Journal of Natural Gas Science and Engineering 23 (2015) 63–69

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Methane and coal exploitation strategy of highly outburst-prone coal seam configurations

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ARTICLE INFO

Article history:
Received 18 November 2014
Received in revised form
8 January 2015
Accepted 10 January 2015
Available online 21 January 2015

Keywords:
Methane exploitation
Methane drainage
Strategy
Coal seam configuration
Outburst-prone coal seam

ABSTRACT

Outbursts are the sudden and violent releases of coal and gas from a coalface, resulting in damage to excavations and equipment, loss of life and even disastrous gas explosion if an ignition source is present. The highly outburst-prone coal configurations are formed of outburst-prone coal seams and some of them have high outburst propensity. The direct applications of traditional outburst control methods on these configurations will lead to various problems in mining safety, technical implementation and economy. This article proposes a methane and coal exploitation strategy for highly outburst-prone coal configurations, combining surface coalbed methane (CBM) recovery with underground methane drainage. In this strategy, vertical surface wells are firstly performed to mitigate or eliminate the outburst hazard of the configurations and thereby creates suitable conditions for the following underground protective seam working or methane pre-drainage. Thus the methane of the configuration is exploited, the outburst hazards of the configuration are eliminated and the outburst-prone seams of the configuration are to be mined safely. It is predicted that the methane contents will decrease from 25 m^3/t to about 6 m^3/t, the outburst hazards will be eliminated completely, and clean and safe mining conditions will be secured by executing this strategy on the Nos. 8, 9 and 10 seams in the Luling mine.

1. Introduction

Coal and gas outbursts are sudden and violent simultaneous ejections of large amounts of coal and gas from a working coalface during underground mining (Shepherd et al., 1981). The ejected coal may damage the excavation, equipment and miners. The ejected gas may cause miners to be unable to escape and even result in suffocation deaths. Worst of all, a gas explosion that is much more damaging than an outburst may be triggered if an ignition source is present. Outbursts are one of the most dangerous hazards of coal production in the world.

Despite extensive research efforts of more than a century, the fundamental mechanisms causing coal and gas outbursts continue to elude the scientific community, but it is generally acknowledged that gas pre-drainage is effective in reducing or eliminating the outburst risk by decreasing the gas content of outburst seams (Noack, 1998). Generally, a gas content greater than 8 m^3/t or 9 m^3/t is considered sufficient to initiate an outburst if other conditions are favorable (Beamish and Crosdale, 1998; Lama and Saghafi, 2002). To reduce gas content and eliminate outburst hazards, the main methods are gas pre-drainage by using vertical surface wells or underground boreholes and, if possible, by pre-working a protective seam in combination with pressure-relief methane drainage (Cheng and Yu, 2007; Cheng et al., 2003; Díaz Aguado and González Nicieza, 2007; Flores, 1998; Hungerford et al., 2013; Hyman, 1987; Lama and Bodziony, 1998; Lunarzewski, 1998; Sang et al., 2010; Wang et al., 2014).

Highly outburst-prone coal seams have a high gas pressure (>5 MPa), high gas content (>20 m^3/t) or large amounts of ejected coal or rock (>10,000 tons). By definition, a 'coal seam configuration' is a formation of coal seams that overlie each other in a vertical depositional sequence. If all of the coal seams in the configuration

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http://dx.doi.org/10.1016/j.jngse.2015.01.018
1875-5100/

are outburst prone and some of the seams have high outburst hazards, the configuration is a highly outburst-prone coal seam configuration. For this configuration, the direct operations of traditional methane drainage methods will face multiple challenges and uncertainties.

The purpose of this paper is (1) to present the general principles of outburst control of coal and gas outburst coal seams, (2) to propose an outburst control strategy for highly outburst-prone coal configurations, and (3) to verify the outburst control strategy by experiments performed in the Luling coal mine.

2. Methane drainage principles for highly outburst-prone coal configurations

Most Chinese coal strata experienced several strong tectonic movements that destroyed the original construction of the coal seams (Karacan et al., 2011). As a result, the coal became structurally complicated, soft, and highly impermeable to gas flow. Therefore, gas drainage from virgin outburst coal seams is very difficult. The main feasible methane drainage techniques are pre-working a protective seam, surface coalbed methane CBM recovery and underground gas pre-drainage in China.

2.1. Surface CBM recovery using vertical surface wells

Methane recovery using hydraulically stimulated vertical wells is a technique that has been applied successfully and widely in many industrial countries. The hydraulic stimulation involves fracturing a series of coal seams using high-pressure fluids pumped into a surface borehole. The fractures are held open by injecting fine sand. Thus, gas and other fluids that are able to flow through the coal seams can enter the borehole without being limited by the resistance of the surrounding coal. The surface CBM recovery includes three stages: methane desorbs from the surface of coal matrix pores, then methane spreads into the factures through matrix and micro-pores, and finally methane flows into surface wells through the sand layer in a mode of Darcy flow.

