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Coal Mine Fire and Explosion Prevention

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Transfer Seminars, Pittsburgh, Pa., March 2, 1978
and Denver, Colo., March 14, 1978

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COAL MINE FIRE AND EXPLOSION PREVENTION

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Pittsburgh, Pa., March 2, 1978 and Denver, Colo.,
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ABSTRACT

These proceedings consist of papers presented at two Bureau of Mines Technology Transfer Seminars for the purpose of disseminating recent advances in mining technology related to coal mine fire and explosion prevention. Primary, although not exclusive, emphasis is placed on underground coal mining.

The papers address research accomplishments ranging from methods for detecting mine fires to remote sealing systems for extinguishing coal mine fires. Each paper represents the current state-of-the-art in the respective research categories. Presentations include research occurring from both Bureau in-house and contract efforts.

INTRODUCTION

by

David Burgess

This report contains the eight papers presented at the Bureau of Mines Technology Transfer Seminars held in Pittsburgh, Pa., and in Denver, Colo., in March 1978. The seminars are part of the Bureau's ongoing program to appraise the mining industry of the results of Bureau of Mines research. It is hoped that the prompt dissemination of this information will expedite in-mine application of safer, more efficient mining techniques and conditions.

Developing new and better ways of preventing, suppressing, and extinguishing fires and explosions in coal mines is the goal of fire and explosions prevention research. Work is underway to eliminate ignition sources, to achieve early detection of combustion or conditions conducive to combustion, and to immediately suppress explosions or fires.

The research is providing insights into the technical causes of fires and explosions in coal mines, and much of it focuses on the chemistry and physics of coal dust combustion and coal dust explosions. For example, the Bureau is studying the relationship of temperature to the rates of coal dust oxidation and the possible importance of particle size in coal dust explosions.

Bureau research is also developing many detectors and warning systems for potentially hazardous conditions, ignitions, and actual fires and explosions. An improved monitor for explosive methane gas is also being worked on, as well as an infrared device that shows promise for detecting overheated rollers on conveyor belts, which could also be sources of fires or explosions.

Elimination of potential ignition sources in the mining environment is another approach the Bureau is taking to prevent fires and explosions. Immediate efforts are focusing on modifying existing equipment to prevent sparking and other hazardous problems. Longer term projects are aimed at developing intrinsically safer mining equipment, and at learning the hazards associated with the pneumatic transport of coal.

The subjects addressed in this Proceedings represent recent technological advancements made through both Bureau in-house and contract efforts of the research program.

MINE FACE IGNITION QUENCHING

by

Aldo L. Furno¹

ABSTRACT

The incidence of frictional spark ignition at the mine face has increased significantly with the advent of the continuous-mining machine. To cope with this problem, the Bureau of Mines initiated research in the early sixties to develop an ignition-quenching device. This paper summarizes the initial in-house and subsequent contract research in which dry powder extinguishing agents were used and the Bureau's recently completed work in which a vaporizable agent (Halon 1301) and hybrid mixtures of Halon 1301 and Purple-K or water were studied. Hybrid mixtures are shown to be the most effective agents. Design requirements are given for an ignition-quenching device proposed for the tunnel-boring machine application.

INTRODUCTION:

In the years preceding the Coal Mine Health and Safety Act of 1969, frictional ignitions were reported at the rate of about 50 per year. This number of ignitions is not particularly significant because there were surely pops and flashes that went unreported. Nor is it very useful to count the injuries or the loss of production from reported ignitions; the major hazard lies in the possibility that a face ignition may initiate an extensive coal dust explosion.

The research that resulted from the 1969 Act included three approaches to the problem of face ignitions. One was the reduction of methane concentrations through improved face ventilation by water infusion and by advances in methane drainage. A second was an attempted reduction of the incendivity of tool bits through improved metallurgy of the bit or through reduced bit speed. The third was the development of an ignition-quenching device that might be incorporated into the design of a continuous miner.

The Graviner² system, which may be called an ignition-quenching device, was developed in the 1940's. Its early application was to fixed installations and the Fenwal Corp., the American Licensee of Graviner from 1957 to 1964, made upwards of 2,000 installations of explosion-suppression equipment.³ The adaptation of the concept from fixed installations to a machine-mounted application was recognized as a formidable problem. Factors that have to be

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²Reference to specific brands or manufacturers is made for identification only and does not imply endorsement by the Bureau of Mines.

³Gillis, J. P. Private communication, Oct. 13, 1977. Available upon request from J. P. Gillis, Fenwall Inc., Ashland, Mass.

considered include the shocks and vibrations on a continuous miner, not to mention roof falls; the dusty, humid atmosphere; and the awkward geometry within which the flame detection and extinguishant dispersal are required to operate. All factors militate against a cheap, effective device that would be reasonably free of false firings.

The Bureau's first undertaking in this area in the early 1960's was preceded by two important advances that was promoted by the armed services. One was the identification of chemical extinguishing agents, such as potassium bicarbonate or Purple-K, which were about an order of magnitude more effective than inert quenching agents such as water or rock dust. The second was the development of sensitive flame detectors that were not affected by extraneous signals, such as cap lamps, which might otherwise give false triggering. The Bureau's immediate research undertaking was to determine the size of a methane-air flame that could be used for detection and the required speed of extinguishant delivery to cope with such a flame. This work was considered so promising that a patent was obtained in 1969.⁴ This outlook also led to the provisions in the 1969 Act, "The Secretary shall require, when technologically feasible, that devices to prevent and suppress ignitions be installed on electric face cutting equipment" (Public Law 91-173, Section 317 (q)).

This paper briefly summarizes the highlights of the in-house and contract research on this problem and the success achieved in developing a practical ignition-quenching device for mining applications.

EARLY BUREAU RESEARCH

The Bureau's early research on this problem was directed toward developing a system that would provide (1) rapid detection of an incipient methane-air ignition, (2) an extinguishing agent effective against such ignitions, and (3) an agent dispersal method that would insure adequate temporal and spatial distribution of the extinguishant. This research used the existing technology in the sixties and demonstrated that the development of a mine ignition-quenching device was a technically viable concept. The main components of the proposed device were as follows:

1. Ultra violet (UV) flame detector.
2. Dry powder extinguishant (potassium bicarbonate).
3. Explosive dispersal system (primacord).

The UV flame detector had a spectral response between 2,000 and 2,800 Å. The detector was sensitive to an open flame but it was not sensitive to the radiation of a miner's cap lamp nor to frictional sparks. It was capable of sensing a methane-air ignition 15 feet away within 20 msec; the expanding

⁴Mitchell, D. W., E. M. Murphy, E. M. Kawenski, J. Nagy, and R. P. Williams (assigned to U.S. Department of the Interior). Process and Method for Quenching Incipient Gas-Air Explosions. U.S. Pat. 3,482,637, Dec. 9, 1969.

⁵Kawenski, E. M., J. Nagy, and J. W. Conn. Further Development of an Explosion Quenching Device. Pres. at Internat. Conf. Safety in Mines Res., Tokyo, Japan, Nov. 20-25, 1969, 22 pp.

fireball would have a diameter of approximately 4 inches assuming a stoichiometric methane-air mixture (9.5 pct CH_4), which has a flame speed of approximately 100 in/sec. The detector served to trigger the Primacord for dispersing the extinguishant.

Initially, the device was successfully demonstrated in quenching stoichiometric methane-air ignitions with the dry powder dispersed from an open V-shaped trough. In the final prototype device, the dry powder and detonating cord were sealed in aluminum tubes of 1 to 4 inches in diameter and at least 3 feet long. Figure 1 shows the disperser tube, which was scored to facilitate rupture without fragmentation and to minimize the explosive charge required.

Quenching tests in a 25-foot-long entry of 6 by 10 feet indicated that about 6 lb of dry powder (KHCO_3) was required to quench a 9.5 pct-methane-air ignition with the extinguisher 4 feet from the ignition point. The extinguishant requirements varied with the disperser offset distance and the time delay between ignition and agent dispersion. The results indicated that the proposed device should quench the simulated mine face ignitions within about 100 msec to be effective. The variation of the dry powder requirements with distance between the disperser and face of the entry (ignition point) is shown in figure 2 for the two types of dispersion tubes used; the UV flame sensor was located 15 feet from the face. Limited trials also showed that the device can be effective against coal dust-air ignitions.

Although the results of this early research were encouraging, some practical problems were evident with the proposed device. For example, the dispersal system generated an unacceptable high level of noise, and the UV radiation received by the flame detector could be greatly attenuated by dust, oil, or grease accumulations on the detector window. Furthermore, a need existed to determine how such devices could be mounted on the mining machines and how many would be required. These and other practical problems were investigated in later research.

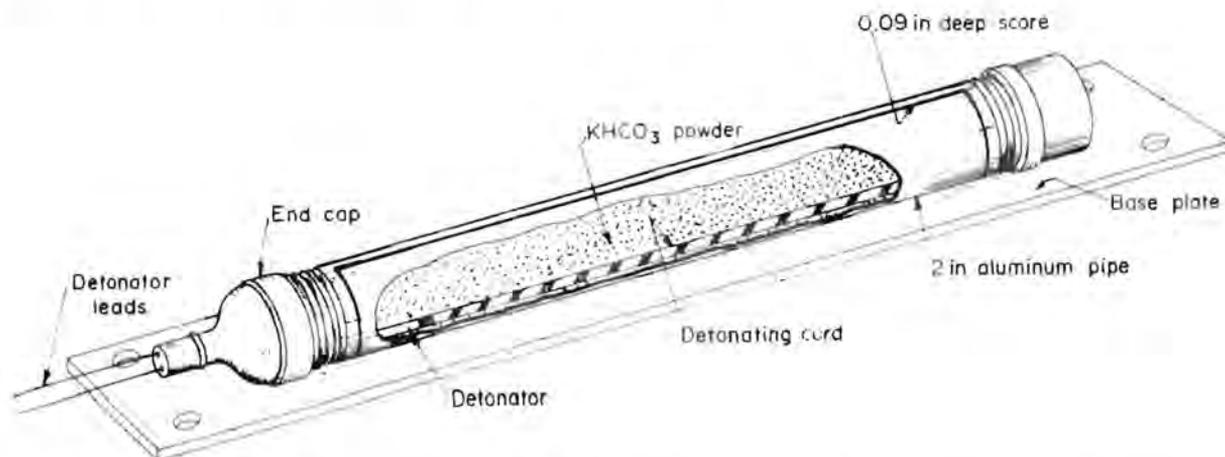


FIGURE 1. - Scored disperser tube for dispensing dry powder extinguishing agent.



FIGURE 3. - Cannon and detector system developed under contract research.

equipped with a diverging nozzle and a scored metal diaphragm which was ruptured upon triggering of a No. 6 electric detonator. The cannon was normally pressurized to 600 lb/in² with nitrogen for dispersing the dry powder agent. Figure 3 shows a cannon (10-lb unit) and a detector both of which met Federal Schedule 2G permissibility requirements; also, the cannon met the requirements of a 140-db "C" peak sound pressure level.

The contractor's dry powder device was evaluated against various methane-air-coal dust ignitions in a surface test facility (25 by 20 by 6 feet) with four different mining machines; coal dust concentrations of up to 0.01 oz/ft³ were used. To insure adequate coverage of the simulated mine face, the detector and extinguisher units were mounted on the top and near the middle level of the mining machine. Most trials were made with the extinguishers 10 to 15 feet from the face of the entry. The test results indicated that 5 cannons (~50-lb agent) were required for a ripper-type miner and 6 cannons (~60-lb agent) for a continuous-type miner. Table 1 summarizes the minimum number of cannons and detectors required for the four miners used.

Although this work was a technical success, the size and number of quenching devices required for the mining machines were considered impractical because of space limitations.

TABLE 1. - Extinguisher and detector requirements for quenching methane-air-coal dust ignitions with Lee Engineering device on four mining machines¹

Machine	No. of detector units	No. of cannon units	Amount of agent, lb
Joy ICM ripper.....	4	5	46.7
Lee Norse 33y-oscillating head.	4	6	59.0
Modified 33y full face drum....	4	6	59.0
Joy 2BT twin borer.....	5	9	66.1

¹Extinguishing agent = monoammonium phosphate, ABC powder.

RECENT BUREAU RESEARCH

As a followup to the Bureau's earlier in-house work, studies were conducted with other extinguishing systems that might be more suitable for the ignition-quenching device. The emphasis of these studies has been on the use of a vaporizable agent, such as Halon 1301 (CF_3Br), and hybrid systems of this halogenated hydrocarbon and a dry powder or water.

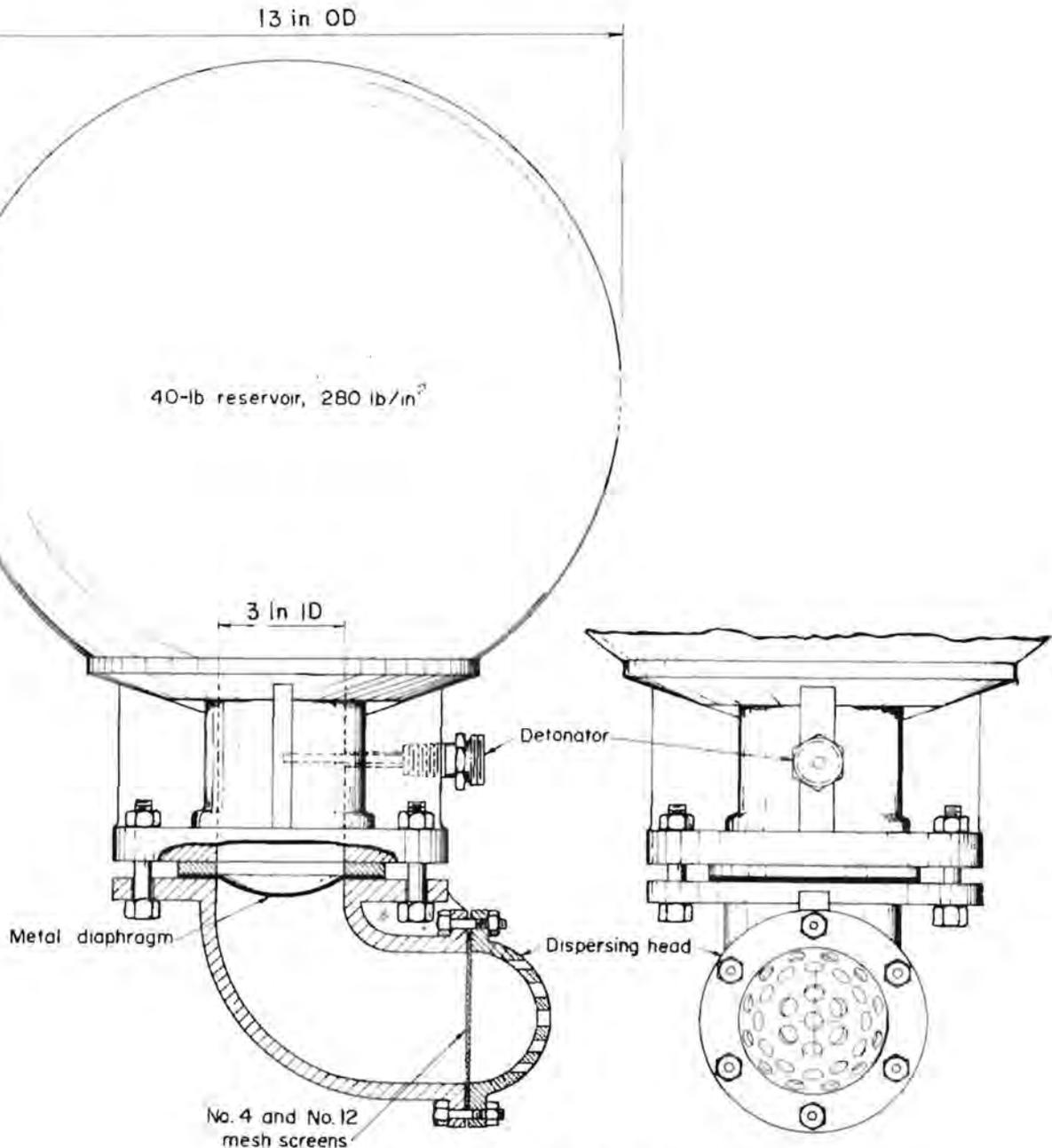


FIGURE 4. - Halon quenching device (Fenwal).

Halon System



Time from ignition, 100 msec
Fireball diam, 20in



Time from ignition, 156 msec
Fireball, 35in vertical, 39in
horizontal



Time from ignition, 188 msec

FIGURE 5. - Extinguishment of
methane-air igni-
tion with Halon
quenching device.

Halon 1301 was selected for the initial studies because of its great effectiveness as a flame inhibitor and because of the availability of a commercial extinguisher (Fenwal) that appeared suitable for this purpose. As shown in figure 4, this extinguisher is a spherical bottle that is equipped with a dispersion nozzle and an explosive release device; the latter is actuated by the signal from a flame detector. The vaporizable agent provides a vapor pressure of about 200 lb/in² at 20° C, which is adequate pressurization for most situations.

At the outset, dispersion tests with the commercial extinguisher indicated that the discharge was characterized by a pattern of lobes between which flame could conceivably propagate.⁷ Therefore, an improved hollow cone nozzle was developed to provide a more uniform spatial distribution of the extinguishant. The effectiveness of the Halon extinguisher was then demonstrated in quenching methane-air ignition in a 1,300-ft³ section of the Bruceston Experimental Mine. With the extinguisher mounted 4 feet from the mine face, fireballs of up to 4 feet diameter could be quenched with 25 lb of Halon; a film clip of a successful extinguishment is shown in figure 5. Furthermore, it was shown that the main toxic products (HF and HBr) from any decomposed Halon do not present a great hazard if extinguishment is achieved early, for example, at fireball diameter less than 2 feet. Table 2 summarizes some of the toxic product data from the mine quenching tests; these toxic product concentrations are low compared with the approximate lethal concentrations (ALC's) reported for 15 min exposures to HF (2,500 ppm) and HBr (4,750 ppm).⁸ The corrosive nature of the condensed toxic products could be objectionable, but this problem could be largely overcome by use of appropriate post-extinguishment procedures.

⁷Burgess, D. S., W. F. Donaldson, A. L. Furno, J. M. Kuchta, and C. R. Summers. Spatial and Temporal Distributions of Halon 1301 From a Commercial Extinguisher. BuMines RI 7515, 1971, 17 pp.

⁸National Fire Protection Association. Standard on Halogenated Extinguishing Agent Systems, Halon 1211. NFPA No. 12B, 1972, 45 pp.

TABLE 2. - Toxic products from quenching methane-air ignitions in the Bruceon Experimental Mine¹

Quenching delay, msec	Fireball diameter, inches	HBr, ² ppm	HF, ² ppm
60.....	16	0.5	0.3
91.....	18	3	3
95.....	20	32	16
118.....	26	31	28
135.....	31	22	34
152.....	40	59	435

¹Halon 1301 25-lb extinguisher, 4 feet from the face.

²Data for sampling point 20 feet from face of entry.

Hybrid Systems

Hybrid extinguishing systems are frequently more effective than the parent components because of chemical or physical synergistic effects. Therefore, it was appropriate to investigate hybrid systems of the highly vaporizable Halon agent (CF₃Br) and a dry powder, such as Purple-K (KHCO₃). Dispersion tests showed that the vaporizable agent completely envelops a cylindrical obstacle shortly after discharge. The dry powder is less effective in closing the void downstream of the obstacle; however, the dry powder displays greater "throwing power." This is evident from the composite photograph in figure 6, which compares the dispersion patterns of the two agents after the same period of discharge. A combination of such agents would be preferred to provide the best temporal and spatial distribution of extinguishant.

Quenching tests in a 6-foot-diameter gallery confirmed that Halon 1301 and Purple-K are more effective when used in combination. Results of such tests are compared in table 3; these data were obtained with near-stoichiometric methane-air ignitions and with the extinguisher 10 feet from the ignition point. Similar results were also found using a hybrid mixture of Halon and water. Accordingly, the Bureau has focused its research on the use of hybrid agents for any mine-quenching device.

TABLE 3. - Quenching effectiveness of hybrid systems for methane-air ignitions in a 6-foot-diameter gallery¹

Purple K, lb	Halon 1301, lb	Quenching delay, sec	Quenching
20.....	0	0.1	No.
10.....	10	.1	Yes.
4.....	4	.1	Yes.
0.....	8	.1	Yes.
0.....	8	.2	No.

¹Fenwal extinguisher, 10 feet from ignition point.

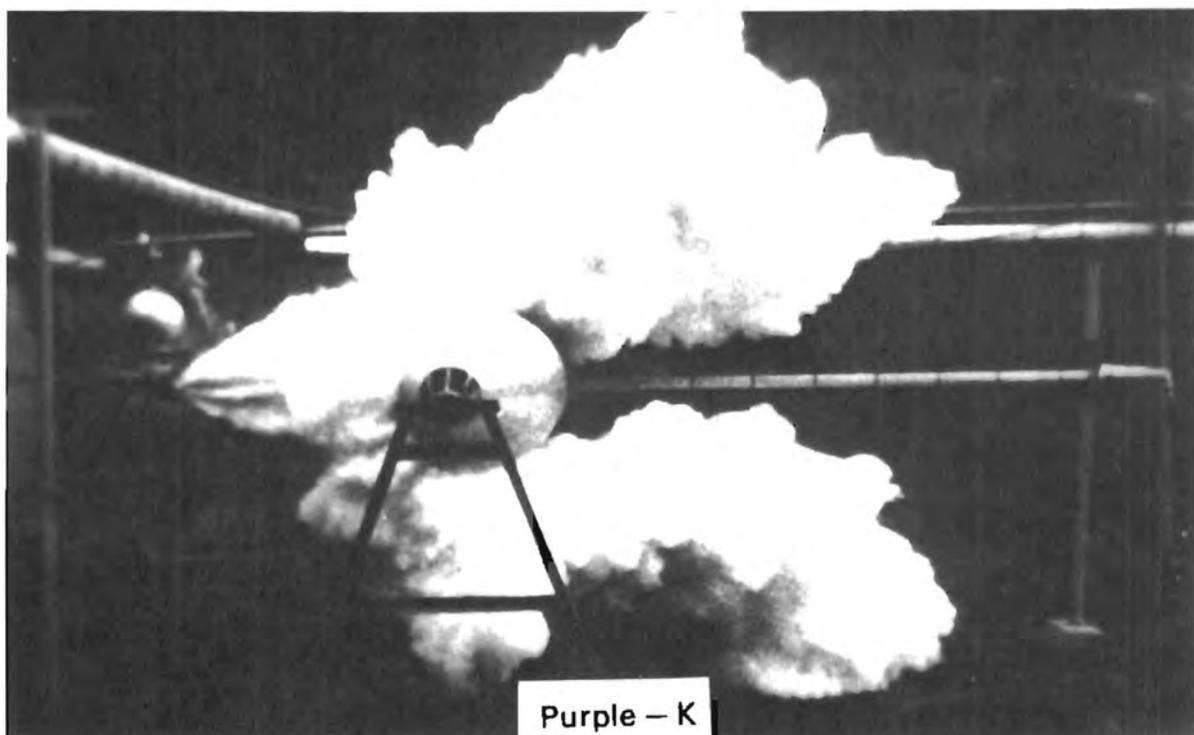
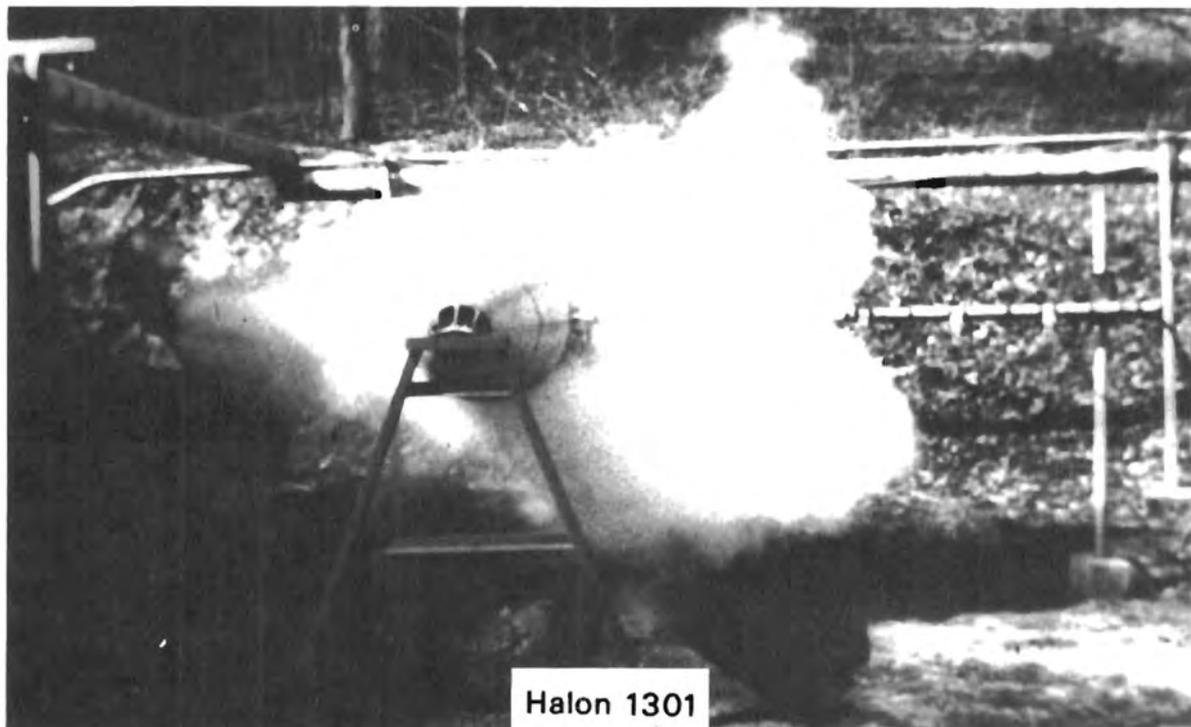


FIGURE 6. - Dispersion of Halon 1301 and Purple-K powder around cylindrical target at 130 msec.

Tunnel-Boring Machine

At the request of the Mining Enforcement and Safety Administration (MESA), the Bureau recently directed its efforts toward developing an ignition-quenching device for possible use on a tunnel-boring machine being used experimentally at Federal Mine No. 2 in Blacksville, W. Va.⁷ The tunnel-boring machine is being explored as a new method of entry development and can develop a frictional ignition hazard like that possible with other coal mining machines. This machine measures 18 feet in diameter and it is equipped with a cutting wheel that may develop frictional sparks at the face and sides of the wheel; the operator of the machine is normally at least 10 feet from the cutting face. A scaled model is shown in figure 7.

Quenching tests were made using a full-scale mockup of the cutting wheel of the machine in an 18-foot-diameter simulated tunnel and installing Fenwal-type extinguisher units and UV flame detectors around the periphery of the cutting wheel. The extinguishers were equipped with Bete spiral nozzles which proved to be satisfactory. Hybrid mixtures of Halon 1301 and Purple-K were used because of their previously proved superiority. Each extinguisher contained 10 lb of Halon and 10 lb of the dry powder. This combination was used

TUNNEL BORING MACHINE

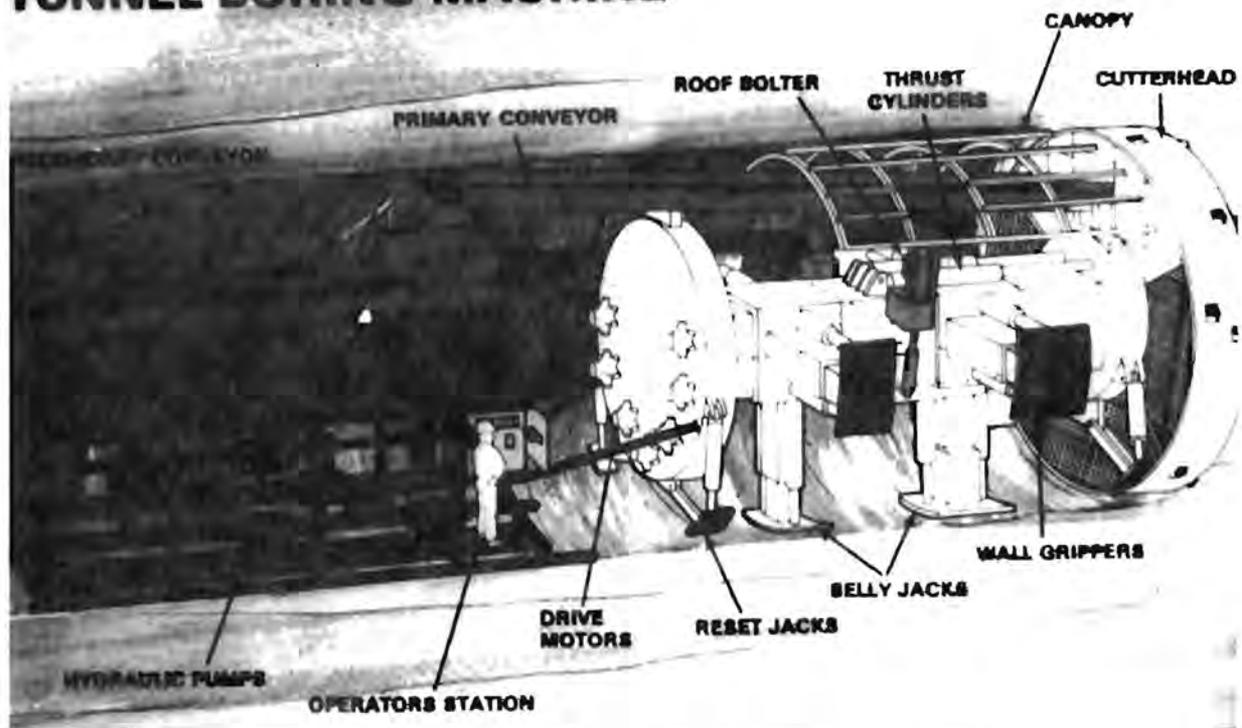
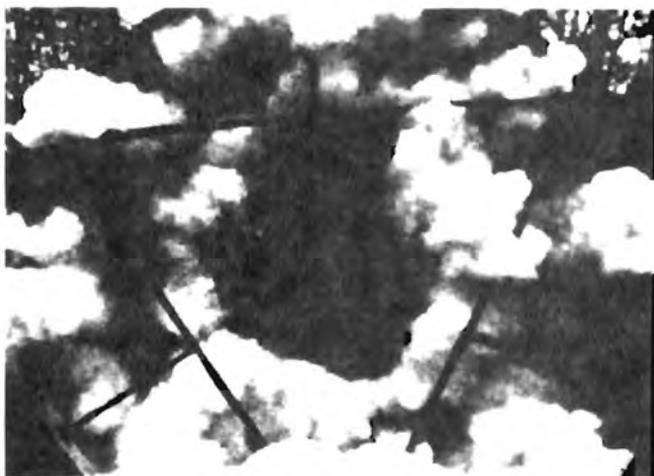


FIGURE 7. - Perspective view of a tunnel boring machine.

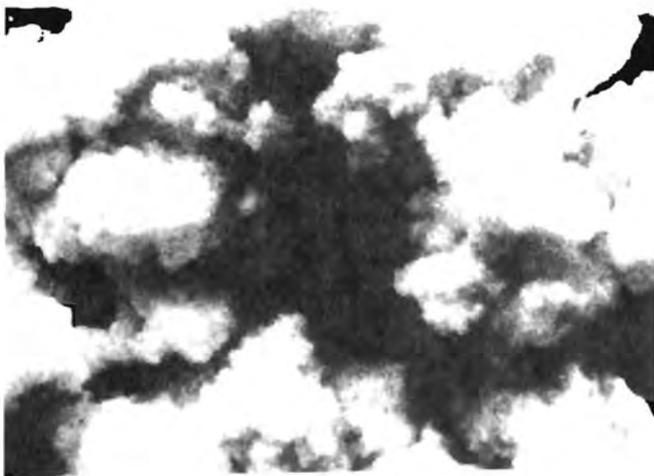
⁷Uthus, D. B., and T. J. Crocker. Application of Tunnel Boring Machine to Coal Mine Entry Development. Proc. AIME, Rapid Excavating and Tunneling Conf., Las Vegas, Nev., June 14-17, 1976, pp. 185-212.



155 msec



300 msec



435 msec

FIGURE 8. - Sequential scenes of quenching test with full-scale mock-up of the tunnel-boring machine cutterhead.

rather than Halon and water because the latter combination could present corrosion problems. Work is underway to define suitable extinguisher hardware for the Halon 1301-water system.

Results of the full-scale tests indicated that eight extinguisher units were adequate for quenching 8 pct methane-air ignitions. However, for 9 pct methane-air mixtures, an additional extinguisher was necessary particularly if ignition occurred near the top rim of the cutting wheel; this area was shielded by a conveyor hopper, and it was the most difficult area to protect. Figure 8 shows the successful quenching of a 9-pct methane-air ignition. This quenching was achieved under a simulated ventilation condition in which the flammable mixture was circulated at a velocity of approximately 200 ft/min. The turbulent conditions in the quenching tests were probably more severe than those generally expected in the tunnel-boring machine application.

These experiments demonstrated that the ignition-quenching device can be technically and practically feasible for mine applications where the spatial or geometrical limitations are not a problem.

CONCLUSIONS

This research has proved the feasibility of the mine ignition-quenching device where the devices can be practically installed on the mining machine, such as a large tunnel-boring machine. The developed technology provides valuable design guidelines and solves many of the major problems visualized at the time of the Coal Mine Health and Safety Act of 1969 for adapting such devices to mining machines. General design guidelines are given for each of the three main components of the ignition-quenching device (1) flame-detection unit, (2) extinguishing system, and (3) extinguishant dispersal system. These guidelines indicate that an UV-type flame detector provides adequate response, hybrid agents of Halon 1301, and dry chemical (for example, KHCO_3) or water are highly effective. An explosive actuated dispersal system is necessary to insure the rapid extinguishment required. Also, toxicity of the extinguishants is not a serious problem if the quenching device is effective; that is, the flame diameter is small during extinguishment.

