Recent developments in the control of respirable dust concentrations following the 12m directive

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Abstract

A directive was issued in 1997 by the South African Department of Minerals and Energy (DME) to reduce the respirable dust concentration level to below 5 mg/m³ for the sampling period at the operator's cab position on continuous mining machines used in coal mines. Furthermore, the directive also set a 12 m rule, i.e., the maximum advance in any cutting sequence should be restricted to 12 m, to assist effective dust control and minimise the dust exposure of workers. The focus of this paper is to make a detailed analysis of the efficacy of the 12 m rule from the perspective of dust control and also to address the question of whether the mere restriction of not mining beyond a distance of 12 m will on its own solve dust problems.

Analysis of the results indicated that the application of a 12 m rule on its own does not solve the dust problems, but that meticulous application of available state-of-the-art dust control technologies, best work practices, and the regular maintenance of the installed system combine to ensure that it works at all times. The authors strongly believe that the use of a cutting block (CB) distance is one of the most important parameter affecting worker exposure to coal dust. As an administrative control measure for effective dust exposure control, the mine environment officers, occupational hygienists and mine management can effectively use this information in order to rotate CM operators during the working shift to ensure that a particular CM operator is not exposed to high levels of coal dust.

Introduction

A directive (1997) of the South African Department of Minerals and Energy (DME) was sent to all coalmines in South Africa instructing them to reduce the dust-concentration level to below 5 mg/m³ for the sampling period at the operator's cab position on continuous mining machines. Further, the directive also specified a 12 m rule to assist effective dust control and minimize the dust exposure of workers. The 12m rule required the following aspects to be considered (DME Directive, 1997):

The directive stated as follows:

1. "No continuous miner (CM) heading must be developed further than 12m from the last row of permanent support or from the point of auxiliary ventilation; and

2. Only ventilation systems that can ensure, at all times, a maximum dust reading of 5 mg/m³, measured at the drivers position on the continuous miner (CM), must be employed."

Background

The interpretation of the DME directive of 1997 suggested that the continuous miner (CM) cannot advance for a distance further than 12 m before the necessary support is installed and the auxiliary ventilation devices such as jet fan or force fan are advanced to the required distance behind the CM. Therefore, in a production section, if there is a normal lag distance between the face and the most forward point of auxiliary ventilation devices such as jet fan or force fan, that exceeds 12 m, then the operation must be stopped in order to obey the directive. In the event of a CM being operated by a remote control device the limit of the unsupported roof is then the length of the CM. From the perspective of roof hazard prevention, the rule is also favourable to the worker and prevents him from traveling under unsupported roof.

The mining industry's initial reaction was that the 12 m rule would negatively impact on the operation of a CM section, because the CM would be prevented from advancing uninterruptedly for more than 12 m in the same heading. However, a research study conducted by Oberholzer (1998) concluded that the introduction of the 12m rule, although detrimental to production, would not have a significant enough effect to exclude its use based on productivity constraint considerations. Aspects like the perceived increase of effort to do the necessary support and installation of secondary ventilation are seen as being necessary and part of the work required for extracting coal safely.

The focus of this paper is to carry out a detailed analysis from the perspective of dust control after following the 12 m rule and also address the question whether the mere restriction of not mining beyond a distance of 12 m will on its own solve dust problems. The 12 m rule would undoubtedly enhance roof support practice, but its efficacy in keeping dust levels down on its own is less certain. Since the introduction of the 12 m rule directive, it has drawn the attention of the industry's environmental officers to the problem of achieving the required dust concentration results. This paper describes the measurement and analysis of results for the dust concentration levels in 30 m development headings in CM sections that comply with the 12 m cutting sequence rule.

Test systems, data collection and analysis

For the analysis of the 12 m rule with regard to its role in reducing dust levels, data was gathered from two bord and pillar CM production sections. For the purpose of this analysis individual headings and splits were divided into various 12 m cutting blocks as shown in Figure 1. The CM followed the cutting sequence in the ascending order of cutting block numbers (designated 1 to 14) as shown in Figure 1. We can observe that the total length of the split was 21m, while the heading was 30 m.

During the underground trials four different dust control systems were evaluated under the 12 m cutting sequence rule. The four different dust control systems were: - half-curtain system, retrofitted hood system, double scrubber system and integrated hood system. Hereafter these systems will be referred to as System 1, System 2, System 3 and System 4 respectively. The four different dust control systems were analysed using the results obtained from over 60 underground sampling shifts, for which the real-time dust concentration data was available.

