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Water Barrier Performance in a Wide Mine Entry

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An analysis of the performance of 80-L water tub barrier units was made at the Lake Lynn Experimental Mine (LLEM). The test entrys cross-section is typical of that currently found in operating mines.

The explosion flame, which interacted with the barrier sets, is generated by the face ignition of flammable methane/air mixtures. The barrier sets were placed in a 119-m long test zone which contained an explosive mixture of Pittsburgh Pulverized Coal (PPC) and limestone rock dust. Barrier sets were evaluated at various locations (40 to 160 m from the face) and configurations in the entry. The barrier units were placed on the entry floor, at mid height, and suspended near the roof, and often, they were triply stacked at the ribs.

Many successful suppressions and some failures were obtained. Suppression of a moderate velocity flame propagating through a zone of 67.8 pct total incombustible content (TIC) was achieved with four centered roof barrier units when they were placed from 60 to 100 m from the face. Non-suppression of the flame occurred at the 40- and 160-m locations. At the 40- to 100-m locations, 2 triply stacked rib barrier units were quite effective for the 67.8 pct TIC zones. Suppression of a moderate velocity flame propagating through a 63.2 pct TIC zone was achieved with 2 stacked rib barrier units placed at either 60 or 80 m from the face. When placed at 80 m from the face, these stacked rib barrier units successfully suppressed the flame propagating through a 58.6 pct TIC zone.

Stacked barrier units are portable, simple to install, and inexpensive to erect. In wide mine entries, they pose less of an impedance problem for men and equipment than do roof-mounted barriers. For some mines having high dust deposition rates, stacked barriers would offer additional protection beyond that afforded by generalized rock dusting.

Introduction

As a consequence of normal mining operation, fine coal dust is generated, transported, and deposited along most of the mine roadways. This dust, once entrained in an atmosphere containing sufficient oxygen, can form a flammable dust cloud. Should such a dust cloud encounter an adequate ignition source, an extremely violent and dangerous explosion can develop and travel along many passageways in a mine.

The majority of coal dust explosions in the last few decades have been caused by the frictional ignition of methane at the coal face — the surface of the solid coal bed at the advancing front of the working place. However, serious explosions have occurred elsewhere and by other ignition means; it is possible to initiate and sustain a coal dust explosion without the presence of methane. Analysis of the history of U. S. explosions which have occurred since the 1960's indicates [2] that at least 90 pct of them involve methane.

Previous studies have indicated that it is difficult to protect certain areas from explosions solely by generalized rock dusting. These areas are as follows:

- Conveyor beltways,
- Belt transfer points,
- High float coal dust deposition rate areas,
- Wet roadways,
- Parked mine cars,
- Development sections and methane drainage areas,
- Return airways
- Longwall faces,
- Isolated sections,
- Room and pillar region near an active face, and
- Very gassy faces.

In U.S. coal mines, rock dusting is currently the primary means of defense against coal dust explosions. In Europe, various combinations of stone dusting, dust binders, and passive and triggered barriers are employed depending on the mining conditions and degree of explosion hazards from mine to mine. European countries have found that rigid water troughs are quite effective in extinquishing moderate strength explosions provided the tubs are a minimum of 45 m from the explosion initiation. Both Polish [2] and West German [3] researchers indicate the minimum quantity of water in the barrier should be at least 183 kg/m^2 (4.5 gal/ft^2). The pasive barrier systems has been shown to be an attractive means of defense against coal dust explosions and are currently used in some European mines. Explosion suppression barriers are devices that contain chemical or thermal extinquishants which, when pressure and/or flame activated, disperse their contents at some critical time ahead of or into the advancing flame front. Passive barriers do not have intrinsic trigger mechanisms to rapidly release or disperse the barrier agent as do triggered barriers. In the case of passive water barriers, the dynamic wind forces, generated ahead of the propagating flame, tips or fragments the container to release and disprerse the water so as to suppress the oncoming flame front.

From 1974 to 1986, studies with water tub barriers were conducted [4-7] in the Bruceton Experimental Mine (BEM). The barrier units most frequently studied were West German manufactured water tubs and were found adequate for suppressing moderate to strong coal dust explosions. The tub is made of polyvinyl chloride (PVC), holds approximately 80 L of water and was found to operate best when supported rigidly in a metal frame by means of its upper lip resting on the frame rather than sitting on roof shelves.

