

Evaluation of a continuous miner half-curtain dust control system in a South African underground coal mine

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The issues of public health and safety in the mining industry have been dealt with around the world through the intervention of governments. In 1977 the South African Department of Mineral and Energy (DME) sent out a directive to reduce the dust concentration level to $<5\text{mg}/\text{m}^3$ at the operator's position for the sampling period. The reasons for the difficulty with compliance are: long headings up to 35m, inherently high dust generation rates of coal, and the increased use of highly mechanised equipment. A project was formulated under SIMRAC auspices with the title of "underground mechanical environmental control" to address the dust problem.

The project was planned in two phases. The first phase involved laboratory tests on a continuous miner model for different ventilation and spray systems at the newly built ventilation simulation tunnel at the Klopperbos research centre. In the second phase of the project, tests were carried out underground based on the findings and recommendations from the simulated tests. This paper focuses on the results and findings for the half-curtain system which have been encouraging. The average dust concentration for the sampling period at the operator's position for the half-curtain system was $3.20\text{ mg}/\text{m}^3$. On the other hand, the equivalent average dust concentration (TWA-CONC) for the half-curtain system for a 8-h period was $2.04\text{ mg}/\text{m}^3$. The outcome of this project has shown that the regulatory dust level of $<5\text{ mg}/\text{m}^3$ can be achieved through close collaboration with all the interested parties.

Introduction

The 1995 report of the Leon Commission of Inquiry (Leon, et al., 1995) into Safety and Health in the South African Mining Industry led to the promulgation of the Mine Health and Safety Act of 1996. In this report, the reasons for the current fatality, injury and disease rates in the mining industry were investigated. A Directive (1997) of the South African Department of Minerals and Energy (DME) to reduce the dust-concentration

level to below $5\text{ mg}/\text{m}^3$ for the sampling period at the operator's cab position on continuous mining (CM) machines resulted in a dedicated research project entitled "Underground Mechanical Miner Environment Control." The reasons for the difficulty with compliance are: long headings up to 35 m inherent high dust generation rates of coal, and the increased use of highly mechanised equipment. The project was planned in two phases. The first phase involved tests on a CM model in a ventilation tunnel at the Kloppersbos Research Center. The evaluation of these findings in an underground mine section was the objective of the second phase of the project. The systems tested needed to comply with two main criteria, viz. adequate methane dilution at the face and keeping the respirable dust-concentration levels below $5\text{ mg}/\text{m}^3$.

Background

As the first phase of the project, tests were conducted on surface in the newly built ventilation tunnel and in the second phase, consisting of the evaluation of several proposed systems (half-curtain, retrofitted hood, double scrubber and integrated hood system), in an underground mine. The outcome of the surface tests resulted in the following recommendations (du Plessis and Belle, 1998), which were implemented on the CM (12HM9) for the underground test:

- Fitted with new hollow cone spray nozzle (1.6 mm inlet diameter and 2.0 mm outlet diameter)
- Directional spray system introduced
- Air movers fitted over flight conveyor
- Scrubber intake extended, with inlet cone fitted
- Physical air curtain introduced

This paper describes the results of the half-curtain tests carried out at Matla Colliery of Ingwe Mines.

Description of experiments

All the tests were conducted in a bord-and-pillar CM production section. Figure 1 shows the typical deployment of the dust-monitoring instruments in the test section (intake, operator's cabin

and return). The respirable dust-concentration levels in the headings were determined by placing gravimetric respirable dust samplers along with the Hund tyndallometers. The air quantities and the direction of airflow were determined using anemometers and smoke tubes.

Dust and methane monitoring

The sampling set-up contains two gravimetric samplers, viz. a BGI sampler and a Cowl sampler, plus a real-time dust monitor (Belle and Du Plessis, 1998). The gravimetric samplers consist of an air pump that draws 2.2 ℓ /min of air through a mini-cyclone, which separates the airborne dust and collects only respirable dust (< 7 μm). At the stipulated flow rate of 2.2 ℓ /min, the instrument conforms to the new CEN/ISO respirable dust curve (ACGIH, 1991) with a 50% cut point (d_{50}) of 4 μm and is not sensitive to charge effects (Bartley, et al., 1993).

