

Coal Mine Explosion Suppression Using Active On-Board Suppression Systems - The South African Experience

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ABSTRACT; Coal mining operations in South Africa commenced in 1874. With the introduction of continuous miners (CM) in the early 1970s to the South African coal mining industry, the number of ignitions and explosions related to frictional ignitions has increased. After the explosion at Middelbult Colliery, South Africa in May 1993, which claimed 53 lives, the South African coal mining industry and the Safety In Mines Research Advisory Committee (SIMRAC) united forces to establish a surface facility to develop and test on-board flame suppression systems for CM and roadheaders (RD) to enhance the safety of South African coal mine workers in collieries. The first test that was conducted in this newly constructed test tunnel at the Kloppersbos Research Facility, CSIR was in July 1995. From July 1995 to December 1997, 42 tests have been conducted using the facility and have focussed on on-board active ignition suppression systems for CM. Since flame propagation speed is an extremely important parameter, the CSIR-Miningtek, the operators of the test facility, made the results of the test programme available for re-analysis and it is this analysis of flame speeds, with and without the application of the suppression system that is reported in this paper.

1 INTRODUCTION

The G. P. Badenhorst Research Facility, which is owned and operated by the CSIR-Miningtek, is situated 40 km north of Pretoria, where in 1987 a 200-meter long circular explosion gallery was completed (Cook, 1995). This gallery has so far been used to test different types of barriers for stopping flame propagation in coal dust explosions. In response to the need for enhanced precautionary measures to safeguard mine workers in collieries from the consequences of methane ignitions in a heading, the coal mine industry expressed the desire for the development and testing of an active on-board suppression system (du Plessis and Bryden, 1997). To serve this purpose, a new 20 m long rectangular shape test tunnel was constructed in 1995.

This facility has been used to develop and test on-board, active suppression systems with a particular view to determining the exposure of CM operators close to the coal face to methane flames. In other words, the flame must be extinguished before it reaches the machine operator's position. This work was conducted by CSIR-Miningtek and funded by contracts with SIMRAC and the system manufacturers, CENTROCEN. The way to determine the effectiveness of the flame suppression

system is to note the reduction or increase in the flame speed. The lower the flame speed, the more effective the flame suppression system. Results from this test work have been made available for further analysis (Gene, 2000) and it is this analysis of flame speeds, with and without the application of the suppression system that is reported in this paper.

The type of suppression system used in the tests is of a proprietary nature and, as such, no details can be made available.

2 DESCRIPTION OF THE TEST TUNNEL

The short test tunnel simulates conditions that could be encountered at the face of a bord and pillar heading in an underground coal mine.

The test tunnel is 20 m long, 7 m wide, with a variable height which can be set at heights of between 2 m and 6 m in increments of 0,5 m. It has a rectangular shape closed at one end. The test tunnel is equipped with sensors (pressure, flame and temperature) to measure the pressure generated by the explosion, to detect the rate of the flame travel and to determine temperature increases especially in the vicinity of the CM operator's position; a data acquisition system to computerise the test output; a methane-mixing and measuring system as well as an ignition source to ignite the methane/air mixture; and

a video camera for the visual recording of the event (Figure 1. Figure 2 and Figure 3).

The tests are carried out on a scale of 1:1 i.e. at full size. Some of the tests were conducted on full-face tunnels while others were conducted with a shoulder in position as shown in Figure 1, to more accurately simulate the underground condition. Earlier tests were done using an actual CM machine, which was on loan from a mine. However, due to production requirements at the mine, this machine was taken back and was replaced by a model of equivalent geometry constructed of steel.

According to the test protocol, provision has been made to simulate the conditions in a heading being mined by a CM after the first lift or part of the first lift has been completed through the addition of a shoulder towards the front of the tunnel as shown in Figure 1. Because the CM is about 3,2 m wide, it cuts the heading in two lifts. This creates the shoulder and this shoulder will be able to simulate a cut of up to a depth of 6 m for all the seam heights. The heading can be simulated at the start or end of the lift and can be done without the shoulder to give a full heading width of 7 m. This is similar to a test being conducted in a full heading as would be the case in the testing of roadheaders.

According to the dimensions of the continuous mining machines, square frames near the closed end of the test tunnel allow the attachment of a plastic membrane thus forming a chamber into which the air-

methane mixture is pumped (Figure 2). The position of the membrane varies depending on whether a shoulder is in position or not. If the shoulder is absent, the membrane is located 5 m from the closed end of the tunnel. If the shoulder is present, the distance varies from 5 m to 7 m according to the test to be conducted.

The specifications of the sensors, data acquisition system and methane mixing in the test tunnel are given in the protocol for testing procedures in the SIMRAC Project Report (du Plessis and Bryden, 1997). There are 76 flame sensors, one dynamic pressure sensor, one static pressure sensor and one temperature sensor inside the tunnel (Figure 3).

