

CFD MODELLING OF LONGWALL TAILGATE VENTILATION CONDITIONS

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ABSTRACT

Face ignitions at the longwall face are a serious hazard in underground coal operation that can lead to a major mine explosion. Despite having methane monitoring system mounted on the shearer and at various locations on the longwall face, undetected accumulations of methane can still occur and result in face ignitions. With the use of Computational Fluid Dynamics (CFD), the interaction between the air flow at the longwall face and factors that contribute to the accumulation of methane around the longwall face can be modeled and visualized in great detail. The results confirm that the tailgate corner of longwall face is a critical area that is prone to face ignitions and needs to be properly monitored. The occurrence of roof falls on the tailgate entry inby the face and/or poor caving conditions behind the shields can pose a safety risk in the longwall operation. Poor gob caving can lead to insufficient face air quantity to dilute methane at the tailgate corner, while blocking of tailgate by a roof fall can carry methane contaminated air from behind the shields back into the face near the tailgate corner and pull the explosive gas zones (EGZs) inside the gob closer to the face.

INTRODUCTION

Ignitions of accumulated methane gas at longwall faces are well known to be among the major causes of methane explosion in underground coal longwall mining operations. Some of these ignitions can lead to major mine explosions, such as the Upper Big Branch mine disaster in 2010, in which methane migrated from the gob to the shearer cutting drum where it was ignited, resulting in a major mine disaster (Phillips, 2012). History has shown that, despite having methane monitoring systems mounted on the shearer and various locations at the longwall face and alarms set to 1% CH₄ (Mine Safety & Health Administration, 2012), undetected accumulations of explosive methane-air-mixtures can still occur and result in face ignitions. Recent study by Verma and Brune (2016) state that frictional ignitions on longwall faces contributed to 379 incidents or 23% of the total 1,637 cases of face ignitions recorded from 1983 to 2014.

The common cause of mine explosions usually involves poorly designed ventilation systems, insufficient ventilation, and inadequate monitoring in critical areas that are prone to methane accumulations. In longwall operation, the tailgate corner of the longwall face can be considered as one such critical area. On-site studies by Krog et al (2006) and Thakur (2008) show that increasing the longwall panel width may also increase cumulative methane emissions at the tailgate. There are also indications that increasing longwall face lengths can result in an increase of the void space behind the face under certain roof conditions (Schatzel et al, 2006). This may cause higher leakage rates from the face to the gob, thus reducing the amount of fresh air available at the tailgate.

A study done by Peng and Chiang (1986) on the air velocity distribution along mechanized longwall faces shows that the extent of air leakage is highly dependent on the caving conditions behind the shields. In longwall faces with stable roof and poor caving conditions, voids would form behind the shields that allowed up to 60% - 80% of face air to leak into the gob. This resulted in only 20% - 40% of fresh

air supplied to the face to reach the tailgate. Other factors such as changes in barometric pressure (Lolon et al., 2016), tailgate ventilation changes due to roof falls (Brune & Sapko, 2012), and failures of the shearer mounted water spray mechanism may also contribute to the accumulation of methane at the longwall face. This paper focuses on the use of Computational Fluid Dynamics (CFD) to study the ventilation conditions at the tailgate of the longwall face in relation to the caving conditions of the immediate roof behind the face as well as changes in tailgate ventilation due to roof falls in the tailgate entry.

CFD MODEL OF A LONGWALL BLEEDER SYSTEM

The CFD model was developed using the commercial software package ANSYS® Fluent®. The model geometry, shown in Figure 1, is based on an actual longwall mining operation in the United States. The panel is 3,300ft long and 1,000ft wide and the coal seam is 7ft high. The gob and fracture zone heights are 33ft and 23ft, respectively. The mine entry dimensions are 20ft x 7ft and the longwall face is supported by 176 shields. The roof directly behind the shield has not fully caved, resulting in a large void behind the shields that extends up to 50ft inby the face on the tailgate side. The longwall shearer is assumed to be cutting out the coal face at the tailgate corner. The model also includes the operational components typically found in a longwall operation, such as shearer, stage loader, face conveyor, shield supports, a face curtain extending up to shield number six at the headgate side, the gob plate and head- and tailgate drives.