Although the results demonstrated that a technical and practical feasible quenching device was possible for a tunnel-boring machine, only a technical success was obtained in the Lee Engineering contract work with continuous miners. However, the application of the superior hybrid agents was not investigated in the latter work. Furthermore, it is important to determine whether spatial limitations can be overcome to permit the installation of quenching devices on the continuous miners. Therefore, our immediate objective will be to explore the possibility of incorporating the quenching device into the design of a continuous miner. It is anticipated that this will be achieved under a contract design study with the equipment manufacturers. At the same time, the Bureau will continue research on hybrid agents to determine extinguishant options for the ignition-quenching device.

COAL DUST EXPLOSION BARRIERS

by

T. Liebman¹ and J. K. Richmond¹

ABSTRACT

The Bureau of Mines is conducting research to develop passive and triggered barriers to be used for protection against coal dust explosions. Commercially available passive water barriers were found adequate for defense against moderate strength explosions, but failed, however, when the explosion propagated at speeds less than 76 m/sec. To expand the useful range of the passive barrier, the Bureau developed novel barriers for suppressing slow moving explosions traveling at speeds as low as 30 m/sec. A plan was written to install a passive barrier system in a working mine on a trial basis.

Two triggered barrier systems were tested against dust explosions. One uses a Cardox cylinder to discharge the suppressant, and the other uses low-pressure gas to power the disperser. Both systems have been demonstrated to be capable of suppressing coal dust explosions. The relative effectiveness of many extinguishing agents and the optimum conditions for explosion suppression were investigated. It is anticipated that a triggered barrier system will be introduced into a working mine on a trial basis within the near future.

INTRODUCTION

Coal dust explosions are a hazard in underground coal mining operations. The spreading of rock dust on mine surfaces to inert the coal dust has been the traditional means of controlling such hazards in U.S. mines. However, effective rock dusting is not feasible in a number of mine regions. Seven such potentially dangerous areas are (1) conveyor beltways, (2) transfer points, (3) wet roadways, (4) parked mine cars, (5) return airways, (6) longwalls, and (7) isolated sections. To augment current protection against explosions, the Bureau of Mines is conducting research to develop passive and triggered explosion barriers to be used as a supplement to rock dusting in these probable hazardous mine regions.

PASSIVE WATER BARRIERS

The passive water barrier, as tested and used abroad, is made up of numerous water-filled containers mounted in the vicinity of the mine roof. During a coal dust explosion, the dynamic wind pressures induced ahead of the propagating flame tilt or fragment the water containers to release and disperse the water, which acts to suppress the oncoming flame. However, foreign research indicates that the effectiveness of the passive water barrier is limited to moderate-strength explosions; the barrier fails when the explosion is weak

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because the wind forces are insufficient for fracturing or tipping the water containers.^{2 3} The studies also show that the barriers are ineffective when positioned at distances closer than about 60 m from the explosion initiation. In recent work conducted at the Bureau of Mines,⁴ a German-made water barrier (80-liter capacity, made of polyvinyl chloride [PVC]) was tested against coal dust explosions and found to be efficient in suppressing dust explosions propagating at speeds of 76 to over 300 m/sec. However, weak explosions propagating at less than 76 m/sec were not stopped. To expand the range of effectiveness of the passive water barrier system, the Bureau recently developed water barriers that operate during low-speed explosions and are described in another report.⁵ The minimum quantity of water in the passive water barrier necessary to stop explosions in the Bureau's Experimental Mine (5.3 m² cross section) was 80 kg (15.1 kg/m² of cross section).

On the basis of experience with passive water barriers and the considerable knowledge gained from researchers abroad, a trial passive water barrier installation is being planned in U.S. mines.⁶ The initial plan is to install a barrier system on a belt conveyor road just outby a loading station. This would protect the beltway from explosions originating prior to or in the loading zone. The barrier would begin just outby the loading region and consist of at least four rows of tubs. Each row is to be one crosscut apart and located near the center between two crosscuts. The quantity of water in each row of tubs would be equal to at least 26 l/m² of roadway cross section. As the section advances, new rows of tubs would be erected and the tub rows farthest outby can be removed.

TRIGGERED BARRIERS

Triggered barriers are a recent innovation. Research efforts are presently in force in the United States and abroad to develop prototypes. The triggered barrier typically consists of three components (1) a flame or explosion sensor, (2) a disperser, and (3) an extinguishing agent. The sensor is an optical, mechanical, or electronic device which activates or triggers the dispersal unit to rapidly expel the extinguishant. The extinguishant can be gas, liquid, or powder and it is contained in the disperser under a stored force. The sensor is located some distance from the dispersal unit to provide sufficient time for the dispersion of the extinguishing agent prior to flame

²Fischer, D., and H. Meerbach. New Tests With Water and Stone--Dust Barriers. 12th Internat. Conf. of Mine-Safety Res. Est., Dortmund, Germany, Sept. 11-15, 1967, No. 41, 29 pp.

³Meerbach, H. Investigations of the Development and Control of Coal Dust Explosions in Very Wide, Low Gate Roads. Internat. Conf. of Mine-Safety Res. Est., No. 138; Donetsk, Russia, June 15-18, 1971, 19 pp.; SMRE Trans. No. 5934.

⁴Liebman, T., and J. K. Richmond. Suppression of Coal-Dust Explosions by Passive Water Barriers in a Single-Entry Mine. BuMines RI 7815, 1974, 34 pp.

⁵Liebman, I., J. Corry, and J. K. Richmond. Water Barriers for Suppressing Coal Dust Explosions. BuMines RI 8170, 1976, 26 pp.

⁶Work cited in footnote 5.

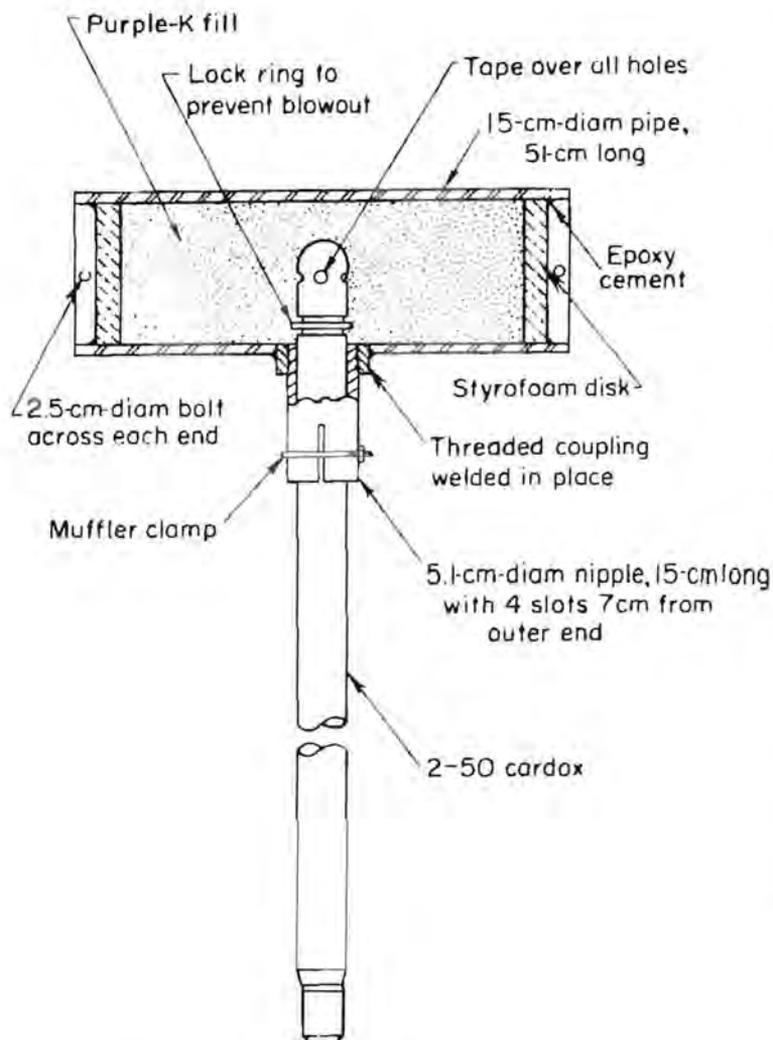


FIGURE 1. - Cardox triggered barrier disperser.

Cardox⁷ Purple-K (KHCO_3) extinguishant device that was used to suppress float coal dust explosions under a variety of conditions.⁸ Two facilities were used in the NSWC explosion suppression tests 1.4-m-wide by 97-m-long metal gallery, and a 762-m-long conical shock tube ranging in diameter from 0.4 m at its closed end to 7.3 m at the opening. One of the Cardox disperser units used in this study is shown in figure 1. The high-pressure carbon dioxide gas (about 1,000 atm) developed by the Cardox ejects the suppressant contained in the pipe in opposite directions to reduce recoil. The pipe holds 10 kg of Purple-K.

arrival at the barrier site. The triggered barrier is superior to the passive system in that the extinguishant can be discharged at an optimum time, and thereby it can be used more efficiently; dispersion of the material does not depend on the explosion-induced wind forces. Triggered barriers are expected to be most appropriate in low-coal operation where there is insufficient head room for passive barriers. The passive barrier, requiring explosion-induced wind forces for operation, is limited to use in open regions of the roadway and as such would interfere with operations in crowded mine regions. The triggered barrier, however, is not subject to this limitation and can be used in all regions of a mine.

CARDOX SYSTEM: NAVAL SURFACE WEAPONS CENTER STUDY

The Naval Surface Weapons Center (NSWC) at Dahlgren, Va., developed a barrier system based on a

⁷Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

⁸Lull, D. D., L. D. Johnson, T. F. Morris, and J. A. Canfield. Final Report on Development of a System To Suppress and Extinguish Fully Developed Coal Dust Explosions. NSWC Tech. Rept. TR-3151, February 1975, 214 pp.

A number of tests in the 1.4-m-wide gallery, and in the conical shock tube, showed that maximum efficiency of the Purple-K powder was attained when the material was delivered directly onto the flame. The tests also indicated that the amount of Purple-K dust necessary to halt an explosion in a large-scale facility is comparable with the amount of dust needed in rock dust barriers.^{9, 10}

CARDOX SYSTEM: BUREAU STUDY

The Bureau continued the triggered barrier study using the Cardox system developed by the NSWG. The explosion suppression tests were conducted in the main entry of the Bureau's Experimental Mine at Bruceton, Pa. This is a single 396-m-long entry having an average cross section of about 5.3 m². The entry is instrumented with optical flame sensors, static pressure transducers, pitot probes, and drag probes. A complete description of the mine and instrumentation is given elsewhere.¹¹ Explosion initiation was accomplished by igniting a 6.5-pct natural gas-air mixture confined to the first 3 m from the face by a thin plastic diaphragm. In the next 3 m of entry--the booster zone--2.3 kg of pure Pittsburgh pulverized coal (PPC) dust was spread on two roof shelves. The test zone consisted of a PPC coal-rock dust mixture distributed from the end of the booster zone towards the portal with the mixture extending to or past the barrier site. The coal-rock dust test zone contained 65 to 67 pct inert coal rock dust. The weight of coal dust in the mixtures spread in the mine was sufficient to yield a concentration of 300 mg/l if dispersed uniformly throughout the entry cross section. Explosion tests in the mine, without barriers, indicated that the explosion will propagate two to three times the length of the test zone.

The barrier consisted of two to six Cardox units containing either Purple-K or water and placed on opposite ribs of the entry (fig. 2) 1.5 m apart starting 99 m from the face. These Cardox devices were modified versions of those in figure 1 in which the horizontal pipe containing the extinguishant was bent at its center to permit the material to exit at each end at an angle of 12° from the rib. The units were triggered by an infrared optical flame sensor placed upstream of the barrier site (either 84 or 91 m from the face); the flame sensor tripped a relay to fire the Cardox ignitor.¹² The time of extinguishant discharge start was noted by a break wire attached to each Cardox outlet. Preliminary tests showed the Cardox unit began to discharge the

⁹Grumer, J. Recent Research Concerning Extinguishant of Coal Dust Explosions. 15th Internat. Symp. on Combustion, the Combustion Institute, Pittsburgh, Pa., 1975, pp. 103-114.

¹⁰Rae, D. Experimental Coal-Dust Explosions in the Buxton Full-Scale Surface Gallery. SMRE Tech. Paper P7, 1973, 71 pp.

¹¹Work cited in footnote 4.

¹²The Bureau has also developed a triggering system using a pressure-arming device and a dual infrared optical flame sensor combination. The pressure-sensing element prevents false triggering by switching on battery power when the static pressure rises about 3.5 kN/m²; each flame sensor views a separate narrow vertical field approximately 25" apart and must operate in coincidence to turn on a firing relay.

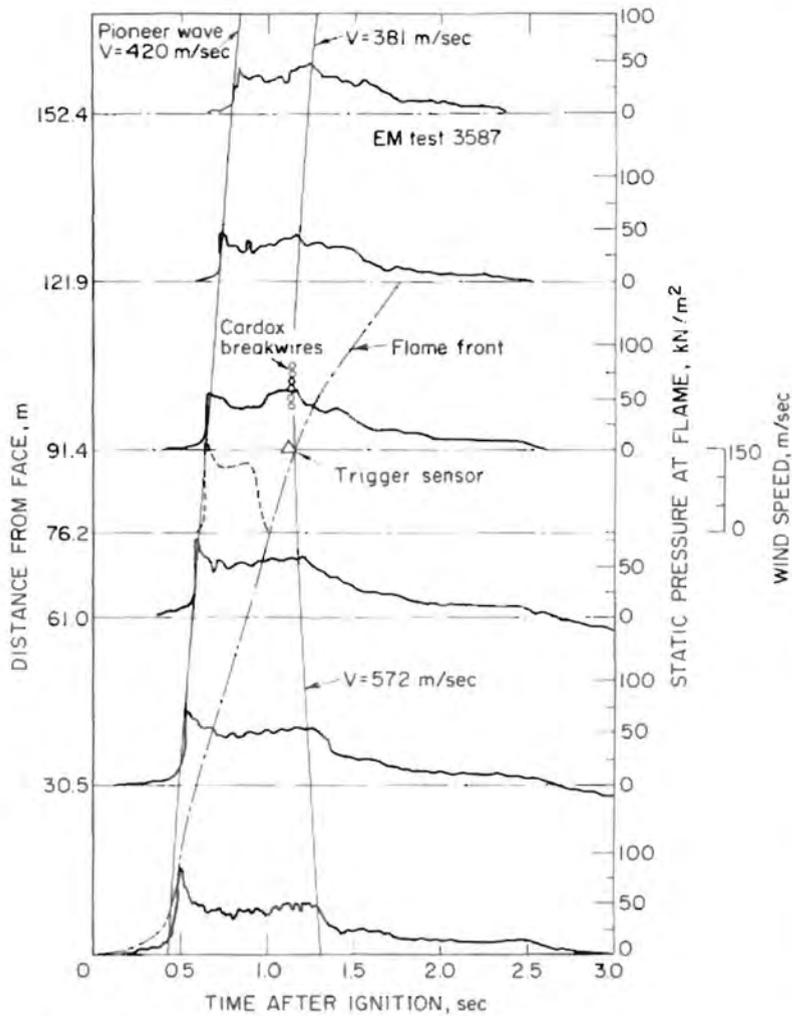


FIGURE 2. - Cardox barrier mounted near rib of Experimental Mine.

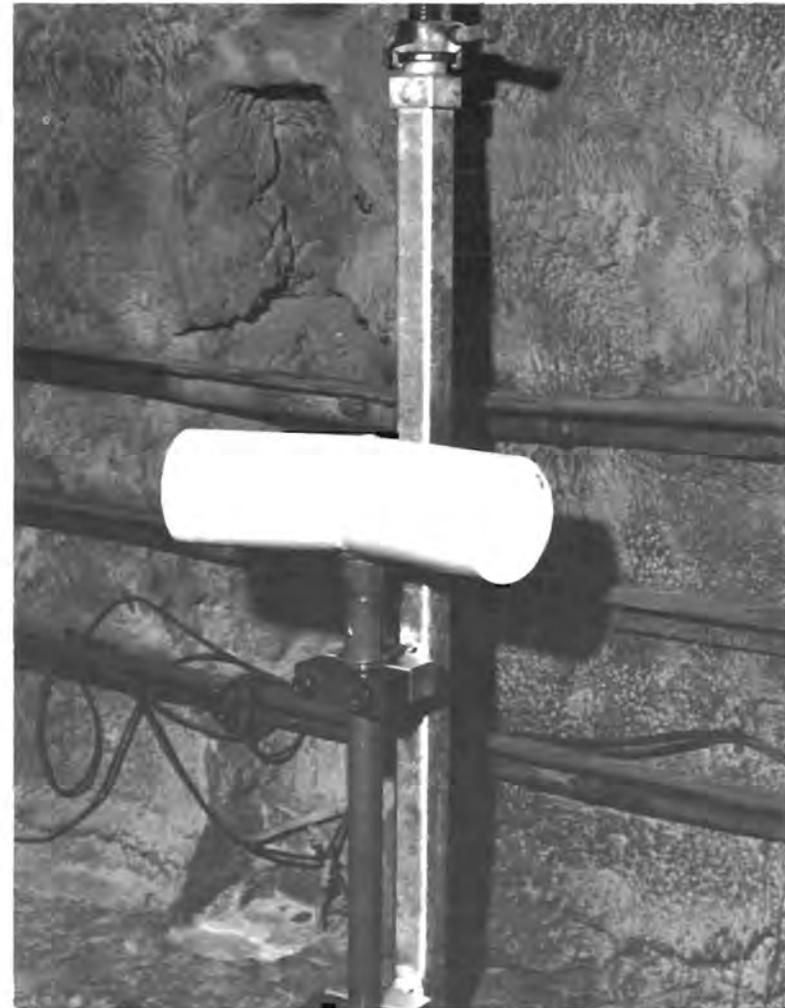


FIGURE 3. - Wave diagram of coal-dust explosion and suppression by six Cardox dispersers placed 99 to 107 m from mine face. EM test 3587.

extinguishant about 25 msec following the triggering pulse, and the extinguishant cloud filled the mine cross section in an additional 30 to 50 msec. Time for most of the material to be expelled from the barrier was estimated to be less than 50 msec.

The objective of the tests were to determine the effectiveness of the Cardox system against dust explosions, the relative effectiveness of Purple-K against water, the minimum quantity of extinguishant required for suppression, and the optimum time for extinguishant discharge. Test variables were the type and quantity of extinguishant, and the time interval between extinguishant discharge and flame arrival at the barrier.

A wave diagram illustrating explosion extinguishment and its effect on flame and pressure development is shown in figure 3; particular attention should be given to the strong compression waves driven in both directions from the vicinity of the barrier site generated by the sudden deceleration and suppression of the flame. Test conditions and results for all the tests are summarized in table 1. For similar test conditions, without a barrier, the flame was always observed to go beyond the last optical flame sensor located 198 m from the face. In the remarks section of table 1, "no suppression" is indicative of a test in which the flame propagates beyond this point. In the tests interpreted as "explosion suppressed" the flame was not observed to propagate past a flame sensor located 122 m from the face (18 m beyond the barrier), whereas tests in which the flame was stopped past the 122-m location but before 198 m were arbitrarily chosen to be "marginal suppression." In test 3587, 60 kg of Purple-K was necessary to suppress the explosion rapidly. In tests 3585 and 3588, 40 kg of material resulted in a marginal suppression, and in test 3589, 20 kg had little effect on the explosion. The optimum time to discharge the powder is about 50 to 100 msec prior to flame arrival (tests 3587 and 3588); this agrees with the NSWG study that the dust should be injected onto the flame for maximum efficiency. When the dust is released prematurely (tests 3585-3586), the flame must propagate some distance past the barrier to reach the extinguishant cloud. The short discharge time (less than 50 msec) inherent to the Cardox seems to be the principal reason for the brief time requirements between extinguishant release and flame arrival. Since exact timing would be impossible to achieve for a wide range of explosion speeds, an effective Cardox barrier must be redundant and consist of many units to cover a considerable length of entry. Table 1 shows that water is at least as effective as Purple-K.

TABLE 1. - Summary of explosion suppression tests in EM with Cardox dispersers

Test No.	Length of test zone, m from face	Extinguishant	No. of Cardox units ¹	Distance of barrier from face, m	Distance of trigger sensor from face, m	Interval, ² sec	Flame speed at barrier site, m/sec	Remarks
3585	107	Purple-K	4	99 to 104	84	0.36	101	Marginal suppression, flame to 152 m.
3586	107	...do...	6	99 to 107	84	.18	152	Marginal suppression, flame to 162 m.
3587	107	...do...	6	99 to 107	91	.10	140	Explosion suppressed, flame to 122 m.
3588	107	...do...	4	99 to 104	91	.05	149	Marginal suppression, flame to 137 m.
3589	107	...do...	2	99 to 102	91	.10	156	No suppression, flame past 198 m.
3590	107	Water...	4	99 to 104	91	-	-	Explosion suppressed, flame to 122 m.
3591	107	...do...	2	99 to 102	91	.10	110	Marginal suppression, flame to 137 m.
3594	107	...do...	2	99 to 102	91	.10	110	Do.
3595	107	Purple-K	2	99 to 102	91	.08	158	No suppression, flame past 198 m.

¹Each Cardox is filled with 10 Kg of extinguishant.

²Time from the beginning of extinguishant discharge to flame arrival at barrier site, measured at the front of the barrier.

LOW-PRESSURE-POWERED DISPERSER

The Cardox develops considerable pressure forces and would be hazardous to mine personnel in its immediate vicinity if triggered inadvertently. Therefore, this device cannot be considered for use in underground mines without modification. Prior to making this effort, it was convenient to conduct experiments with a low-pressure-powered disperser. This disperser (fig. 4) is part of a Fenwal explosion protection system and is readily controlled to yield low external forces and longer discharge times than the Cardox system. The spherical vessel is approximately 33 cm in diameter and was found to operate satisfactorily when 70 pct filled with water or completely filled with Purple-K with the void space pressurized with a gas. The material was released at the base of the vessel through a 7.6-cm-wide burst diaphragm (detonator operated) and then exited through a multihole nozzle or a 7.6-cm-wide pipe. Peak pressures averaged over the spray cross section and measured



FIGURE 4. - Low-pressure-powered disperser.

90 cm in front of the nozzle during discharge of water from a Fenwal vessel pressurized to $1,380 \text{ kN/m}^2$ did not exceed 2 kN/m^2 ; such pressures could be tolerated by personnel if the disperser were accidentally fired. Tests indicated that discharge began about 15 msec following an electrical pulse to the detonator, and the majority of water or dust was released in about 0.2 sec for the nozzle and less than 0.15 sec for the 7.6-cm-wide pipe exit.

In explosion suppression trials in the main entry of the Experimental Mine, two spherical vessels were positioned on opposite ribs at 99 and 101 m from the face with the trigger (flame) sensor located upstream at either 72 or 87 m. Preparations for the explosions were similar to those in previously described Cardox tests--the test zone now being PPC mixed with 65 pct rock dust spread along the entry to 107 m from the face.

Table 2 shows the test

results. In test 3617, less than half of the water was injected in front of the flame and the explosion was stopped; whereas in test 3618 using Purple-K and about the same initial conditions, the explosion was not suppressed. For tests 3624 to 3626, an attempt was made to increase the Purple-K concentration in the entry by increasing the quantity of dust in the vessels and decreasing the discharge time (outlet changed from nozzle to pipe). Practically all the dust was released immediately behind the flame front (test 3625), and the explosion continued to propagate past 198 m. In test 3626, all of the dust was injected immediately prior to the flame front, and suppression was still not attained. The barrier was accidentally triggered (not caused by any reaction within the mine) after completing preparations of the entry for explosion test 3624; the extinguishant powder was carried along the entry to form a layer on the coal-rock dust mixture spread on the mine floor and rib-roof and it extended from 77 to 107 m from the face. The dust explosion, initiated an hour later, propagated past the last flame sensor at 198 m without any

appearance of being influenced by the extinguishant powder. Suppression of explosion was again obtained with only 27 kg of water (test 3627), whereas for similar test conditions (nozzle and discharge time) and for 41 kg of Purple-K (test 3629), suppression was not achieved.

TABLE 2. - Summary of explosion suppression tests in EM with nitrogen gas-powered disperser

Test No.	Length of test zone, m from face	Extinguishant, ¹ total quantity	Discharge outlet ²	Distance of barrier from face, m	Distance of trigger sensor from face, m	Interval, ³ sec	Flame speed at barrier site, m/sec	Remarks
3617	107	Water 27 kg.	Nozzle.	99 to 101	87	0.06	169	Explosion suppressed, flame to 122 m.
3618	107	Purple-K, 27 kg.	...do..	99 to 101	87	.06	183	No suppression, flame past 198 m.
3624 ⁴	107	Purple-K, 41 kg.	Pipe...	99 to 101	-	-	-	Do.
3625	107	Purple-K, 41 kg.	...do..	99 to 101	87	.02	165	Do.
3626	107	Purple-K, 41 kg.	...do..	99 to 101	72	.14	189	Do.
3627	107	Water, 27 kg.	Nozzle.	99 to 101	72	.21	189	Explosion suppressed, flame to 122 m.
3629	107	Purple-K, 41 kg.	...do..	99 to 101	72	.27	122	No suppression, flame past 198 m.

¹ Two barrier units mounted on opposite ribs, each containing equal quantity of extinguishant.

² Extinguishant discharged through a 10-cm-wide multihole nozzle or a 7.6-cm-wide pipe outlet.

³ Time from beginning of extinguishant discharge to flame arrival at barrier site.

⁴ Extinguishant accidentally discharged prior to initiating explosion in test 3624.

Table 2 shows that the time interval between barrier discharge and flame arrival is not a critical factor for the case of water; it is observed to range from 0.06 to 0.21 sec without a loss in barrier efficiency. Also, water seemed to be significantly superior to Purple-K in this trial series. The excellent success obtained in test 3617 may indicate that optimal conditions are obtained when a portion of the water is injected after flame arrival. Comparing tables 1 and 2, it seems that Purple-K has a higher degree of effectiveness when used in the Cardox system. This may be attributed to the increased Cardox barrier length, the increased quantity of powder (test 3587),

and probably of greater importance, the extremely high discharge rate of the Cardox system. The last factor would decrease the time to fill the entry cross section with a higher concentration of extinguishant. Why water performed better than Purple-K in these trials is not clear.

Pure PPC was used in the test zone for the next series of explosion suppression experiments. This was expected to increase the flame temperature over that obtained with the previous coal-rock test zone and in turn increase the efficiency of the Purple-K suppressant. The relative effect of water, Halon 1301 (CF_3BR), and hybrid extinguishing agents (aqueous foam solution or water combined with Halon 1301) was also examined. These hybrid mixtures had previously been shown to be excellent suppressants against gas flames. Preparation for the explosions were similar to previous trials except for the substitution of pure PPC in the test zone using a nominal dust concentration of 75 mg/l. Two Fenwal vessels containing the suppressants were again positioned on opposing ribs of the mine entry, and the infrared trigger sensor was placed 11 to 21 m in by; table 3 summarizes the results. The Fenwal vessels were pressurized with either nitrogen (1,400 to 2,000 kN/m²) or Halon 1301 (vapor pressure 1,350 to 1,450 kN/m²). A pipe discharge outlet was used in the trials with Purple-K to obtain high discharge rates shown to be an important factor in suppressant effectiveness in the Cardox trials. Results of the first three trials of table 3 (two marginal and one successful suppression) is a much better record for Purple-K than noted in the trials of table 2. However, the following test 3727 shows that less than half of the weight of water has an equal or greater suppressant effect. This confirms previous observations that Purple-K is inferior to water as a suppressant of coal dust explosions. Decreasing the water quantity in test 3694 of table 2 resulted in a marginal suppression indicating this to be a minimal amount of water. The failure of test 3723 is attributed to an electronic error resulting in a zero time interval. The two hybrid combinations (tests 3724 and 3725) and pure Halon (test 3728) stopped the flame at 122 m versus 107 m for water (test 3727). Since equal weights of extinguishants were used in all four tests, it would appear that the hybrids and pure Halon are no better than just water.

TABLE 3. - Summary of explosion suppression tests with nitrogen or halon powered disperser

Test No.	Length of test zone, ¹ m from face	Extinguishant and pressure agent ²	Discharge outlet	Distance of barrier from face, m	Distance of trigger sensor from face, m	Interval, sec	Flame speed at barrier site, m/sec	Remarks
3679	49	Purple-K, 36 kg--N ₂	Pipe.....	32 to 34	21	0.09	138	Marginal suppressed, flame to 61 m.
3681	95	Purple-K, 36 kg--N ₂	...do....	32 to 34	21	.10	112do.....
3682	95	Purple-K, 36 kg--N ₂	...do....	32 to 34	21	.12	64	Suppression, flame to 33 m.
3727	104	Water, 15 kg--N ₂ ...	Nozzle...	99 to 101	76	.13	143	Suppression, flame to 107 m
3694	95	Water, 13 kg--N ₂do....	99 to 101	76	.08	183	Marginal suppressed, flame to 152 m.
3723	105	Foam, 10 kg; Halon, 5 kg.	...do....	99 to 101	79	.0	168	No suppression, flame beyond 198 m.
3724	104	Foam, 10 kg; Halon, 5 kg.	...do....	99 to 101	76	.15	91	Suppression, flame to 122 m
3725	104	Water, 10 kg; Halon, 5 kg.	...do....	99 to 101	76	.16	137	Do.
3728	104	Halon, 15 kg.....	...do....	99 to 101	76	.14	107	Do.

¹Test zone--pure PPC, 75 mg/l nominal loading.

²Two barrier units on opposite mine ribs. Total quantity of extinguishant listed. N₂ pressure 1,400 to 2,000 kN/m². Halon vapor pressure 1,350 to 1,450 kN/m².

SUMMARY AND CONCLUSIONS

Commercial passive water barriers were tested and found effective in stopping moderate strength coal dust explosions; they failed, however, for explosions propagating at less than 76 m/sec. To extend the range of effectiveness of the passive barrier, novel barriers were developed and shown to be efficient in suppressing weak explosions propagating at speeds as low as 30 m/sec.

Two triggered barrier systems were investigated. One barrier uses a Cardox cylinder to propel the extinguishant, and the second system used pressurized nitrogen gas or Halon 1301 to power the disperser. With the former barrier, 40 kg of water or 60 kg of Purple-K (KHCO_3) was sufficient to suppress coal dust explosions propagating in a mine entry of 5.3 m² cross section. In the nitrogen powered barrier, as little as 15 kg of water or 36 kg of Purple-K was required to stop an explosion. The time interval between barrier discharge of the extinguishant and the flame arrival at the barrier site is not a critical factor for water as it is for Purple-K; the latter effectiveness is maximized when the powder is injected onto the flame. Relative to weight of extinguishant required for explosion suppression, the tests indicated water is more than twice as effective as Purple-K and at least as effective as hybrid mixtures (aqueous foam solution combined with Halon 1301) or pure Halon.

Low cost is the principle advantage of the passive barrier over the triggered system. However, the passive barrier is restricted to use in open regions of the mine because it depends wholly on wind forces for the operation and dispersion of the extinguishant. In addition, it is not effective when positioned too close or too far from the explosion initiation; therefore, the system must be redundant using many units to protect an entry. The triggered barrier is superior to the passive in that the extinguishant can be discharged at an optimum time and thereby be used more efficiently. Therefore, this barrier can be smaller and use fewer units. Since wind forces are not essential for operation, the triggered barrier is applicable throughout the mine and can be placed in crowded mine regions without interfering with mining operations.

Because of the hazards associated with the Cardox barrier and the good results obtained with the low-pressure nitrogen powered dispersal unit, the latter system is the most attractive prototype. There is little doubt from the present study that water is superior to Purple-K as an extinguishant. A recent but still incomplete study of additional powder extinguishing agents indicate that materials such as NaCl, KCl, and $\text{NH}_4\text{H}_2\text{PO}_4$ may be equal or better than water in suppressing coal dust explosion. However, the corrosive nature of these materials and the increased costs would prohibit their use over water.

REMOTE SEALING SYSTEM FOR EXTINGUISHING COAL MINE FIRES

by

Roger L. King¹

ABSTRACT

This paper describes a feasible remote sealing system that has evolved from the Bureau's sponsored research on the extinguishment of coal mine fires. The complete system includes (1) a sonar probe and close circuit television camera for initial probing of the mine entry to be sealed, (2) a fly ash or fly ash-cement system for constructing the seals, (3) a froth foam topping system for completing each seal, (4) a combustion-type inert gas generator for conveying the fly ash and inerting the sealed area, and (5) acoustical equipment for determining the completion and integrity of a seal. Design requirements are briefly summarized for the currently developed remote sealing system. In addition, field problems are reviewed from the performance of a prototype system that was used in a mine fire situation.

INTRODUCTION

Uncontrolled coal mine fires are of great concern to the mining industry because they cannot be directly extinguished, and because they may require such drastic action as sealing the entire mine. The conventional practice of constructing air-tight stoppings from within the mine is difficult and can involve a high fire or explosion risk; therefore, this approach cannot always be relied upon. In search of a more desirable approach, the Bureau of Mines explored the concept of remote sealing from the surface and found fly ash to be a suitable sealant for this purpose.² This technique minimizes the risk to the firefighter, it limits the sealing to the established fire area, and it expedites the mine recovery operation, thus reducing potential costs and production losses. This paper describes a complete remote sealing system

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²Murphy, E. M., M. O. Magnuson, P. Suder, Jr., and J. Nagy. Use of Flyash for Remote Filling of Underground Cavities and Passageways. BuMines RI /214, 1968, 27 pp.

that has been developed under Bureau-sponsored contracts^{3 4} and the results obtained with a prototype system in a mine fire situation. The system is designed for mine depths of up to 1,500 feet (457 m).