Dust monitoring

The dust-monitoring instruments were deployed at the CM operator's cabin position. The respirable dust concentration levels were determined by gravimetric respirable dust samplers along with Hund tyndallometers. The sampling set-up contained two gravimetric samplers and a real-time dust monitor. The gravimetric samplers consisted of an air pump that draws 2.2 L/min of air through a mini-cyclone, which separates the airborne dust and collects only the respirable dust (< 10 mm) fraction. In each underground shift, data on cutting distance block (CB) either in the heading or the split (12m or 24 m), cutting direction (heading [H] or split [S]), and dust control system type were collected.

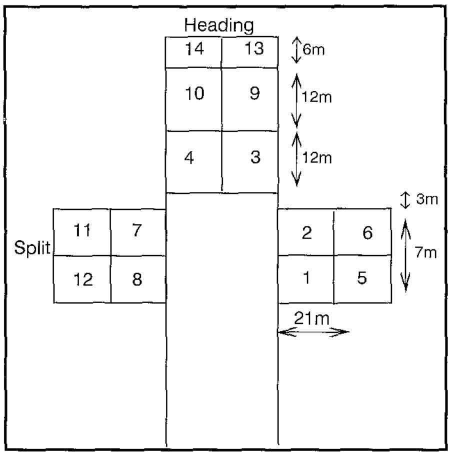

Figure 1. *12 m cutting sequence rule in a development underground bord and pillar section*

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 dust concentration in mg/m^3 was obtained at the operator's location. In order to analyze the dust concentration level at the operator during each cutting block (CB) use was made of real-time dust concentration data. From the dust concentration data for the sampling period, the real-time dust concentration data was adjusted using a correction factor. Also, from the time-study data of individual cutting block (CB) during each shift, the dust concentration levels for each CB scenario were determined. The results of the dust concentration levels during individual cutting blocks (1 to 14) were classified into cutting block (12 m and 24 m) data and cutting direction (H and S) data for four different dust control systems. Figures 2 to 5 show the relationship between cutting blocks (12 m or 24 m) and cutting direction (H or S) on dust concentration levels for four different dust control systems.

Results and discussions

Sampling results

Tables 1 and 2 provide a summary of the experimental results and show the dust concentration levels for the four dust control systems tested underground. The results were tabulated according to cutting block (12 m and 24 m) and cutting direction (heading [H] and split [S]) respectively.

The influence of the test parameters (cutting block and cutting direction) on

Statistic	System 1		System 2		System 3		System 4		Overall	
	12m	24m	12m	24m	12m	24m	12m	24m	12m	24m
Mean	4.199	6.371	1.022	1.457	5.464	7.446	8.560	12.632	4.970	6.829
Median	3.420	4.240	0.820	1.110	3.210	6.150	6.320	11.400	3.380	4.680
Variance	7.704	5.566	0.661	0.548	24.608	23.068	50.136	56.299	27.407	40.333
Minimum	0.970	1.240	0.460	0.670	1.390	3.060	2.430	2.070	0.460	0.670
Maximum	12.230	23.450	3.760	3.340	16.510	20.990	31.440	24.240	31.440	24.240
Sample Size	24	27	15	13	12	11	20	13	71	64

Table 1. *Summary statistic of cutting block (CB) dust concentration levels*

Statistic	System 1		System 2		System 3		System 4		Overall	
	H	S	H	S	H	S	H	S	H	S
Mean	5.869	4.849	1.400	1.072	7.204	5.685	11.065	8.587	6.807	4.822
Median	3.460	4.340	1.110	0.880	5.410	4.230	9.320	6.660	4.205	3.740
Variance	38.227	4.474	0.800	0.487	26.074	22.722	71.417	25.779	49.280	16.280
Minimum	0.970	2.520	0.460	0.460	3.060	1.390	2.070	3.890	0.460	0.460
Maximum	23.450	10.300	3.760	3.340	20.990	16.510	31.440	17.970	31.440	17.970
Sample Size	25	26	13	15	11	12	21	12	70	65

Table 2. *Summary statistic of cutting direction (H and S) dust concentration levels*

