NEW INITIATIVES IN THE PREVENTION OF MINE FIRES AND EXPLOSIONS IN THE USA

by

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ABSTRACT

Recent developments by the Bureau of Mines, U.S. Department of the Interior, for the prevention of fires and explosions in underground coal mines are highlighted. The areas addressed include: (1) instruments to remotely monitor methane and coal dust accumulations; (2) cutting bits with back mounted water sprays to prevent frictional gas ignitions; (3) new ways to distribute passive water tub barriers along the ribs to suppress coal dust explosions and "explosion-powered" triggered barriers that utilize a solar panel as a detector; (4) a sensitive smoke sensor for the detection of incipient fires in the presence of diesel exhaust; (5) an improved laboratory-scale test method for fire-resistant conveyor belting; and (6) inflatable seals to isolate fire areas.

INTRODUCTION

Underground coal mine fires and explosions are a serious threat to life, property and coal resources. Mine disasters in the United States once killed hundreds of miners each year. The U.S. Bureau of Mines fire and explosion prevention research has helped the mining industry to significantly lower this figure. However, more work remains to be done to reduce mine fires and explosions to an absolute minimum.

Between 1980 and 1988, the Mine Safety and Health Administration (MSHA), U.S. Department of Labor, investigated 133 coal mine fires that resulted in 29 fatalities, numerous injuries, the abandonment of several mines, and financial losses totaling hundreds of millions of dollars. During the same period, 65 fatalities occurred due to coal mine explosions and, as recently as September, 1989, 10 miners lost their lives in a methane gas explosion in a Kentucky mine - the worst U.S. mine disaster in five years. MSHA field reports have also indicated about 75 gas ignitions were caused by friction during each of the past several years.

This paper highlights several areas of U.S. Bureau of Mines research to improve coal mine fire and explosion prevention, detection, and control. These include: (1) an optical remote methanometer and a dust deposition meter; (2) water sprays to prevent frictional ignitions; (3) passive and "explosion powered" triggered barriers to suppress explosions; (4) a diesel discriminating fire sensor; (5) an improved flame test for conveyor belting; and (6) inflatable seals to isolate fire areas.

REMOTE METHANOMETER AND DUST DEPOSITION METER

Remote Methanometer

Methane is an ever-present hazard in underground coal mines. To ensure against unsafe methane accumulations, U.S. regulations require mine operators to measure methane concentrations in the face area every 20 min. Miners currently make these measurements using hand-held instruments, standing at the face, often under a temporarily supported roof. In order to reduce, or eliminate, the time-consuming and hazardous process of current measurements, research is underway to develop a remote optical sensing instrument for measuring methane in mines (Litton, 1987). Recent prototypes appear usable at distances up to 12 m and perhaps more. A schematic illustrating the end use of this device is shown in figure 1.

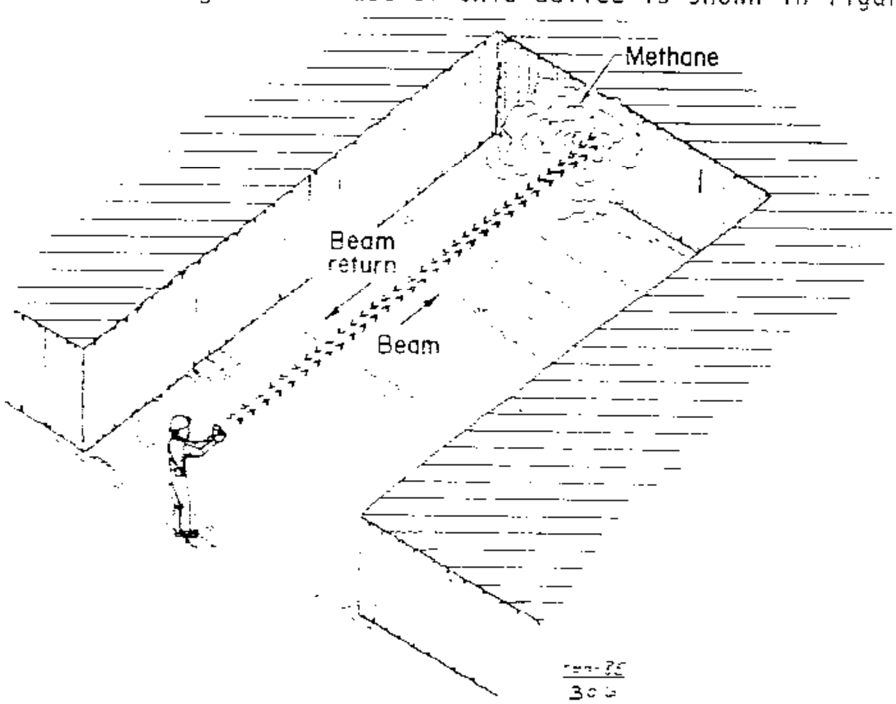

FIGURE 1 - Schematic illustrating the use of a remote methanometer for measurement at a working face.

These prototypes are simple hand-portable devices capable of battery operation. It should be noted that these devices have potential for use other than at the face area. One use is on-board moving mine vehicles to warn of excessive methane in the ventilating airflow or layered near the roof. These devices have been tested for such use and found to provide rapid, reliable detection of methane both in the ventilation flow and layered near the roof. Another potential use is in the inspection of hazardous or inaccessible areas where remote measurements can significantly increase safety. However, the primary intended use is in the immediate face area.