THREE PHASES OF REMOTE MINE SEALING

The remote sealing of underground coal mine fires requires considerable planning to resolve any logistic and site preparation problems and to insure that all the operational phases are properly coordinated. Figure 1 shows three

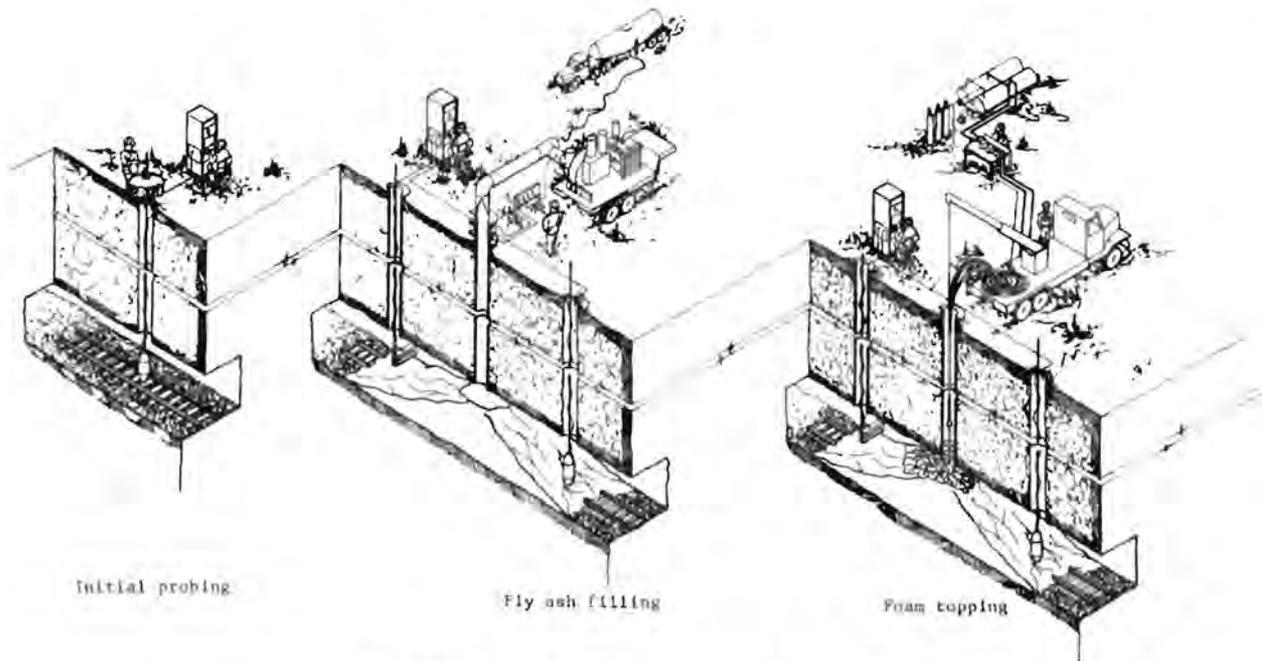


FIGURE 1. - A remote mine sealing system.

³Berry, D. R., K. Maser, D. A. Monaghan, and A. R. Guzdar. Technical Report for Extinguishing Coal Mine Fires by Remote Sealing (Research Contract H0122046 by Foster-Miller Associates, Inc.). BuMines Open Fire Rept. 77(2)-75, 1973, 504 pp.; PB 245 899/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

⁴Monaghan, D. A., A. R. Guzdar, and D. R. Berry. Final Technical Report. Joanne Mine, Remote Sealing Operation (Research Contract H0144004 by Foster-Miller Associates, Inc.). BuMines Open File Rept. 55-77, 1975, 224 pp., PB 265 545/AS; available for consultation at Bureau of Mines facilities in Denver, Colo., Twin Cities, Minn., Bruceton and Pittsburgh, Pa., and Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

main phases of the sealing operation: initial probing, fly ash filling, and foam topping. Initially, a borehole is drilled through which a probe is lowered to determine the geometry or nature of the passageway to be sealed; the borehole (≥ 15 cm or 6 inches wide) must be cased and grouted to prevent water seepage and subsequently serves as a sealant borehole. In the second phase, the passageway is filled with the fly ash bulk sealant that is pneumatically transported from a supply truck on the surface; two adjacent boreholes are drilled prior to this stage for deployment of acoustical equipment that is used to monitor the formation of the gross fly ash seal. In the final phase, a froth foam topping is added to fill the crater formed by the fly ash and to complete the seal; the foam is formed in place at the bottom of the borehole. This system also includes an inert gas generator which is used to minimize the explosion hazard during the fly ash filling phase and to inert the sealed area of the passageway. In addition, a modified fly ash mixture was found necessary if a watertight seal is required. All of the systems are mounted on skids or trailers.

Generally, the greatest amount of time is involved in drilling the boreholes. Thus, accurate mine maps are essential to avoid "blind" or unsuitable borehole sites. The sealant boreholes should be located midway between two crosscuts of a passageway and where the overburden is least and where overcasts are not present.

System Descriptions

Initial Probing System

The initial or preliminary probing system that was designed for this application consists of a downhole probe assembly, a deployment system, and a control console, as shown in figure 2. The downhole probe assembly includes a low light level, closed-circuit television (CCTV) camera for visual observation of the downhole conditions, and a sonar ranging device for accurately determining dimensions of the passageway or distances to large objects. It is also equipped with a rotator to facilitate scanning and a

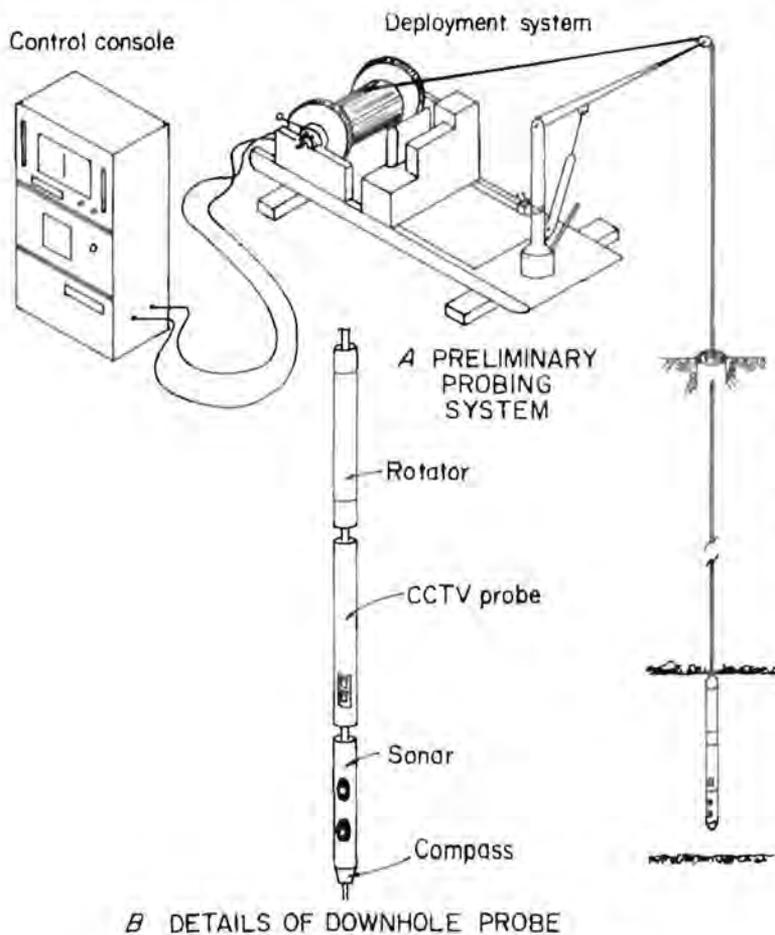


FIGURE 2. - An initial probing system.

remote reading compass for establishing probe orientation. The probing information is useful for determining suitability of borehole locations, sealing material requirements, potential obstructions to sealing, and reliability of mine maps and engineering surveys at the surface.

The probe is deployed into the passageway using an electromechanical cable and a hydraulic winch that is driven by either a gasoline engine or an electrical motor; the winch has a 1,500-foot deployment capability at speeds of at least 100 ft/min (30 m/min). After the probe is oriented in a known direction, the sonar unit transmits ultrasonic pulses and picks up reflections from objects in front of it. The probe is rotated 360° at various elevations to obtain a complete mapping of the passageway by the sonar measurements and the television camera. This downhole information is transmitted to the control console which includes a CCTV monitor, a sonar readout panel that displays probe to target distance, a rotator control, and a digital readout of the remote reading compass.

The sonar probing unit is capable of locating objects in a mine at distances up to 30 feet (9 m), whereas the CCTV camera can view objects up to 200 feet (61 m) away. In a mine fire situation, the smoke density will limit the effectiveness of the latter unit. This probing system has been certified as explosionproof and can be used in gassy mines.

Acoustic Seal Checking System

Another instrumentation system that is vital to the success of the remote sealing operation is one that monitors the filling of the mine passageway and determines the integrity of the seal. The system developed in this work uses acoustic devices, namely a high-intensity speaker and a sensitive microphone. As shown in figure 3, the speaker and microphone probes are lowered into boreholes that are on opposite sides of the sealant borehole. These probes are usually at least 50 feet (15 m) from the seal being constructed and they are deployed by winch systems similar to those used for the initial probing system.

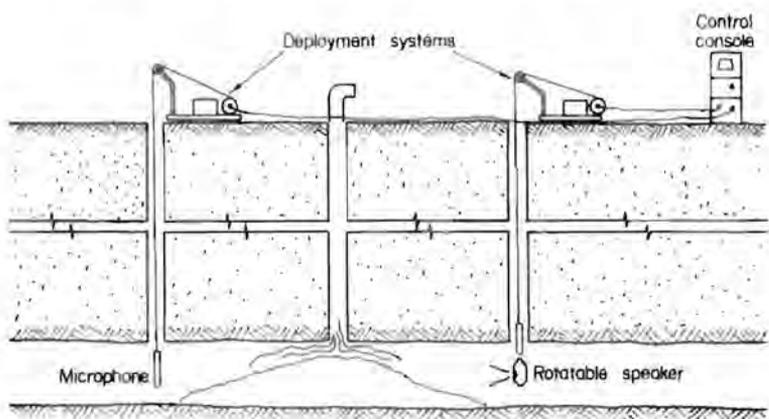


FIGURE 3. - An acoustic seal checker system in operation,

The theory of operation is based on the proved premise that a decrease in the level of signal received by the microphone is proportional to a decrease in the open area of the passageway being sealed. In this system, the speaker probe transmits an amplified noise pulse from a random noise generator which is then picked up by a ceramic-type microphone probe and transmitted to a sound level meter in the control console. A signal processing

module subtracts any background noises. The signal is then displayed in the control console and correlated with existing information to define the completeness of the seal. Sensitivity of the seal checking system is greatest as the seal nears completion (>99 pct). Both microphone and speaker units are intrinsically safe.

Fly Ash System

Fly ash is used as the bulk sealant material because it is incombustible and relatively inexpensive, it is readily fluidized for pneumatic transport, and it is effective in conjunction with a froth foam topping. This material also normally displays little shrinkage upon wetting, although erosion or leakage paths can develop when a fly ash seal is subjected to certain water pressures. A fly ash-bentonite-portland cement combination has been found to be more effective than fly ash alone in providing a watertight seal. Use of this combination requires only a simple modification of the fly ash deployment system described herein.

The main components of the current fly ash system are fly ash supply trucks, a diesel-driven blower, liquid nitrogen supply tankers to provide an inerting medium, and a plumbing network with instrumentation to monitor flow rates and pressures. Fluidized fly ash is fed from 20-ton supply trucks to an eductor where it is mixed with nitrogen-diluted air (≤ 8 pct O_2). The mixture is then pneumatically transported through an 8-inch (20 cm) fiberglass pipe to the borehole by a high-capacity blower (5,000 ft^3/min , 10 lb/in^2 maximum). A maximum flow rate of 2,500 ft^3/min (71 m^3/min) is recommended for pumping the fly ash into most mine passageways; this is generally adequate

to suppress borehole plugging and to insure satisfactory crater formation for seals requiring the foam topping.

Fly ash requirements will depend primarily upon the passageway width and height and whether the seal is to be completed with or without a foam topping. Figure 4 shows requirements that were calculated assuming fly ash alone is used to produce a 100-pct seal; a time scale for the fly ash deployment is also included, based upon one truckload (20 tons) per hour. For a passage height of 6 feet (1.8 m) 10 to 20 feet (3 to 6 m) wide, the weight of required fly ash should be

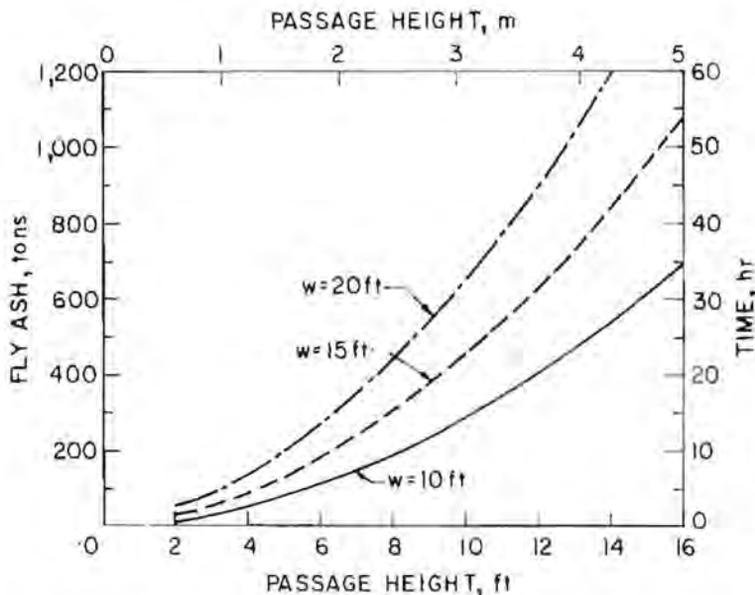


FIGURE 4. - Fly ash requirements and deployment times for 100 pct seals at various mine passage heights and widths.

between 100 and 275 tons. Field tests have shown these estimates to be reliable for normal straight passageways. If a 95-pct fly ash seal is initially constructed and then completed by use of the foam topping, the fly ash requirements can be greatly reduced--reportedly by as much as about 50 pct at the recommended flow conditions. The required fly ash for a 100-pct fly ash seal can be substantially reduced by decreasing the gas mixture (air-N₂) flow rate to minimize the crater formation and lateral spreading of the sealant; these velocity effects increase as the fly ash nears the mine roof.

Froth Foam System

The foam topping system provides an expanding material that is both airtight and watertight, and it is effective in completing a fly ash seal. It is recommended for fly ash emplacements that are 95 pct or more complete. The complete system includes the froth foam generating components, a temperature conditioning and metering system, a downhole mixing assembly, and a deployment system with a skid-mounted hydraulic boom crane. Figure 5 shows a diagram of this system.

Polymeric isocyanate and polyol components are used to produce the foam topping. These components are conditioned at 25° C and fed separately through

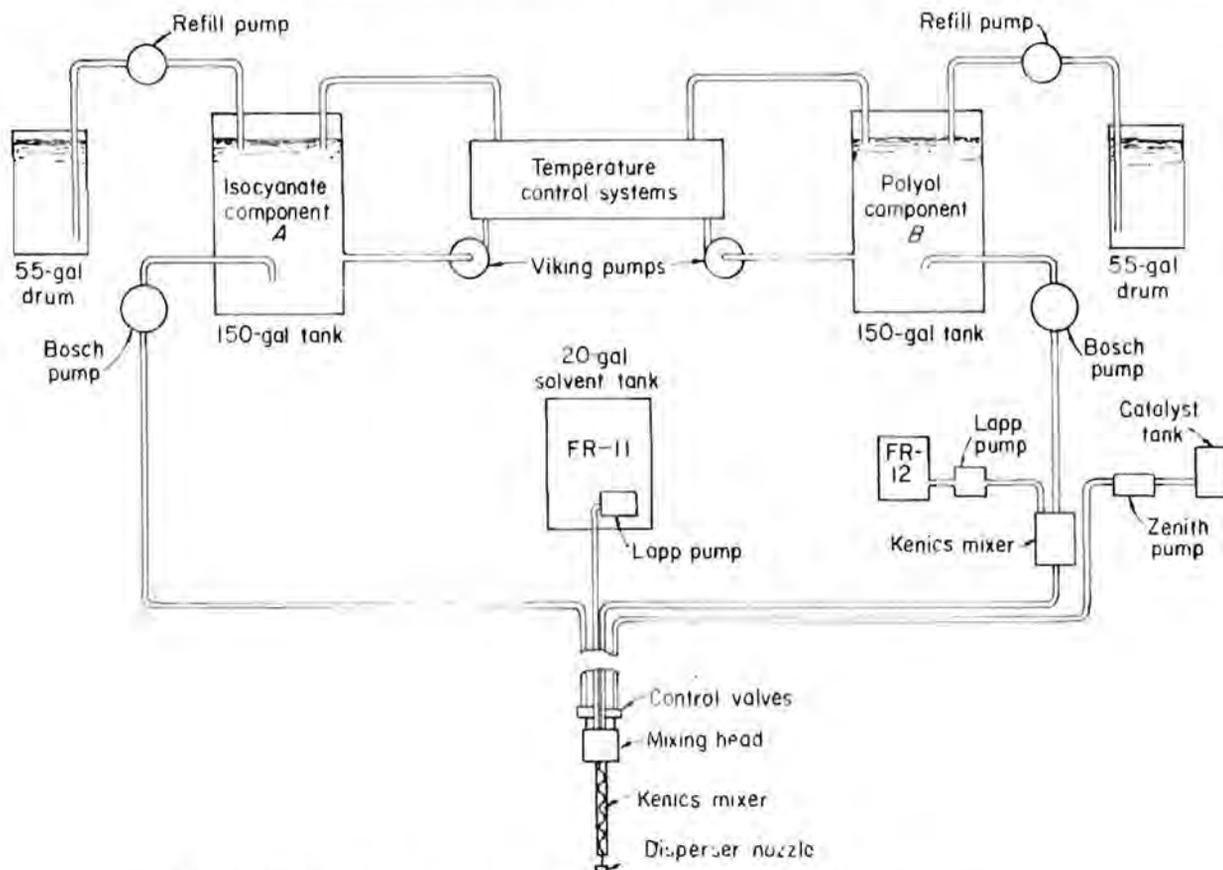


FIGURE 5: - Froth foam conditioning, metering, and mixing systems.

nylon hosing to the downhole mixing assembly where they react together with a catalyst to form a froth foam; Freon 12⁶ is used here as the blowing agent. The chemical constituents are metered at a high pressure of 1,000 lb/in² (70 kg/cm²) to produce the foam at a rate of 40 lb/min (18 kg/min). This foam is a closed cell type (>85 pct) and should be sufficiently fire-resistant to withstand the hot gas temperatures adjacent to the fire zone; a flame spread index of less than 25, as determined by the ASTM E-162 radiant panel test, is a minimum requirement. The amount of foam required will largely depend upon the width of the mine passageway and the completeness of the fly ash sea. About 2,000 lb (908 kg) appears necessary for most 95 pct fly ash seals. In the event of problems, most of the downhole assembly can be retrieved because it is equipped with a pneumatically actuated quick-disconnect coupling.

Inert Gas Generator

The use of an inert gas for the fly ash fluidization and conveyance is mandatory if the remote sealing operation is to be carried out without risk of gas explosions both in the borehole and in the vicinity of the underground seal. Furthermore, inerting the completed seal helps to control and retard the fire. Experience in the field, where liquid N₂ was used for an inert gas supply, indicated that significant logistic and economic benefits could accrue by use of a system based upon combustion gases. A combustion-type inert gas generator can provide an unlimited supply of inert gas and eliminates the uncertainty and difficulty encountered with liquid N₂ tank deliveries. Also, the estimated cost of producing the inert combustion gas should be less than \$1 per 1,000 ft³, compared with about \$8 per 1,000 ft³ (\$0.28 per m³) for liquid N₂.

As part of the Bureau's ongoing contract research on remote sealing, a new combustion-type inert gas generator is being constructed because the commercially available systems in the United States or Europe did not meet the required specifications. The system specifications include a variable output of 600 to 2,200 ft³/min (17 to 62 m³/min) at a pressure up to 15 lb/in² to facilitate the fly ash deployment, a moisture content not greater than 65° C dewpoint to prevent fly ash agglomeration caused by water condensation, and a maximum gas delivery (exit) temperature of 95° C to avoid excessive temperature in and around the sealant borehole.

The combustible inert gas generator is shown in figure 6; it is mounted on two trailers. On one trailer (hot), a forced draft oil burner consumes a No. 2 fuel oil at ~70 gal/hr and produces hot inert combustion products (<1 pct O₂) which are cooled to 260° to 370° C in the thermal liquid heater; this heater contains a petroleum based coolant that is circulated through an air-cooled, finned heat exchanger. The gas is then cooled to 65° C in the "heat pipe" heat exchanger and piped to the other trailer (cold) where it enters a drier (enthalpy exchanger) to remove excess moisture. The final stage of the system is compression of the gas up to 15 lb/in² by a gasoline-engine driver blower that feeds into the line for transporting the fly ash

⁶Reference to specific brands is made for identification only and does not imply endorsement by the Bureau of Mines.

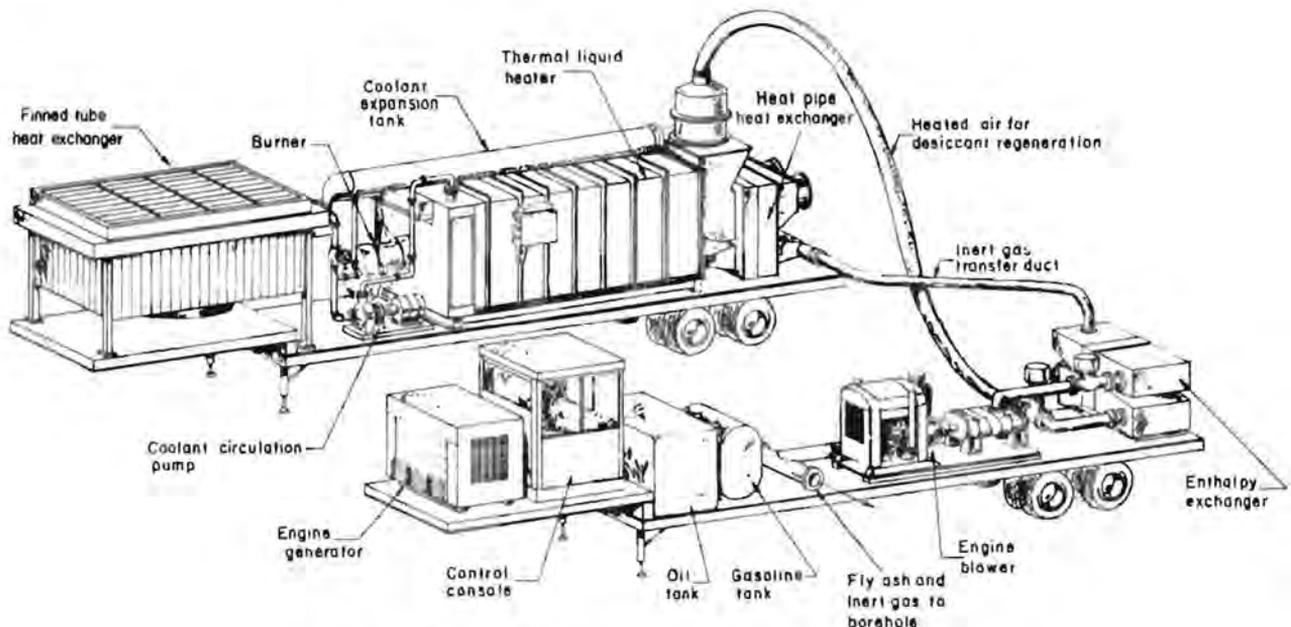


FIGURE 6. - An inert gas generation system.

into the sealant borehole. This system is operable by one person and it is being designed with the capability of maintaining an O_2 concentration between 0 and 8 pct in the sealant borehole and the sealed area.

Experience in Remote Sealing of a Mine Fire

Over the past 15 years, several attempts have been made to apply the remote sealing concept to underground coal mine fires in active mines, most of which were of limited or no success because of inadequate sealant materials, serious equipment limitations, or insurmountable mine water problems. The most successful effort occurred a few years ago when a prototype of the present remote sealing system was used to isolate and extinguish an underground fire at the Joanne mine of the Eastern Associated Coal Corp. in Rachel, W. Va. This fire resulted from a derailment and subsequent short circuit that caused a fan stoppage and made it necessary to evacuate the mine. The decision to attempt remote sealing was made 51 days later.

The remote sealing was made from two surface sites that were over 2,500 feet (162 m) apart and located on opposite sides of a hill above the mine. The major considerations in selecting these sites were (1) proximity to existing roads, (2) sufficient separation distance between boreholes and fire zone, (3) adequate distance from existing gas wells to minimize leakage-paths, and (4) avoidance of burying major pieces of mining equipment. Six seals were constructed and each required drilling two adjacent boreholes to accommodate acoustic seal checkers. The boreholes were 600 feet deep (183 m) or less.

⁷Work cited in footnote 4.

Figure 7 shows a map of the underground mine section with the location of the six seals that were constructed to isolate the fire; permanent stoppings in this section were also used to effect the sealing. Three of the seals (RD-1, RD-3, and RD-5) were 95 pct Fly ash seals that were topped with urethane foam, and the other three (RD-2, RD-4, and RD-6) were 100 pct fly ash seals. Most of these required approximately 150 tons (95 pct seal) or 250 tons (100 pct seal) of fly ash; except for seals RD-3 and RD-4 which were at or near four-way intersections and required about 500 tons of fly ash. Those that were completed with a foam topping required at least 2,200 lb (998 kg) of foam. The sealing operation was carried out using liquid N_2 tankers to provide the inert gas for deploying the fly ash and inerting the completed seals. At least 650,000 ft^3 (18,405 m^3) of N_2 was necessary in constructing a seal.

A gas monitoring system was useful in indicating the effectiveness of the completed seals, the adequacy of the inert gas supply system, and the potential gas explosion hazard before and during the remote sealing operation. Figure 8 shows the varying composition of the mine atmosphere that was monitored at one of the boreholes. The CO and O_2 levels decreased to approximately 0.01 and 1 pct within about 60 days after the fire began; thereafter, they were essentially constant until the remote sealing was started. In comparison, the CH_4 and CO_2 concentrations increased and reached maximum levels of approximately 30 and 4 pct within about 80 days. During the initial stage (preliminary probing) of remote sealing, the CO fell slowly to levels as low as 0.001 pct or less. Some fluctuations occurred in the gas compositions

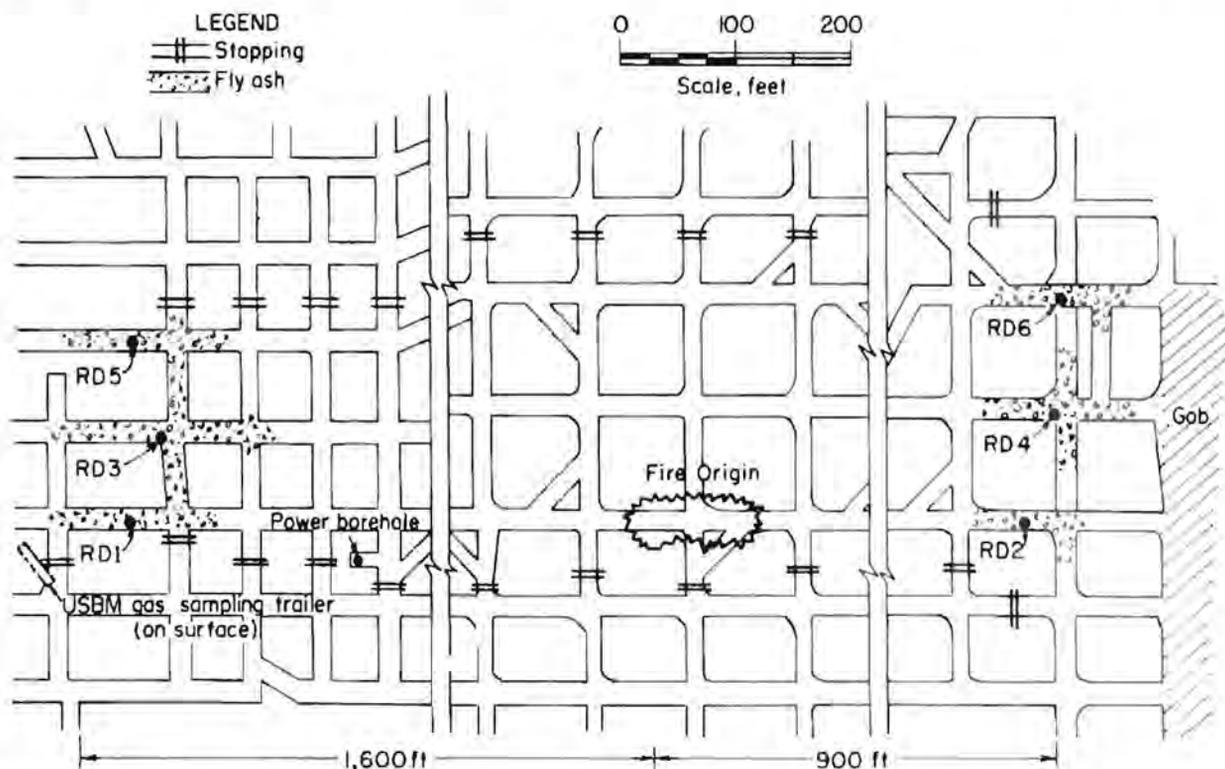


FIGURE 7. - Map of underground section of Joanne mine showing fire zone and fly ash seals.

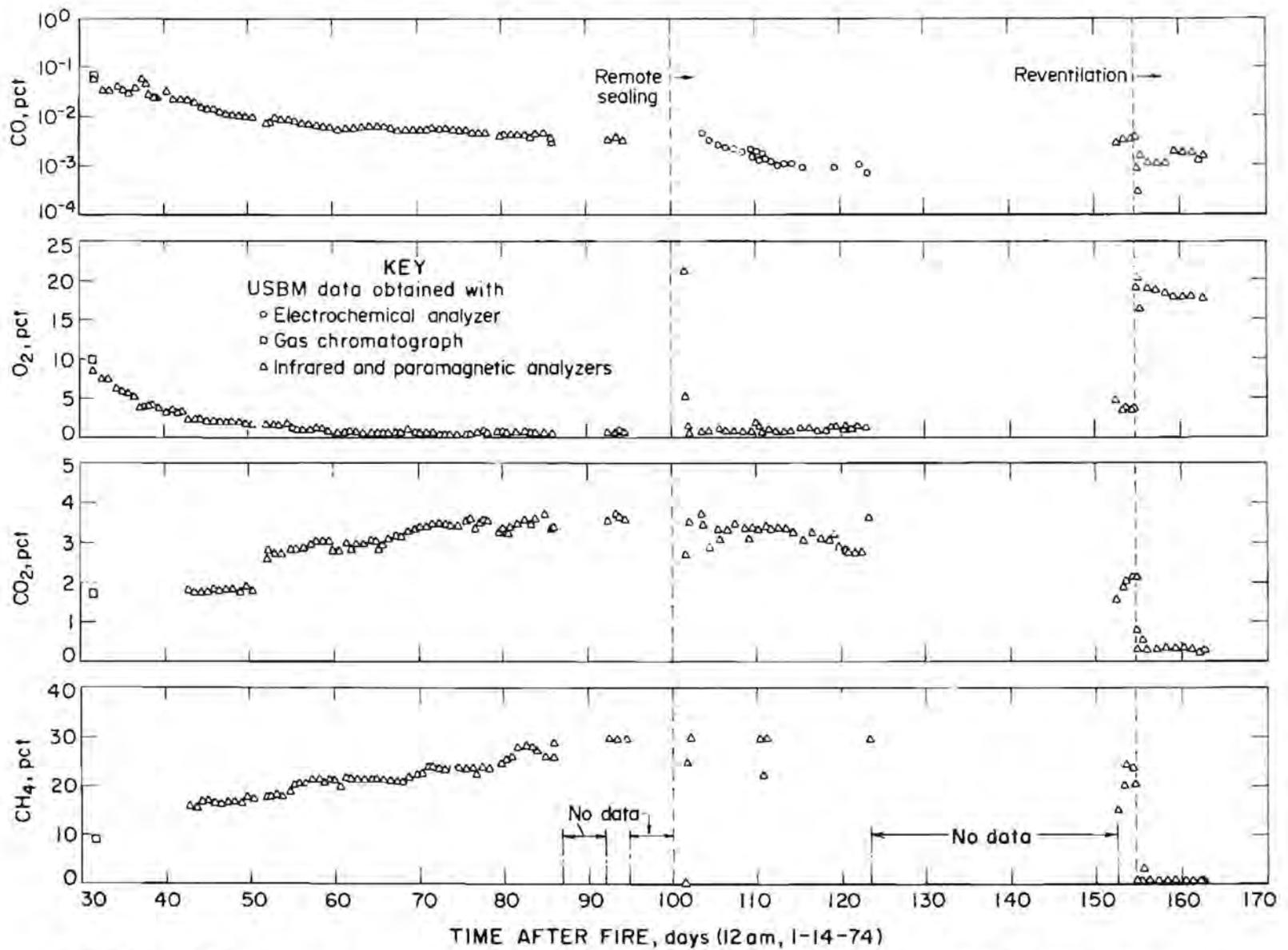


FIGURE 8. - Carbon monoxide, oxygen, carbon dioxide, and methane gas analyses versus time for Joanne mine fire (RD-4 borehole samples).

largely because of leakage or injection of air. Throughout the entire remote sealing operation, the CO- Δ O₂ index (ppm/vol-pct) varied between 0.1 and 1, indicating the amount or level of combustion was relatively small; the CO- Δ O₂ index was over 1,000 at the start of this fire. The CO- Δ CO₂ index (ppm/vol-pct) is also a useful indicator of combustion and was generally an order of magnitude greater than the CO- Δ O₂ index during sealing.