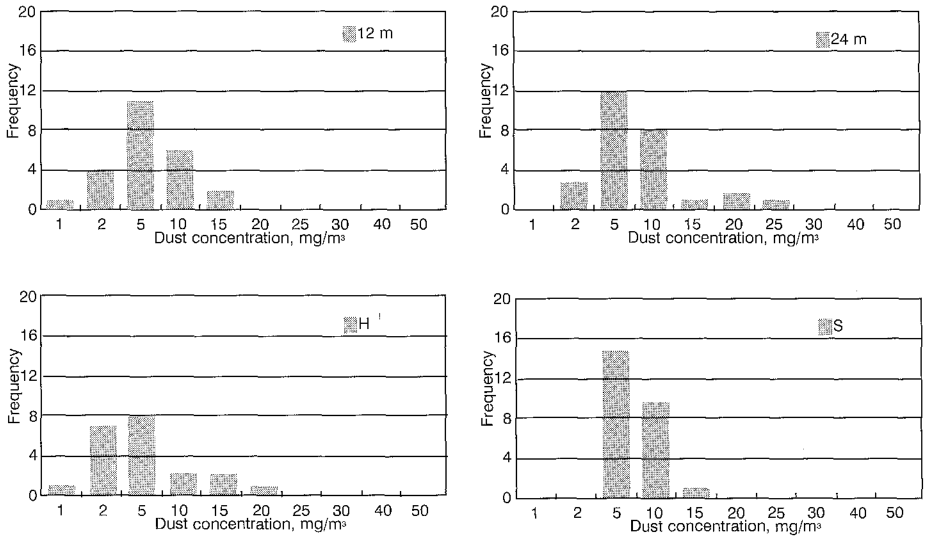

***Figure 2**. Influence of cutting block (both 12 m and 24 m) and cutting direction (both H and S) on dust concentration levels for dust control System 1.*

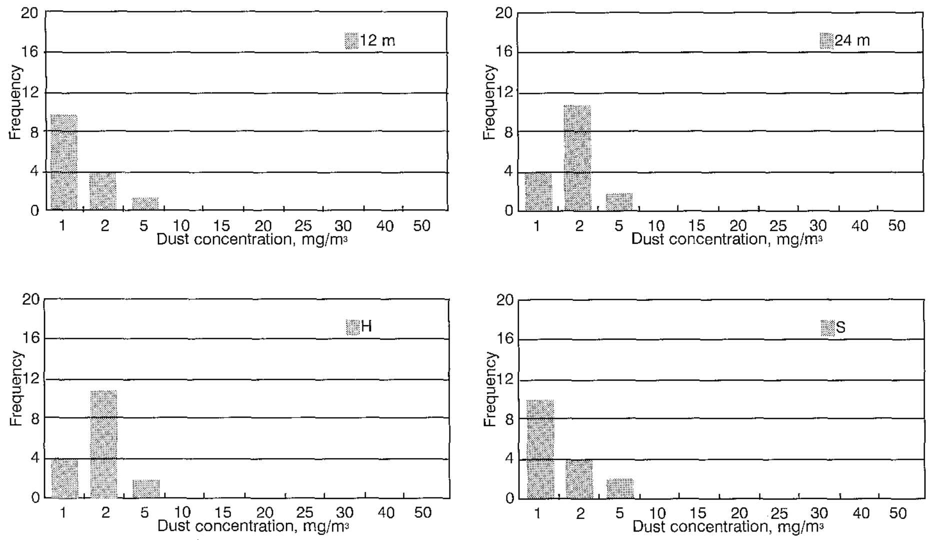

***Figure 3.** Influence of cutting block (both 12 m and 24 m) and cutting direction (both H and S) on dust concentration levels for dust control System 2.*

