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Respirable dust generation and mitigation in Australian underground coal mine development headings – applications of computational fluid dynamics for respirable dust modelling

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RESPIRABLE DUST GENERATION AND MITIGATION IN AUSTRALIAN UNDERGROUND COAL MINE DEVELOPMENT HEADINGS – APPLICATIONS OF COMPUTATIONAL FLUID DYNAMICS FOR RESPIRABLE DUST MODELLING

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ABSTRACT: Respirable coal and silica dust has long been recognised as causing lung diseases such as silicosis and Coal Worker's Pneumoconiosis (CWP). These lung diseases and other lung diseases caused from mining are now placed under an umbrella term Mine Dust Lung Disease (MDLD). The re-emergence of MDLD (particularly CWP) in Australia has necessitated extensive research into the field of preventing MDLD.

Computational Fluid Dynamics (CFD) has allowed the industry to model dust flow in underground coal mines, allowing for extensive testing in ventilation flow and other dust mitigation strategies to determine the best practice for individual coal mines. A literature review identified that further study into the applications and power of CFD in underground mining applications is necessary in the industry. Further study would allow the industry to apply the full power of CFD into modelling practices to test strategies and tailor dust mitigation practices for each individual mine to get the best possible results in dust mitigation.

CFD modelling of an underground coal mine from NSW, using real development heading and equipment geometries, as well as real ventilation and dust monitoring data was conducted. Four modelling scenarios were conducted, with the continuous miner (CM) in roof cut and floor cut position, as well as with poor ventilation and good ventilation practices. The modelling identified that generally, the right-hand side of the CM (opposite side to the ventilation ducting) was at most risk to respirable dust exposure, with exposures well in exceedance of the legal limits during cutting and loading. The study identified the safest places on the CM for operators during cutting/loading, as well as identifying that a wait time of 30 seconds post-cutting and loading is required before operators move forward on the work platforms to commence bolting. The results of this study show that operators on the continuous miner are still at risk of respirable dust exposure in even the best of conditions, so further study into this field is necessary on this topic to aim to eliminate the risk of respirable dust exposure for operators in underground coal mines.

INTRODUCTION

A universal issue in all forms of coal mining is respirable dust, which causes Coal Mine Lung Disease (CMLD), or Mine Dust Lung Disease (MDLD) more generally for all mines (Resources Safety & Health Queensland 2022). With the improvement of technology producing much more productive underground coal mines with larger longwalls and CMs, underground workers are being exposed to significant amounts of respirable dust (Plush, Ren et al. 2011). This has led to more cases of Coal Workers Pneumoconiosis (CWP) arising, which is caused by coal dust, but also a more broad spectrum of lung diseases caused by silica dust (CMLD) (Perret, Plush et al. 2017). Australia has had 87 confirmed cases of CWP and MDLD since 1984, which is unacceptable for an incurable, yet preventable disease (Plush, Watson et al. 2019). This proves the need for research and improved dust mitigation strategies to be implemented, that align with the current production rates of fully mechanised working coal faces, where previous dust mitigation strategies cannot cope with the significant amounts of respirable dust being produced. The current NSW regulations state that the legal limits for an 8hr time weighted average (TWA) for respirable coal and silica dust is 1.5mg/m^3 and 0.05mg/m^3 respectively (NSW Resources Regulator n.d.). It is however crucial that the industry is reducing dust exposures for operators to a level

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that is as low as is reasonably practicable, to ensure the safety of operators underground as there is no known safe exposure to respirable dust.

This study focuses on the application of computational fluid dynamics (CFD) software (ANSYS Fluent) to underground coal mine development headings. There is a particular focus on the flow of respirable dust around the shuttle car and CM during cutting and loading. The aim of this study was to understand the major contributing factors to elevated dust loadings experienced by operators on the CM. It was also an aim to identify areas of further study and recommendations for improvements in dust mitigation strategies.

CFD MODELLING METHODOLOGY – MINE CASE STUDY

A mine case study was conducted to model a real underground longwall development heading to be able to recommend improvements to dust mitigation strategies and to recommend areas of further study to improve the dust exposures experienced by operators underground. A NSW underground longwall coal mine was used as a case study for this research.

