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Analysis of longwall goaf gas drainage trials with surface directional boreholes

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ABSTRACT

Surface directional boreholes (SDB) were recently trialled at two Australian coal mines as a new application to longwall goaf gas drainage. This method has become increasingly attractive for use at coal mines where surface access to drill large numbers of vertical goaf wells are limited or restricted. To demonstrate the performance and effectiveness of the SDB and help improve future design and implementation, results of the field trials at the two Australia coal mines are analysed and presented in this paper. The SDBs, drilled with medium-radius-drilling techniques, had different configuration parameters, including number of branches, diameter, and relative locations above the mining seam and from the tailgate. No borehole stability issues were encountered during the gas drainage operation. The drainage methane flow rate varied in all SDBs; however, if applied properly, they can gain a consistent high flow rate of methane at about 1000 L/s. It was observed that the drainage effectiveness and efficiency were significantly influenced by local geological settings, borehole horizontal and vertical placement, branching, and water filling. The key to having high and consistent gas flow in a SDB is to maintain a sufficient connection with the mining-induced fracture zone. In addition, drilling quality control for such boreholes is also crucial, to avoid any concave sections that might fill with groundwater and block the borehole. The trial results demonstrate that SDBs have the potential to become a common method of longwall goaf gas drainage.

1. Introduction

Extraction of a coal seam with an underground longwall (LW) will induce stress relief and fracturing, caving, and bedding separations of overburden strata. In gassy environments, these effects can release a significant amount of methane gas from the overlying coal seams, which may find its way into the active areas of the mine if not controlled (Karacan, 2015). Because methane is explosive, it remains a significant issue affecting coal productivity and mining safety. In addition, from an environmental point of view, methane vented into atmosphere is also a substantial source of greenhouse gas emissions (Karacan et al., 2011). To control such gas emissions, goaf gas drainage is often adopted to intercept the gas before it migrates into the mine workings. Dependent on geological and mining conditions, goaf gas drainage can be implemented in various ways such as surface vertical goaf wells, cross-measure boreholes, horizontal or near-horizontal boreholes, pipes buried into the goaf, and gas drainage galleries (UNECE, 2010). Of these, the most common are vertical wells drilled from the ground surface and cross-measure boreholes drilled from underground workings.

LW mining in Australian gassy coal mines presents characteristics such as high productivity (up to 7.5 MT a year), wide LW panels (300–400 m) and high gas emission rates (up to 6000 L/s). These characteristics require a sufficient coal mine gas drainage system to be in place to ensure mining safety and productivity. Apart from pre-drainage, Australian coal mines commonly use surface vertical wells in goaf drainage with spacing around 100–300 m. However, this method has become increasingly challenging to use because more mines have complex mining and gas conditions, multi-seam environments beneath previously extracted goafs, and environments where drilling a large number of vertical surface wells is not practical (Guo et al., 2015). An alternative gas drainage method that can minimise the drilling footprint and improve gas drainage performance is therefore required.

Surface to in-seam boreholes based on directional drilling technology has been widely used in Australia for coal mine pre-drainage to reduce the risk of gas outburst and lower the concentrations of seam gas in the underground ventilation (Hungerford et al., 2013). Compared with traditional boreholes, directionally drilled holes can be relatively longer, be more precisely placed, leave fewer drilling footprints, and require less drainage operational processes. With these advantages, surface directional boreholes (SDB) in recent years have become increasingly attractive for use in Australian coal mines for LW goaf gas drainage. From late 2008 to 2013, Illawarra Coal of South 32 systematically trialed SDBs for goaf gas drainage in four of its LW panels at two coal mines. A mine in Hunter Valley also trialed a number of SDBs in an attempt to improve goaf gas drainage effectiveness to address highly gas emissions in a

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multi-seam mining condition (Todhunter et al., 2012). It is noted that the SDBs in the trials at the Hunter Valley mine were not directly connected with surface suction pumps to capture gas from the goaf, but intersected with surface vertical goaf wells to provide connectivity to a large area of gas producing zone to the surface vertical wells.

Fig. 1 shows a schematic configuration of a SDB for goaf gas drainage with a comparison to a directional borehole drilled from underground. To drill a SDB, a vertical section is first drilled, and then the drill bit deviates from the vertical position to enter and steer along the target formation roughly parallel to the bedding plane (UNECE, 2010). Depending on the build rate from vertical to horizontal, the directional boreholes can be characterized as long, medium, or short radius. Of these, medium-radius-drilling is the most common technology. In the trials in Illawarra Coal, the SDBs were all drilled with medium-radius-drilling technology.

Goaf gas drainage with such SDBs can be categorised as horizontal goaf gas drainage, which is usually represented by conventional underground boreholes or tunnels parallel or near parallel to the mining seam in its extraction direction. Recent years have seen a number of applications using underground directional boreholes (UDBs) for goaf gas drainage in various countries, for example in the United States (Brunner and Schumacher, 2012), China (Fang et al., 2012; Wang et al., 2012), and Australia (Brown and Hobden, 2014). In these applications, the borehole lateral sections were placed 9–40 m above the mining seam, and were 95–190 mm in diameter and 250–1200 m long. Lateral locations along the panel width ranged from 15 m from the tailgate to over the mid-panel near the maingate. The gas drainage performance varied greatly, with the methane flow rate in a single borehole ranging from a few L/s to 350 L/s, and methane concentration varying between 12 and 75%. The widely varying performance of these trials, with most being of low drainage methane flow rate, implies that the drainage performance was highly dependent.

