Chapter 2

REVIEW OF DUST CONTROL AT LONGWALL FACES

2.1 INTRODUCTION

Ever since dust has been identified as principal agent in the development of a disease known as 'pneumoconiosis' there has been a growing interest in the development of dust control techniques in coal mines. Allowable dust concentration standards continued this trend, with many dust control methods and operating practices being developed over the past 30 years to reduce miners' dust exposure on longwall faces. Although significant progress has been achieved, respirable dust exposures on longwall faces are significantly higher than in other mining environments, and the problem of containing dust concentration to acceptable levels continues to impede progress towards realizing the full potential of the longwall mining method. Recent longwall mining trends, including higher production levels and longer face lengths, are placing even more stringent demands on dust control.

Although there is extensive scientific and technical literature which addresses dust control measures, few studies have sought to define the spatial and temporal variability of the respirable dust concentration gradients in longwall faces. A U.S. National Academy of Sciences study (Cook et al, 1980) concluded that "improvement in dust control research was obtained principally through the adoption of existing technology, but continuation along these lines is likely to yield diminishing returns. Research should be directed more toward obtaining fundamental understanding of the origin, transport and characteristics of respirable coal mine dust".

In addition, very few attempts have been made either to supplement the field investigations of dust control techniques with numerical simulations or to use mathematical modelling techniques for a better understanding of the airflow characteristics or respirable dust behaviour around the shearer in a longwall face. In view of the enormous progress over the last two decades in other fields, in computer hardware and software technology and in the understanding of airflow and aerosol dispersion systems, it would appear that there is an opportunity for the introduction of new and innovative ideas into dust control technology.

2.2 RESPIRABLE DUST STANDARDS

Respirable dust is defined as the dust which penetrates to the alveolar regions of the lungs. Due to the size-selective nature of the particle removal mechanisms in the nasal passages and lung airways, the criteria defining respirable particles must be a function of the particle size. At present, two criteria are accepted for defining the respirable dust, both approximating the dust deposition in the nonciliated portions of the lung. The first, resulting from work performed by the U.S. Atomic Energy Commission (AEC), is defined by the curve labelled AEC in Figure 2.1. The other criterion for the respirable fraction of dust, recommended by the British Medical Research Council, is defined by the sampling efficiency curve labeled BMRC in Figure 2.1. The pulmonary deposition curve is also shown in Figure 2.1. Particle sizes refer to equivalent diameter, which is defined as the diameter of a spherical particle of unit density having the same falling velocity as the particle in question.

Lung diseases have held the attention of scientists for well over 400 years. Agricola discussed the consequences of dust trades in his 1556 publication De Re Metallica. He understood that the lethal lung diseases resulted from working in mines. The term

Figure 2.1 Comparison of respirable dust criteria and pulmonary deposition (after Morse, et al, 1970).

'pneumoconiosis' was introduced by Zenker in 1867 for the first time (Ulmer, 1988). Bedford and Warner's report (1944) was a major turning point in our understanding of the impact of inhaled coal dust and of dust control in mines. This report stipulated the adoption of airborne dust concentration standards in coal mines. The Particle Number Standards, introduced in Britain in 1949, remained basically the same until 1970, when gravimetric standards were introduced. The International Pneumoconiosis Conference held in Johannesburgh in 1959 (Orenstein, 1960) was a milestone in that it recommended that dust measurements should be made by gravimetric methods. As a result, in the late 1960's, many major coal producing countries adopted gravimetric respirable dust standards in their coal mines in an effort to control the disease.

Prior to establishing the coal mine dust standards, extensive epidemiological investigations were conducted to ascertain the exact mechanism of pneumoconiosis and to estimate the disease risk levels associated with different levels of dustiness. In

England, 25 pits were studied over a period of 10 years to provide the data base for epidemiological studies (Jacobson et al, 1970; 1971; 1972; Jacobson, 1988). The German studies took place in ten coal mines over a 10 year period (Reisner, 1976). The studies suggested a close correlation between the degree of disease contracted and the mass of coal dust accumulated in the lungs. Based on these studies, a U.S. Committee on Education and Labor (1970) has reported that at 7.0 mg/m^3, the rate of development of simple pneumoconiosis per 1,000 miners, after 35 years' exposure, would be 360 (36%); at 4.5 mg/m^3 the expected rate would be 150 (15%); at 3.0 mg/m^3 the expected rate would be 50 (5%); and at 2.0 mg/m^3 the expected rate would be 20 (2%). This shows that the probability of developing simple pneumoconiosis decreases with decreasing dust concentration. The respirable dust standards in different countries are shown in Table 2.1.

Table 2.1 Dust standards in different countries
(after Prinz and Stolz, 1988)

S.No	Country	Tolerable limit (mg/m^3)	Measuring strategy /Location
1	Germany	8.0	fixed point on the face - near the return end
2	USA	2.0	personal sampling
3	UK	8.0	fixed point in the return - 70 m away from face
4	Russia	2.0	fixed point sampling 10 m behind the shearer
5	Australia	3.0	personal sampling
6	France	I = 3.22 log Ct - 10.6	C = dust conc. in ppcc t = percentage of quartz 10.6 = correction for soluble filters
7	Poland	1500 ppcc 500 ppcc	- without incombustibles - incombustible > 70%

8	India	3.0	fixed point near the return end of the face

Because of an increased health risk associated with exposure to quartz, the dust standard in all the above cases decreases if the quartz content of the sample is more than 5%.

Absolute values of respirable dust concentrations obtained from different countries or from different locations are not suitable for a comparison unless the sampling strategy is also included. For example, in Germany, the respirable dust concentration has to be measured where the maximum concentration is expected, i.e at the return end of the face. In the U.K., the values at a fixed measuring point, located in the return airway approximately 70 m behind the face, are used to assess the dust conditions at the face. The reasoning for this location is that it is only there that the measuring results are no longer influenced by the coarse dust or the unequal distribution of the respirable dust. Corrections are used to account for deposition of dust before the measuring point. The measuring strategy in Russia focuses on monitoring dust suppression at the face. When cutting coal with the shearer, the airborne dust concentration, with particles up to 74 μm, is measured directly behind the shearer. The measuring strategy in the USA and Australia provides for a measurement of the respirable dust concentration by means of personal dust samplers directly within the employee's breathing zone. This is normally achieved by placing the samplers on the left upper side of the chest, and over the left-pocket.

The dust control measures applied in the different countries depends on their measuring strategies. The measuring strategies of Germany, U.K, and Russia call for control techniques which reduce the dust concentration in the entire return air section. In the U.S.A. and Australia, dust control measures focus on reducing miners' dust exposure. This becomes particularly clear in the shearer clearer (section 2.5.5) control technique in which dust produced by the shearer is kept away from the operators.

2.3 LONGWALL AND DUST CONDITIONS IN AUSTRALIA

2.3.1 Longwall method

The longwall mining method was introduced in Australia in the 1960's and it is now the predominant trend in underground mining. In 1992, 162 million tonnes of coal was produced in Australia from 124 mines, of which 73 were underground mines and 51 open-cuts. Longwall faces produced 27 million tonnes of raw coal which represented 45% of the total underground coal production (JCB, 1991-92a). The share of longwall in underground coal production in New South Wales, Australia, is shown in Figure 2.2. At present, there are 24 longwall faces in operation in 23 mines, 20 of which are in New South Wales and the remainder in Queensland. Thus, longwall faces are producing an increasing percentage of the output from underground mines, with several longwall faces consistently producing over 6,000 tonnes per day. However, this increase in production has also increased the dust problem.

