	B.O.	URG.	ENGINE
			Check valve clearance
			Change engine over temperature switches
			Clean fuel precleaner
			Change primary fuel filter Code 37-16370
			Change secondary fuel filter Code 23-14999
			Take crankcase oil sample
			Change crankcase oil (HD-30) Code 10-43560
			Clean primary lube oil filter
			Change secondary oil filter Code 23-14889
			Check stall speed R.P.M.
			Check full speed, no load R.P.M.

O.K.	B.O.	URG.	TRANSMISSION
			Change filter element Code 23-15186
			HYDRAULIC SYSTEM
			Clean tank filter
			Change filter element Code 23-14983

AT EACH 1800 HOUR INTERVAL do 600 Hour Inspection and the following:

O.K.	B.O.	URG.	ENGINE
			Adjust valve clearance to .010" cold
			Check blower coupling rubbers
			Change fuel injectors
			TRANSMISSION
			Change oil (Dexron) Code 10-12440
			HYDRAULIC SYSTEM
			Adjust bucket pressure to 1600 P.S.I.
			Adjust steering pressure to 1500 P.S.I.

O.K.	B.O.	URG.	BRAKES
			Remove shields and inspect -
			Brake lining
			Brake shoe anchor pins
			Brake drums
			AXLES - FRONT AND REAR
			Change oil (GX-90) Code 10-34450
			Check for metal particles in oil
			Check Bogie bearings

AT EACH 5400 HOUR INTERVAL OR YEARLY do 1800 Hour Inspection and the following:- Clean entire machine to inspect for cracks, repairs and paintings as necessary

O.K.	B.O.	URG.	ENGINE
			Change exhaust scrubber
			AXLES - FRONT & REAR
			Remove brake drums to check -
			Brake linings and shoes
			Brake drums
			Camshafts and bushings
			Brake anchor pins
			Brake cam rollers
			Wheel bearings
			Oil Seals

O.K.	B.O.	URG.	MISCELLANEOUS
			Check brake activators
			Check brake slack adjusters
			Check quick release valves
			Check inversion valves
			Check air tank safety valves
			Test air tank hydrostatically
			Repair and weld cracks
			Paint entire machine
			Change hydraulic oil Code 10-47280
			Clean hydraulic oil tank

REMARKS:

Signed: _____
Area Foreman

MR. McDOWELL: Are there any questions for Mr. Hews?

FROM THE FLOOR: Is this 1,800 pounds of pellets for all of your machines for the year?

MR. HEWS: Yes, that is right.

FROM THE FLOOR: How often would you regenerate each individual machine, once per year?

MR. HEWS: Once per year. And, of course, the pellets are added whenever it is required on the 2 weekly inspections.

MR. McDOWELL: Are there any other questions?

FROM THE FLOOR: You talked about not having a problem in the heater exhaust. What is your mine temperature or general conditions?

MR. HEWS: The general conditions in the mines are about 60° F. We have some at about 70° F, but it would be a very rare occurrence to have any temperature above 60° F.

MR. McDOWELL: Any more? If not, again, thank you, Mr. Hews. I will now turn the program over to Bruce Grant.

MR. GRANT: Gentlemen, we have a couple of concluding pieces of business. One of them is that we are going to ask our speakers, not only from this session, but from the other sessions, that are with us here to stick around for perhaps 15 minutes for any questions and wrap up questions that you all may have. Don Schlick, our Deputy Director, wants to wrap up the symposium with summary remarks, and after he has done that, I want to acknowledge some of the prepared discussions that we have for inclusion in our record.

MR. SCHLICK: I want to thank all of you for attending this symposium. I believe we had over 600 people. It was a well rounded program, and I hope you got as much information as I did from it. Our speakers were very professional, very intelligent, and directed themselves to the problem. We have heard about the latest in diesel engine equipment design. We have heard the latest information on the emission control procedures. We have heard the latest in the usage of diesel equipment in the coal and metal mines in this country, as well as the foreign countries, and we have heard much on maintenance of diesel equipment itself. I also appreciate the remarks of the United Mine Workers. I know their problems, and I am grateful for the new look that the Union is giving diesel use--that they, as Mr. McAteer said, are not closing the door.

