A Critical Look at Longwall Bleeder Ventilation

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Bleeder ventilation is common and legally required in underground longwall coal mines in the United States. This ventilation technique originated with room-and-pillar retreat mining and is intended to clear mined-out areas or gobs of any explosive methane-air mixtures. A system of bleeder ventilation entries surrounds the gob, intended to draw explosive methane accumulations directly towards a dedicated system of return airways and to a dedicated bleeder fan. Bleeder entries are traveled regularly for inspection purposes and the methane content within these travel ways is limited to 2%.

With the arrival of longwall mining in the United States in the 1970s, bleeder ventilation was extended to controlling methane in longwall gobs. Researchers at the Colorado School of Mines (CSM), under a research project funded by the CDC-NIOSH Office of Mine Safety and Health Research, have studied bleeder ventilated longwall gobs by examining gas compositions and gas flows using computational fluid dynamics (CFD) modeling techniques. Researchers found that bleeder ventilated gobs are surrounded by a fringe of methane-air mixtures in the explosive range. Investigations of numerous mine explosions indicate that these explosive mixtures may have either ignited within the gob or may have been pushed into the active mine workings.

This paper will characterize the explosion and fire hazards stemming from bleeder ventilated gobs and suggests improvements for ventilation practices that reduce or eliminate these hazards.

Keywords: Coal mining, longwall mining, explosion prevention, bleeder system, sealed gob, nitrogen inertization

1. Introduction

A coal mine ventilation system must control explosion hazards by diluting and carrying away potentially explosive mixtures of methane in air. In the United States, Title 30 CFR §75.334(b) [1] requires that, during and after pillar recovery, a bleeder system be used to ventilate the worked-out areas where pillars, including longwall panels, have been recovered, so that methane-air mixtures are continuously diluted and routed into a return air course. The mine operator must file and the U.S. Mine Safety and Health Administration (MSHA) approves a mine ventilation plan that must specify the "design and use of bleeder systems" as well as the "means to determine the effectiveness of bleeder systems."

A concise definition of the terms "bleeder" and "gob" is given by Urosek et al. (2006) [2]:

Bleeder systems are that part of the mine ventilation network used to ventilate pillared areas in underground coal mines. Pillared areas are those in which pillars have been wholly or partially removed, including the areas where coal has been extracted by longwall mining. Bleeder systems protect miners from the hazards associated with methane and other gases, dusts and fumes, and oxygen deficiency that may occur in these mined-out areas. Effective bleeder systems control the air passing through the area and continuously dilute and move any methane-air mixtures and other gases, dusts, and fumes from the worked-out area away from active workings and into a return air course or to the surface of the mine. A bleeder system includes the pillared area (including the internal airflow paths), bleeder entries, bleeder connections, and all associated ventilation control devices that control the air passing through the pillared area. Bleeder entries are special air courses designed and maintained as part of the mine ventilation system. It should be noted that a mined-out longwall panel is considered a "pillared area" in the context of this definition.

Stoltz (2007) [3] states that "effective bleeder systems control the air passing through the area and continuously dilute and move methane-air mixtures and other gases, dusts, and fumes from the worked-out area away from active workings, in an effective manner, preventing hazardous accumulations".

Bleeder systems around longwall gobs are typically inspected by measuring air flow and methane content at key locations, the so-called Bleeder Evaluation Points (BEPs). Figure 1 (after Stoltz, 2007, [3]) indicates the points where air flows in to the bleeder system (yellow) and those where air flows out (red), usually, BEPs. An important part of the bleeder ventilation concept is that the gate road entries surrounding the gob panels are being kept open and free of obstructions such as roof falls and standing water (30 CFR §75.334(c)(3)) so that examiners can travel and inspect these airways. In this example, air can flow from the inlets inby the active longwall panel (right side in Figure 1) to the outlets at the left side. Similarly, air can flow from the inlets along the mains (bottom of Figure 1) to the outlets at the top left.

