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DYNAMIC SEALS: A WAY TO PREVENT LONGWALL GOB EXPLOSIONS

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INTRODUCTION

Longwall coal mining leaves large areas where the coal has been made removed and the roof rock strata collapse, forming a zone of broken rock rubble called the gob. Figure 1 shows a typical longwall gob area along with the gate roads. The ventilation pattern for progressively sealed longwall panels follows a simple "U" pattern where fresh air is coursed inby to the headgate, flows along the face and exhausts through the outby tailgate as shown in figure 1(a). An important variation of this pattern is the back return (BR) arrangement where the exhaust air from the face is drawn inby and around the nearest open cross cut before it turns in the outby direction towards the exhaust fan. Figure 1(b) illustrates the use of back return. This arrangement moves the point of low pressure from the tailgate corner up to 60 m inby and thus maintains fresh air in the tailgate region that could otherwise be contaminated with gob air.

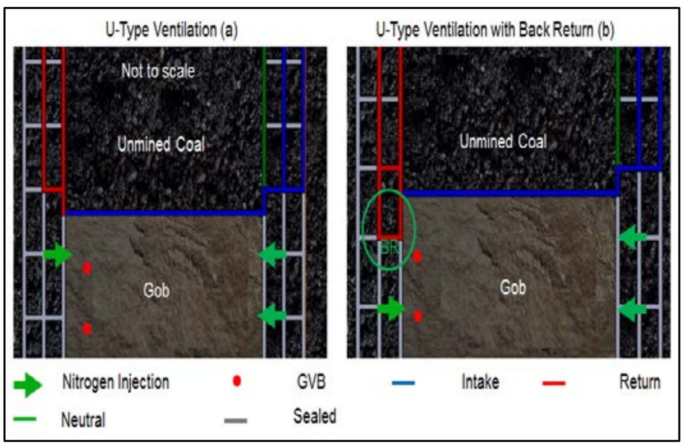

Figure 1. Ventilation layouts used in CFD modeling. BR indicates the back return.

The gob area may contain remnants of unmined coal or parts of overlying coal beds that continue to release methane, eventually filling the gob area with methane in concentrations far above the explosive range of about 4.5 to 15%. Many gob areas must be equipped with gob ventilation boreholes (GVBs) to extract methane, and GVBs often exhaust methane at concentrations from 50% to 90% (Saki, 2016). Due to oxidation processes occurring in the gob, the oxygen content is reduced to a low level, with nitrogen and CO_2 making up the major remaining components of the gob atmosphere.

FORMATION OF EXPLOSIVE GAS ZONES IN GOBS

Since the longwall face area is ventilated with fresh air below 1% methane and the face and gob areas are not separated, an explosive fringe will form where the methane content lies within the explosive range and oxygen content remains above 12%. Figure 2 shows a typical development of such an EGZ. This figure is based on a computational fluid dynamics (CFD) model developed by CSM researchers to analyze gas concentrations and flow patterns in longwall mining. Figure 2(a) shows the formation of EGZ in the gob with a U type ventilation scheme, where EGZ lies right behind the shields in the tailgate corner. Figure 2(b) shows the formation of EGZ in the gob combining U type ventilation scheme with BR, where EGZ is pushed away from the face deep into the gob. The CFD modeling parameters and boundary conditions have been verified with field data from two cooperating, active longwall mines (see Worrall 2012, Marts 2015, Gilmore 2015 and Saki 2016). Other mine geometries, methane inflow rates and gob permeability distributions can be modeled to establish representative gob atmospheric conditions. Two GVBs were operating in the model, extracting 0.165 m^3/sec each. The methane in the working areas and returns was kept below 1%. Methane flowing into the model from a rider coal bed above the mined seam was at the rate of 0.55 m^3/sec.

The color coding in the following figures is based on Coward's triangle, see Figure 2, and shows explosive concentrations in red, near-explosive in orange, methane-rich inert areas in yellow, fuel-lean inert areas in green and fresh air in blue.

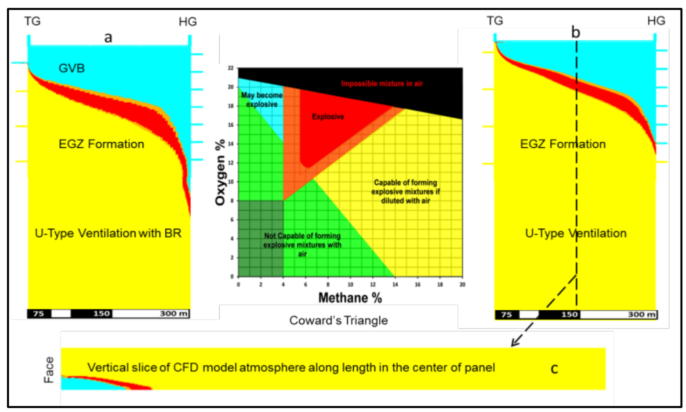

Figure 2. EGZ formation in longwall Gob.

