

SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: ASSESSMENT OF EXPLOSTION BARRIERS

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SYNOPSIS

This report summarizes the test work which has been completed on the comparison of different types of barriers for stopping flame propagation of coal dust explosions in a 200 m gallery. The tests were conducted at the Kloppersbos Research Facility.

A standard test explosion was developed with enough wind pressure and flame propagation at 80 m from the closed end of the gallery to activate passive water barriers, stone dust barriers, active water barriers and automatic belt roadway suppression systems. The barriers were evaluated on their effectiveness at preventing further flame propagation.

At present the passive barriers which have been tested include water trough barriers, stone dust barriers and dispersed barriers, and the active barriers include gas and a mixture of gas and water.

The different passive barriers: water, stone dust and dispersed barriers all proved successful in stopping flame propagation within 20 m from the barrier end position. The active roadway barrier needs further investigation.

The effectiveness of the dispersed barriers must be determined at low dynamic pressures as these might be the system of the future.

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1. INTRODUCTION

The presence of methane and coal dust in underground mines presents an inherent explosion hazard. Various methods have been developed to prevent, or to stop flame propagation of these explosions.

Stone dust is used to create an inert mine environment. The use of protective measures such as passive or active explosion barriers is secondary in that they are only effective if a coal dust explosion does develop. The purpose of explosion barriers is to prevent the flame from propagating throughout the mine.

This report summarizes the test work which has been completed, on the effectiveness of different types of explosion barriers. The standard test to enable comparison of different types of explosion barriers in their effectiveness in preventing flame propagation, is a simulation of a low pressure coal dust explosion.

1.1 Background

The current Regulation 10.24.9 states that if stone dust barriers are installed in a coal mine, the design and construction will be done in consultation with the regional director.

For stone dust barriers to work effectively they must be installed a certain distance from the face to allow for the development of adequate wind pressure (dynamic pressure) to distribute the stone dust effectively. This minimum distance is between 60 - 100 m. As the section advances the stone dust barriers need to be moved forward continuously as the maximum distance between barriers should ideally not exceed 200 m.

At present the use of explosion barriers in the South African Coal Mining Industry is limited as their use has not been a statutory requirement. A

variety of explosion barrier types is utilised worldwide. Four of these have been identified and were evaluated at the Kloppersbos Research Facility. The identified explosion barriers are: passive water barriers¹, stone dust barriers², dispersed barriers³, active suppression barriers^{3,4,5} and active water barriers⁶.

The effectiveness of an explosion barrier is influenced by wind pressure, delay time between wind front and flame front (determined by the severity of an explosion), the amount of inert material and the arrangement and siting of the explosion barrier. The principle factors, acting singly or in combination, that arrest flame propagation are:

1. dispersed inert material (water, stone dust etc.)
2. pressure release
3. amount of fuel present
4. oxygen deficiency of the atmosphere⁷.

Inert material, when dispersed in sufficient quantity, will quench the flame partly through absorption of heat and radiant energy, by hindering diffusion of oxygen and gases and also by screening the coal from burning⁷.

2. EXPLOSION PROCEDURE

A coal dust explosion is an explosion in which coal dust particles smaller than 240 μm participate in an uncontrolled combustion in an underground mine environment, resulting in damage and/or fatalities.

A coal dust explosion can result if all the installed control measures and procedures fail, or if the measures being used are inadequate at the time.

2.1 Ignition

The initiation of coal dust explosions for evaluating the barriers was achieved by igniting 36 m³ of 9% methane/air mixture. This chamber of 36 m³ was obtained by placing a plastic membrane 7,5m from the closed end of the gallery. This amount of methane/air mixture is needed to produce enough wind pressure to lift the coal dust into the air and to supply sufficient heat to the coal dust particles so that flame propagation can take place.

2.2 Gallery Description

The 200 m G P Badenhorst test gallery was used to conduct the different tests. A comprehensive description of the tunnel was given by Cook and Brandt (1991 and 1993)^{7,8}.

The gallery is equipped with static and dynamic pressure, flame and temperature sensors.

2.3 Explosion Procedure

Coal dust

The coal dust used for the experiments was Greenside No. 2 seam coal, which is the standard coal used for experiments at the Kloppersbos Facility.

The coal was milled down to a median particle size of 20 $\mu\text{m} \pm 2\mu\text{m}$ and a top size of 150 $\mu\text{m} \pm 10 \mu\text{m}$ as expressed on a Rossin-Rammler-Bennet size distribution graph. This is considered to be typical of explosive coal dust representing the mean size distribution of float dusts encountered underground.

Barrier explosion

A weak, **standard barrier explosion**⁹, was developed for testing the explosion barrier systems. This is an initiating explosion of 36m³ of 9 % methane/air mixture with a wind pressure of approximately 25 kPa, with flame propagation throughout the gallery from coal dust combustion without producing additional pressure.

Coal dust was distributed on the floor at a rate of 0,75 kg/m for the full length of the tunnel and the barriers were placed at 80 m from the closed end of the tunnel or 72,5 m from the membrane⁹. The flame advanced to the end of the gallery, developing an average wind pressure of 28 kPa at 80 m.

A standard test procedure was developed to be able to compare the different types of barriers against a constant wind pressure and delay time between wind front and flame front. The delay time, between wind front and flame front, and pressure vary with the severity of the explosion. The mean delay time for the standard explosion is 400 milliseconds.

The experimental layout for the standard barrier explosion and barrier explosions is shown in Figure 1.