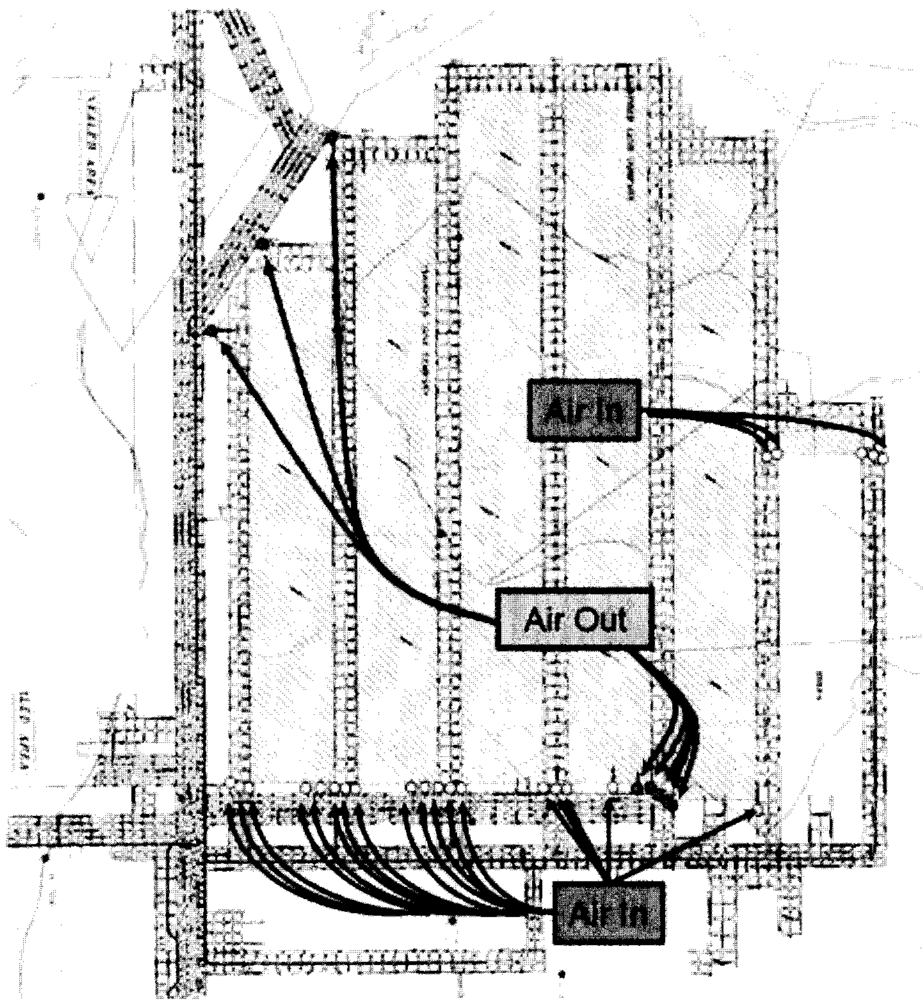

Figure 1: System of bleeder ventilated longwall gobs with air inlets (yellow) and outlets (red), modified after Stoltz (2007) [3]

Bleeder entries that are being traveled for inspection and maintenance purposes may carry a maximum of 2% methane (30 CFR §75.323(e)). Likewise, the air exiting the bleeder outlets or BEPs may not contain more than 2% methane. Therefore, the mine operator must provide sufficient amount of fresh air entering the inlets to dilute the air exiting the BEPs to below 2%. Most recently, MSHA has provided guidance for the establishment and operation of bleeder ventilation systems in Program Policy Letter (PPL) No. P13-V-12 (Stricklin 2013) [4] to provide clarification and improvements to the way bleeder systems are being evaluated. This PPL was also issued to address concerns with the bleeder system at the Upper Big Branch mine.

If methane enters the gob from coal beds above or below the mined seam, there will be one or more regions with methane at higher concentrations in the center of the gob, and only the peripheral bleeder airways are being kept below 2%. This is evidenced by the function of gob ventilation boreholes (GVBs) which routinely carry over 80% methane and are typically shut down if the methane content drops below 50%. As documented by Brune (2013) [5], there exists a fringe explosive gas zone (EGZ) between the methane-rich center of the gob and the surrounding bleeder entries where the methane content lies within the explosive range. In fact, research appears to indicate that it is impossible to prevent the formation of EGZs in bleeder systems.

