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Influence of coal moisture on initial gas desorption and gas-release energy characteristics

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ABSTRACT

Coal and gas outbursts (hereinafter referred to as 'outbursts') result in serious damage and often occur in tectonically-deformed coal that is rich in gas. It has been demonstrated that the level of outburst risk declines with increasing coal moisture content. Moreover, an outburst generally lasts for mere tens of seconds and the required energy is mainly provided by the gas expansion energy. However, the gas desorption and energy release characteristics of tectonically deformed coal with different moisture contents during the first dozen seconds have not often been studied. In this study, a set of self-designed gas desorption equipment was used to carry out gas adsorption-desorption experiments in the first dozen seconds (about 13 s) on coal with different moisture contents. The results show that the drop rate of the gas pressure increases with an increase in coal moisture content, and the total amount of gas desorption and the mass flow rate of gas desorption reduce correspondingly in the gas desorption process. Moreover, the gas velocity also slows with increasing moisture content. Under different gas pressures, the total gas expansion energy (TGEE) and the total gas energy (TGE) released from the coal decrease with the increasing moisture content. Correspondingly, it takes a shorter time for coal to release 90% of the TGEE and the TGE. For all of the coal samples, the time taken for releasing 90% of the TGEE is shorter than that for releasing 90% of the TGE. Meanwhile, the ratio of TGEE in the TGE increases with the increasing moisture content. The TGEE accounts for 14–16% of the TGE released from coal samples of different moisture contents under different gas pressures.

1. Introduction

Coal and gas outbursts are one of the most serious dynamic disasters occurring in underground coal mining [1–4]. Once an outburst occurs, hundreds and even tens of thousands of tons of coal and rocks are ejected from working faces and coal walls to the roadway, accompanying with the emission of a large amount of gas [1,5,6]. To effectively prevent outbursts, accurate outburst risk prediction is a critical link, the accuracy of which depends on the selected prediction indexes and the critical values of corresponding indexes for outbursts [1,7–9]. In China, outburst risk prediction has to be carried out before the mining of coal seams. The prediction generally uses indexes including degree of coal fracturing, Protodyakonov strength index, initial velocity of gas emission (Δp), and gas pressure [2]. The area of coal masses with outburst risk generally only takes up 8–10% (no more than 20–30%) of the whole area of a coal seam [4,10]. As the region with outburst risk in original coal seams is closely related to tectonic movement [4], geological condition is an important factor to be considered in the prediction of regional outburst risk of coal seams. As for the outburst risk in the regions not close to tectonic belts, they are basically predicted based on the gas pressure or gas content [11]. Field investigation reveals that due to the complex occurrence condition of coal, parameters including gas pressure and gas content have different critical values for indicating the outburst risk of coal masses in different regions of a coal seam [1,2,6,12]. Coal moisture is an important factor among those influencing the critical values of parameters for outburst prediction and the level of outburst risk [1]. As coal has stronger adsorption capacity for water molecules than for methane molecules [13,14], the application of water injection into coal seam is able to effectively prevent outbursts [15]. Injecting water into original coal seams, on the one hand, can replace a certain amount of gas; on the other hand, after entering coal fractures and pores, water molecules can block the migration pathways of gas and therefore reduce the desorption capacity of gas in the mining process. That is, the increase in the moisture content reduces the gas desorption rate and gas diffusion coefficient, and thereby decreases the desorption amount of gas [16]. As moisture and

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Table 1
Proximate analysis results and adsorption parameters of the coal samples.

Coal sample	Proximate analysis (%)				f value	Δp (mmHg)	a (m^3/t)	b (MPa^{-1})
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}				
Anthracite	1.31	19.87	10.75	68.07	0.28	13.7	30.53	2.12

Note: M_{ad} – moisture content; A_{ad} – ash content; V_{ad} – volatile content; FC_{ad} – fixed carbon; f value – protodyakonov coefficient; Δp – initial velocity of gas emission in first 10–60 s; a, b – Langmuir parameters.

methane co-exist in original coal masses [17], studying the desorption law after the gas adsorption equilibrium in the coal masses of different moisture contents is of great significance for the accurate measurement of parameters for outburst prediction and the determination of their critical values.

