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GOAF GAS DISTRIBUTION NEAR THE TAILGATE UNDER THREE GATEROAD CONDITIONS

Rao Balusu[1], Bharath Belle[2] and Krishna Tanguturi[3]

ABSTRACT: A collaborative project was undertaken to obtain an understanding of the goaf gas distribution profile near the tailgate area of the longwall goaf under 2 gateroad and 3 gateroad mining conditions for improved explosion risk management in gassy mines. Extensive computational fluid dynamics (CFD) modelling studies were conducted and calibrated using operational longwall goaf gas distribution data. The results of the simulations indicated that there is a significant difference in the spread of explosive fringe (or close to explosive range) gas distribution profiles near the tailgate side of the longwall goaf under 2 gateroad and 3 gateroad conditions, i.e. a significant increase in the spread of explosive fringe zone under 3 gateroad conditions. The results indicated that under 3 gateroad conditions, explosive fringe gas distribution extends into the middle roadway between the longwall panels thereby significantly increasing the area of explosive fringe distribution and likely relative increase in explosion risk. Results indicate that the explosive fringe area in the middle roadway can extend up to two pillars behind the longwall face position. The details and results of various modelling investigations including recommended strategies for gas control and minimisation of the spread of explosive fringe gas distribution in the longwall goaf are presented in this paper.

INTRODUCTION

Gas emissions have increased significantly in recent years in some of the Australian longwall mines due to increased gas reservoir size, high production rates and increase in mining depths. Traditionally, Australian coal mines use 2 gateroad system for longwall panels development and extraction. Extensive research work has been carried out previously to develop optimum gas and spontaneous combustion control strategies for 2 gateroad longwall panels (Balusu and Tanguturi, 2019; Balusu et al, 2017; Belle, 2015; Balusu et al, 2011). To manage high gas emissions, some mines had previously introduced 3 gateroad systems in their longwall panels to provide additional dilution capacity in longwall tailgate return and as the key solution for gas management. Another purpose of the 3 gateroad/heading philosophy was to provide continued (24*7) tailgate access for diesel equipment maintenance activities.

Although 3 gateroad system provides additional ventilation dilution capacity for tailgate gas management during longwall extraction, its effect on goaf gas distribution and explosive fringe gas distribution profiles in the longwall goaf areas is unknown. There is a perception that as the 3 gateroad system provides more ventilation capacity than 2 gateroad system for gas dilution in the longwall tailgate return, it would also reduce the explosive fringe gas distribution profile near the tailgate area in the longwall goaf to manage the explosion risk. To investigate this issue, a collaborative project was undertaken to conduct detailed computational fluid dynamics (CFD) modelling studies to obtain an understanding of the explosive fringe gas distribution profiles near the tailgate area of the longwall goaf under 2 gateroad and 3 gateroad conditions.

The CFD models were built and solved using the commercial CFD software tool ANSYS and the numerical fluid flow solver FLUENT. The main focus of the project during the initial phases was to obtain a fundamental understanding of goaf gas distribution and the extent of explosive fringe areas in longwall goaf under field site conditions using CFD modelling techniques. In the later phases, the CFD modelling studies were also used to investigate the effect of various control options and ventilation strategies to minimise the spread of explosive fringe distribution on tailgate side of the longwall goaf as well as in the middle roadway (B heading) under 3 gateroad conditions. Based on the results of these investigations, appropriate strategies have been identified for gas management and minimization of the spread of explosive fringe gas distribution in the longwall goaf under field site conditions.

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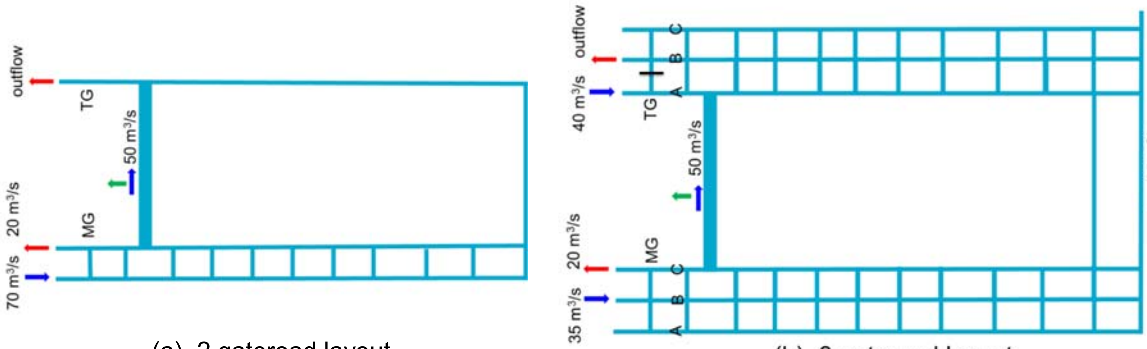
GOAF GAS DISTRIBUTION PATTERNS AT THE TAILGATE AREA

