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Influence of Water on the Desorption Features of Coal Seam Gas

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This paper aims to clarify the effect of water on the desorption and release of coal seam gas (CSG). To this end, lab simulations were combined with field tests to disclose the changes in the amount and rate of gas desorption under different water saturation conditions. The results show that water had an obvious inhibitory effect on gas desorption. Specifically, when the equilibrium pressure and desorption time remained constant, the gas desorption is negatively correlated with the water content of the coal samples; when the water content reached a certain level, the desorption rate no longer decreased with the increase of water. Meanwhile, several water injection tests were carried out on the initial velocity q and desorption rate K_1 of the CSG, trying to effectively prevent and control coal and gas outbursts. The tests results reveal that the values of both indices varied greatly with the increase of the water content, when the latter was between 4.5% and 5%. This means the two indices were highly sensitive to water content in this phase. The decrease of the values slowed down as the water content fell between 6% and 6.5%, and stabilized when the latter increased to 9%~10%.To sum up, water injection of coal seam, i.e. using the q value and K_1 value as the indicators of outburst hazards, only partially mitigate rather than eliminate the potential threat of gas outburst.

1. Introduction

The migration and flow features of the coal seam gas (CSG) directly bear on the extraction of underground gas and the development of surface gas. Hence, the research of the CSG desorption, diffusion and seepage is critical to the management of gas disaster. With the increasing difficulty in gas control in recent years, various measures have been developed and tested to enhance the permeability and eliminate outburst based on water, such as water injection, hydraulic flushing, hydraulic slotting, hydraulic extrusion and hydraulic fracturing. These measures undoubtedly affect the water of coal. As a result, the influence of water should not be neglected in the study on the law of the CSG migration, including both desorption and diffusion.

Over the years, much attention has been paid to the effect of water on CSG migration. For instance, Zhu (2010), through a water injection test, discovered that the mean gas content of the roadway increased by 0.12% after water injection. Wang et al. (2011) observed a 29% growth in the amount of gas emission after hydraulic loosening. Huang et al. (2013), Yang, (2010) reviewed the hydraulic fracturing measures, pointing out the driving effect of water on the CSG. Chen et al. (2016), Xiao et al. (2011) experimentally confirmed that the gas absorbed in coal can be replaced by competitive adsorption due to the natural invasion of water, which effectively promotes the desorption of the CSG, and the promotion effect depends on the water content of coal sample. Chen et al. (2013), Ni et al. (2014), Xiao et al. (2015) and Hu and Wu (2014) found the restraining effect of intruding external water on desorption and migration of CSG. Yin et al. (2011), Hu et al. (2009) ascertained the linear reduction relationship between the water content of coal and the effective permeability of gas. Targeting tectonic coal, Wang and Li (2011) held that the coal porosity decreased with the increase of water content, leading to the reduction of coal permeability. Yuan et al. (2012) suggested that coal permeability is negatively correlated to water and obeys the exponential distribution. Wei et al. (2014), Liu et al. (2005) carried out an experiment that shows the negative correlation between water content and coal permeability. Wei et al. (2016) claimed that gas can hardly pass through coal samples in the saturated state, but gas permeability is not necessarily close to zero in this case. To sum up, there is no consensus on the effect of water on gas desorption.

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In light of the above, this paper selects a typical mine in China and its coal samples as the research object, and combines lab simulations with field tests to disclose the exact impacts of water on CGS desorption and diffusion, aiming to shed theoretical and technical new lights on the hydraulic prevention and control of gas disasters.

2. Simulation Experiment on Gas Desorption Features at Different Water Contents

2.1 Coal samples

Coal and gas outbursts are typical hazards of coal mines in China. In this paper, the field tests were conducted using the samples from Yanmazhuang coal mine, Jiaozuo mining area (Figure 1). As the main mine of Jiaozuo mining area, Yanmazhuang coal mine was put into operation in 1961. Since then, 36 coal and gas outbursts have occurred to the mine.