The mine utilizes a bleeder ventilation system with a T-split on the tailgate side. The stoppings on the tailgate side are removed every five crosscuts to allow the face air pass to the bleeder entry. The gob characteristics used in this study are based on model developed by Marts et al. (2014), with the gob porosity ranging from 20% in the center of the gob to 40% near the face and the gob permeability ranging from 2×10^{-7} to 7×10^{-8} md.

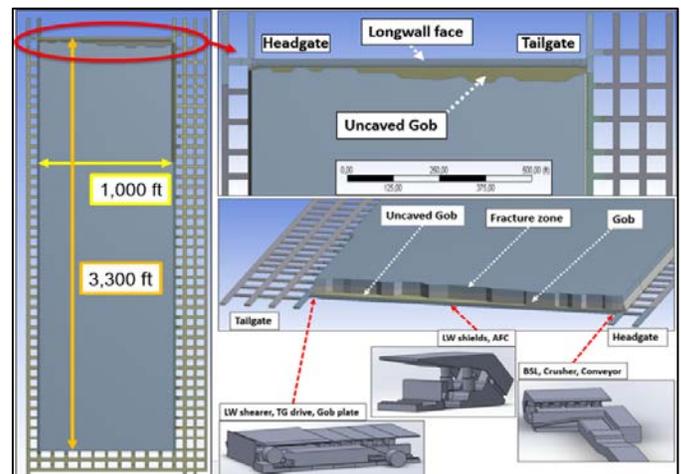


Figure 1. Geometry of longwall model, overview (left) and close up view of longwall face (right).

Two different ventilation scenarios are considered for this study. The first scenario represents the normal ventilation condition for the mine, while the second scenario represents the case when roof fall occurs in the tailgate entry 50ft inby the longwall face, forcing a change in tailgate ventilation. Figure 2 illustrates the two ventilation scenarios.

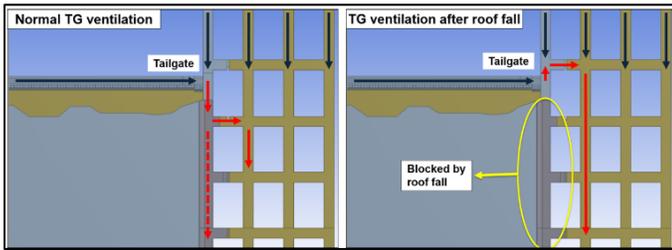


Figure 2. Ventilation models showing normal conditions (left) and after roof fall occurred (right).

Scenario 1: Normal tailgate ventilation setup

The ventilation air quantities used for the base case model can be seen in Figure 3. This base case represent a normal ventilation setup for the mine.

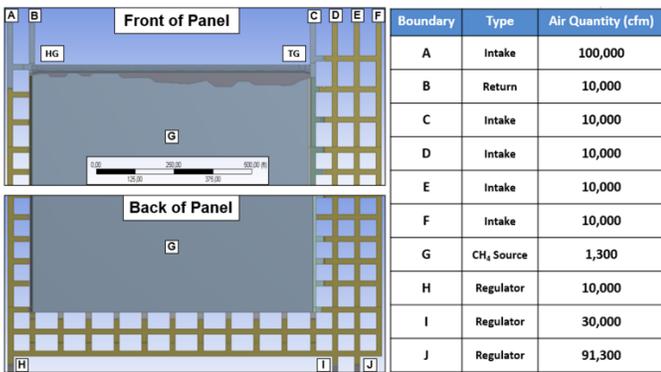


Figure 3. Ventilation network air quantity in a bleeder-ventilated gob.

In the normal ventilation setup, 100,000 cfm of fresh air are delivered from the headgate entry. 25,000 cfm assumed to leak through the headgate curtains and 10,000 cfm of air are returned through the belt entry, resulting in 65,000 cfm of air delivered to the LW face. Each of the tailgate entry and three bleeder entries are set to carry 10,000 cfm of air. The airflow from the longwall face mixes with the fresh air from the tailgate entry and flows to the bleeder entries through the open crosscut inby the longwall face. This allows the air current from the face to sweep and ventilate the tailgate corner of the gob. The air quantities at the back of the bleeder are controlled with a series of bleeder regulators. The result of the CFD simulation for normal ventilation conditions is shown in Figure 4.