The CFD models were developed with the geometries of operational longwall panels at a mine site with 2 gateroad and 3 gateroad layouts covering 1.0 km length of longwall goaf. The actual floor contours of the longwall panels at the field site mine were used for development of the CFD models. The schematics of 2 gateroad and 3 gateroad layouts and ventilation systems used in CFD modelling studies are shown in Figure 1. The CFD models with 3 gateroad layout included the working longwall panel goaf as well as the adjacent sealed goaf to simulate goaf gas distribution in the middle roadway (i.e. B heading) between the adjacent longwall panels. In the 3 gateroad longwall panels, there are two tailgate headings, designated as A and B headings, with A heading for additional intake airflow for gas dilution and B heading for longwall return airflow. Velocity inlet boundary conditions were specified at the maingate (MG) intake roadways and other roadways as shown in Figure 1, such that the total ventilation quantity of 50 m^3/s flows across the longwall face. At the tailgate (TG) return, an outflow boundary condition was specified in the modelling simulations. Longwall inbye airflow of 35 m^3/s was from an inbye mine air cooling shaft to manage the steep geo-thermal gradient and homotropal conveyor heat in high production longwall face.



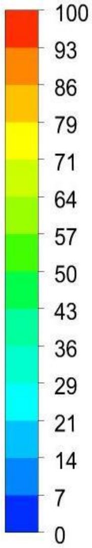
(a) 2 gateroad layout

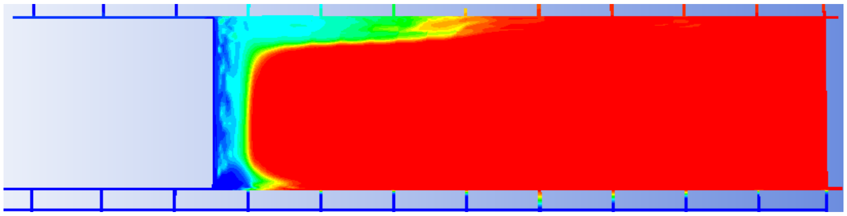
(b) 3 gateroad layout

Figure 1: Longwall ventilation systems – 2 and 3 gateroad layouts used in CFD models

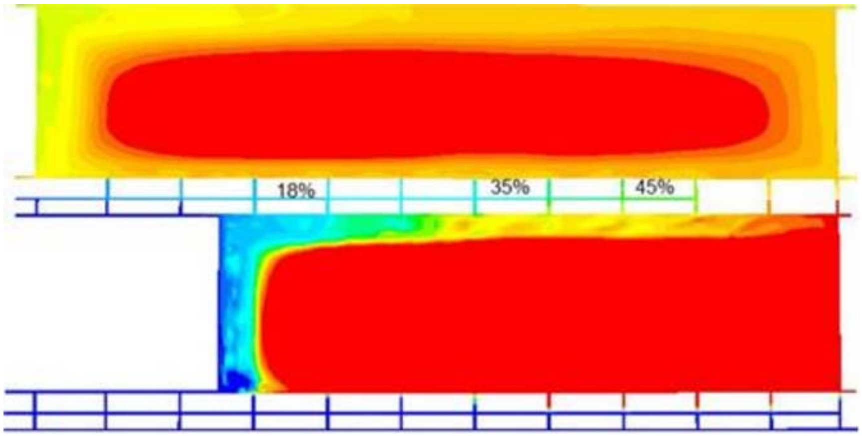
The working seam thickness is 2.6 m, which also represents the face height. The longwall panel width is 300 m and the roadway width on both maingate (MG) and tailgate (TG) sides of the face is 5.4 m. The goaf height up to 80 m above the working seam and the floor strata down to 10 m below the working seam is included in all the models. In these models, MG and TG cut-throughs of 5 m in width have also been incorporated, and these cut-throughs were spaced at 100 m intervals along the panel. A number of goaf gas drainage holes were also incorporated into the CFD models to replicate goaf gas drainage conditions at the field site.