To determine the effectiveness of the half-curtain system, methane levels were monitored using a system developed by CSIR-Miningtek (Van Zyl et al., 1998). Methane levels (0 % to 4 %) were recorded at two positions on the machine during the shift.

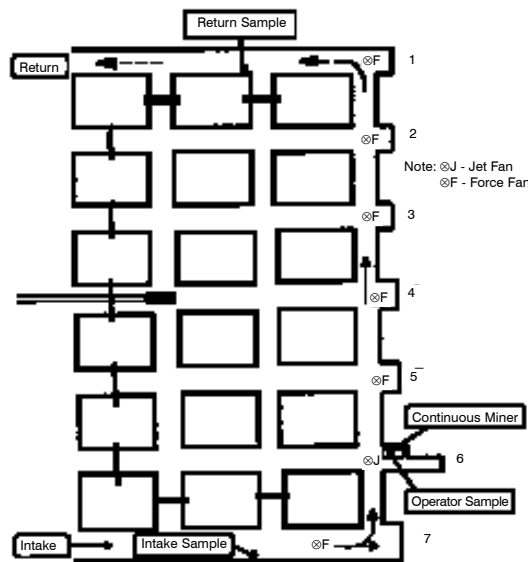


Figure 1. Layout of the test section

Half-Curtain System

A three dimensional view of the standard Kloppersbos spray configuration for the half-curtain system is shown in Figure 2. The system consists of a total of 34 sprays including three air movers. The main feature of the system is that it has a curtain just behind the scrubber inlet in order to contain the escaped dust travelling towards the return or influence re-circulation. The half-curtain covers an area from the scrubber on the left-hand side of the machine to the middle of the machine over the flight conveyor. This curtain is made up

of a conveyor belt, and closes a height of ± 1.0 m on top of the on-board scrubber.

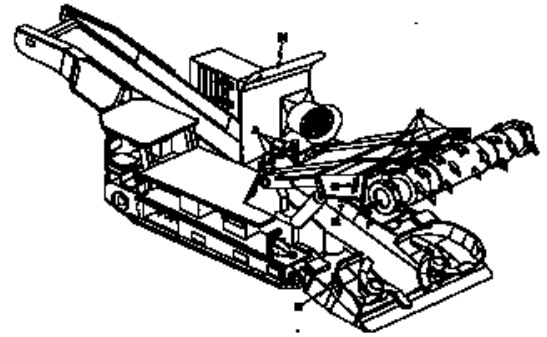


Figure 2. Three-dimensional view of half-curtain system with standard Kloppersbos spray configuration

The half-curtain system consists of:

- A wet fan on-board scrubber with a capacity of 10 m³/s -12 m³/s, fitted with an inlet cone.
- Maintains water pressure of 2000 kPa and a water flow rate of 110 ℓ /min.
- Hollow-cone nozzles with a single inlet diameter of 1.6 mm and an outlet diameter of 2.0 mm.
- Three air movers spraying downwards at an angle > 45° from the horizontal onto the conveyor to prevent dust rollback and to wet the coal (A).
- Four top spray blocks (total 12 sprays) situated above the cutter drum to move air across the face from right to left towards the scrubber intake (B).
- An L-shaped spray block (three spray blocks, each consisting of two sprays) installed on the right-hand side of the machine, ensuring air movement to the front of the machine (C).
- One spray block consisting of two water sprays installed on the spade, directing air to the left of the machine underneath the boom (D).
- One spray block consisting of two water sprays connected to the bottom of the cutter boom, directing air towards left of the machine under the boom (E).
- Two bottom directional spray blocks, each consisting of three sprays installed underneath the cutting head on the left and right sides of the head to ventilate under the cutting drum (F).
- One spray block consisting of three water sprays installed on right hand side of the cutting drum to ventilate the right hand side corner of the face (G).
- A half-curtain on top of the machine (H).