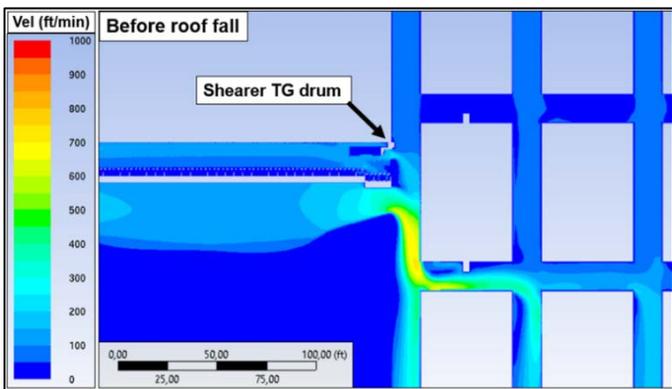


Figure 4. Close up view of tailgate ventilation showing air velocity contours at 5ft above floor.

The plan view shows the airflow distribution at 5ft above the mine floor. The simulation results document that the area near the tailgate corner is poorly ventilated. With the shearer located at the tailgate corner and the gob plate restricting the flow, the opening for the face

airflow is significantly reduced. As a result, given the poor caving conditions, the air will find a path with less resistance through the void directly behind the shields. Most of the fresh air that was supplied to the face is leaking into the gob through the gaps behind the shields. Out of the 65,000 cfm supplied to the face, only around 10,000 cfm remain on the face at the tailgate. This amount of airflow is likely insufficient to dilute the methane along the face and can cause an accumulation of methane at the shearer. The extent of air leakage will vary depending on the caving condition behind the shields. It is also affected by the ventilation system used, whether it is a bleeder system or a progressively sealed gob. In progressively sealed gobs, the fresh air that leaked into the gob at the headgate corner and along the face will be pulled back into the face through the shield gaps as it approaches the tailgate. In bleeder systems, the air that leaks into the gob does not return to the face but flow directly towards the bleeder fan at the back.

Scenario 2: Tailgate entry blocked by roof fall inby the longwall face

If a tight roof fall blocks the tailgate entry inby the face, stoppings outby the face must be opened to allow ventilation access from the longwall face toward the bleeder entries. As a result, the airflow from the face is now directed toward the nearest open crosscut outby the face. The result of the CFD simulation for the ventilation condition after a roof fall is shown in Figure 5.

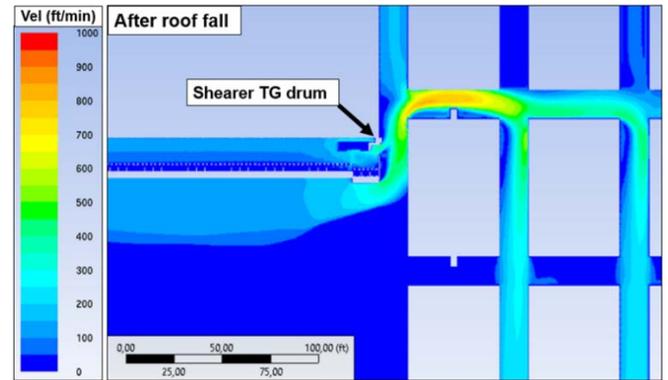


Figure 5. Close up view of tailgate condition after roof fall occurred, showing velocity contours at 5ft above floor.

If blocked by a roof fall, some of the air that leaked into the gob may flow back into the face near the tailgate corner. This airflow pattern is similar to that observed in longwall mines that utilize progressively sealed gobs (Schatzel et al, 2012; Yuan et al, 2012).

This ventilation condition can create explosion hazards, as methane from the gob traveling behind the shields may be carried back into the face and may interact with the shearer drum at the tailgate corner. In addition, this change of airflow patterns may prevent the methane sensors mounted on the shearer body or the tailgate drive from detecting such methane accumulations when the shearer is cutting near tailgate corner.

Effect of Roof Fall on Methane Distribution at Longwall Face Tailgate Area

To study the effect of a roof fall on the inby tailgate on the distribution of methane inside the gob. The CFD model was set up to produce a methane volume concentration of approximately 1% CH₄ at the bleeder fan. The result of the simulation for the two ventilation scenarios can be seen in Figures 6 and 7.

Before the roof fall occurred, the close up view of the tailgate condition shows that the face air sweeps the corner of the gob on the tailgate side and prevents accumulations of methane in this area. The methane behind the shields is also diluted by the ventilation air that leaks from the longwall face, preventing methane from the gob from entering the longwall face.