2. Brief Literature Review

Urosek and Watkins [6] examined different bleeder systems they deemed to be "safe" and "effective" by traveling the entire bleeder system in a series of case studies. They demonstrated that fresh air entered the gob areas and that the bleeder entries were maintained below 2% methane. However, they did not determine if higher concentrations of methane and/or explosive mixtures existed deep within the gobs.

Smith et al. (1994) [7] evaluated bleederless ventilation or progressively sealed gobs used around the world and recommended that bleeder systems be used if the coal is prone to spontaneous combustion and that gobs should be monitored for carbon monoxide as an indicator for spontaneous combustion. Smith et al., however, do not indicate that the absence of a bleeder system would result in explosion hazards.

Mucho et al. (2000) [8] conducted tracer gas studies to investigate gas flows in bleeder ventilated gobs that were equipped with GVBs. The tracer gas analysis demonstrated that the flow paths in the bleeder system were along the peripheral entries and that only minor amounts of tracer gas reported to the GVBs, indicating that a "sweeping" of the entire gob with bleeder air does not happen. Mucho et al. were unable to determine that fresh air injected into the bleeder system through the inlets was indeed able to dilute methane accumulations deep within the gob. This questions the intended function of a bleeder system. The findings by Mucho et al. were confirmed by the CFD modeling research conducted at CSM.

3. Explosion Hazards in Bleeder Systems

Beiter (2007) [9] summarized several other mine disasters where ventilation systems incorporating bleeders failed, including the fatal explosions at Farmington No. 9 in 1968 (78 fatalities), Greenwich Collieries in 1984 (3 fatalities), Pyro (William Station) No. 9 in 1989 (10 fatalities), Southmountain Coal Company No. 3 Mine in 1992 (8 fatalities), A.A.&W. Coal Co. Elmo #5 Mine (1 fatality) and several other cases where miners were injured or no injuries occurred.

Brune (2013) [5] describes a number of mine explosions or methane ignitions that occurred in or near bleeder ventilated gobs, including those at the Willow Creek mine 1998 and 2000 (2 fatalities), those at the Buchanan mine 2005 and 2007 and those at the Upper Big Branch mine in 1997 and in 2010, the latter explosion claiming 29 miners' lives.

It appears that, in these documented cases, the bleeder systems were ineffective. However, based on the research at CSM, it is questionable whether it is at all possible to operate a bleeder system in a way where no EGZs exist, as all bleeder systems carry an EGZ fringe of explosive methane-air surrounding an interior gob that is filled with methane at concentrations above the explosive range, in a fuel-rich, inert state.

4. Modeling of Longwall Bleeder Systems and EGZs

Researchers at the Colorado School of Mines, under funding from the National Institute for Occupational Safety and Health (NIOSH) have conducted computational fluid dynamics modeling studies of bleeder ventilated and progressively sealed longwall gobs. Much of this work, including details on the CFD model calibration and verification, has been published in research papers by Gilmore et al., 2014 [10] and Gilmore et al., 2015 [11].

Figure 2 shows the EGZ fringe surrounding a bleeder ventilated gob. The color code follows the Coward triangle (Coward and Jones, 1952) [12] shown on the right, where EGZ mixtures are colored red, fresh air blue, methane-rich inert mixtures in yellow and green representing both fuel-lean and low oxygen mixtures.

It should be noted that, in Figure 2, lower left inset, the bleeder entries that must be examined and traveled, have an atmosphere of at least 19.5% oxygen and <2% methane, satisfying U.S. mandatory safety standards.

Figure 3 shows a CFD simulation of EGZs in a bleeder system with slightly different regulator settings at the headgate side inlets to the longwall start-up rooms. The two regulators were changed from a total flow of 38,000 cfm (18 m^3/s) to 17,000 cfm (9 m^3/s) to fully closed. In all cases, the outside bleeder entries could be traveled from the headgate to the bleeder fan but the CFD model shows that, depending on these regulator settings, the EGZ changes dramatically in size and shape yet it is not possible to eliminate the EGZ. By closing the regulators in the start-up entries, more fresh air from the headgate is forced to enter the gob, where it creates rather large EGZs.