The mine utilises a JOY 12CM30 single pass CM-bolter with a JOY 10SC32 shuttle car in the development panel, using standard auxiliary ventilation with ventilation tubing (and a slider tube at the face).

The typical development heading dimensions are 5.2m W x 3m H, typically mining the entirety of the coal seam, leaving a stone roof and floor. Generally, very little stone is mined as the coal seam thickness is quite regular, however sometimes up to 30cm of stone can be mined in the roof depending on the location of development. The ventilation layout standards for the current development panel at the mine are as shown below in **Figure 1**, with the auxiliary ventilation setup being dependent on what heading the CM is working in.

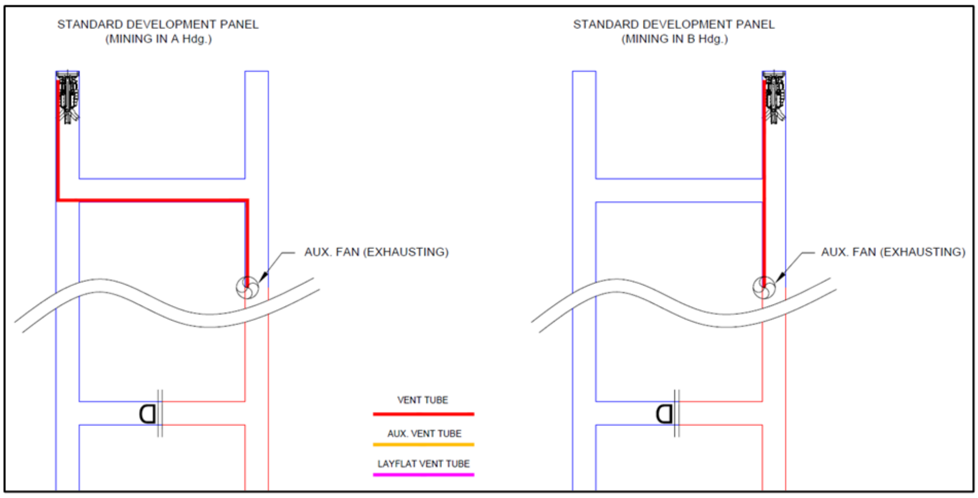

Figure 1: Development Heading Ventilation Standards

Order 42 Coal Services dust auditing data was provided from the mine for the purposes of CFD modelling and to allow for model validation. This dust data provides information on the ventilation, shift activities, cutting dimensions, production and the time weighted average dust concentration reading for the dust being monitored for each worker (based on their primary task for the shift). This information is particularly useful as it also provides ventilation information for the shift, which is a crucial part of establishing an accurate model with the correct boundary conditions being setup.

The main issue with the dust data received is that it is time weighted over the entirety of a shift and that it is not static dust monitoring. It is expected that during cutting with the CM that dust concentrations are much higher than the recorded results as this is the process that creates most of the dust. It is impossible to know just how much larger the concentrations are during cutting without static instantaneous dust monitoring, which was unfortunately unable to be completed at the mine for this study. The issue with dust monitors being attached to the workers is that the workers are always moving and may not actually be completing the task labelled for the entire shift, which means that some of the dust experienced may not be associated with that task. It makes it extremely difficult to tailor the CFD model to the concentrations measured as there is no definite reference point for those dust concentrations, there is just a general area that the workers may have been standing (and assuming that they were standing there for the entire shift). For these reasons the model validity is compromised, and it is recommended that for all CFD modelling studies, static real time dust measurement is conducted at multiple points on the CM to get much more accurate results for different parts of the cutting and loading sequence.

As it is expected that the dust concentrations during cutting and loading would be significantly higher than the provided TWA data, adjusted TWA values were created to attempt to more accurately capture the dust concentrations experienced by the operators during cutting and loading. From experience, cutting only typically takes place for about 15-30% of a shift's duration depending on the mining conditions, so an adjusted TWA concentration range was established. It would be expected that dust concentrations would be 5-10 times higher than the provided data. The expected ranges are shown below in **Table 1**. The models were validated for the miner driver and left-hand bolter adjusted TWA concentration range.

