VENTURI SCRUBBER SYSTEM FOR DUST CONTROL ON A LONGWALL FACE

By N I Aziz, Member, B Srinivasa Rao, and E Y Baaafi, Member

ABSTRACT
A venturi based multi-scrubber air cleaning system has been developed for dust control along a longwall face in coal mines. The system consists of a number of scrubbers, strategically placed along the wall face, which deliver cleaned air at high exhaust velocity into the middle section of the longwall cross-section thus dividing it into two zones. The aim is to maintain the walkway on the powered support side as a zone of relatively clean and good working conditions. Field trials in three longwall faces have shown that, under normal operating conditions, 40 to 50 per cent average protection efficiency can be achieved within 3 m to 4 m downstram of the scrubber. A three-dimensional finite element computational fluid dynamic model, FIDAP, was used to simulate the airflow patterns, the dust concentration and the scrubber dust control technique at a typical longwall face. Results of simulations tally very well with the field results.

INTRODUCTION
The increase in production and productivity on longwall faces has increased the respirable dust problem in underground coal mines. Although the shearer is a major source of dust generation on longwall faces, a significant proportion of the airborne dust is produced during support movement and face spalling, which quickly disperses into the walkway. The unacceptable high level of dust generation on longwall faces has undoubtedly led operators to adopt the uni-directional cutting technique, and in some mines the application of homotropical ventilation to reduce the face operators’ dust exposure. The use of compressed air nozzles to create an air curtain along the face has been tried in the past. This is based on the philosophy of dividing the face into two zones with the walkway being maintained as a low dust concentration area while confining the shearer side as a high dust concentration area (Hewitt, 1990). Field investigations with air curtains showed that although the technique resulted in a slight reduction in dust concentration in close proximity to the curtain, it was not effective in providing a curtain between the high dust level zone and the walkway.

There is still a need to develop techniques which can be used to combat the respirable dust once it becomes airborne. With this objective in mind, the use of a multi-scrubber system on the longwall face was proposed. The concept of a multi-scrubber technique involves the use of a number of reasonable capacity air powered venturi scrubbers delivering the cleaned air into the walkway area to create a relatively clean air zone along the length of the longwall face where operators are normally positioned. This paper therefore examines the concept and also deals with its application. A finite element technique was used to model the airflow fields and dust concentration along the longwall face.

GENERAL DESCRIPTION
The longwall venturi scrubber system consists of a number of venturi scrubber units installed at a predetermined spacing along the longwall face. Each scrubber unit consists of a 100 mm internal diameter compressed air powered venturi (supplied by Senior Australasia Limited), water spray arrangement and a wavy blade type water droplet eliminator (Figure 1). Water is introduced into the unit by injecting it from a point 100 mm upstream of the throat, using low pressure spray nozzles directed at the throat. Primary compressed air enters the venturi manifold through a radial connection and is released through the annular gap to accelerate over the aerodynamic section. Secondary air is induced into the throat of the venturi scrubber by the pressure drop created by the injected compressed air. The ratio of induced air to primary compressed air used is about 10 to 25 depending on load conditions. The dust contaminated secondary air is accelerated to high velocity in the venturi throat section. Water introduced to the throat is atomised by the high velocity air into fine droplets. The high differential velocity between the air and atomised water droplets causes the airborne dust particles and fine water droplets to impact. The demister on the downstream side removes the water droplets along with the dust and delivers cleaned air. The dust water slurry can be piped away to the goaf or to a predetermined location.

When compared with the water powered scrubber (Organiskak, Volkwein and Jankowski, 1983), the air powered venturi scrubber uses very little water. The other advantage of the air powered venturi scrubber is that it uses facilities that are normally available on the longwall face and does not require any special equipment for its operation. The overall length of the unit is 1.15 m, a convenient size to be mounted onto a powered support unit. The other dimensions are: venturi length 600 mm, outer diameter 170 mm; demister unit 200 x 200 x 300 mm.

