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Role of multi-seam interaction on gas drainage engineering design for mining safety and environmental benefits: Linking coal damage to permeability variation

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A B S T R A C T

Methane gas drainage is an effective method to ensure mining-process safety and deliver greater environmental benefits through reducing greenhouse gas (GHG) emissions. As most coal seams actually coexist with one or several other coal seams, i.e. the multi-layer coal seam group. A better understanding of the interaction between the adjacent coal seams could provide better guidance for the gas drainage engineering design to enhance its performance. Extensive studies on the multi-seam interaction have focused on the effect of mining the underlying coal seam on the overlying seam from perspectives of rock deformation, stress change and permeability variation. Meanwhile, as there is few coupled permeability models taking the coal-damage effect into account, previous permeability-variation analysis seldom commonly considered the mining-induced coal damage, coal mechanics changes and gas adsorption, which results in the permeability underestimation. Therefore, in this paper, a mathematical model which incorporates the coal permeability with coal damage, coal mechanical property and the gas adsorption was developed. Then this model was implemented into a finite-element numerical simulation, which was used to investigate the impact of the overlying coal seam mining on the underlying relieved seam from the perspective of damage-based permeability variation. Meanwhile, the effect of damage on gas-emission performance from the underlying seam was analyzed. Results show that there are four permeability areas under the mine-out panel, permeability increases greatly in areas I to III (the highest as over 650 times) while it increases slightly in the area IV. These permeability results are largely consistent with the stress-analysis conclusions obtained by other researchers. By taking the damage into account, the evaluation on gas-emission condition could become more reasonable. Above research outcomes could help to determine the favorable gas-drainage areas under the longwall mining panel and guide the drainage borehole design in the relieved coal seam, to deliver better drainage outcomes for the mining safety and GHG-emission reduction.

1. Introduction

During underground mining, gas-related incidents frequently occur in high-stress gassy coal seams and have great danger generally, e.g. the coal and gas outburst, gas explosion (Hungerford et al., 2013; Zheng et al., 2017b). Statistical analysis on major gas-explosion incidents around world in recent years (Table 1) shows that the explosion has unfortunately resulted in many casualties (United Nations, 2010). Particularly with the increase in mining depth and mining advance rates, the threats of gas disasters becomes more and more severe. Therefore, methane gas in coal should normally be drained to the safety level before mining activities by adopting in-seam boreholes or cross-measure wells, as shown in Fig. 1, to eliminate gas-related incidents (Karacan et al., 2007, 2011; Zhou et al., 2016). Meanwhile, coal mine methane possesses over 20 times more (in a period of 100 years) greenhouse effect compared with the CO_2 (Warmuzinski, 2008). However, it can be used as a clean energy after being captured. Hence, good gas drainage is a practical and effective method to keep mining-process safety, benefit the environmental protection through reducing greenhouse gas (GHG) emissions and increase the supply of a valuable clean gas resource (Zheng et al., 2017a).

In nature, one coal seam generally coexists with some other coal seams, forming a multi-layer coal seam group. To enhance the gas drainage performance, the multi-seam interaction which can increase the permeability of relieved coal should be taken into

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Table 1
Several major gas-explosion incidents in coal mines around world.

Country	Coal mine	Time	Fatalities
China	Sunjiawan, Haizhou shaft, Fuxin	14 February, 2005	214
USA	Sago, West Virginia	2 January, 2006	12
Kazakhstan	Lenina, Karaganda	20 September, 2006	43
Russia	Ulyanovskaya, Kemerovo	19 March, 2007	108
Ukraine	Zasyadko, Donetzk	19 November, 2007	80
USA	Upper Big Branch, West Virginia	5 April, 2010	29
Turkey	Karadon, Zonguldak	17 May, 2010	30
China	Jinshangou coal mine, Chongqing	31 October, 2016	33

Modified from Karacan et al. (2011) and United Nations (2010).

