2013

Design and field trials of water-mist based venturi systems for dust mitigation on longwall faces

Ting Ren
University of Wollongong, tren@uow.edu.au

Shivakumar Karekal
CSIRO Earth Science and Resource Engineering

Graeme Cooper
Tecpro Australia

Zhongwei Wang
University of Wollongong

Brian Plush
University of Wollongong

DESIGN AND FIELD TRIALS OF WATER-MIST BASED VENTURI SYSTEMS FOR DUST MITIGATION ON LONGWALL FACES

Ting Ren[1], Shivakumar Karekal[2], Graeme Cooper[3], Zhongwei Wang[1] and Brian Plush[1]

ABSTRACT: Dust generation from longwall chock movement and the Beam Stage Loader/crusher (BSL) is a major source of air contamination on modern longwall faces. If not controlled effectively, much of these respirable dust particles would disperse quickly into the longwall due to high face ventilation velocities, contributing significantly to higher dust levels. A new water mist based venturi system has been developed for the purpose of suppressing respirable dust from longwall chock movements close to the maingate (MG). The unit is powered by compressed air and water using an ultrasonic nozzle embedded in a venturi body. The ultrasonic nozzle is capable of producing ultra fine water mist with droplet sizes ranging from 1 to 100 µm. Laboratory tests indicate that the ultrasonic nozzle (MAL-1300-B), when combined with a 70 mm (diameter) x 143 mm (length) venturi body, was can produce an optimum spray covering a distance over 10 m. Further tests show that a combination of air supply at 6 bar and water at 4 bar produces the optimum water mist thrust with inducted air velocity over 8 m/s. The venturi system was built as a stand alone unit using fire resistant and antistatic materials and can be easily hooked under the chock canopy with a magnetic base. The system can be powered by compressed air and water supplied to the longwall face and adjusted with the spray angle to achieve the droplet size and velocity needed for dust suppression and diversion. Computational Fluid Dynamics (CFD) modelling was undertaken to gain a better understanding of face ventilation and dust flow patterns to optimise the spray orientation of the venturi system for field trial installation. CFD modelling results show that the operating conditions of sprays with the best mitigation performance vary according to the source of dust, a better dust mitigation effect can be achieved when the venturi units on longwall chock are installed at 20° down towards the floor and tilted 45° along the face. Field trials were conducted at two underground longwall mines in QLD and NSW. Three venturi units were installed on Chock No 6 on the longwall with an additional unit trialled at the BSL to mitigate dust from longwall outbye. Dust measurements with real time monitoring Personal Dust Monitor (PDM) and gravimetric samplers indicate dust mitigation efficiency up to 30% has been achieved in both trials.

INTRODUCTION

Respirable dust particles can be generated from several sources on the longwall, primarily shear cutting, chock movements, BSL and intake contaminations. As the supports are lowered and advanced, crushed coal and/or roof rock drops from the top of the canopy into the air flow on the longwall face. As a result, chock movements can be a significant source of respirable dust for shearer operators when chocks are advanced upwind of the shearer during a maingate to tailgate cut.

Gillies and Wu (2007; 2008) conducted extensive real-time respirable dust monitoring and baseline surveys on Australian longwalls. During the cutting sequence from Maingate (MG) to Tailgate (TG), 1-5 MG Chocks were advanced immediately after the shearer passed. This action leads to dust falling from the advancing chocks; dust levels registered by both PDM units were increased significantly, accounting for about 47.8% of total longwall dust make at the Shearer MG operator's position during the cutting cycle. Similar observations have also been reported at other mines in Australia. The dust baseline survey results demonstrated the importance of reducing respirable dust generated from the movement of MG chocks thereby significantly mitigating total dust make to the longwall face. Dust monitoring also showed that the BSL can be another major dust contributor, even for longwalls equipped with a BSL dust scrubber. Dust surveys indicated that the scrubber can cleanse only a portion of the air travelling to the face, allowing a high proportion of the dust particles to escape over the BSL and to end up on the longwall face, increasing the threshold dust levels in the ventilation air.

[1] *University of Wollongong, tren@uow.edu.au, Tel: +61 2 4221 4186*
[2] *CSIRO Earth Science and Resource Engineering*
[3] *Tecpro Australia*

Water sprinklers/hoses are widely used for dust control on longwalls to suppress the dust particles before they become airborne. However, conventional hydraulic water sprays are not effective on respirable dust. With typical diameters of 200-600 µm sprays, the droplets are much larger than the dust particles they are attempting to suppress. Water drops that are too large will not collide with the finest, most hazardous dust particles smaller than 10 µm. The attraction of water droplets and dust particles is most likely to occur when their dimension is of similar size.

With the support of ACARP, a new type of venturi system based on ultrafine water mist technology has been developed to reduce respirable dust contamination on medium and thick seam longwall faces, particularly those dust particles from the advancement of MG chocks and the intake ventilation passing the BSL. The venturi system was initially fabricated and tested in the laboratory and field trialled near the MG chocks in two longwalls extracting medium to thick seams. Detailed CFD modelling studies of the airflow dust particle dispersion patterns from MG chocks and the BSL was conducted to determine the optimum positioning of the water mist venturi unit(s) for effective dust control. System performance was evaluated in terms of Dust Mititigation Efficiency (DME) in two underground coal mines. This paper describes the design, laboratory testing, CFD modelling and the field trial results of the water mist based venturi units for longwall dust mitigation at two underground coal mines.

DESIGN OF A WATER MIST BASED VENTURI SYSTEM

Several industrial processes need the atomising of liquids into fine and very fine droplets. In the majority of industrial processes a fine liquid atomisation can be obtained by means of air assisted atomisers, where compressed air supplies the required energy to break the liquid and to throw the droplets at a given distance from the atomiser. Ultrasonic atomisers produce the finest sprays available with air assistance for industrial processes such as dust suppression. Water and air do not mix in a confined volume before leaving the nozzle and therefore their feed pressures can be adjusted independently without influencing each other. This allows for a very wide regulation range on the liquid capacity and makes it easier to reach the desired operating conditions. Figure 1 shows a typical ultrasonic nozzle and the fine mist produced by such a device.