Because of supply and delivery problems with the liquid N₂ system, it was not possible to maintain an inert atmosphere (\geq 90 pct N₂) in the sealed area for extended periods throughout the recovery phase. Nevertheless, the seal emplacements proved to be sufficiently successful so that the mine was reventilated within a few days after completion of the seals. The fact that the mine was reventilated prior to its recovery was a significant accomplishment resulting in considerable savings to the mine operator. This field experience has been very useful in current efforts to develop a more reliable and acceptable remote sealing system for use by the mining industry in fighting mine fires.

Present Status

All three subsystems (instrumentation, froth foam, and inert gas generator) were successfully tested. A field test with the froth foam system deployed to depths approaching 800 feet (244 m) is planned. This test will permit accurate calibration of the subsystem and increase the skills of the operating personnel for more reliable service during an actual fire.

Another field demonstration is planned at the Jenny mine, Prestonsburg, Ky. This test will encompass all three subsystems and it will involve approximately 12 operators. It is hoped that this field test will answer questions regarding the effectiveness of fly ash development during instances where the mine's ventilation system is operating and water is flowing on the mine floor. A complete seal will be made through approximately 180 feet (55 m) of cover and then subjected to a head of water to determine the seal's resistance towards flooding mines.

The instrumentation subsystem is available for use by the Mining Enforcement and Safety Administration's (MESA) Mine Emergency Operations group. Recent cases where the subsystem was used include the Scotia mine, Bethlehem mine No. 32, and the Porter Tunnel mine.

The remote sealing technology is also being used in controlling the fires and subsidence associated with abandoned mine workings.⁷ An example of this technology transfer is the recent request by the Bureau's Denver (Colo.) Mining Research Center to borrow the positive displacement blower unit used during the Joanne mine fire to deploy fly ash. Denver Mining Research Center plans to use this blower to emplace fly ash in abandoned mine workings that are susceptible to subsidence near Rock Springs, Wyo.

⁷Report cited in footnote 2.

MINE FIRE DETECTION

by

M. Hertzberg

ABSTRACT

The problem of mine fire detection is considered in terms of types of fires, past history of fire incidence, current regulations, detection methodologies, and the general strategy of fire safety. Several research programs that are in the process of being transferred to in-mine technologies are described. These include the continuing development of a tube bundle (pneumatic sampling) technique, the evaluation of a new, prototype fire sensor for combustion generated submicrometer particles, and general studies of the problem of spontaneous combustion in coal mines.

INTRODUCTION

A Bureau of Mines program to develop and evaluate rapid and reliable detectors for explosions and fires in underground coal mines has been in existence since the passage of the Coal Mine Health and Safety Act (Public Law 91-173, December 1969). Early emphasis was on the detection of methane-air face ignitions and dust explosions. Such detectors were needed to activate quenching devices. The emphasis in recent years has been on the detection of fires during their early or incipient stages. The project objective was to explore the problem fundamentally; to develop instruments that detect conditions that may lead to fires; to evaluate and adapt current fire sensors for mine use; and to design, develop, and build new sensors and new detection methodologies.

An underground coal mine fire is exceptionally hazardous because of a mine's extraordinary size and its confining geometry. A mine is a man-made void carved out of a combustible material. It is, in effect, an underground factory with a low, flat roof and long, combustible, escape corridors. A map of a typical section is shown in figure 1. It is the 4 right section of the Somerset mine in Colorado. This section is of particular interest because it was the seat of a spontaneous combustion incident that will be described later. In this underground factory called a mine, the roof, floor, hallways, and rooms are lined with combustible material as are all the passageways leading to the exits. It contains heavy equipment and machinery: Mining machines, shuttle cars, roof bolters, conveyor belts, transformers, locomotives, trolleys, and power cables. Escapeways are long; for example, for the working section shown in figure 1, the distance to the Hubbard portal is about 2 miles with a similar distance to the Elk Creek return portal. In the event of a fire, the ventilation pattern can rapidly contaminate escapeways. In most mines there is limited egress through vertical shaft hoists of limited

¹ Research chemist, Pittsburgh Mining and Safety Research Center, Bureau of Mines, Pittsburgh, Pa.

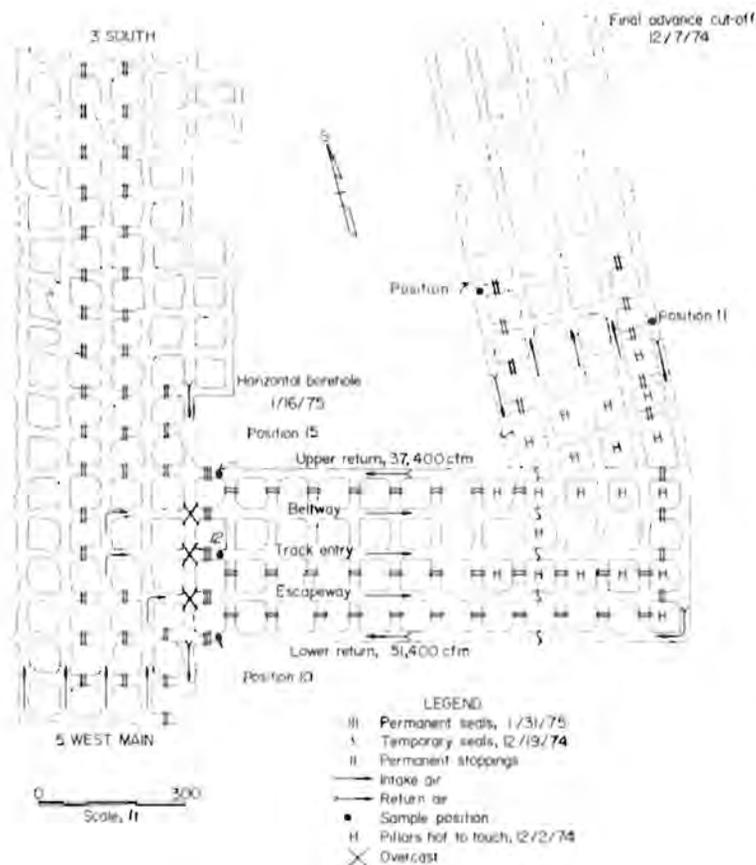


FIGURE 1. - Mine map of the 4 right section of the Somerset coal mine during the occurrence of a spontaneous combustion incident.

measures can be taken to avoid the potential loss of life, equipment, and production that can result from a large, uncontrollable fire situation in an underground coal mine?

Fire and Sensor Types

There are three types of fire situations that are possible:

1. A rapidly developing, open fire.
2. An incipient fire in machinery or equipment.
3. A spontaneous combustion fire in the coal seam itself, in a gob area, or in a sealed area.

capacity, and the time required to evacuate can be extraordinarily long. The fire itself can easily generate flow reversals in passageways that would normally be in intake air, and the everpresent methane emissions add the additional danger of an explosive atmosphere.

A variety of current regulations deal with this problem of fire safety and protection. These are general Code of Federal Regulations (CFR) ventilation requirements (30 CFR 75.3), electrical equipment (30 CFR 75.5-75.10), fire protection equipment (30 CFR 75.11), explosives use (30 CFR 75.13), and escapeways (30 CFR 75.1704-75.1707). We are concerned specifically with one small part of the problem; the problem of detecting the presence of a developing fire situation so that effective

The data in tables 1-2 summarize the fire frequency and fatality rates during the period 1952-70.² The data show that 70 pct of the fires are of electrical origin. These are strong ignitions associated with power sources and machinery. Examples are roof falls shorting a high-voltage trolley wire, a haulage wreck leading to a similar short circuit, or an overheating, faulty splice in a cable reel. If these occur during normal mining operation in attended areas such as the face, they are usually detected by miners and readily extinguished. The same data show that approximately 15 pct were conveyor belt fires. Most of these were caused by frictional heating. Another 10 pct were gob fires that can be classified as spontaneous combustion. The annual fatality rate from fires during the period averaged three deaths per year, and this was only about 2 pct of the total fatality rate from all accidents. This rate dropped to two deaths per year in the period 1970-76. The average fire frequency dropped from 50 per year in the 1952-70 period and to only 10 per year in the 1970-76 period. This dramatic decrease since 1970 reflects the increased vigilance of all concerned and demonstrates the effectiveness of the regulations.

TABLE 1. - Fire frequency and fatality rate in face areas, 1952-70¹

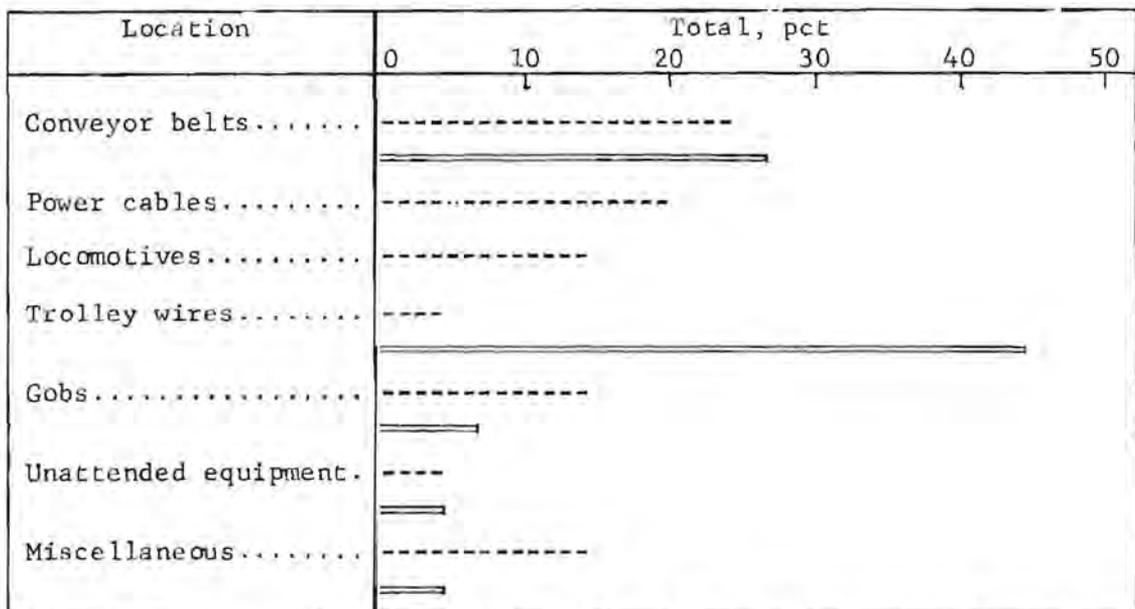
Location	Total, pct					
	0	10	20	30	40	50
Cutter.....	-----					
	=====					
Loader.....	-----					
	=====					
Shuttle car.....	-----					
Continuous miner.....	-----					
	=====					
Roof bolter.....	-----					
	=====					
Blasting.....	-----					
Miscellaneous.....	-----					

¹ 357 fires, 61 injuries, 20 fatalities; most of electrical origin.

----- Frequency rate.

===== Fatality rate.

² These data are for reportable mine fires (longer than 30 min duration) and were supplied by J. Nagy and E. M. Kawenski of the Mining Enforcement and Safety Administration (MESA), Pittsburgh, Pa.

TABLE 2. - Fire frequency and fatality rate in nonface areas, 1952-70

533 fires, 68 injuries, 41 fatalities; 50 pct of electrical origin.

----- Frequency rate.

===== Fatality rate.

But there is no justification for complacency either with the Bureau or at MESA. The data for metal mine fire fatalities show the reverse trend, mainly because of the Sunshine mine fire of 1972 that caused 91 deaths. From a metal and nonmetal mine fatality rate of nearly zero in the 1952-70 period, the rate jumped to 15 deaths per year for the 1970-76 period. The potential for a major fire disaster in underground mines is everpresent, and as indicated earlier, it is almost inherent in the nature and structure of that large underground factory called a coal mine. If the same structure and equipment were located above ground with the same combustible loading, ventilation, and limited egress, there is not a municipality in the Nation that could legally issue a permit for its construction or occupancy.

Another reason for avoiding complacency relates to the expected increase in the spontaneous combustion hazard as mining shifts westward and longwall methods become more prevalent.

There is little doubt that the rapid and reliable detection of a fire is the essential first step in the use of any fire-suppression system or in the activation of any alarm system and escape plan.

The traditional methods of detecting the presence of fires may be classified according to the type of detector used, as follows:

1. Thermal contact.
2. Optical view field.
3. Products of combustion.

4. Flow field or aerodynamic.
5. Human.

Thermal sensors respond to the temperature or the rate of temperature increase at a point, or along a continuous line sensor. Examples are the fusible alloy plug of a sprinkler head, thermocouples, bimetallic elements, twisted wire with insulation that melts at a given temperature, and a variety of other devices. Generally, these thermal sensors require that the detector be very close to the fire for them to alarm.

Optical sensors respond to the light emitted by a fire or flame and these are limited by view field constraints. The sensor must actually "see" flames; the emitted radiant energy from the fire or from surfaces heated by the fire.

Any fire generates products of combustion and these are carried to regions far removed from the fire by the mine ventilation or by the fire's own convection currents. Examples of combustion products that can be detected routinely are carbon monoxide (CO), carbon dioxide (CO₂), smoke (visible), submicrometer particles (invisible smoke), and a variety of pyrolysis products.

Aerodynamic sensors respond to the flow disturbances or convection currents induced by a flame. These are useful for explosion detection but are rarely used for fires.

The human sensor is the most versatile, and it is a combination of the first three types. The human body responds easily to temperatures well below those usually used as the alarm points for thermal sensors. The eye usually responds to flame or smoke long before such temperatures are reached. And, although we are not at all certain of which product of combustion we are smelling, the nose is probably a very effective product of combustion sensor for almost all fires. Virtually all of the fires reported in tables 1-2 were detected by human sensors, that is, by miners.

But the human observer has serious limitations. He is present only part of the time in a limited region; the attended areas. He is absent part of the time in all areas and most of the time in remote areas and older workings. The human observer is not available in sealed areas and gobs. One can actually attribute the improvement in coal mine fire frequency rate since 1970 in part to the trend of replacing the human observer by automated or semi-automated sensing and extinguishing systems. This is specifically the case for the automated prevention, detection, and extinguishment systems that were required on belts and in belt haulageways.

There is little doubt that products of combustion sensors are available that are far more sensitive than human observers, but current practice generally assumes the presence of human observers. The only current coal mine requirements for automatic fire sensors relate to their use with underground belt conveyors. These regulations (30 CFR 75.1103) are summarized in table 3. The regulations for conveyor belt haulageway protection in coal mines are written in terms of thermal, point-type sensors. Products of combustion sensors can be used only if they offer equivalent protection. Equivalency is in the process of being defined by current MESA testing in participation with

the Bureau of Mines. While current metal and nonmetal mine regulations require fire alarm systems and mine evacuation drills (30 CFR 57.4), there are no requirements for automated sensors to actuate the alarms. Hence, current practice in most cases would appear to depend mainly on the human observer.

TABLE 3. - Automatic fire sensors required on underground belt conveyors, CFR 75.1103

(Thermal-type or equivalent)

Thermal (point-type) sensors:

At the beginning and end of each flight.

At the belt drive.

At increments along the belt not to exceed 125 feet high at or above the top belt.

Other sensors:

Equivalent protection must be provided.

Equivalency is in the process of being defined.

Other requirements:

Minimize damage from roof falls.

Protection from dust and moisture if sensor is contaminated by them.

Maximum sensor voltage (120 v).

Sensor system must be operable for at least 4 hr after power is off, otherwise the entire belt haulageway must be walked and examined for hot rollers.

Automatic warnings, both visual and audible, that permit rapid location of fire and alerting endangered miners.

Manual reset and fault locators.

System must be inspected weekly and tested annually.

Tube Bundle Sampling

One area of research that is actively being pursued is the continuing development of a continuous-monitoring technique that was pioneered by the National Coal Board (2, 9).³ Spontaneous heating in the gob (goaf) regions of advancing longwall systems are now routinely monitored by gas sampling tubes. A branching tree of tubes pneumatically conveys mine air from each zone of interest to a central trunk station for analysis. The analysis station is conveniently located above ground, and it is reliably maintained with sensitive detectors. Any unexplained upward drift in the CO level above the normal background is taken as a warning of the onset of spontaneous combustion in an area.

The Bureau of Mines, in cooperation with United States Steel Co. and MESA, is involved in the development of such a system at the Somerset mine in Colorado. An earlier version of the system monitored 38 points at various intakes, returns, working sections, and sealed areas (1). Regions as far as a mile from the sensing station were routinely monitored. During the course of the study, it was possible to follow the actual growth of a spontaneous combustion situation in a conventional room and pillar section. When attempts to

³ Underlined numbers in parentheses refer to items in the list of references at the end of this section.

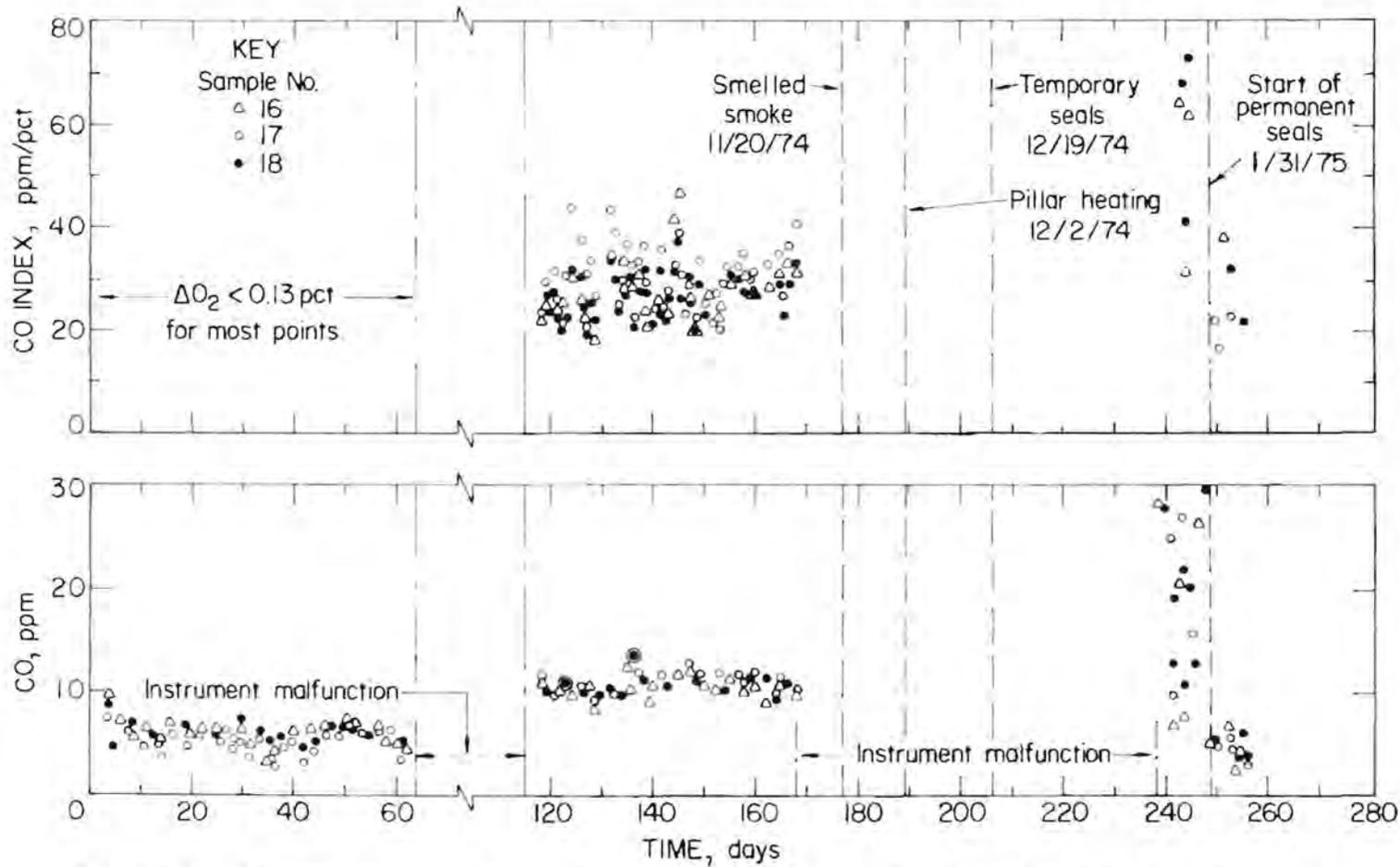


FIGURE 2. - CO concentrations and CO index at three sample points in a return from the 4 right section.

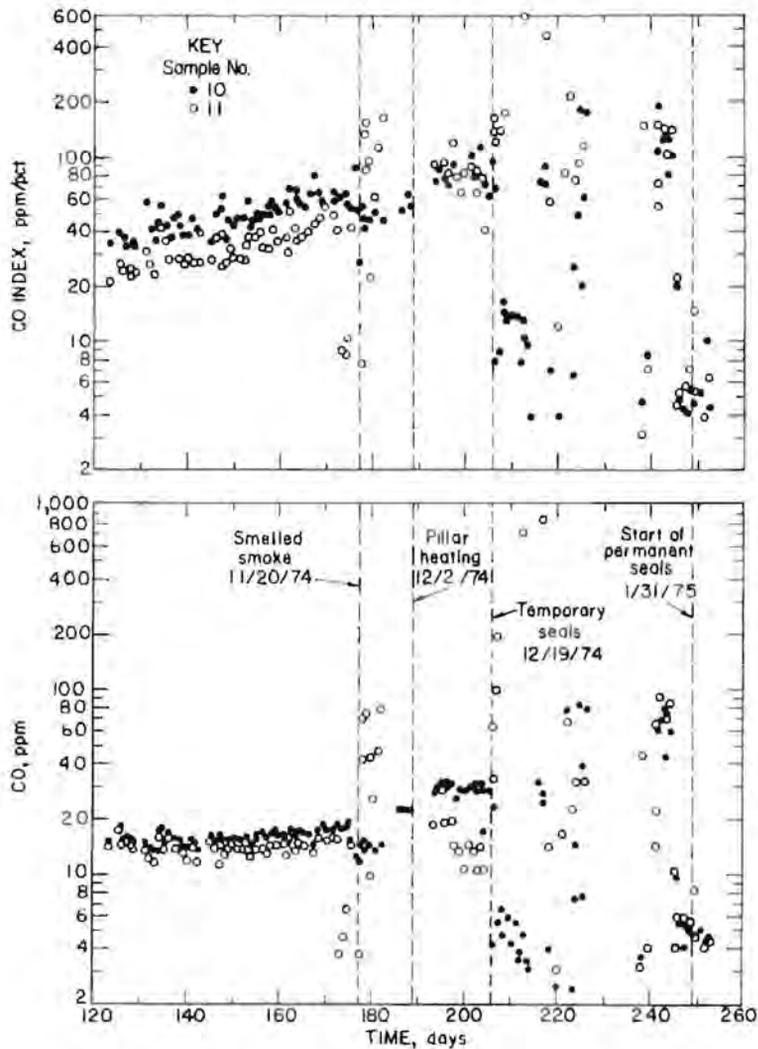


FIGURE 3. - CO concentrations and CO index at two sampling points in the return splits within the 4 right section.

The index shows a clear upward trend until smoke was detected by smell on day 177. During the following 29-day interval from day 177 to day 206, various measures were taken to arrest the self-heating including the use of water sprays on the hot pillars. The pillars that were self-heating so markedly that they were hot to the touch are shown in figure 1. Temporary sealing was started on day 206 and with the final erection of permanent seals, the CO levels and the CO index values eventually fell to their normal values. These normal levels were detected in the sealed section that was not accessible to the human observer. The results show that careful attention to the data trends would have enabled one to detect this spontaneous combustion situation long before it developed into a large smouldering fire problem. Such a system is adaptable to gobs, abandoned regions, and sealed areas of a mine where the

arrest the fire development were unsuccessful, the section was eventually sealed. A map of the section, 4 right of the Somerset mine, was shown in figure 1. The data obtained are shown in figures 2-3. The data in figure 2 are from three stations in the ventilation return from the section. The CO level and the CO index (ppm CO per pct O_2 absorbed) are shown as a function of time. Normal CO levels emanating from the section from day 1 to day 62 were in the range 5 ± 2 ppm. By day 120, the CO level had risen to over 10 ppm. Although the CO index could not be determined between days 1 and 62 because of limitations in the accuracy of the oxygen sensor, there is a clear upward trend in the index between days 120 and 170. It rose significantly from 20 ppm per pct O_2 absorbed to a value of over 30.

The data in figure 3 are for two stations that were actually in the section, in the return splits from the actual face area of 4 right. They also show the high CO level from day 120.

human observer is not present. There is also little doubt that even in attended areas, this type of system detects the problem much earlier than the unaided human senses.

This mine monitoring system at Somerset is undergoing further development. The analysis station is being located above ground so that it is independent of mine power fluctuations, it can be serviced readily, and it will continue to function if the mine is evacuated and the power is turned off. Also, the system is being divided into two subsystems; one for the active areas and another for the sealed areas. In addition, the development of a more accurate oxygen sensor will allow the CO index to be measured in the active areas even when the pct O_2 absorbed is very low.

Other Bureau research involves the general evaluation of the tube bundle sampling method (3). This involved theoretical, experimental, and practical studies of the advantages and limitations of the method, not only as it applied to spontaneous combustion detection, but also its possible application to the more rapidly developing fire scenarios. Travel times through tubes of varying length, width, and pressure drop were measured, cycling time constraints were studied, and the transmission losses of submicrometer smoke particles were measured.

Laboratory studies indicate that submicrometer particles are more universal indicators of spontaneous self-heating than CO detection. Other mine combustibles such as wood, cellulose, and plastics generate these particles at a much earlier stage of heating than the temperatures at which they generate CO (4). A highly sensitive and inexpensive sensor for these particles is shown in figure 4. It is a Bureau of Mines invention (8) that is compatible with a properly designed tube bundle sampling system. Several of these prototype instruments are available for in-mine evaluation of their performance.

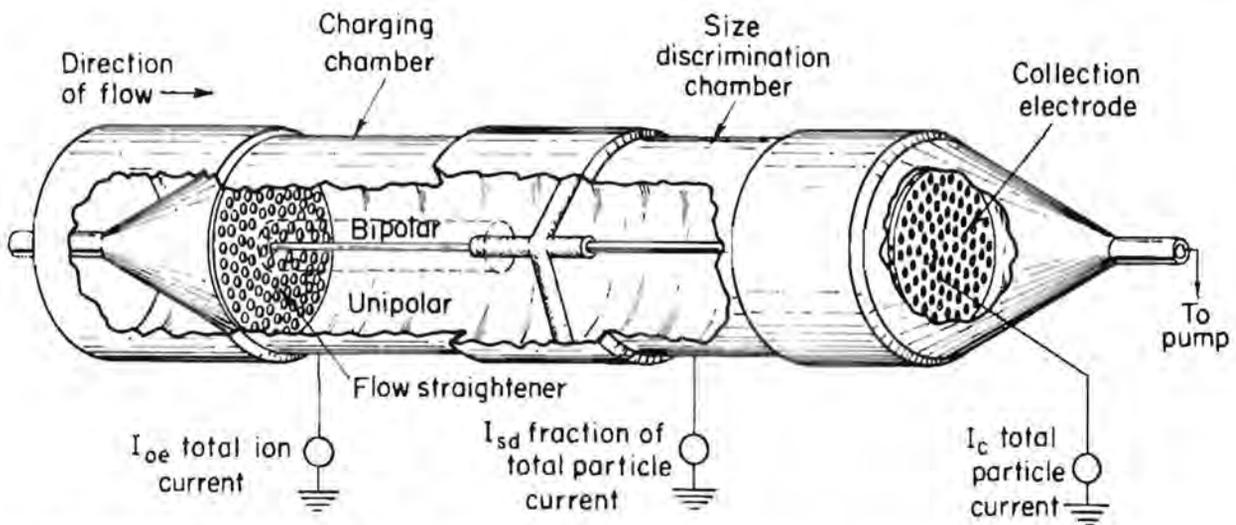


FIGURE 4. - A prototype fire sensor for detecting combustion generated submicron particles.

Spontaneous Combustion and Its Detection

The natural geochemical evolution of a coal seam occurs under anaerobic conditions during an extended geological time scale. A mine is a large, man-made void in the coal deposit which is generated rapidly relative to that geologic time. The deposit that had coalified under anaerobic conditions at high pressure, "suddenly" finds a cavity within itself, and a large surface area is exposed to air at atmospheric pressure and to its oxygen content. This first exposure to air occurs directly during heading development and face cutting or indirectly in the form of roof caving, the fracturing of adjacent parts of the seam by the mining induced stresses, or from large ventilation pressure differences across zones of enhanced permeability. The surfaces that are freshly exposed may consist of the free surface of the roof, floor, and ribs; the pulverized surface area of coal residues in a gob; the fissure area of the fracture pattern; the internal void area left by methane flowing into the lower pressure of the mine void; or finally, the internal surface area generated by the drying of a coal. In all such cases, oxidation is the inevitable result of this exposure of fresh coal surfaces to air. Since the oxidation process is exothermic, heat is generated which can accumulate in the mass that is self-heating. For a given geometric configuration and exposed area, there is a range of airflow velocities for which the self-heating process becomes self-accelerating. The result is first a smouldering mass and then an open fire which can spread rapidly throughout the mine.

Most of the applied research in this field has been done abroad, and the mines studied were predominantly longwall systems in the United Kingdom, the Soviet Union, France, and Central Europe (2, 5, 7, 9, 11). A major factor that determines the spontaneous combustion hazard is the mining method itself, and hence, it may be difficult to apply those longwall studies to other mining methods. The Bureau of Mines research in this area is more recent, and it is limited to the detection studies just described and to laboratory evaluations of the relative tendencies of various eastern and western coals to self-heat in an adiabatic calorimeter (6).

The major factors that contribute to the occurrence of spontaneous combustion in coal mines are (1) the intrinsic reactivity of the coal, (2) the geometry and configuration of the seam (or seams), (3) the geological conditions and structure of the seam and its surroundings, and (4) the mining method and ventilation conditions. Current Bureau research has been concerned with mostly the first factor; however, mining engineers who may be concerned with the development of new mines would do well to study all the factors involved.

The intrinsic activity of the coal can usually be studied in laboratory-scale systems. However, since coal is not a pure chemical substance, its activity can be a strong function of its past history. Various methods are used to measure this intrinsic tendency. Some relate it to the CO generation rate (2), others to the rate of absorption of oxygen (11), some to the pyritic content of the coal (5), and others argue that the low temperatures self-heating properties are dominated by the thermodynamics of the moisture absorption-desorption equilibrium (10). Since the central parameter of interest is the rate of self-heating, the Bureau of Mines approach is to directly measure this property in an adiabatic calorimeter. The calorimeter data show that these various methods of evaluating relative reactivities correlate

reasonably well with one another (6). The rate of temperature rise correlates well with the rate of production of CO and CO₂. Coals with high rates of CO production per unit volume of oxygen absorbed also have high self-heating rates in the adiabatic calorimeter. The CO index correlates well with the initial oxygen content of the coal. Some recent data, table 4, show the relative tendencies of various eastern and western coals to self-heat. The minimum self-heating temperature for a fixed sample mass and particle size is the lowest initial temperature at which the coal will self-heat to ignition in the Bureau's adiabatic calorimeter.

TABLE 4. - Incipient combustion tendencies for eastern and western coals

Coal type	Heating value, Btu/lb	CO index, CO/ΔO ₂ ppm/vol-pct	Minimum self-heating temperature, ° C
Pocahontas, No. 3, W. Va...	14,400	¹ 65	¹ 90
Pittsburgh, (Bruceton), Pa.	14,500	² 75	¹ 85
Sahara, No. 20, Ill.....	12,700	² 75	¹ 60
Somerset, Colo.....	13,500	² 120	¹ 60
Sarpy Creek, No. 2, Mont...	9,500	² 215	² 30
Dravo, No. 80, Wyo.....	11,200	² 285	² 30
Jim Bridger, Wyo.....	10,700	² 190	² 30
Alaskan.....	7,000	² 200	² 30

¹Undried.

²Dried.

The western coals, particularly the lignite and subbituminous coals, show a markedly greater tendency to self-heat. There is a clear consensus (11), supported by these Bureau studies, that the intrinsic activity of the coal is usually directly related to its rank. High rank anthracites present a small hazard; intermediate rank bituminous coals present a moderate hazard; whereas, lignites or brown coals present the greatest hazard.

But there are complications. For example, recent studies with dried coals subjected to moist air confirms the view that the low temperature, self-heating region (20° to 60° C) seems to be dominated by the energetics of the moisture absorption-desorption processes (10).

Does the Somerset mine case discussed earlier represent an isolated occurrence, or is it a foreboding of increasing spontaneous combustion hazards as mining shifts westward to drier areas, lower rank coals, thicker seams, and the more prevalent use of longwall methods? It is difficult to determine, but figure 5 suggests that the problem may not be uncommon. It is of a spontaneous fire in an open pit mine in Wyoming; the freshly uncovered seam is burning spontaneously. While this may not be serious in this open pit situation, it can develop into a very hazardous fire in the confining geometry of a mine.

