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INNOVATIVE CFD MODELLING TO IMPROVE DUST CONTROL IN LONGWALLS

Ting Ren[1] and Rao Balusu[1]

ABSTRACT: Reducing dust exposure of operators on longwall faces remains a challenging issue for mine managements. Most of the Australian mines are adopting uni-di cutting method to reduce operators dust exposure levels. Even in this uni-di cutting mode, the dust roll-up towards the walkway area is very high in most cases and is resulting in high dust exposure levels for shearer and chock operators.

With the support of ACARP, CSIRO has been undertaking several research projects (C12025, C13019 and C14036) based upon CFD modelling to improve the understanding of dust flow patterns around the longwall shearer and walkway under different operating conditions, and the study of a range of dust control options/concepts for reducing operators dust exposure levels. During these simulation studies, a shearer scrubber system has shown to be capable of significantly modifying the airflow patterns around the maingate cutting drum and reducing dust roll-up towards the walkway area.

INTRODUCTION

The behaviour of respirable dust in a longwall face is a complex process because of the nature of longwall operations. The generation, dispersion and transport of airborne dust is governed mainly by the spatial velocity and the movement pattern of the ventilation air. To understand the dust behaviour in a complex longwall mining environment and to evaluate the effectiveness of various dust control techniques, numerical modelling has become a necessity to supplement laboratory experiments and field studies.

CFD codes have been successfully used in South Africa and Australia in areas such as simulation of airflow patterns around coal cutting machines in development headings and longwall faces (Sullivan & Van Heerden 1993, Balusu et al. 1993). Results of the development heading study were used to investigate the effect of onboard scrubber and ventilation systems and to determine if the addition of a jet fan could minimise some of the negative effects of such systems. CFD models also helped in the investigation of the feasibility of different scrubber intake designs and establishing the most effective location for such intakes.

Recent work in CFD modelling of dust problems in longwalls and development roadways has demonstrated that this technique has major advantages over conventional numerical modelling for an improved understanding of air flow fields and dust behaviour in a three dimensional environment (Balusu et al., 2005). CFD techniques also provide a powerful tool for initial concept testing of new and innovative ideas for dust control.

This paper describes the development of 3D CFD models at CSIRO to investigate the airflow behaviour and the use of various controls on respirable dust dispersion on the longwall faces.

LONGWALL CFD MODELS

Three dimensional CFD models have been developed to investigate the airflow behaviour and respirable dust dispersion patterns in longwall faces mining thin, medium and thick seams. These models consist of a section of the full-scale coal face and the maingate, and embody the major longwall components such as chocks, shearer, spill plate, BSL/crusher and conveyor. Figure 1 shows the computational grid of the CFD model of the longwall shearer.

Base model simulations were carried out with a variety of intake airflow rates, ranging from $30m^3/s$ to $110m^3/s$, and were calibrated and validated against field airflow velocity data obtained from three Australian underground coal mines.

In these simulations, a cluster of respirable dust particles (particle sizes between 1~10 μm) were 'released' at various locations, mostly from the face spalling area and at a distance ahead of the cutting drum. The dispersion of particles in the face airflow was tracked by using the stochastic tracking (random walk) model. The function provides a powerful means of visualising the dust dispersion patterns and the impact of dust control methods such as the use of shearer scrubbers on dust capture and diversion. Figure 2 illustrates the tracking of respirable dust particle in the CFD modelling around the longwall shearer.

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The validated longwall CFD models were used to investigate the effect of mining and dust control options on face air and respirable dust flow patterns. These include face ventilation rate, drum cutting sequence, the use of sprays/venturi's and Shearer Clearer system, air curtains and shearer dust scrubbers.