The operating principle is based on the strong absorption of electromagnetic radiation by methane in the infrared spectral region around 3.31 µm. Suppose that a collimated light source is located at a fixed distance from a remote, reflecting surface such as a coal face. The light reflected from the remote surface is collected by a lens, collimated, passed through an interference filter, and the 3.31 µm fraction of the radiation focused onto a detector. The detector signal is related to the methane concentration along the path length. To compensate for changes in path length, reflectivity of the surface, dust along the path, etc., a second wavelength region is isolated at ~3.0 µm, with another interference filter, and is used as a reference signal. The ratio of the absorption signal to the reference signal defines the average methane. As long as the signals are measurable within certain limits, the ratio compensates for any effects other than the presence of methane. This technique is called differential absorption. In the prototypes, the reflected light alternately passes through the methane wavelength filter and then through the reference wavelength filter to a detector.

A photograph of the second prototype of the device is shown in figure 2. It contains three major components; a light source, a light collector system, and electronics for signal processing. The light source is an 18 W tungsten-halogen lamp, with a quartz envelope, mounted in a special reflector. The lamp with reflector is mounted in the center of a plastic Fresnel lens that is used to collect the reflected radiation. The reference and absorption filters are mounted on a disk which rotates at a fixed frequency of 25 Hz and the radiation focused to a single indium arsenide voltaic detector. The circuitry utilizes an electronic bandpass filter to amplify only those signals received at this fixed rotation frequency.

Laboratory experiments and full-scale tests that simulated methane emission and accumulation at a ventilated working face showed the device would accurately measure the average methane concentration along the path length. Current work is centering on improved optical and signal processing techniques that will be incorporated into a prototype that is capable of extensive field evaluation. This device will be very similar in appearance to the common 6-V lantern and will be designed to satisfy requirements for permissibility for use at a working mine face.

Dust Deposition Meter

Coal dust is produced or redistributed during normal mining operations, at conveyors and transfer points, and by the movement of personnel and machines. The mine's ventilating air currents can pick up float dust and carry it into the return airways where is settles on other surfaces. In an explosion, this flammable dust becomes airborne and adds to the explosion.

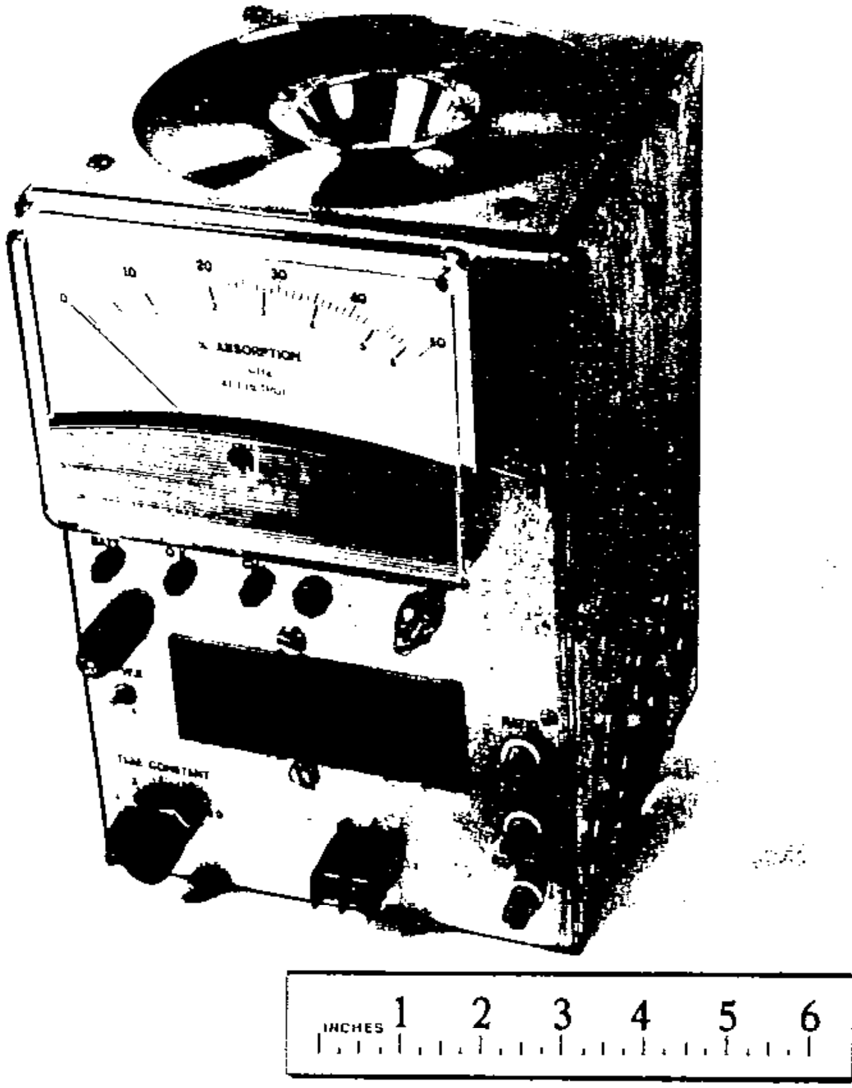

FIGURE 2 - Photograph of the second prototype remote methanometer which uses a quartz-halogen lamp and reflector mounted in the center of the plastic Fresnel collecting lens.

Covering deposited float coal dust with inert (limestone) rock dust makes it nonflammable. However, if a thin, fresh layer of coal dust is deposited on top of an otherwise adequately rock-dusted surface, the new layer can be selectively skimmed off by a relatively weak methane-air explosion. To comply with mine safety regulations, mine operators often place rock dusters in the returns to periodically disperse rock dust into the return airways. However, since little information is available concerning float dust deposition rates in mines, operators must rely on visual inspections to estimate the frequency with which fresh rock dust should be added. As a result, mine operators apply rock dust excessively in some areas, and inadequately in others.

