Hood Type Dust Control Systems on Continuous Miner (CM) in an Underground Bord and Pillar Coal Mine

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Abstract

The changing and stricter regulatory environment has caused the mining industries in South Africa to re-look at their individual mine health and safety departments. In 1997, after the report of the Leon Commission of Inquiry (1995), the South African Department of Minerals and Energy (DME) sent out a directive to reduce the dust concentration level to below 5 mg/m³ at the operator's position for the sampling period. The reasons for the high levels of dust concentrations of dust are: long headings up to 35 m, inherently high dust generation rates of coal, and the increased use of highly mechanized equipment. To aid in developing systems to reduce high dust levels, a project was formulated under SIMRAC auspices with the title of "Underground Mechanical Miner Environmental Control" to address the dust problem.

The project was executed in two phases. The first phase involved laboratory tests on a continuous miner model for different ventilation and spray systems at ventilation simulation tunnel at the Kloppersbos Research Center. 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 of the hood systems, viz., retrofitted hood system and integrated hood system. The average dust concentration for the sampling period at the operator's position for the retrofitted hood, integrated hood system-smaller scrubber and integrated hood system-larger scrubbers were 2.33 mg/m³, 6.08 mg/m³ and 5.98 mg/m³ respectively. On the other hand, the equivalent average dust concentration (TWA-CONC) for an 8-h period for the retrofitted hood, integrated hood system-smaller scrubber and integrated hood system-larger scrubbers were 1.53 mg/m³, 5.51 mg/m3 and 4.83 mg/m³ respectively. Finally, the paper highlights the use of auxiliary ventilation systems during the tests underground.

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 mg/m³ 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 high dust levels are: long headings up to 35 m (114.83 ft), inherent high dust generation rates of coal, and the increased use of highly mechanized 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 mg/m³.

The outcome of the surface tests resulted in the recommendations (Du Plessis, Belle and Vassard, 1998), which were implemented on the CM (12HM9/HM31) for the underground tests. Several systems such as half-curtain, retrofitted hood, double scrubber and integrated hood systems were tested in underground mines (Belle and Du Plessis; Du Plessis and Belle, 1998). The test CMs were fitted with hollow cone spray nozzles (1.6 mm inlet diameter and 2.0 mm outlet diameter) with directional spray system, air movers fitted over the flight conveyor and scrubber intake connected to the hood. This paper discusses the test results of the hood type dust control system, carried out at two different bord and pillar underground coal mines.

Description of experiments

Tests were conducted in bord-and-pillar CM production section at two different mines (retrofitted hood system in mine A and integrated hood system in mine B). The dust-monitoring instruments were deployed in the section intake, operator's cabin and the section return. The respirable dust-concentration levels in the headings were determined by placing gravimetric respirable dust samplers along with a real-time dust monitor. In mine A, CM operator was inside the HM9 CM; while in mine B, HM 31, the CM was operated with a remote control unit.

A total of 24 tests were conducted for evaluating the hood system (nine tests on retrofitted hood and 15 tests on integrated hood). During the integrated hood system, the first five tests were conducted with a smaller scrubber (capacity of 6 m^3/s); for the next ten tests a larger scrubber (capacity of 12 m^3/s) was fitted. Furthermore, jet fan together with an entrainment ring and column was used as an auxiliary ventilation device kept on the floor. Exemption to mine a heading of 25 m depth was obtained by mine B from the DME. This resulted in the jet fan-column outlet being a maximum distance of 25 m away from the face.

Dust and Methane Monitoring

The sampling set-up contains two gravimetric samplers, and a real-time dust monitor (Hund tyndallometer). 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 fraction of respirable dust less than 7 mm. To determine the methane dilution effectiveness of the hood 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 (left-hand side and right-hand side of the CM drum) on the machine during the shift.

Hood System

Retrofitted Hood System - Mine A

The retrofitted hood system (Figure 1) tested at mine A was fitted with the Kloppersbos spray configuration on CM HM 9 with the addition and removal of spray blocks on the machine. Also, an exhaust hood is fitted on the top of the boom, which in turn is connected to the scrubber inlet (a wet fan on-board scrubber with a capacity of 10 m^3/s -12 m^3/s), by means of flexible spiral ducting. The hood draws the dusty air from four different positions underneath the boom towards the scrubber inlet. The spray configuration on the machine is designed to ensure that the dust and methane-laden air will be directed towards the four intake ports of the hood.

