Chapter 1
INTRODUCTION

1.1 GENERAL

Respirable dust is a continuing problem in the mine environment where it adversely affects the safety and productivity of a miner. Dust is an inevitable product of mining, given the nature of mining operations such as cutting, loading, transference and transportation of coal. It is dispersed into the mine atmosphere by the ventilating airflow, and travels downwind. Once airborne, the respirable dust particles are difficult to capture and remove as they fall very slowly because of associated aerodynamic properties. As a result, miners are exposed to high respirable dust concentration levels.

Prolonged exposure to, and inhalation of, airborne respirable dust particles of between 0 and 7 μm, leads to the accumulation of dust in the lung and to the development of a respiratory disease known as 'pneumoconiosis' or 'black lung disease' (Sinha and Fadiya, 1985). It is the most serious occupational health hazard in underground coal mines, with 40,000 new cases estimated as occurring each year (Taylor, 1988). In an attempt to control the respirable dust problem, coal producing countries around the world have imposed mandatory respirable dust standards. Australian New South Wales (NSW) Coal Mines Regulation Act (NSW Govt., 1946) set down that "each mine operator shall maintain the average concentration of respirable dust in the mine atmosphere during each shift to which each miner in the active workings of such a mine is exposed at or below 175 particles per cubic centimetre of air". This standard was converted in 1984 to 3 mg/m^3.

The mines, facing continuous changes, have great difficulty in conforming to these standards. In Australia, three major underground mining methods are employed to extract coal: conventional, continuous and longwall mining. Longwall mining, the most recent and most highly mechanised method of mining, is becoming the most prevalent method used. Whilst it has achieved increased production, improved productivity, better safety for miner's, greater recovery of resources and the general economics of mining coal, the fact remains that, as coal is mined at a faster rate, more dust is generated. Longwalls have been found as having the highest mean concentrations of respirable coal dust (Watts and Parker, 1986) and the greatest number of samples exceeding the statutory dust limits.

Only a small fraction of the total respirable dust does become airborne, (Cheng and Zukovich, 1973), yet it is still too much to be sufficiently diluted by the ventilation airflow so as to maintain respirable dust levels below 3 mg/m^3. Studies have shown that for every 1,000 tonnes of coal produced, 0.5 to 1.5 mg/m^3 dust is added to the longwall face atmosphere (Sinha, 1982; Wang et al, 1991; Bell et al, 1993a). Current methods can effectively control longwall respirable dust for production levels of 2,000 - 3,000 tonnes/shift, but beyond this it becomes very difficult to control dust. Thus, despite the developments in dust control technology over the past 30 years, many longwall faces are still having difficulty in complying with statutory dust levels.

Longwall face dust is created mainly by the shearer, support movement, spalling of coal, crusher/stage loader and roof falls in the goaf. Bi-directional cutting i.e. cutting in both directions, results in shield setters being exposed to the shearer generated dust in the first half of the mining cycle and the shearer operators being exposed to the shield dust during the second half. This is hazardous, and longwall operators are therefore employing uni-directional cutting methods, rather than bi-directional cutting, simply to reduce the operators' dust exposure, resulting in an estimated production loss of 10 to 15% per working face (Gillette, Jankowski and Kissell, 1988). In Australia, this represents a potential revenue loss of approximately $120 million.

In addition, the compensation cost of dust induced illness in coal mines is immense. For example, in the USA alone, black lung disease compensation payments in 1987 was nearly $1.8 billion with the cumulative cost of the program well above $22 billion. There are also hidden costs associated with dust which include equipment wear and decreased worker productivity due to the poor work environment. These high costs may be prevented or reduced through long term research directed at understanding the dust generation, entrainment, and control of respirable dust.

In view of the industry trend towards longwall mining, advancement of dust control technology is imperative if production is to increase with safety. The work in this thesis is directed at developing new control techniques for respirable dust, evaluating them in the field, and understanding dust behaviour more clearly through field and mathematical investigations.

1.2 STATEMENT OF THE PROBLEM

The problem of respirable dust control in coal mines is continuing even after many years of research. Dust concentration levels in longwall mining are higher and dust control is inherently more difficult by virtue of the mode of operations employed. Longwall operations quickly disperse dust, unlike continuous miner sections where dust can be boxed in or controlled with scrubbing techniques. Unfortunately, the dust control techniques, such as machine mounted scrubbers, that are highly successful for continuous miners have not yet proved to be successful for longwall faces.