By measuring the time of activation of the individual sensors, the speed of the flame advance can be obtained as well as the profile of the final positions reached by the (lame front, it should be noted that the system has a distance sensitivity of one meter. A glass cover is placed over each sensor on the tunnel wall to provide protection. These glass protection covers are cleaned and inspected before every test to ensure that the correct flame intensity will be recorded. When each of the four sensors at 1-meter intervals is activated, a digital output is generated. This will indicate if the flame has passed that point or which side of the tunnel the flame has passed. The positions of the 76 flame sensors inside the test tunnel are shown in Figure 4.

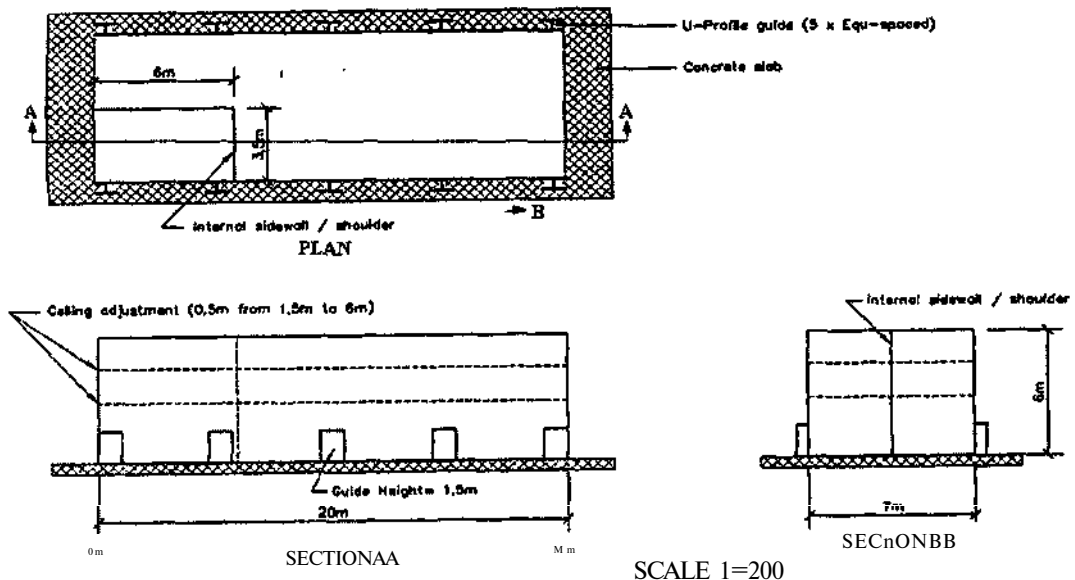


Figure 1 Test tunnel (du Plessis and Bryden, 1997)

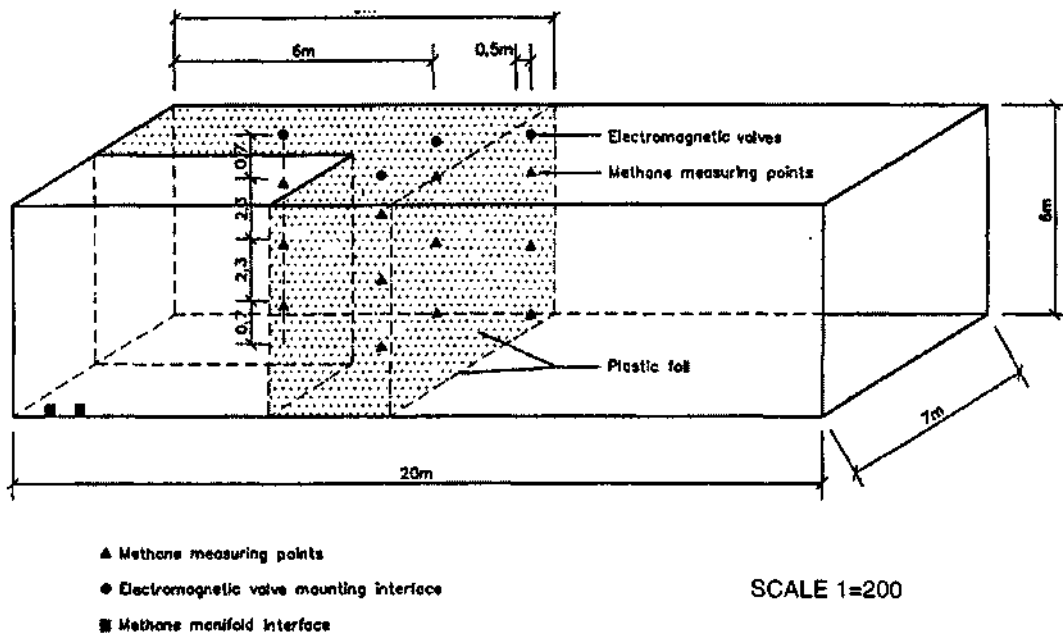


Figure 2. CH₄/air mixture measuring points and electromagnetic valve mounting (du Plessis and Bryden, 1997).