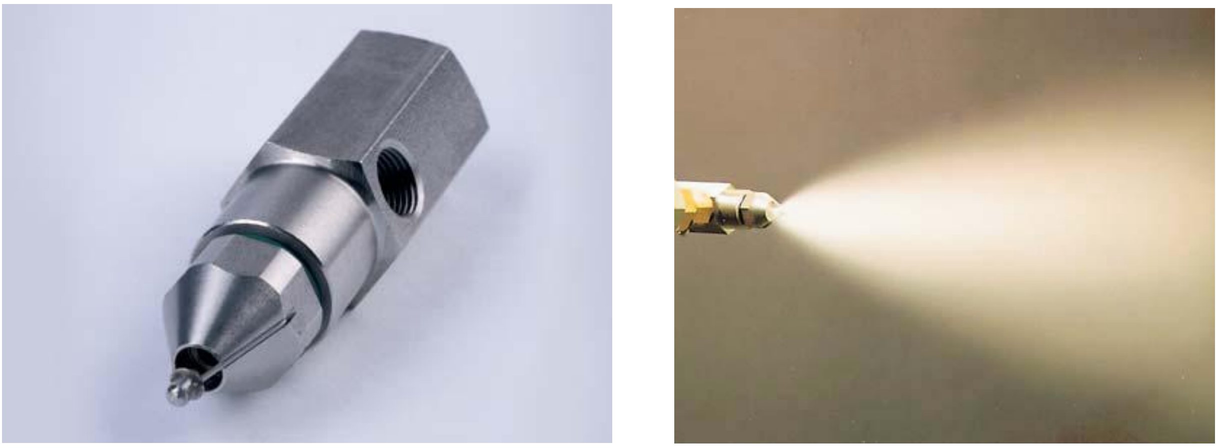


Figure 1 - A typical ultrasonic nozzle and the fine mist produced

Venturi apparatus has been used in many industry processes. As fluid flows through a length of pipe of varying diameter, the velocity of the fluid increases as the cross sectional area decreases, and the static pressure correspondingly decreases. According to the laws governing fluid dynamics, a fluid's velocity must increase as it passes through a constriction to satisfy the principle of continuity, while its pressure must decrease to satisfy the principle of conservation of mechanical energy. A venturi can therefore be used to mix a liquid such as water with gas or air. If a pump forces liquid through a tube connected to a system consisting of a venturi to increase the liquid speed, the diameter decreases, a short piece of tube with a small hole in it, and last a venturi that decreases speed (so the pipe gets wider again), the gas or air would be drawn in through the small hole because of changes in pressure. At the end of the system, a mixture of liquid and gas would appear. Therefore by embedding an ultrasonic nozzle with a venturi apparatus, a water mist venturi system can be built.

Considering the limited space when a chock is lowered, the unit had to be compact enough to leave enough clearance between the AFC and any spalling coal lumps so that the units could avoid being knocked off or damaged after installation. At this stage, it was designed to be operated manually following the movements of the MG chocks but with the potential of being integrated into the longwall automation system should the system prove effective and robust after the field trials.

Figure 2 shows a schematic layout of a prototype venturi developed in this project. The venturi system essentially consists of a water mist generating chamber incorporating mounting holes via which water and compressed air can be introduced to the ultrasonic atomisers to produce very fine droplets. Water is ejected through a number of orifices into the nozzle air outlet channel, where the high velocity air stream produces the first liquid breakup through a shearing action. The air stream, carrying the droplets, collides with a resonator placed in front of the nozzle outlet channel that generates a field of high frequency sound waves. Water delivered to the resonator is shattered into fine droplets which are carried downstream by the air by-passing the resonator. The system was designed to perform the following two functions:

- To produce uniformly distributed ultra fine water droplets for encapsulating and trapping a high proportion of the respirable dust particles before they become airborne and reach the walkway area.
- To induce a controlled volume of water-mist airflow with sufficient momentum for diverting and suppressing respirable dust clouds off the walkway area along the face.

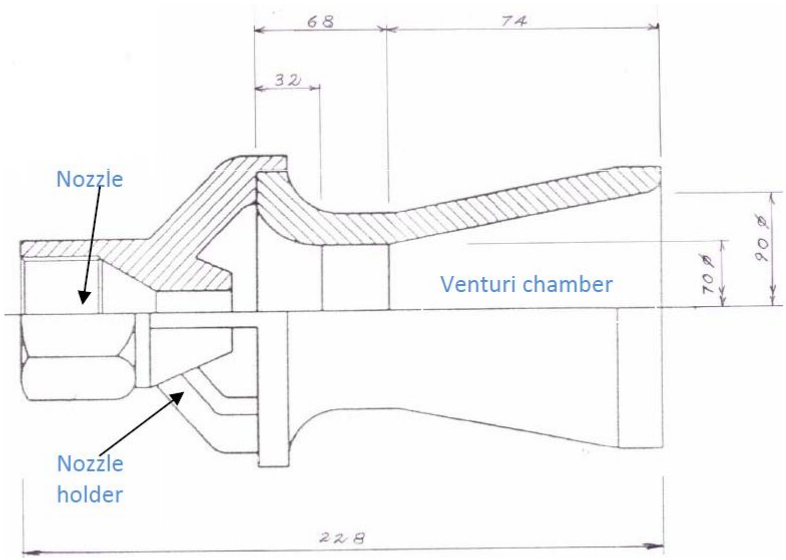


Figure 2 - A schematic layout of a prototype venturi (unit in mm, not to scale)

To achieve the above design requirements, comprehensive laboratory tests were carried out with different venturi chamber diameters (42 ~ 70 mm), venturi lengths, methods for mounting the ultrasonic nozzles, as well as air pressures (ranging from 2~8 bar) and water pressures (ranging from 1~6 bar). The ultrasonic nozzle holder assembly with different nozzles was used to test the best combination by varying the distances between the nozzle and the venturi to optimise the water mist production and air induction effect. Test results indicated that the 70 mm (diameter) x 143 mm (length) venturi was capable of producing an optimum spray coverage and spray distance of approximately 10~12 m in the underground environment. The ultrasonic nozzle used was MAL 1300 B1, as shown in Figure 3. Figure 4 shows the various parts of the venturi unit and laboratory testing process.