In the base case simulations, longwall panel gas emissions and goaf gas drainage conditions of the field site were used. The total gas emissions into the longwall goaf were around 9,000 l/s with 98% methane (CH_4). The total goaf gas drainage rate was around 8,000 l/s, with gas concentration in different vertical goaf holes varying between 80% and 95%. In addition, the total gas emission into the adjacent sealed panel goaf was around 1,000 l/s with 800 l/s of adjacent goaf gas drainage from the sealed panel. The mine utilises closely spaced tailgate goaf holes, adjacent sealed panel goaf drainage and deep goaf gas drainage strategies as the primary controls for longwall tailgate gas management. The ventilation layout and airflows as shown in Figure 1 were used in the base-case simulations. All the mining and ventilation parameters including the goaf gas drainage conditions were same in both 3 gateroad and 2 gateroad simulations. In 2 gateroad panels, goaf gas distribution in the working longwall panel goaf only was simulated, as there was no middle roadway between the adjacent panels. However, in 3 gateroad panels two adjacent panels were included in the modelling simulations in order to incorporate the middle roadway (B heading) between the panels. In the base-case simulations, the last three cut-throughs outbye of the longwall face were not sealed off between A and B headings to allow airflow from A heading into the B heading for gas dilution in the longwall tailgate return, as per the field site conditions. In these simulations, brattice cloth seals were erected in the outbye two cut-throughs to force some air through the last cut-through, i.e. around 15% of the total tailgate intake dilution airflow, and also to allow some leakage through the other two cut-throughs. All other cut-throughs outbye of these last three cut-throughs were sealed off completely.





(a) 2 gateroad layout



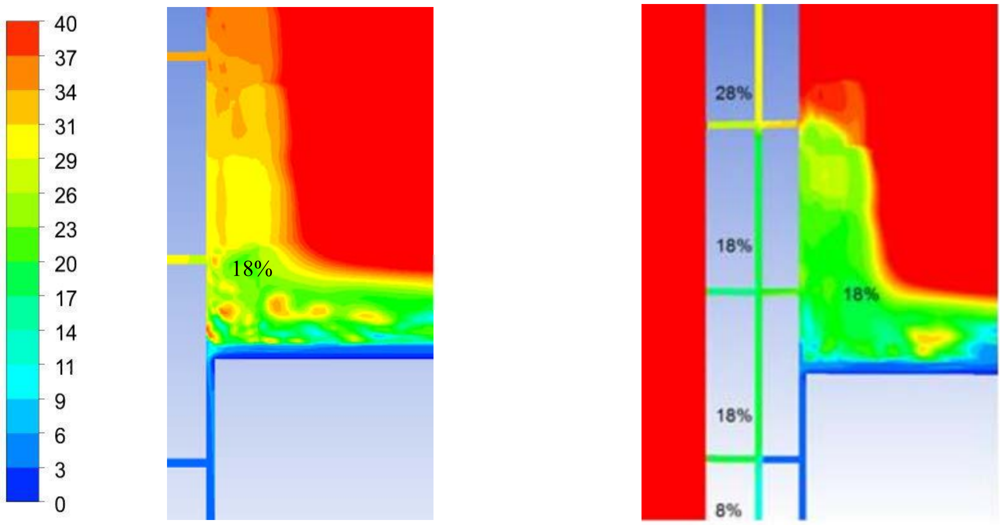
(b) 3 gateroad layout

Figure 2: Methane distributions patterns in longwall goafs and in B heading – Base case

The results of the base-case simulations for 2 gateroad and 3 gateroad layouts are presented in Figure 2(a) and 2(b) respectively, showing methane gas distribution patterns in the working panel goaf, and gas distribution in the sealed panel goaf areas as well as in B heading for 3 gateroad layout. A close-up view of the methane concentration distribution patterns near the tailgate area of the longwall goaf under 2 gateroad and 3 gateroad layout conditions are presented in Figure 3(a) and 3(b) respectively. Methane gas distribution in B heading under 3 gateroad conditions is also shown in Figure 3(b). In the methane gas distribution figures, the red colour indicates higher gas concentration and the blue colour indicates lower methane gas concentration. Gas concentration values at some key locations are also shown in numerical values as 'annotations' on the figures for clarity.