We are interested in promulgating regulations that will provide a maximum amount of health and safety to the Nation's miners, whether they are coal miners or metal miners, and I believe this symposium is certainly a giant step in that effort. Again, I want to thank you very much for attending.

MR. GRANT: I want to acknowledge the presence and attendance of Monsieur Robert C. Deniau, who is the assistant director of the Association of Iron Mines in France. He is a member of the Commission of Research on Health and Safety in Underground Mines of European Commodities for Coal and Steel.

MR. DENIAU: Mr. Chairman, I would like to describe the results of research on methods to combat diesel engine emissions. This work was done in behalf of the European Community for Coal and Steel. This Community is very interested in health and safety in mines and for the period 1965 to 1975 is spending some ten and a half million dollars in a health and safety program. Research on the use of diesels underground is included in that program.

In French iron ore mines of Lorraine, the problem is very important: we use more than 1,200 diesel engines on mobile machines, ranging from 30 to 300 hp. These include: 300 ore trucks from 150 to 250 hp, 150 load haul dump machines or shovels from 150 to 300 hp, 100 drill jumbos of 100 hp, 650 service or personnel trucks from 30 to 100 hp.

In our mines, humidity of the air average is 90 to 100 percent and temperature varies between 55° and 63° F; the rules are to observe the maximum air contaminant (MAC) values fixed by U.S. Government hygienists. The principal problems are reducing emissions of CO, NO_x, and odors.

Five means of reducing diesel emissions have been developed:

1. Choosing a "clean" engine--many trials at the bench and underground have shown that engines fitted with swirl chambers are better than those with direct injection; it is also necessary to have a low fuel-air ratio. Although they have poor performance in terms of weight of fuel burned per horsepower, we recommend use of Deutz, serial 714 or 912W air-cooled and Caterpillar 333 water-cooled engines.

2. Starting a program for good maintenance of engines and of the engine air intake systems.

3. Controlling emissions: Experiments in reducing injection were made, but the reduction of emissions was significant only at low speed and light load. Trials of recirculating exhaust gases were successful for motors with swirl-chamber and without turbocharger. The best rate of recirculation was found to be 20 percent. The quantities of CO produced are about the same, but those of NO_x were reduced to the half and smoke opacity remains under Bosch level 2. This was proved by laboratory trials followed by industrial use of engines underground. Today, two engines of 220 hp and 10 cylinder have been used more than 5,000 hours with a recirculation system, without abnormal wear. The system is quite simple: a 1-1/4-inch steel pipe joins the exhaust pipe to the engine air intake after the air filter; a stainless steel valve allows adjustments of recirculating flow. We are developing this device on all Deutz engines.

Unluckily the recirculating device is not available when the engine is fitted with a turbocompressor; trials in the laboratory using a Caterpillar

engine have proved that it would be necessary to cool the recirculated gases before admitting them in the compressor.

4. Recirculating gases from the oil case. This device is cheap and easy. A hose of 1 inch joins the snifter-valve to a metallic screen and then to an air intake. This screen must be cleaned after 250 hours. It was tried in the field on a Caterpillar engine and has lowered the odors. We shall develop it.

5. Scrubbing exhaust gases. Oxycatalytic scrubbing is not available in our mines, because the exhaust gases from the swirl-chamber engines are not hot enough. Trials with a heating device were not successful, although scrubbing was efficient. But exhaust produced fog and it was impossible to drive the machines.

We use water scrubbers on all machines. Boxes, pipes, and valves are made of stainless steel. The water level in the scrubber must be constant. The scrubbers must have a big volume of water for cooling gases and scrubbing them. About 2-1/2 l of water capacity are provided per horsepower.

These scrubbers are efficient for acids, unburned fuel, aldehydes, and odors. They reduce NO_x about 20 percent.