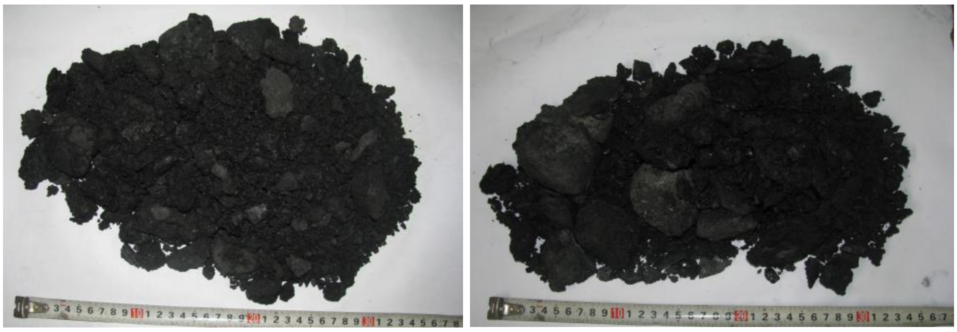
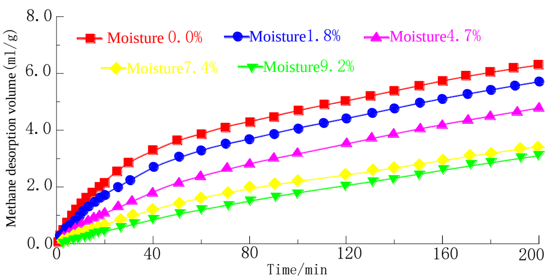


Figure 1: The photos of coal samples collected in yanmazhuang coal mine

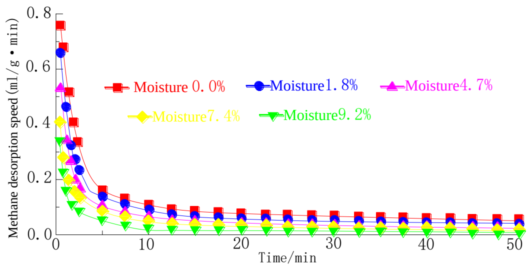
In the coal mine, the main coal seam is No. 2-1 coal of Shanxi Formation, whose metamorphic degree is anthracite. This type of coal has a banded and stratified structure in its occurrence: lump on the top, granular in the middle, and powdery and scaly at the bottom. The other parameters of the coal are as follows: the true density is 1.60m^3/t, the apparent density is 1.47m^3/t, the porosity is 8.12%, and the mean water M_{ad} of the raw coal is 1.88%. During the simulation experiments, the gas content of raw coal samples peaked at 26.13m^3/t, the gas pressure reached 1.39 MPa, and the Protodyakonov coefficient of the coal stood at 0.3.

2.2 Experimental results and analysis

To disclose the impacts of water content on gas desorption law, the gas desorption processes at multiple equilibrium pressure points were simulated under constant temperature (30±1°C). For coal samples with different water contents, the time variation in total gas amount at each equilibrium pressure point and the time variation in gas desorption rate were plotted according to the experimental results (Figures 2, 3 and 4). It can be seen from the experimental results that, when the equilibrium pressure and desorption time remained constant, the gas desorption is negatively correlated with the water content of the coal samples, indicating that the water has an obvious inhibitory effect on gas desorption.

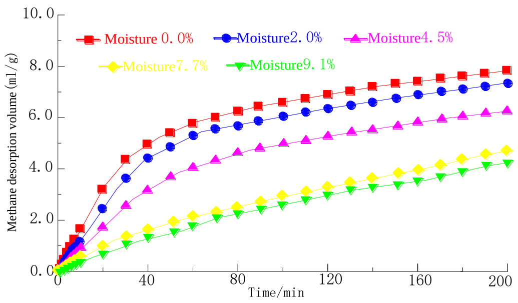


(a) The variation curve of methane desorption amount of coal sample with different moisture content with time

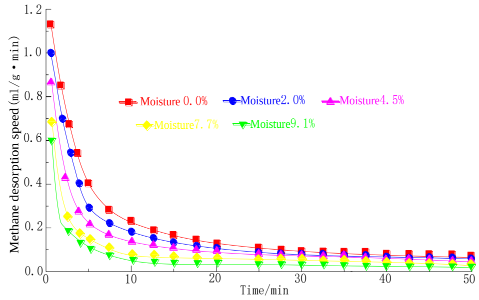


(b) The variation curve of methane desorption rate of coal sample with different moisture content with time

*Figure 2: The characteristic curve of methane desorption for coal samples with different moisture content (*The pressure of adsorption equilibrium is 0.5MPa)