The retrofitted hood system consists of:

- Water supply line and a booster pump maintaining water pressures between 1500 and 2000 kPa (15 and 20 bars) and water flow rate of 100 and 120 ℓ/min to the spray system. Three air movers spraying downwards directed at an angle of 60 to 70 degrees 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).

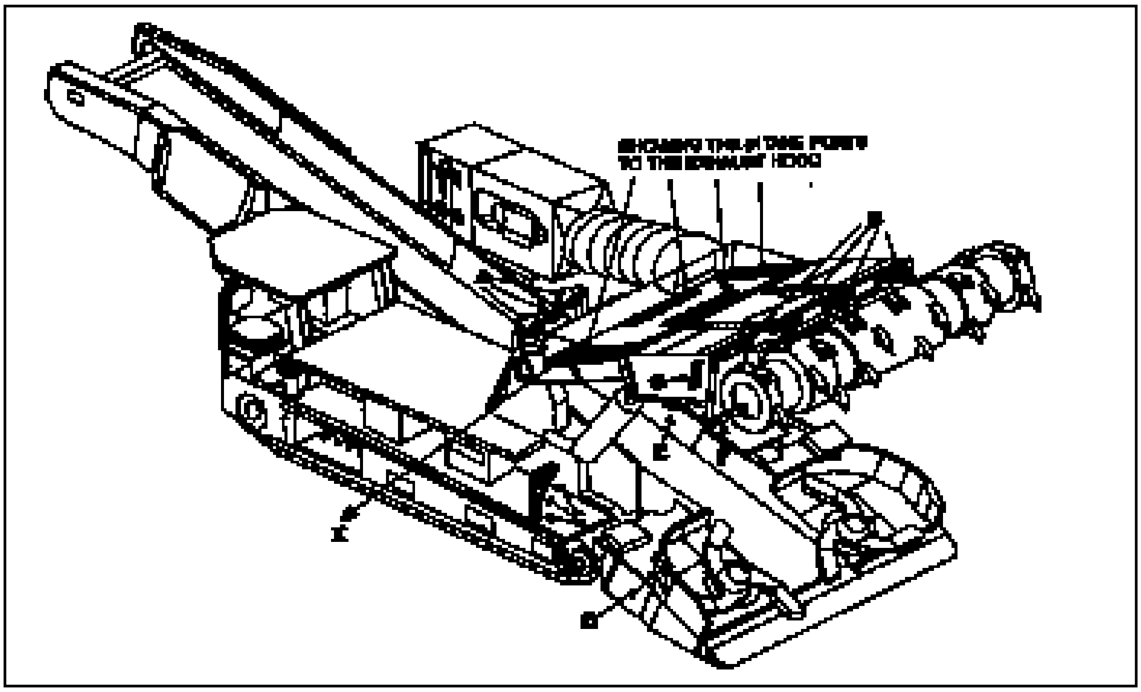

Figure 1. Three-dimensional view of retrofitted hood system

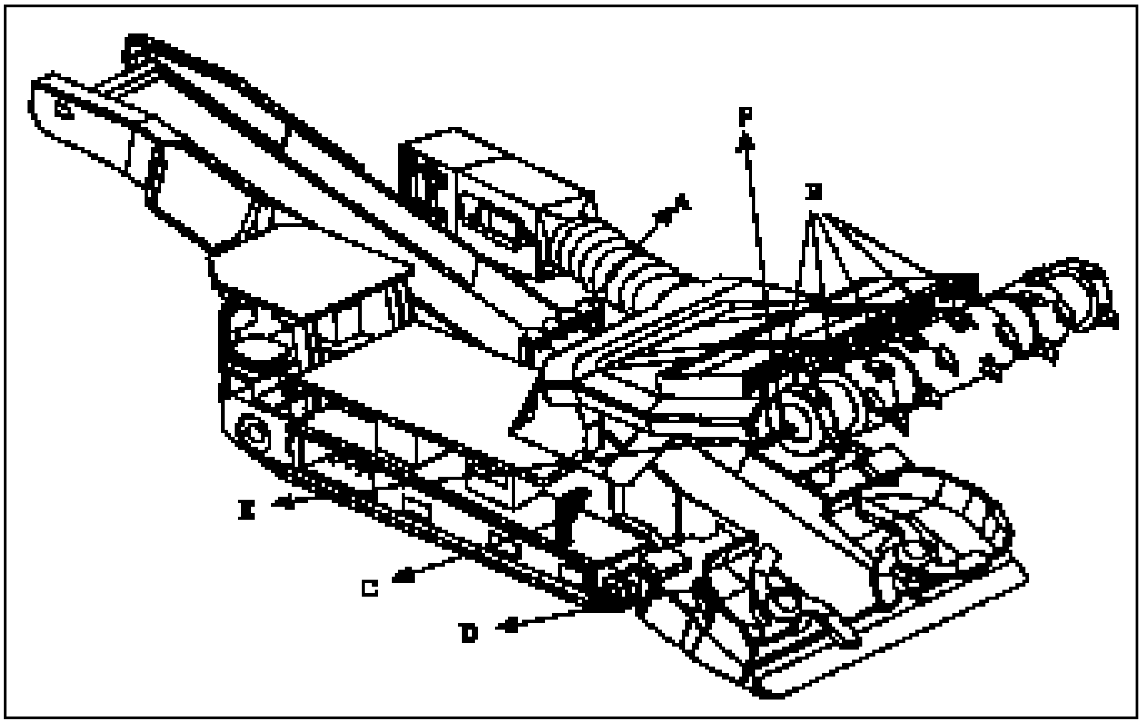

Figure 2. Three-dimensional view of integrated hood system

- One spray block consisting of two water sprays connected to the bottom of the cutter boom, directing air towards left of the machine underneath the boom (45 to horizontal) (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). These were shut-off for the retrofitted hood tests.
- 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).
- One spray block consisting of two sprays was positioned before the left-hand side of the inlet to the hood, directing downwards to prevent rollback (position K).
- An additional two spray blocks (four sprays) was placed on the right-hand side of the machine and on the bottom front of the scrubber. The bottom two spray blocks (six sprays) were shut off. The system consists of a total of 34 sprays including three air movers.

Integrated Hood System - Mine B

The top view of the integrated hood system with the spray configuration on the larger HM31 CM is shown in Figure 2.

The system consists of a total of 41 sprays and four air movers. The details of the individual design specifications that are different from the retrofitted hood system as shown on the drawings are as follows:

- On-board wet fan scrubber:
  a) Handling air quantities between 6,0 and 8,0 m^3/s (referred to as the small scrubber).
  b) Handling air quantities between 10 m^3/s and 12 m^3/s (referred to as the large scrubber).
- Four air movers spraying downwards (> 45 from vertical) onto the conveyor to wet the coal and to prevent dust rollback through the flight conveyor (A).
- Five top spray blocks (15 sprays) situated above the cutter drum to move air across the face from right to left (B)
- One spray block consisting of two water sprays connected to the bottom of the cutter boom, directing air towards the left of the machine underneath the boom (45 to horizontal) (E).

Data analysis

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/m^3 is obtained as follows:

$$SC = \frac{(Cf - Ci)}{(F1) \times (T)} \qquad (1)$$

where:

C_i = corrected initial filter mass (mg)
C_f = corrected final filter mass (mg)
F1 = sample flow rate (m^3/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 eight-hour time-weighted average (TWA) concentration of an airborne coal dust is that average concentration of coal dust, which a worker would receive a dose if he were exposed to this concentration for 8 h/day or 40 h/week. Therefore, the time-weighted average dust concentration (TWA-CONC) in mg/m^3 is obtained as follows:

$$\text{TWA - CONC} = \frac{(\text{SC x T})}{480} \qquad (2)$$

where:

SC = sample dust concentration (mg/m^3)

T = sampling time (min)

Results

Mine A - Retrofitted Hood System

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 results of only two out of nine tests were recorded due to failure of the monitoring system. The peak methane average concentration level for the retrofitted hood system was 0.144 %.