Figure 2.2 Increase in share of longwall face production during the past 10 years in New South Wales, Australia (after JCB, 1991-92b).

2.3.2 Respirable dust regulations

Dust sampling was introduced in NSW in the mid 1930's. Early dust measurement results varied widely between different collieries and different activities in the same mine, reflecting largely differences in ventilation, watering and stone dusting practices. In 1939, a Royal commission conducted by Mr. Justice Davidson enquired into the safety and health of workers in coal mines. As a result, regulations to control dust levels were developed, but were not proclaimed until 1943 (Hewitt, 1990b).

Early dust measurements were based on a particle count and were expressed as particles per cubic centimetre (ppcc), with Owens' dust pump as the designated measuring instrument. The maximum allowable limit was 175 ppcc with less than 10% free silica in the 0-5 micron size. A study by Philips (1983; 1984) found that 175 ppcc is equivalent to approximately 3.15 mg/m^3. In 1984, the mandatory dust standard was changed from 175 ppcc to 3.0 mg/m^3 of respirable dust other than dust containing quartz. Quartz containing dust is that which contains more than 5% quartz, in which case the maximum mandatory limit reduces, depending on the total amount of quartz present.

2.3.3 Respirable dust conditions

Respirable dust samples are regularly taken by the JCB and the results are shown in Table 2.2 - 2.3. These results show that some coal mines are more prone to high levels of dust generation than others. Analysis of the results shows that 40% of the samples collected from mines working the Bulli seam of the Southern district of NSW exceeded the statutory level of 3 mg/m^3 (see Table 2.3) compared to 5% in the Northern / Western district mines. This is because the inherent moisture in the Bulli

Table 2.2 Typical shift average dust exposures of longwall operators in Australia, over the past 4 years (samples collected by JCB, 1984 - 92).

S.No.	Dust level (mg/m^3)					
	Southern district		Northern district		Western district	
	Face 1	Face 2	Face 1	Face 2	Face 1	Face 2
moisture	1.0	1.1	2.2	2.1	2.5	2.4
Hardgrove Grindability Index	76	69	51	54	41	45
1	4.80	2.70	1.23	2.68	2.23	2.08
2	7.90	2.95	1.46	2.34	1.51	2.77
3	3.63	1.81	2.58	1.92	2.15	1.35
4	7.05	4.21	2.03	2.57	2.42	1.80
5	4.06	3.46	1.10	1.38	2.86	0.98
6	3.42	5.08	1.69	1.59	3.19	1.20
7	2.74	3.04	3.52	1.10	1.25	1.37
8	6.10	5.77	2.11	1.98	2.31	3.49
9	5.80	2.10	2.52	3.47	1.29	1.15
10	5.40	3.36	2.39	2.86	1.41	1.96
11	3.30	4.34	2.75	2.51	1.75	1.17
12	2.39	2.80	2.46	2.92	1.63	2.13
13	4.05	3.77	1.81	3.20	1.55	2.05
14	2.21	4.51	1.54	1.47	2.72	2.35
15	6.65	2.15	3.38	2.68	1.76	1.85
16	4.81	2.97	2.63	1.70	2.30	2.90

Table 2.3 Dust compliance record of longwall faces in Australia (Hewitt, 1990a).

Face	First sample	Last sample	No. of samples	% Compliance
1	12-04-84	02-02-90	20	85
2	17-05-84	31-01-90	31	19
3	10-02-86	17-10-89	16	88
4	04-02-86	29-11-89	18	83
5	14-11-84	09-02-89	17	94
6	26-02-87	23-11-89	8	62
7	06-09-84	14-03-89	26	88
8	08-05-84	28-09-89	62	34
9	20-03-87	06-02-90	20	80
10	24-08-84	20-03-89	27	52

11	10-04-84	22-02-90	30	20
12	27-06-89	13-02-90	8	25

seam is about 1%, compared with Newcastle at approximately 2.1%, and Lithgow 2.4% (Hewitt, 1984-92). The methane drainage operations in the Bulli seam also extract moisture from the seam, reducing it to about 0.4%. Another important contributing factor for high dust levels in the Bulli seam is its high Hardgrove Grindability Index. Figure 2.3. shows the results of an extensive dust survey carried out by JCB at three Queensland longwall faces, which shows that the dust levels exceed the statutory limit when coal production is over 7 000 tonnes/day.

Figure 2.3 Increase in dust level with production in longwall faces (after Bell et al 1993a).

2.4 FUNDAMENTAL STUDIES

2.4.1 Dust sources

Potential dust sources in a typical longwall face are shown in Table 2.4 and Figure 2.4. As can be seen, there are a variety of dust sources on longwall faces (Kost, Yingling and Mondics, 1981). The relative contribution of each source to the overall airborne dust concentration may vary from one face to another. To develop any dust control technique, it is necessary to know the dust generation from each source. Many studies (Mundell et al, 1980; Bradley, Hadden and Dodgson, 1983; Olson, 1984; Jankowski and Organiscak, 1983a; Page, Jankowski and Kissell, 1982; Jankowski, Organiscak and Jayaraman, 1991) have been conducted to identify and quantify dust sources in a longwall face using short term gravimetric sampling. Five primary dust sources were identified: intake dust, dust generated by coal transport and the stage loader, dust generated by the shearer during the cutting pass, dust generated by the shearer during the clean-up pass and dust generated during the movement of supports. Table 2.4 and Figure 2.5 show the percentage contribution of each source to the total respirable dust exposure of the shearer operators.

Table 2.4 Dust sources analysis (after Jankowski and Organiscak, 1983a)

		Mine A	Mine B	Mine C	Mine D	Mine E	Mine F
s.n.	Source	%	%	%	%	%	%
1	Intake	1	5	5	5	9	8
2	stage loader	25	57	19	20.5	64	13
3	supports	10	31	1	1	0	29
4	shearer - cutting	60	10	28	53	15	50