No trials of goaf gas drainage with SDBs were found from the literature review. Although both SDBs and UDBs use their lateral sections to capture goaf gases, their working mechanisms still vary to some extent due to configurational differences. Unlike a UDB, a SDB draws gases from the goaf up to the surface and usually has much longer vertical and build sections. This leads to different requirements in borehole operations such as the required suction pressure and borehole water management, and different scenarios the gas drainage may encounter such as borehole build section stability and borehole leakage. In addition, placement of the SDBs in the two coal mines of Illawarra Coal took various configuration parameters into account, such as branching, location, diameter, length and density. These provided an ideal opportunity to systematically investigate the efficiency, effectiveness and influencing factors of goaf gas drainage with SDBs. This paper presents the results of these trials and discusses the major factors influencing gas drainage performance.

2. Site conditions

The two trial sites were located in New South Wales, Australia, at adjoining mines managed by South32 Illawarra Coal: West Cliff Colliery and Appin Colliery. The seam and geological conditions in these two areas are generally similar, and both mining operations extract coal from the Bulli seam with LW mining. Fig. 2(a) shows a typical stratigraphic column in this mining area, in which the overburden strata are dominated by sandstone layers. Thicknesses of these layers vary from place to place but the major layers generally exist in every panel. Fig. 2(b) compares the overburden strata thicknesses and depths between areas near the studied LW panels in the two collieries. The major sandstone layers are Scarborough, Bulgo and Hawkesbury sandstones and the remaining rocks, including shales and claystones, generally exist in discrete or are interbedded within the sandstone.

The major claystone layer, Bald Hill, lies above the Bulgo sandstone and acts as a major aquitard to vertical migration of groundwater. Overlying Bald Hill is the Hawkesbury sandstone, which is the major aquifer. Below the Bald Hill claystone, the sandstone aquifers are much poorer than the Hawkesbury sandstone, and groundwater conditions are interpreted to be unsaturated. Permeabilities in the Bulgo sandstone, Stanwell Park claystone and Scarborough sandstone are variable and very low. The regional piezometric head in the groundwater zone below the Bald Hill claystone may temporarily fall by up to 10 m during mining, but will recover after mining is completed.

The mining seam, Bulli, contains gas at levels ranging from 8 to 14 m^3/t of raw coal and 11 m^3/t on average. Gas pre-drainage from Bulli seam is generally implemented during the development of the LW panel. The major gas-producing sources are coal seams in the floor (Balgownie, Cape Horn and Wongawilli) and sandstone layers in the roof. Specific gas emissions, or relative gas emission rate, from LW operations are experienced at around 30–40 m^3/t of raw coal mined. Of that, the overburden sandstone layers were predicted accounting for up to 35%. However, no accurate measurements of the stratum gas content exist. Table 1 shows an example of a gas emission prediction using Flugge's method for a 300 m wide LW panel at West Cliff colliery (Meyer, 2006). The Flugge method is an empirical function of the gas

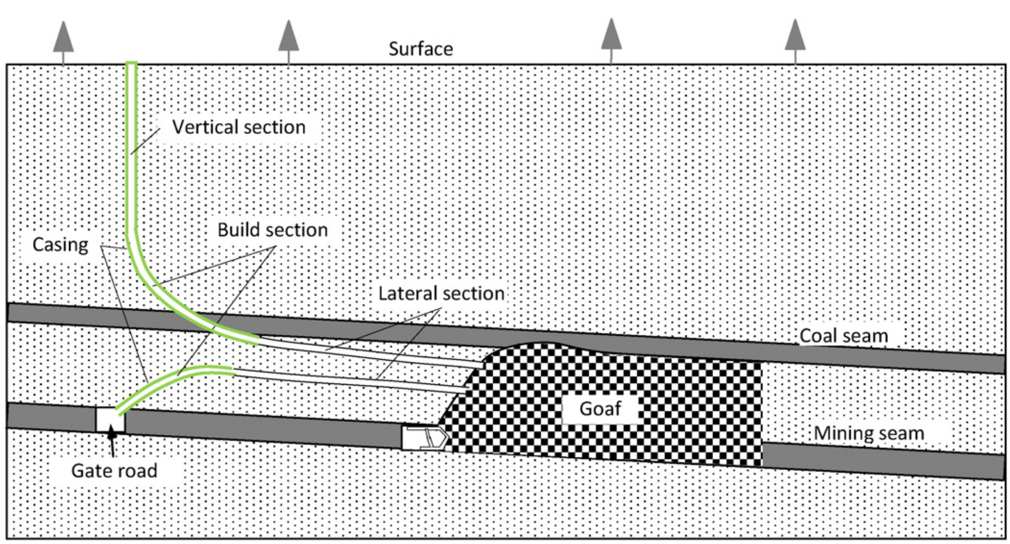

Fig. 1. A schematic illustration of goaf gas drainage with directional boreholes.