The effectiveness of such systems is evaluated by determining the distance that the flame travelled beyond the end position of the barrier.

It is difficult to produce a weaker coal dust explosion in the gallery owing to the vacuum created by the cooling of the heated gasses. This effect prevents the flame from propagating through the whole length of the gallery. The wind pressure used to evaluate barriers is at a pressure where passive explosion barriers work effectively.

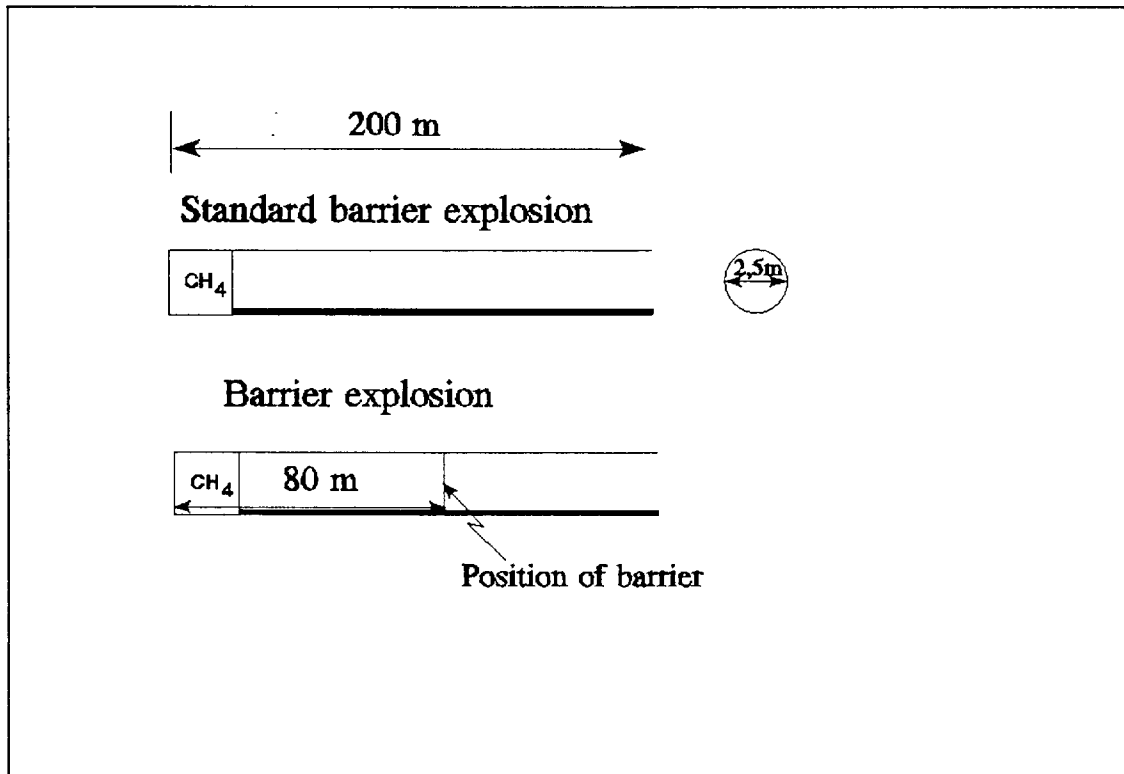


Figure 1: Experimental layout

3. EXPLOSION BARRIER DESCRIPTION

The various explosion barriers tested at the Kloppersbos facility are described briefly.

3.1 Passive Water Trough Barrier

The passive barrier¹ is activated when the wind pressure is high enough to shatter the plastic trough and to disperse the water sufficiently to produce a cloud of water droplets across a roadway to extinguish the flame.

The minimum wind pressure required to crack a trough is 5 kPa and to disperse the water effectively 20 kPa. If the wind pressure is less than the minimum required, either the dispersion of water will be inadequate or the water trough will not shatter. This can result in the failure of the passive

water barrier to stop the flame propagation. The implication of this minimum wind pressure is the limitation of the effectivity of any of the tested passive barriers.

Ten water troughs were filled with 80ℓ of water (800ℓ in total)⁹. The troughs were placed in pairs side by side on wooden frames. The wooden frames were suspended 50 cm from the roof of the gallery and spaced 1 m apart. The position of the first water troughs was 80 m from the closed end of the gallery.

3.2 Stone Dust Barrier

Stone dust barriers rely principally on activation by the dynamic wind force. To be effective 10 kPa dynamic pressure is required to activate them⁸. Different designs (Poland, Germany, USA) have been extensively tested throughout the world^{2,10}. This kind of barrier is still used in Europe especially in return airways.

The design of the barrier tested was based on the light stone dust barrier standard (100 kg/m²). This resulted in a barrier consisting of 11 shelves loaded with 48 kg of stone dust per shelf. The initial design of 10 shelves proved impossible to load to the required mass.

Each shelf consisted of a wooden frame with masonite on top. The masonite dimensions were 350 mm by 150 mm and placed side by side. The wooden frame was suspended from the tunnel roof using chains. This resulted in a free moving shelf. When the wind force reached it, the masonite board was easily toppled, dispersing stone dust and activating the barrier.

3.3 Dispersed Barrier System

This system works on the same principle as the other passive explosion barriers. A certain minimum dynamic pressure is required to activate it and to disperse the stone dust (approximately 5 kPa).