The novelty of this new system is its capability to draw air into the chamber to carry the atomised droplets downstream with sufficient momentum for maximum dust particle attraction and controlled diversion away from the walkway area. In order to utilise the existing water and compressed air supply on the longwall face, the system was built as a stand-alone module with a magnetic base which can be easily attached to the chocks' canopy and adjusted with the right spray angle to achieve the droplet size and velocity needed for dust suppression and diversion.

Laboratory tests showed that having a ratio of 2:1 air to water seems to produce the best atomisation for the ultra fine water mist nozzle, i.e. if liquid pressure is 3 bar, ideal air pressure would be 6 bar. Water consumption at 3 bar liquid pressure and 6 bar air pressure would then be 2.15 L/min or 0.0358 L/s. The mist produced was of such a fine size that it remained airborne as a 'dry fog'. As the mist evaporated, it had an evaporative cooling effect which, over a period of time, could effectively reduce temperatures on the longwall face. Further tests showed that at an air pressure of 6 bar and water pressure of 4 bar, the water mist produced by the venturi unit was found to travel over 8 m with inducted air velocity over 8 m/s. Water consumption in this case was about 2 L/min for a single unit. Figure 5 shows the air and water coupling pipelines and manifold regulating the first prototype water mist venturi systems for field trials.

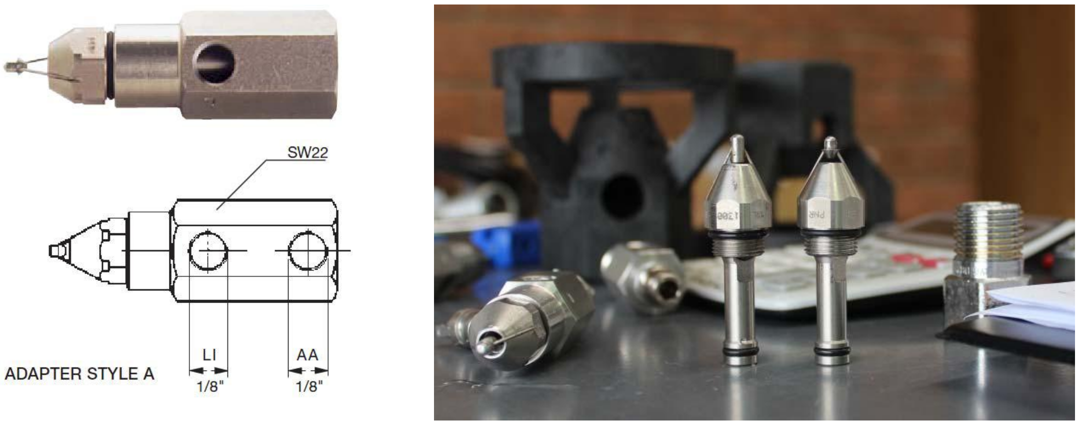


Figure 3 - Ultrasonic nozzles MAL 1300 B1 and MAD 1131 B1

Figure 4 - Design and testing of the water mist based venturi system

A complexity during the development of the venturi system was that all materials used for the unit have to comply with combustion propagation characteristics requirements of MDG 3006 MTR8.8.2.b and antistatic properties (electrical resistivity) requirements of MDG 3006 MTR8. 8.3, prior to any field trials in underground coal mines in NSW. Therefore a new material had to be sourced and tested by the Mine Safety Technology Centre, NSW Department of Trade and Investment. All the materials used for the final venturi units passed the required tests and satisfied the above requirements. Figure 6 shows the complete assembly of four venturi units using the Fire Resistance and Antistatic (FRAS) materials.

Figure 5 - Air and water coupling pipelines and associated manifold regulating the venturi units and the assembled first prototype unit for field trial

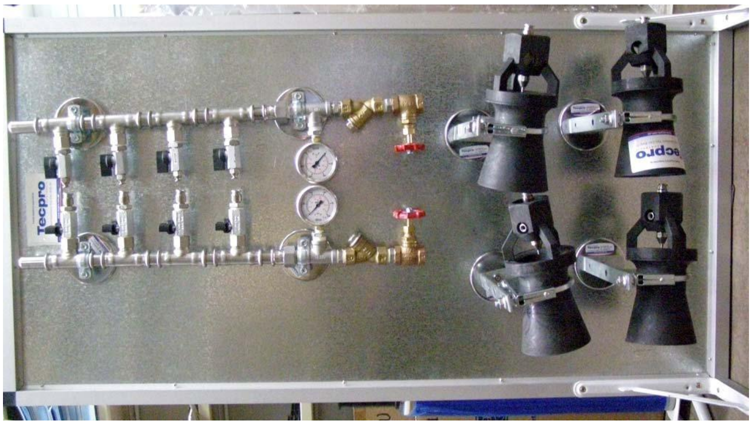


Figure 6 - An assembly of four venturi units made up of fire resistance and antistatic (FRAS) material

CFD MODELLING OF DUST DISPERSION FROM MG CHOCKS AND BSL

CFD models

A major challenge in this study has been the understanding of the dispersion of dust particles from chock movement in the turbulent flows on the longwall face, and the optimum position of venturi units under the canopy to suppress and divert the dust clouds. CFD has proved to be capable of investigating a series of factor affecting the behaviour of longwall dust, such as the impact of ventilation, cutting sequence and local geological conditions (Ren and Balusu, 2005; 2010).