Finally, there is the question of cost. For this first system at Somerset, equipment costs for tubing, sensors, pumps, and solenoids were approximately \$80,000. For a typical coal mine, benefiting from the Somerset



FIGURE 5. - A spontaneous combustion fire in a strip mine in Wyoming. The freshly uncovered seam is burning spontaneously.

experiences, a realistic cost estimate for a similar system would be well under \$50,000. Generally, for large installations involving many sampling points, the tube system is by far less expensive than a system in which each point has a separate detector. Generally, the costs of the pneumatic tubing are comparable with the wiring costs for electronic sensors; however, the electronic system requires a detector at each point, whereas the tube bundle system uses only one sensing station. This can reduce the cost substantially, or alternately one can afford to invest much more in the accuracy, reli-

ability, and degree of sophistication of the sensor. For fire detection, there is generally a trade-off between the traveltime delay imposed by the sampling tube and the enhanced sensitivity one can achieve at the sensing station. Maintenance costs for a single sensor and pumping station should be much lower than for a system containing many individual sensors, each of which must be periodically checked, cleaned, or adjusted for sensitivity. There is also the multiple use potential. For example, the same tube system, once installed, could be used to monitor the methane content throughout the mine in active areas, returns, sealed areas, and gobs.

For a more limited system, for example, one that would involve sampling points every 500 to 1,000 feet along a belt haulageway plus several sampling points in key intake and return roadways, one is dealing with equipment costs of \$10,000 to \$20,000.

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FIRE PROTECTION FOR MINE CONVEYOR BELT SYSTEMS

by

J. M. Kuchta²

ABSTRACT

Conveyor belt fires can present a serious hazard in the confined environment of an underground coal mine; therefore, stringent safety measures are necessary to protect the miner. This Bureau of Mines report briefly summarizes available mine fire statistics and existing fire protection requirements that have been effective in reducing the frequency of coal mine conveyor belt fires. Results of Bureau in-house and contract research are presented to illustrate the limitation of laboratory-scale tests for evaluating the fire-resistance of various conveyor belts and to show the adequacy of the regulations for fire detection and fire suppression systems. In addition, ongoing research designed to help update the Federal Schedule 2G fire-resistance test is described.

INTRODUCTION

Mine fire statistics from 1952 through 1969 reveal that at least 15 pct of the total reported fires (877) in underground coal mines were attributable to conveyor belt ignitions. Also, as shown in table 1, nearly 70 pct (91) of the belt fires were caused by frictional heating, such as that caused by a stuck roller or snarled belt in the belt drive assembly. Since the Federal Coal Mine Health and Safety Act of 1969, the incidence of reported belt fires has reduced drastically, averaging less than two per year from 1970 through 1976. This large reduction in belt fires can be ascribed to the more conservative safety requirements promulgated by the act and specifically defined in the Code of Federal Regulations, 30 CFR 75.1100. These regulations now require that all mine conveyor belts must be fire-resistant, as defined by the Schedule 2G approval test, and that the conveyor must be equipped with a zero speed cutoff switch. Also, rigid requirements are defined for the fire detection and fire extinguishing systems. The development of better fire-resistant belting and better fire-protection hardware has also contributed to the improved safety.

TABLE 1. - Statistics of reported coal mine fires during 1952-69¹

Location	Total fires	Electrical	Frictional	Spontaneous combustion	Injuries	Fatalities
Face area equipment	351	333	-	-	61	20
Conveyor belts.....	134	27	91	-	18	11
Power cables.....	112	112	-	-	13	0
Locomotives.....	38	38	-	-	3	5
Trolley wires.....	57	57	-	-	12	18
Job areas.....	84	-	-	65	3	3
Miscellaneous.....	101	35	-	-	17	4
Total.....	877	602	91	65	127	61

¹Private communication with Edward M. Kawenski, Mining Enforcement and Safety Administration (MESA), Pittsburgh, Pa.

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Bureau of Mines research on conveyor belts in recent years has been directed toward determining the adequacy of existing mining regulations and toward developing the required technology for implementing new or improved regulations. One area of concern is the questionable reliability of the small-scale Schedule 2G test (flame spread) to provide a sufficient margin of safety for all conveyor belting including the polyvinyl chloride type. The European community is also concerned with this problem and many rely upon a small-scale laboratory flame spread test and a drum friction test to evaluate their belts. Another area of concern are the requirements for the fire detection-extinguishing system, although the existing regulations for such systems may account for the large recent reduction in reported belt fires; the fires that are extinguished within 30 min need not be reported. This report briefly summarizes the fire protection requirements for coal mine conveyor belts and the results of Bureau in-house and contract research pertinent to this problem.

Fire-Resistance of Conveyor Belts

Fire-resistance is a relative measure of the ability of a material to resist ignition and the spread of flame and can be expected to vary with such physical variables as material dimensions, space dimensions, ignitor heat flux, air velocity, and burning orientation. The ventilation conditions in conveyor belt haulageways are generally neutral, but actual airflow requirements will depend upon how much methane is being released. In the Federal Schedule 2G test, the fire-resistance of coal mine conveyor belts is determined under laboratory-scale conditions; 1/2- by 6-inch specimens are ignited in a 21-inch cubical chamber with a Bunsen burner flame. The duration of flame or glowing combustion is noted at an air velocity of 300 ft/min. Research is underway to update this test method because the fire-resistance requirements are not sufficiently conservative, as shown later by data from larger scale testing.

Bureau Large-Scale Fire Tests

Fire-resistant-type conveyor belts include those made with neoprene, polyvinyl chloride (PVC), styrene butadiene (SBR), and combinations with natural rubber. The carcasses are generally made of nylon, rayon, cotton, or a combination of these fabrics. The materials used can be the determining flammability factor in the case of used belts.

Results of an early Bureau investigation by Mitchell, Murphy, Smith, and Pollack² are indicative of how much the fire-resistance of conveyor belts can vary in small-scale and large-scale fire tests under different ignition conditions. Table 2 summarizes some of the flame propagation data obtained in a 4-foot-diameter gallery with four conveyor belts, three of which were fire-resistant by the Schedule 2G test; belt width was 2-1/2 or 3-1/2 feet in most trials. These moderately large-scale data show that even approved PVC and neoprene belts can ignite and propagate flame when exposed to flame under certain heating and ventilating conditions. Here, flame propagation was attained when the flame ignition source (4,200 Btu/min) was supplemented with a thermal

²Mitchell, D. W., E. M. Murphy, A. E. Smith, and S. F. Pollack. Fire Hazard of Conveyor Belts. BuMines RI 7053, 1967, 14 pp.

radiation source (~1,300 Btu/min) and the airflow condition was increased from zero to 200 ft/min, above which the flow effect was small. Neoprene belts were the most difficult to ignite but their propagation rates did not differ greatly from those for PVC belting, ≤ 3.5 ft/min. The highest rates occurred with the nonfire-resistant rubber, particularly when the carcass was removed. Such variables as belt preheating, belt width, and coal dust-grease accumulations generally increase the fire hazard. The ability of these belt materials to sustain flame propagation was also demonstrated in full-scale fire tests in the Bureau's Experimental Mine.

TABLE 2. - Fire-resistance of conveyor belts in 4-foot diameter gallery under various airflow and ignition conditions¹

(Belt dimensions, 15 by 3-1/2 feet)

Air velocity, ft/min	Flame propagation rate, ft/min ¹			
	Rubber	Neoprene ²	Impregnated neoprene ²	Impregnated PVC ²
PREHEATING + PROPANE BURNERS (4,200 BTU/MIN) + RADIANT HEATER (~1,300 BTU/MIN)				
~0	NP	NP	NP	NP
200	7.6	2.1	3.5	3.5
500	9.8	1.8	2.1	2.7
PROPANE BURNERS (4,200 BTU/MIN) + RADIANT HEATER (~1,300 BTU/MIN)				
~0	NP	NP	NP	NP
200	4.0	1.1	3.0	3.2
500	5.6	1.2	3.3	2.0
~0, 200, 500	PROPANE BURNERS (4,200 BTU/MIN)			
	NP	NP	NP	NP

NP indicates no propagation.

¹Bureau of Mines data from reference cited in footnote 2.

²Fire-resistant according to Schedule 2G.

Walter Kidde Large-Scale Fire Tests

Results of a recently completed Bureau contract³ with the Walter Kidde Co. provide further evidence of the inadequacy of laboratory-scale fire tests. In this work, full-scale fire and suppression tests were conducted in a 6- by 15- by 175-foot simulated belt haulageway using a flame source (3,500 Btu/min) and radiation source (~8,500 Btu/min) for igniting the belts; the fire suppression tests are described elsewhere in this report. Figure 1 shows a diagram of the experimental setup used in these tests.

³Warner, B. L. Suppression of Fire on Underground Coal Mine Conveyor Belts (Research Contract H0122086 by Walter Kidde & Co., Inc.). BuMines Open File Rept. 27-76, 1974, 105 pp.; PB 250 368/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

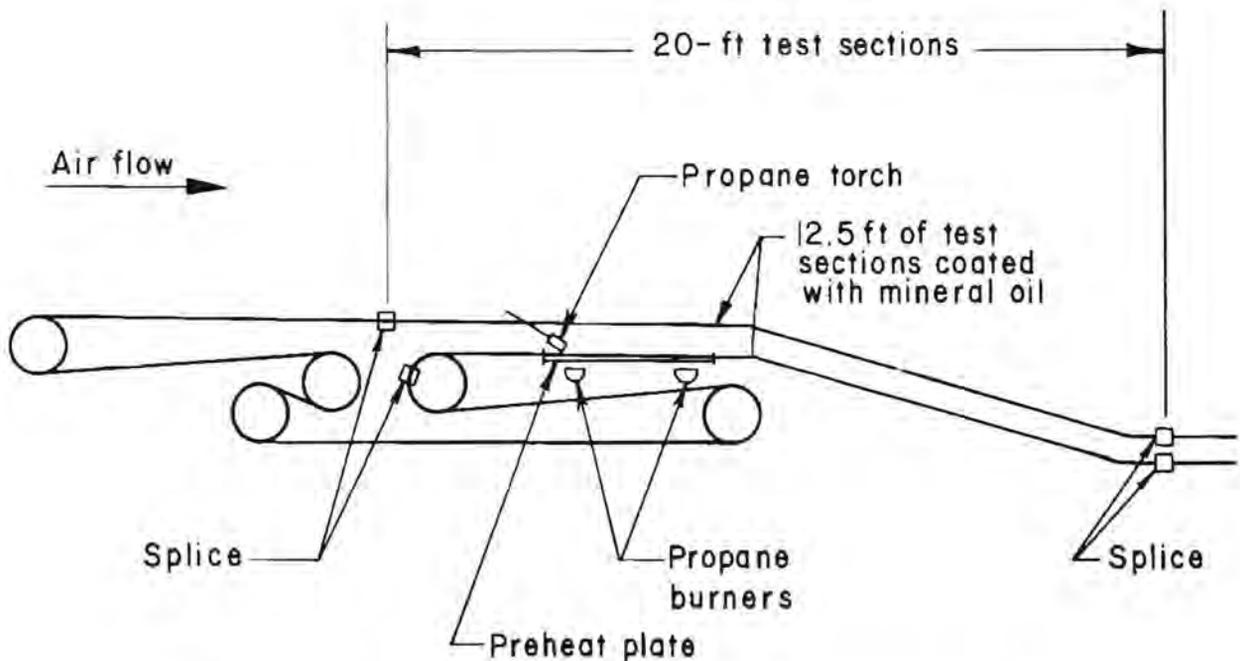


FIGURE 1. - Walter Kidde test gallery setup for conveyor belt fires.

The results of this contract study confirmed many of the trends observed in the Bureau's in-house work, including the greater ease of ignition with belt preheating and great effect of flow conditions. Table 3⁴ lists flame propagation rates that were calculated from the reported data of this work for 10 of the conveyor belts evaluated. Again, it is seen that some Schedule 2G approved belts sustained propagation in large-scale fires under moderately high-flow conditions. The new PVC-3 belt gave the highest propagation rates of all the belts tested. This material had propagation rates of 5 and 6.5 ft/min at air velocities of 125 and 350 ft/min compared with only 0.8 ft/min at neutral airflow; these were obtained with a mineral oil coating. As noted in table 2, flame propagation is generally enhanced by belt coatings of mineral oil and/or coal dust; however, coal dust itself tends to have a retarding effect on ignition. Also, new belts appeared to give higher propagation rates than used belts of the same make, but belt thickness was not the same in all such comparisons.

⁴Reference to specific brands or manufacturers is made for identification only and does not imply endorsement by the Bureau of Mines.

TABLE 3. - Fire-resistance of conveyor belts in 6- by 15- by 175-foot gallery at various conditions¹

(Belt dimensions, 20 by 2-1/2 feet. Total ignitor heat input, 11,500 Btu/min.)

Air velocity.....ft/min..	Flame propagation rate, ft/min		
	125	200	~350
FIRE-RESISTANT BELTS ²			
Neoprene 1 (used), B.F. Goodrich, Caricoal....	-	-	NP
Neoprene 2 (used), Acme Hamilton, Pyroprene:...	-	NP (0.15)	NP
Rubber (used), Republic Rubber.....	-	- (NP)	-
SBR-1 (new), Bridgestone, Nycon.....	-	0.4	-
SBR-2 (new), Goodyear, Glide 220.....	(0.25)	.6	-
PVC-1 (new), B.F. Goodrich, Koroseal.....	(1.8), 0.8	.65	-
PVC-2 (used), B.F. Goodrich, Koroseal.....	(.25)	NP (.6)	-
PVC-3 (new), Scandura, Gold Line.....	(5.0)	.9	(6.5)
PVC-4 (used), Scandura, Gold Line.....	(.4)	-	-
NONFIRE-RESISTANT BELT			
Rubber (new), B.F. Goodrich, medium longlife..	(1.4), 1.9	-	-

NP indicates no propagation; values in parentheses obtained with mineral oil and/or coal dust on belts.

¹Calculated from data of reference cited in footnote 3.

²Fire-resistant according to Schedule 2G.

The PVC-3 belt material produced the most intense fires in the gallery full-scale tests. As shown by the temperature profiles in figure 2, the maximum roof temperatures exceeded 1,000° F, and these occurred near the area of ignition where the initial 5 feet of belt was preheated. With a mineral oil coating, the PVC-3 belt fires propagated over the entire belt test section (20 feet) in as little as 3 min after ignition with a 350-ft/min airflow, and within 25 min with the neutral flow condition. Although the fires are spread more rapidly with increasing air velocity, one can expect ignition itself to be increasingly more difficult because of flame instability and convective heat loss.

Schedule 2G results for conveyor belts are less conservative than those from large-scale fire tests because the laboratory-scale method uses marginal heat source conditions for ignition, and the belt dimensions are not optimum for sustaining flame propagation. Furthermore, the specified air ventilation rate (300 ft/min) for the small-scale fires can result in flame blow-out in some cases. Such deficiencies, as well as the lack of quantitative fire-resistance ratings, need to be rectified to make the approval test more reliable and useful.

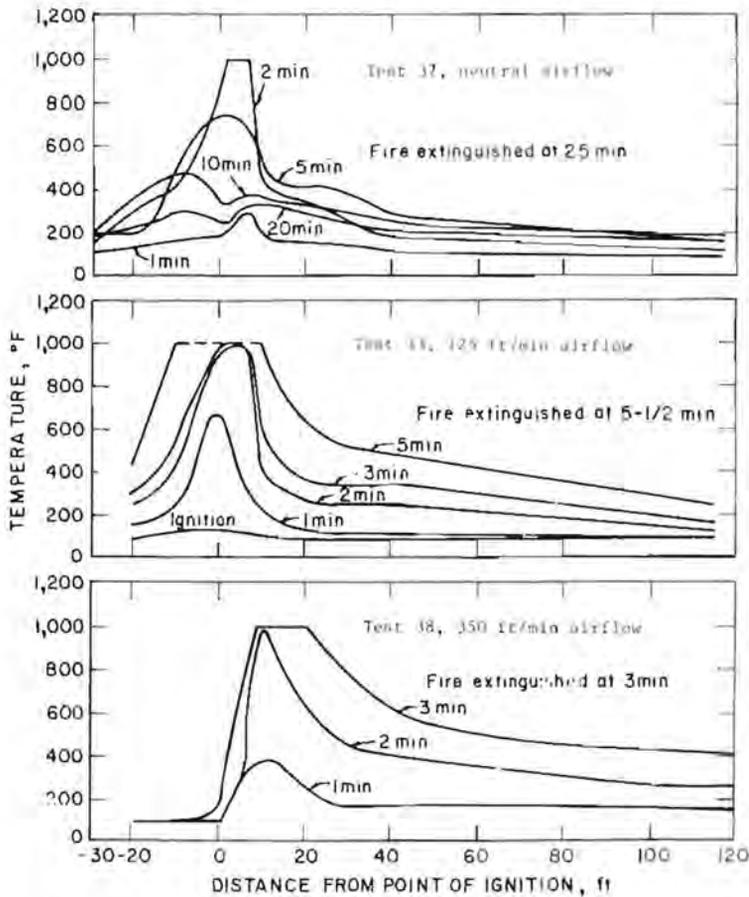


FIGURE 2. - Gallery roof temperature profiles for PVC-3 conveyor belt fires under three flow conditions.

Suppression of Conveyor Belt Fires

Present coal mining regulations (30 CFR 75.1101) require that suitable automatic fire-extinguishing systems be installed at main and secondary belt-conveyor drives and they must provide protection over a belt distance of at least 50 feet. The requirements specified for an automatic water sprinkler- or deluge-type system include an application rate of not less than 0.25 gal/min/ft² on the upper surface of the top belt, adequate coverage between top and bottom belts, a maximum spacing of 8 feet for spray nozzles or sprinklers along branch lines, and a sufficient water supply to provide a 10 min flow. Foam and dry powder chemical systems may also be used if they are capable of providing the minimum fire protection requirements defined in the regulations. The foam-generating system must be

able to produce and deliver the required amounts of foam within 5 min, it must provide full envelopment of the belt head areas and adjacent belting up to 50 feet, and it must maintain the water or foam flow for at least 25 min. Each dry powder system that is required must contain a minimum of 125 lb of multipurpose dry powder and it must be capable of discharging all the powder within 1 min. Only extinguishing agents that would not create a serious toxic hazard to the miner are acceptable. As a backup system, waterlines are required along the entire length of the conveyor belts with fire hose outlets at 300-foot intervals and with a capability of discharging 50 gallons of water per min at 50 lb/in² nozzle pressure. Where applicable, the regulations incorporate National Fire Protection Association recommendations for the installation of fire control components, namely those approved by the Underwriters Laboratories or Factory Mutual Research Corp.

The mining regulations for conveyor belt fire-suppression systems are necessarily based upon simulated full scale studies and practical experience. An evaluation of the existing regulations for water sprinkler, high expansion

foam, and multipurpose dry powder systems was conducted under the Walter Kidde contract sponsored by the Bureau of Mines. Fire detection systems were also evaluated and are discussed later; water deluge systems were not evaluated

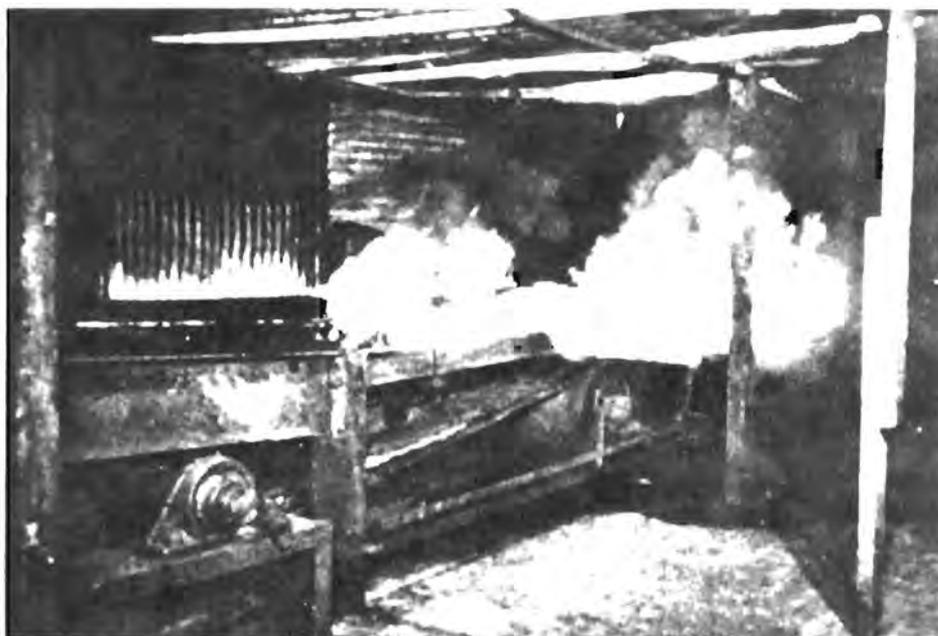


FIGURE 3. - PVC-3 conveyor belt fire prior to actuation of automatic sprinkler system at 350 ft/min air velocity.

because the criteria for water sprinkler systems would also apply to the former. The experiments were conducted in the previously described fire test gallery using the same simulated belt haulageway (fig. 1) and ignitor conditions as in the fire-resistance tests; air velocity was 125 or 350 ft/min in most trials. The test fires were produced by burning the polyvinyl chloride (PVC-3) or nonfire-resistant rubber belting listed in table 3.

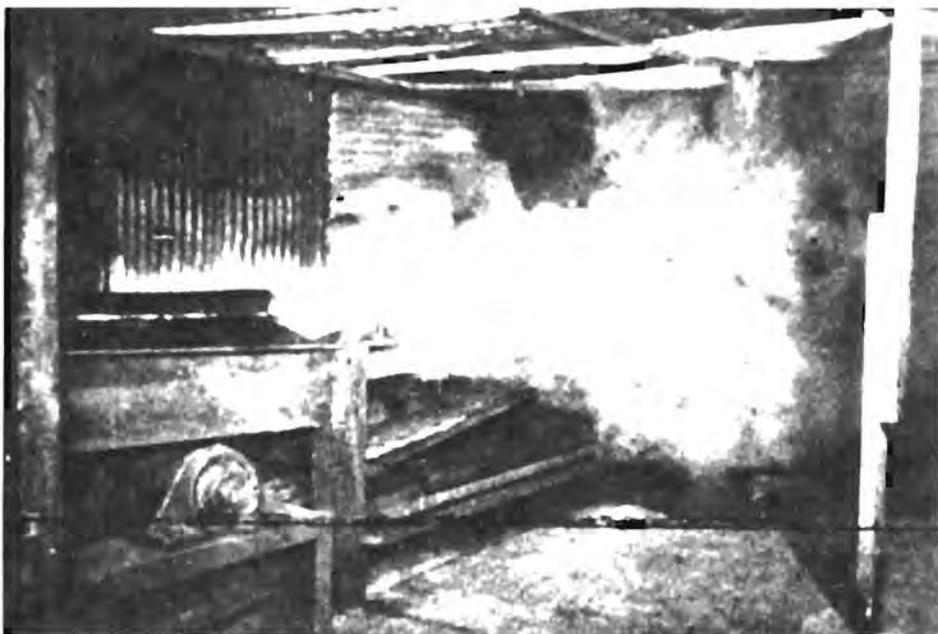


FIGURE 4. - Action of automatic sprinkler system in PVC-3 conveyor belt fire at 350 ft/min air velocity.

Automatic Water Sprinklers

The sprinkler system in the gallery consisted of a 2-inch main at the roof with 1/2-inch branches that were fitted with sprinkler heads and spaced at intervals of 8, 10, 12, and 15 feet over the conveyor belt. Each sprinkler head was equipped with a fusible link that was actuated at 165°, 212°, or 280° F. Figures 3-4 show a typical conveyor belt fire

before and after actuation of the sprinkler system with 10-foot spacing of the sprinkler heads; here the air velocity was 350 ft/min and extinguishment occurred within approximately 15 min. Sprinkler spacing appears to be one of the most critical variables in determining the system effectiveness.

Test results indicated that a single overhead branch line with 1/2-inch orifice sprinklers located on 10-foot centers and with actuation temperatures between 200° and 300° F can be adequate for suppressing conveyor belt fires in most situations; also, the residual water pressure may be as low as 10 lb/in². An exception to these results is that observed at high air velocities (for example, 350 ft/min) which tend to delay sprinkler actuation because of the cooling effect. To cover such situations, the actuation temperature should be no higher than 225° F, or the sprinkler spacing should be no greater than 8 feet, the maximum distance specified in the present regulations. The lowest practical actuation temperature should be used because it is more difficult to extinguish fully developed fires.

In these experiments, the fires were controlled with a spray application rate of 0.72 gal/min/ft² on the top surface of a 30-inch-wide belt. This rate would correspond to 0.36 gal/min/ft² for a 60-inch-wide belt that meets the minimum spray requirement (>0.25 gal/min/ft²) in the mining regulations for the upper surface of a top belt. Although only overhead sprinkler heads appeared to be necessary in these tests, early Bureau work⁵ demonstrated the need for sprinklers between belts, which are also required in existing regulations.

Automatic sprinkler systems are advantageous because of economy, reliability, good suppression capability, moderate water requirements, and minimum maintenance requirements. Also, they are not dependent upon a separate detection system, and the independent actuation of each sprinkler head provides a safeguard against the failure of a given sprinkler. Their primary disadvantage is that they are not practical at freezing temperatures.

High Expansion Foam

A foam generator with a rated capacity of 5,000 ft³/min was used to produce high expansion foam (~1,000:1) for the fire suppression tests (fig. 5). The unit was located on the air intake side, and it was capable of filling approximately 50 feet of the simulated haulageway (6 by 15 feet) within 1 min. Actuation time for the foam system was generally set for 2 min after ignition.

High expansion foam is effective for extinguishing belt-head fires, as evidenced by its performance in the present tests where the fires were rapidly quenched after they became enveloped by the foam. A foam generation rate of 10 ft/min in a belt haulageway was sufficient for extinguishment of such fires. Although the effect of preburn time was not evaluated, adequate protection seems to be possible with as little as 50 to 100 gallons of water. Since higher rates than 10 ft/min are readily achieved, the regulation requirement

⁵Reference cited in footnote 2.



FIGURE 5. - High expansion foam overflowing from test gallery.

of enveloping 50 feet of conveyor belting within 5 min is not unreasonable. Also, if the 25-min operation requirement is satisfied, this provides increased belt coverage and greater assurance of extinguishment.

The main advantages of the foam system are rapid fire suppression and low water requirements. The disadvantages include slow delivery rate, increased maintenance requirements, and potential development of gaps at the roof of the haulageway because of ventilation effects particularly at high air velocities (for example, 350 ft/min).

Multipurpose Dry Powder

The dry powder system utilized an ABC multipurpose powder (monoammonium phosphate) that was contained in a 150-lb extinguisher pressurized to 350 lb/in². The system provided coverage for 50 feet and consisted of branches on either side of the belt drive and takeup sections (see fig. 1), and along one side of adjacent belting beyond the takeup assembly. Nozzles were arranged to provide a powder discharge onto the top surface of the top belt and between the top and bottom belt layers. To simulate worst case conditions, the belt



FIGURE 6. - PVC-3 conveyor belt fire prior to actuation of multi-purpose dry powder (ABC) extinguishing system at 350 ft. min air velocity.



FIGURE 7. - Action of dry powder (ABC) extinguishing system in PVC-3 conveyor belt fire at 350 ft min air velocity.

fire was allowed to progress until a belt layer had burned through and separated. Figures 6-7 show a belt test fire before and after actuation of the extinguishing system with 50 lb of powder and an air velocity of 350 ft/min.

As with high expansion foam, extinguishment with the dry powder system is rapid. Generally, extinguishment occurred within the discharge time, which was less than 1 min as required by regulation. The most important design consideration is powder distribution to insure adequate belt surface coverage. All belt fires, except those involving decking on the conveyors, were extinguished with 75 lb of powder or less, indicating the currently specified requirements in the regulations are satisfactory. Each dry powder system should be individually designed to provide the proper

dispersion and distribution of agent along the conveyor belt system and to overcome any limitations due to shielding by decking, conveyor structure members, or other obstacles.

The advantages of the dry powder system are primarily its suppression effectiveness and capability for low temperature applications. Its disadvantages include powder distribution problems, increased maintenance requirements, and potential reignitions because of little cooling capability.

Fire Warning Systems

Regulations (30 CFR 75.1103) require that a fire sensor system be installed on each coal mine belt conveyor to stop the belt drive and provide an automatic warning, both audible and visual, when a belt fire occurs. Point temperature rise sensors are one recommended type. The sensors must be installed at the beginning and end of each belt flight, at the belt drive, and in maximum increments of 125 feet along each belt flight (50 feet where the ventilation rate is >100 ft/min). Sensors responding to radiation (ultraviolet, infrared), smoke, combustion product gases, or other indications of fire may also be used if they are spaced at proper intervals and if they provide protection equivalent to the thermal point-type sensors. Where applicable, appropriate measures must be taken to protect against loss of effectiveness caused by dust, dirt, or moisture.

Of the various types of fire detectors examined in the Walter Kidde program, the thermal point- and thermal continuous-types were found to be suitable for the mine conveyor belt application. Most are adequately sensitive for early fire detection and sufficiently durable to withstand the mine environment; also, they are relatively economical and simple to use. For belt fires with temperature histories as shown in figure 2, detection by the thermal point-type sensors can be expected to occur within 2 to 4 min; the models in the 135° to 160° F range appeared to be adequate for detector spacings up to 60 feet. In comparison, the thermal continuous-type sensors are somewhat more sensitive and can be suitable at higher temperature ratings for signaling an alarm.

Products of combustion-type detectors are less practical than the thermal-type because of their vulnerability to dust. Both ionization- and photoelectric-types displayed high sensitivity to early fire products but did not perform reliably in dust-laden air such as that possible from rock dusting operations. Smoke or combustion products from areas other than the belt haulageways could also lead to false actuations of the extinguishing system with these detectors; the same limitation applies to carbon monoxide detectors. Spacing requirements for such detectors would necessarily depend upon the ventilation rate and the time within which the detector should operate.

Optical-type detectors also have rapid response capability, but their effective range appears to be too limited for the conveyor belt application. The normal settings of most UV and IR detectors would limit their use to about 20 feet, and this assumes no gross dust obscuration or shielding by any obstacles. Furthermore, the detectors must be insensitive to extraneous light sources and the costs may be prohibitive.

Current Fire Research on Conveyor Belts

Because of the inadequacies of the Schedule 2G fire-resistance test, the Bureau recently initiated research to assist MESA in updating this approval test for conveyor belts. As part of this effort, full-scale fire tests are being conducted with various conveyor belts in a fire test gallery that was constructed for the Bureau by the Factory Mutual Research Corp. Results from this test program are intended to provide necessary design data for developing a reliable, laboratory-scale, fire-resistance test.

Figure 8 shows the fire test gallery, which is T-shaped, with each section measuring 8 by 8 by 150 feet, and with part of one section having a 12-1/2° slope. The test belts are mounted on a conveyor belt-type frame and ignited to simulate various mine fire conditions by varying the belt width, air velocity, burning angle, preheating time, ignitor heat flux, and coal dust-grease or oil accumulation. Both fire-resistant and nonfire-resistant belts are being investigated. Their fire-resistance is determined from measurements of flame spread rates, propagation distances, gallery temperatures, and the heat flux at various stations. Based upon the full-scale fire



FIGURE 8. - New fire test gallery at Factory Mutual Research Corp. test site.

data, a laboratory-scale, flame spread-type apparatus will be designed to provide fire-resistance ratings for conveyor belts that can be correlated with mine fire situations. The test method is being designed to provide quantitative ratings and to discriminate between low, moderate, and high fire-resistant materials. The Bureau is conducting the laboratory-scale study under an in-house project of its Fires and Explosions Group at Bruceton, Pa.

The toxic products formed by conveyor belts are also to be determined in the full-scale fire tests. These will include such gaseous products as HCl, NO_x, CO, and CO₂. These data will be compared with those obtained in laboratory-scale studies under an ongoing contract with Ultrasystems, Inc.⁵

Results to date from the full-scale fire tests indicate that the most important variables are the air ventilation rate, ignitor heat flux, and the distance between the belt and the roof of the simulated mine entry. An air velocity of approximately 200 ft/min and an ignitor heat flux of at least 6,000 Btu/min (8 ft² belt surface) appear to be required for any noticeable flame spread of fire-resistant conveyor belts. Furthermore, the spread of flame is much greater when the belt is mounted nearer to the roof than to the floor of the entry. This information is being used to design the initial prototype of a laboratory-scale fire-resistance test for conveyor belts. Final design of the prototype test apparatus will necessarily depend upon the determination of a realistic mine fire situation.

⁵ Paciorek, R. L., R. H. Kratzer, J. Kaufman, and J. H. Nakahara. Coal Mine Combustion Products Identification and Analysis (Research Contract H0133004 by Ultrasystems, Inc.). BuMines Open File Rept. 8-75, 1973, 158 pp., PB 226 944/AS; BuMines Open File Rept. 32-76, 1975, 158 pp., PB 250 527/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

IMPROVED FIRE SAFETY OF COAL MINE HYDRAULIC SYSTEMS

by

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ABSTRACT

Mobil Research and Development Corp. is the primary contractor to the Federal Bureau of Mines for an ongoing research contract, "Improved Fire Safety of Coal Mine Hydraulic Systems." The objectives of the contract are to develop design and performance criteria for fire-resistant hydraulic fluid systems for use in underground equipment in the U.S. coal mining industry, and to develop fire-resistant hydraulic fluids for use in systems meeting these criteria.

Prior to initiation of experimental work under the contract, published U.S. and foreign experience with fire-resistant hydraulic fluids was reviewed together with the cost-performance features of the various classes of fire-resistant hydraulic fluids available. It was concluded that HS-B fluids (water-in-oil emulsions containing approximately 45 wt-pct water) was the preferred fluid that should be studied for possible use in underground hydraulic systems such as those employed in continuous miners, shuttle cars, and roof bolters.