The systems tested consisted of a different number of stone dust bags of specific design hanging from the roof of the tunnel. The tests conducted started from a low load of inert material per cross sectional area (20 kg/m^2) to the same amount of inert material required for a light stone dust barrier (100 kg/m^2). This was achieved by changing the number of bags suspended from the roof of the test gallery (20 to 100 stone dust bags). A photograph showing the installed barrier is shown in Figure 2.

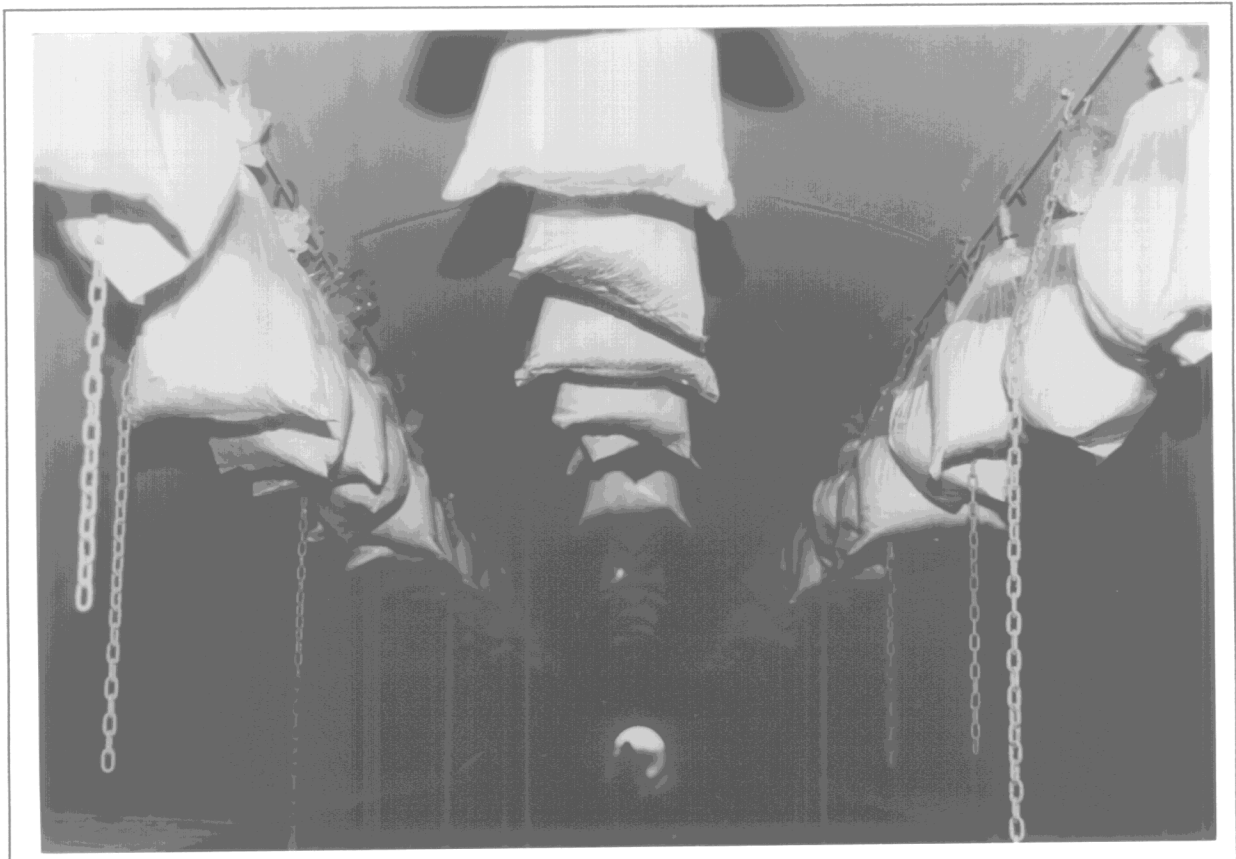


Figure 2: Dispersed barrier system

3.4 Active Roadway Barrier

Active suppression systems^{3,4,5} contain an extinguishing agent and are activated by a triggering system. Triggering systems include: an electronic light sensor detects the flame or an electronic pressure sensor detects an increase in wind pressure and the system is activated to disperse gasses, dust or other means of extinguishing the flame.

These barriers can be used in cases where passive barrier systems are ineffective, since their operation is not dependent on the strength of the wind pressure.

3.4.1 Active suppression system using gas

The active suppression system tested used NAFSIII gas. Ten bottles were filled with 3,2 kg of NAFSIII gas each, attached to a frame and installed in the tunnel at 80 m from the closed end of the gallery. A combination of infrared sensors was used to discriminate between the actual burning coal dust or methane/air mixture flame, and other light which could trigger the system erroneously.

The light sensor is installed 30 cm from the roof of the gallery, 6m in front of the mounted suppression system to detect the advancing flame. The direction of the flame sensor is perpendicular to the advancing flame. This distance of 6 m is specific for the weak standard explosion and calculated from the delay time between wind front and flame front. The mean delay time for flame detection and gas release obtained during the tests was 13 milliseconds. The gas release time obtained was 120 - 180 milliseconds.

The direction of the released extinguishing agent is towards the

advancing flame. On detection, the infrared sensor activates the gas releasing mechanism of the bottles and the gas is dispersed to extinguish the flame.