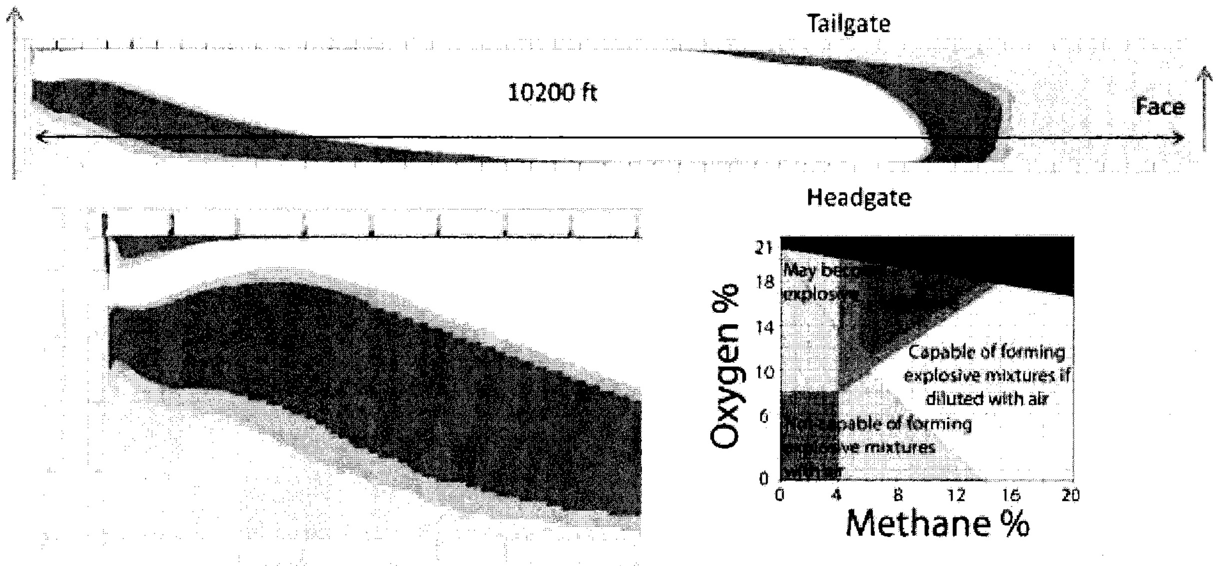

Figure 2: EGZ surrounding a longwall gob. The image at bottom left shows detail near the start-up entries of the panel. Coward's triangle illustrates the color coding.