Data analysis

Evaluation of Dust Concentration level

The dust samples collected underground were weighed and the procedure for determining the particulate mass was followed according to DME

guidelines (DME, 1995). Using the mass of dust collected on the filters, the sample dust concentration (SC) in mg/m³ is obtained as follows:

$$SC = \frac{(C_f - C_i)}{(F1) \times (T)} \quad (1)$$

where:

- C_i = corrected initial filter mass (mg)
- C_f = corrected final filter mass (mg)
- F1 = sample flow rate (m³/min)
- T = sampling time (min)

The dust concentrations presented throughout this paper reflect gravimetric dust measurements taken over a specific sampling period. In order to assess a maximum dose to which a miner is exposed, a value of nine hours per day is considered as the most likely daily occupational exposure period for most South African miners. The 8-h time-weighted average (TWA) concentration of an airborne coal dust is that average concentration of coal dust to which a worker may be exposed, such that he will receive a dose equal to that which he would receive if he was exposed to this concentration for 8 h/day or 40 h/week. Therefore, the time-weighted average dust concentration (TWA-CONC) in mg/m³ is obtained as follows:

$$TWA-CONC = \frac{(SC \times T)}{480} \quad (2)$$

where:

- SC = sample dust concentration (mg/m³)
- T = sampling time (min)

Results

Sampling Results

The relationship between the concentration values obtained from the BGI sampler and the Cowl sampler was plotted (Figure 3). The correlation coefficient obtained between the two samplers was 0.95. Therefore, the average of the two samplers was taken for determining concentration levels at each position.

Methane concentration results

The methane levels never exceeded the maximum permitted concentration (Minerals Act and Regulations, 1991) of 1.4% CH₄ per volume for the scenarios tested. The peak methane average concentration level for the half in system was 0.173%.

Half-curtain system: observations and results

A total of 31 tests were conducted on the half-curtain system with two types of auxiliary ventilation devices (19 tests with force fan and column

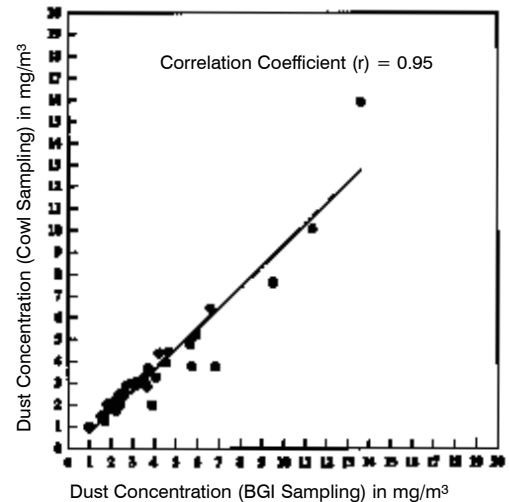


Figure 3. Relationship between BGI and Cowl sampling results

and 12 tests with jet fan and column). The results of tests 1, 2, 3, 4 and 12 were discarded due to the low water pressure, low water flow rate and incorrect cutting sequences. The following critical observations were made during the first few tests; they greatly enhanced the dust control measures:

- A water pressure of 2000 kPa and a flow rate of 110 ℓ/min need to be maintained for the entire spray system.
- The cutting sequence should be from right to left in a heading/split when the position of the on-board scrubber is on the left-hand side of the machine.
- Section ventilation must be maintained effectively (last through road air velocity ≥ 1.0 m/s)
- Auxiliary ventilation devices must be properly positioned and attention must be given to the operation and proper use of such devices.
- The force fan or jet fan should not be operated without the column.

Results with force fan and column

Table 1 shows the dust concentration levels at the intake, operator and return during the sampling period for the half-curtain system with force fan and column. The calculated average dust concentration levels (14 tests) at the section intake, operator and section return for the sampling period were 0.36 mg/m³, 3.32 mg/m³ and 1.06 mg/m³ respectively. In test # 12, the concentration level at the operator was 14.74 mg/m³ due to the incorrect cutting sequence, poor ventilation and non-aligned roadway while cutting. The average coal production and sampling period during the tests were 597 tons and 300 minutes respectively. The box plot of the concentration levels during the half-curtain tests using the force fan and column is shown in Figure 4.