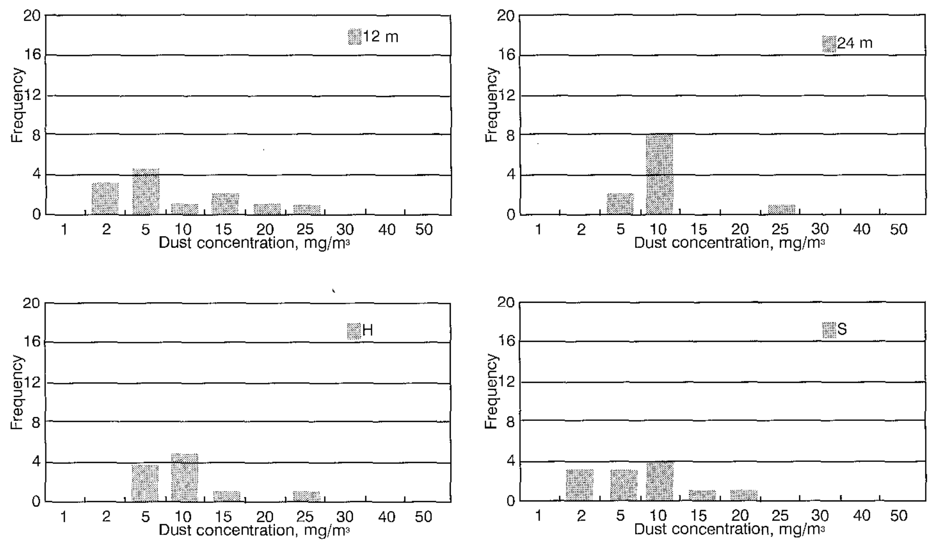

***Figure 4.** Influence of cutting block (both 12 m and 24 m) and cutting direction (both H and S) on dust concentration levels for dust control System 3.*

the dust concentration levels at the operator's position was examined by drawing scatter diagrams for the four different dust control systems.

The combined plot of the influence of cutting block and cutting direction on dust concentration levels from four different dust control systems is shown in Figure 6. From the plots the following conclusions may be deduced: -

- For each of the dust control system types, the mean dust concentration levels in the 24 m cutting blocks was higher than the 12 m cutting block
- Similarly, for the various dust control system types, the mean dust concentration levels in the headings were greater than the split
- However, for dust control system 2, the scatter was narrow and the mean dust concentration levels were comparatively lower than the other system types.
- As can be expected (see above statements) the overall plots show there is a difference between the mean dust concentration levels when the CM was cutting either headings or splits and 12 m or 24 m cutting blocks.

In order to come to a conclusive relationship and rank the significant factors that reduce the dust levels in an underground section, statistical analysis (two-sample t-test and ANOVA) was subsequently carried out

Statistical analyses

An analysis of frequency distribution of the dust concentration values for the four different dust control systems resulted in a set of histograms. The sample distributions of the histograms were not normally distributed. The histogram plots of the $\log_e$-transform of the dust concentration data lead to the conclusion that the dust levels were $\log_e$-normally distributed.

Since there was an uneven number of concentration values for pair-wise statistical comparison, a two-sample *t*-test was performed on the set of all the sample data combinations to determine if there was a statistical difference in the $\log_e$-transformed (normally distributed) concentration levels. A two-sample *t*-test of hypotheses was developed to compare the mean concentration level

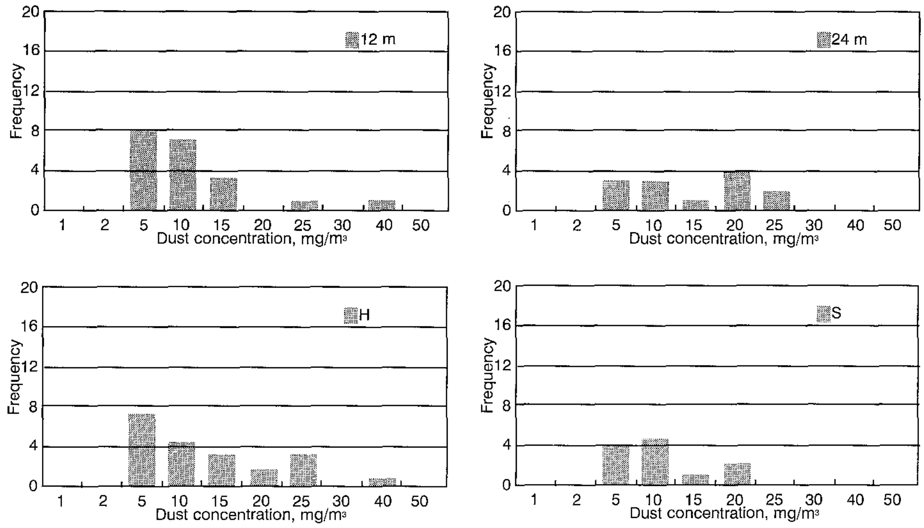

Figure 5. *Influence of cutting block (both 12 m and 24 m) and cutting direction (both H and S) on dust concentration levels for dust control System 4.*