Subsequently, advanced emulsion fluids were developed and performance under laboratory-test conditions were documented in detail. Mine demonstration tests are now in progress in two continuous miners, with active participation from the builders of the test pumps and of the continuous miners. One of these miners uses both constant and variable volume axial piston pumps with operating pressures up to 3,200 lb/in²; the second employs tandem gear test pumps with pressures up to 1,700 lb/in².

After 5 months, the experimental water-in-oil emulsion hydraulic fluid selected for the test has given good in-mine service performance with no lubricant-related system problems. Completion of the scheduled 9-month demonstration test should provide the best available performance documentation for these fire-resistant fluids in well-maintained underground equipment in the United States.

INTRODUCTION

Fire-resistant hydraulic fluids have been increasingly used worldwide during the past 20 years in underground mining equipment. Different countries have adopted different legislative philosophies toward these fluids. At the present time, underground usage ranges from compulsory for essentially all

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hydraulic systems, as in the United Kingdom, to advisory (as an alternate to fire-suppressant devices on unattended hydraulic systems) as in the United States.

In 1975, the Federal Bureau of Mines awarded a research contract to Mobil Research and Development Corp.³ entitled "Improved Fire Safety of Coal Mine Hydraulic Systems." It was envisaged that satisfactory completion of the contract objectives would provide an improved documentation of the scope and limitations of advanced fire-resistant hydraulic fluids for potential use in underground mining equipment in the United States. Emphasis was to be placed on equipment used at the coal face; namely, continuous miners, shuttle cars, roof bolters, and supports. The contract was defined in the six phases shown in table 1.

TABLE 1. - Federal Bureau of Mines contract No. H0357108 objective

Phase	Objective
I.....	To review available information and determine what system deficiencies exist in the United States and should be corrected.
II.....	To develop design and performance criteria for fire-resistant hydraulic fluids for use in large underground mining equipment and supports.
III.....	To develop fluids meeting the existing MESA Schedule 30 ¹ requirements for fire resistance and other practical performance requirements from phase II.
IV.....	To define suitable procedures for checking the condition of the fluid, particularly with respect to fire-resistance, at the mine site.
V.....	To recommend any changes necessary to improve or update the MESA Schedule 30 approval tests.
VI.....	To conduct full-scale mine demonstration tests using fire-resistant fluids developed under the contract.

¹Code of Federal Regulations, Title 30, Chapter 1, Part 35.

This interim report is largely limited to (1) a brief review of available fire-resistant hydraulic fluid technology, (2) consideration of some of the lubricant-related factors documented under phase III of the contract, and (3) a status report on the phase VI mine demonstration test. A complete report will be published after completion of the contract.

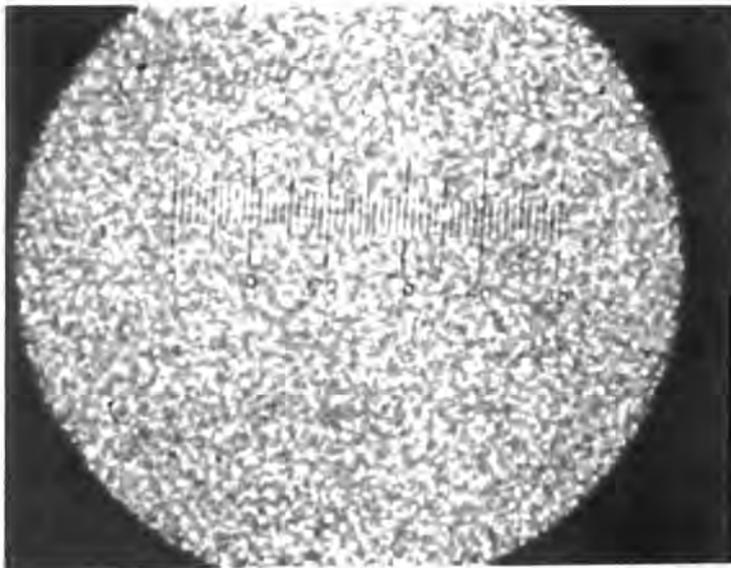
FIRE-RESISTANT HYDRAULIC FLUID CLASSIFICATION

Four classes of fire-resistant hydraulic fluids have been recognized by members of the International Standards Organization (ISO), and all four have been considered. Some are in use now on some underground mining applications. The fluid classifications are shown in table 2.

TABLE 2. - ISO fire-resistant hydraulic fluid classifications

Class	Description
HS-A.....	Oil-in-water emulsions containing a maximum of 20 pct combustible material. These usually contain 95 pct water.
HS-B.....	Water-in-oil emulsions containing a maximum of 60 pct combustible material. These usually contain 40 to 45 pct water.
HS-C.....	Water-glycol solutions. These usually contain at least 35 pct water.
HS-D.....	Water-free fluids. These usually refer to phosphate ester-containing fluids.

³Reference to specific manufacturers does not imply endorsement by the Bureau of Mines.



Emulsion magnified 1,000 times

FIGURE 1. - Mineral oil and water-in-oil emulsion hydraulic fluids.

Considering the cost and performance features of the four fluid types, HS-B fluids have evolved as the preferred class for underground mining applications in the United States.

Water-in-oil or inverted emulsions depend upon their water content for fire resistance. The oil phase of the emulsion is much like the mineral oils for which most industrial systems are designed. The oil surrounds finely divided droplets of water that are uniformly dispersed throughout the mixture by chemical emulsifiers. This can be seen under the microscope as illustrated in figure 1.

THE DEVELOPMENT OF ADVANCED WATER-IN-OIL EMULSIONS

Definition of Fire Resistance

The contract specifically requires that the fire resistance levels afforded by high-quality, commercially available emulsions cannot be compromised. Therefore, considerable attention was paid to identifying and quantifying the interrelationship between (1) the physical properties (for example, viscosity) of the oils used as the continuous phase of the water-in-oil emulsions, (2) the physical properties of the fully formulated emulsions, (3) the water content of the emulsions, and (4) the fire resistance of the

emulsions as measured by the procedures published in the Federal Schedule 30 and in the Factory Mutual Standard 6930. The latter is under review by the American Society of Testing and Materials (ASTM) as a possible ASTM standard, and it was therefore considered appropriate to include the Factory Mutual

procedure in the contract studies. As indicated earlier, the contract also specified that the existing Schedule 30 test be retained as one measure of fire resistance.

Typical data shown in figures 2-4 are as follows:

1. That the kinematic viscosity of water-in-oil emulsions⁴ increases with increasing water content and increasing viscosity of the oil phase of the emulsion (fig. 2).
2. That the minimum amount of water required to give passing results in the Mining Enforcement and Safety Administration (MESA) and Factory Mutual flammability tests is dependent on the oil phase used (fig. 3). Higher viscosity (lower volatility) base oil requires less water.
3. That the emulsions developed for the in-mine demonstration test (fig. 4) are close to the minimum water content. This exemplifies the need for careful in-service monitoring of these emulsions as well as conventional hydraulic fluids.

It should be emphasized that both the Schedule 30 and the Factory Mutual spray flammability test requirements are based on "go-no go" evaluations rather than on detailed numerical or relative ratings. Therefore, there can be no borderline ratings by definition. However, the presence of water, even though not sufficient to pass these tests, still offers considerable capability as a fire-resistant fluid on an absolute scale. Figures 5-6 compare an emulsion with a conventional mineral oil which clearly failed to meet the spray flammability test requirements.

Evaluation and Use as Functional Fluids

Fluid performance criteria and system and operational guidelines developed for use with water-in-oil emulsion hydraulic fluids have been identified under the contract and will be published separately. These guidelines relate to:

1. The definition of satisfactory emulsion stability. The emulsions can separate into their oil and water components after prolonged static storage at a constant temperature or after multiple freeze-thaw cycles.
2. Proof of performance in established laboratory rust and corrosion tests.
3. Proof-of-performance testing in laboratory vane, axial piston, and gear pumps of the types used in underground mining systems.
4. The definition of limiting operating temperatures and pressures together with filtration and maintenance recommendations consistent with the special requirements of water-containing hydraulic fluids.

⁴Emulsions are measured in centistokes (cs) at 37.8° C.

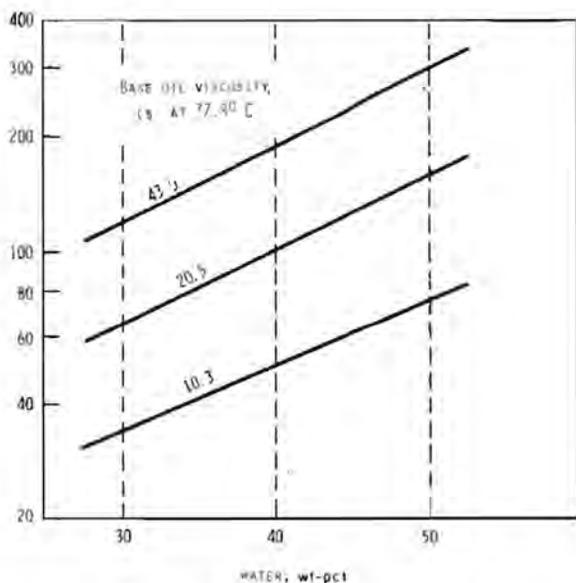


FIGURE 2. - Effect of water content and base oil viscosity on emulsion viscosity.

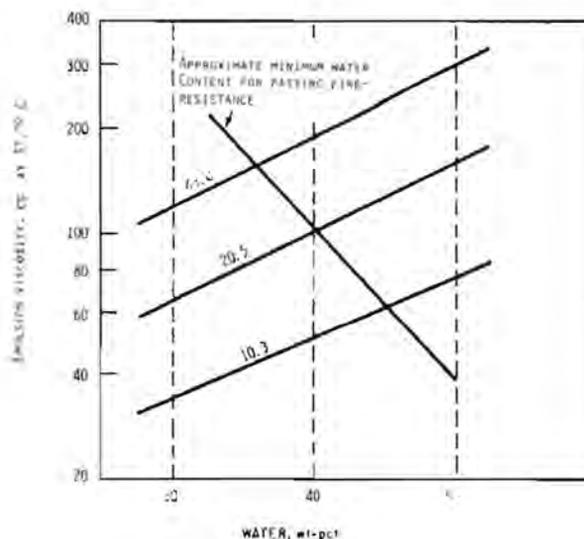


FIGURE 3. - Definition of minimum acceptable water content for fire-resistant emulsions.

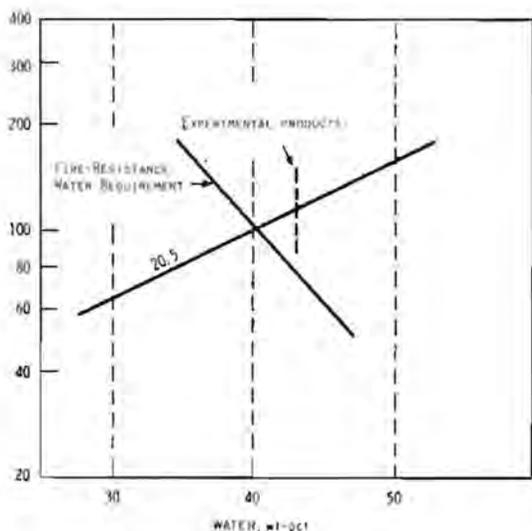


FIGURE 4. - Definition of experimental products for detailed study.



FIGURE 5. - Spray ignition fire test with failing emulsion.

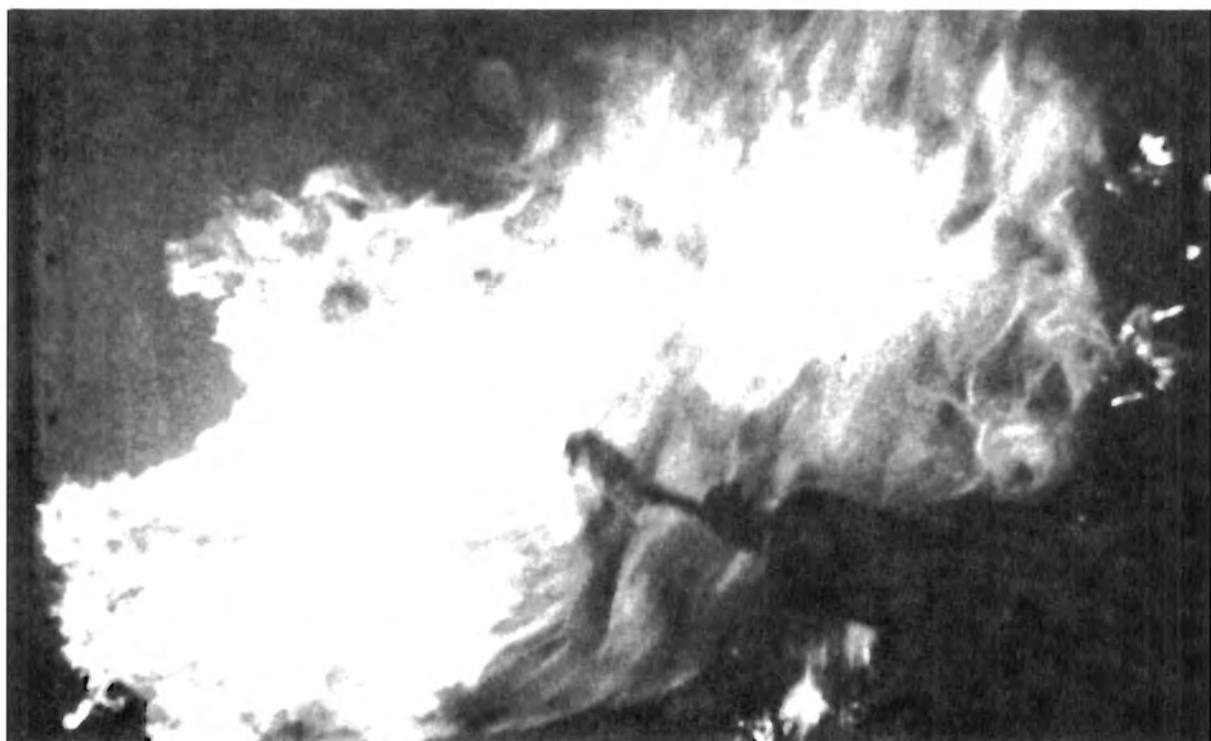


FIGURE 6. - Spray ignition fire test with conventional mineral oil.

MINE DEMONSTRATION TEST

The proof of any development is a trial under actual use conditions. Thus, a trial was planned in underground mining equipment of an advanced water-in-oil emulsion hydraulic fluid (designated XRL 1110) developed to meet the performance criteria guidelines defined in the earlier project phases. The fluid was installed in May 1977 in two continuous miners, one using both constant and variable volume axial piston pumps with hydraulic pressures up to 3,200 lb/in², the other using three tandem gear test pumps operating at hydraulic pressures up to 1,700 lb/in² as shown in Tables 3-4.

During the 5 months of testing, the experimental water-in-oil emulsion hydraulic fluid XRL 1110 has performed satisfactorily both as a lubricant and as a fire-resistant hydraulic fluid during actual field service in continuous miners. Test results and conclusions based on both pump and fluid inspections are summarized in table 5 which indicates that:

1. Four production batches of XRL 1110 have met the contract phase II fluid performance criteria guidelines demonstrating that the fluid can be made repeatedly in normal production facilities.

2. Pump inspections run prior to the contract test and during the actual test with XRL 1110 showed that essentially all problems possibly related to hydraulic system malfunction during this period were nonlubricant-related and could be explained in terms of:

- (1) Pump changes as precautionary measures were later identified with problems elsewhere in the hydraulic system.
- (2) Malfunction resulted from gross contamination of the hydraulic fluid.
- (3) Misalignment of components occurred during or after installation.
- (4) Nonlubricant-related pump component failure had occurred.

3. Used XRL 1110 fluid characteristics have been determined after mine service temperatures in the 110° to 120° F range for continuous miner 1 and the 135° to 152° F range for continuous miner 2 as follows:

- (1) Apparent viscosities of XRL 1110 in each miner have remained relatively unchanged as shown in figure 7.
- (2) Water contents have remained essentially unchanged at a nominal 43 to 45 wt-pct in both miners as shown in figure 8.
- (3) Contamination levels have generally been in the 3 to 8 mg/100 cc range except in continuous miner 2 (fig. 9) which resulted in the need for a lubricant change.
- (4) Fire resistance of XRL 1110 from both miners remains good as measured by the Schedule 30 test procedure.

TABLE 3. - Hydraulic system test components, continuous miner 1

Hydraulic pumps:			Filtration:	
Displacement.....	Variable volume ¹ ...	Constant volume. ¹	Type.....	Return line.
Type.....	Axial piston.....	Axial piston.	Filters: ²	
Maximum operating pressure.	3,200.....	3,200.	Type...	Wire mesh.
			Size...	74 micrometers. ³

¹Number on miner, 1.

²Number on miner, 3.

³Space limitations precluded installation of the recommended finer filters.

NOTE.--Initial condition: New with components premeasured and preinspected by the pump builder.

TABLE 4. - Hydraulic system test components, continuous miner 2

Hydraulic pumps:	Tandem gear						Filtration:	Suction.....	Pressure (installed for this test).	
	Boom jacks ¹		Tram circuits ¹		Clutches ¹					Type.....
	A ₁	A ₂	B ₁	B ₂	C ₁	C ₂				
Function.....										
Designation.....										
Maximum operating pressure.....	1,700	1,000	1,700	1,700	1,700	500				
Gear width.....	1.5	0.75	2.0	2.0	0.5	0.5				
							Filters: ¹			
							Type...	Paper, resin treated.		
							Size...	40 micrometers		
								Paper, resin treated. 10 micrometers		

¹Number on miner, 1

NOTE.--Initial condition: New with components premeasured and preinspected by the pump builder.

TABLE 5. - Mine demonstration test using the experimental fluid XRL 1110

(Summary of 5 months of test results)

	1	2
Continuous miner.....		
New XRL 1110 fluid properties: ¹		
Temperature range.....° F..	110 to 130.....	130 to 152.
Test duration.....days..	150.....	150.
Tons of coal mined.....	60,000.....	53,000.
Used XRL 1110 fluid properties:		
Viscosity, cs.....40° C..	140 to 146.....	130 to 146.
Water content.....wt-pct..	43 to 46.....	43 to 46.
Contamination.....mg/100 cc..	3 to 8.....	3 to 8.
Fire-resistance:		
MESA Schedule 30.....	Pass.....	Pass.
Factory Mutual Standard 6930.....	Estimated pass.....	Estimated pass.
Hydraulic pump condition:		
Number of pumps inspected prior to and during test.	4.....	5.
Type.....	Variable and constant volume axial piston.	Tandem gear.
Failure mechanisms.....	None or nonlubricant-related.	4, nonlubricant-related; 1, incipient-bearing fatigue (trace spalling).

¹Within phase II specified limits.

NOTE.--Operating characteristics are within phase II guidelines except for filtration on miner 1 which is 74 micrometers versus 10 micrometers recommended. Number and frequency of changes may eliminate the need for 10-micrometer filter.

In conclusion, the data available thus far suggest that the type of water-in-oil fire-resistant emulsion hydraulic fluid defined under the contract will give good performance as a functional lubricant in well-maintained underground coal mining systems. A detailed report will be prepared after completion of the ongoing studies.

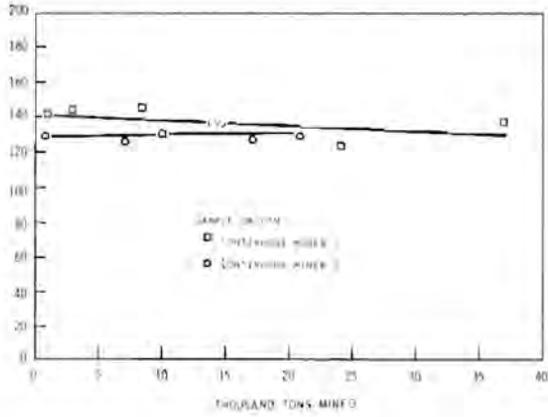


FIGURE 7. - Viscosity variation of XRL 1110 fluid in mine demonstration.

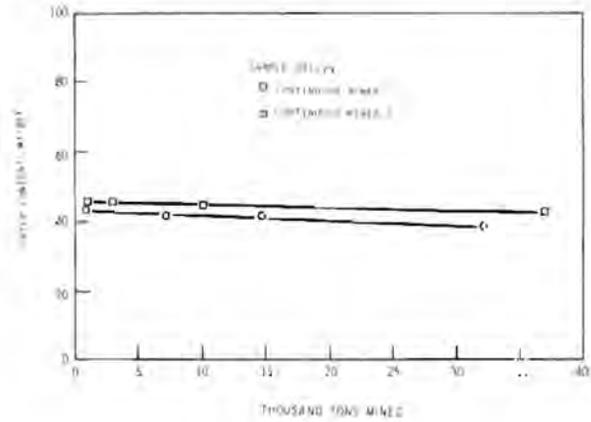


FIGURE 8. - Water content variation of XRL 1110 fluid in mine demonstration.

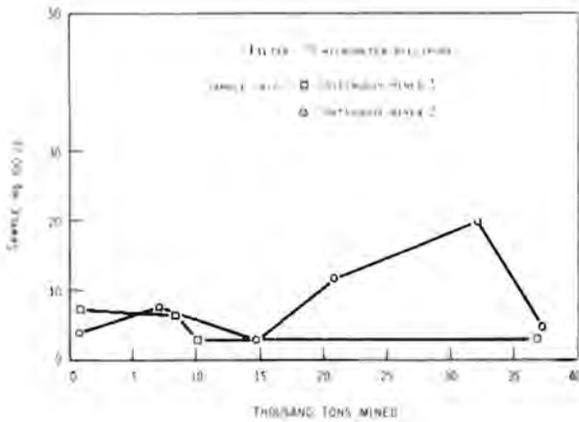


FIGURE 9. - Particulate contamination of XRL 1110 fluid in mine demonstration.

IMPROVED FIRE PROTECTION SYSTEMS FOR SURFACE COAL MINING EQUIPMENT

by

G. A. Johnson¹

ABSTRACT

As surface coal mining equipment becomes larger, the danger to a driver during a fire emergency is increased because of the greater height of the cab above ground. Also, property damage from fires on the larger equipment can be substantial. To help solve this problem, the U.S. Department of the Interior's Bureau of Mines has developed automatic fire sensing and suppression systems for engine compartments and fuel storage areas of large, mobile mining equipment.

The prototype systems sense the flame and/or heat of a fire, then automatically suppress the fire with a B-C class, dry chemical. The systems can also be manually activated. The first system was developed in the fall and winter of 1972-73, and was successfully demonstrated during in-mine fire tests on a 100-ton-capacity truck. Other systems have been developed and in-mine tested on coal augers and large dozers. Bureau plans call for modification and long-term endurance testing of alternate systems on large drills, shovels, and draglines.

INTRODUCTION

As surface coal mining trucks, shovels, dozers, etc., become larger to increase productivity, the danger to drivers during a fire emergency increases. The cabs are usually located high above the ground, and the access ladder is usually next to the engine compartment where most vehicle fires occur. Also, some operating compartments are cramped and egress is difficult.

To help solve this mine equipment safety problem, and to better protect expensive pieces of equipment, the Bureau of Mines, through contract and in-house research, has developed reasonably priced, reliable automatic fire protection systems. This work was initiated with two open pit metal mining safety contracts with FMC Corp., San Jose, Calif., in 1972-74. One objective of the first contract was to define the large mobile vehicle fire problem and then to develop improved fire system design criteria to solve it. Another objective of the first contract was to find the most fire-prone class of equipment. Once this type of vehicle was found, its fire problem was to be solved with a system flexible enough to be modified for other large mobile mining equipment.

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HAULAGE TRUCK FIRE PROTECTION

As a result of this hazard analysis study, a "dual sensing, automatic with manual override, fire detection and suppression system" was designed for rear-dump haulage trucks of over 100-ton capacity, which were the most hazardous. The first system protected both the engine compartment and brake grid areas of the truck and suppressed the fire with pressurized, B-C class dry chemical. Near-infrared and thermal wire sensors detected the fire. The system's electronic controls had a time sequence which allowed the driver to use manual switches to suppress the fire; but, if the driver did not activate the system, it discharged automatically. This "automatic, with manual override" control feature was preferred to a totally manually activated system because of the panic situation usually prevalent during a large vehicle fire emergency. Most drivers during a fire think only to get away from the truck and they seldom activate the manual systems currently available on trucks. Automatic engine shutdown is not a part of the system's design, but the option can be added easily if the user wishes.

The third objective of the first FMC truck fire contract was to fabricate a prototype system and test it at a mine site. The "first generation" automatic truck fire protection system was successfully demonstrated in April 1973, on a 100-ton-capacity truck at the Pima mine, Tucson, Ariz.²

The second FMC truck fire contract sought to first reinstall the automatic fire protection system prototype on the 100-ton-capacity Pima mine truck for long-term, reliability testing. This testing pointed out weaknesses in the first system, thus a modified, "second generation" truck fire system was developed. It was then subjected to long-term on-vehicle testing at the Erie Mining Co., Hoyt Lakes, Minn., in the winter of 1973-74. During the long-term testing at Pima, an accidental fire occurred on the test truck and the prototype system automatically sensed and extinguished the fire. This "real life" system test gave the Bureau's technology a lot of creditability in the Tucson area.

Both truck fire systems were designed so they would be rugged, easy to install, and be of reasonable cost (about \$3,000 to \$5,000) compared with the

²FMC Corporation. Improved Sensors and Fire Control Systems for Mining Equipment (Research Contract H0122053). BuMines Open File Rept. 25(1)-74, 1972, 252 pp., PB 232 405/AS; BuMines Open File Rept. 25(2)-74, 1973, 178 pp., PB 232 406/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

\$300,000, and higher, costs of large haulage trucks. FMC Corp. produced a final report and a user's manual describing the second truck fire system.^{3 4}

A later Bureau publication⁵ summarizes the FMC Corp. efforts and outlines the Bureau's plans for further mine equipment fire safety work.

COAL AUGER FIRE PROTECTION

Following the open pit truck fire work, the Bureau expanded its mine equipment fire protection efforts to surface coal mining. This involved awarding a contract to the Lease APEX Corp. of Raleigh, N.C., to modify and in-mine test a low-cost automatic fire protection system for surface coal augers. This system was fabricated and then tested on a Compton⁶ auger at the Cedar Coal Co., Chelyan, W. Va. The APEX system involves point-source-type heat sensors and two independent dry chemical extinguishant subsystems, one for each engine-operator area on the auger. The system was subjected to 6 months of in-mine testing, then test fired in 1975. Details of the design and effectiveness of this system are in a final contract report.⁷

The Bureau then added a cooperative agreement with the Ansul Co., Marinette, Wis., in its 1975 work to help in the evaluation of a new, pneumatically

³FMC Corporation. System Modification and Validation Testing of Fire Protection Systems for Mine Haulage Trucks. Final Report (Research Contract H0122053). BuMines Open File Rept. 33-74, 1974, 170 pp.; PB 234 577/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

⁴FMC Corporation. A Guide to the Selection of Automatic Fire Protection Systems for Mine Haulage Equipment (Research Contract H0122053). BuMines Open File Rept. 34-74, 1974, 8 pp., PB 234 575/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

⁵Johnson, G. A., and D. R. Forshey. Automatic Fire Protection Systems for Large Haulage Vehicles. Prototype Development and In-Mine Testing. BuMines IC 8683, 1975, 16 pp.

⁶Reference to specific equipment or manufacturers is made for identification only and does not imply endorsement by the Bureau of Mines.

⁷Lease, W. Development and Testing of a Fire Protection System for Coal Augers (Research Contract S0251046 by Lease APEX, Inc.). BuMines Open File Rept. 25-76, 1975, 13 pp., PB 249 865/AS; available for consultation at Bureau of Mines facilities in Denver, Colo.; Twin Cities, Minn.; Pittsburgh, Pa.; Spokane, Wash.; Department of Energy, Morgantown Energy Research Center, Morgantown, W. Va.; the National Library of Natural Resources, U.S. Department of the Interior, Washington, D.C.; and National Technical Information Service, Springfield, Va.

operated, low-cost, automatic fire protection system. The main activity of this project was testing on front-end loaders and haulage trucks. Ansul's system is currently undergoing further testing and refinement.

MINING DOZER FIRE PROTECTION

The Bureau's most recent work concerning improved fire protection systems involves testing an AFEX-type system on large dozers. The Bureau's Twin Cities Mining Research Center, Minneapolis, Minn., is conducting this in-house project with the help of the Lemmons Coal Co. of Boonville, Ind. As of the spring of 1976, the AFEX system has been installed on a Fiat-Allis HD 41 tractor at the company's Boonville and Shoals mine for a period of approximately 6 months. The system was test-fired in March 1976, and the dry chemical appeared to cover the fire hazard areas of this large dozer well. No dry chemical entered the cab and the system expelled the 40 lb of dry chemical in approximately 15 sec, an adequate time interval for the operator to shut down his machine and exit.

Concurrent with the dozer fire system work, the Bureau of Mines is also working with other mines, fire protection equipment companies, and mine equipment manufacturers to make available rugged, cost-effective, automatic fire protection systems for other classes of large, mobile mining equipment such as shovels and large blasthole drills. Also underway is a major metal and non-metal health and safety contract to improve fire protection for shafts and shaft stations. Information on the availability of this prototype hardware will be published soon.

The following discussion describes the highlights of the Bureau's ongoing mine equipment fire systems work:

Figure 1 shows a fire on a haulage truck in 1972. This vehicle has a manually activated, fixed fire-protection system, but the driver did not activate it prior to jumping from the cab. Figure 2 shows the factors considered in the design of the first system. Note that cost was a major concern. No matter what the Bureau developed, if its cost-effectiveness was not proved to the industry, the novel hardware would have little acceptability. Figures 3-4 show the first prototype system. Figure 5 shows the lighting of the first truck fire test of the system on the 100-ton-capacity truck. Figure 6 shows the system automatically sensing and successfully extinguishing the test fire. Figure 7 shows the modified truck fire system. Note that two 20-lb dry chemical subsystems protect the engine-fuel tank area of the vehicle. Figure 8 shows the components of the FMC-type, automatic truck fire-protection system. Figure 9 is a schematic of the entire AFEX-type automatic surface coal auger fire-protection system. Figure 10 is the West Virginia mine where the prototype system was tested for 6 months, and figure 11 is a view of the Compton auger used in the test. Figures 12-13 show a distributor test of the dry chemical from the system where good coverage was obtained. Figure 14 shows the details of the AFEX-auger system. Figure 15 shows a new large coal hauler the class of which will be used for more in-mine testing of AFEX-type, low-cost automatic fire protection systems.

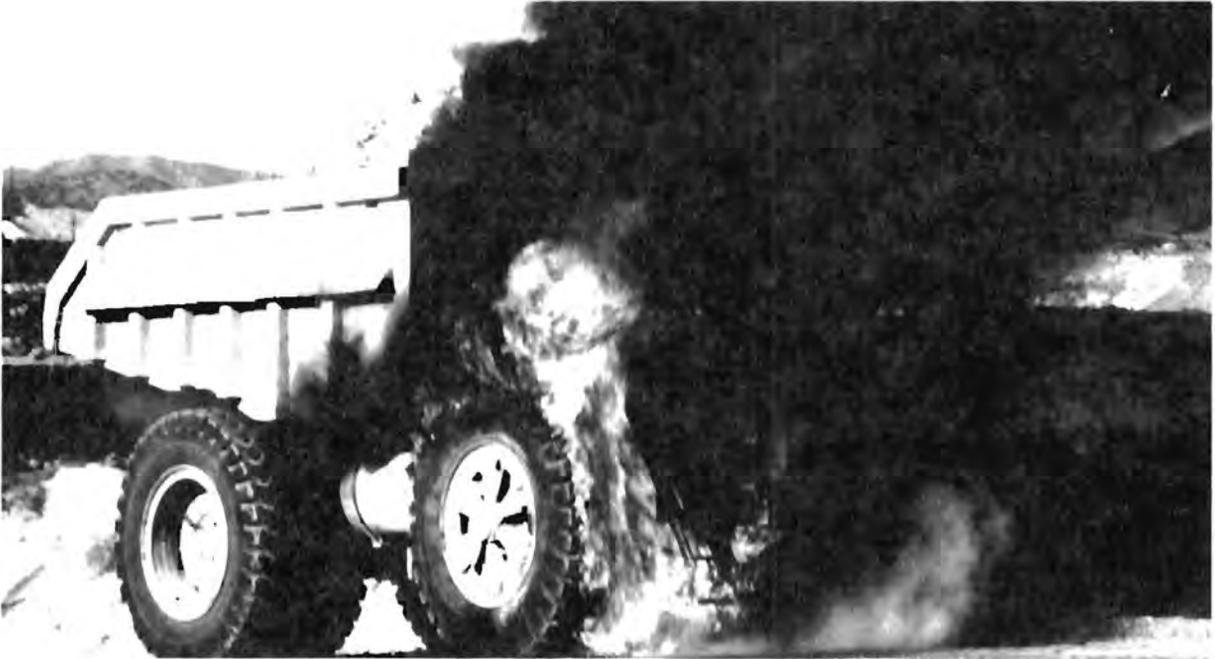


FIGURE 1. - Typical open pit haulage truck fire.

FIRE

- CLASS
- SIZE
- SPEED OF PROPOGATION
- COMPONENT

EXTINGUISHING AGENT

- DRY POWER
- FOAM
- WATER
- GAS

SENSOR

- OPTICAL
- THERMAL
- GAS/SMOKE
- PRESSURE

CONTROL SYSTEM

- MANUAL/SEMIAUTOMATIC/AUTOMATIC
- VISUAL/AUDIBLE WARNING
- LOGIC

COST

- DEVELOPMENT
- PRODUCTION

FIGURE 2. - Typical factors considered in developing systems.