In Figure 7, a roof fall in the tailgate entry inby the face forces a large air current to flow to the newly opened crosscut outby the face. In addition, methane from inside the gob will be pulled towards the tailgate corner. The close up view of the tailgate area shows that contaminated air travelling behind the shields returns to the face near

the tailgate and then travels outby the face, passing close to the tailgate side shearer drum. The impact of the roof fall on methane accumulation and mixing patterns in the tailgate area depend largely on the tightness of the roof fall and the amount of methane outgassing from the gob at the tailgate corner, as demonstrated in the study done by Brune and Sapko (2012).

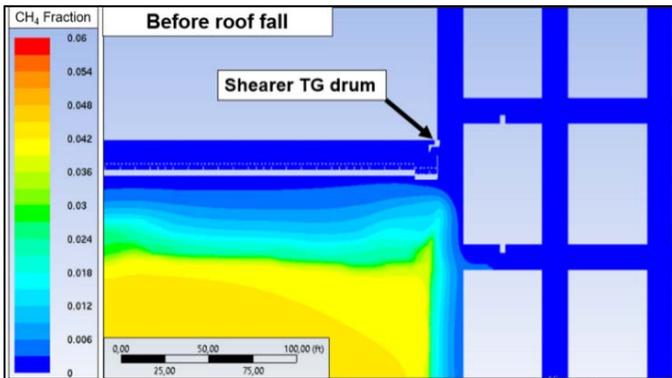


Figure 6. Methane distribution around longwall face tailgate before the roof fall. Unit in mole fraction.

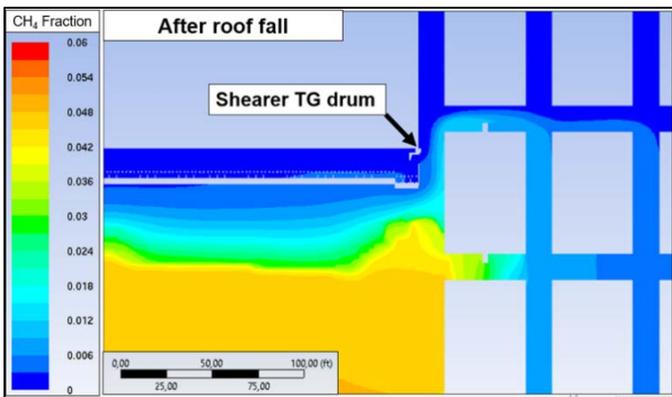


Figure 7. Methane distribution around longwall face tailgate after roof fall. Unit in mole fraction.

Effect of Roof Fall on Methane Distribution inside Gob

The impact of roof fall on the methane distribution inside gob can also be analyzed by observing the formation and movements of EGZs in the gob. The diagram in Figure 8 illustrates the explosibility of the methane-air mixtures, based on the Coward's triangle (Gilmore et al., 2015).

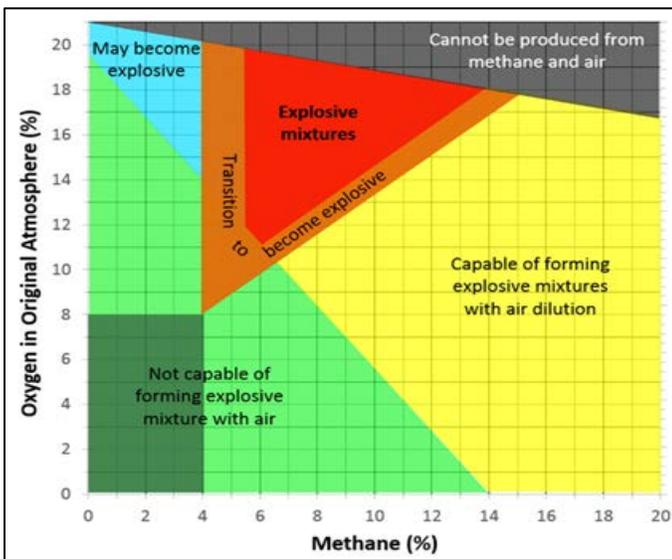


Figure 8. Explosibility diagram of methane and air mixtures (Lolon, 2016; redrawn from Gilmore et al., 2015).