These are the results we have obtained in European underground mines for developing the use of diesel engines. I will provide written reports for those who wish to have more information.

Thank you.

WRITTEN COMMENTS SUBMITTED AFTER THE SYMPOSIUM

by

Keith Alcock¹

GENERAL BACKGROUND

The Hunslet Engine Company of Leeds, England, first built locomotives for underground tunneling use in 1887; these were condensing steam units. In the past 35 years, well over 1,000 underground diesel locomotives have been manufactured, about half of these being of permissible types for use in gassy coal mines. In the past 10 years some 200 diesel-powered trackless vehicles have been supplied to gassy coal mines.

EXHAUST EMISSIONS

Until about 1960 very little was known about the effects and the relative hazards of the toxic constituents of diesel exhaust gases. Carbon monoxide was always recognized as a potential hazard and strict ventilation requirements to dilute CO were introduced in England in 1949.

It is now generally recognized that oxides of nitrogen are formed in the instant of highest temperature and pressure in the diesel combustion cycle. This means that as diesel engine manufacturers have been striving to improve combustion efficiency in their new designs, the tendency has been for CO levels to be reduced but at the expense of higher NO_x levels. Diesel engines used by Hunslet in the 1950's typically had exhaust emissions of 1,500 ppm CO and 500 ppm NO_x, whereas a typical modern direct-injection diesel has concentrations of 500 ppm CO and 1,500 ppm NO_x in the exhaust. When it is considered that the TLV values for CO and NO_x are respectively 50 ppm (proposed 35 ppm) and 5 ppm, it must be assumed that medical researchers consider NO_x between 7 and 10 times more dangerous than CO.

From the above figures it will be obvious that the ventilation volume to dilute the exhaust gases of an underground diesel unit to safe levels will nearly always be calculated from the NO_x concentration in the engine exhaust. Although there are still some unknowns regarding the toxicity of some of the trace constituents of the diesel exhaust, present technology and medical research strongly indicate that provided there is sufficient ventilation to dilute the NO_x element to safe levels, all other pollutants will automatically be diluted to considerably below safe permitted concentrations.

In the early 1960's most diesel engine manufacturers had switched their production to direct-injection types, and it seemed very possible that by the end of the decade no production precombustion chamber-type diesel would be available for use in underground diesel equipment. As a result, in 1964

¹Marketing Director, Hunslet (Holdings) Ltd., Leeds, England.

Hunslet initiated a 5-year sponsored research program to be carried out at Leeds University to study various ways of reducing the NO_x concentration of diesel exhaust gases. This research work concentrated on the effects of fuel additives on the ignition delay and combustion rate in the cylinder of a diesel engine, both of which affect the formation of NO_x during the combustion cycle. A copy of a report covering this research has been left with the U.S. Bureau of Mines for their records.

Several well-known methods of reducing NO_x levels in diesel emissions already exist as outlined by Hurn during the symposium. These consist of (1) derating the engine, (2) altering the injection timing, (3) recirculating the exhaust gases, and (4) altering the fuel injection rate.

Most diesel engine manufacturers pay particular attention to the fuel injection systems, and no further significant advantage can usually be obtained by changing the manufacturer's standard.

Current Hunslet underground locomotives all employ derated engines with altered injection timing; the larger models also have a degree of exhaust recirculation. Derating is limited in that excessive derating (or reducing the amount of fuel injected at maximum load) can cause starting problems, especially in cold climates. Altering the injection timing reduces the peak combustion temperature and pressure with a corresponding reduction in NO_x emissions; however, a side effect is that combustion is not so complete, and more CO, hydrocarbons, and smoke are produced.

Recirculation of exhaust gases also results in a trade-off: less NO_x , but more CO, smoke aldehydes, and unburnt hydrocarbons. Exhaust gases in the intake of the engine reduce the oxygen concentration, and hence have the same effect as increasing the fuel air ratio. Almost identical exhaust emissions are obtained by temporarily throttling the air intake to simulate a clogged intake filter.