In this study, a full scale longwall face, with 103 chocks, shearer, AFC, BSL and belt conveyor equipped along the face and MG was built up in the design modeller under the Ansys 13 Workbench (2010) on the basis of information collected from a mine site. The longwall face has a physical domain of 156.5 m (face length) X 50 m (MG length) X 3.5 m (face cutting height), and the last cut through 45 m outbye the face. The longwall shearer was located 10 m away from the MG. The model was meshed using the tetrahedron method with over 1.8 million elements. Figure 7 is a snapshot of the longwall CFD model and computational mesh.

Base model simulations were carried out with a face airflow rate of 45 m3/s without the intervention of any dust controls. The base-case CFD models were calibrated and validated against field ventilation survey data and subsequently used for further parametric studies of the water mist venturi systems.

Modelling of water mist venturi

To optimise the position of the water mist venturi units on the MG chocks, the base CFD models were used to conduct parametric studies on a number of combinations of venturi positions along the MG chocks (1-6) and on the AFC/BSL plate, including:

1. With venturi attached the chock canopy, with

- Venturi at canopy level - towards the coal face;
- Venturi at canopy level but tilted along the face (10~45˚);
- Venturi tilted down and along the face.

2. With venturi stationed on the AFC/BSL plate, with

- Venturi spray towards the coal face;
- Venturi spray with angles along the face.

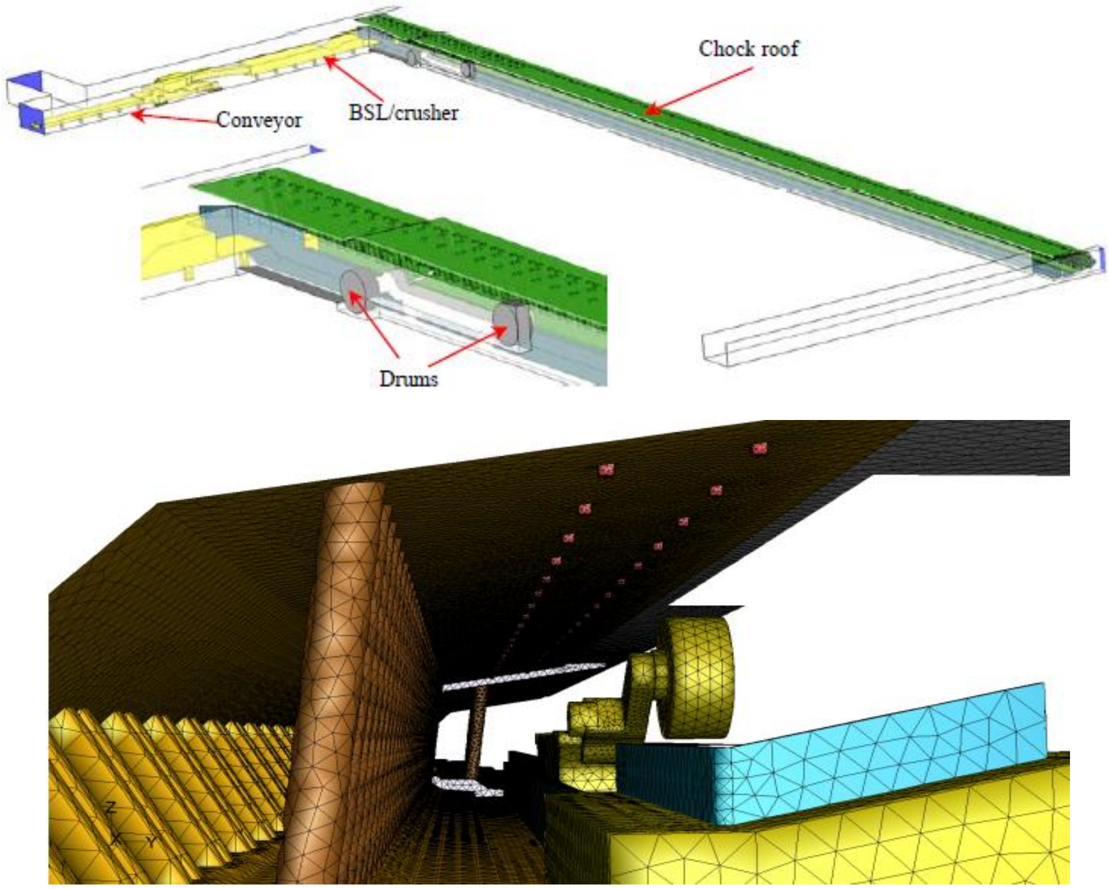
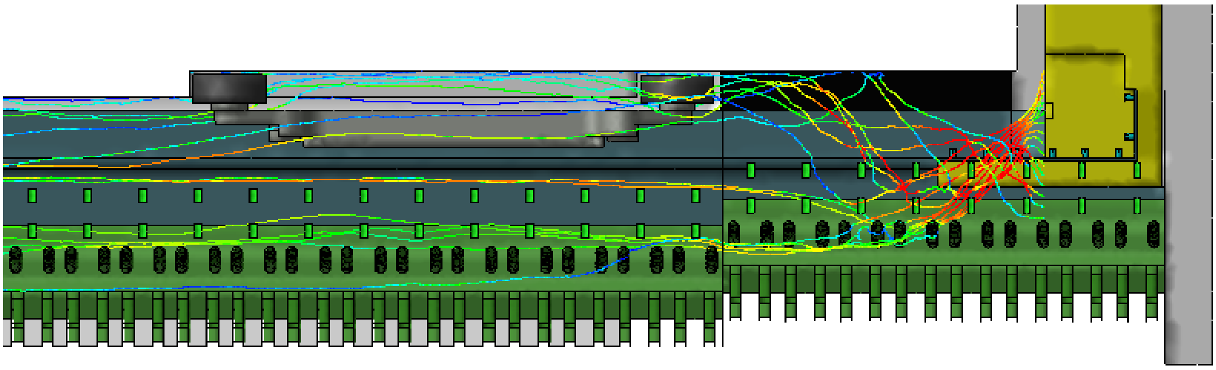