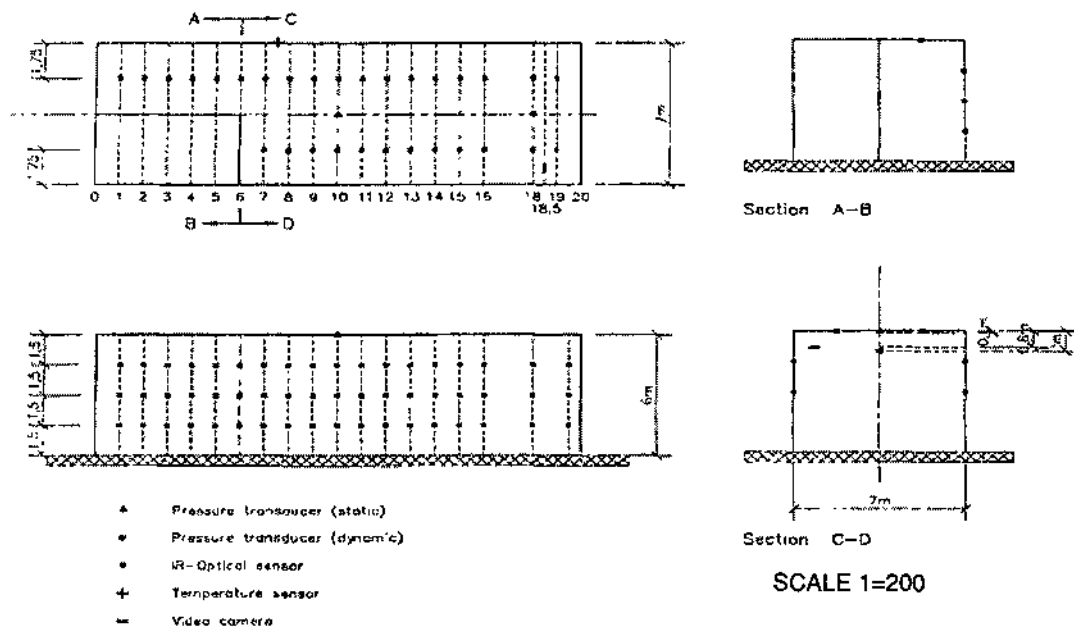


Figure 3. Position of measurement equipment for evaluation of suppression systems (du Plessis and Bryden, 1997).

The data are retrieved sequentially from each channel after an explosion. They are stored in binary form and 128 channels are used. A sampling rate of 30 KHz

over a period of 2 seconds means that each channel can be sampled 60,000 times in a single explosion test.

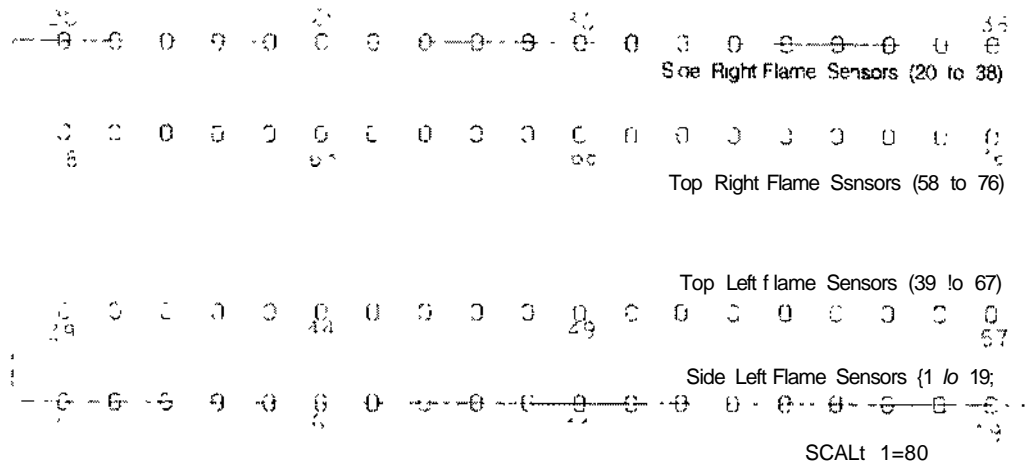


Figure 4. Position of the flame sensors

3 EXPERIMENTAL PROCEDURE

The tests conducted can be categorised into two different groups:

- tests conducted without a suppression system
- tests conducted with a suppression system

The tests conducted without a suppression system were aimed not only at determining the extent of the flame, the flame speed and the value of the dynamic pressure and the temperature increase inside the tunnel, but also to calibrate the test tunnel equipment and prepare the tunnel for active suppression system tests.

