EVALUATION OF THE BAGGED STONE DUST BARRIER EFFECTIVENESS IN A BORD AND PILLAR MINE

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ABSTRACT

A project to evaluate the South African bagged stone dust explosion barrier was successfully completed at the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory's (PRL), Lake Lynn Experimental Mine (LLEM) during the period November 1999 through May 2000. The tests were conducted in a three-entry section of the LLEM. Two types of explosions were used to evaluate the distributed and concentrated bagged barrier performance in a multi-entry mine section. The fuel zone of the first explosion type was only in the center B-drift. In the second explosion type, coal and stone dust mixtures were place in all three drifts. A total of six explosions, including two baseline and four barrier evaluation explosions, were conducted. Of the four barrier explosions, the distributed and concentrated barriers were each evaluated against the two explosion types. For these explosion tests, the distributed barrier extended from about 74 to 170 m and the concentrated barrier from about 74 to 104 m in B-drift. The distributed barrier successfully stopped flame propagation in both types of explosion tests. The flame extended further for the explosion tests where the dust was loaded in all three entries compared with dust loaded only in the center entry, but in both cases the flame was stopped within the barrier zone. The concentrated barrier was also successful in stopping flame propagation in both explosion tests. From the full-scale experimental mine test results, it can be concluded that both bagged barrier designs were effective in stopping coal dust explosions in the multiple entries of the LLEM.

KEYWORDS

Explosion, suppression, coal mine, explosion barrier, stone dust

INTRODUCTION

During the past three decades, the South African coal mining industry has experienced a significant number of explosions leading to a considerable loss of life. Since 1993, the strategic thrust of local research has been to prevent the accumulation of methane by good ventilation practice, to eliminate frictional sparking by the use of water, to minimize dust generation and dispersion, and to use stone dust to prevent a dust explosion. South African regulations require fugitive dust in the mine entries to contain 80% incombustible content within the face area which is defined as 180 m outbye the last through road. The final line of defense, however, is the use of barriers to prevent a coal dust explosion from propagating beyond the affected working section.

Over the past four or five years, a great deal of research effort has been expended on developing a bagged stone dust barrier. Following the successful selection of bag material and the development of closure mechanisms, the bags have proved effective in suppressing explosions in the South African gallery at Kloppersbos (5-m^2 cross sectional area) and at the Experimental Mine Tremonia in Germany (20-m^2 cross sectional area). These two programs verified that the concept of a bagged stone dust barrier could be used with considerable confidence in protecting long single entries. The results of these programs are reported in du Plessis and Vassard (1997), Margenburg and du Plessis (1996), and Michelis, Margenburg, and du Plessis (1996). However, in South African coal mines, multiple-entry mining methods are invariably used, but little was known of how explosions propagate under these conditions. As the effect of intersections on the explosion propagation was unknown and the simultaneous arrival of pressure waves from different

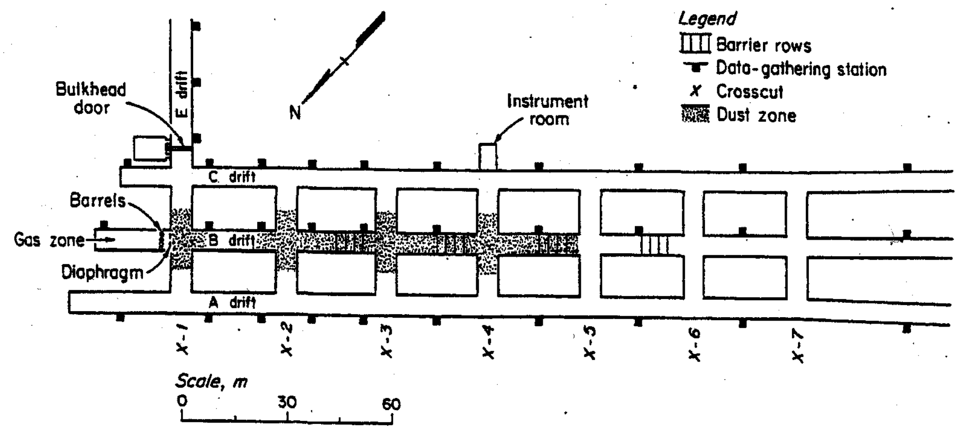

Figure 1. Multiple entry area of the Lake Lynn Experimental Mine, showing B-drift dust zone and distributed barrier positions

directions may render the bag breakage mechanism ineffective, it was felt important that the final series of tests for these barriers should be conducted in a room and pillar section. This report summarizes these multiple-entry explosion tests. Additional details are in the comprehensive Final Report by du Plessis, Weiss, and Cashdollar (2000).