Table 1: Adjusted TWA Dust Exposure Data

Primary Task	TWA Respirable Coal Dust Exposure (mg/m^3)	Adjusted TWA-5x TWA (mg/m^3)	Adjusted TWA-10x TWA (mg/m^3)
Operate CM	0.25	1.25	2.5
Drive Shuttle Car	0.38	1.9	3.8
Bolting on LHS of CM	0.22	1.1	2.2

The setup of the development heading and the indicative 300mm breathing zones of the operators on the CM is as shown below in **Figure 2** and **Figure 3**. The boundary conditions were setup to parallel the ventilation conditions provided in the dust data, with the dust sources modelled in this study including:

- Cutting source (cutting drum contact area on the mining face)
- Miner throat
- Miner conveyor
- Shuttle car body (where the coal lands in the shuttle car, liberating dust)

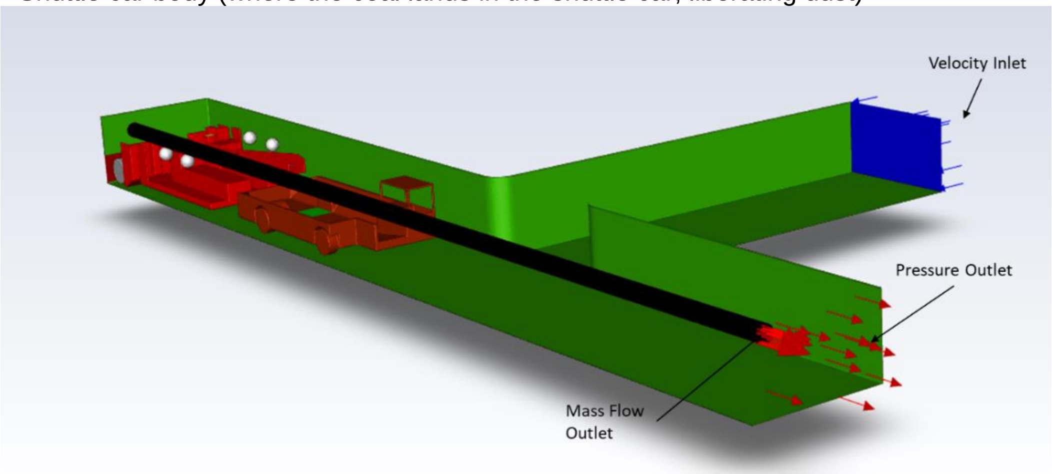

Figure 2: Development Heading Boundary Conditions

Models were setup to replicate the CM completing a roof cut and a floor cut, with different ventilation standards being tested. A 'good' ventilation standard setup was made whereby the ducting inlet is 2m back from the mining face, which is indicative of the slider tube being fully extended, and a 'bad' ventilation setup was made whereby the ducting was placed 5m back from the working face. This was done to establish how much of an impact the ventilation setup had on the dust concentrations the operators on the CM were exposed to. It was assumed that the ventilation standards were good during the Order 42 testing, so the models were validated to the data for the 2m ducting cases. The effect of changing heading air flow rate/velocity was also studied to determine its impact and importance with respect to the dust concentrations experienced by operators.