According to the testing protocol, when suppression tests were conducted, the ignition source was positioned between the drum and the face so that it was in the sighting shadow of the sensors of the suppression system. The methane/air mixture was ignited by means of a fuse cap (200 joule) or a chemical detonator. The ignition source and the data acquisition system were activated simultaneously, thereby allowing the controlled capture of the explosion data. An in-tunnel video camera captured the visual material. The visual material and the data acquisition system output were used to determine the extent of the flame, the values recorded by the dynamic and static pressure sensors as well as the temperature sensor.

Different methane/air volumes and concentrations for a CM, CM model and finally CM mounted on-board suppression systems were used. During the tests conducted, the roof height of the test tunnel was set at 2,5 m and during the shoulder tests, the depth of shoulder was 2 m and its width 3,5 m. Plastic membranes were used to create an explosive

methane/air mixture in a chamber covering the head of the machine. Methane/air concentrations of 7,5 to 12 % were used. The volume of the mixture depends on the height of the seam being simulated, the position of the membrane and the required methane/air concentration.

4 EXPERIMENTAL RESULTS

There were 76 (4x19) flame sensors inside the test tunnel. Two sets of flame sensors in linear array (19 each) were located on the sides of the tunnel, while the other two sets were on the roof (total of 4 sets of flame sensors, Figure 4). Figure 5 shows how the flame arrival time at a specific flame sensor was determined. The channel numbers from 1 to 76 correspond with the number of the flame sensors, e.g. channel 24 corresponds with flame sensor number 24. Similar readings were obtained for the 76 flame sensors to obtain the exact flame arrival time. Figure 6 combines all flame sensor-reading results for one test and demonstrate the flame propagation in seconds. The maximum time for which data can be recorded is 2 seconds.

From a research point of view, one of the most important parameters to study is flame speed. However, depending on the method of calculation, different results may be obtained. From an initial study of the data, it was apparent that the early stages of ignition, where the interaction between the initiator and the methane/air mixture takes place, contribute to the degree of experimental error. While it was important to calculate the flame speeds and arrival time from a fixed datum ($t_i=0$), the results were also calculated from the time the flame passes

through the membrane position (t_6). The equations used for these four calculations are

$$1 \text{ Flame speed}_1 = V_1 = [(1/(t_1-t_0) + 1/(t_2-t_1) + 1/(t_3-t_2) + 1/(t_4-t_3) + 1/(t_5-t_4) + 1/(t_6-t_5)) / 19] \text{ (m/s)}$$

$$2 \text{ Flame speed}_2 = V_2 = [19 / (t_{19} - t_0)] \text{ (m/s)}$$

$$3 \text{ Flame speed}_3 = V_3 = [(1/(t_6-t_0) + 1/(t_7-t_6) + 1/(t_8-t_7) + 1/(t_9-t_8) + 1/(t_{10}-t_9) + 1/(t_{11}-t_{10}) + 1/(t_{12}-t_{11}) + 1/(t_{13}-t_{12}) + 1/(t_{14}-t_{13}) + 1/(t_{15}-t_{14}) + 1/(t_{16}-t_{15}) + 1/(t_{17}-t_{16}) + 1/(t_{18}-t_{17}) + 1/(t_{19}-t_{18})) / 14] \text{ (m/s)}$$