EXPERIMENTAL MINE AND INSTRUMENTATION

Lake Lynn Experimental Mine

The National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory's (PRL), Lake Lynn Laboratory (LLL) is the only facility worldwide where suitable tests could be conducted in a room and pillar section. The LLL is located approximately 80 km southeast of Pittsburgh, near Fairchance, Pennsylvania, U.S.A. The facility occupies more than 1.6 km^2 at a former commercial limestone mine. This site was formerly developed in the 1950's as a limestone quarry, with underground room and pillar workings excavated from the highwall. Due to changes in mining geometries and the need for isolation for conducting large-scale explosion research, the U. S. Bureau of Mines (USBM) developed LLL in the early 1980's. Even though the principal purpose for constructing the laboratory was mine explosion testing, the underground experimental mine design, the expansive surface areas, and the high-speed data-gathering and computer systems afforded an opportunity for a broad range of mine safety and health research. In October 1996, the PRL facility, including the LLL, was transferred from USBM to NIOSH.

Mattes, Bacho, and Wade (1983) described the development of the LLL site. The underground Lake Lynn Experimental Mine (LLEM) is the main experimental area of the LLL site. The LLEM consists of two distinct sections. There are approximately 7,620 m of 16 m wide by 9 m high entries that were developed in the mid 1960's as part of the commercial limestone mining operation. The 2,286 m of new workings were developed by the USBM to simulate the dimensions of modern U.S. coal mines. The entries are about 6 m wide and about 2 m high. The average cross sectional area of the entries is about 12 m^2. The LLEM was designed to withstand explosion overpressures up to approximately 700 kPa (100 psi). Figure 1 shows the multiple-entry section of the LLEM. In order to simulate room and pillar workings during the explosion tests, drifts A, B and C were isolated from E-drift by closing the bulkhead door between C- and E-drifts. Each of the three drifts is approximately 520 m long, with seven crosscuts at the inbye end as shown in the figure. The pillars created by this configuration are each approximately 24 m long by 11 m wide.

One of the original objectives of establishing LLEM was to study the effect of multiple entries on the strength and propagation of methane and coal dust explosions, but only limited work in that area had been completed before this project. Greninger, Cortese, and Weiss, 1995, have described some of that work.

Instrumentation

Each drift has ten environmentally controlled data-gathering stations (locations shown in Figure 1) inset in the rib walls. Each data-gathering station houses a strain gauge transducer to measure the explosion pressure and an optical sensor to detect the flame arrival. The pressure transducer is perpendicular to the entry length and therefore measures the static pressure generated by the explosion. The flame sensors used silicon phototransistors, with response times on the order of microseconds. These devices were positioned back from the front window of the flame sensors in order to limit the field of view.

Table of LLEM Explosion Tests

LLEM Test #	Date	Type	Static Pressure* kPa	Flame Travel, m	Notes
389	4 Nov 1999	dust explosion baseline	100	160	coal and 65% stone dust to 104 m in B-drift plus halfway into crosscuts
390	7 Dec 1999	dust explosion baseline	110	250	coal and 65% stone dust to 140 m in B-drift plus halfway into crosscuts
391	12 Jan 2000	distributed barrier	100	100	same as for test #390, plus distributed barrier from 74 to 170 m
392	2 Feb 2000	distributed barrier	80	150	coal and 65% stone dust to 140 m in B-drift plus halfway into crosscuts, coal and 80% stone dust in A- and C-drifts plus halfway into crosscuts, plus distributed barrier from 74 to 170 m
393	23 Feb 2000	concentrated barrier	105	95	same as for test #390, plus concentrated barrier from 74 to 104 m
394	29 Mar 2000	concentrated barrier	90	110	coal and 65% stone dust to 140 m in B-drift plus halfway into crosscuts, coal and 80% stone dust in A- and C-drifts plus halfway into crosscuts, plus concentrated barrier from 74 to 104 m