5	shearer - cleaning	4	7	47	20.5	12	0

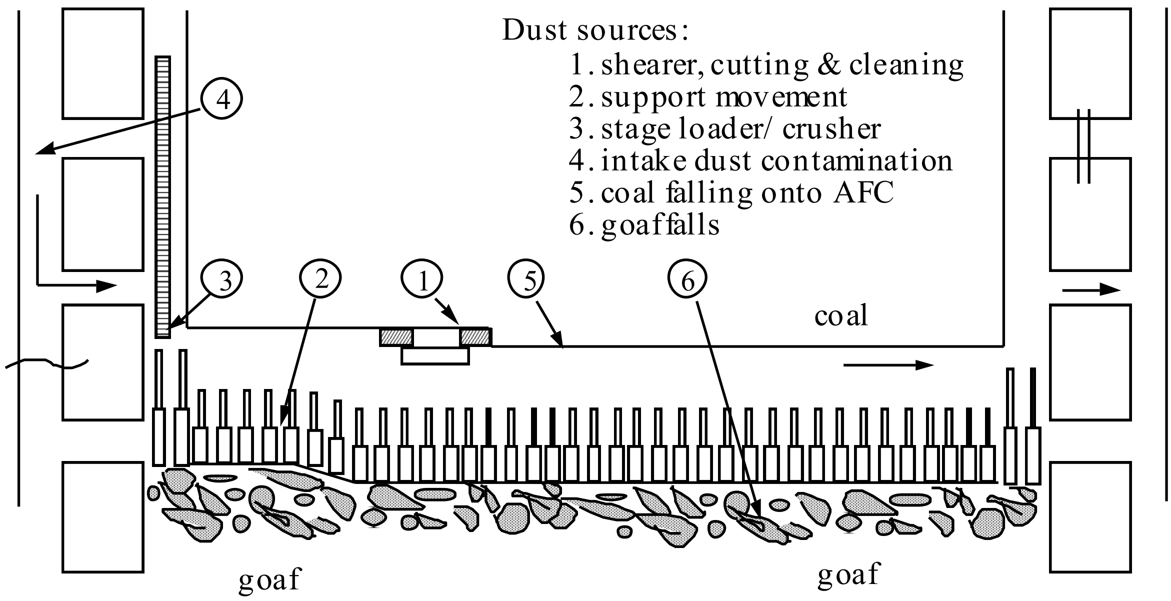

Figure 2.4 Dust sources on a typical longwall face

Figure 2.5 Average percentage contribution of the three major sources of dust in a longwall face (after Foster Miller Associates Inc., 1982).

Although, in most instances, the shearer is the major primary dust source, secondary sources in particular the stage loader and support movement also contribute a significant proportion of the total respirable dust. Additional dust sources in some longwall faces include face spalling and caving material falling behind the chock shields. In estimating the effectiveness of machine mounted dust control devices, such as water sprays or scrubbers, it is useful to have an estimate of the total quantity of respirable dust produced during the face operations. Studies by Mundell and Taylor (1977) showed that the respirable dust make from a longwall face varied from 1000 mg to 5000 mg per tonne of coal production. Therefore, in a longwall face producing 10,000 t/day, the total quantity of respirable dust produced amounts to between 10 and 50 kg/day.

2.4.2 Coal characteristics and dust generation

It has been determined that inherent rock properties do influence dust formation (Das, 1973). Panov (1967) similarly concluded dust formation to be a function of the composition, hardness and moisture content of the rock. Another study by Baafi and Ramani (1979) investigated the effect of rank of coal on the generation of dust and concluded that the respirable dust content of coal samples increases as the rank of coal decreases. According to Skochinsky and Kamarov (1969), drilling in hard rock results in the production of large quantities of fine dust.

Moore and Bise (1984) concluded that the Hardgrove Grindability Index of a rock affects dust formation and more recently, Guyaguler (1991; 1993) concluded that the hardness and the brittleness:toughness ratio of a rock are the properties that most significantly influence dust generation (Figure 2.6). Khair and Xu (1991) also concluded that coal with a higher grindability index has high dust concentration coefficients. Evaluation of Pennsylvania and West Virginia data confirmed that there is a very good correlation between the Hardgrove Grindability Indices of coals and the

Figure 2.6 Dust-producing index as a function of brittleness:toughness ratio for different values of rock hardness (after Guyaguler, 1991).

prevalence of coal workers pneumoconiosis (Mutmansky and Lee, 1984; Ting, 1988). These studies showed that the Hardgrove Grindability Index is a good indicator of the prevalence of CWP because it encompasses many dust generating factors such as rank, ash content, petrographic composition and other factors yet to be isolated.

Large quantities of respirable size dust particles are formed and liberated by the fracture process. A study by Cheng and Zukovich (1973) found that a surprisingly large amount of respirable particles adhere to the broken coal. Their studies revealed that between 10^{11} and 10^{12} respirable dust particles cling to the surface of each pound (0.45 kg) of coal; approximately 3.6×10^7 respirable dust particles adhere to each square centimetre of the surface of broken coal. At this rate, 0.45 kg of broken coal would be sufficient to contaminate 30 m^3/s of air at a level of 3 mg/m^3.

Fortunately much less than 1% of these respirable size particles ever become airborne.

Most of the earlier research on dust generation focused on developing empirical correlations between machine operating parameters such as depth of cut, rotational speed, tool geometry and airborne respirable dust concentrations near a cutting tool. Evans and Pomeroy (1966) and Pomeroy (1968) presented their extensive work on the mechanical properties of coal and on the analysis of the design of coal mining machines. The empirical relationship established led to design recommendations for cutting machines and wedge type bits.

The effect of different types of shearer bits on coal cutting forces and dust generation has been well researched (Roepke and Voltz, 1983; Bartholomae and Becker 1983). Strebig and Zeller (1975) found that bit type did not significantly effect dust production, whereas cutting depth was very significant. Zipf and Bieniawski (1989) have applied fracture mechanics principles in their study and proposed that a mechanism for fine fragment formation involves four steps: (i) development of a crushed zone under the tool tip, (ii) macrocrack propagation, (iii) shear movement along macrocracks, and (iv) additional fragmentation from shearing. The dust generation mechanism involves two sources of fine fragments, namely crushing under the tool tip and shearing along the macrocrack surfaces. A review by the U.S. National Academy of Sciences (Cook, et al, 1980) concluded that our present knowledge of the fundamental mechanisms of coal dust generation and entrainment is very meagre and not sufficient to clarify, let alone control, the processes involved.

2.4.3 Air velocity and dust distribution profiles

Studies conducted in four U.S. longwall faces indicated that a significant amount of air leaks into the goaf (Figure 2.7), and that air velocity distribution at the face varies from mine to mine (Peng and Chiang, 1984a; 1986; Ramani, Qin and Jankowski, 1991).

Figure 2.7 Air quantity distribution along a longwall face (after Peng and Chiang, 1986).

Air velocity distribution along and across the longwall face were presented and visual observations were made on the influence of shearer movement on air velocity distribution. The study found that leakage into the goaf resulted in less dilution of airborne dust and affected the spatial distribution of dust. Air measurements made in Australia by Liu (1991) showed that in some cases, air leakage into the goaf was insignificant, particularly when a 'U' type ventilation system was used.

In addition to understanding air velocities, it is necessary to know airborne dust concentration distribution at the longwall face in order to effectively prevent or reduce the miners' respirable dust exposure. Many gravimetric and instantaneous sampling surveys have been conducted to pin-point dust sources and to evaluate the effectiveness of various dust control measures (USBM, 1982a; 1982b; Organiscak, Listak and Jankowski, 1985; Scott, 1984). These studies showed dust concentration profiles along the face and around the shearer with, and without, the dust control measures. However, all these studies only presented dust concentration profiles along the face. They were constructed from dust data measured either over the AFC or over the Bretby cable handler along the face. Dust concentration distribution across the face, i.e. at right angles to the face line, an important factor in the development of dust control techniques, was not presented.

The dispersion, transportation of the entrained dust and the variation of respirable dust concentration along and across a longwall face has also been studied by Chiang et al (1984; Chiang, Luo and Peng, 1987), using instantaneous sampling instruments. The dust distribution profiles were found to be somewhat similar to those of the air velocity distribution profiles along the longwall face. The high dust concentration zone was located above the armoured face conveyor, and the dust concentration in the walkway area was usually lower except during support advance. An example of respirable dust concentration distribution around the shearer is shown in Figures 2.8 and 2.9.