$$4 \text{ Flame speed}_4 = V_4 = [13 / (t_{19} - t_6)] \text{ (m/s)}$$

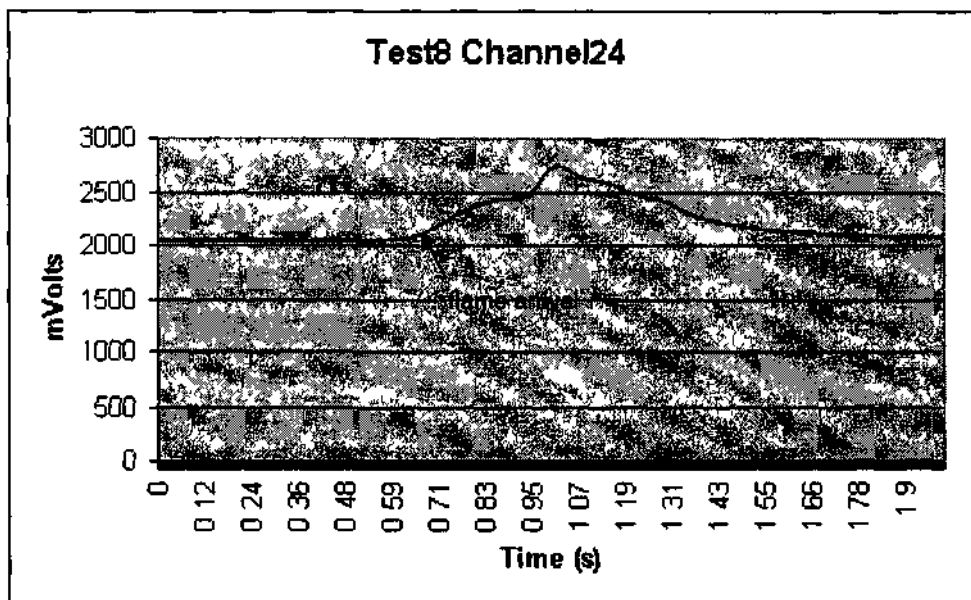


Figure 5 Flame arrival time

In the first method of calculating the flame speed (V_1) the distance between two consecutive flame sensors which is 1 m, is divided by the difference between the two consecutive flame sensor readings. The sum of these values is then divided by 19 where 19 was the distance between the first sensor (t_0) and the last sensor (t_{19}). This formula was applied to all 4 sets of flame sensors (as described above). The average results obtained from the four linear arrays of flame sensors were then added together and divided by 4 to calculate the total average flame speed through the test tunnel. In the same way, the average results obtained for each set of flame sensors when calculating with the second, third and fourth formulae were also added together and divided by four to obtain the total average flame speed.

In the second method the flame speed (V_2) was calculated by dividing 19 into the flame arrival time at the last flame sensor. In the third and fourth method the distance between the face of the tunnel and the membrane position was ignored. Depending on the test conducted, the membrane was positioned at 5 m and 7 m respectively from the face. The flame speed calculation formulae (V_3 and V_4) were used accordingly. When the membrane was positioned 5

m from the face, the formula for the flame speed (V_3) was $[(1/(t_6-t_0) + 1/(t_7-t_6) + 1/(t_8-t_7) + 1/(t_9-t_8) + 1/(t_{10}-t_9) + 1/(t_{11}-t_{10}) + 1/(t_{12}-t_{11}) + 1/(t_{13}-t_{12}) + 1/(t_{14}-t_{13}) + 1/(t_{15}-t_{14}) + 1/(t_{16}-t_{15}) + 1/(t_{17}-t_{16}) + 1/(t_{18}-t_{17}) + 1/(t_{19}-t_{18})) / 14]$ and when the membrane was positioned 7 m from the face, the formula for the flame speed (V_4) was $[13 / (t_{19} - t_6)]$ where 12 was the distance between the first sensor (t_0) and the last sensor (t_{19}).

When comparing the flame speed results it can be seen from the flame sensor readings, explosion videos and the test graphs (Figure 3) that it takes up to 200 milliseconds for an explosion to develop. During this time, the explosion develops inside the membrane, the methane/air mixture burns, and thereafter the methane explosion starts propagating from the membrane position onwards. From this point of view the flame speed $V_4 = [13 / (t_{19} - U)]$ would be the most realistic approach to calculate the flame speed. When using V_4 the distance between the face of the tunnel and the membrane position was ignored and in some tests, the active suppression system successfully stopped flame propagation, within the membrane. As a result, some of the results show no flame speed inside the test tunnel. In this case, the formula V_3 was used instead to calculate the flame speeds where applicable, even though the accuracy of the result is

in doubt. In the Tables of results that follow, the flame speed quoted has been calculated by method 4, i.e. (V_f)

As discussed earlier, the 42 tests that were conducted between July 1995 and December 1999 in the 20 m tunnel at the Kloppersbos Rescaich Facility can be categorised in two different ways:

- tests conducted without a suppression system
- tests conducted with a suppression system

5 TESTS CONDUCTED WITHOUT A SUPPRESSION SYSTEM

There were four ways to conduct tests without a suppression system, namely:

- empty tunnel tests
- tests with a CM in place
- tests with a CM model in place
- tests with a CM model in place and with the

shoude in position

5.1 Empty Tunnel Tests

The empty tunnel tests results are shown in Table 1. Tests 5 to 12 fall into this category. Flammable gas mixtures were generated using the mixing and monitoring procedures described by du Plessis and Bryden (1997). Two concentrations were used; 9% and 12% and the volume of the mixture was kept at 87,5 m throughout this series of tests. Flame speed was found to be independent of the change in the methane concentration from 9% to 12%. The flame propagated throughout the test tunnel, which can be seen in Figure 6. The average flame speed was 45,2 m/s when 9% methane/air concentration was used and it was 44,9 m/s when 12% methane/air concentration was used. The highest flame speed was 53,4 m/s, which was recorded in test 12.