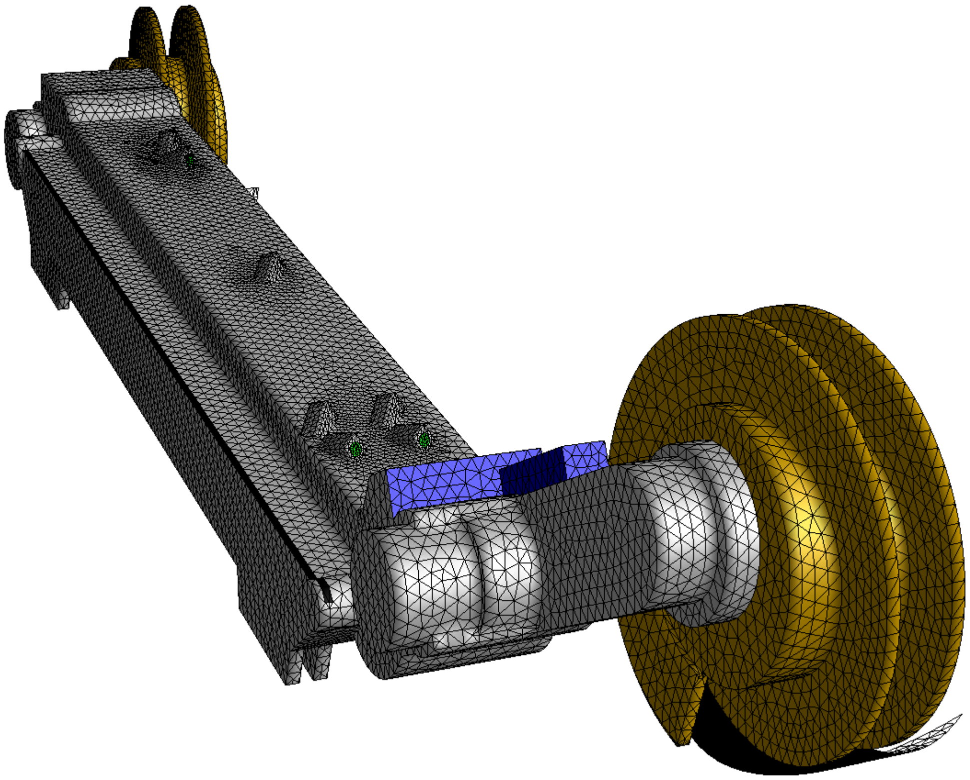


Figure1 - Computational mesh of the CFD model – the longwall shearer

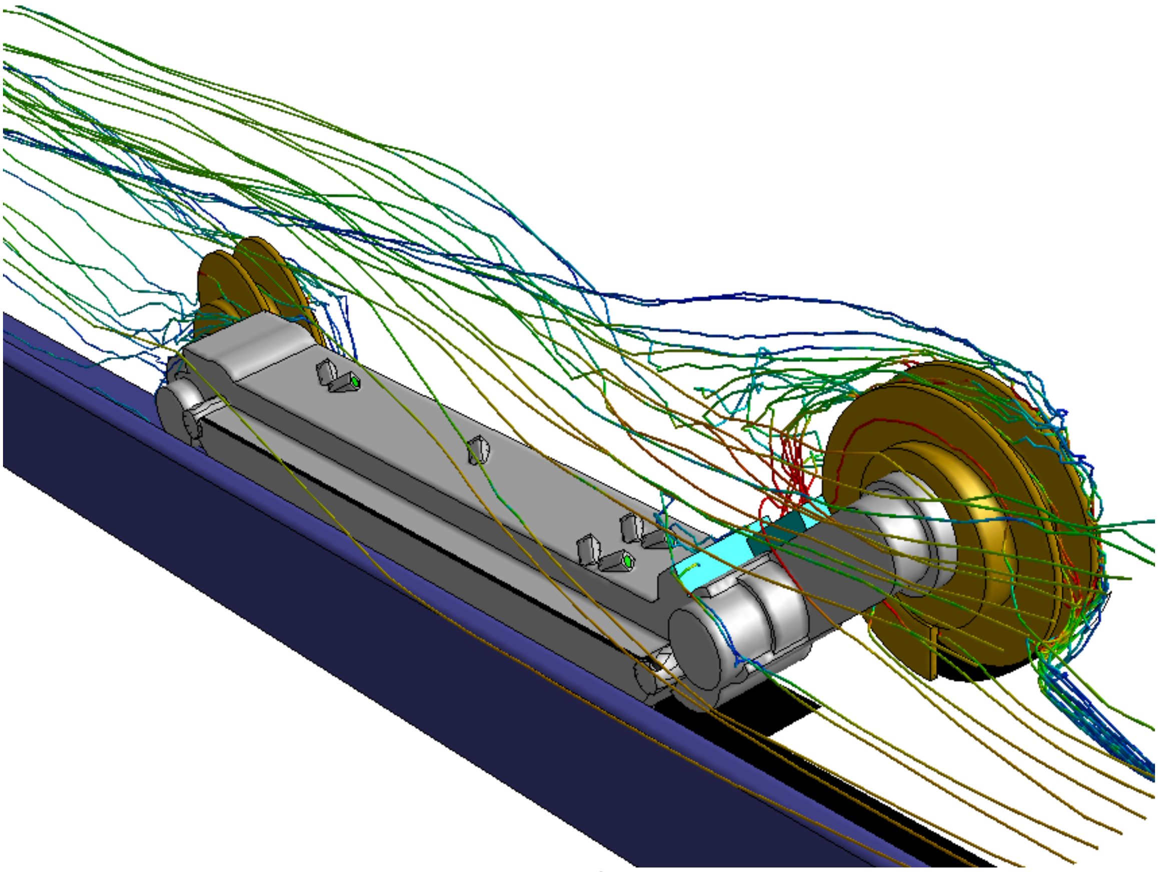


Figure 2 - Respirable dust particle tracking in CFD modelling around the longwall shearer

CFD MODELLING OF VENTILATION AND DRUM CUTTING SEQUENCE

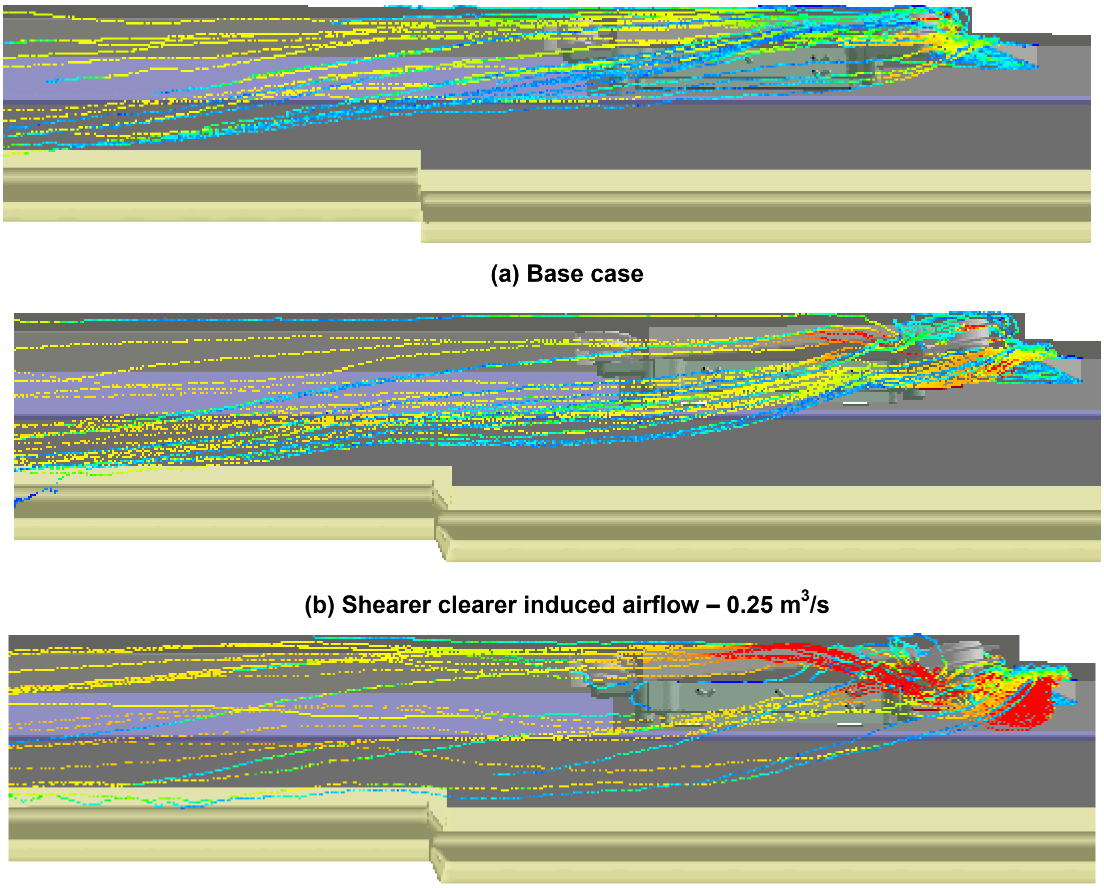
CFD results indicate that the dispersion of respirable dust on a longwall face is largely dependent on the location of dust generation and airflow patterns in that area. The dust dispersion from the cutting drum and face spalling is slightly more extensive on thick seam longwall faces with low airflow rate of around 35 m^3/s compared with higher airflows of around 55 m^3/s and 80 m^3/s. With face ventilation increased to 55 m^3/s, most of the dust particles from face spalling would be confined to the face/shearer area and away from the working zone of face operators.