Liebman et al. [5] found in the BEM (1.8 m high by 2.7 m wide) tests that a single barrier with a water density of 13.5 kg/m^2 (0.33 gal/ft^2) of mine cross section proved effective against explosions prapagating at flame speeds of 76 m/s (250 ft/s) to over 305 m/s (1000 ft/s). The Bureau has also developed a modified barrier tub that is effective against slow-moving explosions. These are the same German tubs with part of the upper lip removed.

Ng et al. recently conducted barrier tests using German water tubs in the BEM [7]. The velocity of the flames interacting with the barriers ranged from 167 to 285 m/s (548 to 935 ft/s). For these tests, the volume of barrier agent ranged from 160 to 320 L. The cross-sectional area of the BEM test zone is 5.0 m^2 (54 ft^2) which is much less than that for LLEM's D-Drift.

An in-mine study was conducted to evaluate the endurance of roof mounted water tub barriers [8]. Some barrier units have been deployed in a Pennsylvania mine and were found to be adaptable to the size and shape of existing cross sections of the beltway where the height is 2.1 m (7 ft) or higher. In lower coal, roof mounted barriers would impede vehicular flow along many U.S. mine entries. However, if tubs could be deployed along the ribs of wide entries and not seriously impede transportation of men and equipment, these would be applicable to U.S. coal mines.

This report describes recent Bureau of Mines efforts with passive water barriers to evaluate the suppression performance of roof mounted and rib stacked barriers in a wide single enty. The range of conditions for which barriers can successfully suppress explosions and those conditions with which the barriers can not cope were determined and compared with water requirements for explosion suppresssion in the BEM single entry. A comparison of the entry lengths and cross-sectional areas of the BEM and LLEM is shown in Fig. 1. Since

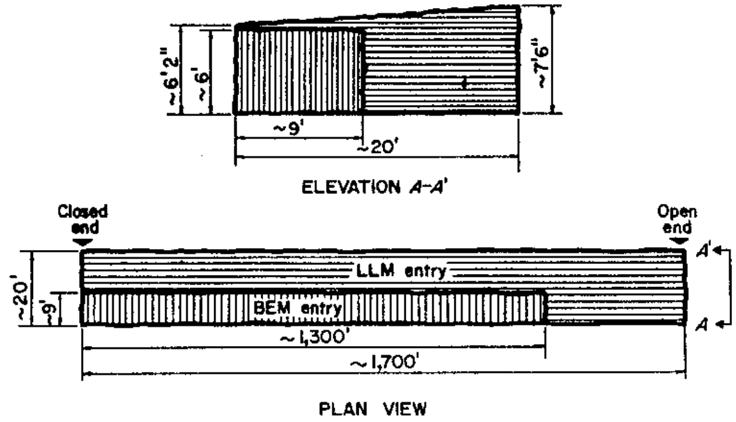

Fig. 1. Comparison of entry sizes for the BEM and the LLEM

the LLEM geometry closely matches that typically found in current U.S. operating mines with high seam height and wide room width, the LLEM research findings on the propagation and suppression of coal dust explosions have more direct applicability to the U.S. mining industry than those from experimental mines with small cross-sectional areas.

Experimental procedure

The dust explosion suppression tests with barrier units were conducted in the single entry D-Drift of the LLEM. The entry is 518 m (1700 ft) long with a cross-sectional area ranging from 11.2 to 13.0 m^2 (120 to 140 sq ft). D-Drift is instrumented with pressure transducers and optical flame sensors located at the face and approximately 10, 15, 30, 45, 60, 90, 120, 150, 180, and 230 m from the face. A sketch of the LEM is shown in Fig. 2. The mine has four parallel drifts — A, B, C, and D. Drifts C and D are connected by E-Drift, a 152 m (500 ft) long entry which simulates a longwall face. D-Drift, for this study, was isolated from E-Drift by means of a 67 st movable bulkhead. Mattes et al. [9] have provided a detailed description of the test facility in a previous report.