The Bureau is developing an optical dust deposition meter to remotely monitor the accumulation of deposited airborne coal dust (Sapko, Pinkerton and Bubash, 1988). The meter works by distinguishing the way coal dust and rock dust reflect light. Since coal dust is black and rock dust white, and since a float coal dust layer density of 10 mg/cm^2 is optically opaque, it is reasonable to believe that the thickness of such a coal dust layer deposited on a rock dust substrate, or vice versa, could be determined by measuring the layer's optical reflectivity.

Figure 3 shows a drawing of the apparatus used to measure the dust layer's optical reflectivity. It consists of a halogen lamp, parabolic reflector, and diode detectors. An electrical circuit measures the ratio of reflected-to-incident radiation. Laboratory studies under controlled conditions and experiments conducted in the Bureau's Lake Lynn Experimental Mine showed the device is capable of measuring the loading density of float coal dust on a rock dust substrate and vice versa to within an accuracy of 5 pct. Figure 4 shows the data obtained for rock dust deposited on coal dust. A portable battery-powered- meter that displays the dust loading density directly is being fabricated for field evaluation.

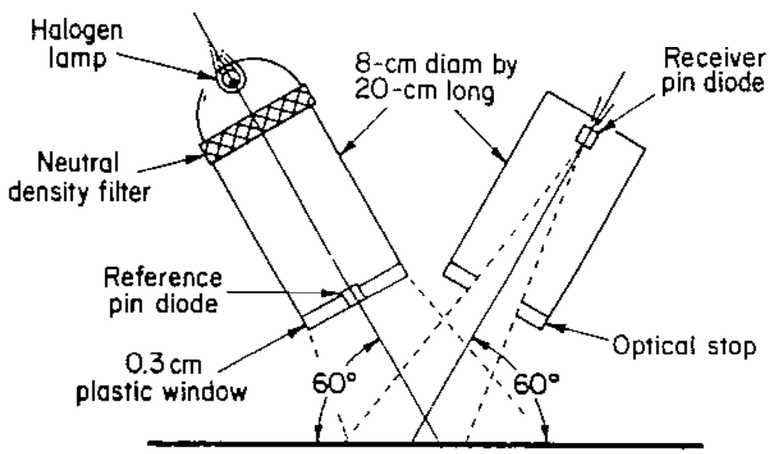

FIGURE 3 - Apparatus used to measure infrared reflectivity of stratified dust.

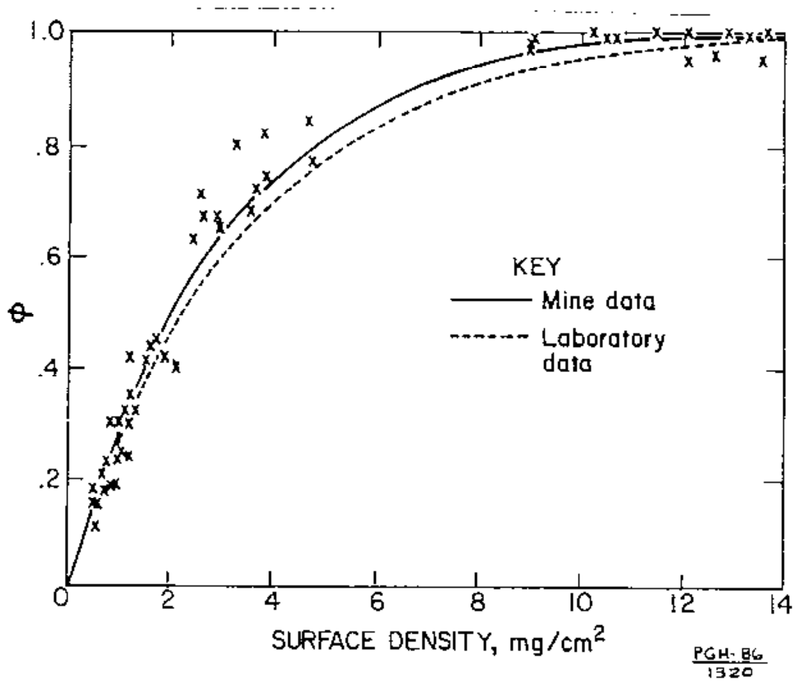

FIGURE 4 - Reflectance versus surface density of rock dust deposited on coal dust in experimental mine and in laboratory chamber.

WATER SPRAYS TO PREVENT FRICTIONAL GAS IGNITIONS

In the U.S., frictional gas ignitions at the face almost always involve a metal bit cutting into sandstone. A luminous hot streak is formed on the surface of the sandstone because of abrasion by the bit. The bit tip becomes heated under repeated impact of the bit with the strata. Large mushroom shaped carbide tips for conical bits and dovetail-shaped carbide tips for rectangular bits were designed to physically protect the steel shank and thereby reduce the likelihood of frictional ignition due to abrasion by the more incendive steel shank (Cheng, Liebman, Furno and Watson, 1983). The risk of frictional ignition under moderate cutting conditions was also reduced using conical bits with an increased initial bit clearance angle (Cheng, Furno and Courtney, 1987). These measures are valuable, but only postpone the time when the bits have been worn to a condition likely to cause frictional ignition. To find a longer lasting solution, the Bureau has examined the use of water sprays in back of cutter bits to reduce the likelihood of frictional face ignitions (Courtney, 1990).