The results of the simulations indicated that there is a significant difference in the spread of explosive fringe gas distribution profiles in the longwall goaf under 2 gateroad and 3 gateroad conditions, i.e. a significant increase in the spread of explosive fringe (or close to explosive range) zone in the goaf under 3 gateroad conditions. The results presented in Figure 3(b) indicate that under 3 gateroad conditions, explosive fringe (or close to explosive range) gas distribution also extends into the middle roadway between the longwall panels, thereby significantly increasing the area of explosive fringe gas distribution. Results indicate that the explosive fringe area in the middle roadway can extend up to two pillars behind the longwall face position. Beyond the two pillars, the methane gas concentration in B heading quickly rises above the explosive range, i.e. turns into methane rich region. Field gas monitoring data from B heading also showed that methane gas concentration values were in the explosive range only up to two pillars behind the face and then the gas concentration steeply rises to 50% to 60% levels.

Additional base case simulations were also carried out with slightly different gas emission rates into the working and sealed goafs and with different goaf gas drainage rates from both working and sealed longwall panels. There is only a marginal difference in the B heading gas distribution patterns in various base case simulations. A field gas monitoring programme was implemented during 3 gateroad longwall panel retreat operations at the field site to measure actual gas concentration values in B heading and its changes with face retreat. Field measurements also showed that methane concentration rises above the explosive range at two pillars behind the longwall face. Comparison of the simulated results and field measured values show that simulated results are in close agreement with field measured data.



(a) 2 gateroad layout (b) 3 gateroad layout

Figure 3: Methane distributions patterns near tailgate and in B heading – Base case

B-HEADING CLOSING OPTIONS TO MINIMIZE THE SPREAD OF EXPLOSIVE FRINGE

A number of control options involving closing/sealing off B heading at different locations were proposed to minimize the spread of explosive fringe area in B heading under 3 gateroad conditions. The modelling studies were carried out to simulate the effectiveness of various control options in minimizing the spread of explosive fringe area. To replicate sealed goaf conditions at the field site, CO_2 gas was also introduced into the sealed longwall goaf in all these simulations. The details of the control strategies and the results of various simulations are presented in the following sub-sections.

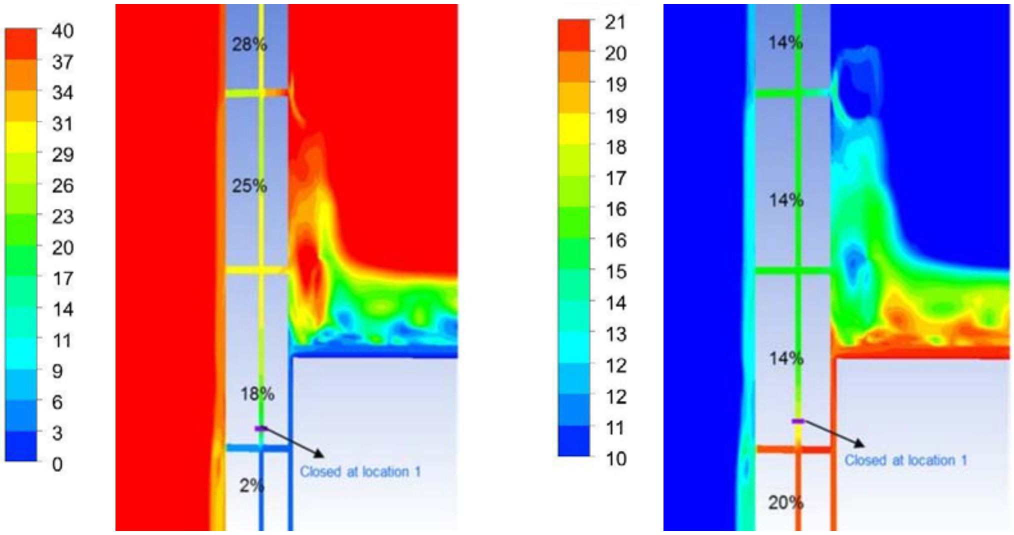
(a) B heading closed at inbye of the last cut-through (Location 1)

It was proposed to close off B heading to control/prevent explosive gas composition in B heading. In order to investigate the effect of closing off B heading, several CFD modelling simulations were carried out by closing B heading at various locations. In the first simulation, B heading was closed off at inbye of the last ventilation cut-through location (shown as 'Location 1' in the following figures) to simulate its effect on the gas distribution profile in the longwall goaf and in B heading. All other conditions, such as ventilation airflow on the longwall face, goaf gas emissions and goaf gas drainage rates were kept at the same values as those in the base case simulations.

Results of the simulation with B heading closed at location 1 (inbye of the last ventilation cut-through between A and B headings) are presented in Figure 4, showing a close-up view of methane and oxygen gas distribution in the longwall goaf areas near the tailgate as well as in B heading. Results presented in Figure 4(a) indicate that methane gas concentration in some sections of B heading continue to be closer to the explosive range. Results also indicate that the methane gas concentration in B heading rises above the explosive range (i.e. into methane rich range) with the face retreat.