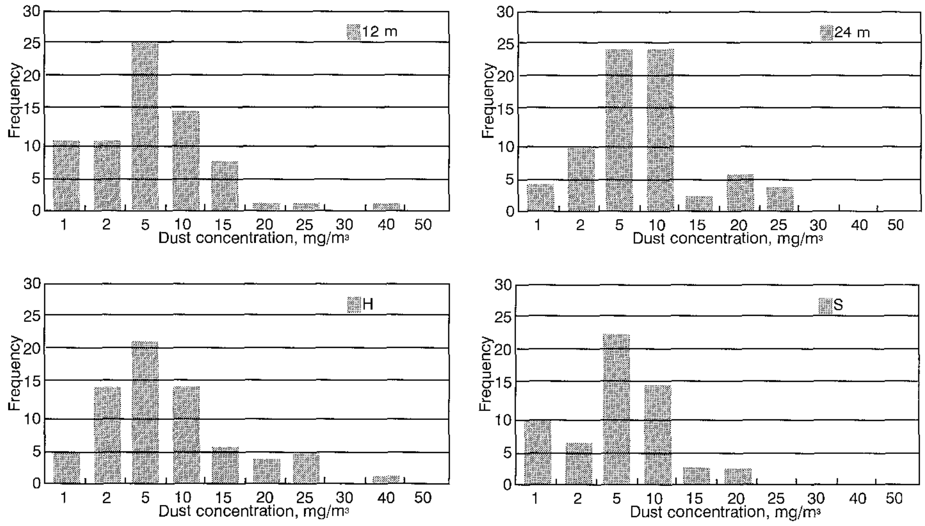

Figure 6. *Combined plot of the influence of cutting block (both 12 m and 24 m) and cutting direction (both H and S) on dust concentration levels for various dust control systems.*

measured between the test parameters (μA and μB). The null and alternative hypothesis for the tested sample pairs were:

H_0: $\mu_A = \mu_B$

H_1: $\mu_A \neq \mu_B$

In the two-sample *t*-test, hypothesis H_0 states that the mean dust concentration levels between test parameters (μ_A and μ_B) are equal. On the other hand, the alternative hypothesis states that the test parameters in fact have different mean concentration levels. It is therefore necessary to use hypothesis testing to accept or reject H_0. For the analysis, a standard 95% confidence level was chosen. As the hypothesis stated were $\mu_A = \mu_B$ and $\mu_A \neq \mu_B$, all analyses were two tailed to account for both conditions $\mu_A<\mu_B$ and $\mu_A>\mu_B$. Hypothesis tests were carried out on each of the test parameters in terms of cutting block (12m and 24 m) and cutting direction (heading and split) for individual dust control systems as well as the overall system.

Results of the two-sample *t*-test statistical analyses are given in Tables 3 and 4. The p-value represents the probability of making a Type 1 error, which is rejecting the null hypothesis when it is true. In this study a cut-off p-value of 0.05 was used (95 % confidence level).

From the analysis table, we observe that with various degrees of freedom, the large p-value (> 0.05) suggesting that the measured mean concentration levels are consistent with the null hypothesis, H_0: $\mu_A = \mu_B$, that is, the dust concentration levels between the test parameters are not affected at 95 % level of confidence.

From Table 3, it can be observed that, for individual dust control systems as well as for overall dust control system, *t*-statistic C_{12}-C_{24} (concentration C at 12m-concentration C at 24 m) was negative confirming that the mean dust concentration levels during 24 m cutting block were generally greater than the mean dust concentration level from the 12 m cutting block. However, the null hypothesis was rejected (small p-value, < 0.05) for system 2 and this does not hold true for the system 1, 3 and 4, where there was no significant difference between the concentration values obtained for the 12 m and 24 m cutting blocks at the 95 % confidence level.

A two-sample *t*-test was performed on all the data to determine if there was a statistical difference in the concentra-

	System 1		System 2		System 3		System 4		Overall	
	12m	**24m**	**12m**	**24m**	**12m**	**24m**	**12m**	**24m**	**12m**	**24m**
Mean	1.241	1.570	-0.149	0.275	1.364	1.882	1.916	2.313	1.158	1.512
Std Deviation	0.646	0.743	0.546	0.455	0.830	0.484	0.657	0.766	0.981	0.943
Sample Size	24	27	15	13	12	11	20	13	71	64
P - Value	0.100		0.036		0.085		0.120		0.035	
t - statistic	-1.680		-2.220		-1.810		-1.590		-2.130	
Hypothesis	Accept H_0		Reject H_0		Accept H_0		Accept H_0		Reject H_0	