Experiments were conducted in D-drift to determine the effectiveness of conventional roof-mounted barriers versus floor stacked barriers deployed at diferent distances from the face. Explosions were initiated by igniting near

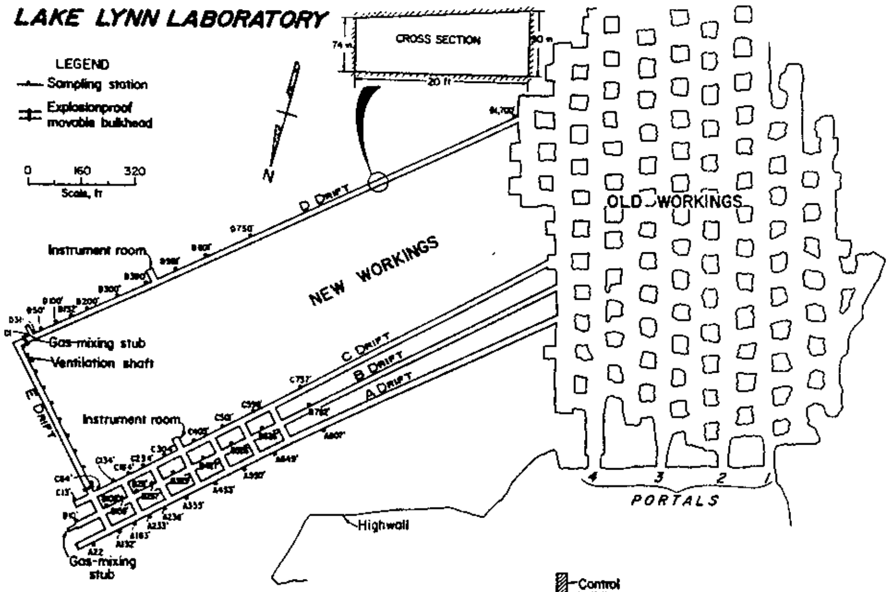

Fig. 2. Plan view of the LLEM

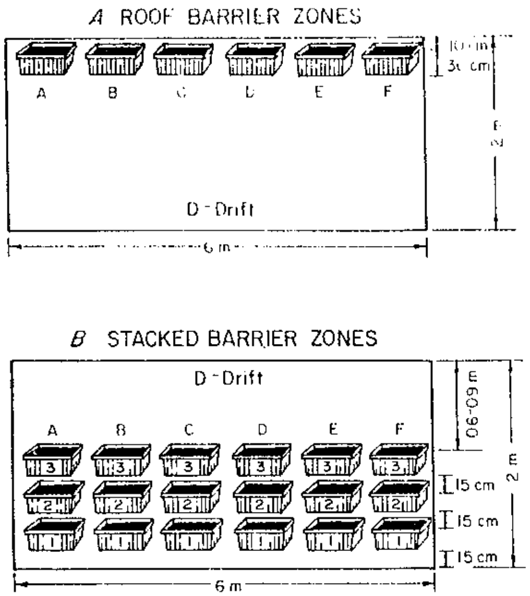

Fig. 3. Barrier deployment configurations

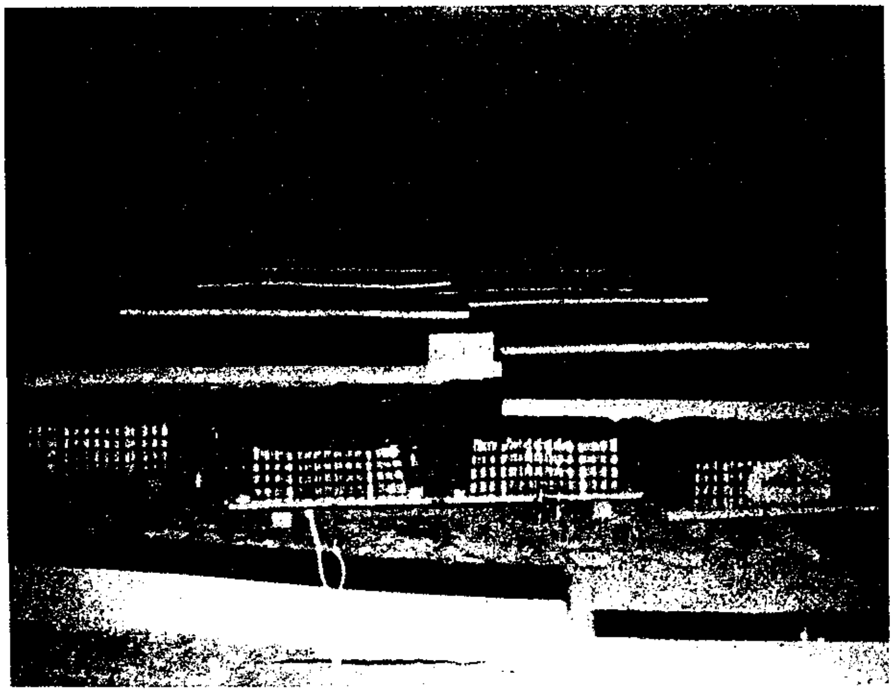

Fig. 4. Roof mounted water tub barrier

stoichiometric methane-air mixtures confined to the first 12.2 m (40 ft) from the closed end (face) by a plastic diaphragm [10]. A mixture of rock dust and PPC (80 pct les than 74 m particles) is spread on the floor and on the chemical foam roof shelves in the dust zone (edge of gas zone at 12.2 m up to 131 m from the face) to provide a PPC nominal dust concentration near 200 mg l. A nominal concentration assumes a complete and uniform entrainment of the dust throughout the cross-section of the mine entry during the explosion test. This standard test coal dust was mixed with limestone rock dust (70-80 pct less than 74 m particles) to provide mixtures ranging from 58.6 to 67.8 pct TIC (55 to 65 pct rock dust) in order to vary the explosion intensity. Explosion tests in the single entry without barriers would propagate flame 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 were designed to hold 80-l of water, and they were aporoximately 30 cm in height, 50 cm in width, and 75 cm in length. These water barrier experiments were conducted at 30 m and also at 40- to 160 m, in 20 m increments, from the closed end.

Figure 3A shows the experimental configurations for suspending the 80-l PVC tubs from the roof. The majority of the roof barrier tests were conducted with 4 tubs using zones B, C, D, and E. Figure 4 shows a typical view of a roof mounted water tub barrier in D-Drift. The tubs are supported by metal frames secured to the roof by bolts. Small diameter wires (break wires) were attached to the tubs to indicate when the tubs start to rupture or tip during the explosion. Details of the construction supports and frames are described by Liebman et al [6]. The roof installation requires support framework, roof bolts, plates, and suspension hooks. Considerable fabrication and installation time are involved. Roof mounted tubs are usually deployed in high roof regions (such as where yieldable steel arches are used) in order not to impede transportation.