A comparison of the methane gas concentration distribution patterns in the longwall goaf near the tailgate area as well as in B heading with and without closing off the B heading are presented in Figure 5. Results of these simulations indicate that closing off B heading does not significantly change the methane gas distribution patterns in B heading and results in only a marginal difference in methane gas concentration profiles. Methane gas distribution in B heading at inbye of the longwall face is close to the explosive range in both cases. Analyses of the results also indicate that a higher methane gas concentration fringe behind the chock-shields moves closer to AFC tailgate drive motor area and tailgate corner when B heading is closed off. Therefore, the option of closing off B heading at location

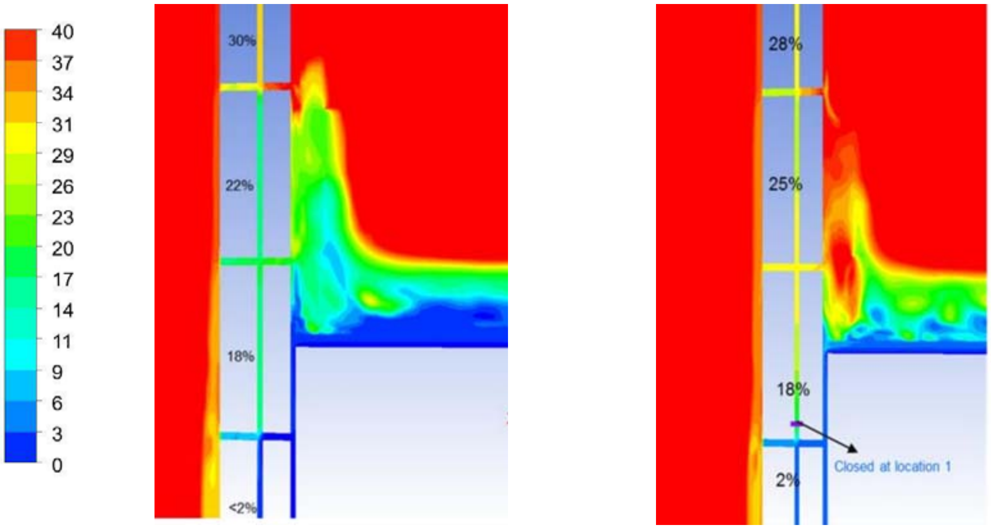
1, i.e. at inbye of the last ventilation cut-through, is not recommended if 3 gateroad ventilation system is deployed for longwall gas management.



(a) Methane distribution

(b) Oxygen distribution

Figure 4: Methane distribution near tailgate – with B heading closed at Location 1



(a) Methane distribution – with B heading open (not sealed off)

(b) Methane distribution - with B heading closed at Location 1

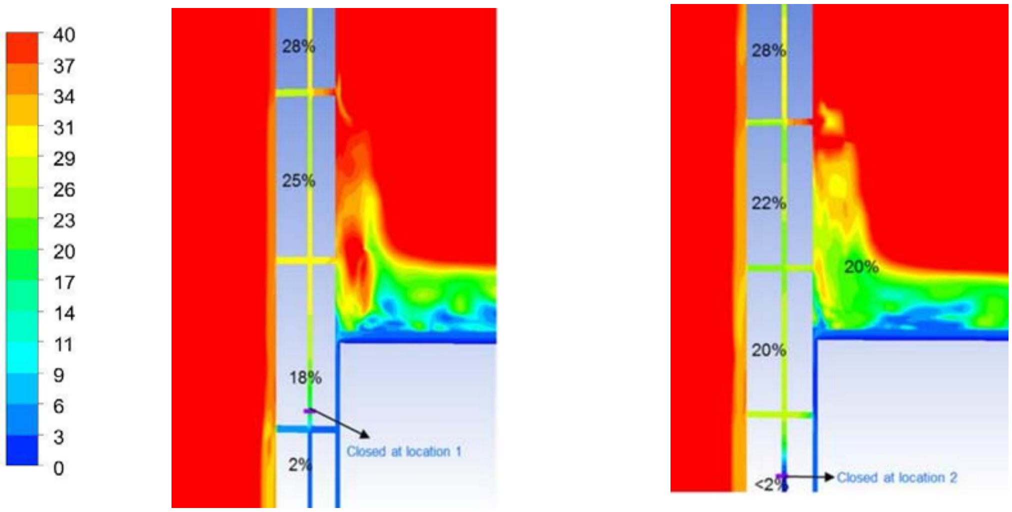
Figure 5: Methane distribution near tailgate – without and with B heading closed

(b) B heading closed at inbye of the second last cut-through (Location 2)

In this simulation, B heading was closed off at inbye of the second last cut-through location (shown as ‘Location 2’ in the following figures) to simulate its effect on the gas distribution profile in B heading. All other conditions, such as ventilation airflow on the longwall face, goaf gas emissions and goaf gas drainage rates were kept at the same values as those in the base case simulations.