The following observations were made during these tests: The force fans should not be oper-

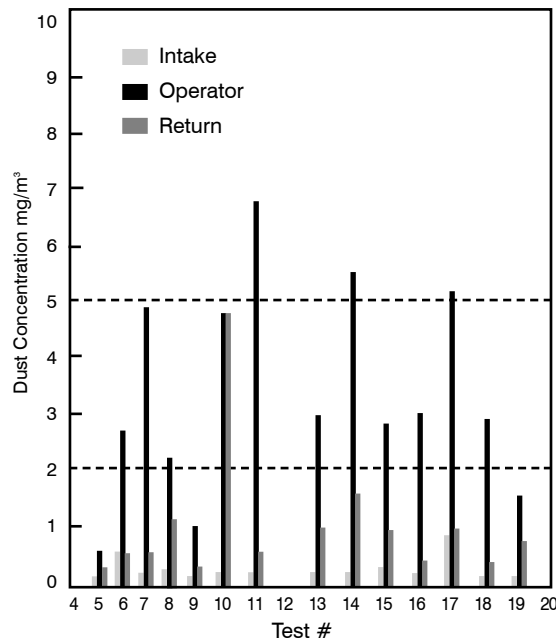


Figure 4. Dust concentration levels in half-curtain system with force fan and column

ated without the column, due to continual air recirculation. The half-curtain system on the CM was able to ventilate the face area adequately for the first 12 m of the cut. The use of the force fan and column at a distance of 12 m from the face under good section ventilation results in extreme dusty conditions at the operator. Force column ventilation of the second left-hand side cut is advised. Beyond 20 m from the last through road (LTR), the force column ventilation should be such as to ensure that the air velocities over the operator do not exceed 1.0 m/s. This implies that lower quantities of airflow during the second right-hand cut will be utilised.

| Test Number | Sampling Position | | |
|-------------|-------------------|----------|--------|
| | Intake | Operator | Return |
| 1 | - | - | - |
| 2 | 0.787 | 7.409 | 1.456 |
| 3 | 0.500 | 7.463 | + |
| 4 | 0.394 | 7.916 | 1.696 |
| 5 | 0.189 | 0.690 | 0.273 |
| 6 | 0.631 | 2.664 | 0.587 |
| 7 | 0.308 | 4.924 | 0.603 |
| 8 | 0.427 | 2.292 | 1.213 |
| 9 | 0.164 | 0.863 | 0.371 |
| 10 | 0.297 | 4.763 | 4.770 |
| 11 | 0.294 | 6.524 | 0.675 |
| 12 | 0.157 | 14.740 | 1.962 |
| 13 | 0.322 | 2.943 | 0.938 |
| 14 | 0.373 | 5.583 | 1.518 |
| 15 | 0.571 | 2.796 | 0.987 |
| 16 | 0.355 | 3.256 | 0.540 |
| 17 | 0.830 | 5.209 | 1.022 |
| 18 | 0.244 | 2.988 | 0.579 |
| 19 | 0.107 | 1.478 | 0.739 |

+ sample discarded

Table 1. Results of half-curtain tests with force fan and column (dust concentration values in mg/m³)

The half-curtain system was effective enough to blow the return air towards the LTR with less air recirculation. Beyond 24 m from the LTR, the on-board scrubber along with the sprays should not be allowed to stop in between the cutting periods as it induces airflow across the face. The ventilation column and the fan should be placed on the floor for ease of operation and control. The stability of the system is dependent on the discharge air velocity from the column. Therefore, the discharge velocity from the column should be controlled between 10 m/s and 12 m/s.

Results with jet fan and column

Table 2 shows the dust concentration levels at the intake, operator and return during the sampling period for the half-curtain system with jet fan and column. The calculated average dust concentration levels (12 tests) at the section intake, operator and section return for the sampling period were 0.39 mg/m³, 3.02 mg/m³ and 1.34 mg/m³ respectively. The box plot of the concentration levels during the half-curtain tests using the jet fan and column is shown in Figure 5.