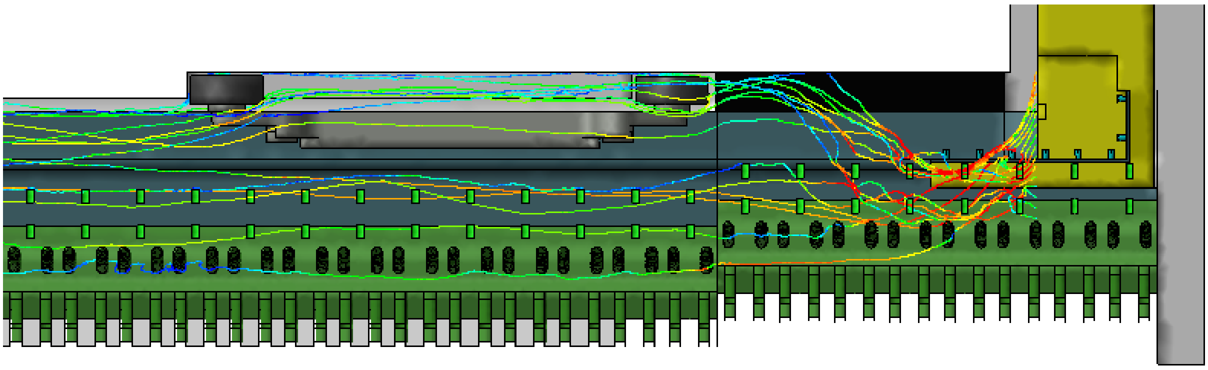
Figure 7 - Layout of the longwall CFD model and computational mesh

In all cases, the water mist injection was modelled as 'air spray' as much of the spray would be of compressed air with a small portion of fogged water droplets. This also avoids the complexity of modelling multiphase flow which would require much computing power and time. Figures 8 to 10 respectively show the impact of venturi units oriented at different locations on the diversion of dust particles from both MG chocks and the BSL transfer point.

CFD modelling results show that the operating conditions of sprays with the best mitigation performance may vary according to the source of dust. To achieve an overall good mitigation effect, it is suggested that sprays in the face should be operated at 20° down and tilted 45° along the face; sprays on the AFC/BSL spill plate should be operated at 30° towards the floor and 20° along face. Results from the CFD modelling were used to assist field trials of the newly developed water mist based venturi systems as described below.

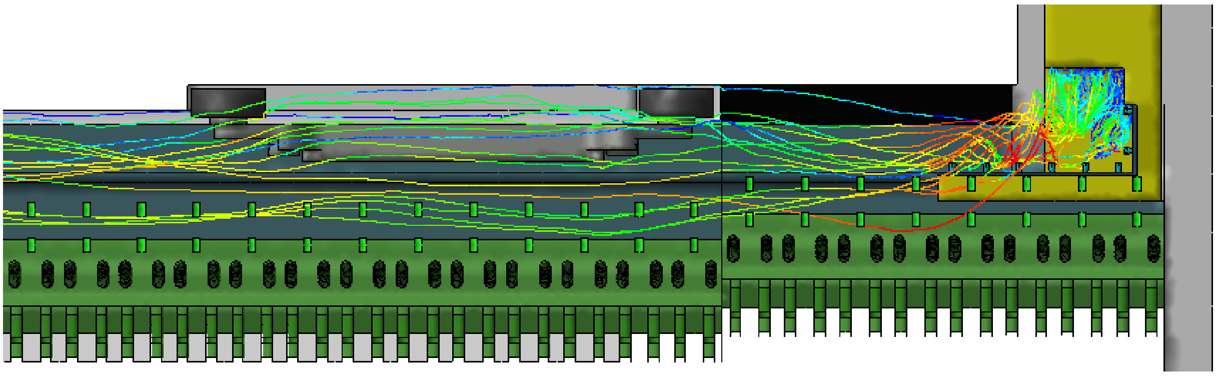


(a) Venturi units operating at level and titled 20° along face

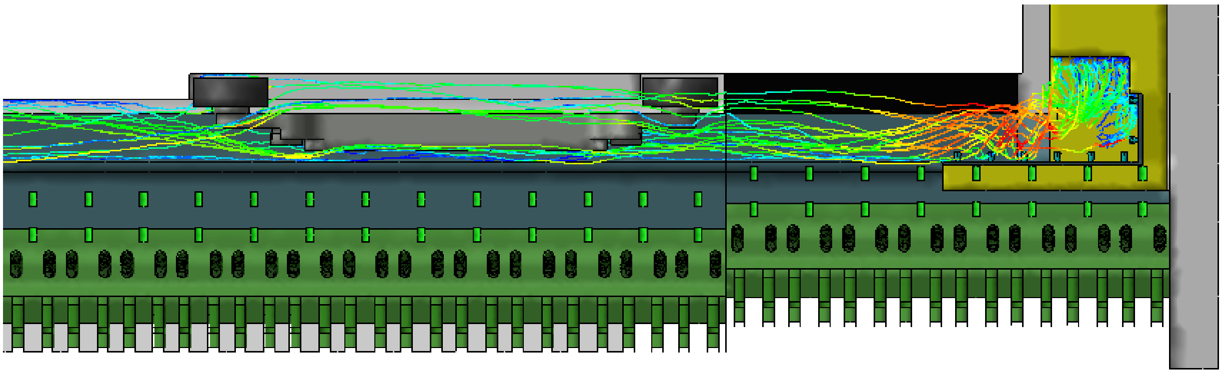


(b) Venturi units operating at 20° down and titled 30° along face

Figure 8 - Dust dispersion pattern with venturi units operating at different orientations - dust from MG chocks and BSL