Results of the simulation with B heading closed at location 2 (inbye of the second last cut-through between A and B headings) are presented in Figure 6(b), showing methane gas distribution patterns near the tailgate area of the longwall goaf as well as in B heading. Results indicate that methane gas concentration in some sections of B heading is still very close to the explosive range. Analyses of the results also indicate that moving the seal location in B heading towards the second last cut-through (i.e. one pillar back) resulted in the explosive range gas composition zone extension by one more pillar length towards the outbye side of the longwall panel. Therefore, the option of closing off B heading at the second last cut-through is not recommended, as this would significantly increase the explosive gas composition risk in the longwall panel.

A comparison of the close-up view of methane gas concentration distribution patterns with B heading closed at two different locations (Location 1 – inbye of last cut-through, and Location 2 – inbye of second last cut-through) are presented in Figure 6. Results of the simulations indicate that closing off B heading at any location does not significantly change methane gas distribution patterns in B heading and results in only a marginal difference in methane gas concentration profiles along the B heading roadway. Methane gas distribution in B heading at inbye of the seals location is close to the explosive range in both cases. As discussed earlier, sealing of B heading at an outbye location far from the face (i.e at location 2) is not at all recommended, as this option increases the gas explosion risk.



(a) Methane distribution – with B heading closed at Location 1

(b) Methane distribution - with B heading closed at location 2

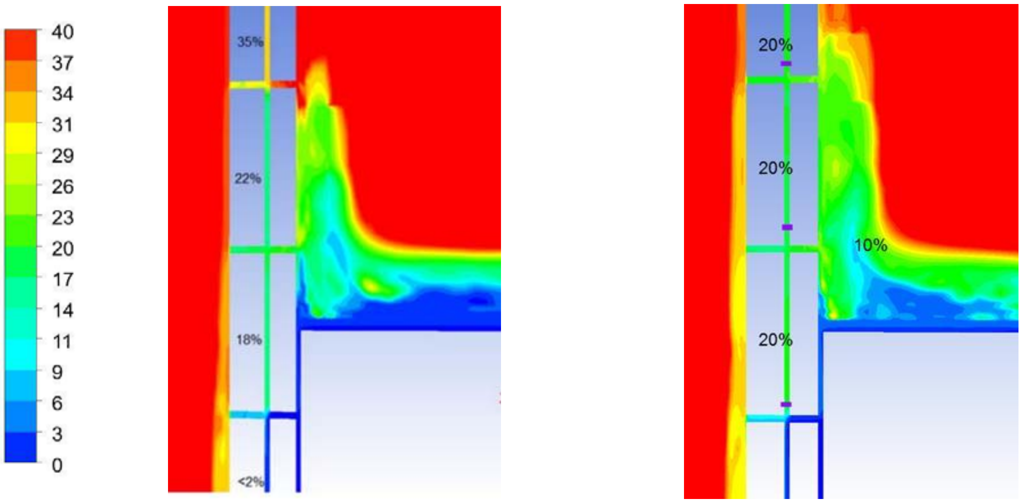
Figure 6: Methane distribution near tailgate – with B heading closed at Locations 1 & 2

(c) B heading closed at all cut-through locations

In this simulation, B heading was closed off at all cut-through locations to simulate its effect on the gas distribution profile in B heading. All other conditions, such as airflow on the longwall face, goaf gas emissions and goaf gas drainage rates were kept at the same values as those in the base case simulations. Results of the simulation with B heading closed at all cut-through locations are presented in Figure 7(b), showing close-up view of methane gas distribution patterns near the tailgate area of the longwall goaf as well as in B heading. Results indicate that methane gas concentration in different sections of the B heading is close to the explosive range up to four pillars behind the longwall face. Further into the inbye goaf area, the methane gas concentration in B heading rises above the explosive range (i.e. turns into methane rich region).