Figure 2.8 Dust distribution map in a longwall face on horizontal plan at 0.9 m above the floor (after Chiang, Luo and Peng, 1987).

Figure 2.9 Dust concentration at no.50 support position (after Liu, 1991).

2.4.4 Size distribution and dust deposition

Studies on size distribution of respirable dust in coal mines (Dumm and Hogg, 1987; Bhaskar, Ramani and Jankowski, 1988; Mutmansky and Xu, 1989; Rubow, Cantrell and Marple, 1988) suggest that airborne respirable dust does follow some size distribution relationship. When the log of the fraction smaller than a certain size is plotted against the log of that size, the result is a straight line. These studies also indicate that size distributions vary considerably from one source of dust to another.

Laboratory and field investigations showed that the dust deposition rate decreases exponentially with distance from the source (Bradshaw, Godbert and Leach, 1954; Ontin, 1965). Courtney, Kost and Colinet (1982) conducted extensive studies in eight U.S. mines and found that the rate of dust deposition in the roadways depends upon the concentration of airborne dust and decreases exponentially with distance from the dust source. The study also found that the rate was seemingly independent of the size of the airborne dust particles. Dust deposition studies in mine airways have also been performed by Bhaskar (1987), with the results showing that dust concentration declines sharply within the first 100 m of the source and the deposition rate depends on dust particle size, concentration and air velocity.

2.5 DUST CONTROL METHODS

Many types of dust control measures have been developed to reduce dust generation during cutting, minimise its entrainment, extract and collect airborne dust, and prevent its dispersion to work locations. Different methods of operation to keep workers away from dust have also been adopted. Some methods are more effective than others, but there is no single control technique that can adequately control the dust at all times in all mining operations. The industry must therefore continue to use several controls simultaneously and to continuously refine and advance them to lower dust levels, so as to comply with regulation standards.

2.5.1 Ventilation

Ventilation is one of the principal methods used to control dust on longwall faces. Increasing the air quantity through the face reduces the respirable dust concentration at a longwall face by diluting it. Extensive research has been done over the years to determine the relation between air velocity and dust concentration in coal mines (Hall, 1960; Hodkinson, 1960). Their experiments found that 300 fpm (1.5 m/s) was the optimum air velocity in coal mine roadways.

Studies in the U.S. show that face air velocities of 350 to 450 fpm (1.8 to 2.5 m/s) appear to be the most appropriate for longwall dust control (Mundell et al, 1980; Jankowski and Kissell, 1983; Kelly et al, 1990). The effect of air velocity on the shearer operator respirable dust exposure is shown in Figure 2.10. This figure shows that an increase in the face velocity up to 450 fpm (2.5 m/s) decreases the shearer operators' dust exposure, but beyond that the dust concentration increases due to higher entrainment of dust on the face. Above 4 m/s the problem is not so much a health hazard as it is the physical discomfort of large particles striking the skin. According to German studies (Breuer, 1972; 1983) the optimum velocity may be increased to 700 to 900 fpm (3.5 to 4.5 m/s) when the moisture content of the dust particles is more than 6% (Figure 2.11).

However, an analysis of a large amount of respirable data from U.S. longwall faces does not confirm this conclusion, and does not show any correlation between operators' dust exposures and face air velocity (Foster-Miller Associates, Inc., 1982). Underground observations by the present author in two faces, working the same coal seam under similar conditions, with different velocities (1.9 m/s and 4 m/s), showed that the dust concentration in the face with the high face air velocity was less than that at other face. Recent studies (Tomb, 1992) have also confirmed that as face air velocity increases beyond 5.1 m/s, dust levels along the face decrease.

It should be noted that all of these air velocity *vs* dust concentration studies were carried out without a shearer clearer. These results show an increase in dust concentration at the shearer operators' position with an increase in air velocity. However, with the shearer clearer, the optimum face velocity may be increased beyond 2.5 m/s, and with modern slow speed drums which allow high water flows through them, air velocity may be increased up to 5 m/s.

Figure 2.10 Relationship between face air velocity and dust levels at the face (after Mundell et al 1980).

Figure 2.11 Effect of moisture content on optimum air velocity for minimal dust levels (after Breuer, 1972).

Goaf curtain

Studies have shown that a significant amount of air leaks into the goaf near the main entry (Shirey, Colinet and Kost, 1985; Peng and Chiang, 1986) and this results in less dilution of dust at the face. A 'goaf curtain' (Figure 2.12), installed from roof to floor between the first support and the adjacent rib on the gallery, forces the airflow to stay on the face side, rather than leaking into the goaf. During underground trials, the average face air velocity was 35% greater with the curtain than without it (Jayaraman, 1981b; Niewiadomski, Jankowski and Kissell, 1982; Jankowski, Kissell and Daniel, 1986).

Wing curtain

An effective way to minimise the shearer operators' dust exposure during maingate sumping/ cut-out is to install a 'wing curtain' (Figure 2.13) between the rib and the stage loader. This shields the maingate drum from the air stream as it cuts into the maingate entry, and can reduce shearer operators' dust exposure by 50 to 60% during maingate cut-out (USBM, 1982c; Babbitt et al, 1984).

Homotropal ventilation

The simplicity and reproducibility of the longwall face ventilation system makes antitropal ventilation the preferred system (Stevenson, 1985). In this system coal is transported against the airflow, and intake dust from the maingate stage loader and crusher creates a significant proportion of total dust which is often overlooked on many longwall faces (Organiscak, Jankowski and Kelly, 1986). Homotropal ventilation, in which air travels in the direction of the coal transport, places the out-by dust sources downstream of the face workers, eliminating dust exposure from these sources. Tests have shown that homotropal ventilation can lower instantaneous intake dust concentrations along the face by about 90 % (Jayaraman, 1982; Kelly and Jankowski, 1984).

Figure 2.12 Goaf curtain to lower air leakage into the gob and raise the airflow along the face (after Jayaraman, 1981b).

Figure 2.13 Wing curtain to reduce dust exposure of shearer operator's when cutting out at the main gate (after USBM, 1982c).

2.5.2 Drum water sprays

Water sprays on the shearer cutting picks on the drum is the second most important airborne dust control method. Studies in the U.S. (Taylor and Jankowski, 1982; Scott, 1982; Jankowski, 1982) have found that the longwalls which were consistently maintaining compliance with dust standards were using large volumes of water, more than 65 gpm. Figure 2.14 shows the effects of high water flow to the cutting drums. Many investigations were conducted to determine the optimum water quantity to the shearer drums , and they showed that increasing water flow from 45 gpm to 65 gpm (245 l/min) reduces shearer operators dust exposure by 40% (Shirey, Colinet and Kost, 1985; Ruggieri and Babbitt, 1983; Chiang et al, 1984). Where this is not possible, directing a large proportion of the water to the upwind drum results in lower respirable dust exposure for the shearer operators (Jankowski, 1982; Pimental, Adam and Jankowski, 1984). Recent studies have found that increasing the water flow beyond 70 gpm no longer proportionally decreases dust levels, and should be maintained around 65-70 gpm for optimum results (McClelland, Babbitt and Jankowski, 1987).