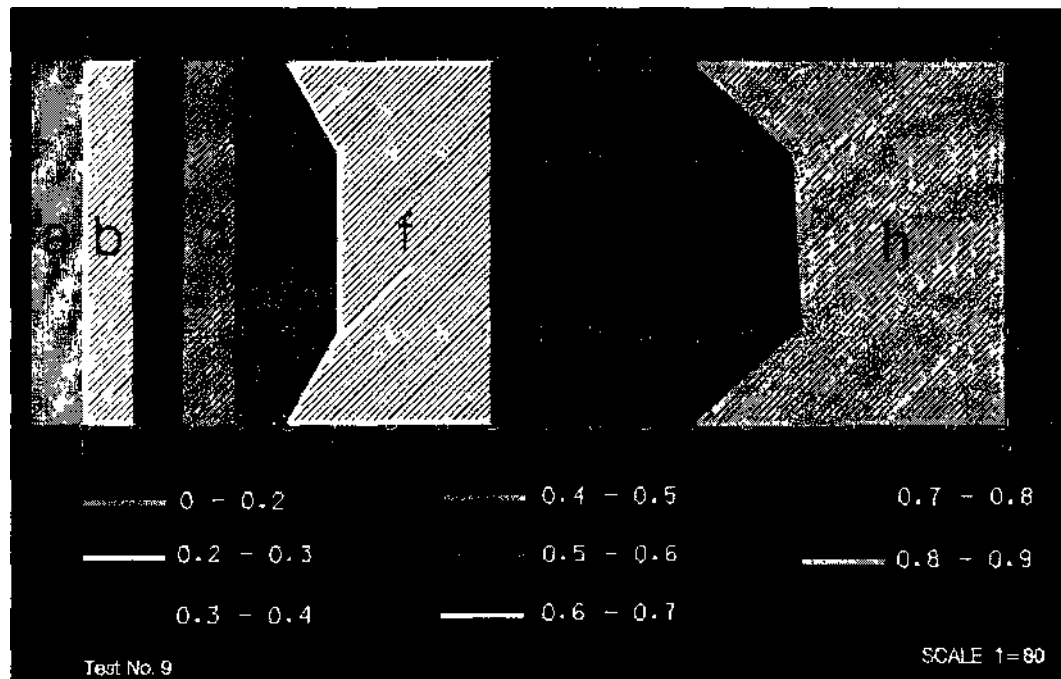


Figure 6 Flame propagation inside the test tunnel. The shading denotes the arrival of the flame.

5.2 Tests with a Continuous Miner in Place

Only two tests were conducted with a Joy 14 CM in place inside the test tunnel: These were test 5 and 6. Flame speeds of 118,9 m/s and 69,2 m/s were recorded respectively. The results of the tests conducted with the presence of a CM are shown in Table 1. While using the same volume of mixture that

was used in the empty tunnel tests, only 9% methane/air concentration was used. Because the presence of the CM inside the test tunnel created an obstruction and reduced the cross-sectional area of the tunnel, the flame propagated more quickly. The 70% difference between the flame speeds could have been caused by experimental error, however, compared to

empty tunnel tests, the flame speed increased by more than 100%. The average flame speed was 94,1 m/s.

Table I Flame speed without suppression system

Empty Tunnel			Test with a CM			Test with a CM Model			CM Model with a Shoulder		
No	(%)	S (m/s)	No	(%)	S (m/s)	No	(%)	S (m/s)	No	(%)	S (m/s)
8	9	30,3	5	9	118,9	13	9	68.4	28	7.7	55,1
9	9	51.9	6	9	69.2	15	7.5	28.1	37	7.8	117,5
10	12	41.7				16	9	70.1	38	7.8	101.9
11	12	48.1				17	7.5	35,8	39	7,8	118,2
12	9	53,4				18	7.5	33,9	40	7.8	109,4
						19	9	78,2	41	7.8	106.8
						20	9	79.2	42	7,8	109.6
						21	9	68.5			

No- Test No, (%) : CH₄/ Air %, S: Flame Speed. Volume CH₄/Air = 87.5 m³

5.2 Tests with a Continuous Miner Model in Place

Eight tests were conducted with the presence of a CM model inside the test tunnel, the results of which are given in Table 1. Even though two methane/air concentrations were used, 7,5% and 9% respectively, the volume of the mixture was again kept at 87,5 m³ the same as for the two previous series of tests conducted.

In this category, the cutting head of the CM model was positioned at one of three positions: on the floor, in the middle of the tunnel or at the ceiling (roof position). In tests 13, 19, 20 and 21, the cutter was on the floor. In tests 15 and 16, the cutter was in the middle of the tunnel, while in tests 17 and 18; the cutter was at the roof. The position of the cutter did not influence the flame speed.

One significant result from the tests conducted was that when comparing the results of tests conducted with 7,5% methane/air concentration and 9% methane/air concentration, it can be seen that the flame speed more than doubled. The reason for this was the change of the methane/air concentration from 7,5% to 9%. The average flame speed was 32,6 m/s when 7,5% methane/air concentration was used and it was 72,9 m/s when 9% methane/air concentration was used.