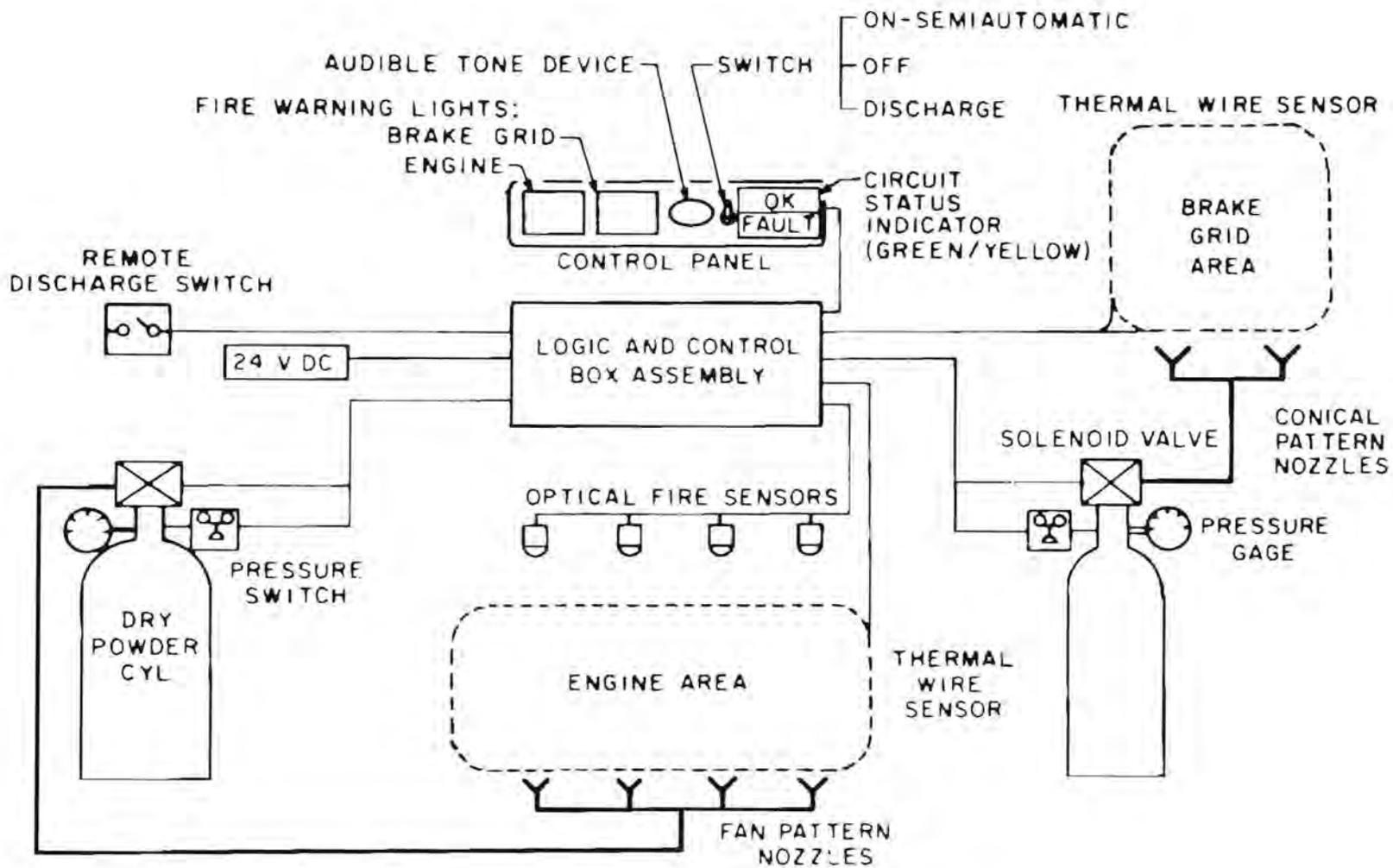
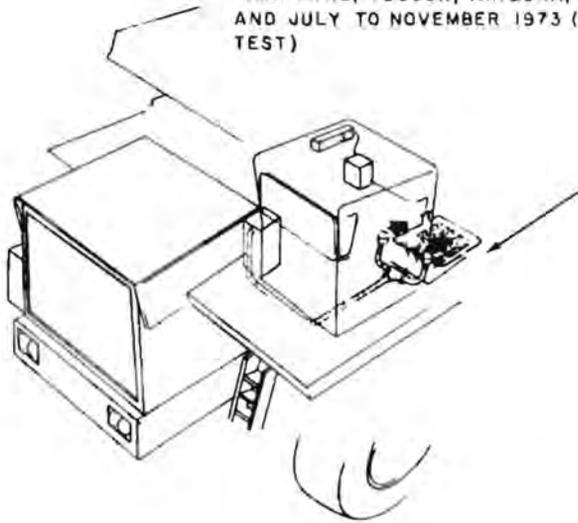


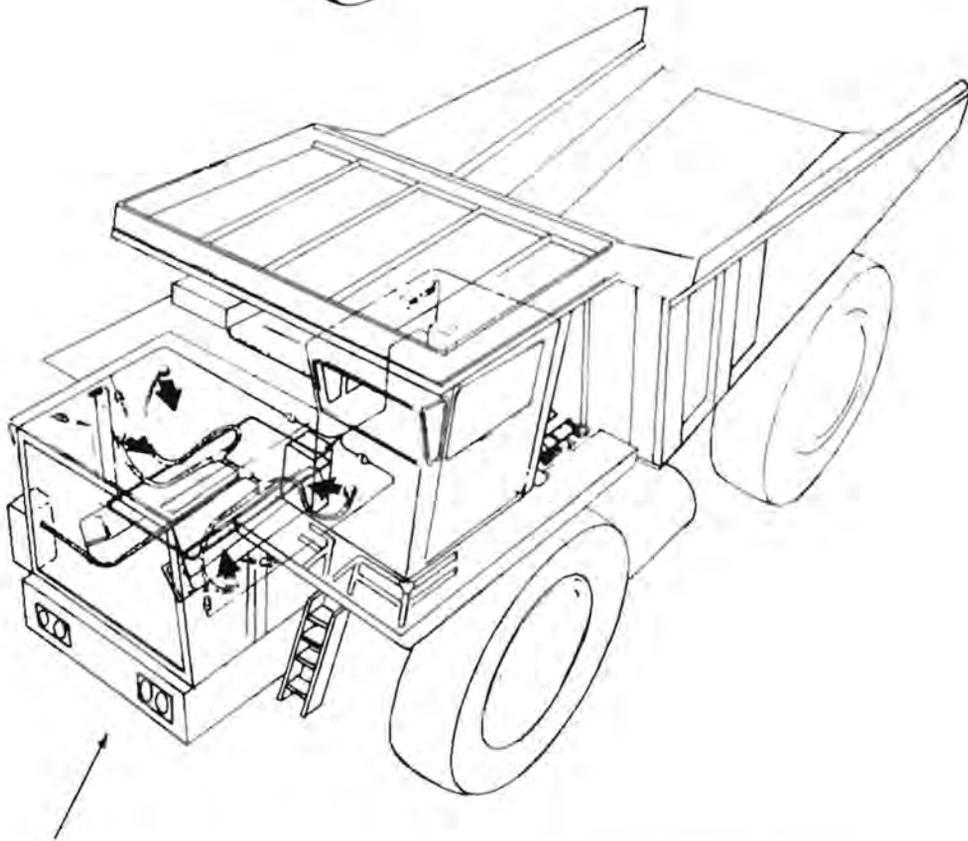
FIGURE 3. - The first automatic truck fire protection system.

FIRST PROTOTYPE

SHOWN AS INSTALLED ON THE 100-TON-CAPACITY TEST TRUCK AT THE PIMA MINE, TUSCON, ARIZONA, IN MARCH 1973 (SYSTEM DEMONSTRATION) AND JULY TO NOVEMBER 1973 (LONG TERM, HOT WEATHER SYSTEM VALIDATION TEST)



BRAKE GRID FIRE PROTECTION: THERMAL WIRE SENSOR AND 25 POUNDS OF DRY POWDER (B-C CLASS) SUPPRESSANT



ENGINE AREA FIRE PROTECTION: BOTH OPTICAL AND THERMAL WIRE SENSORS AND 18 POUNDS OF DRY POWDER (B-C CLASS) SUPPRESSANT

FIGURE 4. - First prototype installed on the 100-ton-capacity truck.



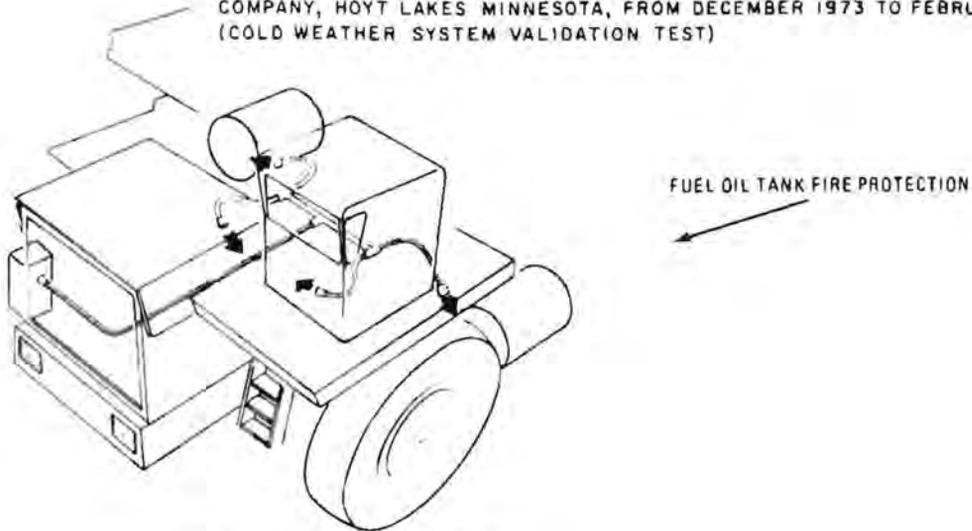
FIGURE 5. - Lighting the 1973 truck fire test on a 100-ton-capacity truck at the Cyprus Pima mine, Tucson, Ariz.



FIGURE 6. - The first generation automatic truck fire protection system successfully extinguishing the 1973 Pima fire test.

SECOND PROTOTYPE

SHOWN AS INSTALLED ON THE 100-TON-CAPACITY TEST TRUCK AT ERIE MINING COMPANY, HOYT LAKES MINNESOTA, FROM DECEMBER 1973 TO FEBRUARY 1974 (COLD WEATHER SYSTEM VALIDATION TEST)



DESIGN CHANGES FROM 1ST PROTOTYPE
 SIMPLIFIED CONTROL PANEL
 NO BRAKE GRID FIRE PROTECTION
 TEMPERATURE COMPENSATED THERMAL SENSOR
 ADDITIONAL TEST AND FAIL SAFE CIRCUITS

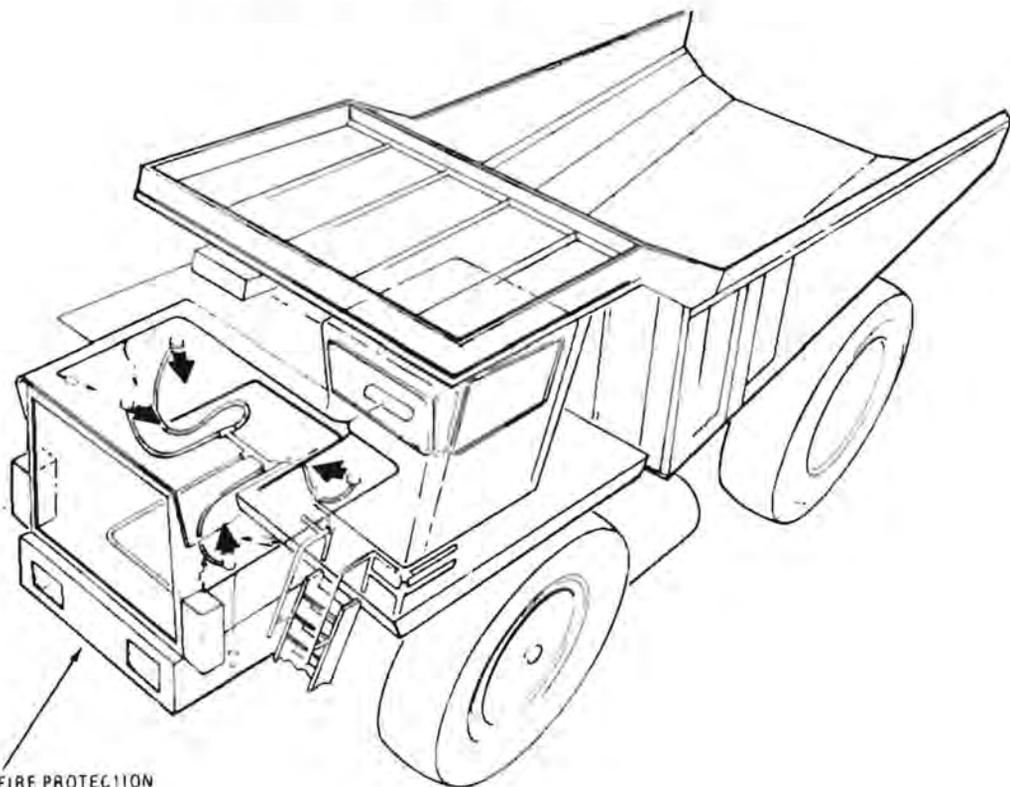


FIGURE 7. - Second prototype installed on the 100-ton-capacity truck.



FIGURE 8. - Components of the second generation system.

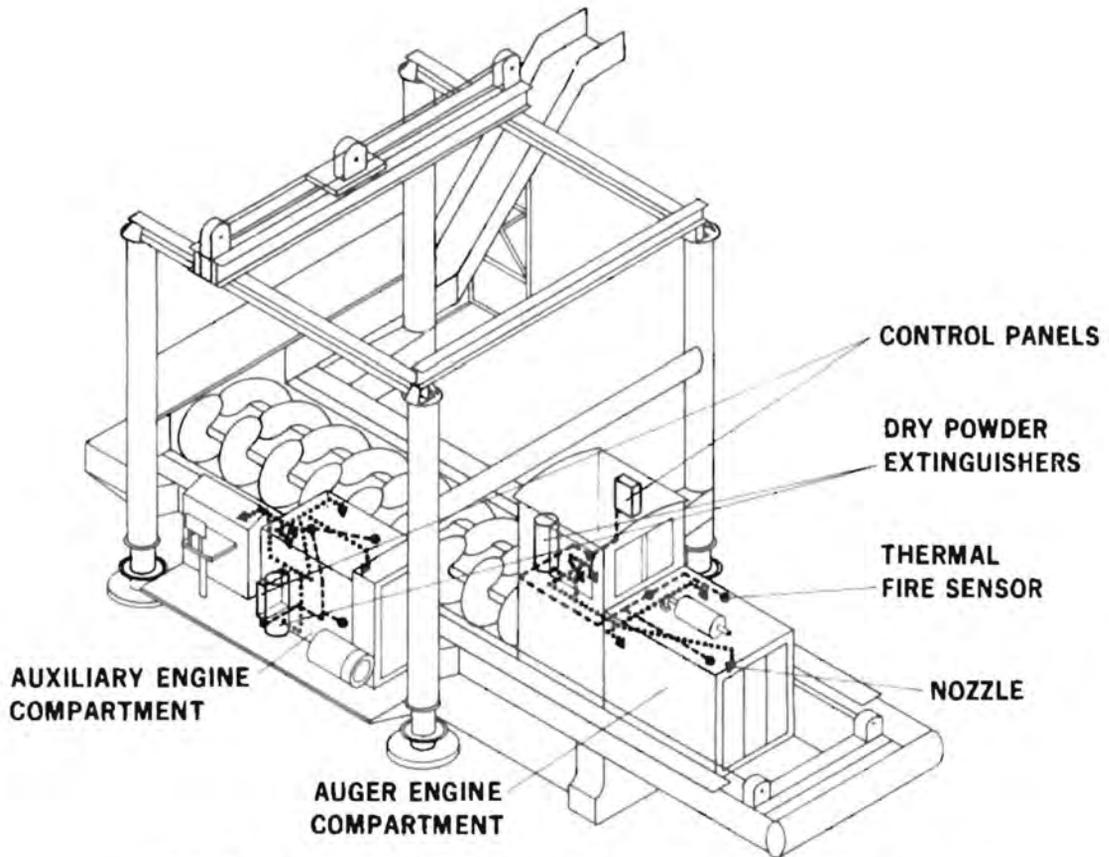


FIGURE 9. - Automatic fire protection system for coal augers.



FIGURE 10. - Compton coal auger, Cedar coal mine, Chelyan, W. Va.

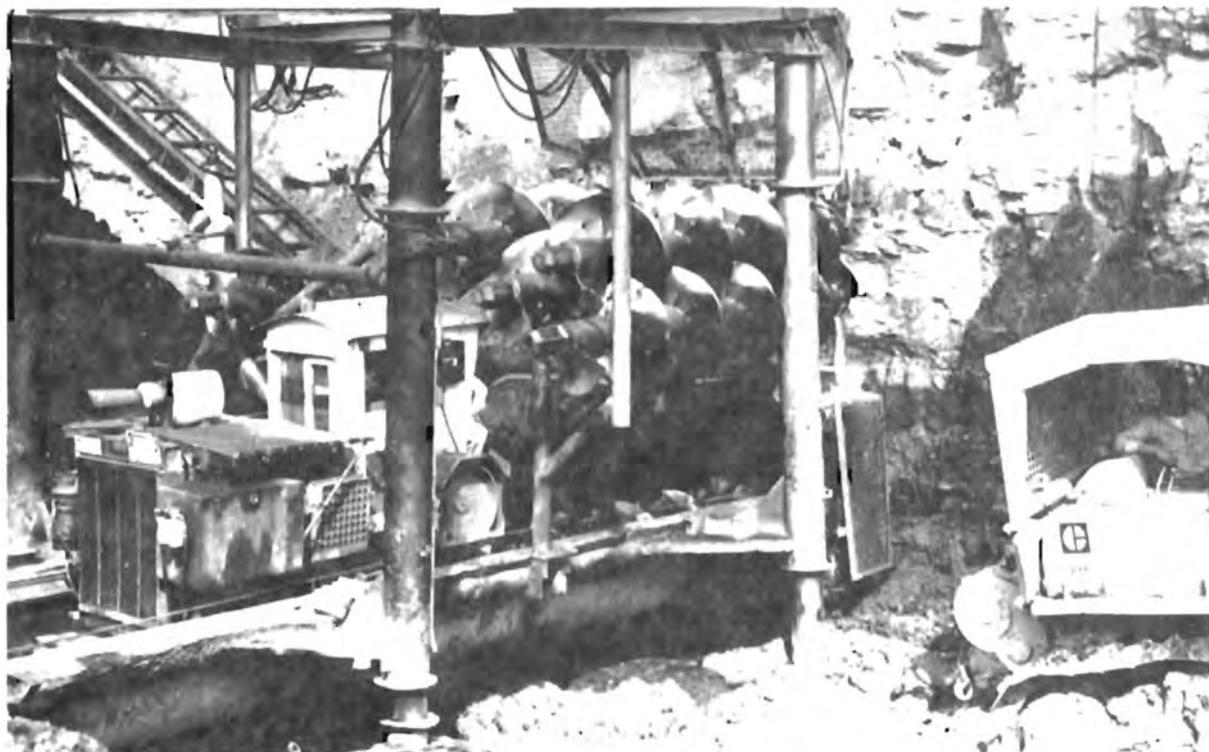


FIGURE 11. - Compton auger with AFEX system.

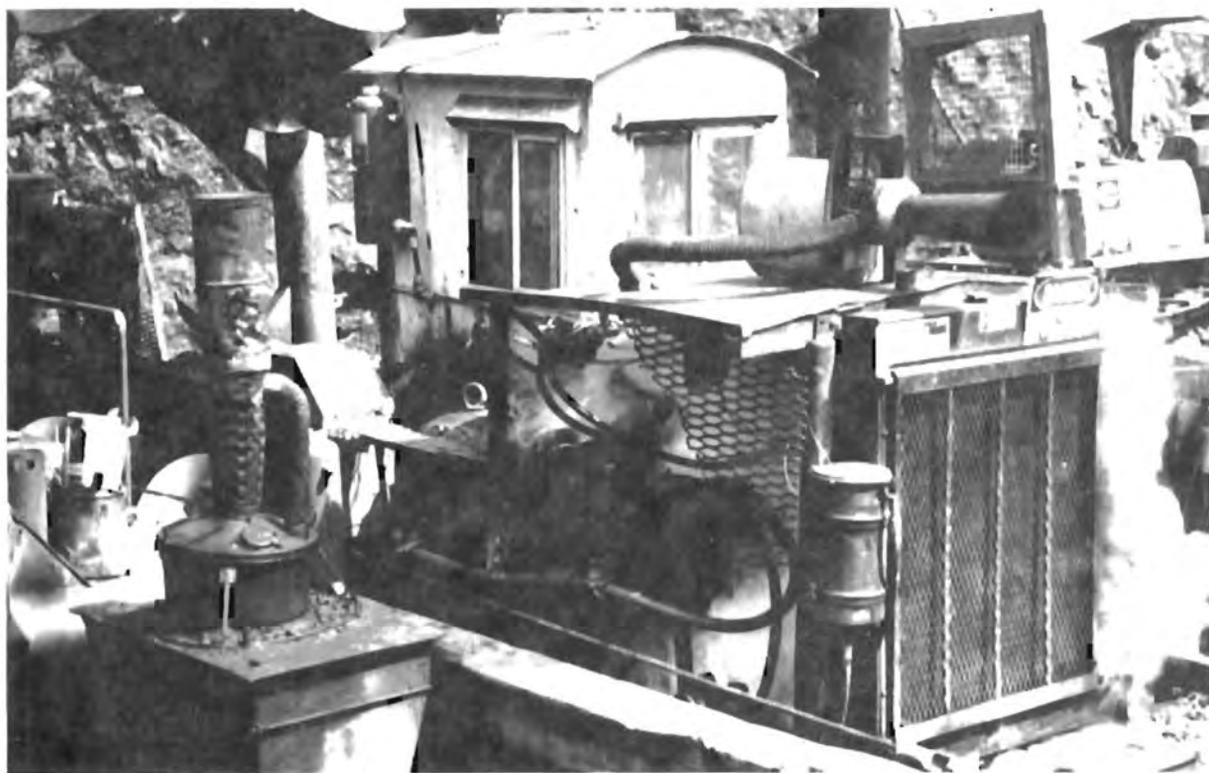


FIGURE 12. - Test of the AFEX system, phase 1.



FIGURE 13. - Test of the AFEX system, phase 2.

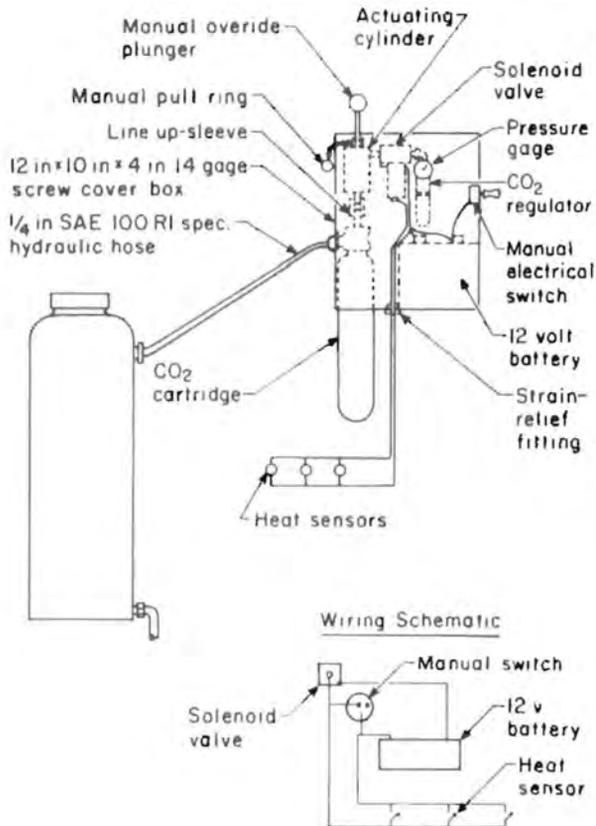


FIGURE 14. - The AFEX automatic vehicle fire protection system.



FIGURE 15. - Large coal hauler of the future.

Figure 16 shows the components of the Ansil's SCAD-type automatic system. Red tubing is installed in the engine area and melts, thus releasing stored pressure, to activate the dry chemical on a fire. Figures 17-19 show Ansil's SCAD system suppressing a fire on a small front-end loader. Figure 20 shows the large loader used by the Bureau and Ansil for the in-mine endurance testing of SCAD. A system discharge test shows the dry chemical distribution.



FIGURE 16. - Bench testing the Ansul SCAD system.

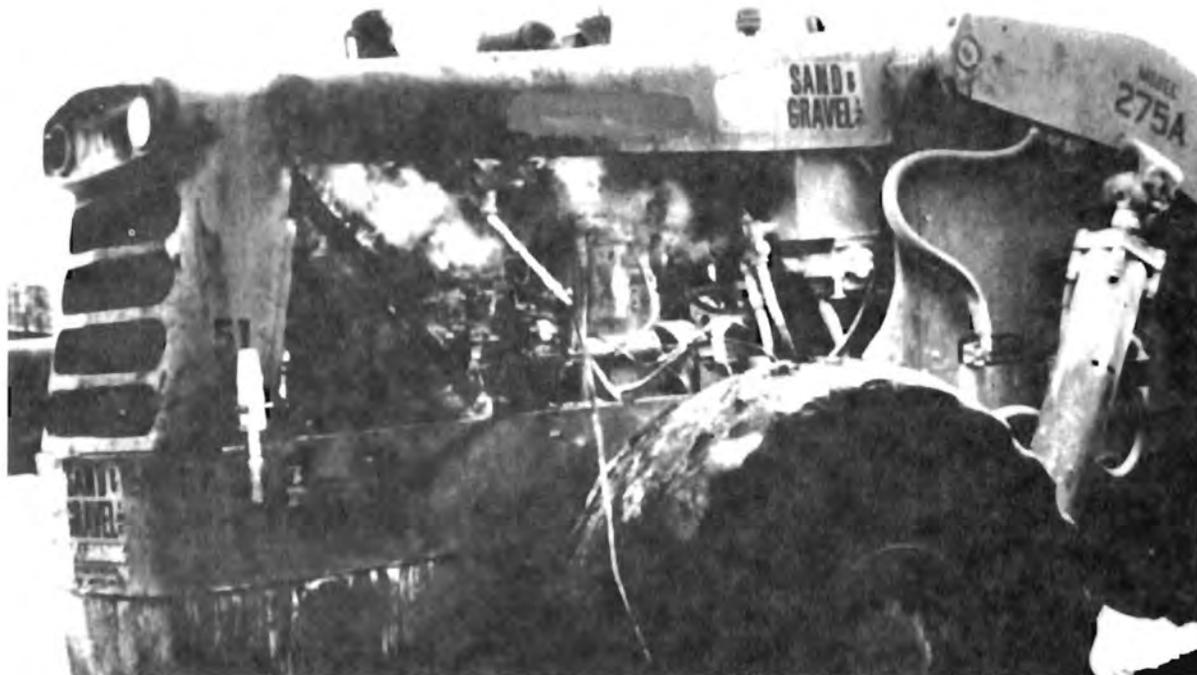


FIGURE 17. - Fire testing the Ansul SCAD system, phase 1.

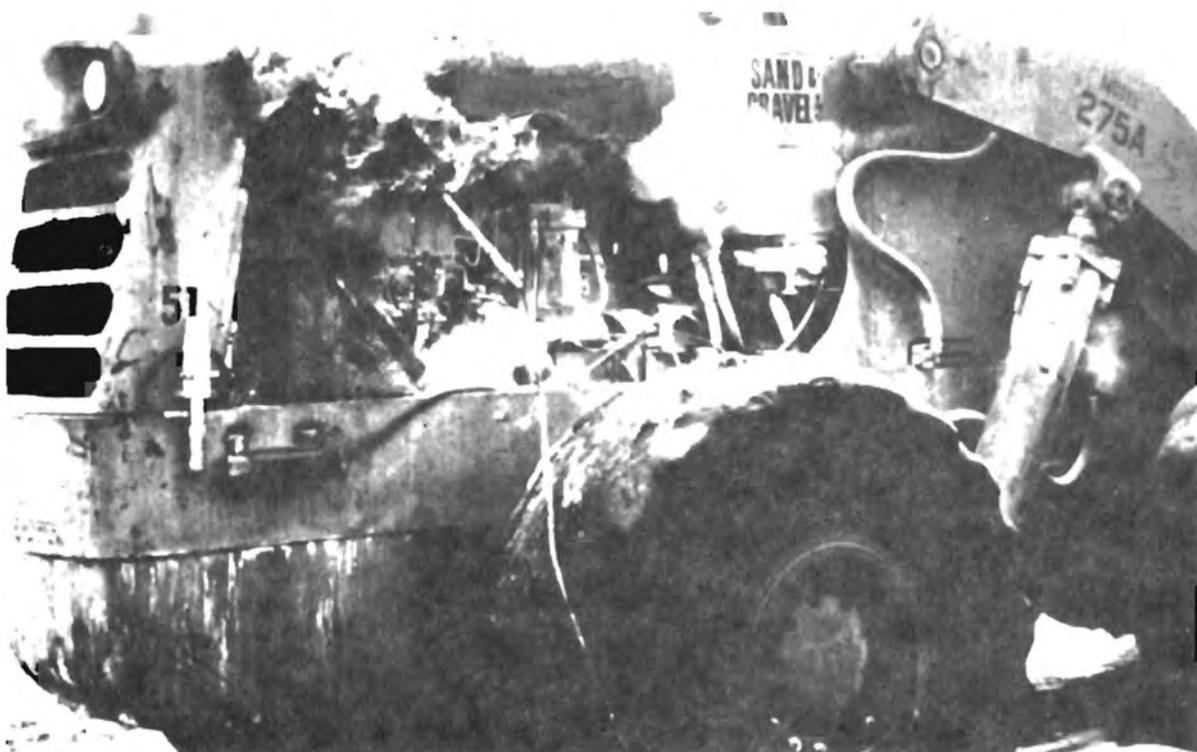


FIGURE 18. - Fire testing the Ansul SCAD system, phase 2.

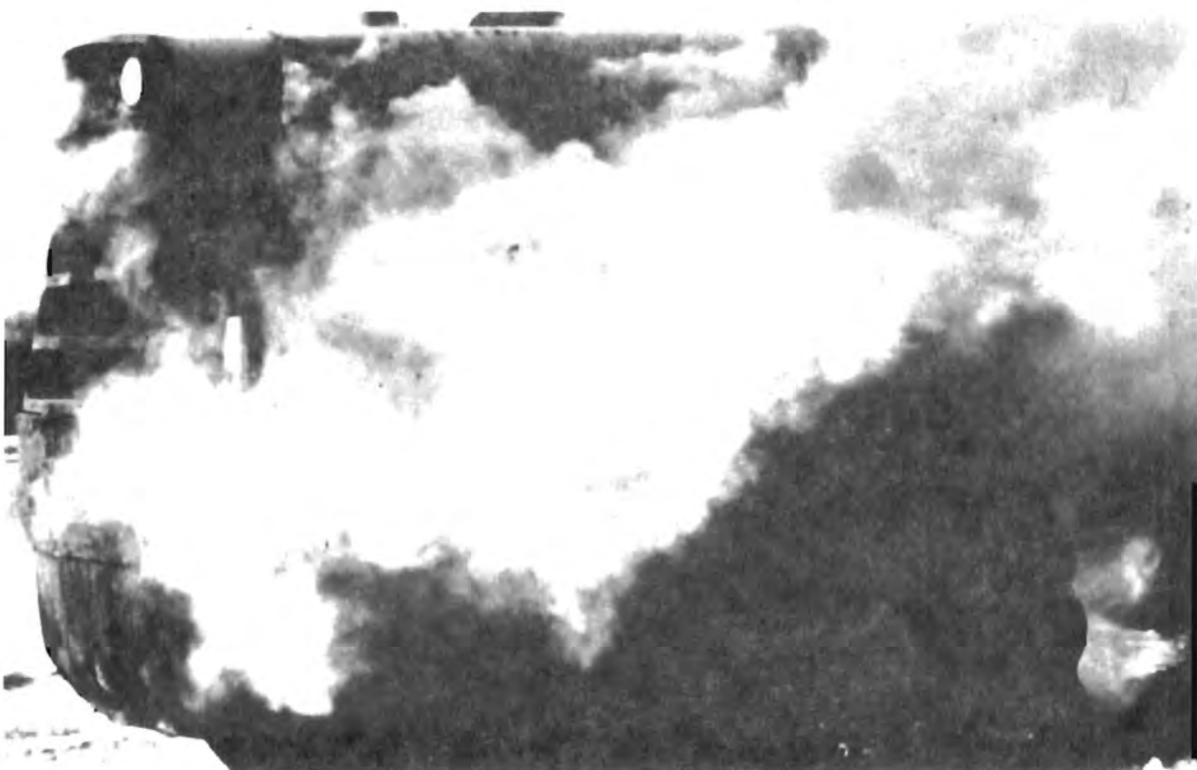


FIGURE 19. - Fire testing the Ansul SCAD system, phase 3.