The type of trade-off described above can be justified to a certain degree, particularly if the engine is equipped with both a catalytic scrubber that oxidizes the CO to CO_2 and a water scrubber that precipitates a large proportion of the particulate matter together with the heavier hydrocarbons that are adsorbed on carbon particles. A typical water scrubber also absorbs between 50 and 75 percent of the aldehydes. All Hunslet production locomotives employing exhaust recirculation are currently fitted with both types of scrubber in series for the reasons described above.

It was hoped that research in the field of fuel additives would eliminate the need for this type of trade off, which is caused by all existing methods of controlling NO_x emissions. In practice it was found that certain additives could in fact significantly reduce the NO_x levels while at the same time improving combustion efficiency, resulting in less CO and smoke formation. However, such additives, apart from being expensive, all had the unacceptable side effect of considerably reducing the ignition temperature of the fuel oil; hence it was decided to discontinue this line of research in 1969.

Research was continued in the field of water injection and exhaust dilution. The work on water injection continues, whereas the research on dilution has been recently completed. The conclusion is that in order to obtain better than 7 to 1 mixing with a venturi-type air induction diluter, unacceptably high back pressures have to be imposed on the engine. Dilution ratios of between 10/1 and 20/1 can readily be obtained by mixing the exhaust gas with the air stream passing through engine coolant radiator. The need to employ further dilution systems is therefore eliminated. Water injection seems to provide the ultimate answer to the NO_x problem; great reductions are possible without significant increases in the concentration of very severe exhaust emissions. Because of regulations in the United States, in particular the 1975 California requirements, it seems likely that the diesel engine manufacturers themselves will be producing production engines with low NO_2 emissions in the near future. This will take a great research load off the mining machinery manufacturer and will automatically increase safety of diesels in underground operations.

Other development projects which are of extreme interest to the mining equipment manufacturer are the possibility of a compression ignition Wankel engine and the continuous combustion Stirling engine which is in an advanced stage of development at the present time.

FLAMEPROOF REQUIREMENTS

As detailed in Gilbert's symposium paper, diesel locomotives have been in operation in British coal mines for over 30 years with no recorded cases of methane ignitions. However, several localized fires have been caused by slipping fan belts, overheating axleboxes, slipping friction clutch, and coal dust ignition on hot surfaces.

It should, however, be noted that the great majority of diesel locomotives in operation with the National Coal Board were supplied before 1962. These units all had bronze axlebox bushes and not roller bearings, and nearly half had mechanical transmissions with an open dry plate friction clutch.

Only during the 1960's have new regulations been introduced specifying the use of flame-resistant materials for the fan belt and other nonmetallic components as well as the water jacketing of the entire exhaust system. Current practice also recommends that the fuel tank be positioned remotely from the engine/transmission compartment so the fuel spillage hazard is reduced.

It is interesting to note that over half of the diesel locomotives currently in use with the National Coal Board have had over 12 years service, and although they were built to the old flameproof standards they are still considerably safer than trolley and battery locomotives.

From the above comments together with the figures given by Gilbert it can safely be assumed that, provided the U.S. Bureau of Mines is strict in the enforcement of safe flameproofing standards, there will be a significant reduction in the fire hazard in U.S. coal mines with the introduction of diesel-powered mobile equipment.

MINE ATMOSPHERE MONITORING

A great deal has been said during the symposium about the need for regular monitoring of the mine atmosphere for excessive concentrations of diesel exhaust emissions.

It was noted that British regulations call for once-a-week sampling in diesel haulage roadways and three-monthly sampling of the neat exhaust gas of each diesel unit. The argument for more regular sampling or even continuous monitoring is that lack of maintenance on the diesel engine could result in rapid deterioration of the diesel exhaust. The only other cause of increased pollutant level would be a physical change of the mine ventilation system in which case it should be mandatory that a complete new set of samples be taken.

