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Mining-induced strata stress changes, fractures and gas flow dynamics in multi-seam longwall mining

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ABSTRACT

This paper presents key findings from a recent comprehensive study of longwall mining-induced strata movement, stress changes, fractures, and gas flow dynamics in a deep underground coal mine in Anhui, China. The study includes field monitoring of overburden displacement, stress and water pressure changes at the longwall panel 1115 (1) of the Guqiao Mine. In addition, 3D modelling of strata behaviour at the longwall panel using a 3D finite element code and goaf gas flow simulations with a CFD code are carried out. This research has resulted in many new insights into the complex dynamic interaction between mining induced strata stress changes, fractures, and gas flow patterns. Based on the findings from the field monitoring and numerical modelling, a three-dimensional annular-shaped overlying zone along the perimeter of the longwall panel is identified for optimal methane drainage during mining. A practical method that helps define the geometry and boundary of this zone is proposed. This study provides a new methodology and a set of engineering principles for the design of optimal co-extraction of coal and methane.

1. Introduction

The concept and practices of co-extraction of coal and methane have emerged in recent years to improve coal mining safety and productivity, utilise coal seam methane resources, and reduce fugitive emissions [1–3]. The system of the co-extraction effectively integrates the two previously separate operations of coal extraction and methane drainage. The coal mining operation reduces the coal seam gas pressure and creates strata fractures that enhance gas migration and capture from working and surrounding coal seams. Effective methane drainage operation produces a source of clean energy and reduces the methane concentration in underground workings and the methane content in the adjacent coal seams. This is a significant benefit in preventing gas explosions and outbursts and promotes a safer and more productive coal mining environment. In addition, utilisation of coal mine methane directly leads to a reduction in Green House Gas emissions.

To implement the co-extraction of coal and methane, a clear understanding of mining-induced strata stress changes, fractures, and gas flow are essential. To date, extensive studies in these areas have been carried out for various purposes such as mine ground control, water inrush prevention, and gas control, respectively. Front and side abutment stresses about a longwall (LW) panel, de-stressing behind the coal face, and goaf consolidation processes have been investigated and characterised by many researchers [4–7]. Overburden strata fractures are generally classified into three zones vertically: the caved zone, the fractured zone, and the continuous deformation zone, the heights of which are normally expressed as a function of mining thickness [7–10]. Palchik [11,12] recently measured the height of the interconnected fracture zone which is connected to mine workings, and the locations of horizontal fractures along rock layer interfaces in the overburden for goaf gas drainage, using a method of methane emission measurement from vertical boreholes. LW goaf flow mechanisms have been investigated by many researchers using gas tube bundle systems to collect and analyse goaf gas samples, underground tracer gas tests, and computational fluid dynamics (CFD) numerical modelling techniques [13–16] for gas drainage as well as fire control. The understanding of spatial distribution of goaf gas concentration and pressure has been used to improve the design and operation of goaf gas wells and goaf inertisation (for heating control).

These studies have contributed to improved understanding of complex coal mine gas flow mechanisms in the recent years. However, to integrate and optimise coal extraction and methane drainage design, particularly in the multiple coal seam environment with low permeability conditions common in China, it is important to understand the dynamic interaction between strata, water, and gas desorption and migration during mining. Huainan Coal Mine Group (HCMG) in China and The Commonwealth Scientific and Industrial Research Organisation (CSIRO) in

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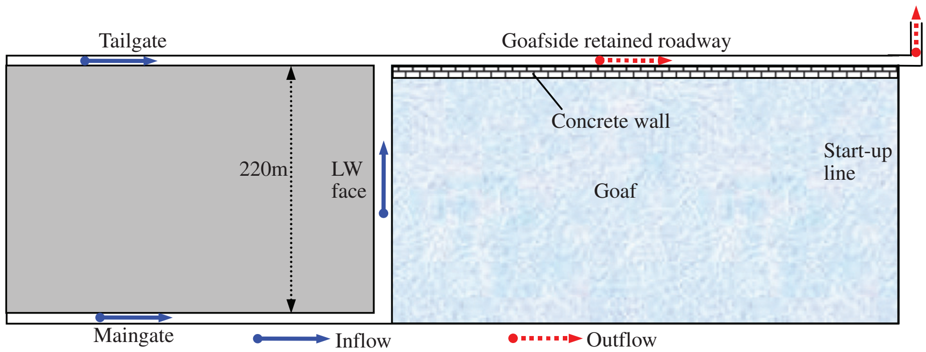

Fig. 1. Plan view of Panel 1115(1).