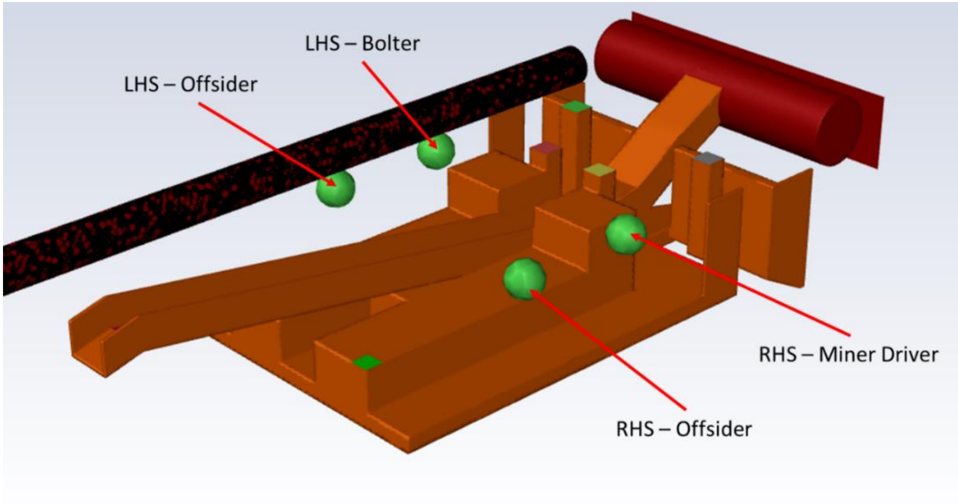

Figure 3: CM Operator Breathing Zone Locations

A mesh independence study is crucial for model validation to ensure that only the variables that are being changed (dust sources, boundary conditions etc.) are influencing the results. The mesh will always have some impact on results, however comparing different mesh sizes is a very good way at ensuring the impact is negligible for the results being measured. As a student Fluent licence was used, the cell count for modelling was limited to 510,000 cells, which is not ideal as having any coarser of a mesh can cause model convergence issues. A mesh independence study was conducted for three different mesh sizes, with a maximum cell size of 130mm, 300mm and 500mm, denoting a fine mesh, medium mesh and coarse mesh respectively. Mesh independence was validated by comparing the air velocity magnitude along the centreline of the development heading, with the results being shown below in **Figure 4**, where x=-5m is the mining face, and x=-40m is the pressure outlet and mass flow outlet from **Figure 2**. It is clear that close to the CM (where mesh independence is the most important) there is negligible velocity difference between the three meshes. However, in the return heading the coarse mesh begins to deviate from the other two meshes, meaning that there is a significant skewness of results in this area due to the mesh. As this area is not of importance to modelling, and only the area where the shuttle car and CM are placed is of importance, it can be concluded that the mesh size is having a negligible impact on results. The results are therefore independent of the mesh size for this study.