Each venturi scrubber unit consumes about 0.047 m³/s of primary compressed air, inducing up to 0.6 m³/s of secondary air (Air is induced by the venturi alone, without the demister, at a rate of 1.10 m³/s. Water is introduced into the unit at the rate of 4.0 L/min to 6.0 L/min. The inlet pressure is approximately 3-4 kPa when measured at the mouth of the venturi inlet. The number of venturi scrubbers used in a longwall face can vary between 5 and 10, depending on the length of the face, the nature of the coal cutting system and the method of face ventilation.

LABORATORY STUDIES
A special facility was constructed in the laboratory so that a quantitative evaluation of the prototype air powered venturi scrubber could be carried out. The facility (Figure 2) consisted of a wind tunnel formed by two separate ducts linked by the scrubber itself. Ducts of 300 mm (1.0 ft) diameter were used to keep frictional losses to a minimum, yet maintain adequate transport velocity for the dust. A vibrator type dust feeder, located at the inlet, was used to provide a consistent respirable dust concentration in the range from 2 mg/m³ to 100 mg/m³. Dust from the vibrator was dispersed into the wind tunnel by a blower. Dust sampling probes and pitot-static tubes were positioned in the

1. Department of Civil and Mining Engineering, University of Wollongong, NSW 2522.
A series of tests was conducted to determine the dust capturing efficiency of the compact scrubber. The airborne dust concentration before and after passing through the scrubber was measured using gravimetric samplers. The dust capturing efficiency was thus measured in terms of the reduction of respirable dust concentration at the outlet. Results of laboratory investigations to determine the efficiency of the scrubber are given in Table 1. It was found that a minimum of 40 L/min of water at 670 kPa was required to achieve an efficiency of approximately 90 per cent. Although it was possible to increase the efficiency further by increasing the water pressure and quantity, it was not practicable to use such a scrubber on the longwall coal face. Also, it was found that a minimum of 0.4 m/s (800 ft/min) total air should be passing through the venturi throat for effective atomisation of the water. At total air quantities of more than 0.7 m/s, or at exit velocities greater than 15 m/s, the scrubber discharge still had some water droplets. The scrubber therefore needs a larger demister, and thus would not meet the design requirements. Thus, to meet the design criteria, the quantity of air flowing through the scrubber should be between 0.4 m/s and 0.7 m/s, which can be obtained with a compressed airflow consumption of 0.05 m³/s at 420 kPa pressure. At this level of induced airflow it was observed that the demister was effective and the effluent airstream was free of visible water drops.

As the efficiency of the scrubbers is dependent on the particle...
size, it was important to ascertain the size dependent efficiency of the scrubber. The efficiency of the scrubber over various particle sizes is shown in Figure 4. The results show that the removal efficiency of the scrubber is 45 per cent, 80 per cent and 90 per cent for the ranges 0.5 to 1.5, 1.5 to 3.0 and 3.0 to 7.0 microns respectively. As the mean size of the respirable particles on a longwall face is well above 2 microns, this scrubber can be used successfully to capture the dust on the longwall face.

FIELD INVESTIGATIONS

Extensive field investigations were conducted to evaluate the dust protection that the airpowered scrubber provides to personnel along the walkway and to optimise scrubber location so as to maximise its protection efficiency. The longwall faces selected had the worst dust compliance record. The thickness of the coal seams varied between 2.1 m and 2.6 m and the air velocity along these faces varied from 1.9 m/s to 4.5 m/s. In all three test faces a double-ended ranging-drum shearer and the unidirectional cutting method were employed. The cutting direction on longwall faces A and C was from tailgate to maingate in the same direction as the airflow. On longwall face B, the cutting direction was against the airflow direction. The scrubber was installed at 0.3 m below the roof canopy near the front legs in the front walkway, which all face personnel use rather than the back walkway between the legs. In practice, if at this position it were to cause an obstruction to the workers, could be installed in the back walkway and clean air could then be ducted to the front walkway. The scrubber was chained to the canopy in a horizontal position.