Australia have recently completed a major collaborative research programme. This programme used Panel 1115(1) of the Guqiao Mine at Huainan, China as the experimental site and carried out a systematic and integrated study into mining-induced strata stress changes, fractures and gas flow dynamics by means of field measurements, numerical modelling, and theoretical development. This paper describes key results from that study.

2. Mining conditions of Panel 1115(1)

The Guqiao Mine is located in the central to western part of the Huainan Pan-Xie Coal Field, 20 km west of Fengtai City of Anhui Province, China. It currently produces 12 Mt of raw coal annually. The key geological features at the Guqiao Mine include thick alluvium layers, deep coal seams, high methane content in minable seams and high geothermal temperatures. The coal-bearing geological section has a total thickness of 734 m, and it contains thirty-three coal seams, nine of which can be mined with a total thickness of 24 m. The five key minable seams include Seams 13-1, 11-2, 8, 6-1, and 1. Currently the mine is extracting Seams 11-2 and 13-1, both classified as low permeable seams with a methane content of 1.96–13.2 m^3/t and 2.7–12.9 m^3/t, respectively.

The working seam at Panel 1115(1) is Seam 11-2. It has an average thickness of 3.0 m, an average dip angle of 5° ranging from 3° to 8°. Overburden depth ranges between 640 and 760 m with a 400–450 m thick alluvium section at the top. The panel length is 2600 m and panel width is 230 m. It was mined by the retreat LW mining method with full seam extraction. The LW face was ventilated using the "Y" type of ventilation system with the maingate (belt road) and inby part of the tailgate (material transport road) being the intake roadways and the outby part of the tailgate being the return roadway. The tailgate behind the LW face was kept open by constructing a 2.2 m wide concrete wall to replace the mined-out roadway wall on the goaf side, to form "goafside retained roadway" (see Fig. 1). The coal seam within a distance of 200 m from either side of the panel was not mined. The working seam is overlain by Seam 13-1 (thickness = 3.5 m) at a distance of 75 m and Seam 17-2 (thickness = 1.4 m) at a distance of 179 m. The plan view of this panel is shown in Fig. 1. Simplified geological settings from a typical borehole log of this panel are listed in Table 1.

Table 1
Simplified geological settings in Panel 1115(1).

Layer number	Lithology	Thickness (m)	Floor depth (m)
1	Alluvium	453.3	453.2
2	Mudstone & coarse sandstone	102.0	555.3
3	Coal seam 17-2	1.4	556.6
4	Siltstone & mudstone	25.7	582.4
5	Fine sandstone	14.8	597.2
6	Mudstone & coarse sandstone	5.7	602.9
7	Mudstone	42.4	645.3
8	Siltstone & mudstone	12.1	657.4
9	Coal seam 13-1	3.5	660.9
10	Mudstone & siltstone	22.3	683.3
11	Fine sandstone	14.2	697.4
12	Mudstone	3.9	701.3
13	Fine sandstone	8.0	709.3
14	Siltstone	8.1	717.5
15	Medium sandstone	4.4	721.8
16	Siltstone	6.1	728.0
17	Fine sandstone	2.1	730.0
18	Mudstone	5.5	735.5
19	**Coal seam 11-2 (Working seam)**	**3.0**	**738.5**
20	Mudstone	6.4	744.9
21	Coarse sandstone & siltstone	25.3	770.2
22	Mudstone & coarse sandstone	20.0	790.2

3. Field monitoring of strata movement, stress changes and water pressure at Panel 1115(1)

3.1. Monitoring design

For the purpose of an in-depth investigation of mining-induced strata movement, stress changes, fractures, gas flow and their dynamic interaction, an integrated real-time monitoring system was designed (Fig. 2) based on the specific mining and geological conditions at Panel 1115(1). The monitoring programme focused on the part of the panel that covered a retreat distance of 1300 m from the LW start-up. The monitoring programme included:

(a) Monitoring stress change and displacement of the roadway roof: 10 monitoring stations were set up in a 450 m section of the tailgate, located at a retreat distance of 1100–1550 m from LW start-up. At each station, one multi-point roof extensometer was installed which has five anchors located at depths of 8 m, 6 m, 4 m, 2 m and 1 m into the roof. At every second monitoring station, three uniaxial stressmeters were installed in vertical and inclined upward boreholes that monitored the stress changes in the roof of the roadway and sidewalls.
(b) Monitoring overburden strata movement: Two multi-point surface extensometers were installed in the panel at distances of 90 m and 30 m, respectively from the tailgate. Twenty anchors of each extensometer were installed in the key overburden strata layers to measure their displacements.
(c) Monitoring water pressure change in overburden strata: Seven piezometers were installed in two deep boreholes