When comparing the results of tests conducted with the presence of a CM and CM model inside the test tunnel using a methane-air concentration of 9%, the average flame speed was 94,1 m/s when the CM was present inside the test tunnel, and 72,9 m/s when the CM model was present. Despite the fact that the average flame speed was 94,1 m/s when the CM was

present inside the tunnel (with considerable variation in the results of the two tests), the flame speed of test 6 was 69,2 m/s. This comparison shows that the CM model can be used as a replacement for the CM.

5.3 Tests with a CM Model with Shoulder in Position

Seven tests were conducted with both the CM model and shoulder in position as illustrated in Table I. Two methane/air concentrations were used: 7,7% and 7,8% and the volume of the mixture was increased to 105 m³ throughout this series of tests. In this category, the cutter of the CM model was positioned in the middle of the tunnel.

Adding a shoulder inside the tunnel and increasing the methane/air volume from 87.5 m³ to 105 m³ affected the flame speed. 7,8% methane/air concentration was used for tests 37 to 42 and the average flame speed was 110,6 m/s. Only one test (test 28) was conducted with a 7,7% methane/air concentration which resulted in a 55,1 m/s flame speed. This difference in flame speed of more than 100% between test 28 and the average flame speed of the rest of the tests in this category was probably due to an experimental error.

5.4 Discussion of Results of the Tests Conducted without a Suppression System

A summary of the results of the tests conducted without a suppression system can be seen in Table 2. When comparing the average flame speed between

tests with a CM model inside the test tunnel (9% methane/air concentration) and tests with a CM model with shoulder in position (7,8% methane/air concentration), the flame speed increased from 72,9 m/s to 110,6 m/s. This is almost a 52% increase in the average flame speed. The reason for this difference was as a result of the decrease in the cross-sectional area caused by the presence of the shoulder.

Although the flame speeds with a 7,8% methane/air concentration (CM model with a shoulder) was 40% faster than those at 9% (CM model without a shoulder), it can still be reasonably

concluded that the tests conducted without a suppression system resulted in the most violent explosions when the methane/air concentration was 9% while weak explosions occurred when the methane/air concentration was 7.5%. The reasoning behind this conclusion is because of the absence of the shoulder in the tests conducted with a 9% methane/air concentration, thus the 40% difference in flame speed. Unfortunately no test with a 9% methane/air concentration with the shoulder in position were conducted to make a more accurate comparison.

Table 2. Average flame speed without suppression system.

<i>Empty Tunnel</i>		<i>Test with a CM</i>		<i>Test with a CM Model</i>		<i>CM Model with a Shoulder</i>	
(%)	S (m/s)	(%)	S (m/s)	(%)	S (m/s)	(%)	S (m/s)
9	45,2	9	94,1	7,5	32,6	7,7	55,1
12	44,9			9	72,9	7,8	110,6

TESTS CONDUCTED WITH THE SUPPRESSION SYSTEM

Seventeen tests have been conducted with an active on-board suppression system present inside the test tunnel. Test 0 was the first and only test conducted using a local on-board suppression system. For the other sixteen tests, an international system (Centrocen / DMT Explo-Stop System) was used. The Centrocen / DMT Explo-Stop System is a German based system which proved to be very effective in suppressing flame propagation. The tests conducted with the suppression system can be categorised in three different areas:

- on-board suppression tests with a CM
- on-board suppression tests with a CM model (full face)
- on-board suppression tests with a CM model with the shoulder in position

According to the test protocol for tests conducted under this category, the machine operator's position was 8 m from the face of the test tunnel.

6.1 On-board Suppression Tests with a CM

Only three tests were conducted with a CM (Joy 14 CM 6). Test 0 was the first test conducted using the local on-board suppression system with the shoulder in position. A 9% methane/air concentration was used and the volume of the mixture was kept at 87,5 m³ for this test. This test caused severe damage to the test tunnel with a failure of the suppression system to stop the flame propagation. The fastest flame speed recorded was 189,9 m/s (Table 3). The flame propagated throughout the test tunnel. This vast disparity in the flame speed was caused by two factors: the 9% methane/air concentration and the presence of the shoulder.

Table 3 On-board suppression tests with a CM and a CM model (full-face tests) results

Test with a CM

Test with a CM Model (Full Face Test)

No	(%)	S (m/s)	L	P	No	(%)	S (m/s)	L	P
0	9	189,9	>19	Roofs&Sides	22	9	11,9	4	TLF
3	7,5	19,6	2	TLF	23	9	9,1	4	TLF
4	9	7,6	3	TLF	24	9	13,9	4	TLF and TRF
					25	9	17,7	4	TLF
					26	9	14,5	4	TLF
					27	9	14,4	4	TLF

TLF; Top left flame; TRF: Top right flame; SLF: Side left flame; SRF: Side right flame; L: Flame length; P: Flame position; Volume $CH/Au = 87,5$ m

The other two tests (test 3 and 4) in this category were full-face tests and the international system (Centrocen / DMT Explo-Stop System) was used. Two methane/air concentrations were used, 7,5% and 9% and the volume of the mixture was again kept at $87,5$ m³ throughout the tests. Both tests were successful and the flame stopped propagating at 2 m and 3 m respectively long before it could reach the operator's position. The highest flame speed was 19,6 m/s or about 10% of that in Test 0. The results of the on-board active suppression system tests with a CM machine are shown in Table 3. In Table 3, flame positions e.g. TLF (Top Left Flame), TRF (Top Right Flame), SLF (Side Left Flame) and SRF (Side Right Flame) indicates whether the flame has been detected on the sides and/or the roof of the tunnel.