Dust was sampled simultaneously upstream and downstream of the scrubber using gravimetric samplers to determine the effectiveness of the scrubber system in providing a clean air zone along the walkway (Figure 5). It was found that the Hand instantaneous dust measuring instrument, which uses a light scattering principle, was not useful for measuring downstream dust concentrations due to the presence of water mist in the scrubbed air. Therefore, the Dupont model P2500 samplers and Carlex cyclones were used throughout the investigations. Sampling instruments were positioned 0.3 m to 0.5 m below the roof, so as to read the concentration in the miners’ normal breathing zone. At each station two samplers were used to account for sampling errors. During the field investigations, cyclones were positioned next to the sampling instrument to shield the cyclones from high velocity effects. Dust samples were collected for about 60 minutes, during which time coal production was between 500 and 900 tonnes.

Typical results of the underground investigations carried out on Longwall face A at 2.1 m/s face air velocity are given in Table 2. These results show that an average protection efficiency of 50 per cent can be obtained within 3 m of the scrubber at normal air velocity. Results from Longwall face B showed an average protection efficiency of 30 per cent, at 4.5 m/s face air velocity which is higher than normal. The reduced efficiency in this case is due to high turbulence caused by high face velocity airflow at

![Graph](image1.png)

**Figure 5** - Sampling arrangement during field investigations.

![Graph](image2.png)

**Figure 6** - Variation in protection efficiency with face air velocity.

![Graph](image3.png)

**Figure 7** - Variation in protection efficiency with distance from scrubber.

**Table 2**

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the face. Results from longwall face C showed an average protection efficiency of 57 per cent at 1.9 m/s face air velocity. These field tests indicate that the use of a scrubber on a longwall face can significantly reduce the dust concentration along the walkway.

Analysis of the results shows that the dust protection efficiency depends on the scrubber capacity, the cleaned air exit velocity, the primary air velocity at the longwall face, the relative distance from the scrubber and the location of the scrubber. Tests were conducted to investigate the effectiveness of the scrubber when installed at 1.0 m below the roof canopy, and results indicate that the effectiveness of the system is reduced considerably. Also, if the scrubber exhaust velocity is less than 6 m/s, the scrubber will have very little effect on the dust concentration and this results in protection efficiencies of less than 15 per cent. Figure 6 shows the variations in efficiency with different longwall face air velocities. In Figure 7 the reduction in protection efficiency with increasing distance from the scrubber is shown. These results indicate that the protection efficiency decreases with increasing distance from the scrubber and with increasing longwall face air velocity.

NUMERICAL MODELLING

Model development

A three-dimensional full-scale model of a 2.5 m high longwall face with shearer and four-legged check shields was created. Field investigations were conducted to obtain basic information on dimensions, airflow characteristics and respirable dust behaviour in an actual longwall face to obtain practical values for the input parameters and to select the boundary conditions properly. The average velocity of air flow was 2.1 m/s and air leakage into the gob was considered to be insignificant. Since the main focus of this study was on system level characteristics, a component level simplification in the geometry was therefore made. In modelling cables and legs, it was assumed that between the spill plate and the back row of legs a certain percentage of the flow passage was blocked by the front row of legs.

On all solid surfaces of both physical and blocked regions, a no-slip velocity boundary condition was specified, in which all components of velocity are zero. At the inlet boundary, a constant velocity for developing flow was specified as were values for the turbulent kinetic energy and dissipation. At the outlet boundary no boundary conditions were specified and it was assumed to be stress free to ensure that this boundary did not influence the fluid flow field inside the solution domain. During the modelling of dust behaviour it was assumed that the

respirable dust particles/pollutants have negligible inertia and follow the air flow closely apart from diffusional effects.