U.S. Bureau of Mines studies have shown that poorly designed water sprays, especially high water pressure, however, can increase shearer operators' dust exposure (Jankowski, Kissell and Daniel, 1986). Many studies have been conducted on the optimal flowrate and pressure, size and velocity of droplets in the spray, nozzle type and the arrangement of spray nozzles (Courtney and Chang, 1977; Mundell et al, 1980; Jayaraman et al 1981; Mukherjee and Singh, 1984; Whitehead, Erchard and saltsman, 1976). Their studies indicate that the maximum drum spray pressure should be between 480 and 700 kPa (70 and 100 psi), and that the water flow rates should be increased by increasing the orifice size, rather than by increasing the spray pressure.

Figure 2.14 Comparison of dust level profiles along the face, showing the effects of high water flow to the cutting drums (after Jankowski and Organiscak, 1983b).

The three commonly used drum water spray systems, namely pick point flushing (Jankowski and Hetrick, 1982), cavity filling system and water through bit system, were compared in two longwall mining conditions (Jankowski, 1986; Shirey, Colinet and Kost, 1985). The studies indicated that the pick point flushing with jet nozzles was the most effective in reducing dust exposure of the shearer operators. The pick point system with cone type sprays was only 70% as effective as the pick point jet spray system, the water through the bit system was 60% as effective and the cavity filling system was 47% as effective.

2.5.3 Deep cutting with reduced drum speed

Deep cutting with reduced drum speed is another important dust control technique to reduce respirable dust levels in a longwall face. Many studies have endeavoured to determine the relationship between coal cutting and the generation of respirable dust (Hamilton, 1972; Roepke, Lindroth and Myren, 1976; Hanson and Roepke, 1979; Niewiadomski, Jankowski and kissell, 1982). Deep cutting, in the sense of increased bit penetration rather than a wider web, is a function of drum speed, pick spacing and gauge length and machine advance rate. Several field tests (Ludlow, 1981; Wilson, 1981; Ludlow and Wilson, 1982; Ludlow and Jankowski, 1984) established that deep cutting with reduced drum speed achieved a 60% reduction in dust generation when drum speed reduced from 70 to 35 rpm (Figure 2.15), with bit penetration increased from 43 to 86 mm.

Studies with a single pick show that under constant drum speed, the average dust generation decreases as the cutting depth increases (Figure 2.16). Studies to determine the effect of deep cutting with fewer bits per line show that dust levels were reduced by 20% when the bit penetration was doubled by removing alternate vane bits (Brooker, 1979a; 1979b; Babbitt et al, 1984; Peng and Chiang, 1984b; Ludlow and Wilson, 1982). These studies show however, that increased bit penetration by reducing the number of bits is not as effective as lower drum speeds.

Several other studies confirm that different bit geometries do not influence airborne respirable dust generation as much as cutting depth (Roepke and Hanson, 1983a; 1983b; Roepke and Voltz, 1983; Strebig and Zeller, 1975; Black and Schmidt, 1977). Recent field trials (Olson and Roepke, 1984) have shown that the clearance, or backface bits, are the single greatest dust source on the longwall face and should therefore be minimised wherever possible. Roepke (1984) has recommended that in order to minimise airborne respirable dust operators should "cut at maximum depth at all times, at minimum RPM with the lowest possible bits, that have the lowest possible included tip angle".

However, deep cutting at slower drum speeds does present some potential pitfalls that the operator must be aware of. Increasing the vane angle is a viable means of counteracting the effect of reduced drum speed on loading efficiency. Increased loads on the bits, bit blocks, gear boxes and ranging arms must also be taken into account. Finally, when fewer bits are used, the drive train components will experience greater torque variation and require equipment that will withstand the increased vibration.

Figure 2.15 Effect of drum speed on dust production (after Niewiadomski, Jankowski. and Kissell, 1982).

Figure 2.16 Effect of depth of cut on dust level (after Hamilton, 1972).

2.5.4 Modified cutting sequences

A bi-directional cutting sequence, cutting full face height in both directions, results in the support setters being exposed to shearer dust for one pass of the mining cycle, and the shearer operators being exposed to the dust from the support for the other pass. For this reason, longwall faces operators are employing uni-directional cutting sequences, cutting coal only in one direction, to reduce the operator's exposure to dust (USBM, 1981b; Peng and Chiang, 1984b).

In a conventional uni-directional cutting sequence, during a typical maingate-to-tailgate cut, the lead drum takes a full cut while the trailing drum cuts the remaining bottom coal. The shearer only cleans up the coal on the return phase. This cutting sequence reduces dust exposure of support personnel by locating the majority of the support and conveyor movement upwind of the shearer. However, the shearer operator's dust exposure still exceeds statutory levels due to the dust generated by the cutting drum upwind of the operator position, and this problem is the impetus for much research.

To this end, a modified uni-directional cutting sequence has been developed (Niewiadomski, Jankowski and Kissell, 1982; Ruggieri and Jankowski, 1983; Scott, 1982), whereby the lead drum continues to take a full cut during the maingate-to-tailgate pass while the trailing drum is free wheeling or cutting a minimal amount of coal, and during the return clean up pass the trailing drum cuts the remaining coal (Figure 2.17). This enables both operators to remain on the intake side of the primary dust generating source thereby significantly reducing their exposure to dust. This modified cutting sequence has been acclaimed by the USBM (1981b) as an effective and simple method of reducing the shearer operators' respirable dust exposure, especially when cutting rock in the bottom.

Figure 2.17 Modified uni-directional cutting sequence to reduce longwall shearer operator's dust exposure (after USBM, 1981b).

Field studies show that the operators' dust exposure was 40-50% higher when cutting against ventilation as opposed to cutting with ventilation (Jankowski, 1984a; Aziz et al, 1993a; Jankowski and Hetrick, 1982). Therefore, cutting in the direction of ventilation is another way of reducing operators' exposure to dust. In addition, when cutting with ventilation, any dust generation caused by spalling of coal ahead of the lead cutting drum occurs downwind of the shearer operators.

2.5.5 Shearer clearer

A major advancement in the prevention of shearer generated dust into the operator's position is the development of a novel shearer spray system, called the 'shearer clearer' by the U.S. Bureau of Mines and Foster-Miller Assoc., Inc., (USBM, 1981a; Kissell et al, 1981; Jayaraman and Kissell, 1981; Taylor and Jankowski, 1982; Ruggieri and Babbitt, 1983; Ruggieri et al, 1983). This system takes advantage of the air moving capabilities of water sprays, and consists of several shearer mounted water sprays oriented downwards, that split the air flow around the shearer into clean and contaminated air (Figure 2.18(a)). The dust generated by the cutting drum is confined to the coal face, while the clean air passes over the shearer operator. Underground evaluation showed that the shearer operator's exposure to dust was reduced by 30 to 50% (Figure 2.18(b)).

In the original shearer clearer system, some water sprays were mounted on top of the shearer, which caused some practical difficulties. Thus an 'improved shearer clearer system' was developed, which eliminates all sprays mounted on the top of the shearer body and uses fewer sprays than the original system (Jayaraman, Jankowski and Kissell, 1985; Jayaraman, 1986; Jankowski, Kissell and Daniel, 1986). Field tests showed that this reduced the dust exposure of both the operators significantly.