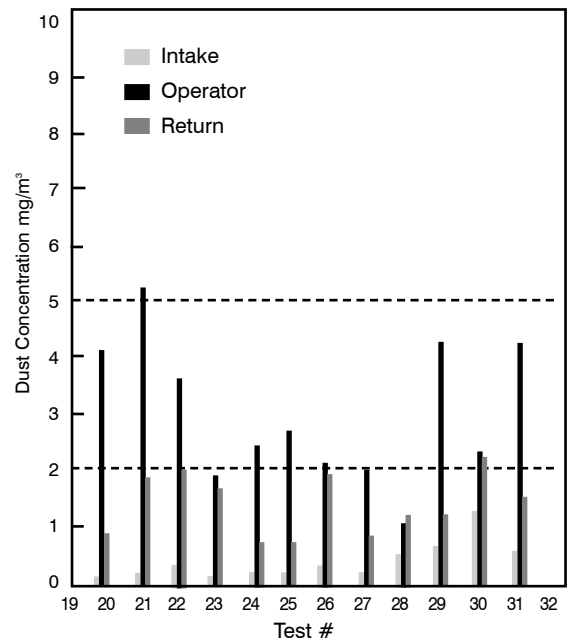


Figure 5. Dust concentration levels in half-curtain system with jet fan and column

Table 3 shows the summary statistics of the half-curtain system. The calculated average dust concentration levels (26 tests) at the section intake, operator and section return for the sampling period were 0.38 mg/m³, 3.18 mg/m³ and 1.19 mg/m³ respectively. The TWA (8-h) levels at the intake, operator and return positions were 0.23 mg/m³, 2.04 mg/m³ and 0.74 mg/m³ respectively. The relationship between the dust concentration level and the production for the half-curtain system was plotted and is shown in Figure 6. It was observed that the dust concentration level increases with an increase in production at the operator and return positions. Despite

| Test Number | Sampling Position | | |
|-------------|-------------------|----------|--------|
| | Intake | Operator | Return |
| 20 | 0.149 | 4.296 | 0.849 |
| 21 | 0.182 | 5.272 | 1.795 |
| 22 | 0.244 | 3.663 | 2.028 |
| 23 | 0.153 | 1.910 | 1.294 |
| 24 | 0.193 | 2.519 | 0.736 |
| 25 | 0.197 | 2.781 | 0.742 |
| 26 | 0.310 | 2.050 | 1.843 |
| 27 | 0.252 | 1.989 | 0.873 |
| 28 | 0.397 | 0.967 | 1.124 |
| 29 | 0.560 | 4.241 | 1.163 |
| 30 | 1.365 | 2.336 | 2.276 |
| 31 | 0.784 | 4.186 | 1.342 |

Table 2. Results of half-curtain tests with jet fan and column (dust concentration values in mg/m³)

this relationship, at the operator's position, during the highest production level of 1040 tons, compliance with the 5.0 mg/m³ requirement was still achieved for the sampling period. The observations with regard to ventilation practices when using the jet fan and column as an auxiliary ventilation device were similar to those made with the force fan and column.

Conclusions

The half-curtain system tests with both the force fan and column and the jet fan and column