Previous studies indicated that the outburst intensity declined with the increase of the original moisture content in coal mass [18,19]. The gas adsorption-desorption experiments on coal of different moisture contents indicate that, for the coal masses of high original moisture content, the gas desorption amount reduces in the same gas desorption time after reaching gas adsorption equilibrium [20,21]. Meanwhile, after the moisture content of coal mass reaches a certain value (equilibrium moisture content), increasing the moisture content further exerts slight influence on the gas adsorption capacity [22,23]. It is generally considered that the reason for the reduction of gas desorption amount is as follows: the increasing moisture content reduces the adsorption space for gas and then correspondingly decreases the gas desorption amount [14,24,25]. Besides, in the coal mass of high original moisture content, the gas desorption rate and the gas diffusion coefficient also decline correspondingly to different extents in the gas desorption process [21]. The two factors jointly lead to the falling level of outburst risk of coal masses. However, previous researches are generally based on gas desorption data in tens of minutes or several hours; while the whole process of most outbursts in the field merely lasts for several seconds to tens of seconds [26]. Unfortunately, scholars rarely study the influence of coal moisture on the gas desorption characteristics in the initial tens of seconds. An outburst is a continuously developing and multi-cycle process. The unstable failure and pulverized damage of coal masses in the outburst process is mainly caused by the effect of gas [2,3,10,27]. Although the increase in the coal moisture content can reduce the gas desorption amount from coal, existing studies have revealed that not all the gas emitted in the outburst process participates in the tearing, ejection, and transport of coal masses. A large portion of gas does not facilitate the development of outbursts [28,29]. The gas actually participating in the occurrence and development of outbursts is that with pressure effect. The expansion energy generated by this part of gas is actually the energy source that propels the occurrence and development of an outburst [2,3]. Therefore, to figure out the influence mechanism of the moisture content on the outburst risk of coal masses, it is of great importance to study the release characteristics of gas expansion energy in the initial dozen seconds or so from coal of different moisture contents. Based on a self-designed platform which is able to collect gas desorption data of about dozen seconds in the initial period, the gas desorption law and the release characteristics of gas energy from coal masses with different moisture contents in first about 13 s were studied. By doing so, it is conducive to further consummate the field outburst prediction and prevention technology and especially to provide reference for the accurate measurement of parameters for outburst prediction of coal seams and the determination of critical values of these parameters.

2. Experimental

2.1. Preparation of coal samples

Coal masses with outburst risk in the field are generally formed due to the damage of tectonic stress [30,31]. Compared with coal masses not subjected to the damage of tectonic stress (called non-tectonic coal or primary-undeformed coal), coal masses with outburst risk has lower mechanical strength and larger gas desorption rate after being exposed [32]. This type of coal is generally known as tectonic coal or tectonically-deformed coal [33]. Generally speaking, the higher the coal rank is, the larger the gas adsorption volume inside the coal and therefore the greater the possibility of an outburst occurrence [1,20,31,34]. For this reason, the tectonically-deformed coal acquired from an original coal seam was used in the experiment. The coal sample was collected from the No. II_2 coal seam of Xuehu Coal Mine (Shenhuo Co., Ltd in Henan province, China). The coal rank is anthracite, belonging to tectonically-deformed coal. On May 15th, 2017, a relatively intense outburst took place in a coal lane about 200 m from the sampling site in which 116 tons of coal were ejected, causing the death of 3 people. The coal samples were taken and well sealed at the underground sampling site. They were then taken to the laboratory and used for testing (mechanical strength and adsorption constants, as well as proximate analysis). The results of the tests are shown in Table 1.

A scanning electron microscope (SEM) was further used to observe the microscopic characteristics of the internal structures of the primary-undeformed and tectonically-deformed coal samples (See Fig. 1). It can be seen from Fig. 1(a) that the primary-undeformed coal samples had a compact structure overall. The surfaces of the particles were relatively smooth with angular geometries — there were only a small number of pores and no obvious fractures can be observed even at magnifications of $\times 4000$. In contrast, at a magnification of $\times 100$, the tectonically-deformed coal exhibits a much looser structure overall. Its appearance is rather 'honeycomb-like' with lots of pores and clear fractures on the particles surfaces (See Fig. 1(b)). Many studies also show that the huge difference between the gas adsorption capacity and the gas desorption rate between the primary-undeformed coal and tectonically-deformed coal is closely related to the internal microstructure of the coal mass [33–37]. Other research has also revealed these common differences in the geometric shapes of the coal particles of primary-undeformed and tectonically-deformed coal [38].

Three coal samples of different moisture contents were prepared. The experimental process for obtaining these coal samples is divided into three steps:

1) Lump coal collected from the coal mine was crushed and screened to attain coal particles with the particle size of 1–3 mm. The coal samples of about 1800 g in total were obtained and divided into three portions, each of which weighed 600 g and was stored in sealing bags.
2) Two portions of coal samples (600 g of each) were placed in two storage tanks. Then certain amount of distilled water was poured in the storage tanks to submerge the coal samples. Isolated from the atmosphere, the coal samples were immersed in the water for more than two weeks in the shade.