Laboratory studies with water sprays were performed with four different rectangular bits and two different conical bits. The experiments were conducted in a test chamber containing a 51-cm-high block of sandstone and a cutter drum with a single bit rotating downward in the vertical plane at typical drum rotation speed. The limestone block was precut, positioned on a cart, and moved horizontally across the rotating drum so that a 0.6-cm-deep cut was made by the bit along the entire length of the arc. The chamber contained an explosive methane-air mixture and had plastic blowout panels to relieve the pressure when ignition occurred. The total number of cuts to obtain ignition was counted as a measure of how readily ignition would occur with and without water sprays. Various types of spray nozzles, flow rates, and pressures were evaluated. The table shows the results for a commercial rectangular bit that had a fan-type spray nozzle installed directly in the back part of the bit shank. The spray significantly reduced the likelihood of frictional ignition. Similar results were obtained for the other bits tested.

Table - Ignition results with rectangular bit using fan-type back spray (Courtney, 1990)

Spray		Av number of cuts
Flow rate, gpm	Pressure, psig	for ignition
Dry	Dry	[1]3.7
0.9	50	[2]>64
1.1	100	[3]>67
1.1	300	[4]>64
1.1	500	[5]>63

[1]1,2,2,2,2,2,3,3,3,3,3,3,4,4,5,7,8,10.
[2][64];no ignition with 64,64.
[3]No ignition with 65,68,68,68.
[4]No ignition with 62,64,67.
[5]No ignition with 62,64

A study of conical bits and back sprays mounted on a wet-head continuous mining machine was conducted in the field. The drum was laced with a total of 76 conical bits in the center part of the drum. The bit blocks gave a bit attack angle of 52°. Sufficient space was available to install water spray nozzles about 18 cm behind the tip of each of the 72 center bits. No spray nozzles were used behind the four end bits because of engineering difficulties in channeling water to the end locations. The solid-cone spray nozzle had a 20° internal angle and delivered a well-formed spray at 1.1 L/min and 345 kPa, gage. Each nozzle was carefully oriented using a template so that about 75 pct of the spray water impacted the mineral surface directly behind the bit and 25 pct of the water impacted the bit and bit block.

The wet-head-modified machine was installed in an ignition-prone mine in a section having a 30-cm high sandstone parting. Results indicated no water leakage with the water seals during the mining of 150,000 tons, despite several early shifts of dry operation with no water being passed into the seals. Miscellaneous conical bits were used. No frictional ignitions occurred, airborne respirable dust was dramatically reduced according to visual observation, bit life increased 50 pct, and the wet-head-drum was well received by face personnel because of increased visibility (Merritt, 1987).

A field study on controlling ignitions on a longwall face in a mine prone to face ignitions also demonstrated the effectiveness of water sprays located behind each cutting bit of a shearer drum (Cecala, Watson and Bruno, 1988). Fabrication of an anti-ignition shearer drum involves moving the antidust water spray nozzles on the commercially available wet-head shearer drum so that they are located directly behind each of the bits and are carefully oriented so that their sprays impact the mineral surface directly behind the bits. Several anti-ignition back spray and bit systems are commercially available and have been used in the field. However, wet-head cutter drums for continuous mining machines are not readily available at present.

In summary, the likelihood of ignition with worn bits significantly decreases if water spray nozzles are located in back of each bit and are carefully oriented so that the water spray impacts and cools the hot streak on the surface immediately behind the bit as well as the bit. The likelihood of ignition with all bits tested was reduced by using a carefully designed back spray. Commercial versions of back spray and bit systems that use waterflow rates of 3.8 L/min are readily available for shearer drums.

BARRIERS TO SUPPRESS EXPLOSIONS

Stacked Versus Roof Water Barriers

As a means of suppressing coal dust explosions, water tub barrier units are being tested in the large (6-m-wide by 2-m-high) entries of the Lake Lynn Experimental Mine. The performance of rib stacked barriers and roof-mounted barriers were evaluated in D-drift (Weiss, Greninger and Sapko, 1989). The barrier results are from single entry experiments and may not be applicable to multiple entry scenarios. Explosions were initiated by igniting near stoichiometric CH_4-air mixtures confined to the first 12.2 m from the closed end (face) by a plastic diaphragm. A mixture of rock dust and Pittsburgh Pulverized Coal (PPC) was spread on the floor and on foam roof shelves in the dust zone (edge of the gas zone at 12.2 m up to 131 m from the face) to provide a PPC nominal dust concentration near 200 mg/L. This standard test coal dust was mixed with limestone rock dust to provide mixtures ranging from 58.6 to 67.8 pct total incombustible content (TIC) in order to vary the explosion intensity. In explosion tests in the single entry without barriers the flame propagated about 3 to 4 times the length of the dusted test zone (>230 m from the face). The water tub barriers used in this study were standard German-manufactured troughs made of polyvinyl chloride (PVC). They are designed to hold 80-L of water and are approximately 29-cm-high, 48-cm-wide and 75-cm-long. These water barrier experiments were conducted at 40 to 160 m, in 20 m increments, from the closed end. Figure 5A shows the experimental configurations for the 80-L PVC tubs suspended from the roof. The roof barrier tests were conducted with 4 tubs using zones B, C, D, and E. The roof installation requires support framework, roof bolts, plates, and suspension hooks. Considerable fabrication and installation time are involved. The experimental configurations for the stacked barriers are shown in figure 5B. The stacked barrier tests were conducted by erecting a triply stacked barrier unit along each rib (zones A and F) for a total of 6 tubs per test. In the stacked configuration, the first 80-L tub was set on two cribbing timbers which lie on the mine floor. The second barrier tub straddled the first using two more timbers and so on. To help distribute the weight, vertical wood strips were nailed to the exposed end of the horizontal timbers.