Poor maintenance of the diesel engine itself leads to the following malfunctions:

- (1) Restricted air inlet by clogged filters.
- (2) Restricted air inlet by unclean inlet flametrap.
- (3) Incomplete combustion caused by dribbling injector, leaking valve, or sticking piston ring.
- (4) Increased back pressure on engine through buildup of particulate matter in the exhaust scrubber.

All these malfunctions will result in a rapid increase of concentration of CO, aldehydes, and smoke in the exhaust, and anyone who has traveled behind a poorly maintained diesel truck on the highway will agree that, both from the smell and the visual emissions, it is easy for even a layman to tell when a diesel engine needs attention. Happily, as explained previously, whenever there is an engine condition tending to increase CO and smoke, such as loss of compression or fuel-rich mixture, there is an immediate corresponding reduction in NO_x formation. Remembering that NO_x is some 7 to 10 times more toxic than CO, it is therefore true to say that within reasonable limits the exhaust emissions from a badly maintained diesel engine are less toxic than those from a perfectly maintained unit. Certainly the smoke and odor level become physically objectionable before the unburnt CO and hydrocarbon levels have risen to hazardous levels.

It will be seen therefore that every piece of mobile diesel equipment operating in the mine has at least two permanent monitoring systems; the eyes and nose of the operator and of all other personnel working in the vicinity. There is, therefore, a built-in safety mechanism with all diesel units because lack of maintenance shows up in the form of objectionable fumes before there is any increase in hazard.

Obviously, a far greater hazard exists if there is any lowering of volume of the ventilating stream which passes over the diesel vehicle and dilutes the exhaust. To some extent an experienced miner, can gauge the strength of the

wind and hence will notice any vast change in the ventilating current. As the dilution of diesel exhaust is so vital to the safe operation of diesels underground, it is suggested that, should continuous monitoring be considered necessary, ventilating current is the most important parameter.

NOISE POLLUTION

Noise can easily become a serious problem in the confined spaces of an underground mine. Sutton's paper notes that unacceptable noise levels are often recorded in mines using diesel equipment. Fully enclosed insulated cabs (as used in the construction industry) and ear muffs (as used at airports) are considered unsafe for underground operation, and some form of noise insulation on the vehicle may become necessary.

It should be noted, however, that a precombustion-type diesel engine is normally quieter than a direct injection type and that a water-cooled engine is far quieter than an air-cooled engine. A water-jacketed exhaust manifold and pipe and a water-type exhaust scrubber also help to reduce noise levels and to act as a damper to reduce vibration.

It is seen therefore that manufacturers of machinery for metal mining who conventionally use air-cooled engines and dry-type catalytic scrubbers will almost certainly have more difficulty than people working under Title 31 in meeting any future noise level regulations that may be established by the Bureau of Mines.

WRITTEN COMMENTS SUBMITTED AFTER THE SYMPOSIUM

by

V. E. Dawson¹

I would like to raise a few questions and make the following comments.

1. Several operators outlined their experiences with diesel-powered equipment underground, but little mention was made of fuel injection pump calibration and sealing. It is essential for the effective control of exhaust gases that the fuel injection pump of any diesel engine be correctly set to deliver not more than the quantity of fuel specified in the appropriate U.S. Bureau of Mines Approval for that engine. This setting must take into account the operating altitude of the equipment. In British Columbia, for each diesel engine operating underground we require written certification from the supplier of the equipment or from an independent fuel pump specialist that the pump has been correctly set and sealed.

The usual procedure is for a metal plate to be secured to the pump showing the maximum fuel injection rate in pounds per hour. One problem that we have encountered, however, is the method of sealing the pump. This is normally done by means of a twisted wire and lead seal arrangement secured in such a way as to prevent unauthorized tampering with the governor and fuel rack adjustment. Unfortunately, it is very easy for the wire to be broken and retwisted together and this condition is almost impossible to discover on an underground inspection visit. We believe that there is a real need for an improved method of sealing fuel injection systems, and we would welcome other ideas on this from interested parties.