However, surface CBM recovery is not very successful for most outburst-prone coal seams and can even be called a failure in China (Yun et al., 2012). The special reservoir characteristics of outburst-prone coal seams cause great difficulty to the well completion and stimulation and, ultimately, restrict methane productivity. As a result, the methane yields are always lower than 1500 m^3 per day, which is not worth commercial exploitation.

Vertical surface wells are implemented from the surface, and methane recovery is carried out independently of underground operation; thus, these wells can be constructed and drain methane in advance of coal mining. Though methane recovery effects are poor from a business perspective, long duration recovery can gradually reduce the methane content and alleviate the outburst risk of outburst-prone coal seams.

2.2. Pre-working a protective seam and pressure-relief methane drainage

For a coal seam configuration, the first mining of one selected seam (protective seam) can reconstruct the other seams (protected seams). The idea behind this method is to mine the coal seam with the least stress and/or lowest gas content first so that the other outburst-prone coal seams can be over- or under-mined (Wang and Cheng, 2012). This is the most important and effective outburst control method in China.

The rock surrounding the mining area can be divided into several zones in section and plan views (Yu et al., 2004; Palchik, 2003). In the vertical section above the roof, the rock strata can be divided, working upward, into a caved zone, a fractured zone and a bending zone (Cervik, 1979; Singh and Kendorski, 1981). In the vertical section under the floor, the rock strata can be divided, working downward, into a floor fractured zone and a floor dilating zone (Wang et al., 2013a) (Fig. 1). Along the direction of the advancing working face, the upper and lower rock strata can be divided into three zones: a stress concentration zone, a stress relief zone and a stress resume zone (Fig. 2). The three zones move in advance of the working face, and the protected seams experience the three zones in sequence (Yu et al., 2004). The methane in the stress relief zones desorbs and flows easily, and the methane drainage efficiency is far better than in other zones. For eliminating the outburst hazards of the protected seams and ensuring worker safety, pressure-relief methane must be extracted properly and timely.

Unfortunately, all minable seams in a highly outburst-prone configuration are outburst prone. The selection of the protective seam should take these considerations into account, such as the relative position, thickness, outburst hazard, stability and protected effects (Wang et al., 2013b). The outburst hazard magnitude in the configuration may be quite different: some are highly hazardous, some are medium hazardous and some are only slightly hazardous. A less outburst-prone and minable coal seam and even a soft rock seam can be selected as a protective seam.

2.3. Methane pre-drainage using underground boreholes

In virgin outburst-prone seams, the fractures are generally compressed and the opening and connectivity of these fractures are poor, resulting in poor drainage. Drilling boreholes for methane drainage prior to coal mining is the most common outburst control solution (Diamond and Garcia, 1999). The drilling of boreholes discharges coal mass that helps to relieve local stress. Methane drainage reduces the gas pressure and content, which results in an increase of coal hardness. Stress relief and reduction of the gas content mitigate the triggering energy of outburst seams, increase the outburst resistance and then eliminate the outburst hazard.

Boreholes for pre-drainage may be cross-measure boreholes or in-seam boreholes drilled from underground entries (Cheng et al., 2009; Diamond, 1994; Zhou et al., 2014). In China, boreholes are commonly drilled from a rock tunnel measuring 20 m–25 m in thickness below the outburst-prone coal seams. The rock strata between the outburst seam and the entry are barriers to defending a possible outburst hazard, such as borehole drilling.

During the drilling of boreholes into outburst-prone seams, especially highly outburst-prone seams, drillers often note gas “kicks,” increasing gas flows and disproportionately large volumes of drill cuttings (Paul, 1980). Gas “kicks” mean miniature outburst events that occur in boreholes. The more outburst-prone the seam is, the more violent “kicks” will be encountered. Therefore, it is very dangerous to drill into coal seams that are highly outburst-prone. Only when their outburst hazards are greatly mitigated can the boreholes be allowed to drill.

3. Coal and methane exploitation strategy for highly outburst-prone coal configurations

The above analysis indicates that surface CBM recovery, pre-working a protective seam and underground gas pre-drainage have some difficulties when they are directly applied to a highly outburst-prone configuration. However, the orderly combination of the three techniques constitutes a complete technological system for the coal and methane exploitation of the highly outburst-prone configuration (Fig. 3). In this strategy, pre-working a protective seam is the core, so one proper coal seam should be selected as a