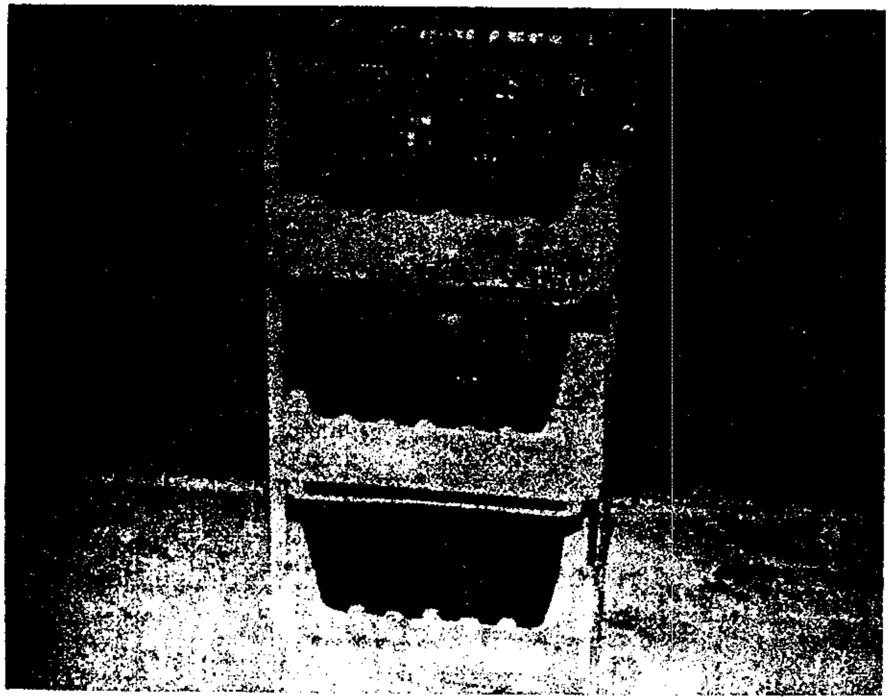

Fig. 5. Stacked water tub barrier unit

The experimental configurations for the stacked barriers are shown in Fig. 3B. The majority of the stacked barrier tests were conducted by erecting a triply stacked barrier unit along each rib (zones A and F). Figure 5 shows a typical stacked water tub barrier in D-Drift near the rib. In the stacked configuration, the first 80-l tub is set on two cribbing timbers which lie on the mine floor. The second barrier tub straddles the first using two more timbers and so on. To help distribute the weight, vertical wood strips are nailed to the exposed end of the horizontal timbers. Break wires were also attached to the stacked tub units to indicate when the tubs start to rupture or tip during the explosion. No anti-evaporation lids were placed on the water filled tubs. See the Appendix for further details.

Results and discussion

A typical pressure/flame diagram of a coal dust explosion (67.8 pct TIC) without a barrier system is shown in Fig. 6. The figure shows the wall or static pressure history recorded at various distances from the face. The pioneer wave moves toward the open end at the speed of sound. Flame travels past 228 m (750 ft) maintaining a rather constant speed. Notice that there is little attenuation of pressure with distance over much of the dusted zone [10]. Superimposed on this plot are the leading edge of the flame and the end of the hot radiation zone (trailing edge). At a particular station along the entry, the interval between the leading edge of the flame front and the trailing edge of the flame represents the duration of the flame at that station.

Table 1 summarizes the conditions and results of the explosion tests with roof mounted barriers in the single entry. All of the experiments in Table 1 were initiated using a 150 m^3 zone of 10 pct methane. For these experiments, four 80-l modified tubs of water were hung from the roof at zones B, C, D, and E except in test 92 where the tubs were installed in zones A, B, E, and F. In test 93, only two tubs awere installed in zones B and E (see Fig. 3A).

The precursor wave, generated from the ignition of the methane/dust mixture, initiates the barrier operation depending on the strength of the barrier mount. Roof mounted barriers start to operate at as low as 1.8 psi overpressure

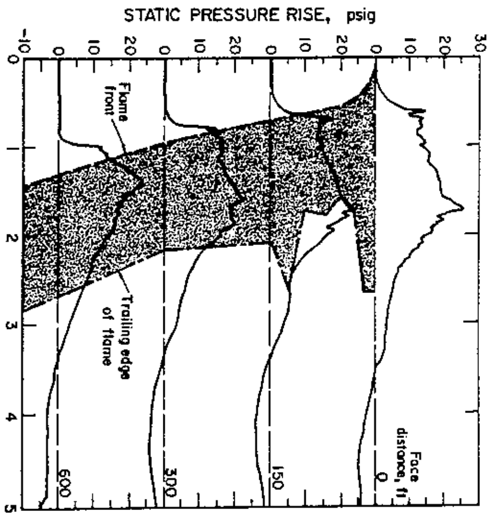

Fig. 6. Explosion wave diagram without a barrier

— this pressure is acting at about the time of the rupture of the break wire. For tests in which suppression occurred, flame speeds at the barrier ranged from 153 to 211 m/s (500 to 690 ft/s).

It is observed that the barrier effectiveness decreases at large distances from the face. Non-suppression 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 s during which time a significant fraction of the water drops 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 zone; however, they failed to suppress the explosion when it propagated along a 63.2 pct TIC (60 pct rock dust) zone.

Table 2 summarizes the conditions and results of the explosion tests with stacked barrier units in the single entry. Each of the experiments in Table 2 were initiated using a 150 m³ zone of 10 pct methane. For the majority of these experiments, three 80-l tubs of water were stacked near each rib (zones A and F) except for tests 99, 112, and 114 (zones B and E); and test 104 (zone C and D).