It should be noted here that most US longwall mines use bleeder ventilation schemes. In bleeder ventilated gobs, continuous EGZ fringes surround the gob as they form between all fresh-air ventilated bleeder entries and the center of the gob. The following considerations apply only to non-bleeder ventilated, progressively sealed gobs that are common worldwide.

Nitrogen or other inert gas injection into the gob is common practice if remnants of coal left in the gob pose a spontaneous combustion (spon com) hazard. Australian mine operators frequently inject Tomlinson boiler gas to inertize gob areas to inertize gobs and prevent spon com while other mines generate nitrogen on-site and pump it into the gob.

CSM research has shown that, despite injection of inert gases, the formation of EGZs closely behind the longwall face cannot be prevented in all cases. A 2011 ignition and methane fire occurred at the San Juan mine in the US State of New Mexico despite ongoing nitrogen injection. The fire was ignited from flame cutting on the face (Hansen, 2016). It was quickly detected, controlled and extinguished by additional nitrogen injections after all miners had been successfully evacuated.

DYNAMIC SEALS

Marts (2015) demonstrated that, through targeted injection of nitrogen from both headgate and tailgate sides, a "dynamic seal" of inert nitrogen-air mixtures could be formed to separate the oxygen-rich face air from the methane-rich atmosphere deep in the gob. Figure 3 shows this effect in a color-coded CFD output for a reference plane 1.5 m above the bottom of the coal bed. Figure 3 illustrate that with U-Type ventilation scheme, the dynamic seal formation is incomplete; in the tailgate corner an EGZ exists directly behind the shields. During barometric pressure drops or if a roof fall changes air pressures around the longwall, EGZs may enter the face and pose fire or explosion hazards.

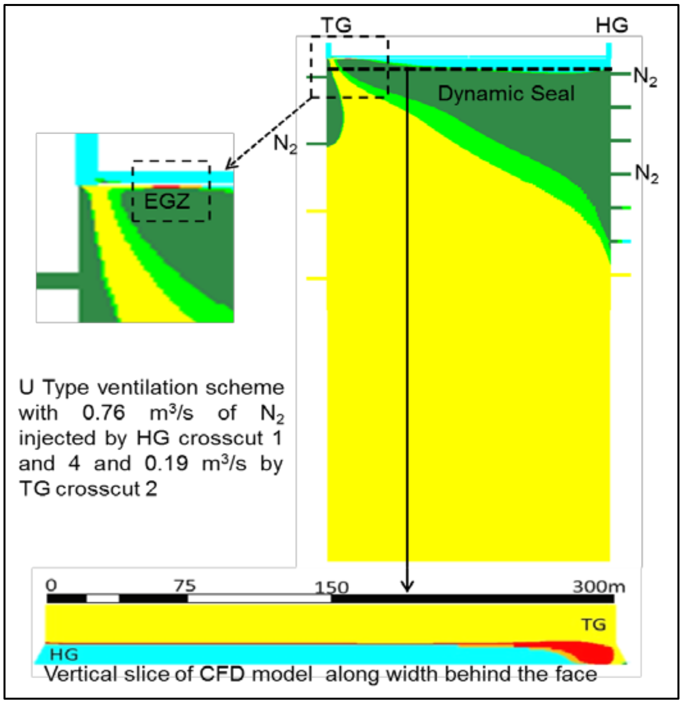

Figure 3. Formation of dynamic seal in the gob behind the face with U-type ventilation.

In his studies, Marts also indicated that, while it was possible to create a continuous, dynamic seal within this reference plane, EGZs may still form in higher elevation regions of the gob, closely behind the face. Marts was able to create a continuous, dynamic seal using the combination of U type ventilation and back return, as shown in Figure 4. This figure illustrates a remnant EGZ in the upper fracture region of the gob, approximately 12 m above the coal. While unlikely, it is possible that this EGZ is ignited either through spon com or through rock-on-rock frictional ignition. Initial research by Fig et al. (2015) indicates that a methane-air ignition can propagate through rock rubble but further work will be necessary to determine if flames and pressure waves from such a high location can actually reach the face and pose a fire or explosion hazard to miners.

Researchers have further examined this phenomenon, seeking ways to eliminate these remnant EGZs and to reliably mitigate fire and explosion hazards. There are two ways to influence the formation and location of the dynamic seal: control via nitrogen injection or installation and operation of GVBs. A back return is an additional control designed to move the dynamic seal further inby from the tailgate.