Dust Concentration Results

Table 1 shows the dust-concentration levels at the intake, operator and return during the sampling period for the retrofitted hood system. The calculated average dust-concentration levels (nine tests) at the section intake, operator and section return during the sampling period were 0.55 mg/m^3, 2.33 mg/m^3 and 1.11 mg/m^3 respectively. The average production during the hood tests was 780 tons. The average sampling time for the entire test system was 315 minutes. The box plot of the concentration levels during the retrofitted hood system tests is shown in Figure 3.

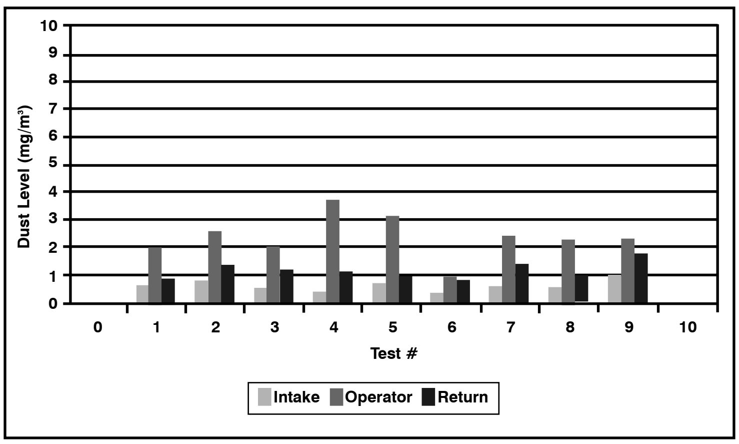

Figure 3. *Dust concentration levels for the retrofitted hood system*

Test Number	Sample Position		
	Intake	Operator	Return
1	0.495	1.917	0.863
2	0.732	2.511	1.223
3	0.453	1.962	1.089
4	0.263	3.661	1.032
5	0.615	3.068	1.017
6	0.341	0.984	0.716
7	0.559	2.347	1.317
8	0.516	2.236	0.966
9	1.000	2.267	1.740

Table 1: *Results of retrofitted hood tests (dust concentration values in mg/m^3)*

Critical observations noted:

- Ventilation principles used and adhered to in this system were:
  - 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 a reduction of dust concen tration levels.
- The retrofitted hood system is sensitive to force ventilation as the inlets to the hood are located underneath the boom. Also, the potential for dust rollback towards the operator from the right-hand side of the machine, near the L-spray block, is high.
- The spray block on the boom (position K), close to the L-spray block, greatly reduced the dust levels at the operator.
- The dust concentration was high when the CM was cutting the roof and shearing downwards. Concern is expressed regarding the flow of fresh air across the roof area when the machine is cutting the top of the face in seams with high methane content.
- The maintenance of spray nozzles on the machine, and adherence to the required water pressure (1500 to 2000 kPa) and flow rates (100 to 120 ℓ/min), significantly reduced the dust levels.