*Average static pressure from just outbye crosscut 1 to just inbye crosscut 6 in B-drift

In the evaluation of an explosion barrier, it is essential to know the dynamic pressure approaching the barrier, since that is the pressure that breaks the bags and disperses the stone dust. Barrier operation is then correlated with a rated dynamic pressure. For this program, two types of dynamic pressure sensors were used: the first measures the force acting on a known area and the second measures the differential between the pressures upstream and downstream of the flow. A total of three of the first type and six of the second type were installed on various platforms/stands in the middle of the entries or crosscuts.

Since the measurement of the explosion temperature at the barrier positions proved valuable in barrier evaluations done at the DMT Tremonia Experimental Mine (Michelis, Margenburg, and du Plessis, 1996 and Margenburg and du Plessis, 1996), temperatures were measured using heat flux gauges during the LLEM tests. The temperature (T in kelvins) was calculated from the heat flux (H in W/cm^2) using the Stefan-Boltzmann Law:

$$H = 5.67 \times 10^{-12}\, T^4. \qquad (1)$$

The sensor data gathered during the explosion tests were relayed from each of the data-gathering stations to an underground instrument room located off C-drift and then to an outside control building. A high-speed, 64-channel, PC-based computer data acquisition system (DAS) was used to collect and analyze the data. This system collected the sensor data at a rate of 1,500 samples/s over a 5-s period. The data were then processed and outputted in graphic and tabular form. The reported pressure data were averaged over 10 ms (15 point smoothing). Some of the data were also collected on an older backup data acquisition system.

EXPERIMENTAL MINE PROCEDURES AND TEST RESULTS

The objective of the multiple-entry test program was to show whether coal dust explosions in room-and-pillar workings could be suppressed by bagged stone dust barriers. Six full-scale coal dust explosions were conducted: two baseline tests (without barriers) to ensure flame propagation well beyond the end of the proposed barrier position and four barrier evaluation tests, as listed in the following summary table of LLEM explosion tests. Two explosion tests were conducted against each of the two barrier configurations installed in B-drift. For each barrier, the first explosion test had a coal and stone dust mixture (65% stone dust) in B-drift only. The second explosion test for each barrier had coal and stone dust mixtures in all three drifts (65% stone dust in B-drift, 80% in A- and C-drifts). The coal dust used was pulverized Pittsburgh seam bituminous with ~36% volatility and ~80% minus 200 mesh. The stone dust was limestone with ~70% minus 200 mesh. The barriers were installed in B-drift, which was to simulate a coal mine belt entry with a reduced stone dust concentration due to coal dust from the belt. These tests were designed to evaluate the effectiveness of the two barrier configurations in preventing flame propagation. It must be noted, however, that these barrier evaluation tests did not include a conveyor belt structure in B-drift.

Before each explosion test, a 60-t hydraulically operated, track-mounted, concrete and steel bulkhead door was positioned across the opening to E-drift to contain the explosion pressures to the A-, B-, and C-drift multiple-entry area. Natural gas (~97% methane) was remotely injected into the face area (closed end) of B-drift. An electric fan with an explosion-proof motor housing was used to mix the natural gas with air in the ignition zone. A plastic diaphragm was used to contain the natural gas and air mixture within the closed end of the drift. A gas sampling tube within the ignition zone was used to continuously pull a sample and monitor the gas concentration using an infrared analyzer. In addition, samples were collected in evacuated test tubes and sent to the PRL analytical laboratory for more accurate analyses using a gas chromatograph. Electrically-activated matches, in a triple-point configuration equally spaced across the face (closed end) of the entry, were used to ignite the flammable natural gas and air mixtures. Water-filled barrels were located in the gas ignition zone to act as turbulence generators to achieve a higher resulting pressure pulse.