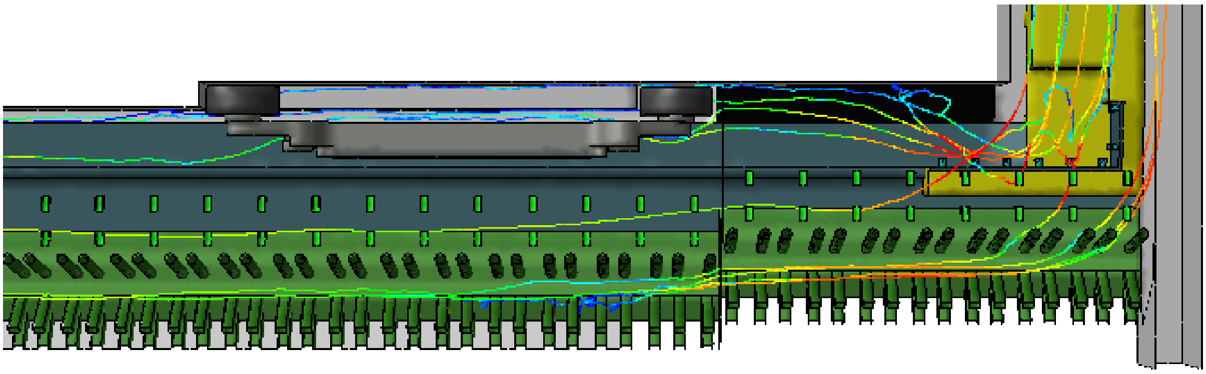


(a) Venturi units operating at level and titled 20° along face

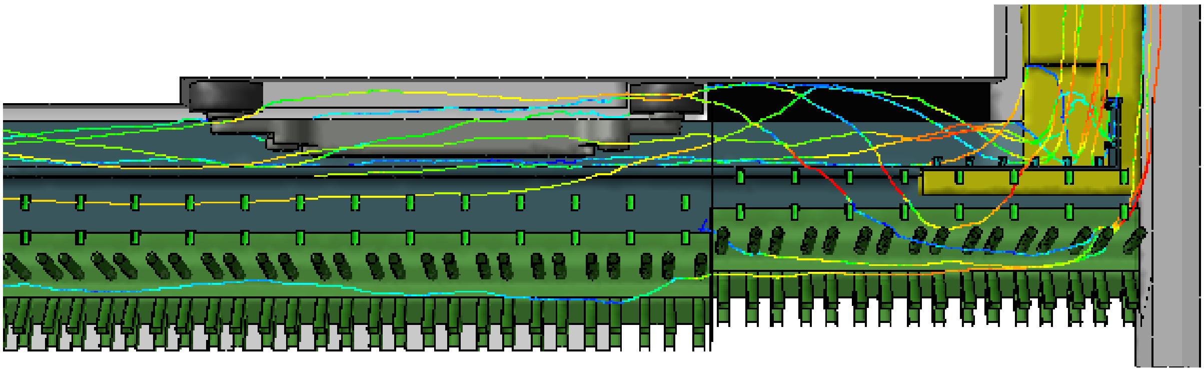


(b) Venturi units operating at 20° down and titled 30° along face

Figure 9 - Dust dispersion pattern with venturi units operating at different orientations at the spill plate - dust from BSL



(a) Venturi units operating at level and titled 20° along face



(b) Venturi units operating at 20° down and titled 30° along face

Figure 10 - Dust dispersion pattern with venturi units operating at different orientations - dust from BSL and outbye dust

FIELD TRIALS AND PERFORMANCE EVALUATIONS

Field trials at MINE A

The first field trials were conducted at a longwall face in the Bowen Basin, QLD. Wu Mining Technology Pty Ltd was commissioned by MINE A to undertake a real time dust survey on their production face to establish the improved longwall respirable dust situation during cutting operational cycles after the installation of a water mist venturi system. Figure 11 shows the face layout indicating the location of the water mist venturi system. The dust sampling was undertaken at MG Drive, Chock No 8 and shadowing shearer operators. Ventilation conditions and the position of shearer and manned position during cutting operational cycles were also recorded.

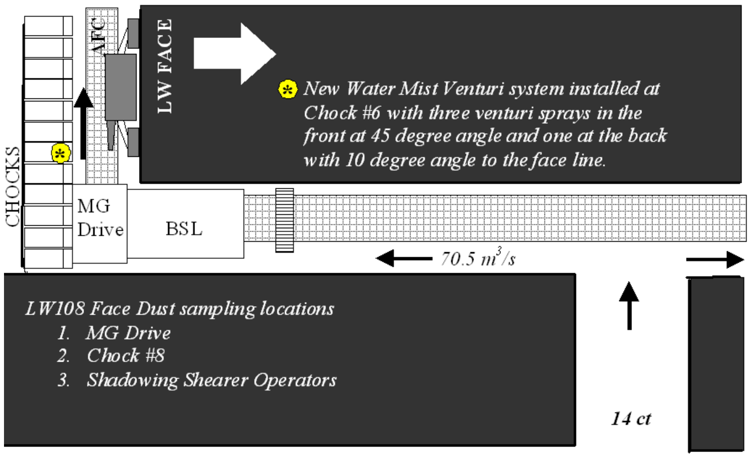


Figure 11 - Venturi units attached to the canopy of the longwall chock for field trials

Table 1 shows a summary of the test results on the effectiveness of the installed venturi system on dust mitigation. A comparison of the dust levels and dust made at the Chock No 8 (PDM stationary) and shearer operator (PDM shadowing) shows that the water mist venturi system has reduced the dust levels by 20~30% at Chock No 8 and 8~31% for the dust exposure levels of shearer operator.