Figure 7 shows a pressure-flame diagram illustrating suppression of the coal dust explosion by stacked barrier units and its effect on the flame and the pressure development. The figure shows (test 121) that the barrier stacks begin to tip when the flame has propagated about 33 m (110 ft) from the face, allowing

Table 1

Summary of test conditions and result of roof mounted barrier experiments

Test No.	TIC pct	Barrier location m	Static pressure[1] psi	Fleme speed approaching barrier m/s	Time between tub operation and flame arrival s	Flame travel beyond barrier m	Result
90	67.8	- - - - - - - - - -	- - - - - - - - - -	control test[2]	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
91	67.8	100	15.0	186	0.24	19	sup
92	67.8	100	15.5	183	.23	19	sup
93	67.8	100	15.9	195	.20	> 53	non-sup[3]
108	67.3	60	19.0	184	.11	0	sup
109	67.3	80	11.0	173	.21	12	sup
110	67.3	160	15.2	181	.44	69	mon-sup
111	63.2	100	21.0	211	.18	19	sup
113	63.2	80	12.5	205	.16	12	sup
115	63.2	60	14.0	202	.09	169	non-sup
117	63.2	40	12.0	210	.07	189	non-sup
118	67.8	40	10.2	182	.07	189	non-sup
119	67.8	120	11.8	153	.39	63	non-sup
120	67.8	140	19.0	190	.32	89	non-sup
122	67.8	100	14.5	192	.23	19	sup

[1] Static pressure at the baterier site at the flame arrival time.

[2] Baseline test — no barriers; avg. flame speed from 40-160 m is 196 m/s; flame travel > 230 m from the flace.

[3] Only 2 tubs.

Summary of test conditions and result of stacked barrier experiments **Table 2**

Test No.	TIC pct	Barrier location m	Static presure[1] psi	Fleme speed approaching barrier m/s	Time between tub operation and flame arrival s	Flame travel beyond barrier m	Result
90	67.8	control test[2]					
99	67.8	100	12.0	150	0.32	19	sup
102	67.8	100	14.8	188	.23	19	sup
103	67.8	100	13.5	191	.22	19	sup
104	67.8	100	11.3	155	.31	19	sup
112	63.2	100	16.2	173	.24	19	sup
114	63.2	80	13.5	202	.15	11	sup
116	63.2	60	14.5	160	.15	1	sup
121	67.8	40	12.3	230	.02	13	sup
123	67.8	30	8.0	139	.06	199	non-sup
124	58.6	100	18.0	202	.23	19	sup
125	58.6	80	16.2	200	.15	11	sup
126	58.6	40	12.3	220	.05	143	non-sup

[1] Static pressure at barrier site at flame arrival time.

[2] Baseline test — no barriers; avg. flame spee from 40-100 m is 195 m/s; flame trawel >230 m from the face.

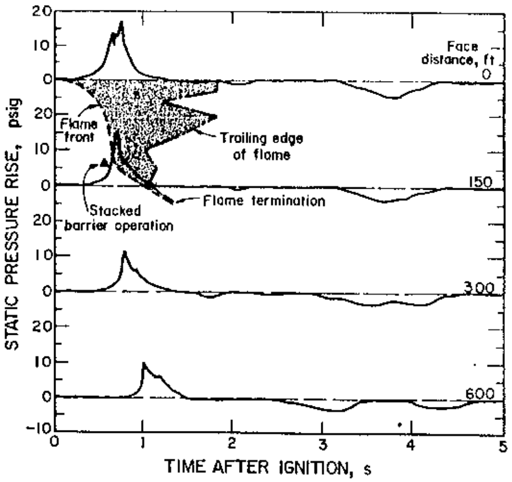

Fig. 7. Explosion wave diagram with a stacked barrier unit along each rib at 40 m from face (closed end)

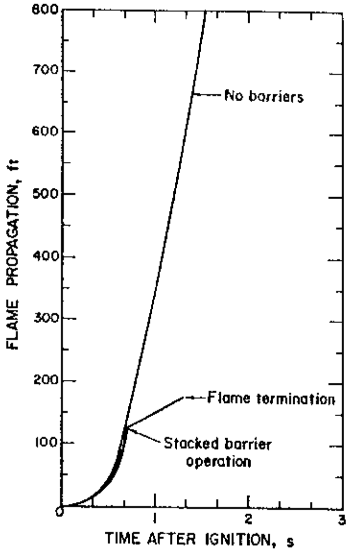

Fig. 8. Effect of a stacked barrier unit along each rib at 40 m on the explosion flame generated from a 67.8 pct TIC test

about 0.02 s of water discharge prior to the flame arival. Suppression occurs at 53 m (175 ft) which is just beyond the barrier site of 40 m (131 ft).