3.4.2 Active suppression system using gas and water

This system is similar to the previous system described above. The major difference being the use of a combination of water and NAFSIII gas. The suppression system was designed so that water made up 65% of the extinguishing agent and the gas made up the difference (35%). All the equipment was supplied and installed in the 200m G P Badenhorst test gallery by HS Design Engineering (Pty) Ltd.

4. RESULTS

For the evaluation of the barriers a standard test explosion was established (standard barrier explosion) to determine the repeatability of wind pressure and delay time between wind front and flame front of the explosion. The results obtained for these standard tests are shown in Table 1.

TABLE 1: STANDARD BARRIER TEST

Exp no.	Static pressure (kPa)	Flame speed (m/s)	Flame distance (m)	Visual flame at gallery mouth
132	63	98,5	> 200	YES
134	78	141,8	> 200	YES
138	66	128,2	> 200	YES
140	74	170,9	> 200	YES

If the flame advance passes the end of the gallery the distance is indicated as > 200 m. An example of the flame path for the standard test is shown in Figure 3.

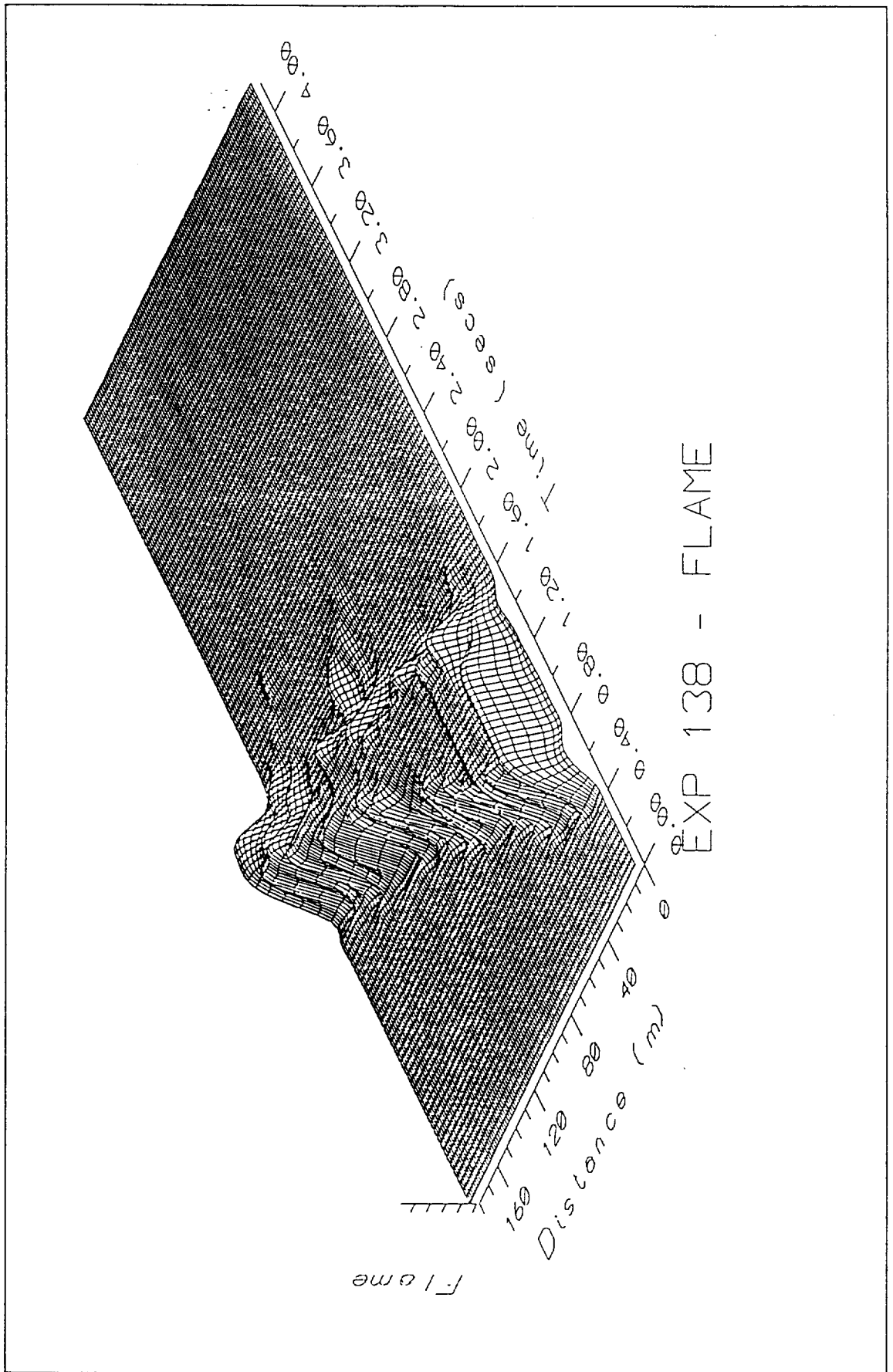


Figure 3: Standard explosion flame length.

4.1 Water Trough Barrier

The water troughs were installed as previously described and the results obtained for the passive water barrier tests are shown in Table 2.

TABLE 2: WATER TROUGH RESULTS

Exp no.	Barrier type	Static pressure (kPa)	Flame speed (m/s)	Flame extinguished (m)
141	Water trough	66	124,4	110
143	Water trough	70	106,4	110
144	Water trough	70	122,0	110

The distance at which the flame was stopped by the passive water trough barrier was 20 m beyond the end position of the barrier. An example in which the flame was stopped by the passive water trough barrier is shown in Figure 4.