Table 3. *Results of two-sample t-test hypothesis (on transformed values)*

	System 1		System 2		System 3		System 4		Overall	
	H	**S**	**H**	**S**	**H**	**S**	**H**	**S**	**H**	**S**
Mean	1.325	1.501	0.173	-0.061	1.816	1.425	2.112	2.003	1.420	1.219
Std Deviation	0.939	0.390	0.588	0.491	0.549	0.830	0.806	0.556	1.030	0.907
Sample Size	25	26	13	15	11	12	21	12	70	65
P - Value	0.380		0.260		0.200		0.680		0.220	
t - statistic	-0.880		1.150		1.320		0.420		1.220	
Hypothesis	Accept H_0		Accept H_0		Accept H_0		Accept H_0		Accept H_0	

Table 4. *Results of two-sample t-test hypothesis (on transformed values)*

tion levels between two parameters (cutting direction and cutting blocks) for the overall dust control system. The result of the two-sample *t*-test was a test statistic with 133 degrees of freedom, and p=0.035 confirming that there is a significant difference between measured dust concentration levels when the CM was cutting the 12 m and 24 m cutting blocks.

From Table 4, it can be observed that except for System 1 (half-curtain system), *t*-statistic C_H-C_S (concentration C in heading [H] - concentration C in split [S] was positive indicating that the mean dust concentration levels in the heading (H) were generally greater than the mean dust concentration levels in a split (S). Further, the null hypothesis was accepted (large p-value, >0.05) for the individual dust control systems as well as for the overall system confirming that there was no significant difference between the mean concentration levels in a heading (H) or a split (S) at 95 % confidence level.

Analysis of variance (ANOVA)

The dust concentration data were also used to perform an analysis of variance (ANOVA). In order to statistically quantify the influence of cutting blocks (CB), cutting direction and type of dust control systems on the dust concentration levels in the section, a factorial analysis was carried out. Essentially the airborne dust concentration at the operator's data that was used was in the form of C_{ijk} (mg/m^3). The subscripts have the following definitions:

i = cutting block (CB), i = 1 is a 12 m cutting block, i = 2 is a 24 m cutting block

j = cutting direction, j = 1 is a heading (H), j = 2 is a split (S)

k = dust control system, k = 1, 2, 3, and 4 respectively indicate the half-curtain dust control system, retrofitted hood system, double scrubber and integrated hood system respectively.

The results of analyses of variance (ANOVA) on the data are summarised in Table 5. The main factors of the statistical analysis were: dust control system type; cutting direction; and cutting block (CB). The ANOVA table gives, for each term in the model, the degrees of freedom (Df), the sums of squares (SS), the adjusted means squares (MS), the F-statistic from the adjusted means squares, and its p-value. In the ANOVA table, some p-values were less than 0.05, indicating that these factors are significant.

From the results of ANOVA, the following conclusions can be deduced:

- Effect of dust control system type on the dust concentration levels is highly significant with a mean square (MS) value of 407.43.
- There is a slight evidence (p – value of 0.017) of the effect of cutting block (12m and 24 m) on dust levels recorded at the operator's position during the coal cutting operation for various dust control systems (the MS value for the cutting distance is 147.78).
- The effect of cutting direction (heading or split) on the results of dust concentration levels at the operator's position is insignificant with a p-value of 0.236.
- From the magnitude of each test parameter the dust control system and cutting block can be placed in a descending order of importance. As we note from the table, the dust control system has a pronounced effect on the dust concentration levels (p-value of 0.000 and highest MS value of 407.13).
- The following two-factor interactions viz., cutting distance×cutting direction, cutting distance×dust control system type, cutting direction×dust control system type in the analysis are statistically insignificant. Also, three-factor interaction effect, dust control system type×cutting direction×cutting distance do not have significant effect on concentration levels at the operator's position.
- Finally, the main factors, such as dust control system type and cutting distance (to some extent) influencing the dust concentration levels at the operator's position are well demonstrated.