However, this shearer clearer technique does not reduce the overall dust concentration in the face nor does it affect the tailgate workers' exposure to dust. It also needs about 90 l/min (20 gpm) of water at 1000 kPa (150 psi) to be effective. Improper design of the system, such as using more than 1000 kPa water pressure will, in fact, increase the shearer operator's dust exposure. In general, shearer clearer type water sprays are not compatible with extraction drums that rely on capture of dust from a highly concentrated, relatively undisturbed region.

Figure 2.18(a) Characteristic dust transport profile with conventional and shearer clearer external water spray systems (after Jankowski, Kissell and Daniel, 1986).

Figure 2.18(b) Effectiveness of shearer clearer system on reducing dust levels in a longwall face (after Organiscak, Listak and Jankowski, 1985).

2.5.6 Extraction drum

Research work on small, water powered dust capture tubes in the 1970's (McQuaid, 1975; Jones, 1978; Jones and James, 1987; Clarke and Wilkes, 1989) led to the development, in the UK, of effective dust extraction systems for use on longwall shearers (Hamilton, French and James, 1980). In these systems, open ended tubes were integrated with coal loading doors or cowls around the cutting zone. But these resulted in low capturing efficiency (French, 1983; Ford, Brierley and Brooks, 1987; Divers, Jankowski and Kelly, 1987). Later, the extraction drum was devised in 1981 for use with shearer cutting drums (James, 1983; Ford et al 1986; James and Browning, 1988).

This extraction drum utilises water sprays, in tubes mounted through the drum, to collect dust laden air, to scrub the dust and discharge the clean air and dirty water on the goaf side of the drum (Figure 2.19). Each tube houses one water spray which

Figure 2.19 Cut-away view components and airflow paths of the extraction drum (after Divers, 1987).

operates at very high pressure to induce air through them. A water pressure of 11 MPa
(1600 psi) is required to produce an air flow of approximately 1.9 m^3/s for each drum, and a booster pump mounted on the shearer is necessary to generate such pressure. The spray tubes acts as scrubbers removing 90% to 95% of respirable dust from the air drawn through them.

Tests carried out on single-ended ranging drum shearers in U.K. showed reductions in respirable dust of 60% to 80% compared with conventional wet cutting (Hamilton and French, 1984; Ford and Hole, 1988; Ford, Brierley and Brooks, 1987; Ford et al, 1987). However, tests carried out in U.S.A. on double-ended ranging drum shearers were not so promising; the 40% to 50% reduction in respirable dust concentration in some faces was marred by frequent blockage of tubes (Divers, 1987; Kelly and Muldoon, 1987). During trials with extraction drums in Australia, mines have experienced difficulties with blocked sprays (Hewitt, 1989). In summary, this method is not being used on many faces due to drum diameter restrictions, high cost, and limited hub space available on some shearers.

2.5.7 Water infusion

Longwall water infusion techniques have been recognised and widely practised for many years in European mines as an effective means of dust control. Belgium has used this technique for over 20 years, and in the northern coalfields of France it is the main dust control technique for 89% of the coal produced (Neels and Dequildre, 1973; Ducrocq, 1973). Field tests in Belgium show that water infusion at the rate of 10 litres/tonne of coal suppressed 95% of the respirable dust produced at the face. Mining regulations in Germany require water infusion where possible and over 50% of their longwalls are infused (Schlick, 1970). There, experience has shown that a minimum of 1.9 gal of water per ton of coal is necessary to suppress dust (Becker, 1973; Heising and Becker, 1980).

The water infusion technique involves drilling holes and injecting water into the coal seam at low flow rates and at low pressure prior to coal extraction. This increases both the moisture content of the coal seam and the wettability of the coal, and therefore reduces the dust generated during mining. The success of water infusion depends on the natural or induced permeability of the coal seam. Figure 2.20 shows the relationship between cleat systems and infusion zones. In Europe, the coal seams tend to increase in permeability towards the east which explains why the technique is successful in Germany and other Eastern European countries, but has limited success in the UK.

Water infusion investigations conducted in the U.S.A. showed a 38% to 50% reduction in dust concentration levels in the infused zones (Cervick, 1977; Occidental Research Corp, 1983; Cervick, Sainato and Baker, 1983; Shirey, Colinet and Kost, 1985; McClelland et al, 1987). Trials in the Bulli coal seam of Australia indicated that infusion did not significantly reduce dust levels and the researchers attributed this to the heavy fractures and to the seams' high permeability (Hewitt and Lama, 1988).

In summary, water infusion is a viable longwall dust control technique, but its success and cost effectiveness depends primarily on coal seam conditions. Relevant characteristics are fracture porosity, moisture content in fracture pores prior to infusion, the cleat system and its orientation relative to the axis of the longwall panels and depth of cover. Infusion has the disadvantage of being a slow process if it is to be effective, and it should not be used in weak roof or floor strata areas or close to faults. It is important to investigate the in situ permeability of the coal before using water infusion.

Figure 2.20 Relationship between cleat systems and water infusion zones (after McClelland, et al, 1987).

2.5.8 Support generated dust control

According to Australian and U.S. Bureau of Mines studies significant amount of respirable dust is produced during support movement and goaf fall (Hewitt, 1990b; Jankowski and Organiscak, 1983a) (Figure 2.21). The severity of this problem will depend on the amount of fallen debris that has accumulated on the canopy and can range from negligible to very severe. U.S. Bureau of Mines investigations found that as much as 30 - 40% of the respirable dust that shearer operators are exposed to is generated by the movement of longwall roof supports.

Figure 2.21 Dust level profile around shearer showing intake contamination due to dust generated by support movement (after Jankowski and Organiscak, 1983a).

So far most research effort has been directed towards controlling dust from the shearer and very little research has been carried out on the control of support generated dust (Hewitt, 1990a; Jankowski and Organiscak, 1983b; Organiscak, Listak and Jankowski, 1985). Some of the methods suggested for controlling dust from support movement are minimising debris on top of canopies, advancing supports during the clean-up pass cycle against the airflow, maintaining a distance of at least 15 m between support movement and shearer, washing down supports, wetting the immediate roof with shearer water, mounting water sprays on supports and increasing the airflow to promote dilution and diffusion (Organiscak, 1984). However, most of the above methods have some limitations and are not practicable in many cases. For example, water application in some seams can cause deterioration and ground control problems, and delaying the advance of supports can cause roof control problems.

Work by European researchers has resulted in limited practicable dust control technology for support generated dust (Becker, Goretz and Kemper, 1981). The research concentrated on redesigning the shields to minimize gaps on the goaf side, and included water sprays on shields, contact advance of supports, plastic mesh to bridge the gap between the canopies and the use of dust collecting troughs. Dust measurements in longwall faces equipped with water sprays on shields showed dust suppression efficiencies of between 42% and 68%. However, it was reported by Goretz (NCB, 1982) that the water sprays proved unsuitable in practice, as it resulted in roof deterioration and the face crew were wetted by the sprays. Becker et al (1988) found that dust collecting troughs and plastic mesh are not practicable either.