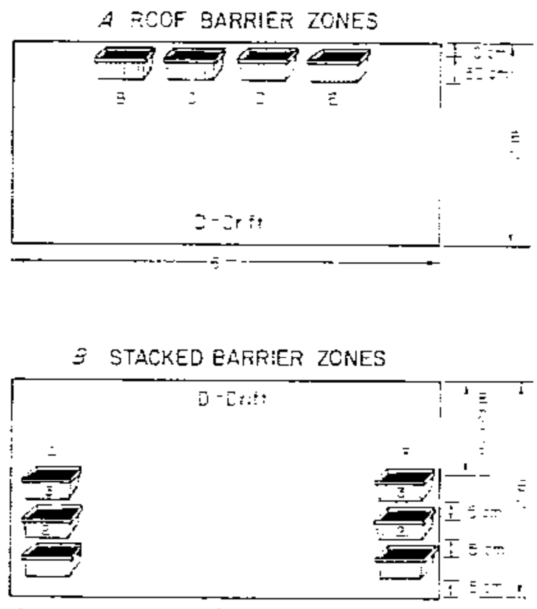

FIGURE 5 - Barrier deployment configurations.

The precursor wave, generated from the ignition of the CH_4/dust mixture, initiates the barrier operation depending on the strength of the barrier mount. Roof-mounted barriers start to operate at as low as 0.1 bar overpressure. For tests in which suppression occurred, flame speeds at the barrier ranged from 153 to 211 m/s. It was observed that the roof-mounted barrier effectiveness decreases at large distances from the face. Non-suppressions occurred when the barriers were located at 120, 140, and 160 m from the face. The water dispersed early due to the rupture of the barriers by the pressure wave and the flame was not able to interact with the water cloud. The time between barrier operation and flame arrival ranged from 0.32 - 0.44 s during which time a significant fraction of the water dropped out of suspension. At a location of 60 m from the face, the roof-mounted barriers suppressed the explosion propagating through a zone of 67.8 pct

TIC; however, they failed to suppress the explosion when it propagated along a 63.2 pct TIC zone. The roof-mounted barrier effectiveness also decreased at small distances from the face (<60 m). For stacked barriers at 40 m, the stacks began to tip when the flame had propagated about 33 m from the face, allowing about 0.02 s of water discharge prior to the flame arrival. Suppression occurred at 53 m which was just beyond the barrier site of 40 m. Figure 6 shows a comparison of flame propagation without a barrier and one with a stacked barrier unit located at each rib at 40 m from the face. The stacked barriers suppressed the explosion propagating through the 67.8 pct TIC zone. A triply stacked barrier unit along each rib at 80 m from the face suppressed an explosion in a dust mixture as low as 58.6 pct TIC. In tests which suppress, the stacked barriers started to operate at as low as 0.8 bar and the flame speeds at the barriers ranged from 150 to 230 m/s. The explosion suppression tests with water barriers showed that stacked tub units located along the ribs are quite effective in suppressing dust explosions. They are significantly less expensive, in terms of materials and labor, to install than roof-mounted barriers. Optimally, a triply stacked water barrier unit would be placed near each rib in 60 to 100 m increments from the advancing face.

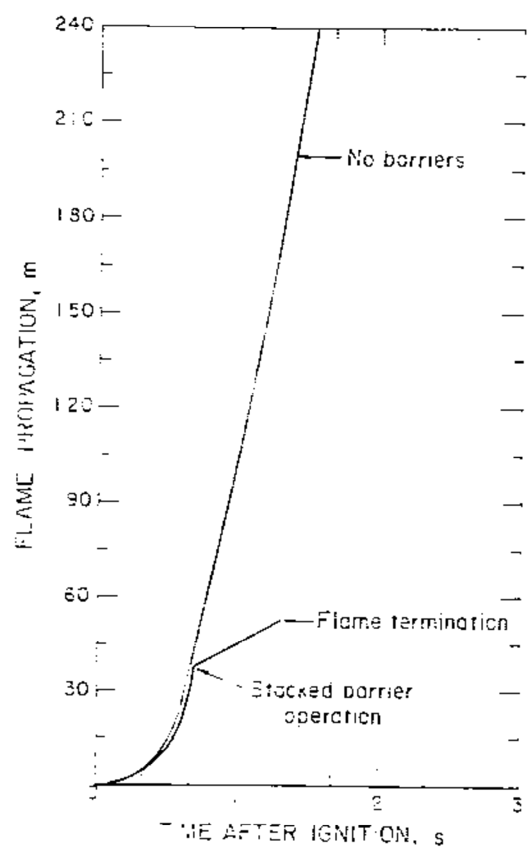

FIGURE 6 - Effect of a stacked barrier unit along each rib at 40 m on the explosion flame generated from a 68 pct TIC test.

"Explosion Powered" Barriers

An "explosion powered" trigger device has recently been developed to explosively activate suppression barriers to quench gas and coal dust explosions. The important feature of the device is a silicon solar panel, which collects 0.3 μm to 1.1 μm wavelength radiation from the developing explosion, and generates electrical energy to initiate a detonator, which in turn causes the rapid explosive release of an extinguishing agent into the advancing flame front. Solar panels that are rated to produce 20 W of electrical power when exposed to the sunlight are producing about 200 W when exposed to full-scale dust explosions propagating in the Lake Lynn Experimental Mine. Due to silicon's limited spectrally active region and the typical 13.7 pct conversion efficiency of the solar panel, this 200 W is only a small fraction of the 80,000 W of radiation striking the panel.

The solar panel is electrically isolated from the detonator by a pressure sensitive switch until the arrival of the precursor pressure pulse, which always precedes a deflagration. This combination of pressure arming and flame radiation prevents false barrier activation and requires no external power supply.

A typical installation with roof mounted water tube barriers is shown conceptually in figure 7. In such an installation, the sensor would be located in the proximity of the suspected explosion source, and the extinguishment dispersal unit would be located sufficiently far from the sensor to provide time for the extinguishing agent to be discharged prior to flame arrival.

