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Role of the rapid gas desorption of coal powders in the development stage of outbursts

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A B S T R A C T

Based on the desorption experiments of coal particles with different sizes, the possibility of the existence of coal powders in the outburst development stage was studied from the perspective of energy balance and pneumatic conveying. The energy involved in outbursts (gas expansion energy, transport energy and remaining kinetic energy) and the general range of the transport critical particle size (TCPS, the coal particle size with the lowest gas desorption speed causing the outburst coal transport over a certain distance) were calculated. This study concludes that to convey outburst coal, it is necessary to capture the desorbed gas supply because the limited amount of free gas cannot meet the high energy demand. Rapid desorption within a short period is an essential condition for the development of an outburst. Only coal particles with small sizes can exhibit this high desorption speed. Based on the relationship between the initial desorption speed and the particle size, a mathematical model that could be used to estimate the TCPS of the Zhongliangshan outburst (117 μm) was established. Historical data regarding the Zhongliangshan outbursts and other mines support the results of calculations and certify the important role that coal powders play in outbursts.

1. Introduction

Coal and gas outbursts or outbursts are geological failures that occur in underground drainage or mining and consist of the ejection of thousands of coal and rock pieces, as well as considerable amount of gas, into a limited working space within a short period. Different from typical coal extrusions (induced by underground stress) or coal slips (induced by coal weight), outbursts require huge amounts of gas to participate to carry the coal or rock, resulting in a much longer ejection distance. An outburst generally involves the following stages (Farmer and Pooley, 1967; Yu, 1978; Hargraves, 1980; Litwiniszyn, 1985; Paterson, 1986; Lama and Bodziony, 1998; Beamish and Crosdale, 1998; Li et al., 2013a,b; An, 2014; Guo, 2014; Wang et al., 2015):

I Preparation stage: The potential outburst energy increases as the coal damage appears which is attributed to the underground stress and gas pressure.
II Trigger stage: The potential outburst energy exceeds the balance state, leading to a break and an energy release from the coal.
III Development stage: The damage front sinks deeper into the internal side gradually. Meanwhile, the broken coal outside is consistently transported by a rapid gas flow to the working space.
IV Termination stage: The ejection ceases, while the gas flow continues for a long period.

Gas pressure and underground stress are generally considered as the main causes of outburst disasters. Hodot (1966) regarded outbursts as the breaking and ejecting processes, indicating that coal is broken by the static and dynamic stress of the ground at first and then a large pressure gradient generated by gas removes the coal to the working space. Jiang (1994) supported this idea by

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noting that there is an "I"- shaped crack behind the destruction front and at where the gas is stored to form huge energy for transporting the outburst coal (Xu et al., 2006). Guan et al. (2009) indicated that an outburst is driven by the gas pressure and took it as an explosive eruption. During the crushing process, although gas pressure and underground stress behave cooperatively, it is commonly accepted that the gas pressure can be neglected because of the large difference in their contributions to an outburst (typically, the underground stress is several times larger than the gas pressure). Hence, underground stress is recognized as the primary contributor in the outburst preparation stage. During the ejection process (the development stage), outburst coal is separated from the steady wall, indicating that no force from the ground engages in this transport process. Indeed, in this case, gas is the main factor affecting the process.

However, a small volume of gas cannot generate this large transport energy. Outbursts need a large volume of gas to be generated instantaneously to produce a high pressure gradient, pushing the crushed coal into the mining space. Without a rapid gas emission rate, the pressure will not grow fast and the mass transport of coal will be impossible. In the investigations of outbursts, specialists usually consider the gas exhausted during the period beginning from the moment of concentration rising to the time when the gas has decreased to the normal level as the final gas emission amount. This period typically lasts several to dozens of days, whereas the effective outburst dynamic process only lasts around few tens of seconds (Lama and Bodziony, 1998). Therefore, gas emission statistics primarily pertain to low-concentration gases released from nearby cracks or outburst coal itself after an outburst ends. Fig. 1 shows the roadway gas concentration variations of three recent outbursts that occurred in 2013 and 2014; the effective gas (gas required to carry the coal), where lies in the rapid increasing zone of gas concentration, constitutes only a small proportion of the total investigated amount. Gas concentrations can reach or even exceed the limit of the monitor immediately after an outburst begins, forming a gas flow with concentrations dozens or hundreds of times higher than the normal.