2.5.9 Scrubbers, Air curtains and Air sprays

A mechanical dust collector or scrubber typically consists of an air mover to direct the dust laden air into the scrubber, a dust removal system to separate the dust particles from the air stream and a demister to remove the water from the air stream. Scrubbers are being used successfully in continuous miner development sections to control the dust levels at the face (Hill, 1974; Divers, 1976; 1977; Divers, Lascola and Hundman, 1981; Niewiadomski, 1983; Sartaine, 1985; Rawicki, 1983; Gillies, 1983; James, 1983; Jayaraman, Volkwein and Kissell, 1990; O'Green, 1983; 1990). The USBM has tested and reported the results of evaluation of many scrubbers in an attempt to increase the use of scrubbers in the coal mines (Divers and Janosik, 1978; 1980). However, to date, dust collectors have only been installed on longwall shearers (Figure 2.22) for research purposes. Several USBM attempts to retrofit existing shearers with scrubber systems have ended in failure (Grigal, 1980).

Fan-powered Scrubbers

Many of these scrubbers have been tested on longwall shearers with little success (Jayaraman and Grigal, 1977; Kelly, Muldoon and Schroeder, 1982; Kelly and Muldoon, 1987). Various problems encountered include: inadequate vertical clearance, a tendency for the intake and discharge ducts to clog and a low collection efficiency caused by inadequate fan capacity which is a result of space limitations and therefore undersized fans. Other problems included maintenance, replacement of filter panel in a flooded bed scrubber etc. These problems led to rejection of the high capacity machine mounted scrubber as a viable dust control technique for U.S. longwall faces.

Water-powered Scrubbers

These scrubbers are simply water powered dust capture tubes mounted on the shearer body. Studies conducted in the U.K. and U.S.A. have shown that these devices can achieve high dust capture efficiencies and result in dust reductions of over 50% (Ford, Brierley and Brooks, 1987; French, 1983; USBM, 1981c; Organiscak, Volkwein and Jankowski, 1983; O'Green, 1983). However, the requirement of high pressure water (more than 10,000 kPa) has restricted their use in the longwall faces. Therefore, there is a need for the development of a reliable scrubber with low water usage, high capture efficiency and effective mist elimination, which also must be very compact to fit into the limited space available in the face.

Figure 2.22 A double-ended ranging drum shearer equipped with a set of dust collectors (after Jayaraman, 1977).

Air curtains

Air curtains are being used in development headings successfully over the years. Two types of curtains are in use; 'canopy air curtains' to provide a zone of clean air around the operator and 'air curtain tubes' to confine the dust cloud in front of the operator (Krisko, 1975; Ford and Hole, 1984; Volkwein, Page and Thimons, 1981). Studies have been conducted in Australia to evaluate the effectiveness of compressed air curtains in a longwall face (Hewitt, 1986a; Lama et al, 1990; Liu , 1991). Twenty seven air curtains were used in every second chock from the 5th chock to the 51st chock. This method has reduced dust levels near the curtains, but it did not effectively provide a curtain between the high dust concentration zone and the walkway. It was concluded that, to be effective, air curtains have to be installed along the full face in every second chock.

Air sprays

The effectiveness of air sprays mounted on roof supports for dust control was simulated using a physical longwall face model by Engineers International, Inc., (1983; Mukherjee et al, 1985; Laurito and Singh, 1987). A total of 2,100 cfm (1.0 m^3/s) of compressed air was used for 33 m length of face, and the air spray system reduced dust by between 30% and 75%. In another document (Shirey, Colinet and Kost, 1985) the improvement in dust levels was attributed to the increased total amount of air present in the face. It was not clearly explained in their analysis how 2100 cfm (1.0 m^3/s) added to the intake flow of 40,000 cfm (20.0 m^3/s) effected reductions of between 30-75%. However, as both air curtain and air spray techniques use only large amounts of compressed air, the systems are not economical.

2.5.10 Other Methods:

Water jet assisted cutting

The use of a high-pressure water jet to assist a mechanical drag bit is known as water-jet assisted cutting. It evolved from a need to overcome the thermal deterioration of the tool, which occurred when cutting strong abrasive rocks (Hood, 1976). It was discovered that suitably directed jets, at pressures of around 70 MPa, would substantially reduce both the forces acting on the bits and the generation of respirable dust (Hood, 1985a; 1985b; Tomlin, 1982; Taylor and Evans, 1985). Other studies (Thimons, 1987; 1988; Taylor, Kovscek and Thimons, 1986; Kovscek et al, 1986) have shown that an increase in the water pressure from 1 to 7 MPa did not significantly change dust levels, but that an increase from 7 to 20 MPa reduced dust levels by 78%. Further increasing the water pressure from 20 to 40 MPa resulted in only a very small additional reduction in dust levels (Figure 2.23).

Figure 2.23 Effect of water jet pressure and fluid horsepower on dust levels (after Taylor, Kovscak and Thimons, 1986).

Intake/ stage loader dust control

Dust sources at the intake of a longwall face can contribute significantly to face workers' dust exposure. Field surveys have shown that in many longwall faces, 20-40% of face workers dust exposure was generated at the in-bye side of the face or at the crusher (Jankowski and Organiscak, 1983b; Aziz et al, 1993b). The most effective method of controlling intake dust is homotropal ventilation, in which the stage loader/crusher is placed on the downstream side of the face, thereby reducing intake dust levels by as much as 50 - 90% (USBM, 1982d; Scott, 1984). Other control techniques, such as the water powered scrubber and water sprays located strategically on the stage loader, were developed for use in faces where the homotropal ventilation was too difficult or expensive to implement. These techniques can reduce intake dust levels at support 10 by 45 - 80% (USBM, 1981c; 1982d; 1985; Grigal et al, 1982; Jayaraman, Jankowski and Organiscak, 1992).

Reversed drum rotation

Recent studies have shown that the shearer operators' dust exposure is reduced by 40 to 85% when the direction of the drum rotation is reversed, i.e. the leading drum cutting from the floor to roof rather than from roof to floor (Jankowski and Kelly, 1988; Niewiadomski and Jankowski, 1993). However, there was no evidence that dust levels downwind of the shearer were different in either mode, nor did it significantly affect dust levels during tramming from main to tail gate.

Wetting agent

Although the use of wetting agents has been effective in reducing dust levels in some mining operations, their application in longwall faces has not resulted in significant dust reductions. Tests conducted in U.K. show that wetting agents can be beneficial with coals containing 20 to 30% volatiles (NCB, 1981), but there is no advantage with high volatile low rank coals or anthracite coals. Studies by USBM (Kost, Shirey and Ford, 1980; Scott, 1983; Wang et al, 1991) have also shown that the addition of a wetting agent to the sprays had no apparent effect on the dust concentration. In Australia, recent studies (Bell, et al 1993b; Hewitt, 1990b) show that the suppressant has a minimal impact on shift average dust levels, but is useful near the stage loader.

External foam application

A number of studies have been conducted to assess the usefulness of foam in suppressing dust (Hiltz and Friel, 1973; Hiltz, 1975; Mukherjee and Singh, 1984; Singh and Laurito, 1984; Laurito and Singh 1987; McClelland, 1989). In most cases the dust reductions were about 20% with some cases showing a 50-70% reduction. Numerous operational difficulties such as special equipment requirements , high cost, possibility of refoaming in the washing plant etc. for a modest dust reduction precludes this method as a practical longwall dust control technique.