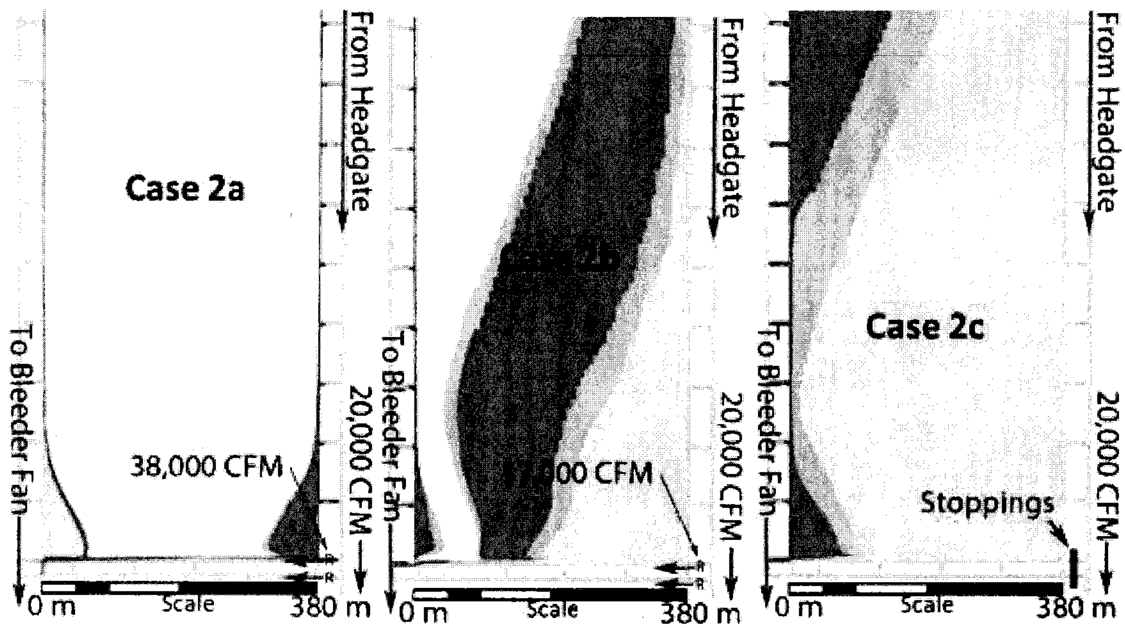

Figure 3: Change of EGZ shape as a function of regulator settings

All simulations result in a contiguous EGZ fringe that surrounds the entire gob area. The CFD modeling research of bleeder ventilated gobs clearly demonstrates that the EGZ fringes exist and may pose significant explosion and fire hazards for miners working in or near the bleeder entries, for example, to examine these entries, operate pumps or maintain roof support.

5. Comparison of Bleeder Ventilated and Progressively Sealed Gobs

In the United States, coal mines may be permitted to operate progressively sealed gobs without a bleeder system. Such permission is granted by MSHA only on an exception basis – only a few U.S. mines are running progressively sealed gobs. Researchers at the Colorado School of Mines have documented with CFD modeling and measurements in operating mines that progressive sealing can significantly reduce and, in combination with nitrogen injection, practically eliminate EGZs in the gob. This was documented by Brune et al. (2015) [13] and Marts et al. (2015) [14]. Nitrogen injection from the headgate side can form a dynamic seal behind the longwall face that separates the methane-rich area deep inside the gob from the oxygen-rich atmosphere in the face, as shown in Figure 4. This dynamic seal effectively eliminates any EGZ fringe zone and the associated explosion and fire hazard. Researchers are still conducting parametric studies on dynamic seal formation to confirm that the EGZs can be eliminated, particularly during barometric pressure fluctuations. Studies also show that gob ventilation boreholes are effective and must be operated to drain excessive methane from the gob. If GVBs cannot extract sufficient methane from the gob, excessive methane will migrate to the tailgate exhaust where its concentration may exceed the statutory limit of 1%.

Progressively sealed gobs are common in European and Australian mines and have proven to be effective in the prevention of spontaneous combustion, especially in combination with nitrogen injection.

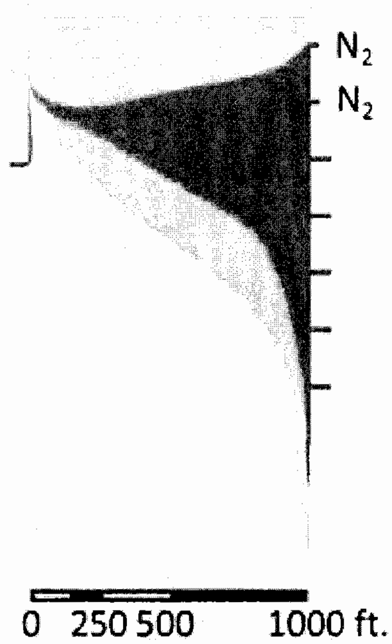

Figure 4: Dynamic seal (green) formed in a progressively sealed gob (Marts et al., 2015) [14], separating the methane-rich interior of the gob (yellow) from the face air (blue).

6. Conclusions, Recommendations and Further Research

Researchers at the Colorado School of Mines (CSM), in a project funded by NIOSH, have documented that bleeder ventilated longwall gobs contain explosive gas zones (EGZs). These EGZs occur as complete fringes that surround the gob along the mixing zones between the face and bleeder entries that contain fresh air with a maximum of 2% methane and the center of the gob, where methane accumulates at concentrations high above the explosive range. CFD modeling shows that the EGZ fringes exist adjacent to bleeder entries that are traveled by miners regularly, exposing these miners to explosion and fire hazards. Numerous mine explosions and fires have occurred in and around bleeder ventilation systems, documenting that EGZ hazards in bleeder ventilated gobs exist and are real.

In a follow-up project, CSM researchers will determine how explosions and flames can propagate through EGZs in longwall gobs. CFD modeling, along with physical experiments, will serve to determine how far flames can travel through the rubble in the gob and how high explosion pressures become.

Acknowledgement

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