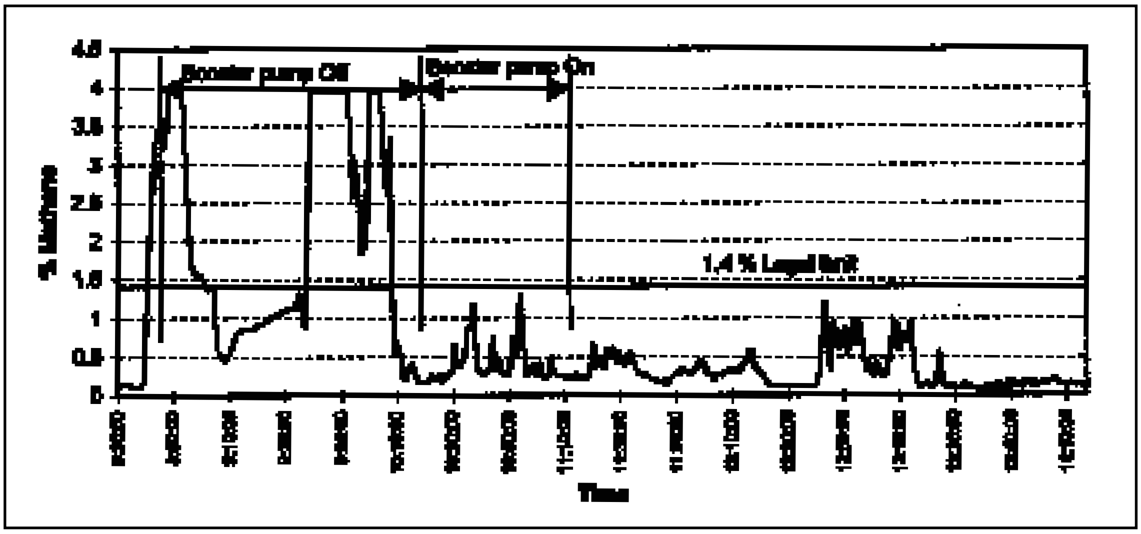

Figure 4: *Influence of water spray system on methane concentration*

Test Number	Methane Concentration, %		
	Peak Value	Average	Variance
12	1.3	0.33	0.054
13	0.62	0.22	0.011
14	0.64	0.18	0.012

Table 2: Methane concentration results of integrated hood system tests with a smaller scrubber

Test #	Peak Value	Average	Variance
15	1.85	0.26	0.111
16	0.80	+	0.370
17	1.32	0.81	0.229
18	0.96	0.70	0.034
19	0.84	0.39	0.035

\+ negative average value

Table 4: *Methane concentration results of integrated hood system tests with a larger scrubber*

Test Number	Sample Position		
	Intake	Operator	Return
10	1.195	5.741	3.349
11	1.313	1.194	1.117
12	0.993	7.189	2.255
13	2.650	5.317	3.033
14	1.786	2.958	1.855

Table 3: Results of integrated hood system tests with smaller scrubber (concentration values in mg/m^3)

Test Number	Sample Position		
	Intake	Operator	Return
15	1.430	7.510	2.972
16	+	6.474	3.537
17	1.334	17.79	3.187
18	0.960	7.151	1.784
19	+	5.902	3.208
20	0.853	2.034	1.086
21	1.051	1.272	1.193
22	0.904	2.697	1.369
23	1.819	9.016	3.261
24	0.814	3.087	2.429

\+ Failed

Table 5: *Results of integrated hood system tests with larger scrubber (concentration values in mg/m^3)*

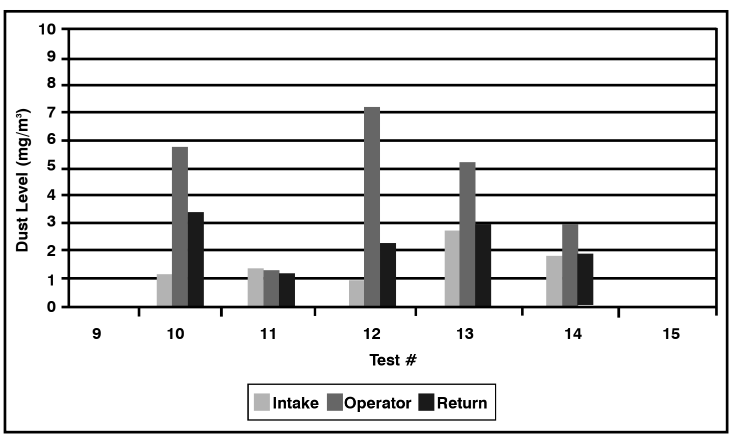

Figure 5. *Dust concentration levels for the integrated hood system with a smaller scrubber*

Mine B - Integrated Hood System Results-Smaller scrubber:

Methane concentration results

Table 2 summarizes the methane levels during the underground tests with the integrated hood system with smaller scrubber tests. Figure 4 shows the influence on the methane levels with and without operating the booster pump on the CM. The correct operation of the pump resulted in