A comparison of the close-up view of methane gas concentration distribution patterns with B heading sealed off at all cut-throughs and in the base case (without any seals in B heading) are presented in Figure 7. Analyses of the results indicate that sealing off B heading at all cut-through locations results in a significant change in the methane gas distribution profile along the B heading, with ‘close to explosive range gas composition’ zone length in B heading extending up to four pillars behind the longwall face. Therefore, the option of closing off B heading at all cut-throughs is not recommended, as this would significantly increase the explosive fringe gas distribution area risk in the longwall panels.

It is to be noted here that none of the options of closing off B heading at different locations offered any significant benefits in terms of reducing the spread of explosive fringe gas distribution in B heading. In fact, some of the options of closing off B heading resulted in significant increase in the spread of explosive fringe gas distribution zone. Therefore, the option of closing off B heading is not recommended, as this would significantly increase the explosive fringe gas distribution area risk and uncertainty in the longwall panels.



(a) Methane distribution – with B heading open (not sealed off)

(b) Methane distribution – with B heading closed at all

Figure 7: Methane distribution near tailgate – without and with B heading closed at all C/T's

VENTILATION STRATEGIES TO MINIMIZE THE SPREAD OF EXPLOSIVE FRINGE

A number of ventilation control strategies involving closing off outbye cut-throughs at different locations were proposed to minimize the spread of explosive fringe area in B heading under 3 gateroad conditions. CFD modelling studies were carried out to simulate the effectiveness of various control options in minimizing the spread of explosive fringe area. The details of the ventilation control strategies and the results of simulations are presented in the following sub-sections.

(a) Changes in tailgate ventilation dilution strategy – more airflow through the last cut-through

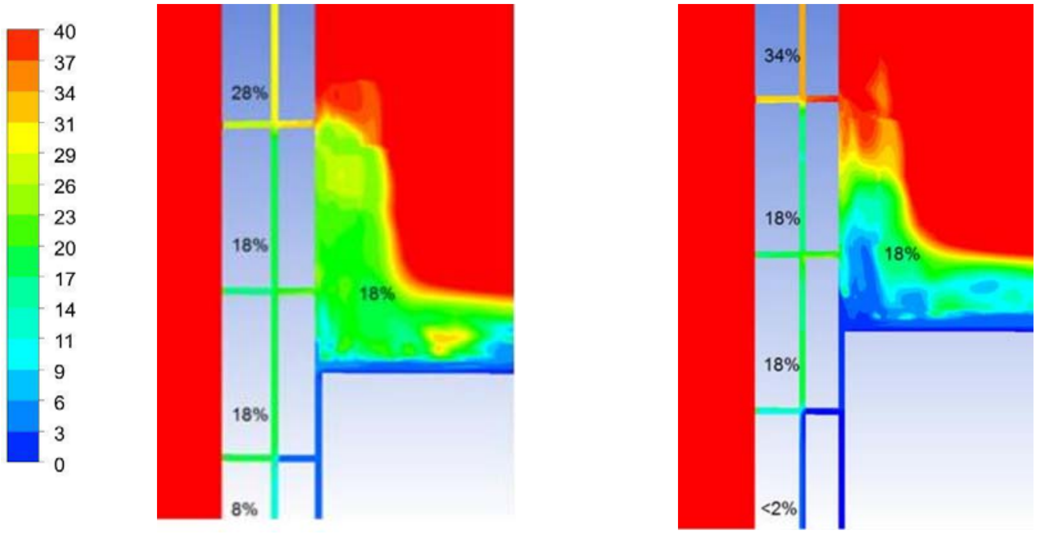
In the base case simulations, the last three cut-throughs outbye of the longwall face between A and B headings were not closed off completely to allow airflow from A heading into B heading for gas dilution in the longwall tailgate return, as per the field site conditions. Brattice cloth seals were erected in the outbye two cut-throughs to force some air to flow through the last cut-through (around 15% of the total tailgate intake dilution airflow), and also allowing some leakage through other two cut-throughs. All other cut-throughs outbye of these last three cut-throughs were closed off completely.

To investigate the effect of increased airflow through the last cut-through on explosive fringe gas distribution in B heading, simulations were carried out with different brattice cloth resistance values in the outbye two cut-throughs. In this simulation, resistance of brattice cloth in the two outbye cut-throughs was increased to force more airflow through the last cut-through between A and B headings, with around 27% airflow in the last cut-through close to the face. Results of the simulation indicate that the methane gas distribution in B heading behind the longwall face is still in the explosive range even with 27% airflow through the last cut-through. Analyses of the results also indicate that although methane gas concentration in B heading outbye of the face decreased significantly with increased airflow through the last cut-through, it is still in the explosive range outbye of the longwall face.