The pursuit of statutory dust levels world-wide has resulted in more than 40 methods of longwall dust control being introduced during the past three decades. These methods include ventilation controls (Mundell et al, 1980; USBM, 1982c; Jayaraman, 1982; Jankowski and Hetrick, 1982; Kelly and Jankowski, 1984; Breuer, 1972; 1983), drum water sprays (Chiang et al, 1984; Shirey, Colinet and Kost, 1985), deep cutting (Babbitt et al, 1984; Peng and Chiang, 1984b; Knight, 1985; Strebig and Zeller, 1975), modified cutting sequences (USBM, 1981b; Jankowski and Organiscak, 1983a), shearer clearer (Kissell et al, 1981; Jayaraman, Jankowski and Kissell, 1985), extraction drum (James and Browning, 1988; Ford and Hole, 1988; Divers, 1987), water infusion (Neels and Dequildre, 1973; Schlick, 1970; McClelland et al, 1987), use of scrubbers (Divers, 1991; Grigal, 1980; French, 1983; Kelly et al, 1982), and other methods (Tomlin, 1982; Taylor, Kovscak and Thimons, 1986; Mukherjee and Singh, 1984; Babbitt and Ruggieri, 1990; Lama et al, 1990; Hewitt and Aziz, 1993).

A critical review of these techniques shows that although substantial progress has been made, because of the complex and interactive factors involved not all these techniques are applicable in every longwall face. The physical characteristics of each face directly impact on the dust control requirements to be implemented. As a result, 8 out of 20 longwall faces in New South Wales, Australia, are still facing a difficult task in consistently complying with mandatory dust standards, according to a Joint Coal Board study involving more than 1000 gravimetric respirable dust samples collected between 1984 and 1992.

Much research has been directed at suppressing dust at the shearer, but very little has focussed on reducing dust production from other principal sources, such as from support advance, coal spalling from the face and goaf falls (NCB, 1982; Jankowski, Organiscak and Jayaraman, 1991; Hewitt, 1990a). The increasing use of powered supports has presented a new and difficult problem in dust control, providing a new challenge for further research. Recent field investigations, carried out by the author of this thesis in three coal mines of New South Wales to understand the behaviour of dust clouds in a longwall face, showed that even though the shearer is the major source of dust, often much is produced during support movement and face spalling, and specifically, during falls of crushed roof rock when the supports yield and advance. Most of this dust becomes airborne, quickly disperses into the walkway and increases the concentration to unacceptably high levels. Methods developed so far to deal with this problem are the use of filters and mats over the supports canopy; however, they are labour and capital intensive and are not practicable. There is therefore a need to develop a new control technique to combat the respirable dust once it becomes airborne.

The movement and distribution of respirable dust in a longwall face is complex because of the nature of longwall mining operations. The generation and transport of airborne dust is governed mainly by the velocity and the movement pattern of the ventilating air. In order to develop an effective dust control technique it is necessary to thoroughly understand the airflow characteristics and respirable dust behaviour in the longwall face. A few experimental studies on airflow characteristics and dust concentration levels in the longwall face have been reported (Hall, 1960; Skubonov, 1973; Peng and Chiang, 1986; Chiang, Luo and Peng, 1987; Ramani, Qin and Jankowski, 1991). A critical review indicates that there are large variations in dust concentration profiles at different longwall faces world wide. Such data are inappropriate for Australian longwall faces which differ in their physical characteristics, ventilation plans and operating procedures. The Australian gravimetric data that has been collected over the last 8 years (JCB, 1984-92) on longwall miners' dust exposure was not sufficiently detailed to permit analysis with respect to mining activities to establish the spatial and temporal behaviour of dust in longwalls. Very little information is available on the aerodynamic and dust concentration gradients around the shearer. To develop a dust control technique it is considered necessary by the author to conduct detailed and extensive instantaneous sampling at longwall faces together with face activity surveys to understand the transient, ambient dust levels in relation to the face activities.