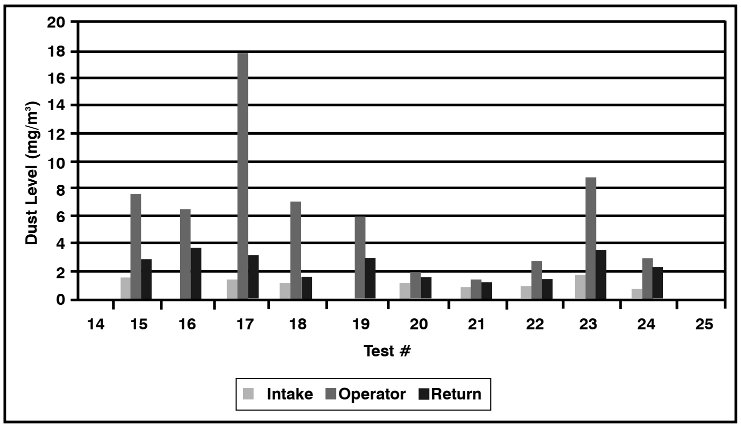

Figure 6: *Dust concentration levels for the integrated hood system with a larger scrubber*

a reduction in the methane levels measured, despite the normal production. Prior to this the methane sensor saturated at 4 % CH4 per volume. From this we infer that the sweeping action of the directional spray system is severely hampered unless the design water pressure is adhered to.

Respirable dust concentration results

Table 3 and Figure 5 shows the dust-concentration levels at the intake, operator and return for the sampling period. Five tests were attempted with the smaller scrubber connected to the integrated hood. The calculated average dust-concentration levels at the section intake (tests 10 to 14), operator and section return (tests 10, 12 and 13) were 1.58 mg/m^3, 6.08 mg/m^3 and 2.88 mg/m3 respectively. Tests 11 and 14 were discarded as there was little cutting done during these tests. The average production during the use of the integrated hood system was 810 tons and the average sampling period for the three tests was 435 minutes.

Some of the identified shortcomings of the smaller scrubber system were: lower-than-required water flow rate to the machine; scrubber design volume flow too low for mining height. The initial test results showed promise and a recommendation to increase the scrubber capacity (to increase the volume flow rate at the face) was made. To meet this objective, a scrubber with a larger capacity (30 inches) was fitted.

Mine B - Integrated Hood System Results-Larger Scrubber

Methane concentration results

Table 4 summarizes the methane levels during the underground tests with the integrated hood system with the larger scrubber (tests 15 to 19). During test 20, the methane-logging system became dislodged from its position and the CM flattened the system, resulting in irreparable damage and subsequent failure to log the data for the last five tests (tests 20 to 24).

Respirable Dust Concentration Results

The respirable dust-concentration results for the individual tests with the larger scrubber (30 inches) are shown in Table 5.