With shearer cutting from MG to TG, instead of the standard TG to MG, it would reduce air diversion and the subsequent dust migration towards the walkway area. Cutting from TG to MG with a reversed drum (MG drum cutting at floor or mid-seam level, instead of at roof level) would reduce dust migration towards the walkway significantly, compared with dust migration in standard cutting mode. However, it is to be noted that some operational issues may restrict the application of these modified cutting sequences.

CFD MODELLING OF SPRAYS/VENTURI'S AND SHEARER CLEARER SYSTEM

Modelling results demonstrate that sprays/venturi's mounted' on the shearer body operating at a low flow rate of 0.1m^3/s would have only a limited impact near the upwind cutting drum area. However venturis operating at higher flow rates of about 0.5m^3/s would have a significant effect on airflow and the behaviour of respirable dust at both the cutting drums. In both cases, the sprays/venturis facing the downwind TG drum on the shearer body tend to pull the dust cloud towards the face. However, sprays/venturis directed at the upwind cutting drum significantly increases dust dispersion towards the walkway area.

As shown in Figure 3, a Shearer Clearer operating at 0.25 m^3/s flow rate would help reduce the dispersion of dust particles towards the face operators by inducing the dust cloud towards the face area, and at a higher flow rate of 0.5m^3/s, the performance of the Shearer Clearer system can be improved significantly. However, the area of influence of a 'Shearer Clearer' is very limited in thick seam environments and seems to have only marginal effect in reducing dust migration towards the walkway area. Shearer Clearer operating at higher flow rates of around 0.5m^3/s in a less than optimal direction can cause excessive turbulence, and may result in a significant dust migration towards the walkway area.



(a) Base case

(b) Shearer clearer induced airflow – 0.25 m^3/s

(c) Shearer clearer induced airflow – 0.5 m^3/s

Figure 3 - Effect of shearer clearer on respirable dust flow patterns – plan view (dust released near the coal spalling area)

CFD MODELLING OF AIR CURTAINS

CFD modelling results indicate that standard square air curtains along the shearer would only have limited impact on diverting the mainstream airflow in general and therefore marginal effect on separating the respirable dust particles from the shearer operators. Low height curtains installed over the shear body in parallel to airflow seems to be negligible in reducing face operators' dust exposure levels. Curtain installed near the shearer at an angle to the airflow seems to substantially alter the air and dust flow patterns and develop some recirculation zones around the curtain. The correct combination and orientation of curtains near the stage loader would substantially reduce the face operators' exposure to intake dust levels.

Airfoil curtains appear to have good potential in diverting airflows and subsequently dust particles away from shearer operator. These airfoil curtains, as indicated by CFD modelling in Figure 4, when properly aligned and attached to the shearer or ahead of the shearer, have the potential to modify the airflow patterns significantly in the vicinity of the shearer by diverting the air stream towards the face, thus helping the confinement and separation of respirable dust particles away from the walkway of the shearer operator.