To understand thoroughly the dust behaviour in a complex longwall mining environment and to evaluate any dust control technique, mathematical modelling is necessary to supplement field studies. Most of the early published studies by modelling (Grayson and Peng, 1984; Chiang, Peng and Luo, 1986) focussed on development of empirical models based on dust data collected from longwall faces. These models were input data intensive and ignored the physics of the airflow and respirable dust behaviour in a face, with the result that they are only applicable to the few faces which have similar characteristics. Many expert systems were also developed based on similar studies (Roepke, Hanson and Schmidt, 1985; Hanson and Roepke, 1988; Wirch, Kelly and Jankowski, 1988; Kissell and King, 1988). Some of the recent studies (Partyka, 1989; 1990; Bhaskar, 1987; Qin, 1992) consider the physics of the airflow and dust, but are one dimensional models. These models cannot be used either to understand the three dimensional behaviour of airflow fields and dust particles around the shearer nor to determine the effectiveness of dust control techniques, which depends on their spatial location. Very little research has been conducted on three-dimensional modelling (Nichols and Gregory, 1987; Meyer, Grange and Meyer, 1991) and the use of three dimensional modelling of the behaviour of dust at a longwall face, with mathematical model validation through detailed field investigations in underground coal mines was considered necessary by the author.

In summary, it became evident from early research that there was a need for the development of a dust extraction system once dust became airborne. This would require detailed and extensive sampling at longwall faces to understand the airflow characteristics and behaviour of respirable dust in the longwall face. In addition, mathematical modelling of air velocities, dust behaviour and dust control techniques was considered necessary to supplement field investigations in the development of effective dust control techniques.

1.3 SCOPE OF WORK

The objective of this research was to advance the technology for respirable dust control in longwall mining through the development of a new technique. To achieve the set objective, the research described here has co-ordinated several elements and the scope of work is discussed under three distinct areas:

(i) The first part of the research concerned with conducting underground experiments in operating longwall faces to obtain data on respirable dust levels, on the spatial and temporal behaviour of such dust along the longwall faces, and on airflow patterns to provide input data for mathematical modelling.

(ii) A major part of the research was the design, development and evaluation of a new dust control technique. A new multi-scrubber concept was proposed to reduce miners' exposure to dust in a longwall face. A prototype compact scrubber was developed for that purpose, and comprehensive laboratory experiments and large scale underground investigations were conducted to evaluate the effectiveness of the scrubber technique in the field.

(iii) Another important aspect of the research was the development of a three dimensional model of a longwall face to simulate the airflow patterns, the respirable dust behaviour and the dust concentration distribution to supplement the field evaluation of dust control techniques. Field studies conducted to validate the modelling results, are also included in this study.

1.4 THESIS OUTLINE

The thesis contains eight chapters as follows:

Chapter 1 briefly examines the longwall dust problem and outlines the scope of the research work. A review of fundamental studies on longwall dust behaviour, dust control methods and modelling studies, is given in chapter 2.

Chapter 3 describes studies carried out in four longwall faces of the Southern coalfields of NSW to understand the respirable dust behaviour with respect to face operations. The design of the underground experiments, sampling procedures, the experimental results, and an analysis of the data to determine the spatial dust concentration and its temporal behaviour to assist in better understanding the dust problem are discussed. The instantaneous dust data were correlated with shearer location, face operations and time.

Chapter 4 details the design and development of a compact prototype venturi scrubber for use in longwalls. Laboratory experiments, examining the effect of parameters such as compressed air consumption, water flow rates and air quantity through the venturi on the scrubber's efficiency are discussed. Its efficiency over various respirable dust size ranges was also investigated.

Chapter 5 details extensive field investigations conducted to determine the influence of face air velocity, scrubber exhaust velocity and the location of the scrubber on its efficiency. The results supported the concept of a multi-scrubber system as a dust control technique in a longwall face, providing 40 to 50% protection from respirable dust in faces with less than 3.5 m/s air velocity.

Chapter 6 discusses the development of a three dimensional finite element longwall face model to simulate airflow patterns and respirable dust behaviour and to evaluate the effectiveness of various dust control techniques, including the scrubber system. Prior to modelling, an extensive literature review was made on turbulent airflow and dust dispersion modelling. Path traces of particles introduced near the cutting drums, with different dust control techniques installed, were computed to show the behaviour of respirable dust around the shearer.

Chapter 7 deals with the validation of the mathematical modelling results. It presents the results of the field investigations and comparisons with modelling results, which shows that the model is a reliable predictor of air velocity profiles and dust concentration along a longwall face. The results also show that finite element techniques can be used successfully to predict the effectiveness of different dust control techniques and, when used in conjunction with field investigations, are invaluable in developing new dust control technology .

The conclusions and recommendations for future research are presented in chapter 8.