4.2 Stone Dust Barrier

The results for the conducted tests are shown in Table 3.

TABLE 3: STONE DUST BARRIER RESULTS

Exp no.	Barrier type	Static pressure (kPa)	Flame speed (m/s)	Flame extinguished (m)
177	Stone Dust	72	85,5	100
179	Stone Dust	78	106,4	90

In both the tests the flame was stopped within 10 m of the end of the barrier position. This compares favourably with the other barriers tested but their installation was labour intensive (\pm 8 hours for the test tunnel).

In Figure 5 the flame path for test 179 is indicated showing the flame.

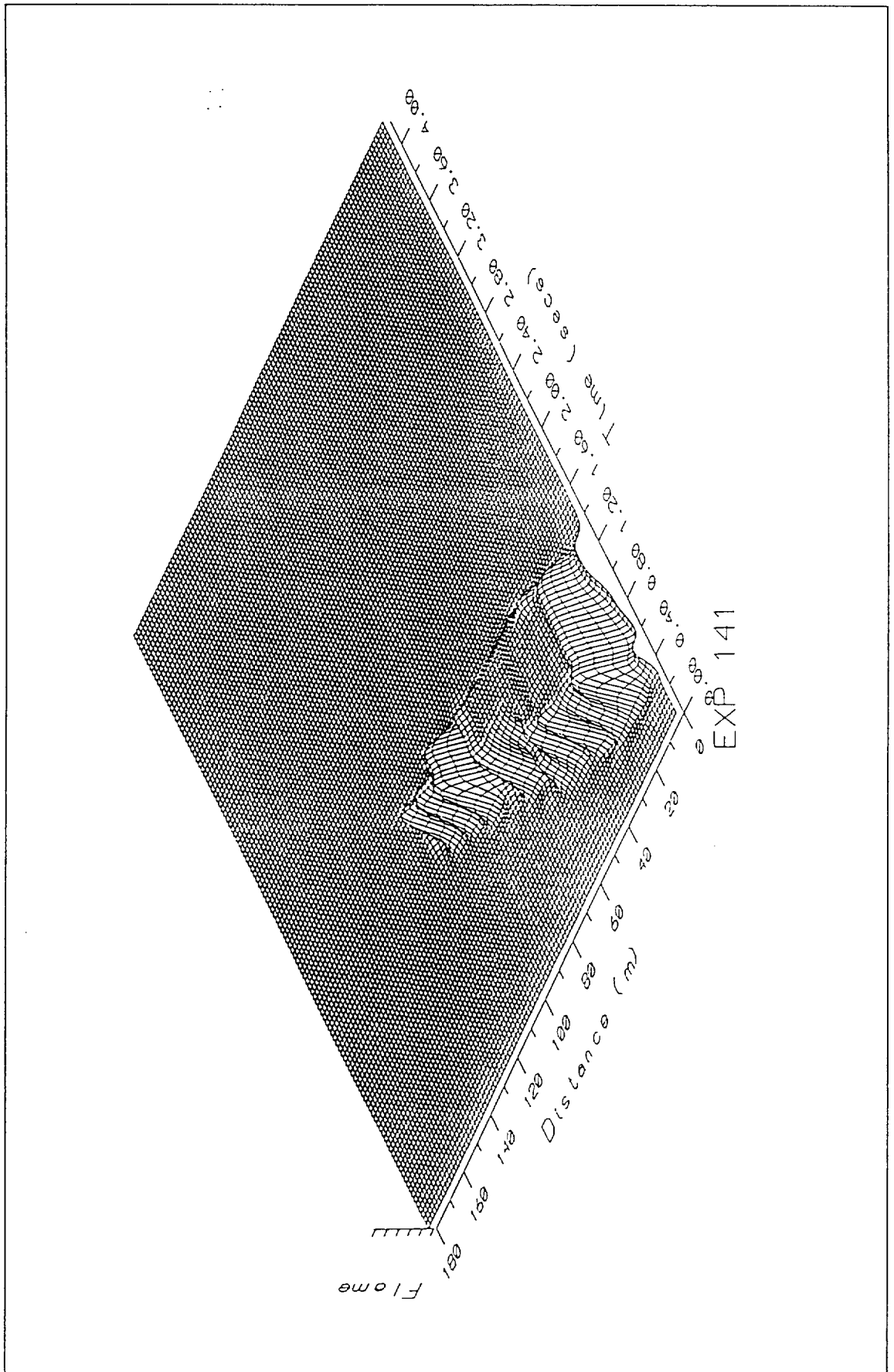


Figure 4: Flame path for passive water trough barrier.