Researchers developed further CFD models and injected nitrogen from the first two GVBs in addition to nitrogen injection from the headgate and tailgate entries. Modeling showed that GVB injection considerably reduced the volume of EGZs at the higher elevations but still could not completely eliminate them, as shown in the vertical section in Figure 5. Most of nitrogen injected through GVBs flowed into the longwall return airways. The research goal was to completely eliminate all EGZs. Researchers succeeded reaching this goal by injecting additional nitrogen directly behind the shields, as shown in Figure 6.

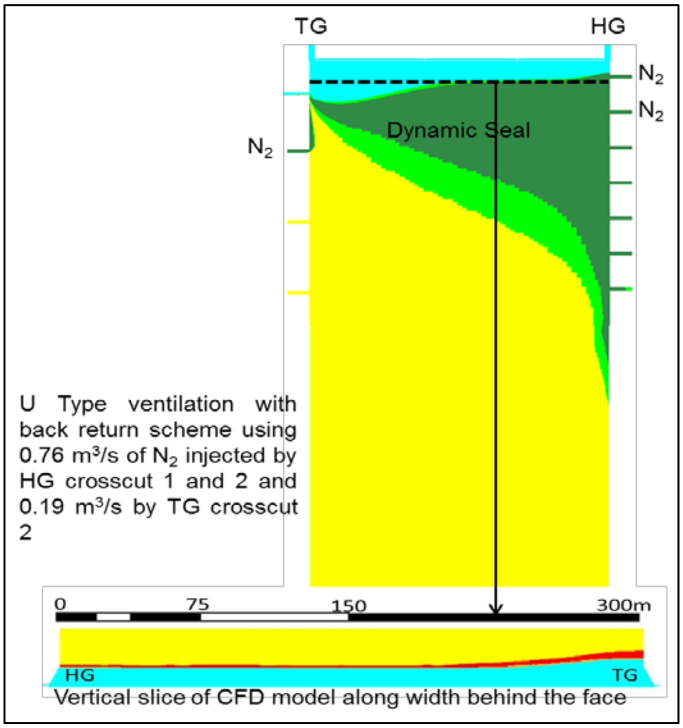

Figure 4. Formation of dynamic seal in the gob using U-type ventilation with BR.

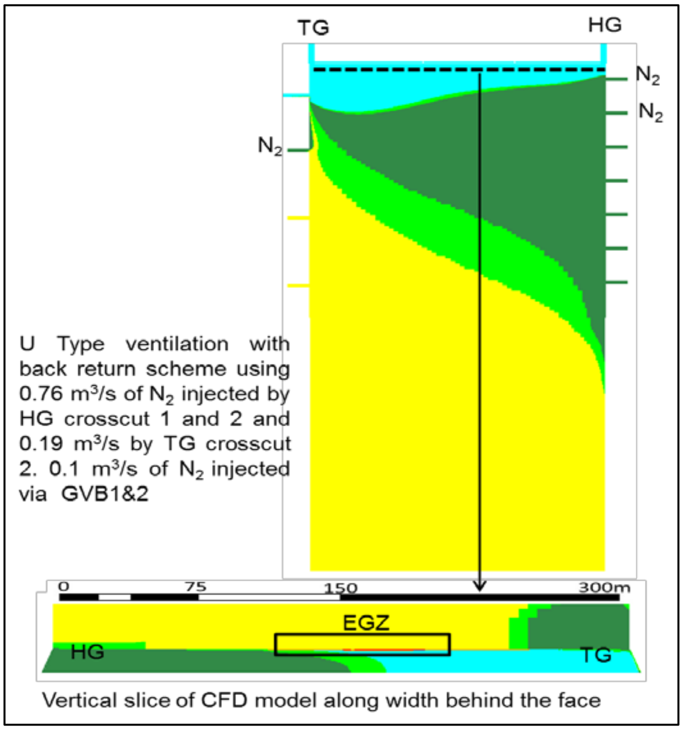

Figure 5. Effect of nitrogen injection via GVBs on EGZs, showing minimal remaining EGZ.

ROLE OF FACE AIR QUANTITY AND GVBS OPERATION ON EGZS FORMATION

Saki (2016) demonstrated that the volume and location of EGZs can be controlled by the optimized location and operation of GVBs but GVBs alone cannot eliminate EGZ formation. Researchers also documented the relative volume of explosive mixtures as a function of varying face air quantity to understand the role of face air on EGZ formation. Figure 7 shows that the EGZ volume in the gob increases with increasing face air quantity. The EGZ volume is normalized to make the results comparable independent of the absolute size of the longwall panel. This phenomenon is explained as follows: As the face ventilation quantity is increased, a higher pressure differential is created between the face and the gob and more air will migrate into the gob through gaps between the shields. Oxygen ingress into the gob will enhance the formation of explosive mixtures. Where the coal has a high propensity for spontaneous combustion, this oxygen ingress may also increase the potential for spontaneous combustion.