Simulations

All simulations were performed using FIDAP, a three-dimensional finite element computational fluid dynamics analysis program (Engelmann, 1991). This program, developed by Fluid Dynamics International, consists of a suite of computer programs for the analysis of fluid flow, heat and mass transfer and chemical reaction. A finite element approach for the discretisation of the equations and the segregated algorithm (Engelmann, 1991) was used to solve the equations. The turbulent viscosity was modelled using a k-epsilon model with standard values for the constants (Lauder and Spalding, 1974). As it was assumed that respirable dust particles have no effect on the flow pattern, the approach employed was to solve the flow field equations independent of the pollutant equation. The pollutant equation was then solved directly using the computed velocity field values. The numerical simulations were carried out in stages. Initially, only the longwall face was modelled, then the dust behaviour was simulated. Finally the dust control technique was introduced into the model. All simulations were carried out on a Sun Sparc workstation running under UNIX environment.
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MODELLING - RESULTS AND ANALYSIS

Longwall face

The air flow velocity across the section of the longwall face is shown in Figure 8. This plot shows that the air velocity at right angles to the face is not uniform and varies from a maximum over the armoured face conveyor (AFC) area to a minimum in the walkway. The maximum velocity in the walkway between the legs is between 40 and 50 per cent of the maximum value over the AFC area. Several simulations with different types of supports showed that the variation in velocity across the face depends largely on the type of supports and with them the cross-sectional shape of the longwall face. Dust concentration contours at more than 30 m from the source of dust and at right angles to the longwall face are shown in Figure 9. These contours show that dust concentration in the walkway is less than the concentration in the AFC area. This relatively low dust concentration in the walkway could, in some cases, be well above the Australian statutory limit of 3 mg/m². These findings indicate that dust behaviour largely depends on airflow characteristics.

Air-powered venturi scrubbers in walkway

The results of the simulations, with venturi scrubber located in the front walkway, are shown in Figures 10 and 11. Velocity vectors in Figure 10 show that the scrubber exhaust modifies the airflow pattern in the walkway area. The dust concentration shown in Figure 11 shows that an average protection efficiency of 40 - 50 per cent can be obtained within a distance of 3 - 4 m from the scrubber at 2.1 m/s face air velocity (compare Figures 9 and 11). Similar computations with different conditions show that the protection efficiency of this system depends on the scrubber exhaust velocity, quantity and face air velocity.

Comparison with field data

Field measurements of the air velocities and dust concentrations were carried out in working longwall faces. A comparison of the numerical results with the experimental values for dust profiles is presented in Figure 12, which shows that the numerical results agreed very well with the experimental results for 90 per cent of the face area. The coarse mesh used at walls resulted in a variation between the predicted and experimental values near the walls. Numerical modelling results with the venturi scrubber agreed very well (within ten per cent) with the field results presented above.

CONCLUSIONS

A prototype air powered venturi scrubber has been developed for use in longwall faces. The observed system protection efficiencies were between 32 per cent and 56 per cent, obtained at air velocities of 4.5 m/s (14.8 ft/s) to 2.0 m/s (6.6 ft/s) on the longwall faces. The scrubber capacity, the cleaned air exit velocity and the scrubber location determine the system's protection efficiency. Furthermore, the velocity of air in a longwall face greatly determines the amount of turbulence and effectiveness of the system in reducing dust exposure. The air powered scrubber is highly flexible and can be used in other applications such as:

1. in the shearer extraction drum or as a shearer mounted scrubber,
2. at transfer points,
3. on continuous miners in development headings, and
4. at the tailgate to reduce tailgate workers' dust exposure.

To augment field investigations, airflow fields, dust levels and the effectiveness of the scrubber system in a longwall face were simulated using finite element techniques. The simulated and field measured values for air velocities and dust concentrations tallied well. The effectiveness of the dust control techniques were also predicted to within ten per cent of the field values. Analysis of results shows that finite element modelling techniques are advantageous for a thorough understanding of airflow fields on a longwall face and for initial testing of new dust control techniques.

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REFERENCES