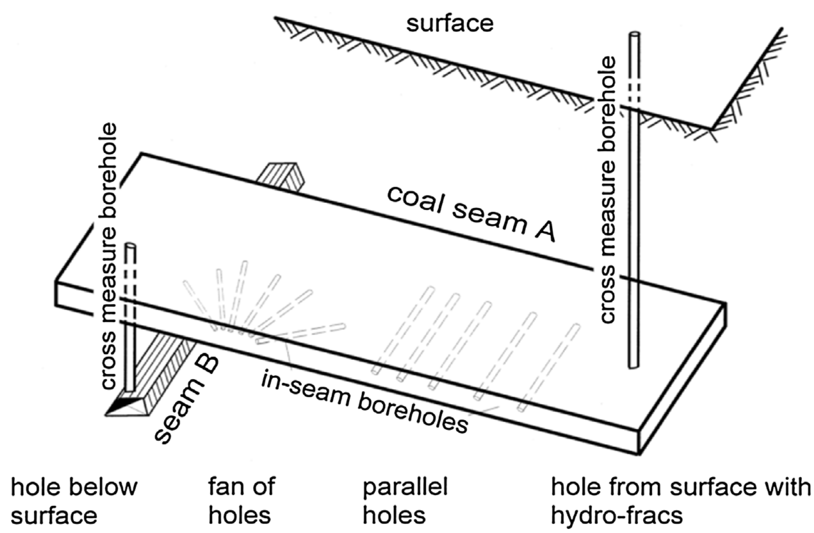

Fig. 1. Schematic diagram of methane gas drainage methods.

After Noack (1998).

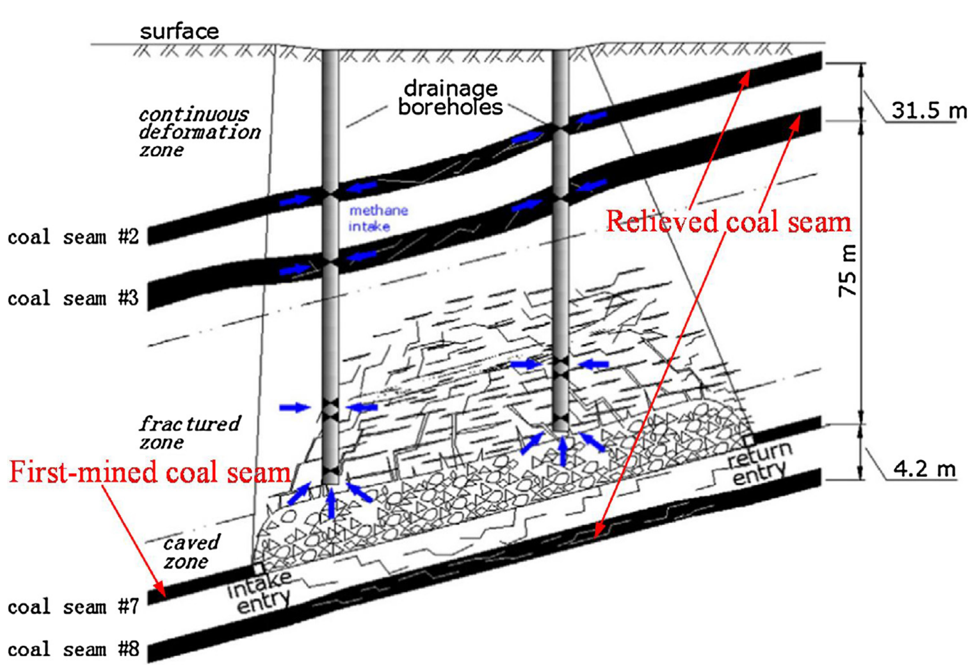

Fig. 2. Effects of seam-interaction on gas drainage in multi-layer coal seam group.

Modified from Liu et al. (2011).

account when designing drainage boreholes. This interaction can be illustrated using a typical coal seam group in Fig. 2: the coal seam #7 is mined first and thus called the first-mined coal seam. Then the crustal stress in the roof strata and floor strata of the seam #7 is relieved substantially, and coal damage occurs, leading to an increase in coal permeability. Hence the seams #2, #3 and #8 can be