Figure 8 shows a comparison bettween an explosion propagation without a barrier and one with a stacked barrier unit located at each rib at 40 m from the face. The stacked barriers suppress the explosion propagating through the 67.8 pct TIC zone. A triply stacked barrier unit along each rib at 80 m from the face can suppress an explosion in a dust mixture as low as 58.6 pct TIC in which the standard roof mounted barriers fail. In tests which suppress, the stacked barriers start to operate at as low as 11.3 psi and the flame speeds at the barriers range from 150 to 230 m/s (490 to 755 ft/s).

To better understand the action of the stacked barrier units at the 40-m location, high speed motion pictures were taken. These pictures showed (1) the interaction between the stacked water tubs and the air blast preceding the ignitor flame and (2) the formation of the water cloud. The pictures revealed the following:

(1) Initially, some water was aspirated off the top of the tubs.

(2) Under the influence of the air blast, the wooden structure (made from cribbing and firring strips) which supported the tubs pivoted; and the balance of the water was dispersed.

(3) Approximatly 5 m from the barrier site, the water had dispersed, extending a water cloud boundary almost from the floor to the roof.

Although some water was dispersed through aspiration, it appears that the bulk of it dispersed following the pivoting action of the barrier unit. A barrier tub design which facilitates pivoting of the individual unit might provide earlier dispersion, and this would promote more effective barrier action when the barrier site is closer to the point of ignition. Selected scenes from these high speed motion pictures are shown in Fig. 9.

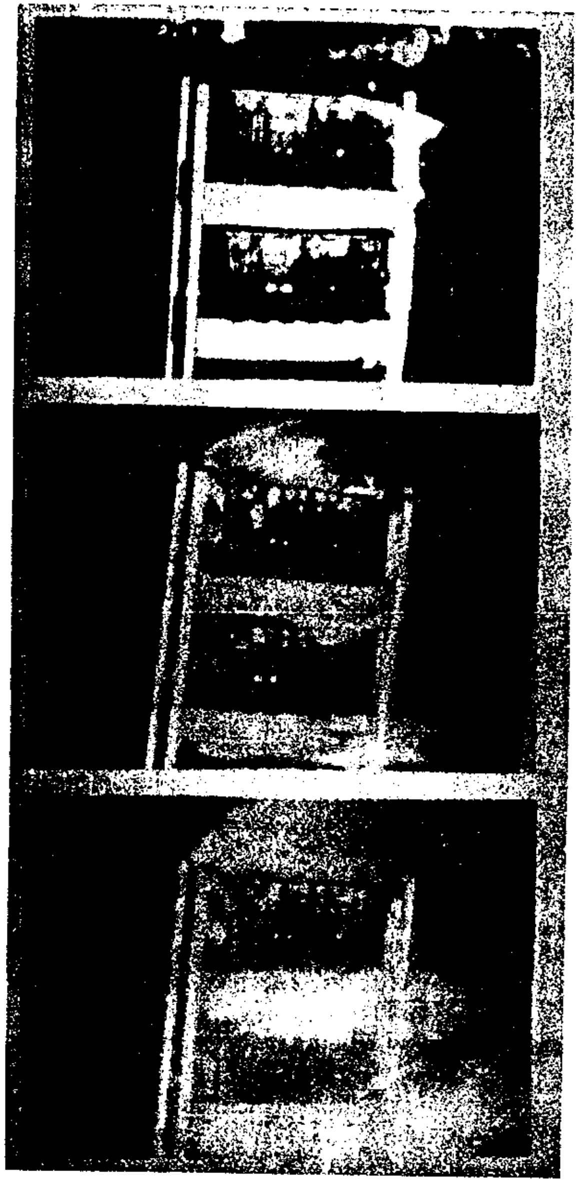

Fig. 9. High speed photographs of a stacked barrier unit operating 40 m from the face

Our explosion suppression tests with water barriers show that stacked tub units located along the ribs are quite effective in suppressing dust explosions and are signifantly less expensive to install than roof mounted Barriers.