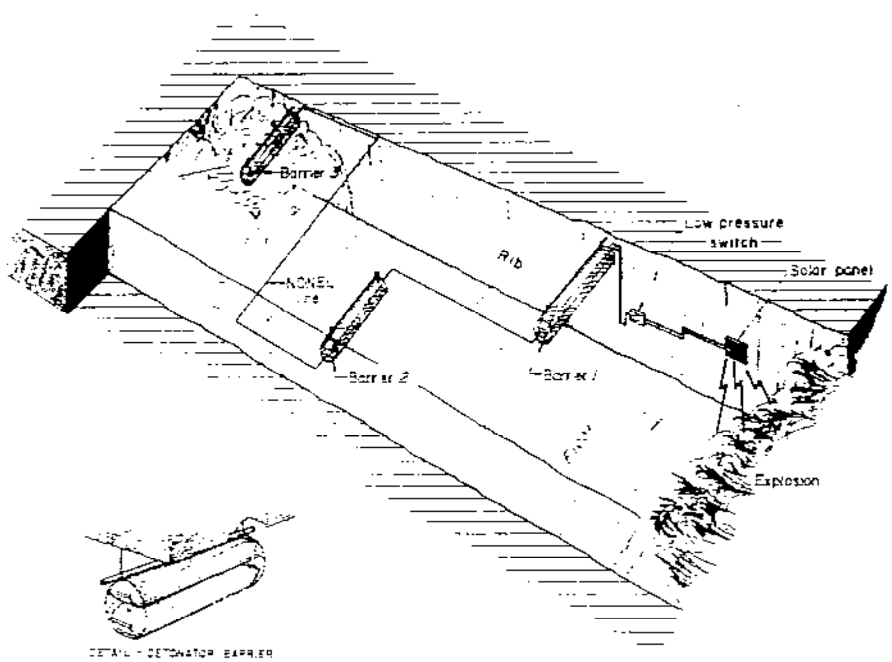

FIGURE 7 - Conceptual installation of solar panel triggered suppression system.

The solar panel used measures 23.5 cm by 59.7 cm and consists of 36 silicon cells, each configured as a semicircle with a diameter of 10.2 cm. Under a constant irradiance of 1 kW/m^2, the current output is about 1.3 amps. Gas and dust explosion test conducted in D-drift of the Lake Lynn Experimental Mine, with solar panels mounted on the ribs, showed that sufficient power is generated by the panel to fire a 1 W detonator, since the minimum electrical power obtained was 21 W.

Reduction of the solar panel sensitivity due to contaminant coatings on the window was also examined during explosion tests. With the window mounted on the vertical and coated with coal dust or rock dust, the wind forces preceding the flame cleansed the window, such that there was no measurable difference in output power with or without the coatings.

DIESEL DISCRIMINATING FIRE SENSOR

In an underground mine that uses diesel-powered equipment, diesel exhaust products can mix with the airflow resulting in concentration levels sufficient to produce frequent false alarms of smoke and CO fire sensors. Further, if a fire were to occur in the presence of these elevated product levels, it would go undetected until reaching a substantial size. To address these problems, a novel fire detector that can be used to discriminate between smoke produced by a fire and smoke produced by a diesel engine was developed (Litton, 1989). The device is based on the principle that fire smoke particles pyrolyze upon passage through a short, heated tube whose surface temperature was held constant between 300° and 350° C. Upon passage through this pyrolysis tube, the number concentration of fire smoke particles significantly increased. At the same time there was a corresponding reduction in the number mean particle diameter. Diesel smoke particles were unaffected upon passage through the same pyrolysis tube.

A series of laboratory experiments was conducted with smoldering samples of coal, wood, conveyor belt, and plastic brattice in the presence of diesel smoke and without diesel smoke. Measurements of diesel smoke alone were also made. The unpyrolyzed and pyrolyzed signals were measured alternately by a sensitive smoke detector that had been previously developed (Litton, Graybeal and Hertzberg, 1979). This sensor uses an ionization chamber to efficiently charge smoke particles and measure their concentration. The pyrolysis tube was a 2.8-cm-long piece of 0.64-cm-diameter stainless steel tubing heated resistively to a surface temperature of 350° C. The tests verified that diesel smoke showed no effects of pyrolysis. Fire smoke particles were found to pyrolyze linearly with their average diameter, d_o, for the four combustible materials; $G_n = n/n_o \approx 55\ d_o$, where G_n represents the ratio of number concentrations of the particles leaving the pyrolysis tube, n, to the number concentrations entering the pyrolysis tube, n_o. For the fire smoke, the average unpyrolyzed diameter varied from 0.05 to 0.70 µm. These laboratory results indicated that a pyrolysis detector using the Bureau's smoke detector as the primary sensor and utilizing the difference between pyrolyzed and unpyrolyzed signals to distinguish between fire smoke and diesel smoke has the potential to reliably detect fires in the presence of significant diesel background levels.

The use of the pyrolysis concept requires that both a pyrolyzed and an unpyrolyzed signal be measured. One option is to devote a separate detector to each sampling line. This option, however, requires not only two sensors, but two sensors whose response characteristics are very similar (ideally, identical). Now, the conventional Bureau smoke detector utilizes an ionization chamber consisting of a set of parallel plate electrodes with one electrode having 5 µCi of americium 241 deposited uniformly on its surface. To create two identical chambers, a piece of fluorocarbon polymer was used to divide the original chamber into two separate, distinct chambers. Each of these new chambers has its own electrically isolated negative electrode, while the positive, radioactive electrode is shared by the two chambers so that only one common voltage source is needed to power both chambers. The result is two identical, independent ionization chambers, one chamber continuously measuring the pyrolyzed smoke particles while the other measures the unpyrolyzed smoke particles.