Red color represents explosive gas mixtures or EGZs, yellow is fuel-rich inert and green is fuel-lean inert. Orange color represents methane-air mixtures that are close to becoming explosive. Blue color represent inert, oxygen-rich mixtures with less than 4% methane, including fresh air. Figure 9 shows the comparison of the formation of EGZ inside the gob before and after the roof fall occurred. After the roof fall, the EGZ marked in red becomes significantly larger and moves closer to the active face where it can be ignited by shearer cutting action.

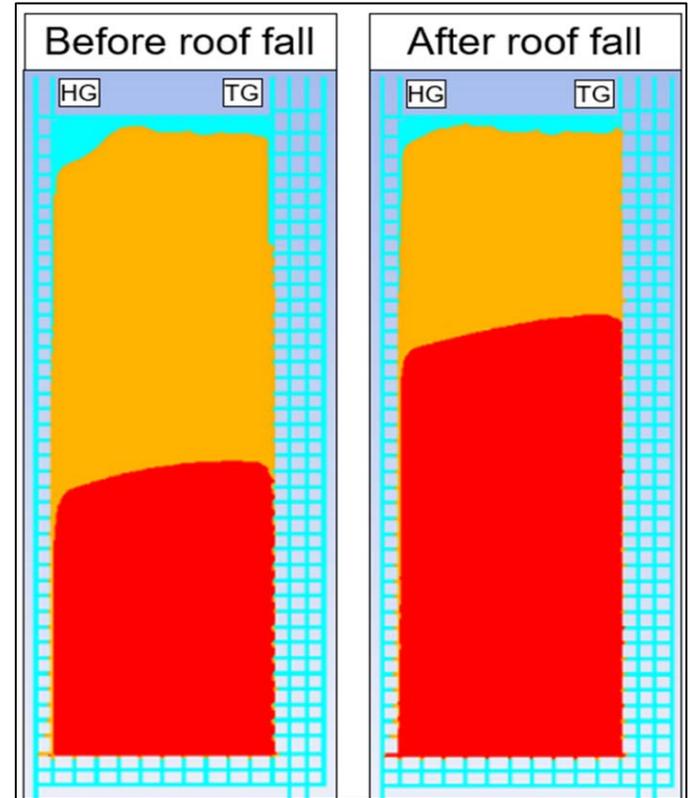


Figure 9. Comparison of EGZ distribution inside gob before roof fall (left) and after roof fall (right) at 5ft above floor based on Coward's triangle.

The EGZ distribution inside gob show that although the leaks of fresh air across the longwall face has significantly reduced the air quantity at the tailgate corner, this leaked air help preventing methane buildup in the gob area immediately behind the longwall face. Before the roof fall occurred, the EGZ is located at the back of the gob and far from the longwall face. After the roof fall blocked the tailgate entry, the roof fall area is now filled with near explosive gas mixture and the EGZ is being pulled closer to the longwall face. The extent of the EGZ movement will vary based on the gob characteristic and the amount of methane originated from the gob. If the EGZ managed to reach the active roof fall area behind the shields, this will create an explosion hazard due to the possibility of ignitions caused by rock-on-rock friction when the immediate roof caved into the gob, such in the case of Willow Creek mine explosion in 1998 and 2000 (Elkins et al., 2001; McKinney et al., 2001).

CONCLUSIONS

The use of Computational Fluid Dynamics can provide a detailed interaction between the air flow at the longwall face and leakages in the void behind the shields. In addition, the impact of a roof fall in the immediate tailgate entry can be modeled and visualized. The resulting airflow profiles and methane-air mixtures conditions can provide a better understanding of tailgate ventilation hazards caused by explosive accumulations of methane near the tailgate corner.

Roof falls in the tailgate entry inby the face can create an explosion hazard. Not only does the roof fall hinder the ability of the face air to dilute methane accumulations in the tailgate corner, it can also bring contaminated air from the gob back into the face and pull the

EGZ inside the gob closer to the face. Roof control on the tailgate and monitoring of tailgate ventilation conditions are therefore important to prevent longwall face ignitions.

Caving conditions behind the shields can also have a significant impact on the ventilation conditions in the tailgate corner area. Poor gob caving can lead to insufficient fresh air at the tailgate corner and also make this area prone to methane accumulations and explosion hazards.

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