Conclusions

1. For moderate explosions propagating through dust mixtures of 63.2 wt pct TIC, good barrier dispersion and effective quenching can be achieved in roadways typical of that found in current operating high seam U.S. mines. Both roof mounted and stacked barrier units were quite effective in stopping moderate strength explosions in a 63.2 and 67.8 pct TIC zones.
2. Explosions could be suppressed with barriers located between 40 and 100 m from the face in a single-entry configuration.
3. One row of four roof mounted barriers worked effectively against moderately strong explosions propagating through a 67.8 pct TIC zone when placed at 60 to 100 m from the face. On the other hand, they failed to suppress the explosion when they were placed at 40, 120, 140, or 160 m from the face. A stacked water tu barrier unit located at each rib at 40 m from the face suppressed an explosion propagating through this 67.8 pct TIC zone.
4. A stack of three tubs located near each rib at 60 m from the face were very effective in suppressing coal dust explosions in dust mixtures of 63.2 wt pct TIC, where conventional roof mounted barriers failed to suppress in this zone. At 80 m from the face, this stacked water tub configuration can suppress a coal dust explosion in a mixture as low as 58.6 pct TIC.
5. Stacked water tub barrier units are portable, simple, quick, and relatively inexpensive to erect.
6. Stacked water tub units optimally located near the ribs would provide rasonable clearance for most vehicular traffic expected in mines and have the potential to provide an additional gas and dust explosion protection in certain areas that are difficult to protect solely by generalized rock dusting.

Appendix

Construction details for a stacked barrier are provided in Fig. 10. The bottom tub is placed on the cribing which is on the floor and filled with water. Cribbing is then placed on the top of the bottom tub. The middle tub is placed on the cribbing and is half filled with water. Wooden strips are nailed to the cribing on the floor and to the cribbing just above the bottom tub. Water is then added to fill the

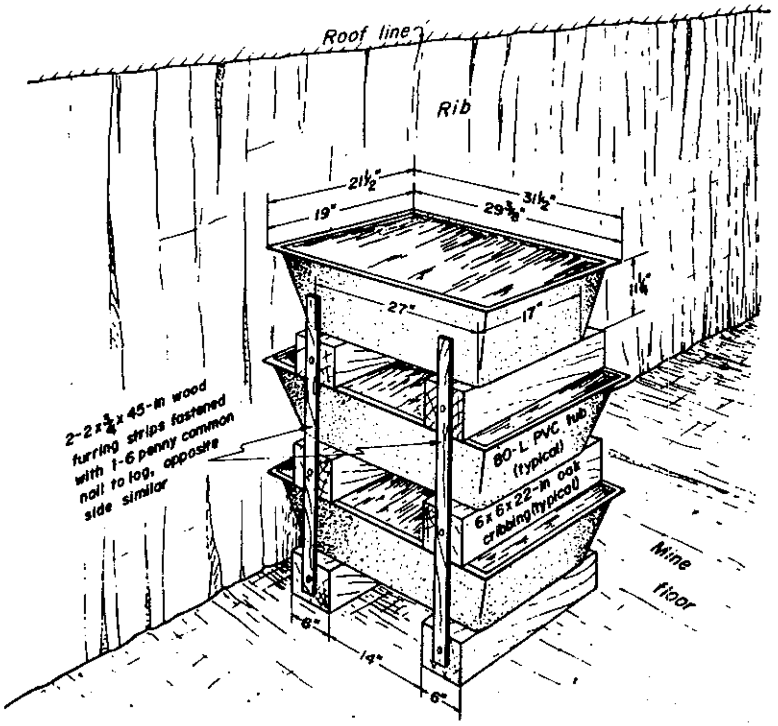

Fig. 10. Sketch of stacked water barrier unit

middle tub. Next, cribbing is placed on the top of the middle tub. The top tub is then put into position and half filled. The wooden strips are nailed to the cribbing for the top tub and additional water is used to fill the top tub.

Acknowledgments

Mr. Francis Fuller of PRC's Theoretical Support Group operated the LLEM computer for the real time acquistion of the mine explosion data and prepared selected plots of the test data for subsequent interpretation. Mr. Jennings „Randy" Lipscomb coordinated preparations for the shot and initiated the shot firing sequence. He performed the initial assessment of the experimental results and tabulated the data. Both Ken Jackson and Jack Ward assisted in the maintenance of the LLEM instrumentation system.

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