Sources of Variation	Df	SS	MS	F value	Pr > F
A (Cutting Distance: 12m or 24m)	1	147.78	147.78	5.82	0.017
B (Cutting Direction: Heading or Split)	1	35.97	35.97	1.42	0.236
C (Dust Control System Type)	3	407.43	407.43	16.04	0.000
A*B	1	15.78	15.78	0.62	0.432
A*C	3	63.53	21.18	0.83	0.478
B*C	3	23.83	7.94	0.31	0.816
A*B*C	3	15.50	5.17	0.20	0.894
Error	119	3022.67	25.40		
Total	134				

Table 5. *Results of Analysis of Variance (ANOVA)*

Conclusions

Although recent international analyses of the incidence of pneumoconiosis show favorable trends, the latest studies by British scientists and by NIOSH indicate that the risk of developing the most serious form of CWP at the current exposure level standard (2 mg/m^3) is higher than had been previously believed. However, Australian researchers have reported that they have no evidence of CWP at levels greater than the 2.0 mg/m^3 standard (US Federal Register, 1995).

Previous studies have shown that the risk of progression to a higher category of pneumoconiosis due to coal dust exposure increases with increasing intensity of the exposure, represented by the mean dust concentration (Jacobsen et al., 1970, 1971), and with increasing cumulative exposure, represented by the product of intensity and duration (Jacobsen, 1973, 1979). Therefore, from this study we can indirectly deduce that a worker positioned inside the cabin of a CM during the cutting of a 24 m block is usually at higher exposure risk than the worker when cutting a 12 m block. Based on the mean dust concentration results, the miner who is operating in a heading is exposed to more dust than when operating in a split position.

From this study, a dust exposure level chart based on dust levels during coal cutting operations in a section can be shown pictorially (Figure 7) and an index of approximate exposure of workers present in the working face are summarized in Table 6. The plot

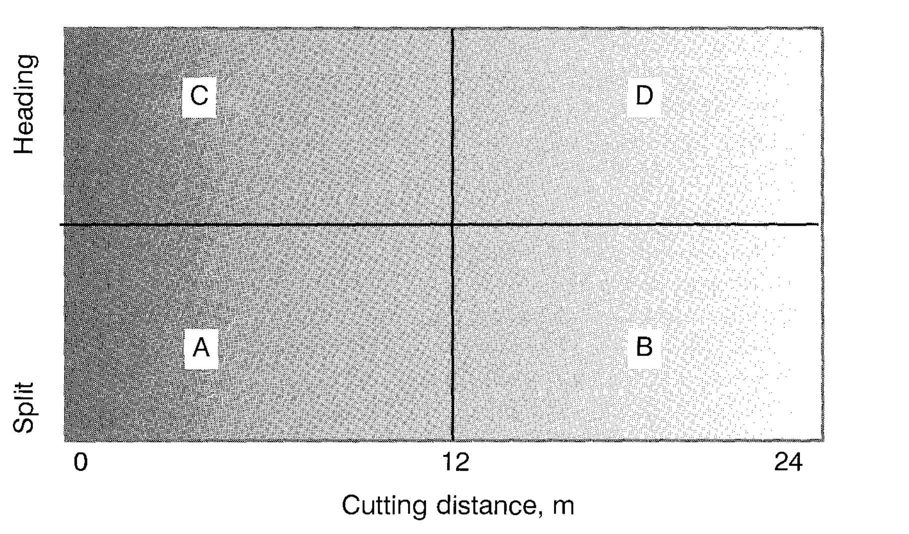

Figure 7. *Dust exposure level index chart based on cutting direction and cutting distance*

Exposure Parameter	Code	Descriptor
Split-12 m	A	Good
Split - 24m	B	Unhealthy to Hazardous
Heading - 12 m	C	Good
Heading - 24 m	D	Unhealthy to Hazardous

Table 6. *Dust exposure level index based on cutting distance and cutting direction*

shows in the x-axis cutting distance for a length up to 24 m and y-axis representing cutting direction (split or heading). The cutting distance was limited to 24 m as face ventilation becomes totally ineffective beyond 24 m hence dust level will be very high.

Finally, the analysis of the dust concentration results at the operator's position indicated that the mere application of the 12 m rule on its own does not solve the dust problems, but that meticulous and regular maintenance, together with the application of available state-of-the-art dust control technologies, effective dust control strategies and best practices, ensures the reduced workers exposure. The introduction of remotely controlled cutting operation in the section may effectively lower the duration, severity and intensity of workers' exposure to coal dust. The authors strongly believe that the use of the cutting block (CB) distance is one of the most important and easily controlled parameters in assessing the worker exposure to coal dust. As an administrative control measure for effective dust exposure control, the mine environment officers, occupational hygienists and mine management can effectively use this information by rotating the CM operators during the working shift so that a particular CM operator is not constantly exposed to the higher levels of coal dust.

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