(b) Changes in tailgate ventilation dilution strategy – only one last cut-through open

In this simulation, the second and third last cut-throughs were also closed off completely and all the tailgate intake airflow would flow from A heading to B heading through the last ventilation cut-through near the tailgate, i.e. only one last cut-through was open for airflow between A and B headings with all other cut-throughs closed off completely. All other conditions, such as airflow on the face, goaf gas emissions and goaf gas drainage rates were kept at the same values as those in the base case simulations. Results of the simulation with only the last cut-through open for dilution airflow from A heading to B headings are presented in Figure 8(b), showing close-up view of methane gas distribution near the tailgate area of the longwall goaf as well as in B heading. Results indicate that the extent of the explosive gas fringe in longwall goaf has reduced significantly with this control strategy.

A comparison of the gas concentration distribution patterns in B heading with two different ventilation practices are presented in Figure 8. In the first case, the last 3 cut-throughs between A and B headings outbye of the longwall face were not closed off completely, i.e. outbye two cut-throughs were sealed with brattice cloth only, resulting in only 15% airflow through the last cut-through near the face. In the second case, only the last cut-through was open for airflow between A and B headings with all other cut-throughs closed off completely. Results of this simulation indicate that in the first case, methane gas distribution in B heading up to two pillars outbye of the longwall face would also be in the explosive range. In the second case, methane concentration in B heading outbye of the last cut-through is below 2%, thereby significantly reducing the length of the explosive fringe zone in B heading.



(a) Methane distribution - with 3 c/t open

(b) Methane distribution - with 1 c/t open

Figure 8: Comparison of methane distribution at TG – 3 outbye C/T's open vs 1 C/T open

Analyses of the results indicate that the ventilation practice of having more cut-throughs open (not closed off completely) outbye of the longwall face results in the explosive range zone in B heading extending up to four pillars, i.e. two pillars outbye of the face and two pillars behind the face, which would significantly increase the risk in operating coal mines. The results indicate that the practice of not closing off the cut-throughs outbye of the longwall face significantly increase the risk. Therefore, it is strongly recommended that mines should implement the ventilation control strategy of having only one last cut-through open for airflow between A and B headings for gas dilution. All other outbye cut-throughs between A and B tailgate headings should be closed off completely.

CONCLUSIONS AND RECOMMENDATIONS

The results of the CFD modelling simulations indicate that there is a significant difference in the spread of explosive fringe gas distribution profiles in the longwall goaf under 2 gateroad and 3 gateroad conditions, i.e. a significant increase in the spread of explosive fringe (or close to explosive range) zone in the goaf under 3 gateroad conditions. The results indicate that under 3 gateroad conditions, explosive fringe (or close to explosive range) gas distribution also extends into the middle roadway (B heading) between the longwall panels, thereby significantly increasing the area of explosive fringe gas distribution. Results indicate that the explosive fringe area in the middle B heading can extend up to two pillars behind the longwall face position. The modelling results also indicate that methane gas concentration in B heading quickly rises above the explosive range (i.e. into methane gas rich range) beyond that two pillars inbye of the longwall face. Field gas monitoring data from B heading also showed that methane gas concentration values were in the explosive range only up to two pillars behind the face and then the gas concentration steeply rises to 50% to 60% levels.

The modelling simulations indicate that closing/sealing of B heading at different locations close to the face does not significantly change methane gas distribution patterns in B heading and results in only a marginal difference in methane gas concentration profiles along the B heading roadway. It is also to be noted that sealing of the B heading at all cut-through locations would result in a significant change in the methane gas distribution profile along the B heading, with 'close to explosive range gas composition' zone length in B heading extending up to four pillars behind the longwall face. Therefore, the option of closing off B heading is not recommended, as this would significantly increase the explosive fringe gas distribution area risk and uncertainty in the longwall panels.

The modelling simulations indicate that the ventilation layout with only one last cut-through open for airflow between A and B headings for gas dilution would result in a minimum length of the explosive range zone in B heading. Results indicate that the practice of not closing off all the remaining cut-throughs outbye of the longwall face for any reason/operational convenience would result in an extension of the explosive range zone in B heading. Therefore, it is strongly recommended that mines should implement the ventilation control strategy of having only one last cut-through open for airflow between A and B tailgate headings for gas dilution. All other outbye cut-throughs between A and B tailgate headings should be closed off completely.

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