Table 1 - A summary of test results from field trials at MINE A

Test cycle conditions (22 December 2010)	Average dust concentration at monitoring positions (mg/m^3)	
	Chock #8 position	MG shearer operator
Shearer cycle #1 sprays Off	0.24	0.93
Shearer cycle #2 sprays On	0.19	0.64
Dust reduction (%)	20.6%	31.3%

Test cycle conditions (23 December 2010)	Average dust concentration at monitoring positions (mg/m^3)	
	Chock #8 position	MG shearer operator
Shearer cycle #1 sprays Off	0.73	0.94
Shearer cycle #2 sprays On	0.51	0.86
Dust reduction (%)	30.5%	8.4%

Observations of field trial at MINE A

The mine management was happy to see the trial results and the longwall crew welcomed the venturi system. This initial trial demonstrated that the water mist based venturi units can be used to reduce dust contamination from longwall chock movements. During the trial period, the venturi units adequately cleared of the floor and other equipment and posed no interference to the longwall production process. This enabled the units to survive the longwall environment allowing its continued use for dust mitigation. A concern raised during the trial was the wetting of water mist. When the venturi units were turned on, the water mists can travel quite some distance (greater than 20 m) along the face and can wet the longwall operator(s). This problem could be avoid or minimised by positioning the units further under the canopy or by turning off the units once the advance of the first five MG chocks was completed. During the trials, the venturi units were turned on during the entire production cycle (even after the advance of first five MG chocks). These units were designed to be used only during the advance period of these MG chocks and they should be turned off once the chock movement is completed. This would avoid the wetting and visibility problems.

Field trials at MINE B

Field trials were conducted at MINE B in NSW along with dust surveys to evaluate the dust mitigation efficiency on the venturi units installed on the MG chock and BSL. A benchmark test was undertaken specifically designed to measure the amount of dust produced during shield movement in the maingate area as the longwall progresses with further sampling taken for venturi sprays installed at the maingate (BSL) and at Chock No 6. The longwall was vented with an air flow rate of around 45 m^3/s during the field trial.

Based on the trial experience at MINE A, four venturi units were delivered to MINE B and installed for field trials of which three units were installed on Chock No 6, and one unit on the maingate BSL. Figure 12 shows the installation of the venturi units on the BSL/maingate (Figure 12.a) and the longwall Chock No 6. As shown in Figure 12.b, these units were installed just under the canopy forehead and tilted along the face at angles between 15-20° down and 45° along the face, as indicated by CFD modelling. Air and water supplied to these units were around 6 bar and 3.5 bar respectively, with a water consumption of 2 L/min per unit (total of 6 L/min for three units). The induced airflow velocity at the outlet mouth of the venturi unit would be around 8 m/s according the lab test results, thus having some momentum for diverting and streamlining respirable dust clouds off the walkway area along the face.

(a) Venturi unit installed on the BSL in the maingate

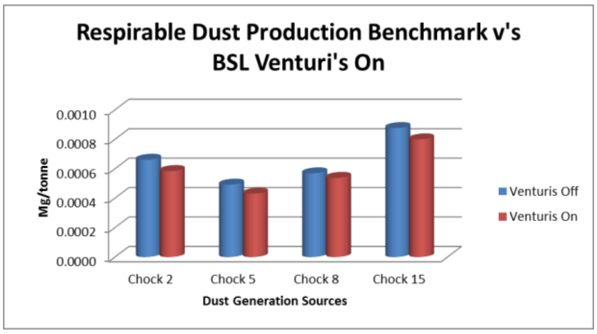
(b) Venturi units installed on MG Chock

Figure 12 - The installation of the venturi units on the longwall face

Dust Mitigation Efficiency evaluation

Dust Mitigation Efficiency (DME) was conducted according to AS2985 (Workplace Atmospheres - Method for sampling and gravimetric determination of respirable dust) using an approved universal pump and sample heads (Plush, *et al.*, 2012). The gravimetric sampling for exposure levels relies on a time weighted average to determine personal exposure levels of employees working on a producing face. The gravimetric heads would need to be changed during the testing process in order to measure dust loads generated firstly as a benchmark dust production of the operating longwall and then when the venturi sprays are operating. The weighed difference would indicate DME.

Figure 13 shows the dust production at different longwall chocks when the BSL venturi was off and on. The results show that this single venturi unit has reduced dust production along the longwall face between 5~13%.



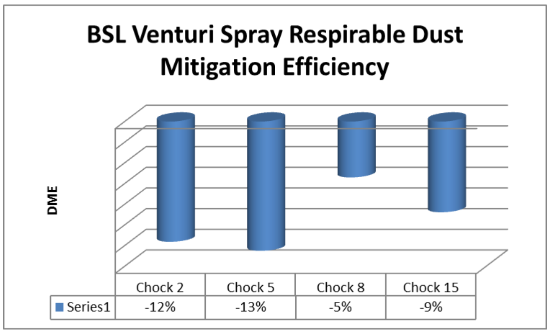
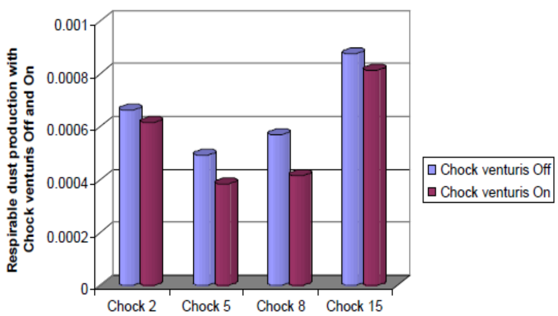


Figure 13 - Respirable dust production with BSL venturi system off and on

Figure 14 shows the dust production at different longwall chocks when the venturi units on Chock No 6 were off and on. The results show that dust reduction up to 27% on Chock No 8 has been achieved.



