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Prevention of gob ignitions and explosions in longwall mining using dynamic seals

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A B S T R A C T

Most, if not all longwall gob areas accumulate explosive methane-air mixtures that pose a deadly hazard to miners. Numerous mine explosions have originated from explosive gas zones (EGZs) in the longwall gob. Since 2010, researchers at the Colorado School of Mines (CSM) have studied EGZ formation in longwall gobs under two long-term research projects funded by the National Institute for Occupational Safety and Health. Researchers used computational fluid dynamics along with in-mine measurements. For the first time, they demonstrated that EGZs form along the fringe areas between the methane-rich atmospheres and the fresh air ventilated areas along the working face and present an explosion and fire hazard to mine workers. In this study, researchers found that, for progressively sealed gobs, a targeted injection of nitrogen from the headgate and tailgate, along with a back return ventilation arrangement, will create a dynamic seal of nitrogen that effectively separates the methane zone from the face air and eliminates the EGZs to prevent explosions. Using this form of nitrogen injection to create dynamic seals should be a consideration for all longwall operators.

1. 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 or goaf. The active faces of longwalls are ventilated with fresh air and, in most jurisdictions, the maximum methane content is limited to 1%. Gob areas cannot be ventilated effectively, causing methane to accumulate. The gob area may contain remnants of unmined coal and under- or overlying coal beds may continue to release methane, eventually filling the gob area with methane in concentrations far above the explosive range, which is at about 4.5–15%. Many gob areas must be equipped with gob ventilation boreholes (GVBs) to extract methane excessive, and these GVBs usually exhaust methane at concentrations from 50% to 90% [1]. Due to coal oxidation processes occurring in the gob, the oxygen content of gob air is reduced to a low level, with methane, nitrogen and CO_2 making up the major remaining components of the gob atmosphere. If methane-rich gob gases mix with fresh ventilation air to form an explosive gas zone (EGZ), this can present a significant and deadly fire and explosion hazard for miners. The existence of such EGZs has been confirmed by other researchers, including [2–4]. In United States mines, methane explosions related to gob gas have caused several fatal explosion disasters, including the explosion at the Willow Creek mine in 2000 with two fatalities and the explosion at the Upper Big Branch mine in 2010, where 29 miners lost their lives [5].

Zipf et al. have examined mine explosions in sealed gob areas and found that several major explosions had occurred in recently sealed gobs, confirming that methane-air mixtures continue to build up in these areas and present hazards to miners even after the areas have been sealed [6]. Zipf et al. point out that, since 1976, 185 coal mine workers were fatally injured in explosions in United States coal mines and consequently recommend that the atmosphere inside sealed areas be monitored - a practice that is common in European and Australian coal mines but not required by law in the United States [6]. Brune et al. documented that, in the United States, the methane explosion hazard in mines is often underestimated and that additional monitoring of sealed areas and longwall gobs should be done to increase awareness of explosive methane accumulations [7]. Methane-air explosions can reach overpressures of several atmospheres, depending on the degree of confinement, and, as Fig. et al. have shown, can easily propagate through rock rubble in the gob [8]. Under certain circumstances, methane-air mixtures can also detonate, developing pressures up

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to 1.7 MPa, as demonstrated in [9]. Such detonation may have happened in the Sago mine explosion in 2006, where military experts estimated an overpressure of nearly 90 atmospheres [10].

Fig. 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 Fig. 1a.

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. Fig. 1b illustrates the use of back return. This arrangement moves the point of low pressure from the tailgate-face corner to the next cross-cut, in this case about 60 m, inby the face. This ventilation arrangement is common in United States longwall mines and maintains fresh air in the tailgate region that could otherwise be up contaminated with potentially explosive gob air.

2. Formation of explosive gas zones in longwall 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%. Fig. 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.

Gilmore described in detail the development of the CFD modeling tools, boundary conditions, assumptions and mesh design for the CFD model used by the researchers in this project [11,12]. In CFD modeling, the Navier-Stokes equations for a given single-phase gas flow in the mine ventilation realm are discretized in a computational mesh and solved iteratively. The boundary conditions for the model were defined by ventilation quantities and pressures measured in longwall mines whose operators cooperated with the researchers. Methane concentrations in the gob were verified with gob ventilation production data and other field measurements that researchers obtained from the cooperating mines.

Marts conducted rock mechanics modeling studies using Itasca's FLAC3D to estimate gob porosities and permeability [13]. Marts et al. used measured mine subsidence profiles to calibrate the FLAC models. They also compared their results to several studies published by other research groups and found them to be reasonably accurate. Marts et al. then developed a three-dimensional curve fit function to apply spatially variable permeabilities across the entire longwall gob area.

The results of the CFD models provide the concentrations of methane, oxygen and nitrogen in the gob area. The color coding in the following figures is based on Coward's triangle [14] as modified in [15], see Fig. 2. The color coding scheme 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.

Fig. 2a shows a typical formation of an EGZ, shown as a red sliver, in a typical longwall gob ventilated with a U-type scheme. The EGZ starts right behind the shields in the tailgate corner of the longwall face. Several longwall mines have experienced face ignitions in the tailgate area from such or similar EGZs, including the fires and explosions at the Buchanan mine in 2005 and in 2007 [16].

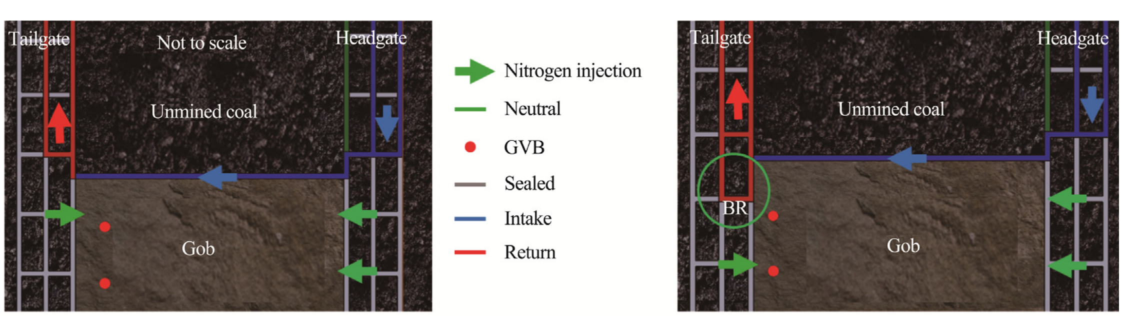
Fig. 2b shows the formation of a similar EGZ in the gob when U-type ventilation is combined with a back return. Here the EGZ is pushed about 60 m away from the face, deeper into the gob. Researchers are currently investigating whether 60 m is sufficient to mitigate the explosion hazard in the gob. The CFD modeling parameters and boundary conditions have been verified with field data from two cooperating, active longwall mines (see also [1], [11], and [15]). Other mine geometries, methane inflow rates and gob permeability distributions can be modeled to establish representative gob atmospheric conditions. Two Gob Ventilation Boreholes (GVBs) were operating in the model, extracting 0.165 m^3/s 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/s.

The plan views show gob gas concentrations in a horizontal slice 1.5 m above the bottom of the coal seam. The vertical section at the bottom of Fig. 2 extends along the center line of the gob and shows that the EGZ also extends upward, due to the buoyancy of methane.

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 hazard. Australian mine operators frequently inject Tomlinson boiler gas to inertize gob areas to inertize gobs and prevent spontaneous combustion 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 by flame cutting on the face. It was quickly detected and, after all miners had been success-



(a) U-type ventilation

(b) U-type ventilation with back return

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

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