The original pyrolysis tube required ~45 amps at a voltage of 0.27 V to maintain the 300° C temperature necessary for operation. To reduce the current requirements for the pyrolysis tube, a new tube was fabricated which utilizes a 5.1-cm-long, 1.6-mm-diameter ceramic rod. Resistance wire is wound around the ceramic rod and the ends of the wire electrically connected by a 6-V power supply which consumes ~0.70 amps. This rod is then inserted into the air space between two fittings. At the gas inlet port to the new sensor, a T-connection allows one-half of the flow to pass through this new pyrolysis tube to its ionization chamber while the other half of the flow passes through a plain section of tubing to the other ionization chamber. When no smoke particles are present in the air being sampled, the output signals of both chambers are amplified and electronically adjusted to identical levels of -7.0 V. When smoke enters either chamber, the signal levels decrease.

For example, at an average smoke particle diameter of d_0 = 0.20 μm (2 x 10^{-5} cm), a 1 pct reduction in unpyrolyzed signal occurs when the smoke concentration is 4 x 10^5 p/cm^3. However, the corresponding signal reduction in the pyrolysis chamber is ~5 pct. This means that the unpyrolyzed signal minus the pyrolysis signal is ~0.28 V. Subsequent data acquired with the prototype indicates that an alarm threshold around 0.3 to 0.5 V appears reasonable. Several of the prototype diesel-discriminating fire sensors are currently being field tested in underground coal mines that use diesel-powered equipment.

CONVEYOR BELT FLAME TEST

About 25% of the reportable U.S. underground coal mine fires between 1983 and 1988 involved conveyor belting. The current U.S. flammability test for acceptance of fire-resistant belting for coal mines is performed in a 0.53 m cubical test chamber with 4 samples 152-mm-long by 12.7-mm-wide by the belt thickness. Each sample is subjected to a Bunsen type burner flame for 1 min (U.S. Code of Federal Regulations, 1988). A study was conducted by the U.S. Bureau of Mines, in cooperation with MSHA, to assess the flammability of conveyor belting in a large-scale gallery and develop an improved laboratory-scale fire test for belting (Lazzara and Perzak, 1989).

The large-scale arched gallery was 27-m-long, 3.8-m-wide and 2.4-m-high, with a 7.5-m-square cross sectional area. For the gallery tests, 9.1-m lengths of belting were placed on the top rollers of a conveyor belt frame, about 1.2 m from the roof, and thermocouples installed to measure flame spread rates. The airflow was 1.52 m/s and the ignition source was a 7.6 L liquid fuel tray fire. Previous studies in the gallery on the effect of ventilation on conveyor belt fires (Lazzara and Perzak, 1987)(Verakis and Dalzell, 1988) demonstrated that flame propagation at these test conditions was most likely to occur at an airflow of 1.52 m/s. The tray, 0.6-m-long by 1-m-wide, by 0.3-m-deep was located at the upstream end of the belt sample. The criterion of belt fire damage, excluding blistering, was selected to decide whether a belt passed or failed the large-scale gallery test. A belt passed if fire damage did not extend to the end of the 9.1-m-long sample and a portion of the sample was undamaged across its width.

Nine synthetic rubber belts and eight polyvinyl chloride (PVC) belts were subjected to the gallery test. All the belts, except one rubber belt, passed the current U.S. acceptance tests for fire-resistant belting. The belts were all about 1 m wide and varied in thickness from 9 mm to 15 mm.

Four types of flammability behavior were observed in the gallery: (1) rapid flame spread, >4m/min, followed by the entire sample burning, (2) rapid flame spread that charred the entire top surface of the belting, but left the bottom surface undamaged, (3) a slowly propagating flame, with spread rates ranging from 0.3 to 1.3 m/min, that completely consumed the belting (4) and a nonpropagating fire with a portion of the 9.1-m-long sample left undamaged. Of the 17 belts tested, 11 (7 rubber and 4 PVC) failed the large-scale gallery test and 6 passed.

The laboratory-scale fire test for belting was conducted in a ventilated tunnel shown in figure 8. The test chamber is 1.8-m-long by 0.46-m-square and is constructed from 2.5-cm-thick refractory material. The igniter is a commercial 12 jet methane gas burner (two rows of 6 jets). The belt sample is fastened to a steel rack constructed of slotted angle iron.