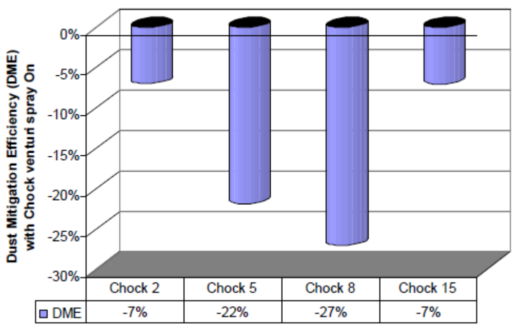


Figure 14 - Respirable dust production with venturi system off and on

Figure 15 shows the combined respirable dust mitigation efficiency. Overall dust mitigation efficiency up to 35% has been achieved at Chock No 5 and 16% down to Chock No 15. The results of the testing show that the venturi sprays have a significant effect on respirable dust in the maingate area, more specifically from Chock No 2 to Chock No 15. The BSL venturi saw a reduction of respirable dust by 12% at Chock No 2, 13% at Chock No 5, 5% at Chock No 8 and 9% at Chock No 15.

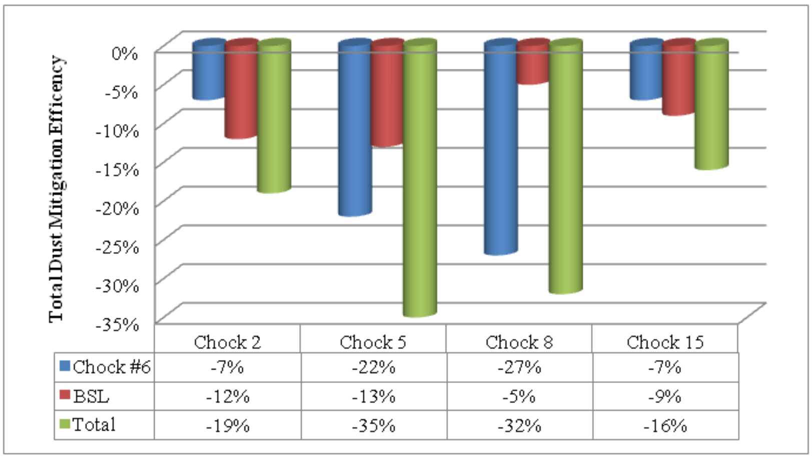


Figure 15 - Total respirable dust mitigation efficiency with both BSL and Chock No 6 venturi units operating

Field trial observations at MINE B

The management team at MINE B strongly supported the field trials during the entire project and was pleased to see the encouraging results. The longwall crew also welcomed the venturi system as a new tool for combating dust contamination on the longwalls. Field trials demonstrated that the design of the water mist based venturi units has been a success to reduce dust contamination from longwall chock movements and the maingate/BSL.

The positions of these venturi units, either on the BSL or MG chocks, are important in diverting and suppressing the dust clouds with minimum wetting issue on the longwall. The installation and adjustment of these units has been simple and straight forward without any disturbance to existing equipment or operation. Again these venturi units demonstrated their robustness and remained clear of the floor and other equipment without being damaged during the trials. However the issue of wetting by the water mist travelling along the face has been noticed during the tests. When the venturi units are turned on, the water mist can travels some distance along the face, and at some point, the water mist cloud would be more widely dispersed across the face. Although offering additional benefits of dust suppression and cooling, it does however have the side-effect of wetting and in some case, causing poor visibility.

This problem can be minimised by positioning the units further towards the front under the canopy or by turning off the units once the advance of the 1~5 MG chocks were completed. Again during the trials, the venturi units were turned on during the entire production cycle (even after the advance of 1~5 MG chocks). It should be noted that these units should be used only during the advance period of 1~5 MG chocks and be turned off once the chock movement is completed. This would avoid the problem of over wetting and potential visibility problems.

CONCLUSIONS

Longwall chock movements have been identified as a significant source of dust exposure to longwall operators when chocks are advanced upwind of the shearer during MG to TG cutting. Using the latest development of ultrasonic nozzle technology and CFD modelling results, a new water mist venturi system has been designed and field trialled successfully to mitigate dust particles from MG chock movements. Field trials at two underground longwall mines indicated a respirable dust reduction up to 30% when these units are installed on longwall Chock No 6 and BSL discharge point. Field observations proved that the design of the water mist based venturi unit is robust and safe to use in underground coal mines for dust mitigation. Further trials are needed to improve its operation and eliminate face wetting by incorporating the venturi operation into the longwall automation system. The potential for the application of this technology in other areas of mining are enormous, particularly in underground coal mines and hard rock mines. Such units can be deployed for dust mitigation in roadway drivage heading, tunnelling, surface stockpiling and mineral processing plants.

ACKNOWLEDGEMENTS

The authors are grateful to ACARP for funding the research work presented in this paper, and the strong support from many mines for the development and field trials of the venturi systems, particularly Broadmeadow, Moranbah North and Metropolitan mines.

REFERENCES

Gillies, S and Wu, H W, 2007. Mine real time personal respirable dust and diesel particulate matter monitoring, Proceedings, *Queensland Mining Industry Health and Safety Conference*, Townsville, pp 407-416.

Gillies, S and Wu, H W, 2008. Underground atmosphere real time personal respirable dust and diesel particulate matter direct monitoring, in *Proceedings of 8th Underground Coal Operators' Conference* (Eds: N Aziz and J Nemcik), 14 - 15 February 2008, Wollongong, Australia. pp 143-154. http://ro.uow.edu.au/coal/14/.

Ren, T and Balusu, R, 2005. Dust control technology development for longwall faces - simulation studies, ACARP Project C13019, Exploration and Ming Report, P2005/394, September 2005, pp90.

Ren, T and Balusu, R, 2010. The use of CFD modelling as a tool for solving mining health and safety problems, in *Proceedings of 10th Underground Coal Operators' Conference* (Eds: N Aziz and J Nemcik), 11-12 Feb 2010, Wollongong, Australia. Pp 339-349. http://ro.uow.edu.au/coal/319/.

Plush, B, Ren, T and Aziz, N, 2012. A critical evaluation of dust sampling methodologies in longwall mining in Australia and the USA, in *Proceedings of 12th Coal Operators' Conference*, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2012, pp 193-201. http://ro.uow.edu.au/coal/407/.