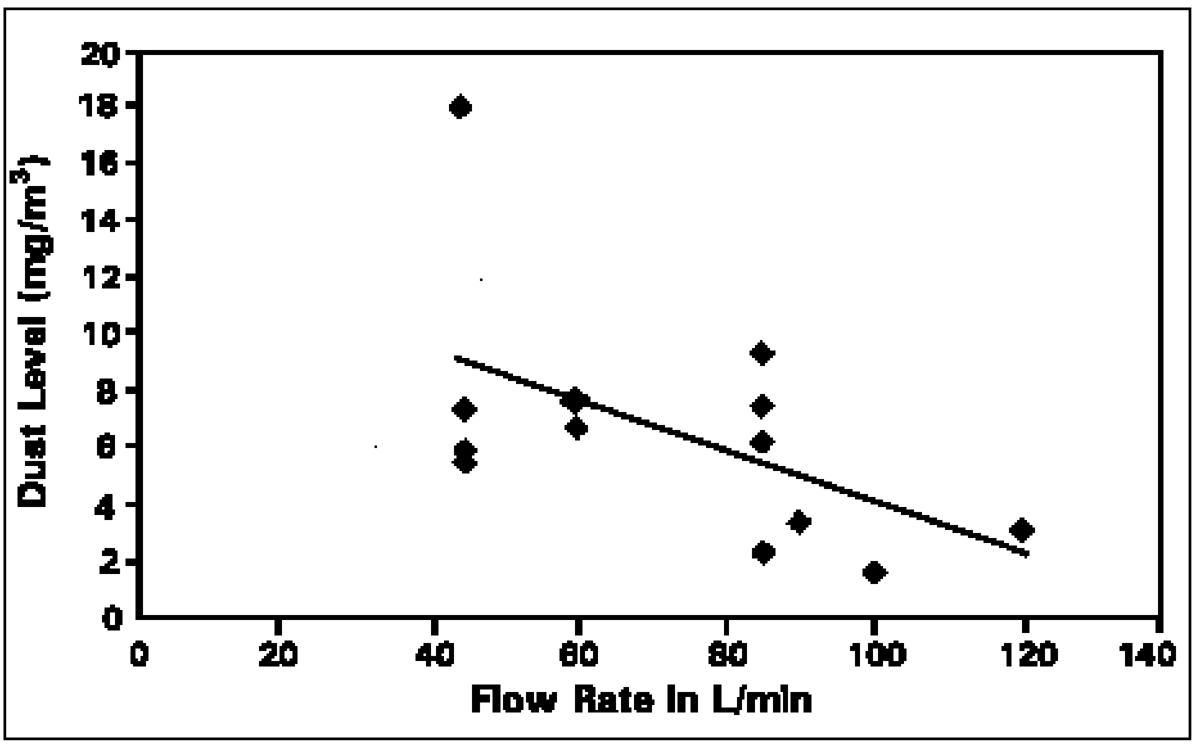

Figure 7: *Relationship between dust concentration and water flow rate to the spray system*

During tests 15 and 16, the water sprays kept on blocking up resulting in a water flow rate that was lower than required. In test 17, very low water flow rates resulted in terribly dusty conditions (17.79 mg/m³) at the operator. The intake average was calculated with tests 16 and 19 excluded. The operator and return averages were both calculated with tests 20 and 21 excluded as there was no production. The calculated average dust-concentration levels at the section intake, operator and section return were 1.15 mg/m³, 7.45 mg/m3 and 2.72 mg/m³ respectively. If test 17 is discarded because of the exceptionally low water flow rate, the calculated operator average concentration is 5.97 mg/m³. The average increase (intake to return) in tests 20 and 21 was 0.198 mg/m³ whilst very little production occurred. The dust thus added to the return air amounts to 0.918 mg/m³. This is an indication of the dust-capture efficiency of the system. The concentration levels at intake, operator and return positions for the tests on the integrated hood system are shown in Figure 6.

The sensitivity of the dust-suppression system to water flow rates and pressures was clearly demonstrated during this set of tests. This relationship is shown in Figure 7.

Conclusions

In summary, the results obtained during the trials of the retrofitted hood system in mine A were encouraging, with keeping the dust concentration levels within the 5 mg/m³ design criterion. On the other hand, both the integrated hood systems as evaluated in mine B, failed to comply with the < 5 mg/m³ directive. The results of the hood systems tested can be concluded as follows:

Retrofitted Hood

- Methane levels never exceeded the maximum concentration of 1.4% CH_4 per volume for the scenarios tested. The peak average concentration for the systems was 0.144 %.
- It was observed that this system is more sensitive to force ventilation.

Integrated Hood System

- The smaller scrubber hood system failed due to lower-than-required airflow rate through the scrubber and problems encountered with water flow to the machine.
- The larger scrubber also failed primarily because of the lower-than-required water flow rates. The tests showed the interdependence of all the components of the dust-suppression strategy, although all the individual systems, except the water system complied with recommendations, i.e., correct cutting sequence; proper working of jet fan auxiliary ventilation system; and proper maintenance of water spray system and nozzles.
- Also another major design problem of the integrated hood system was maintenance that was not required in the case of retrofitted hood system. The hood blocked up readily, resulting in poor airflow rates underneath the boom.

Also, the effect of greater methane contents and seam methane emission rates must be borne in mind. For this reason, the need for caution when designing the dust control systems for higher methane emission rates is stressed. Although each mine and section differs in its operation, use of a combination of the ventilation and dust-control systems will be able to bring the dust levels within the regulation requirements.

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