Baseline Dust Explosion Test Plan

The first baseline (without barriers) explosion test (LLEM test #389) consisted of a 21-m long, 9.5% methane-air ignition zone extending from the closed end of B-drift. The 82-m long coal dust zone extended from just outbye the methane zone to about 104 m. Dust was also loaded halfway into crosscuts 1 to 3. The coal dust loading was 150 g/m^3, assuming uniform dispersion throughout the cross section. The coal dust was premixed with 65% limestone dust. Including the ash and moisture in the coal, this corresponded to a 68% total incombustible content in the mixture. The total amount of coal and stone dust mixture was 560 kg, of which half was suspended on shelves and the other half distributed on the mine floor.

The second baseline explosion test (LLEM #390) was identical to the first baseline test except that the dust zone was extended out to 140 m, resulting in a 119-m long dusted zone, as shown in Figure 1. The dust mixture was also loaded halfway into crosscuts 1 to 4. The total amount of coal and stone dust mixture was 793 kg, of which half was suspended on the roof shelves and the other half on the entry floor.

Baseline Dust Explosion Test Results

The first baseline coal and stone dust explosion test #389 had an 82-m long zone in B-drift of premixed coal and stone dust at 65% stone dust or 68% total incombustible. There were no dust zones in A- or C-drifts. The average static pressure in B-drift was ~100 kPa, over the distance from just outbye the methane ignition zone to just inbye crosscut 6 (where the last sub-barrier would be located in later tests). There were slightly lower average static pressures in A- and C-drifts (no dust loadings). In a 90-m distance in B-drift (spanning three intersections), the dynamic pressure decreased from 121 kPa between crosscuts 1 and 2 to 16 kPa between crosscuts 4 and 5. The dynamic pressures at the positions where the first three sub-barriers would be were:

First sub-barrier position:	41 kPa
Second sub-barrier position:	~25 kPa
Third sub-barrier position:	16 kPa

For this baseline test, the flame travelled ~160 m from the face in B-drift, not quite as far as the planned position of the last row (170 m) of the fourth sub-barrier of the distributed barrier. The flame also went into crosscuts 1 through 4, and reached the second and third flame sensors in A- and C-drifts, The maximum flame speed of ~298 m/s was calculated between the 64-m and 78-m flame sensors, near where the first sub-barrier would be located in later tests. The temperatures calculated from the heat flux data were ~1560°C at 64 m and ~1410°C at 100 m from the face.

The delays between the time of peak dynamic pressure and the time of flame arrival were calculated at the positions of the dynamic pressure sensors by interpolating the flame arrival data. The delay times were 148 ms at the first sub-barrier, 180 ms at the second sub-barrier, and 406 ms at the third sub-barrier proposed positions. The minimum delay time would be 148 ms at the proposed first sub-barrier position for the stone dust to disperse and effectively inhibit the flame propagation. The last recorded flame position was within the planned zone for the distributed barrier. Therefore, a longer coal dust zone was needed for the next baseline test in order to produce a flame extending well beyond the final sub-barrier position.

The second baseline test, LLEM #390, was conducted with a longer, 119-m dusted zone in B-drift of premixed coal and 65% stone dust. The average static pressure in B-drift was 110 kPa (a slight increase compared to the first baseline explosion), with comparable or slightly lower average static pressures in A- and C-drifts. The peak dynamic pressures were not recorded due to a triggering delay malfunction on the PC data acquisition system The static pressures and flame data were available because they had also been recorded on the older backup data acquisition system.

The explosion flame extended to ~250 m in B-drift, well beyond the planned position (170 m) of the last row of the barrier. The flame also extended into crosscuts 1 through 5 toward A-drift and into crosscuts 1 through 4 toward C-drift. The maximum flame speed was calculated as 805 m/s between the 48-m and 64-m flame sensors. At 74 m from the closed end of B-drift (the position where the first sub-barrier would be located), the interpolated flame speed was ~161 m/s. At the positions where the other sub-barriers would be located, the interpolated flame speeds were ~104 m/s for the second, ~80 m/s for the third, and ~54 m/s for the fourth sub-barrier. The temperatures were ~1470°C at 64 m and ~1370°C at 100 m from the face of B-drift for this explosion.