6.2 On-board Suppression Tests with a CM Model (Full-Face Tests)

Six tests were conducted with a CM model (simulation of a Joy 14 CM 9). While using the same volume mixture that was used in the on-board suppression tests with a CM, only 9% methane/air concentration was used. A Centrocen / DMT Explo-Stop System successfully stopped flame propagation at 4 m in all six tests. The average flame speed was 14,2 m/s. The on-board suppression tests with a CM model (full-face tests) results are shown in Table 3.

6.3 On-board Suppression Tests with a CM Model with the Shoulder in Position

Seven tests were conducted with a suppression system on board the CM model and shoulder in position, the results of which are shown in Table 4.

Two methane/air concentrations were used; 9% and 12%, and the volume of the mixture was increased to 105 m³ throughout this series of tests. In all the tests, the flame propagated beyond the operator's position as prescribed by the test protocol except test 36.

Tests 29 to 32 where 9% methane/air concentrations was used were partially successful and the flame propagated up to 3 m beyond the operator's position with an average flame speed of 23,8 m/s. In test 33 the flame propagated up to 19 m with a flame speed of 33,1 m/s while in test 34 the on-board suppression system failed to operate and the flame propagated throughout the test tunnel with a speed of 38,1 m/s. The overall average flame speed with 9% methane/air concentrations was 25,7 m/s. Test 36 was a repeat of test 34 where the flame propagation stopped within 8 m.

6.4 Discussion of Results of the Tests Conducted with the Suppression System

Both the on-board suppression tests with a CM and with a CM model were successful and the flame propagation ceased before reaching the operator's position, except in test 0 which was a failure. All the tests that succeeded were full-face tests while the failure was a shoulder test.

The results of the on-board suppression tests with a CM model with the shoulder in position were all unsuccessful except for test 36. The reason for the failure was the presence of the shoulder in position as well as an increase of the methane/air volume from $87,5$ m³ to 105 m³. Therefore we can once again conclude that the most violent explosions occurred when shoulder tests were conducted.

Table 4. On-board suppression tests results with a CM model with the shoulder in position.

Test No.	CH/Air (%)	Flame Speed (m/s)	Flame Length (m)	Flame Position
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29	9	22.8	10	TRF
30	9	23,8	10	TRF
31	9	26.8	9	TRFandSRF
32	9	21,8	11	TRF
33	9	33,1	19	TRF
34	12	38.1	> 19	Roof and sides
36	12	4,6	8	TRF

Volume CHVAir = 105.0m*

When we compare the average flame speeds of the shoulder tests conducted with a suppression system and without a suppression system, the average flame speed of the tests with the suppression system where 9% methane/air concentrations was used was 25,7 m/s while tests conducted without a

suppression system with a 7,8% methane/air concentrations was 110,6 m/s, the results of which are given in Table 5. From these results we can conclude that even though there were failures with the shoulder tests, the suppression system still reduced the flame speed by up to 76,8%.

Table 5 Average flame speed with suppression system

Test with d CM		Test with « CM Model		CM Model >with a Shoulder	
(%)	S (m/s)	(%)	S (m/s)	(%)	S (m/s)
7.5	19,6	9	14.2	9	25.7
9	7.6			12	21,4

7 CONCLUSIONS

It can be concluded from the tests conducted with an on-board suppression system that the Centrocen / DMT Explo-Stop System successfully stopped flame propagation inside the test tunnel. Despite a few failures, this system has a potential of significantly reducing the risk of harm to CM and RH operators involved in underground methane ignitions.

As expected, the most violent explosions occurred when the methane/air concentration was 9%. This was, in general, also the concentration that resulted in the highest flame speed. The presence of an actual CM or full-size models of a CM resulted in a very significant reduction in the tunnel cross-section and a consequent increase in flame speed. In fact, on the occasion of the first test, the failure of the suppression system on a Joy 14 CM 6 resulted in massive damage to the test tunnel when 87,5 m of 9% methane/air mixture was ignited.

In South Africa, the coal mining operations are highly mechanized with more than 175 continuous miner machines in use. Even though the risk of a coal mine explosion can never be reduced to zero by a single line of defence, the Centrocen / DMT Explo-Stop System active on-board suppression system has the potential of stopping explosions and could be

deployed in high risk areas to reduce the possibility of a coal mine explosion.

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