Face /walkway curtains and curtains over shearer

Face curtains are intermittently spaced along the face and over the shearer in an attempt to keep the shearer generated dust near the face. Experiments have been conducted with varied curtain lengths, orientation and spacing (USBM, 1981d; Shirey, Colinet and Kost, 1985; Jankowski and Babbitt, 1986), and all curtain configurations caused eddying of the airflow into the walkway, and consequent increases in walkway dust levels.

Remote control

Remote control of shearer reduces the shearer operators' exposure to dust by enabling them to be upwind of the cutting drum most of the time. Two types of remote controls, umbilical and radio controls, are generally used (Jankowski, 1984b). The problem of dust exposure of support personnel has resulted in the introduction of electro-hydraulic shields, a set of which can be electronically controlled by computer.

This allowed shield setters to achieve the upwind position from this dust source (Haney et al, 1988). Where dust exposure cannot be controlled, personal protection equipment such as face mask respirators, and air helmets are used on longwall faces to reduce the respirable dust exposure. However, personnel protection should only be used as a last resort and should not take the place of dust prevention or dust control techniques.

2.6 MODELLING STUDIES

2.6.1 Expert systems

Expert systems on longwall dust control have been developed by the U.S. Bureau of Mines to provide information and advice on primary dust control techniques (Roepke, Hanson and Schmidt , 1985; Hanson and Roepke, 1988; Wirch, Kelly and Jankowski, 1988; Kissell and King, 1988). These programs have been developed from data obtained from the Bureau's past research on reduction of primary dust generation. The programs use both stored and interactively entered data to evaluate the dust reduction potential of various mining practices. However, the expert systems are not useful in the development of a mathematical model of the dust distribution at a longwall face.

2.6.1 Dust generation, transport and deposition

Fine dust generation depends on the interaction between the cutting tool and the coal. Many mathematical models have been developed to simulate the action of cutting bits and crack growths (Pariseau and Fairhurst, 1967; Nishimatsu, 1972; Zipf and Bieniawski, 1989), but there are very few published mathematical modelling studies of dust transport from basic engineering and scientific data. Examination of the current literature on dust transport shows that most of the early models were focussed on deriving empirical formulae from research in some operating longwall faces.

Courtney, Kost and Colinet (1982) proposed an exponential decay model for calculating dust concentration as a function of time. This represents the results of a physical phenomenon without regard for the mechanisms of deposition. A mathematical model to predict the size distribution and concentration of dust as it travels along the longwall face was proposed by Chiang, Peng and Luo (1986), which assumes an exponential drop in dust concentration with distance. Grayson and Peng (1984) devised a simple model to predict the respirable dust concentration at specific locations along the longwall face. This empirical equation was derived by performing a linear regression analysis on sampling data collected from two mines. A simple algebraic mathematical model has been developed by Liu (1991) to evaluate a multi-scrubber system. The models described are input-data-intensive and ignore the physics of the airflow and respirable dust behaviour in a face. As a result, they are only applicable to those few faces which have similar characteristics.

Partyka (1989; 1990; 1991) developed a dust distribution model for one-dimensional flows which took into account convection-diffusion mechanics. Bhaskar (1984; 1987; Ramani and Bhaskar,1988) developed a convective-diffusion mathematical model for transport and deposition of dust in mine airways which considered source strength, dust cloud characteristics and basic mechanisms affecting particle behaviour in mines. Results showed that the deposition rate per unit of concentration increases with an increase in airborne concentration (Figure 2.24). A mathematical model for predicting dust concentration along the longwall face (Figure 2.25) has been developed by Qin (1992). However, all the above models are one dimensional and cannot be used either to understand the three dimensional behaviour of airflow fields and dust particles around the shearer or to determine the effectiveness of the dust control techniques.

Figure 2.24 Comparison of model output with mine experimental data of ambient dust concentration in a roadway (after Bhaskar, 1987).

Figure 2.25 Comparison between experimental results and model predictions of respirable dust concentration along longwall face (after Qin, 1992).

2.6.3 Airflow patterns and dust control methods

Understanding of the entrainment of dust particles is fundamental to the development of a dust control technique. Studies showed that respirable dust particles follow the turbulent motion of the ventilating air more closely (Hodkinson, 1960), and therefore the study of airflow patterns in a face, particularly around the shearer, is also very important to advance dust control technology. Skobunov (1973) has carried out extensive field investigations and developed equations to determine the coefficients of transverse and longitudinal turbulent diffusion and the coefficients of heat and mass transfer for mine workings. The resistance of a longwall face significantly affects dust deposition along the face, and a theoretical method for determining such resistance has been suggested by Bruner and McPherson (1987). These studies are helpful in deriving the input parameters for the longwall dust model.

Very little research work has been done in the area of three dimensional modelling of airflow patterns and respirable dust behaviour. Nichols and Gregory (1987) developed a computer program that simulates the airflow and particle transport around sampling devices and predicts the particle sampling rate. Airflow fields and air improvement methods in a developing heading were modelled by Meyer, Grange and Meyer (1991). Therefore, there remains a need for the development of a three dimensional model of dust distribution at a longwall face, and validation of the mathematical model through detailed field investigations in underground coal mines.

2.7 SUMMARY

A critical review of studies on airflow characteristics and dust concentration levels in the longwall face indicates that there are large variations in dust concentration profiles at different longwall faces. Very little information is available on the aerodynamic and dust concentration gradients around the shearer. The variations in the physical characteristics of the longwall face, ventilation plan and operating procedures make the data inappropriate for Australian longwall faces. The full shift average gravimetric data available in Australia is not sufficient to characterise longwall dust behaviour. There is a need for detailed and extensive dust sampling at longwall faces to understand the transient and ambient dust concentrations, the knowledge of which is essential for the development of new dust control techniques.

Many of the dust control methods developed so far have been aimed at reducing the shearer operators' dust exposure. Dust suppression around powered supports is, in general, not yet satisfactory. As some techniques are not suitable for all longwall faces, local conditions should be considered to determine the appropriate control measures, and several techniques must be used in combination to reduce the dust concentration. In many longwall faces, the control measures described above would not achieve an acceptable degree of dust suppression. In such cases, installing separating elements, such as local airflow systems between the AFC and walkway area, would be useful in reducing the face operators' exposure to dust. Further research and development is needed to overcome the limitations of the existing techniques and to advance dust control technology at longwall face supports.

The flow of air in a longwall face is highly turbulent and very complex in the presence of machinery and various dust control techniques. Mathematical modelling is therefore necessary for a thorough understanding of the behaviour of dust and for the development and evaluation of dust control techniques. So far, only very simple, input-data-rich and some one dimensional mathematical models have been developed. No known published literature exists on three dimensional modelling of airflows, dust concentration or dust control techniques in a longwall face, and there is a need for the development of such a model. The mathematical model would require validation through detailed field investigations in underground coal mines.

In summary, there is a need for the development of a longwall dust extraction system once the dust sources becomes airborne. There is an additional need for the mathematical modelling of air velocities and dust concentrations in the face for the development of new effective dust control techniques. Detailed and extensive dust sampling at longwall faces, in order to understand the airflow characteristics and behaviour of respirable dust in the longwall face, is described in chapter 3.