The estimated delays between the time of peak dynamic pressure and the time of flame arrival were calculated for this explosion test. To estimate the time delays at the sub-barrier positions, it was assumed that the peak dynamic pressure coincided with the peak static pressure, since no dynamic pressures were recorded. The times of peak static pressure and the times of flame arrival were interpolated at the sub-barrier positions. The estimated delay times (Δt) at the proposed positions of the sub-barriers are shown below.

First sub-barrier	~132 ms
Second sub-barrier	~320 ms
Third sub-barrier	~450 ms
Fourth sub-barrier	~880 ms

These delay times were comparable to the range of values during the first baseline test. The minimum delay time would be 132 ms at the proposed first sub-barrier position for the stone dust to disperse and effectively inhibit the flame propagation.

Distributed Barrier Test Plan

The first explosion test (LLEM #391) against the distributed barrier configuration used the same ignition and dust zones as baseline test #390; i.e., a 21-m long, 9.5% methane-air zone and a 119-m long dusted zone (premixed coal and 65% stone dust) in B-drift and halfway into crosscuts 1-4. The distributed barrier configuration in B-drift was divided into four equal sub-barriers, as shown in Figure 1. The first sub-barrier was positioned between crosscuts 2 and 3 and started at 74 m from the face. The other three sub-barriers were positioned between crosscuts 3 and 4, crosscuts 4 and 5, and crosscuts 5 and 6, with the last row of the fourth sub-barrier positioned 170 m from the face. Each sub-barrier consisted of four 5-mm diameter steel cables stretched across the entry and spaced 2 m apart (Figure 2). Twelve stone dust bags were suspended and equally spaced across the entry on each cable of the sub-barrier. Therefore, there were a total of 48 bags per sub-barrier. At 6 kg of stone dust per bag, this gave 288 kg per sub-barrier. The total of four sub-barriers resulted in a total of 192 bags for the distributed barrier configuration. The total mass of stone dust suspended in the bags was 1,152 kg, resulting in an average stone dust concentration of ~96 kg/m^2 of cross section or ~1.0 kg/m^3 over the length of the barrier, if all of the stone dust were uniformly dispersed. This distributed barrier was based on the design by du Plessis and Vassard (1997).

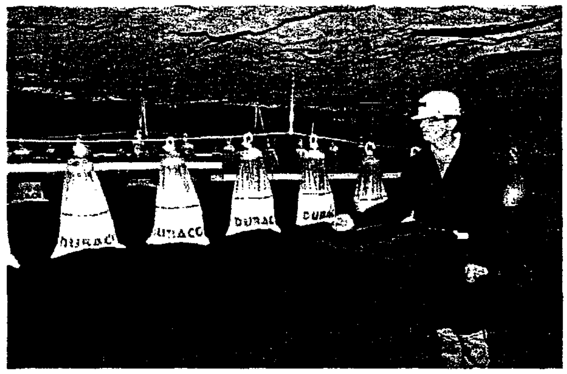

Figure 2. Mining engineer with distributed barrier

The second test to evaluate the performance of the stone dust bags in the distributed barrier configuration was identical to the first performance test (#391) with the addition of 119-m long dust zones in A- and C-drifts. The coal and stone dust mixture used in A- and C-drifts was premixed to provide 80% stone dust or 82% total incombustible in the mixture. The dust was loaded on the floor and on the shelves in a manner similar to that in B-drift. The dust zone in B-drift remained the same as for test #391 (65% stone dust or 68% total incombustible). The triple-entry dust zones required a total of 767 kg of coal dust and 2,475 kg of stone dust for a combined dust mixture of ~3,242 kg. The barrier stone dust bags were suspended on steel cables in B-drift in the same configuration as for the first distributed barrier test #391.