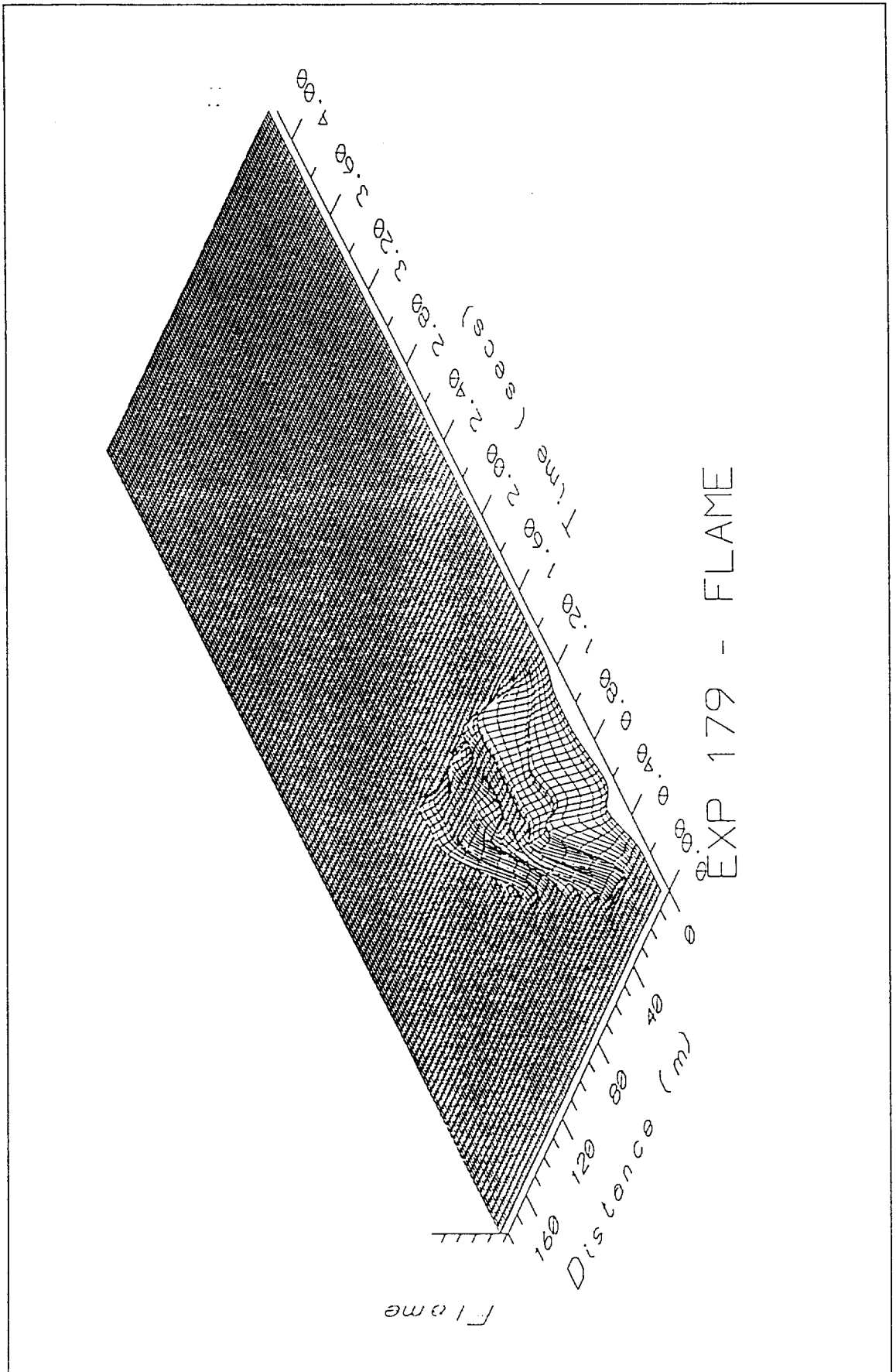


Figure 5: Flame path for passive stone dust barrier

Since the light stone dust barrier worked effectively in stopping flame propagation, it was deemed unnecessary to test the heavy stone dust barrier with its required concentration of 400 kg/m², or 2 tons of stone dust contained inside the barrier.

This also illustrates the safety margin built in by previous researchers, to compensate for inadequate installation, maintenance and positioning of the barriers.

4.3 Dispersed Barrier

The results for the dispersed stone dust barrier are shown in Table 4. An example of the flame path for a concentration of 100 kg/m² is indicated in Figure 6.

In all the tests conducted the flame propagation was stopped. Even at the lowest tested stone dust concentration (20 kg/m²) the flame was quenched.

At the higher concentrations the flame was stopped at the barrier position, indicating the effect of energy (heat) removal from the coal dust explosion.

TABLE 4: PASSIVE DISPERSED STONE DUST BARRIER

Exp. no.	Concentration per cross-sectional area (kg/m ²)	Static pressure (kPa)	Flame speed (m/s)	Flame extinguished (m)
174	20	73	n.a.	160
172	40	71	150,4	120
173	60	76	94,8	120
175	80	72	85,5	90
176	100	75	91,7	90