CFD MODELLING OF SHEARER SCRUBBER SYSTEMS

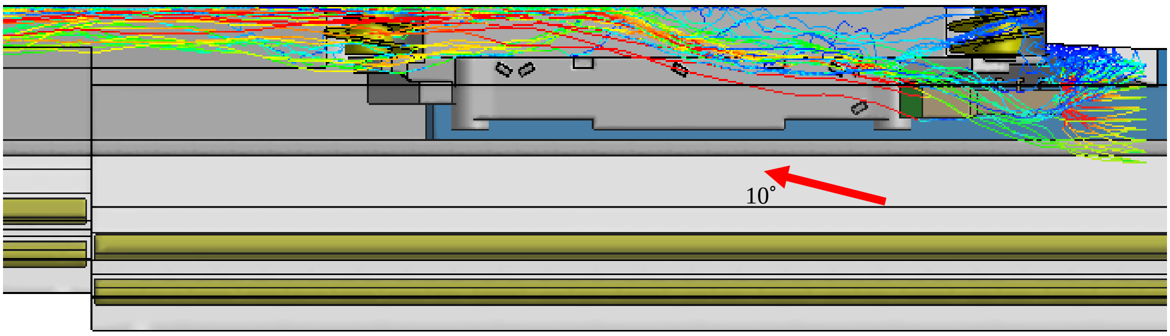
To prevent dust from becoming airborne, one of the several successful control measures in longwall faces is the use of dust scrubbers which cleanse the air and help to prevent the contaminated air from reaching areas used by mine personnel. Scrubbers have proven to be highly successful in reducing airborne dust at BSL and other conveyor transfer points. However, shearer-mounted scrubbers have not been used successfully on longwall faces. The capacity of a shearer dust scrubber is important in terms of dust capture efficiency and diversion impact on face airflow patterns.

Modelling results indicate that shearer scrubbers with flow capacity up to 4 m^3/s will have only a marginal effect on respirable dust flow patterns near the shearer, and the capture and diversion of the respirable particles would be significantly improved with a shearer scrubber operating above $8m^3/s$.

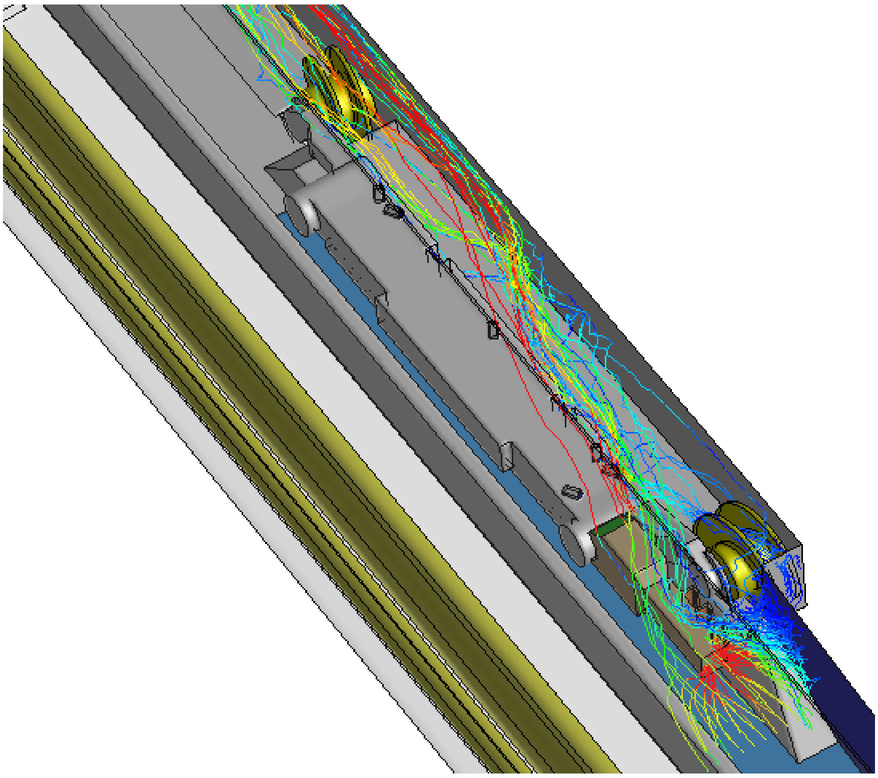
The scrubber capacity must be appropriate in relation to the prevailing face airflow rates (velocities) around the shearer. Scrubbers with a capacity around $8m^3/s$ would have a good impact on dust capture and dust flow patterns at moderate face ventilation of around 55 m^3/s. However, the capture efficiency of the scrubber (at $8m^3/s$) would be significantly compromised for longwall face with a high ventilation flow rate (above $80m^3/s$). In practice, a $10m^3/s$ scrubber might be the maximum capacity that can be installed on the shearer due to restrictions on the longwall faces. With this capacity and a moderate face ventilation rate (less than $60m^3/s$), the scrubber should be sufficient to capture a good portion of the dust particles and in the meantime modify the flow patterns near the shearer.