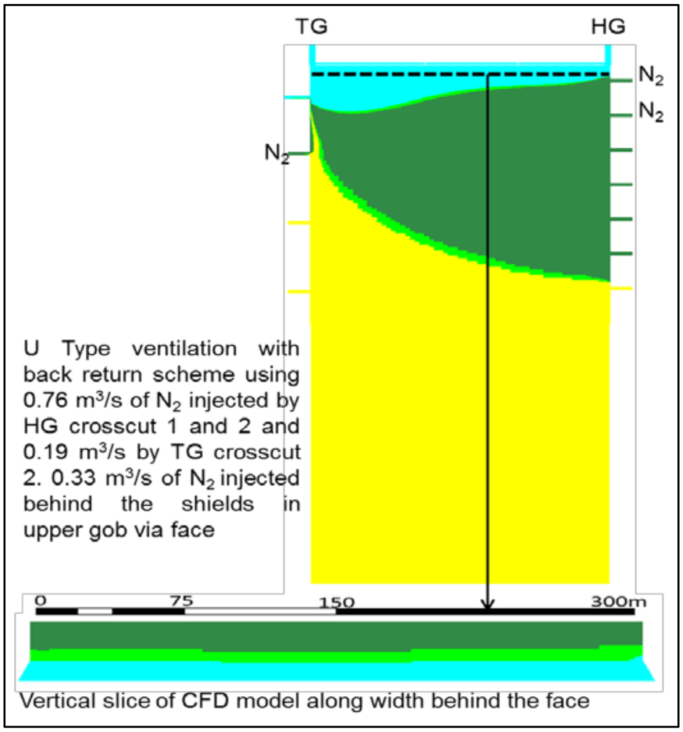

Figure 6. EGZs fully eliminated by injecting the nitrogen behind the face.

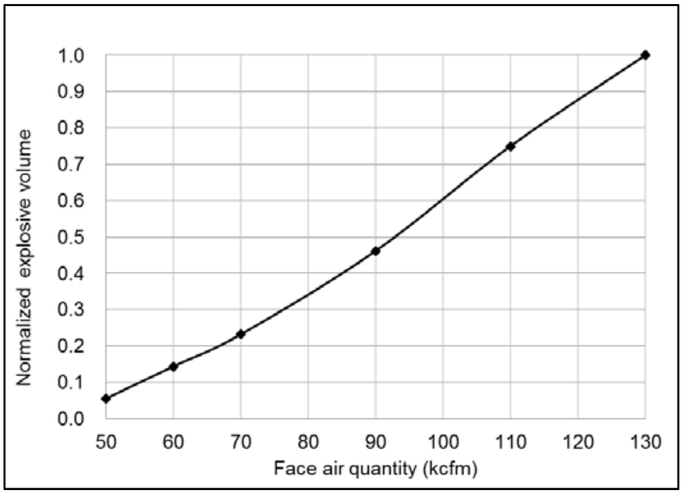

Figure 7. Effect of face air quantity on the formation of EGZs.

SUMMARY AND RECOMMENDATIONS

Computational fluid modeling demonstrates that explosive methane-air mixtures close to the operating face of longwall gob areas of coal mines can be eliminated by injecting nitrogen or other inert gases through cross cut seals behind the face. Eliminating these explosive gas zones will greatly reduce ignition and explosion hazards in longwall coal mines. In the past, such explosions have had devastating consequences, including in 2010 at the Upper Big Branch mine, where 29 miners lost their lives.

Based on this work, researchers have the following best practice recommendations for operating longwall mining systems in coal mines:

- Instead of a bleeder system, longwall operators should operate a progressively sealed gob to minimize EGZ formation.
- Along with the sealed gob, a back return ventilation arrangement should be maintained at the tailgate corner. This will sweep the tailgate corner with fresh air, removing the EGZ hazard inby the face. It should be noted that, if the coal is prone to spontaneous combustion, a back return may increase fresh air ingress into the gob. Operators can prevent this by injecting inert gas behind the shields.
- Operators should install infrastructure and contract with suppliers to continuously inertize the gob with nitrogen or Tomlinson boiler gas. Inertization is done mainly from the headgate, but additional inert gas may need to be injected behind the shields to completely eliminate EGZs in higher regions.

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