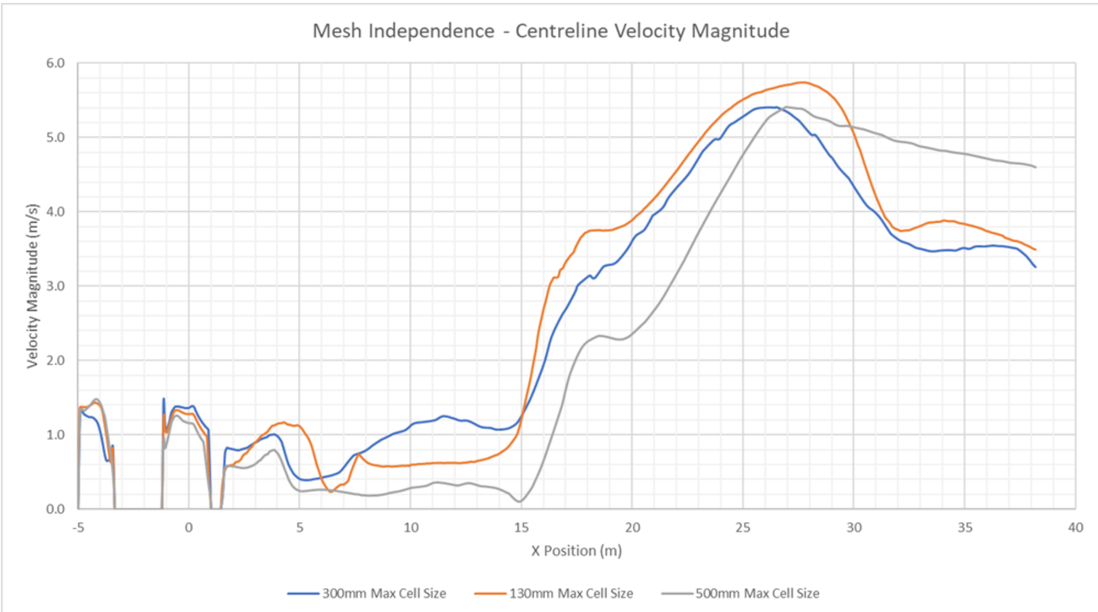

Figure 4: Mesh Independence Results

RESULTS

The following section shows the results for the CM in the floor cut position, comparing the dust concentrations experienced by the operators when the ducting is 2m and 5m back from the cutting face. **Figure 5** below shows the respirable coal dust concentration contours along the left-hand side of the working platform. It is clear that there is a considerable amount of dust released from the shuttle car, but is diluted quite quickly, with the left-hand bolter having only small portions of the breathing zone with dust concentrations of about 2mg/m^3. The left-hand offsider however has portions of their breathing zone in excess of 5mg/m^3, so actually moving forward on the CM would be beneficial during cutting and loading. It is also clear that the dust generated during cutting is trapped by the front of the miner and negligible dust from the face is reporting to the working area. With the ducting moved back to 5m from the face it is clear that there is a substantial amount of dust flowing over the front of the miner into the working area. This leads to a portion of the left-hand bolter's breathing zone having concentrations well in excess of 5mg/m^3 and is a very dangerous place to be standing. The offsider is still experiencing similar dust exposures in the 5m ducting case.