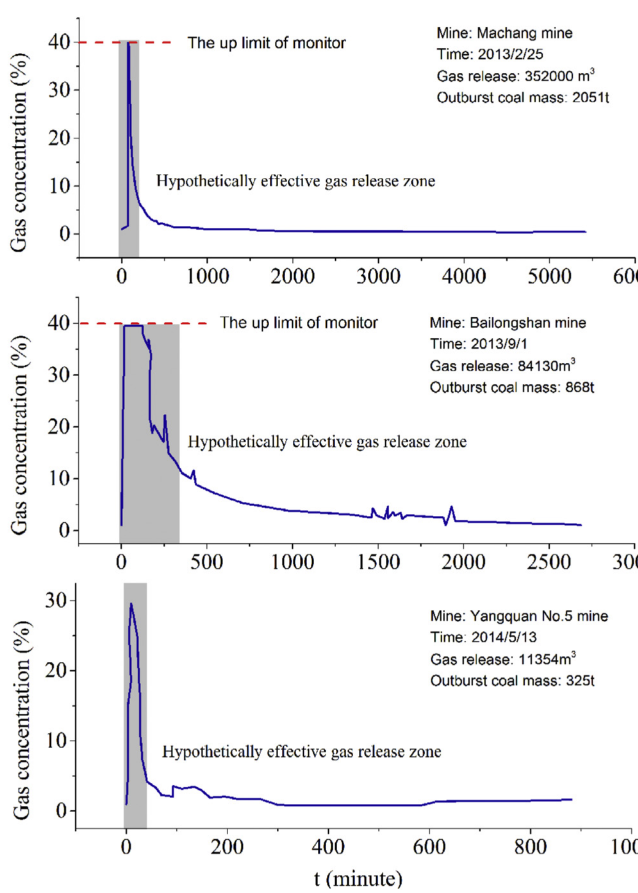

Fig. 1. Variation in roadway gas concentration over time for three recent outbursts.

Obviously, gas can appear via one of two pathways: either gas is thrown from coal or it is not. The area around an outburst hole, which contains rather integrated and unbroken coal, continues to release copious amounts of gas but at a much slower rate compared with the crushed coal. Thus, the primary contributor to the transport of coal is the gas from the outburst coal itself. When exploring the category of gas, i.e., either free or adsorbed gas, researchers concluded that no adsorbed gas contributes to outbursts because no adequately fast speed is observed during the initial seconds following an outburst for the integrated or big size coal lump (Sobczyk, 2011; Wen et al., 2002). In contrast, the regions easy to produce outbursts, which often features ample fractures, faults and folds, are usually of heavily broken or small size coal particles. The Table 1 and Fig. 2 provide statistics pertaining to 31 outbursts that occurred in China. Among them, 25 outbursts, which account for nearly 81% of the total outbursts, occurred in the special structural regions, with rapid desorption and poor strength. Besides, after an outburst ends, there was a certain percentage of coal particles with a radius less than 100 μm, whose desorption goes much faster (Hu, 2007). Thus,the role of gas and underground stress during outbursts can be summerized as Fig. 3 shows.

High desorption speed benefits the instant storage of gas in outburst fractures, making the pressure threshold easy to reach (Hodot, 1966; Williams and Weissmann, 1995; Wang et al., 2015). Therefore, it is important to clarify the true contribution of these two types of gas to outbursts and to discuss the possibility of coal powders existing in outbursts theoretically. Trough comparison between transport energy and gas expansion energy obtained from the free or adsorbed gas, we can determine whether it requires the adsorbed gas to supply the free gas to transport outburst coal. If the desorption cannot be neglected, we will clarify how this desorption is produced, how fast desorption the transport needs, and how small the particle size is. These efforts will greatly contribute to further clarifying the mechanism of outbursts and allow for better predictions of these phenomena.

2. Theory

2.1. Outburst energy

Because of the complexity and variability of outbursts, it is more possible to analyze this phenomenon from an energy perspective. Significant researches conducted by Hodot (1966), Gray (1980), Valliappan and Zhang (1999), Jiang and Yu (1996), Wen et al. (2002), Cai and Xiong (2005), Li et al. (2012) and Tan (2013) has provided a detailed analysis of outburst energy. It is generally concluded that the gas expansion energy in addition to the elastic energy of coal is transferred to the coal crushing energy, the transport energy and the remaining kinetic energy of gas after carrying the coal, as shown in the following equation:

$$W_1 + W_2 = W_3 + W_4 + W_5 \tag{1}$$

where W_1 is the gas expansion energy, W_2 is the elastic energy of coal, W_3 is the coal crushing energy, W_4 is the coal-gas transport energy, and W_5 is the remaining kinetic energy of the gas.

Zheng (2004) calculated the elastic energy of coal and the expansion energy of gas for several outburst accidents, which