Distributed Barrier Test Results

Test #391 was a repeat of baseline test #390, except that the distributed barrier was installed in B-drift (74 to 170 m from the face). The average static pressure was ~100 kPa. The peak static pressures in the three drifts were nearly equal at 80 m and greater from the face. The peak dynamic pressure decreased from ~138 kPa to 14 kPa over a 90-m distance (spanning three intersections). The peak dynamic pressures at the first three sub-barrier positions were:

First sub-barrier position:	70 kPa
Second sub-barrier position:	20 kPa
Third sub-barrier position:	14 kPa

The flame propagation was stopped at ~100 m in B-drift, with flame extending into the first three crosscuts toward A-drift and into the first two crosscuts toward C-drift. The flame only extended to the beginning of the second sub-barrier, indicating extinguishment of the propagating flame within 30 m of the first sub-barrier. The total flame reduction was approximately 150 m in B-drift, relative to flame travel in baseline test #390. The flame reached a maximum speed of 171 m/s between the 48-m and 64-m flame position. The minimum delay time of 158 ms was comparable to those at the first sub-barrier position in tests #389, #390, and #391.

The increase in the flame speed in test #392 relative to that in test #391 could be related to the added fuel zones in A- and C-drifts for test #392. This may have acted as a channel effect, increasing the flame speed and flame propagation rate in B-drift. Another contributing factor may have been the final concentration of methane in the gas zone prior to initiation (1.7 m^3 of additional natural gas was added during test #392, compared to test #391). However, the flame in B-drift beyond the first sub-barrier position during test #392 was barely propagating and could be described as a wandering flame. The flame observed in A- and C-drifts cannot be classified as a propagating explosion, but should be considered rather as flame extending through the crosscuts from B-drift. This was confirmed by the flame sensor time-plots for A- and C-drifts, which showed that the flame arrived later in A- and C-drifts than in B-drift.

It can be concluded that the distributed barrier effectively stopped the coal dust explosion flame propagation within the barrier zone during both of the LLEM evaluation tests, although the flame extended an additional 50 m in test #392, compared with the results of test #391 where there was coal dust only in B-drift.

Concentrated Barrier Test Plan

The two concentrated barrier explosion tests (LLEM #393 and #394) were the same two explosion types as for the distributed barrier tests (LLEM #391 and #392). The stone dust bags used for the concentrated barrier configuration were suspended on 16 steel cables starting at 74 m (between crosscut 2 and 3) from the closed end of B-drift. This was the same starting position as that for the distributed barrier. The other 15 rows of steel cables were equally spaced (2 m apart) outbye this position. The last row of the concentrated barrier was positioned 104 m from the closed end (between crosscuts 3 and 4). This resulted in a 30-m long concentrated barrier system. Twelve 6-kg stone dust bags were suspended and equally spaced along each of the 16 steel cables. A total of 192 bags were installed for the concentrated barrier configuration. The total mass of stone dust suspended in the bags was 1,152 kg, the same as that for the distributed barrier. The average stone dust concentration was ~3.2 kg/m^3 over the length of the concentrated barrier. This concentrated barrier was based on the design by du Plessis and Vassard (1997).

Concentrated Barrier Test Results

Two coal dust explosion evaluation tests (LLEM #393 and #394) were conducted against the concentrated barrier, which was installed in B-drift from 74 to 104 m. The two evaluation tests were analogous to the two tests (#391 and #392) for the distributed barrier. The first test (#393) was conducted with the premixed 68% total incombustible coal and stone dust zone only in B-drift; the second test (#394) also had this same B-drift dust zone with the addition of 82% total incombustible dust zones in A- and C-drifts.

The first test (#393) against the concentrated barrier configuration utilized the same ignition zone and dust zone as the baseline test #390 and the first test (#391) against the distributed barrier (21-m long 9.5% methane ignition zone with a 119-m long 68% total incombustible dust zone). The average static pressure in B-drift was ~105 kPa The peak dynamic pressure in B-drift decreased from 123 kPa to 14 kPa over a 90-m distance which spanned three intersections.