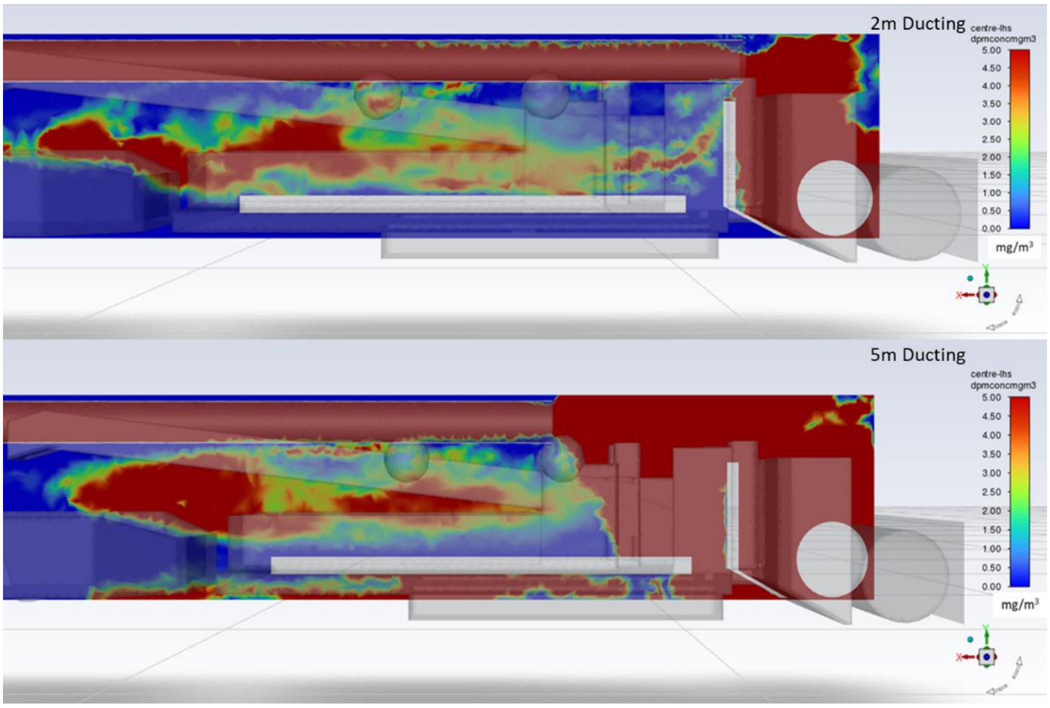

Figure 5: Floor Cut - LHS Platform Respirable Coal Dust Concentration Contours

Figure 6 shows the respirable coal dust concentration contours for the right-hand side working platform. It is clear that on the right-hand side there is some respirable dust flowing over the front of the CM in high concentrations even for the 2m ducting case, which is due to an overall lower air velocity on the right-hand side. For the 5m ducting case this dust flows much further into the working area, causing the miner driver to be experiencing significant dust concentrations, well in excess of 5mg/m^3. The right-hand offsider is experiencing quite high dust loadings in the 2m ducting case due to much slower dilution of the shuttle car dust. The ventilation change caused by moving the ducting backwards does protect the right-hand offsider however. It is therefore imperative that the safe locations on the CM are known for different combinations of cutting position and ducting position as the safe positions do change as shown in the figures.

A variety of flow rates were modelled to determine the impact that velocity has on dust exposure. The 1.5mg/m^3 respirable coal dust isosurfaces for changing heading flow rates of 10.5m3/s, 15m3/s and 20m3/s are shown in the **Figure 7**. The increasing air velocity has a significant impact on how fast the shuttle car dust is diluted, as well as how much respirable dust is able to flow over the front of the CM.

It is therefore imperative that the air velocity in the development heading is as far above the legislative limits as is reasonably practicable to reduce the dust concentrations that operators are exposed to.