2. Several speakers mentioned that samples were being taken regularly from the raw exhaust gas of diesels operating with oxycatalytic conditioners underground. Apparently, however, most of these samples are being taken from the exhaust gases after they have passed through the conditioner. We have found that raw exhaust samples offer a very reliable guide to the overall condition of a diesel engine, and that changes in the CO content of the raw exhaust are a clear indication of changes in the fuel/air ratio. Samples taken from the exhaust gases beyond the conditioner do not show the true CO content of the exhaust gas. In British Columbia, samples are taken ahead of any scrubber or conditioner through a regular sampling nipple on the exhaust which is, of course, closed during normal operations.

3. In his paper entitled "Diesel Haulage Experience in the Martin County Coal Corporation," I believe that a statement was made by Mr. R. A. Bradbury to the effect that high CO and NO_x readings in the exhaust could be corrected by flushing out and refilling the scrubber tanks. This indicates that

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chemicals are being used with the water, and any further information on this would be appreciated.

4. We believe that a positive mechanical flametrap should be fitted to the intake and exhaust on every diesel engine approved for operation in gassy atmospheres. Although a water scrubbing system will normally provide an effective flametrap, there is always a possibility that the safety shutdown controls of the engine will be defeated manually and the engine operated with a low water level in the scrubber. Under these circumstances the presence of a physical barrier to flame would be essential for safety in a gassy mine. With an efficient water scrubbing system and a daily change of the flametrap assemblies, there should be very few problems in operating with such equipment.

5. We would be very interested in receiving information on any test results that have been obtained relating to the minimum temperature at which different types of coal dust will spontaneously increase in temperature up to the ignition point. We understand that some coal dusts will ignite spontaneously if their temperature is raised to between 300° and 400° F, and we would appreciate any available data on this subject.

6. The point was raised by several authors that the ventilation rate for any particular diesel engine is based on the worst operating condition found during dynamometer tests and, therefore, has an excessively high safety factor. It has, however, been our experience in British Columbia that even though 100 percent of the minimum ventilation rate is required for each diesel engine operating underground, we still have problems in some of our larger mines with unacceptable levels of NO_x in the general mine air. The reasons for this include--

a. Ineffective control of the mine ventilation especially in large mines where the active workings are spread out over many operating levels.

b. The diesel equipment passing several times through its own or another vehicle's exhaust.

c. The difficulty, in remote areas, of establishing a reliable maintenance program. At some mines in British Columbia, the annual turnover rate of personnel has been as high as 400 percent.

In view of our experience, therefore, we feel very strongly that the safety factors inherent in the minimum ventilation rates established by the U.S. Bureau of Mines are valid and necessary in many cases.

7. We understand that the use of paper air filters is becoming more and more popular for underground mobile diesel equipment although Schedules 24 and 31 still require oil-bath air cleaners.

The main objection to the dry type of air cleaner has been the greater risk of unnoticed air restriction in the intake to the engine with a consequent increase in the fuel-air ratio. We have had a limited experience with paper filters and, provided that a reliable device is fitted to indicate a predetermined degree of intake restriction, there does not appear to be any serious objection to their use. We would be very interested to hear of other persons experience with these dry cleaners and the reliability of indicators.

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16. Abstract A symposium was held on January 30-31, 1973, at Pittsburgh, Pa., to review the state-of-the-art in designing and utilizing diesel-powered equipment in underground mining. The office of the Assistant Director--Health and Safety of the Bureau of Mines sponsored the symposium with major assistance from the American Mining Congress, the United Mine Workers of America, the National Independent Coal Operators' Association, and the Bituminous Coal Operators' Association, Inc. Seventeen papers were presented devoted to the general subjects of: the diesel engine; the place of the diesel in underground mining; health protection using diesels underground; and maintaining safety of diesels underground. Eleven of the speakers were from industrial organizations here and abroad; one represented the Provincial Government of Nova Scotia; two were with the Department of Health, Education, and Welfare; and three reported on Bureau of Mines work related to diesels. In addition to the papers that have been reproduced, the questions from the audience and the replies from the authors also have been included.					
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