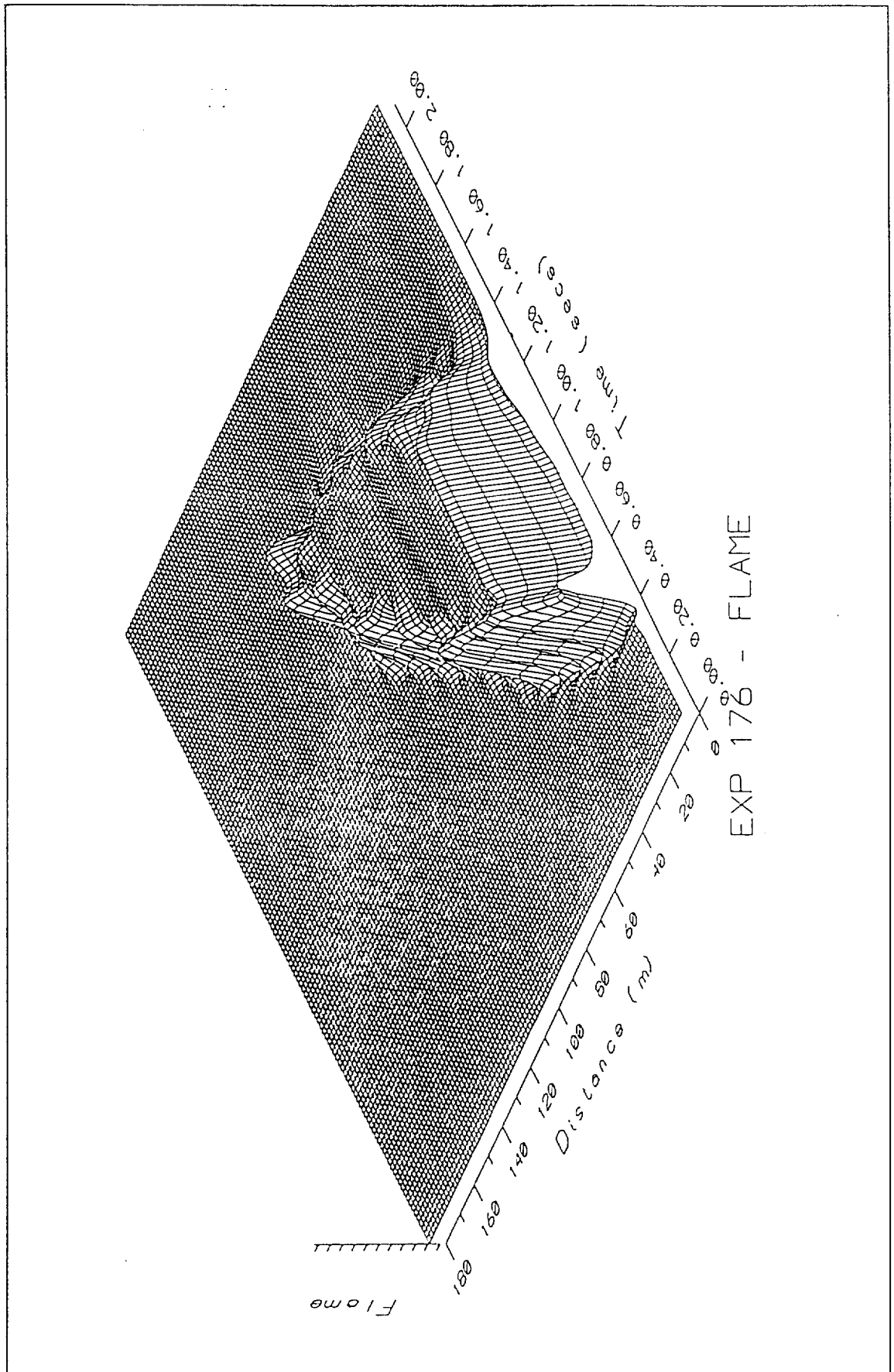


Figure 6: Flame path for passive dispersed barrier

4.4 Active roadway suppression system

The results obtained for the active suppression system are shown in Table 5.

TABLE 5: ACTIVE ROADWAY SUPPRESSION SYSTEM RESULTS

Exp no.	Barrier type	Static pressure (kPa)	Flame speed (m/s)	Flame extinguished (m)
137	Active suppression	69	n.a.	100
139	Active suppression	70	n.a.	110

The active suppression system stopped the flame from propagating between 10 m and 20 m beyond the barrier. These tests are an indication of the system's ability as the configuration and the amount of extinguishing agent have not been optimized.

The test conducted with the combination of water and gas failed. The system quenched the flame to an extent but it re-ignited and ran through to beyond 180 m in the tunnel. This failure can be attributed either to the failure of one of the brackets which would topple a set of bottles in the wrong direction, or to the interference between the nozzles used for water and gas. An example, where the flame was stopped by the active suppression system using only NAFSIII gas, is shown in Figure 7.

The test results obtained for the active suppression system using NAFSIII gas or the combination of gas and water are not conclusive as neither has been optimized, nor have they been proven extensively for use underground. For the system to be proved for underground use a series of tests, with successful outcome, has to be conducted varying flame speeds, pressures and geometries.