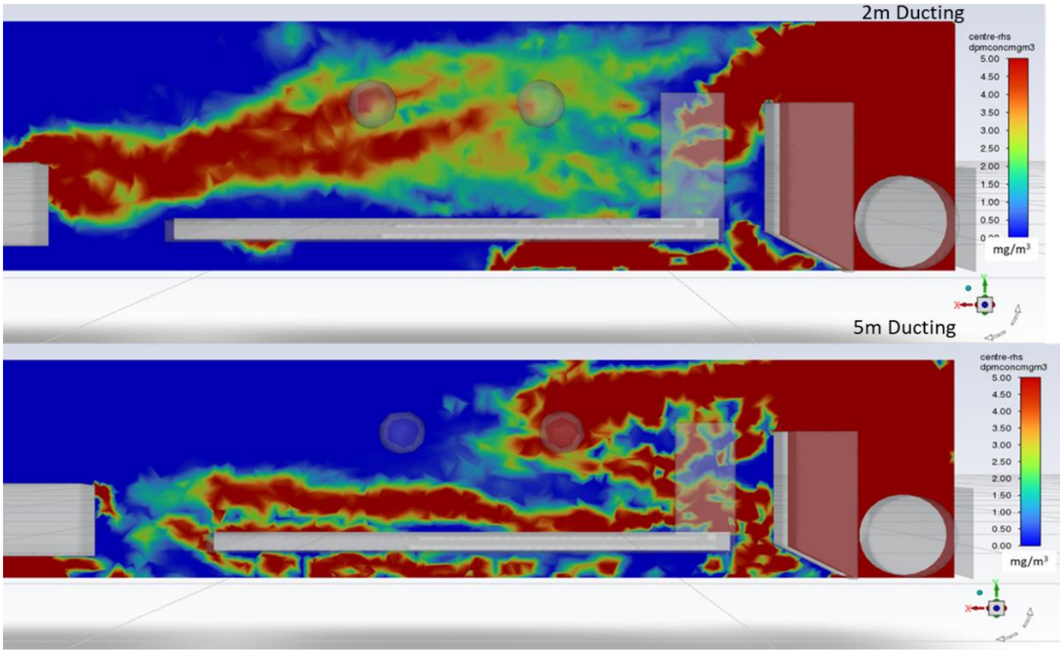

Figure 6: Floor Cut - RHS Platform Respirable Coal Dust Concentration Contours

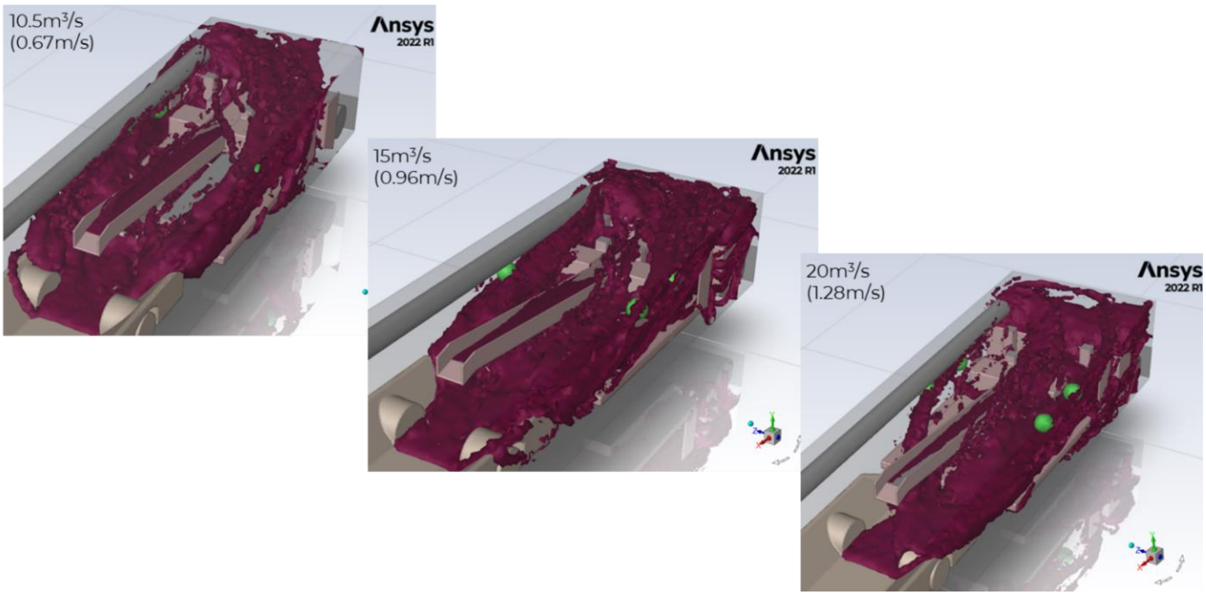

Figure 7: Effect of Changing Velocity - 1.5mg/m³ Isosurfaces

CONCLUSIONS

This study found that operators on both sides of the CM (CM) can experience significant dust loading on both sides of the CM during cutting and shuttle car loading. In general, having the ducting further from the face significantly increases the dust concentrations that operators on both sides of the CM are exposed to as large amounts of respirable coal dust can flow over the front of the CM and into the working areas on both sides of the CM. It was also found that air velocity plays a significant role in the dust concentrations that operators on the CM are exposed to. Increasing the air flow to the working area significantly reduces the dust exposure by diluting the respirable coal dust released by the shuttle car significantly faster, as well as reducing the amount of respirable dust that can flow over the front of the

CM (which is by far the most significant dust source in terms of quantity and concentration of respirable dust). It is therefore imperative that good ventilation practices are always maintained in the development heading, in terms of good ducting practices being maintained (ensuring that the slider tube is fully extended during cutting) and that the air velocity to the heading is as high as reasonably practicable.

It was also noted in this study that the particle residence times can be particularly high (exceeding 30s), so it is a recommendation that operators on the CM stay behind the ventilation ducting for 15-30s after cutting before moving forward to begin bolting.

This study proved the effectiveness of CFD modelling in identifying issues in development headings that can lead to significant dust concentrations that operators are exposed to. CFD has a great potential as an educational tool as it can visualise the respirable dust in a development heading, whereby safe practices can be made that identify where operators are safest to stand during different cutting and loading conditions.

Recommendations for further study in terms of applying CFD in development headings includes:

- Shuttle car and conveyor boom dust mitigation strategies
- VR coupling with CFD for training purposes
- Gas modelling and frictional ignition studies
- Elephant's trunk vs traditional ventilation tubing
- Models using real time dust data
- Accurate 3D models (eg. Laser scanning of machines and the development heading)

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