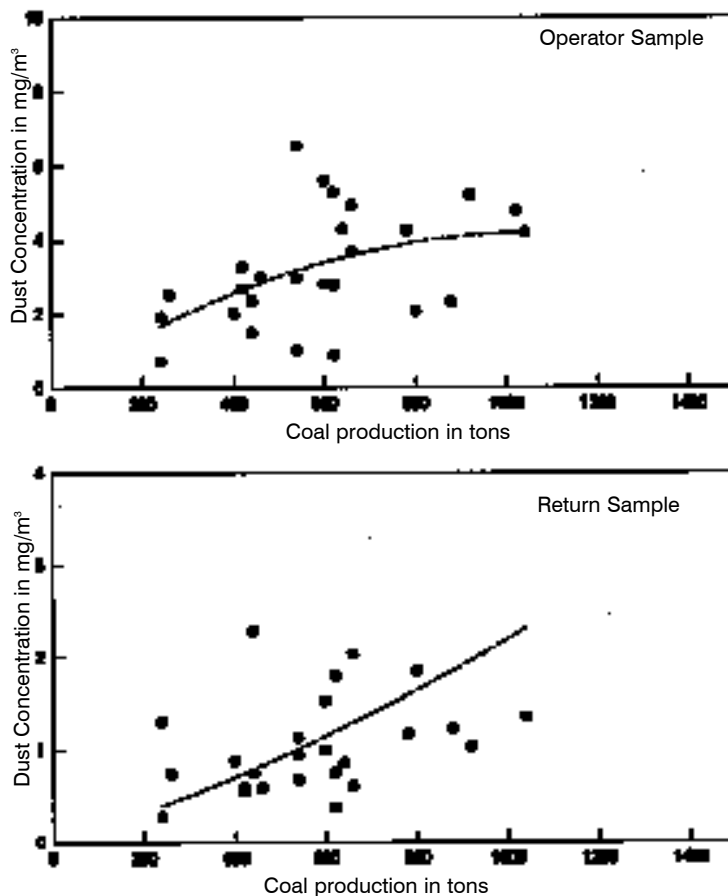


Figure 6. Relationship between dust concentration and production in half-curtain systems

| | Sampling Position | | |
|---|-------------------|----------|--------|
| | Intake | Operator | Return |
| Mean, mg/m ³ | 0.380 | 3.199 | 1.187 |
| Standard Deviation, mg/m ³ | 0.277 | 1.560 | 0.893 |
| Variance, (mg/m ³) ² | 0.076 | 2.435 | 0.797 |
| Minimum, mg/m ³ | 0.107 | 0.60 | 0.272 |
| Maximum, mg/m ³ | 1.365 | 6.523 | 4.779 |
| Median, mg/m ³ | 0.302 | 2.869 | 0.962 |
| Number of samples, N | 26 | 26 | 26 |
| 1st Quartile, mg/m ³ | 0.187 | 2.171 | 0.74 |
| 3rd Quartile, mg/m ³ | 0.412 | 4.529 | 1.656 |

Table 3. Summary statistics of half-curtain system

resulted in the following conclusions:

- Methane levels never exceeded the maximum concentration of 1.4% CH₄ per volume. The peak average concentration for the system was 0.173%.
- There appeared to be an increase in the sample dust concentration level with an increase in coal production. However, the concentration level was less than 5 mg/m³ for the maximum production of 1040 tons/sampling period at the operator position.
- The right and left cuts of the first 12 m should not be force-ventilated. Depending on the section ventilation, beyond 20 m from the LTR, the force column ventilation should be such as to ensure that air velocities over the operator do not exceed 1.0 m/s.
- Auxiliary fans (force or jet) in conjunction with the columns should be used on the intake side of the machine (i.e. on the CM operator side).
- The use of a jet fan, positioned on the floor, with an air-entrainment attachment and 570 mm columns resulted in better dust concentration levels.
- Because of their robustness and capacity, jet fans with columns would be a better auxiliary ventilation device than large force fans, unless controls were set up to ensure that the required discharge velocity from the outlet of the column of 10 m/s to 12 m/s was maintained.
- Maintenance of all dust suppression components, i.e. spray nozzles, spray blocks, air movers and scrubbers, is absolutely essential. Flushing of the water filters prior to cutting, together with checking of the water flow and pressures, is recommended at the start of every shift.
- Regular replacement of worn-out bits greatly decreased the dust levels at the face.
- Ensuring that the half-curtain remains in its upright position is also of the utmost importance.
- It was also observed during the tests that it is essential to train and educate the miner about

the sampling objective, sampling procedure and the resulting dust-related decisions based on the samples collected underground.

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Paper 2: 27 October 1999
Paper 3: 28 October 1999
Paper 4: 19 October 1999
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