As shown in Figure 5, both the location of scrubber inlet and outlet are important in the design of an effective dust scrubber system. Scrubber inlet located on the edge of the shearer body facing the ventilation direction and close to the dust generating sources offers an improved advantage in capturing dust particles from both the spalling area and the roof ahead of the shearer. This position is particularly effective for capturing dust particles dropping from the roof and chock movements ahead of the shearer near the spalling area.

Scrubber outlet discharge angled slightly towards the face would help the confinement of dust particles to the face and the overall diversion of dust clouds away from the walkway; whilst if the outlet discharge is set at an angle against the general airflow stream, it would deflect a high portion of the escaped dust particles towards the walkway and downwards along the face, even if the scrubber has a high dust capture efficiency. Reduced scrubber outlet airflow velocity and turbulence would also help reduce dust particles roll-up into the operators' walkway on downwind side of the shearer.



(a) Plan view of dust particle capture and flow patterns - scrubber discharge at 10˚ towards the face



(b) 3D view of dust particle capture and flow patterns - scrubber discharge at 10˚ towards the face

Figure 5 - Dust particle capture and flow patterns with the new shearer scrubber capacity at 10m3/s – scrubber discharge 10˚ towards the face

In general, the modelling results indicate that total dust capture is not feasible for a dust scrubber attached to the shearer. The design of the scrubber system should be aimed to capture a proportion of the dust particles and modify the face flow patterns to divert respirable dust clouds from the shearer operator's position in the walkway area. This can be achieved by correctly positioning the scrubber inlet, discharge direction and matching the scrubber capacity with the face ventilation rate.

DEVELOPMENT OF A NEW SHEARER SCRUBBER FOR FIELD TRIAL

A new dust scrubber has been designed as a key part of the ACARP project C14036. The design of the new scrubber has incorporated the CFD modelling findings, including the desired scrubber capacity, the inlet locations and the airflow discharge direction from the elutriator. The manufacture of the shearer scrubber has been completed and is ready for trialling at a suitable mine site to evaluate the system's airflow pattern modifying capability near the leading cutting drum. These initial field trials will include evaluation of the scrubber system robustness, its interaction with other face cutting or shearer maintenance activities, its noise levels and the effect of curtains on operator's vision of the face cutting operations. The scrubber system's airflow modifying capability will be investigated in detail by taking a number of field measurements of airflow across a number of sections along the face. This will ensure trial results will be measured against CFD modelling results.

CONCLUSIONS

CFD modelling simulations proved to be an invaluable tool in understanding air and dust flow patterns on a longwall face and in studying the effect of various mining and operational parameters on dust dispersion and flow patterns.

Modelling results showed that cutting from MG to TG direction would reduce air diversion and the subsequent dust migration towards the walkway area; Simulations with modified cutting sequence in TG to MG direction with reversed drum showed that respirable dust migration towards the walkway reduces significantly, compared with dust migration in standard cutting mode. However, other operational issues may restrict the application of these techniques in some mines.

Sprays or venturis directed at the upwind cutting drum significantly increases dust dispersion towards the walkway area. Simulation results indicate that the area of influence of a 'Shearer Clearer' is very limited in thick seam environments and seems to have only a marginal effect in reducing the face operators' dust exposure levels.

A new dust scrubber has been designed and manufactured as a key part of the ACARP project. The design of the new scrubber has incorporated the CFD findings, including the desired scrubber capacity, the inlet locations and the airflow discharge direction from the elutriator. The manufacture of the shearer scrubber has been completed and is ready for trialling at a suitable mine site.

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