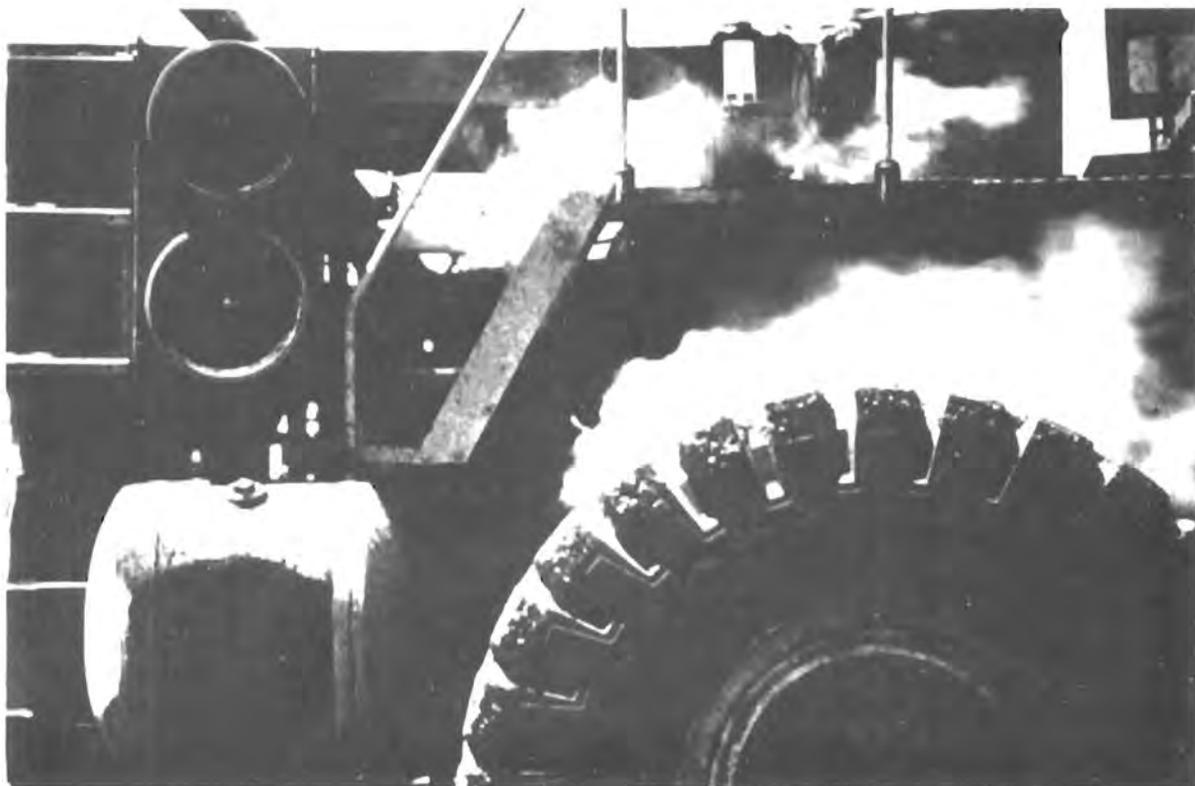


FIGURE 20. - Ansul SCAD system being tested on a large front-end loader at Cleveland Cliff's Tilden mine in northern Michigan.

The vehicle used in the ongoing AFEX-Fiat-Allis HD 41-B system test is shown in figure 21. Figure 22 shows the dozer the Bureau and the Lemmons Coal Co. of Indiana are using for the on-vehicle testing of the AFEX-dozzer system. Figure 23 shows the components of the prototype hardware. Figures 24-29 show a recent system discharge test conducted near Shoals, Ind.

Some large draglines, like Big Muskie shown in figure 29, now have CO₂ hoseline fire suppression systems, as seen in figure 30. The Bureau is improving such systems by testing Halon systems to see if they are more reliable and cost-effective.

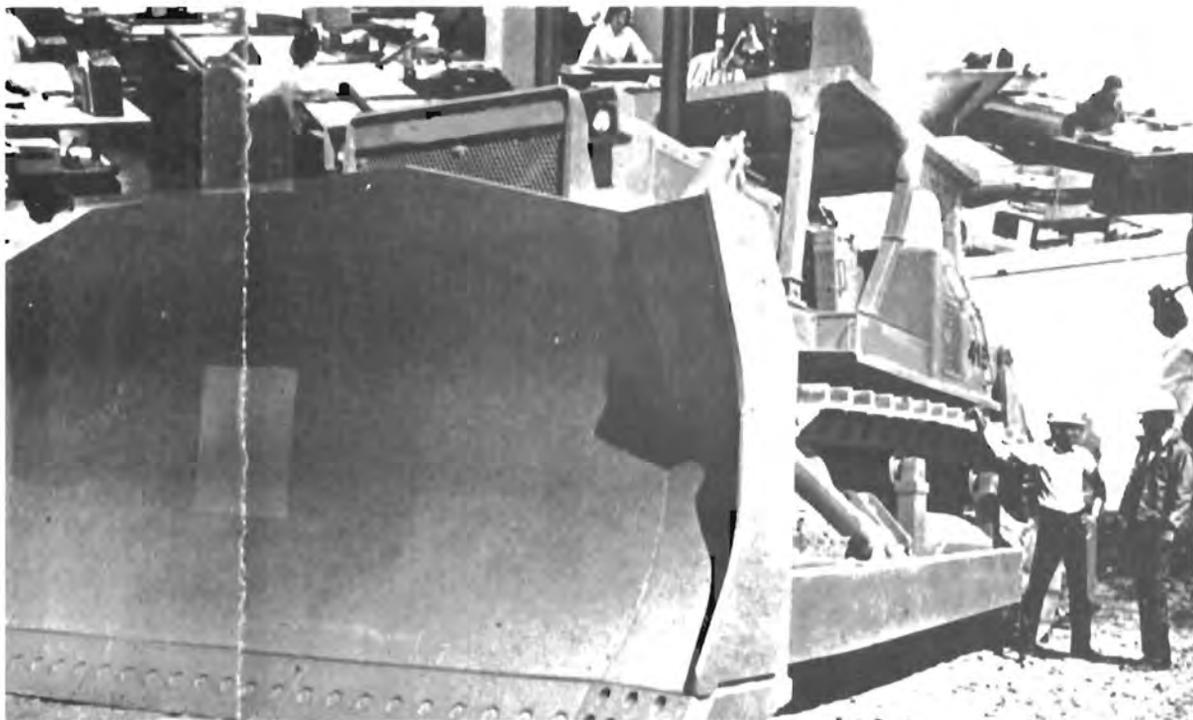


FIGURE 21. - Fiat-Allis 41B dozer.



FIGURE 22. - Fiat-Allis 41B dozer at the Lemmons Coal Co. mine near Boonville, Ind.

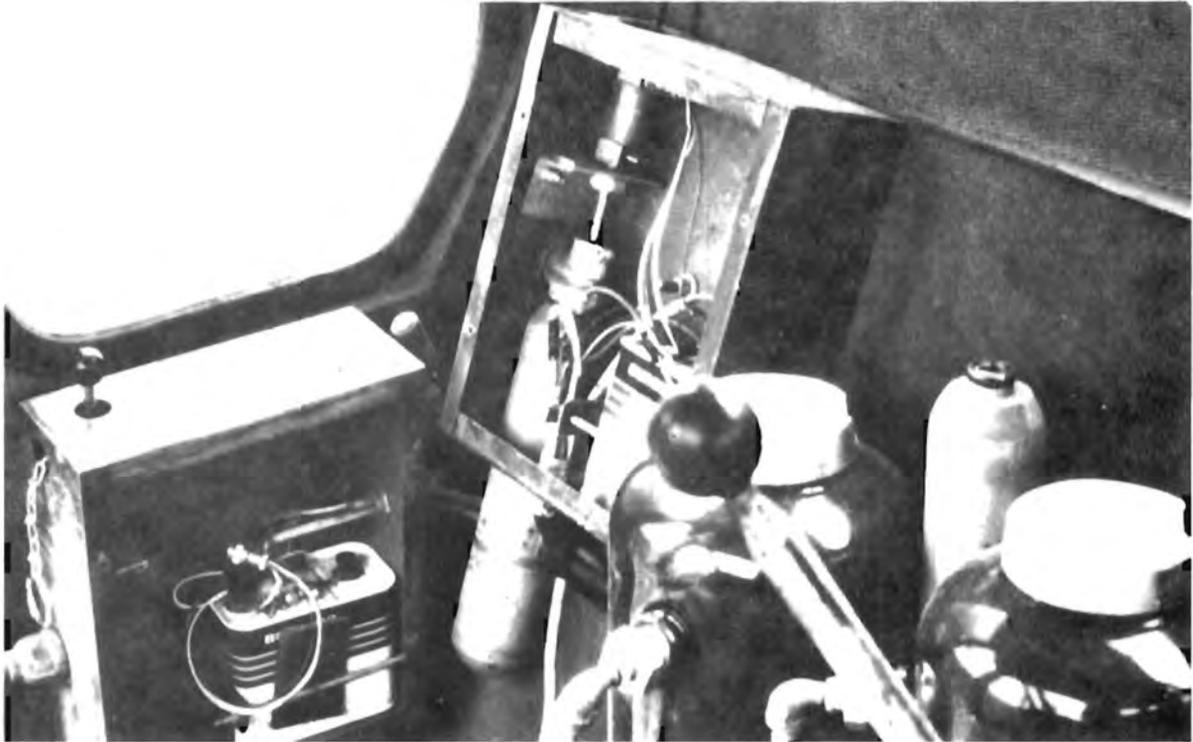


FIGURE 23. - Second generation AFEX system installed on Lemmon's Fiat-Allis dozer at Boonville, Ind.



FIGURE 24. - Testing the modified AFEX system on the Fiat-Allis dozer, phase 1.

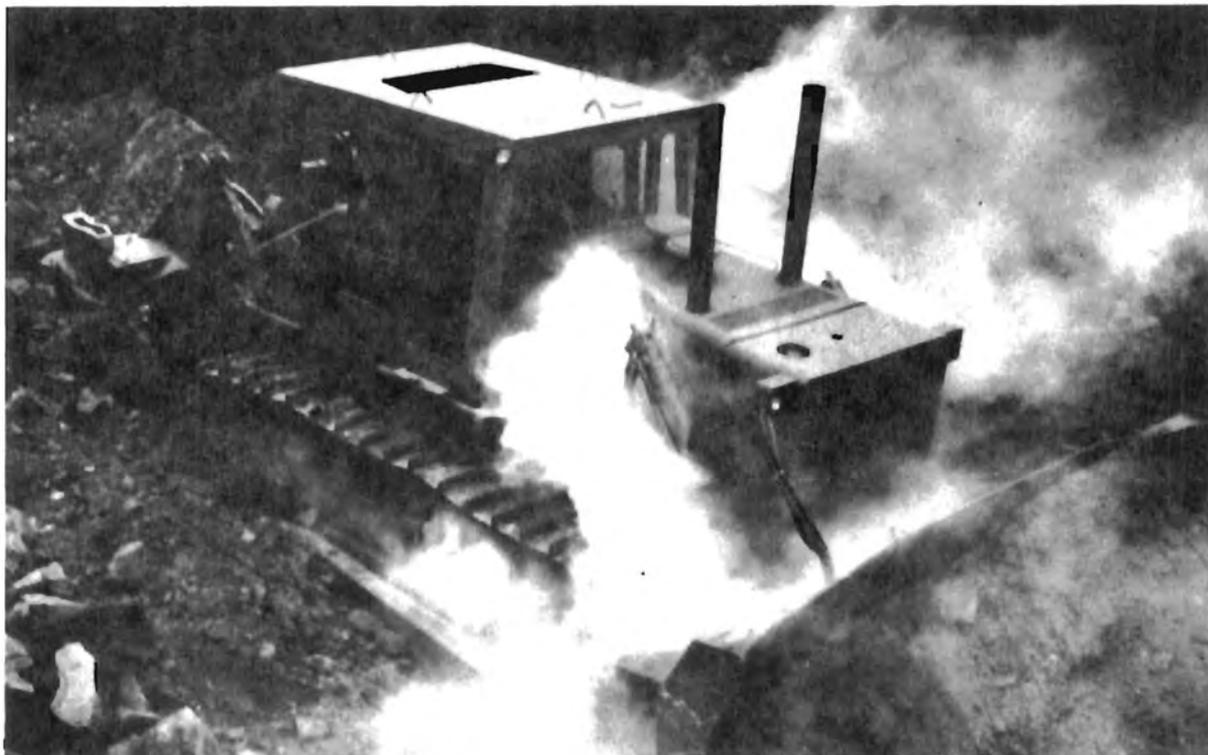


FIGURE 25. - Testing the modified AFEX system on the Fiat-Allis dozer, phase 2.

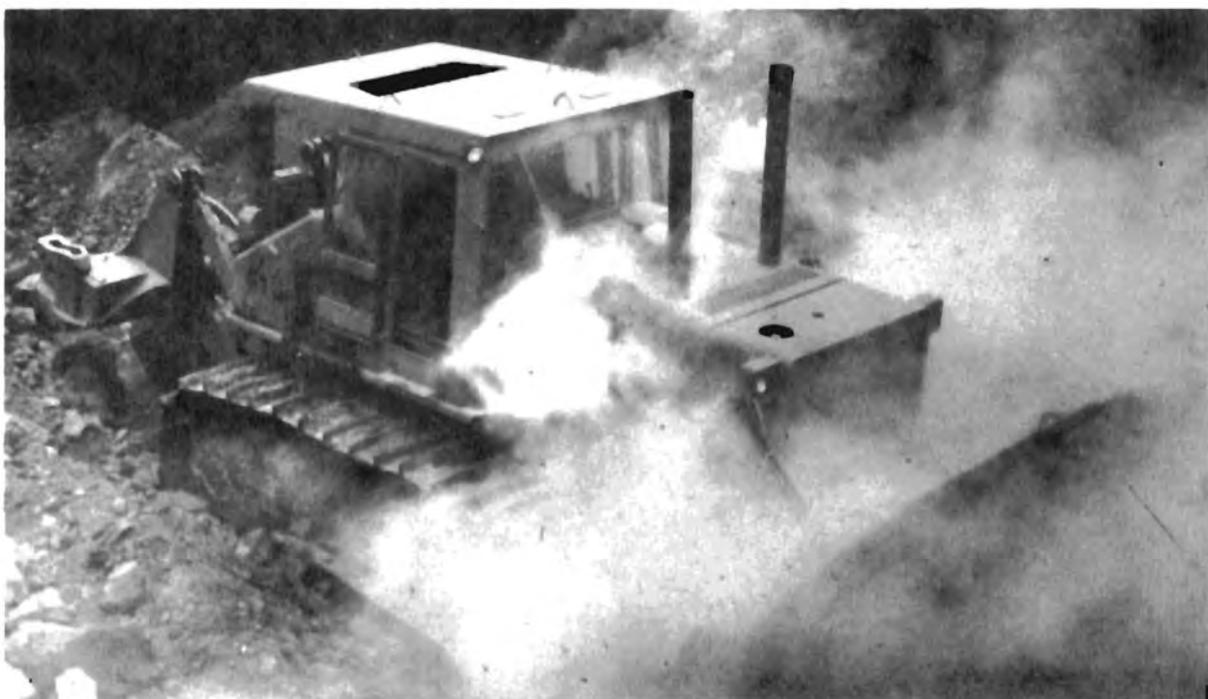


FIGURE 26. - Testing the modified AFEX system on the Fiat-Allis dozer, phase 3.

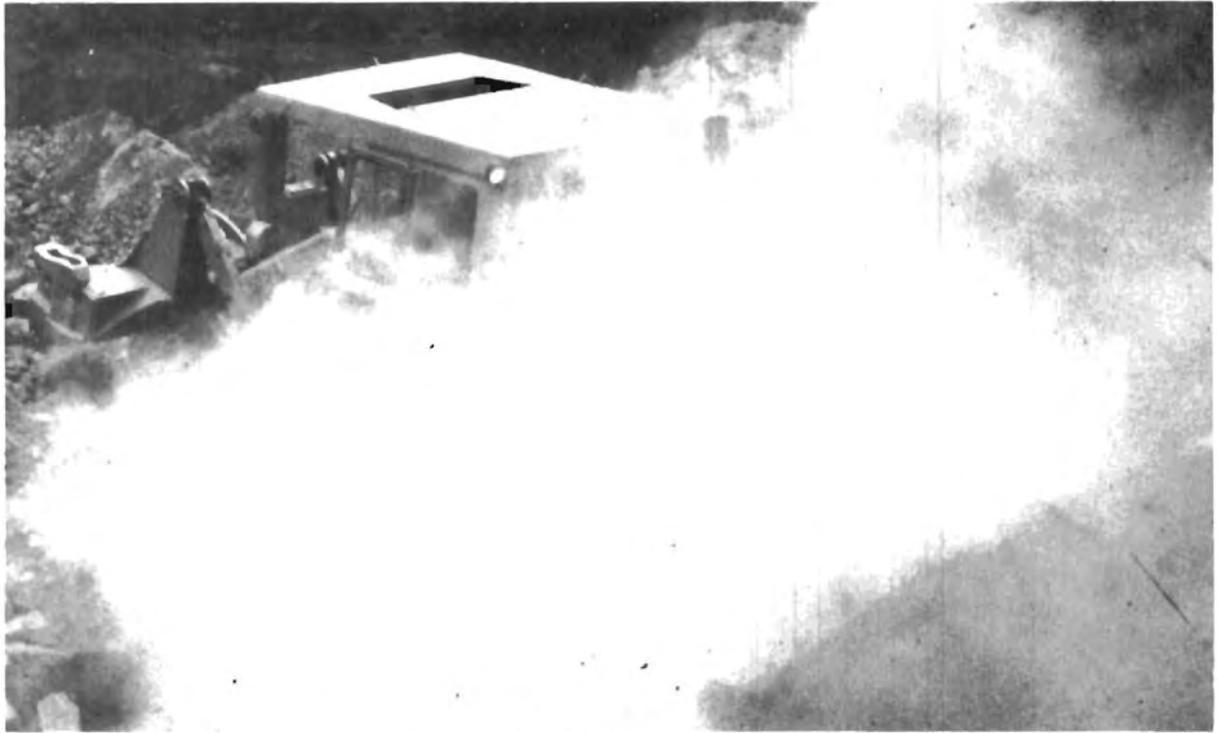


FIGURE 27. - Testing the modified AFEX system on the Fiat-Allis dozer, phase 4.

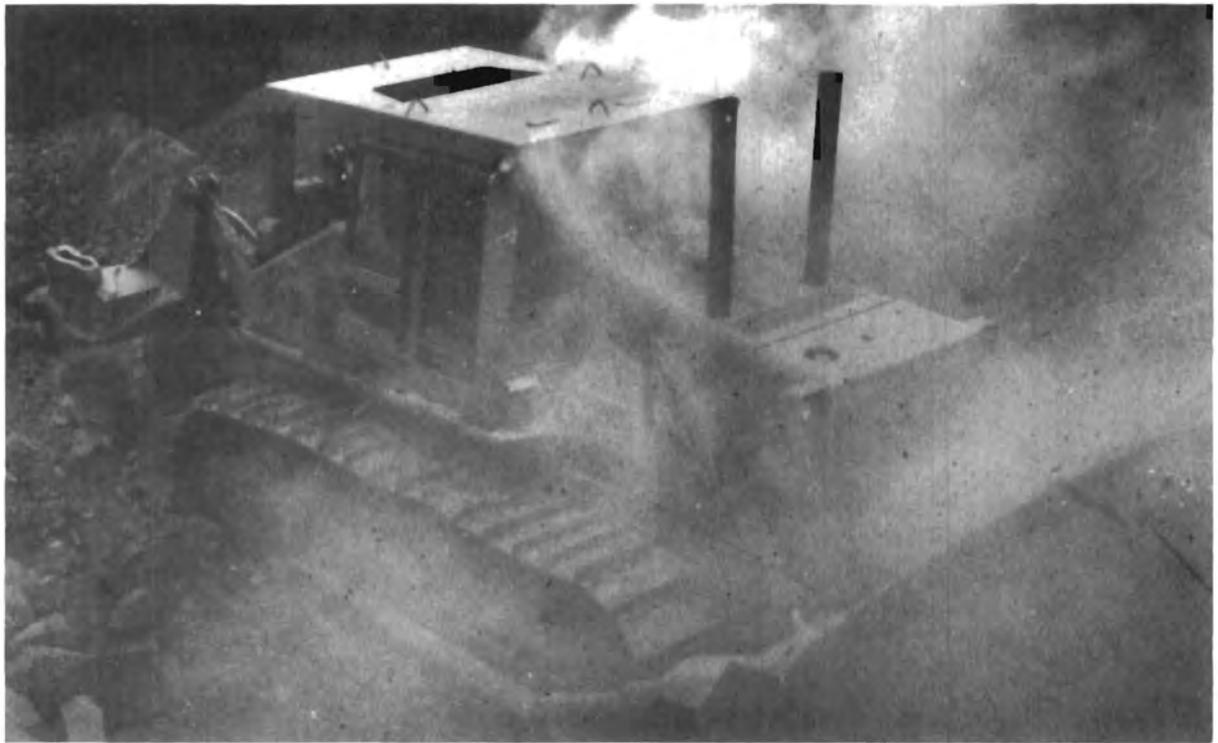


FIGURE 28. - Testing the modified AFEX system on the Fiat-Allis dozer, phase 5.

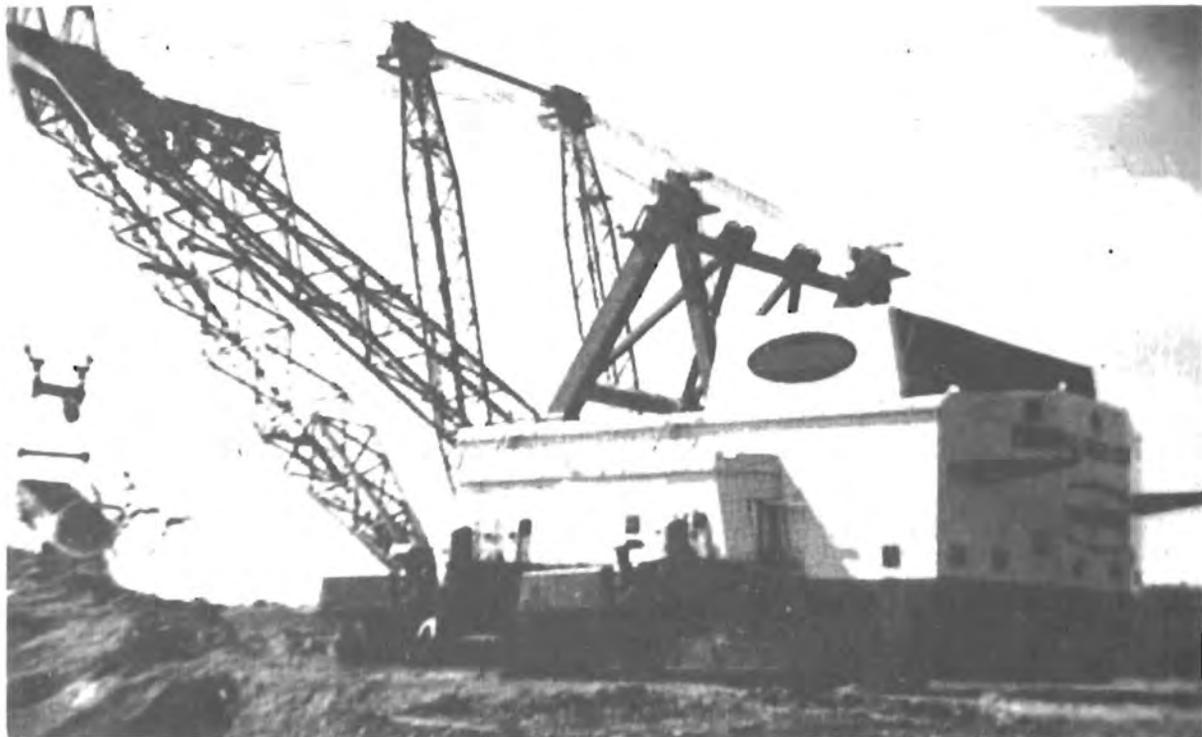


FIGURE 29. - Large dragline.

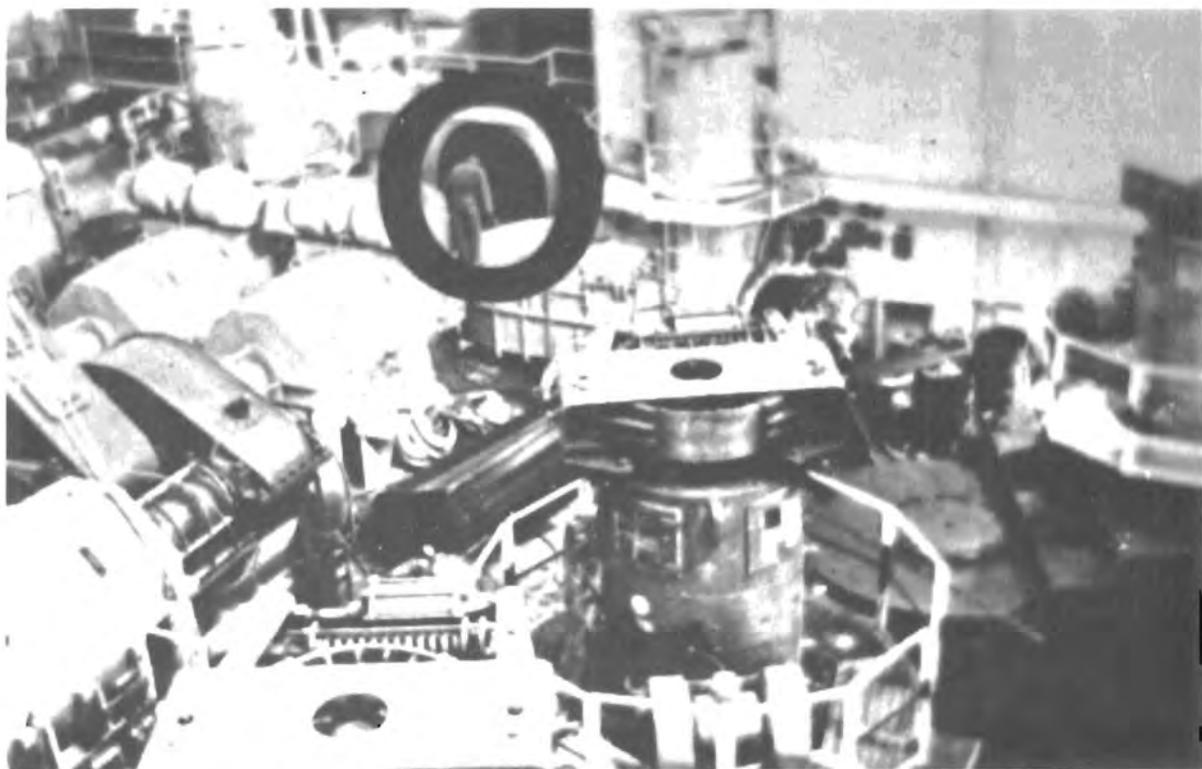


FIGURE 30. - CO₂ system installed on a large dragline.

MESA'S VIEWS ON MINE EXPLOSION AND FIRE RESEARCH

by

John Nagy¹

INTRODUCTION

The Mining Enforcement and Safety Administration (MESA) views on the explosion and fire research projects that were discussed in this report are offered along with commentary on their application by the mining industry. Emphasis is placed on how these projects might interface with regulations. Each of these research projects was requested of the Bureau of Mines by MESA. All except that on remote sealing of mine fires relate to current regulations and may be affected by future regulations. Should any future regulations be proposed mine operators, as well as all persons or organizations having an interest, will have an opportunity to provide input. Regulations, if proposed, will reflect MESA's consensus at the time of proposal which may differ from the preliminary opinions expressed at this time.

QUENCHING DEVICE

MESA is deeply concerned with the continued and increasing number of frictional ignitions at the working face. There were 66 face ignitions in 1976 and 56 in 1975. These ignitions occur despite vigorous requirements for ventilation, testing for methane, and use of the methane monitor. Section 317(q) of the Coal Mine Health and Safety Act of 1969 authorizes requirement of quenching devices when these are "technologically feasible."

The Bureau of Mines is commended for their past effort in providing contractual research to develop such a device and for the current in-house followup. Unfortunately, the results of the contractual study showed that although the basic concept is sound, the use of a quenching device on existing equipment is not technologically feasible. The continued efforts by the Bureau now result in a technique and device which might be applicable to tunneling machines currently used in coal mines.

The question to be resolved is whether the device should be made mandatory to improve mine safety. MESA could be in an awkward position should an explosion occur in coal mine tunneling if the device were not adopted. However, at this time MESA does not anticipate precipitous action. It is yet to be determined whether new hazards are introduced by this device and whether these might outweigh the potential gains. Will the discharge of the extinguishant present toxicity hazards? Will the discharge of the extinguishant blind or confuse miners at the face (roof bolters) causing them to make improper and hazardous movements? What is the misfire frequency, and is the equipment suitable for the rigors of the mine environment? Will the device be as effective in practice as in the laboratory?

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These questions can and should be answered by field tests before regulations are considered. MESA is cooperating with the Bureau to perform these field tests. Adoption of the quenching device by the coal mining industry would have direct impact on the tunneling industry.

BARRIERS

Barriers for explosion control are used to some extent in nearly all of the major coal-producing countries except the United States. Can it be assumed that everybody is wrong except the United States? Perhaps it could if there were no coal mine explosions. The Bureau of Mines in response to MESA's request has studied barriers as a major effort. The current policy in the United States is to rely on generalized rock dusting for control of explosion propagation. However, proper inerting by this method cannot be achieved in an entry having a conveyor belt loaded with fine coal, in an entry where parked mine cars are loaded and topped with fine dust, at transfer points where fine coal is disseminated over many feet of passageway, and in longwall and short-wall mining systems where literally hundreds of feet of unneutralized coal dust deposits exist.

MESA recognizes these unique situations and the potential use of barriers for control of the hazards. Barriers may be the only, or one of several possible, solutions in these special problem areas. Before any regulations are proposed, field trials must be made to evaluate barrier practicality, their effect on ventilation and travel, their ability to withstand the mine environment, and to ascertain if field effectiveness is equivalent to laboratory results.

REMOTE SEALING

The Bureau is commended for their work in development of effective techniques and equipment for remote control of mine fires. This work provides a new tool to minimize the hazardous tasks in the extinguishment and fire recovery operations. At this time, however, new regulations affecting its use are not anticipated. Application in mines will be the responsibility of the mine operators working with the district manager.

INCIPIENT FIRE DETECTION

Prompt detection of a mine fire is a primary factor in minimizing the fire hazard in mines. The use of correct followup measures for control by extinguishant is correlated with detection. Fires which start in nonwork areas or during idle periods, if not detected promptly, can develop into major problems. The research discussed in this report addresses this problem and reflects systems widely used in Europe where possibly as many as 100 fires have been detected successfully. However, European mining systems differ from most of those in the United States in that fires from spontaneous heating are much more prevalent.

Considering the American mining systems, when practical instrumentation, techniques, and field trials are completed, and the fire hazard from the aforementioned sources become significant, regulations for the detection of incipient fires will be proposed.

FIRE-RESISTANT CONVEYOR BELTS

The criteria for fire-resistant belts (30 CFR Section 18.65) formerly identified as Schedule 2G has been in effect for more than 20 years. Implementation of these criteria resulted in significantly superior conveyor belting with regard to flammability. Nevertheless, parts of this schedule need updating. The system does not encourage industry to develop a better product, the carcass is not effectively tested, some approved belts are more flammable in large-scale tests than are nonapproved belts, the toxic products during a fire are not considered, the 2G test is not specifically defined permitting its use to a myriad of products for which it was never intended, and quality control is not considered.

It is anticipated that upon completion of the present study, Section 18.65 will be rewritten--not to offer highly restrictive regulations, but to reduce further the fire hazard and to minimize such fires as occurred at the Feds Creek Mine in which 600 feet of approved conveyor belting burned fiercely.

FIRE-RESISTANT HYDRAULIC FLUIDS

MESA requested assistance of the Bureau to determine specific deficiencies in existing fire-resistant hydraulic fluids, to develop improved fluid, to suggest improvements in the procedures given in 30 CFR Part 35 which has been in effect since 1959, and to help encourage the use of fire-resistant hydraulic fluids in mines.

Our records show that no fire in a coal mine can be attributed directly to fire-resistant hydraulic fluids in the mining equipment. This is not true when petroleum based fluids are considered. This outstanding record begs the question why should not all hydraulically operated equipment use fire-resistant fluids. Actually more and more operators are converting to the fire-resistant fluids even though these do not perform mechanically as well as the petroleum fluids.

The current research has developed third generation fluids. These fluids offer further improvement in performance. Admittedly they are not yet equivalent to the petroleum based fluids, but considering the hazards of a fire and the cost and maintenance of fire suppression systems, it is anticipated mine operators will increase their use--not just as a simple substitute but as a planned program of modification of the hydraulic systems considering the pressures, temperatures, and improved cleanliness as well as the improved overall safety.

Public Law 91-173, Section 311, gives the operators the alternatives of using fire-resistant hydraulic fluids or petroleum fluids with a fire suppression system. We do not, at this time, see an amendment to this provision. MESA's approach will be to try to make it sufficiently attractive to the industry to make the changeover voluntarily.

CONCLUSION

Discussion of these research projects and considering how they relate to regulations prompts one to review the general subject of regulations.

Section 101(a) of Public Law 91-173 authorizes the Secretary of the Interior to develop, promulgate, and revise, as may be appropriate, improved mandatory safety standards for the protection of life and the prevention of injuries in a coal mine. Section 101(c) states that development and revision of mandatory safety standards shall be based upon research, demonstrations, experiments, and such other information as may be appropriate. The current research studies demonstrate the application of the law.

There are three basic avenues that MESA pursues in improving health and safety. Regulations are drafted and proposed that are intended:

1. To prepare regulations to minimize new hazards introduced by the everchanging mining practices.
2. To correct deficiencies and ambiguities in existing regulations.
3. To minimize anticipated hazards.

Coal mining is still about the most hazardous occupation in the United States. It must be made less hazardous. MESA fulfills its legislative responsibility through improved regulations which are frequently based upon Bureau research results.