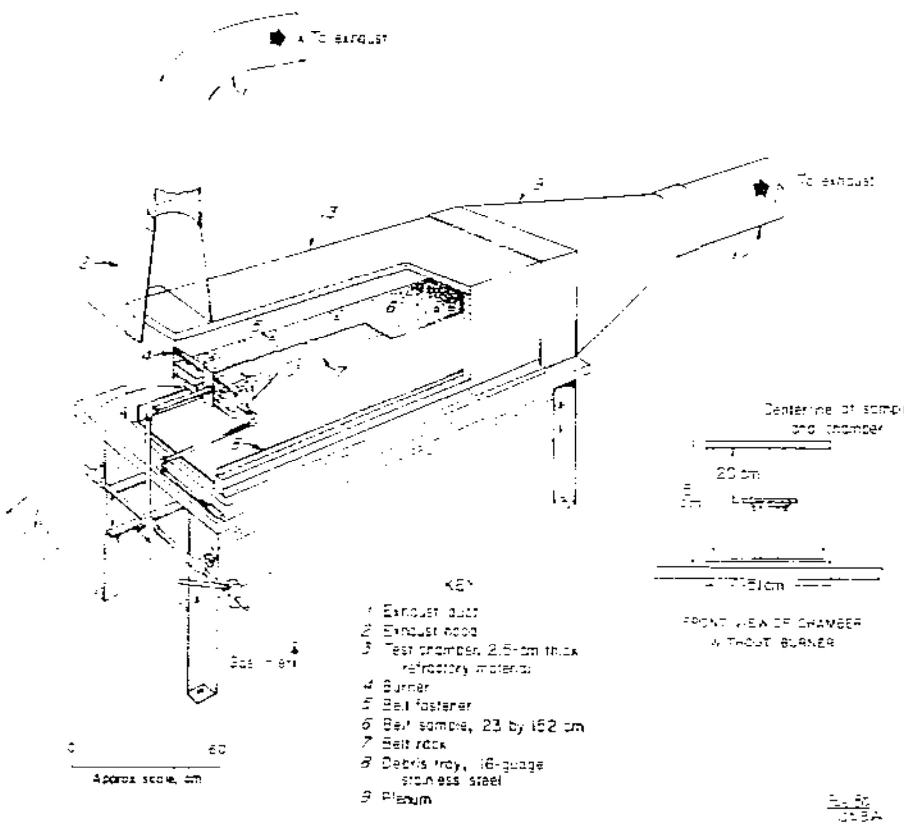

FIGURE 8 - Schematic of laboratory-scale fire tunnel.

In preliminary experiments to establish a set of standard test conditions, several variables were examined, including airflow, sample width, distance of rack to tunnel roof, and burner duration. Several of the belts that exhibited different burning characteristics in the large-scale gallery test were used for these tests. The laboratory test conditions were adjusted to give similar fire damage results to the large-scale gallery test for these belts. The test conditions that were finalized: sample size, 1.52-m-long by 0.23-m-wide, by nominal belt thickness (6 to 19 mm); distance of sample rack from tunnel roof, 20 cm; tunnel airflow, 1.02 m/s; duration of gas igniter, 5 min; methane flow to burner, 35 L/min at 22° C and 101 kPa.

To conduct a test, a belt sample is fastened with the top cover up, if applicable, to the steel rack with cotter pins and thin washers to prevent the belt from shrinking away from the burner. The rack is placed in the tunnel and the airflow (1.02 m/s) set. The burner is applied to the front edge of the belt sample with the flames impinging equally on the top and bottom surfaces of the sample. After 5 minutes, the burner is removed, and the belt sample allowed to burn until the flames are out. If a portion of the sample remains on the rack, the rack is removed and the extent of any undamaged belting, across the width of the sample, is measured. A belt is judged to have passed the laboratory-scale test if, in three trials, there remains a portion of the 1.52-m-length sample that is undamaged across its width, excluding blistering. A belt fails the test if in any single trial, fire damage extends to the end of the sample.

All 17 belts that were examined in the large-scale fire gallery test were subjected to the laboratory-scale fire test. For most of the belts, the fire damage was similar to that found in the large-scale fire gallery test. Of the 9 rubber belts tested, 7 failed the laboratory-scale test by being totally consumed and 2 passed. For the 8 PVC belts, 4 failed the laboratory-scale test and 4 passed.

A comparison of the pass/fail results for the large-scale gallery and laboratory scale fire tests for the 17 belts showed that they were in very good agreement. For the 9 rubber belts, the results were in complete agreement, with the same 7 belts failing the gallery and laboratory-scale test, and 2 belts passing both tests. For the 8 PVC belts, the pass/fail results for 6 of the belts were in agreement, with the same 3 belts failing the large-scale gallery and laboratory-scale fire tests and 3 belts passing both tests. There were discrepancies in the comparison for 2 of the PVC belts.

MSHA has announced plans to replace the current conveyor belt flammability acceptance test with the Bureau's new laboratory-scale fire test for belting. The rulemaking process for this change has been initiated.

INFLATABLE SEALS

Feasibility studies are being conducted on the development of relatively inexpensive inflatable seals that can be used for rapidly isolating mine fire areas to allow for fire suppression by self-inerting and/or gas injection. The seals were fabricated of nylon in the form of cylindrical bags, with an air injection port on the curved surface near the base. These waterproof, lightweight bags are oversized to the mine entry to provide greater surface contact area. The cylindrical design of the bags ensures proper deployment in the entry regardless of the initial orientation of the deflated unit. Two seals, one 2.4-m-high and 6.7-m in diameter the other 3-m-high and 9.1-m in diameter, were tested in a 2-m-high, 6.7-m-wide entry of the Lake Lynn Experimental Mine. An explosion-proof axial fan (71 m^3/min) was used to rapidly inflate the seals. It was possible to stop airflows of over 1,400 m^3/min within 2 minutes and to restore full entry ventilation within 3 minutes. Differential pressures of 0.5 cm of water were measured across the seals. These lightweight seals were inflated to pressures of up to 17.8 cm of water gage. A pressure of 5.1 cm of water was needed to keep the bag inflated under conditions of minimal leakage. Work is underway to determine if a seal filled with a quick-setting foam would be able to withstand an explosion. In addition to this in-mine application, experiments are being conducted to determine if this inflatable seal can be remotely deployed from the surface through a borehole to the mine entry near the fire zone.

SUMMARY

Underground coal mine fires and explosions continue to occur in U.S. mines. The U.S. Bureau of Mines has an active research program on mine disaster prevention that addresses this problem. The fruition and implementation of the research developments described in this paper will further reduce the risk and severity of mine fires and explosions. Novel instruments to remotely detect dangerous methane and coal dust accumulations and sense incipient fires in the presence of diesel exhaust, water sprays to suppress frictional gas ignitions, improved fire-resistant conveyor belting, and better techniques to suppress explosions and erect rapid seals will significantly enhance our present capabilities to prevent and combat mine disasters.

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