The flame extended to ~95 m in B-drift, with flame into the first three crosscuts toward A-drift and into the first two crosscuts toward C-drift. Flame propagation was stopped within the barrier and the flame extended only about 20 m from the barrier start position. The total flame reduction when compared with the baseline dust explosion test #390 was approximately 155 m in B-drift. Less flame was recorded in A- and C-drifts compared with the baseline test due to the reduction of the flame in B-drift. The flame speed in B-drift for test #393 is shown in Figure 3. The flame reached a maximum flame speed of 368 m/s between the 65-m and 77-m flame sensors. At the position of the first barrier, the interpolated flame speed was ~314 m/s. The flame speed decreased rapidly within the concentrated barrier zone and the flame was quenched well within the barrier zone. The temperature calculated from the heat flux was ~1580°C at 64 m; the instrument at 100 m did not measure any temperature increase.

The delay time at the barrier start position was 175 ms. The concentrated barrier configuration was effectively activated. Only three piles of stone dust were observed in the crosscut in the middle of the barrier. The stone dust was well distributed with heavy stone dust loadings observed on the mine floor throughout the barrier zone and for a distance of ~10 m beyond the end position of the barrier

Test #394 with the concentrated barrier configuration installed in B-drift was similar to test #392 with the distributed barrier configuration in B-drift; i.e., 21-m long 9.5% methane ignition zone with a 68% total incombustible coal and stone dust loading in B-drift and an 82% total incombustible coal and stone dust loading in A- and C-drifts. The concentrated barrier was positioned in B-drift from 74 to 104 m, the same as for test #393. The average static pressure in B-drift was ~90 kPa. The peak dynamic pressure in B-drift decreased from 117 kPa to 13 kPa over a 90-m distance which spanned three intersections.

The flame extended to ~110 m in B-drift, with flame into the first four crosscuts toward A-drift and into the first three crosscuts toward C-drift. Flame propagation was stopped within the barrier and the flame extended no more than 30 m from the barrier start position. The total flame reduction was approximately 140 m in B-drift. The flame speed in B-drift for test #394 is shown in Figure 3. The flame reached a maximum flame speed of 166 m/s between the 48-m and 64-m flame sensors. At the position of the first barrier, the interpolated flame speed was ~140 m/s. The flame speed decreased rapidly within the barrier zone and the flame was quenched near the outbye end of the barrier zone. The calculated temperature was ~1560°C at 64 m; the instrument at 100 m did not measure any temperature increase.

The mean delay time at the barrier start position was 147 ms. The concentrated barrier was effectively activated during this test. The stone dust was well distributed, with heavy stone dust loadings observed on the mine floor throughout the barrier zone and beyond.

CONCLUSIONS

The evaluation of the bagged stone dust barrier system against coal dust explosions was successfully completed at the Lake Lynn Experimental Mine of NIOSH. Two barrier designs were evaluated: the distributed barrier configuration and the concentrated barrier configuration. Each configuration was performance evaluated against two types of explosions. The first type used a 21-m long 9.5% methane ignition zone and a 119-m long 68% total incombustible coal and stone dust zone loaded only in B-drift. The second used the same methane ignition zone and 119-m dust zone with 68% incombustible in B-drift, plus additional 119-m long dust zones with 82% incombustible in both A- and C-drifts.

The distributed barrier configuration was successful in stopping flame propagation within the barrier zone for both explosion test types. Similarly, the concentrated barrier configuration was successful in stopping flame propagation within the barrier zone for both explosion test types. The average total flame reduction during the barrier system evaluations was ~135 m, compared to the flame travel during the baseline test (without the barrier).

The bagged stone dust barrier has thus proven successful in stopping flame propagation in small (5-m^2 gallery at Kloppersbos in South Africa), medium (12-m^2 gallery at LLEM in the U.S.), and large (20-m^2 gallery at Tremonia in Germany) explosion galleries. The results from the barrier evaluation programs that were conducted at these facilities appear to have successfully resolved the potential concern regarding the adequacy of the barrier design and operation as a function of entry size and configuration (single entry or bord and pillar entries). Barrier operation still is dependent on the type and strength of the explosion to be extinguished. Furthermore, all barrier designs, including the stone dust barrier bag systems, have limits to their operational extremities.

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