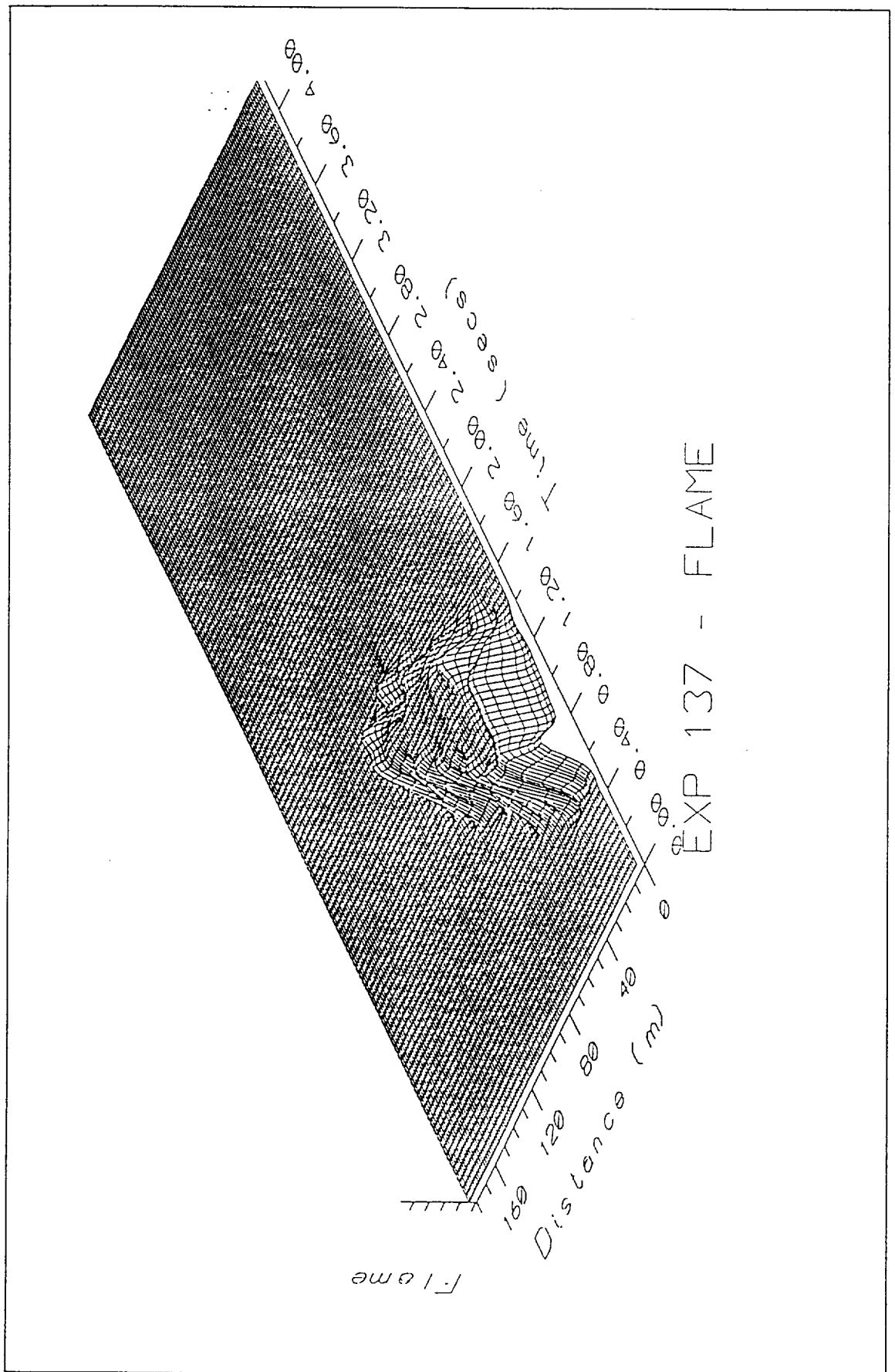


Figure 7: Flame path for active suppression barrier.

The results indicate that it might be possible to install the active suppression system closer to the face area, limiting the extent of flame propagation of the explosion and thus the amount of damage caused by it. The effect that the flame speed has on the critical activation time needs to be investigated as this can lead to the flame passing through the barrier.

5. DISCUSSION

The average distance beyond the position of the barriers, where the flame was extinguished is indicated in Table 6.

TABLE 6: BARRIER EFFECTIVENESS

Barrier type	Flame extinguished at (m)
Water trough	20
Stone dust	5
Dispersed barrier	Inside barrier
Active suppression	15

The test results from the tested systems indicated that they are capable of preventing flame propagation; so that other aspects, such as the costs involved, time and ease of construction and the amount of maintenance required, become the issues influencing the choice.

Water trough and stone dust barrier systems have been developed for longwall mining layouts which typically consist of long single mine entries. The use of a barrier system in bord-and-pillar mining is subject to difficulties arising from the positioning and layout of the barriers. For example it is not certain whether a concentrated barrier would be effective or if a concentrated barrier supplemented by distributed barriers would be required to prevent a flame from by-passing the barrier.

Barriers are only intended as the final solution if all other preventative measures fail. However, the records show a greater proportion of barrier failure than confirmed successes; however, most of the failures were due to improper location, improper design, poor installation, and inadequate maintenance. Propagation of a coal dust explosion can be arrested by a properly designed, located and maintained barrier¹⁰.

6. CONCLUSION

The results indicated in this report should be interpreted in the context of the experimental set-up and procedure described using a smooth, round gallery of 2,5 m diameter and a weak standard explosion which ensures effective operation of the passive barriers tested. This report presents results for an explosion with enough wind pressure to activate passive explosion barriers and the minimum pressure required to activate the passive explosion barriers was not ascertained.

The results indicate that the barriers tested prevented the flame from passing 20 m beyond the barrier when the barriers were installed 80 m from the closed end of the gallery.

The water trough barrier stopped flame propagation within 20 m.

The light stone dust barrier showed that if installed correctly and maintained properly it would work effectively in stopping coal dust explosions from propagating.

The developed dispersed barrier system shows great promise. Certain aspects still need to be addressed, which include the minimum pressure for activation and proper dispersal. The major advantages of this system are the ease of installation, the minimum maintenance required and the low cost of the system.

The effectiveness and reliability of the active suppression system depends on the

proper functioning of the sensors and the dispersal system. This requires qualified personnel.

7. RECOMMENDATIONS

The effectiveness of the dispersed explosion barriers must be determined at low dynamic pressure as this system might be the easiest to implement.

The tests conducted on the active suppression barrier are not conclusive as the system has not been optimized. More work should be done in close co-operation with the manufacturer.

8. ACKNOWLEDGEMENTS

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