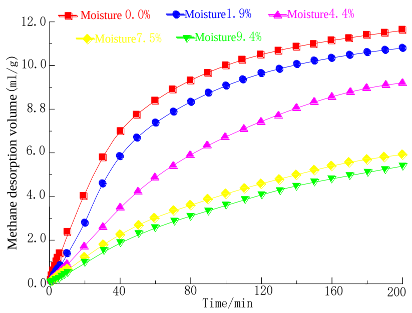


(a)The variation curve of methane desorption amount of coal sample with different water content with time

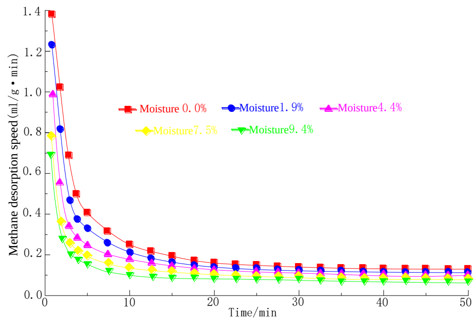


(b)The variation curve of methane desorption rate of coal sample with different water content with time

Figure 3: The characteristic curve of methane desorption for coal samples with different moisture content（The pressure of adsorption equilibrium is 1.0MPa)



(a)The variation curve of methane desorption amount of coal sample with different water content with time



(b)The variation curve of methane desorption rate of coal sample with different water content with time

Figure 4: The characteristic curve of methane desorption for coal samples with different moisture content (The pressure of adsorption equilibrium is 2.0MPa)

As shown in Figures 2(a)~4(a), water exhibited insignificant impact on the cumulative desorption amount of gas water the water content in the coal sample reached 8%~10%. Whichever the water content, the cumulative desorption amount increased over time, forming a monotonous increasing curve in the first 200minutes.

From Figures 2(b)~4(b), it is clear that, when the equilibrium pressure remained the same, the water content of the coal sample is negatively correlated with the desorption rate. In the beginning, there was a marked difference in the initial desorption rates at different water contents. However, the difference was no longer obvious after 20minutes. According to the variation curve of gas desorption rate, the gas was desorbed at a relatively fast speed at the beginning, and a much slower rate with the elapse of time. In the first 5 minutes, the gas desorption rate of the coal sample, whichever the water content, plunged deeply by over 70% on average. The decline started to slow down from the 10th minute and stabilized after 20 minutes.

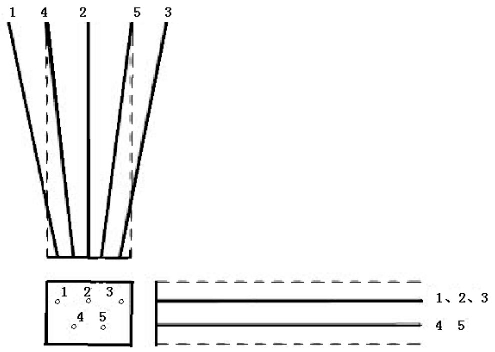
As shown in Figures 2(b)~4(b), the water exerted insignificant impact on the desorption rate after reaching a certain content. In other words, the desorption rate no longer decreased with the increase of water content after the latter arrived at a certain threshold. In our experiments, this threshold was observed as 8%~10%. Overall, the water content is negatively correlated with the gas desorption. The time variation curve of the desorption volume was monotonous increasing in the first 200minutes. The decline of the desorption rate was reduced by 70% in the first 5 minutes, and the increase of water content had no obvious effect on the desorption rate when it reached 8%~10%.

3. Field Tests on Gas Desorption Features using Original Coal Seam Water Injection Measures

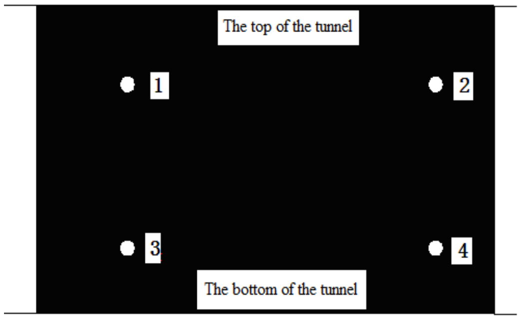
3.1 Test preparations

The effect of outburst prevention measures is usually evaluated by two indices: the initial velocity q and the desorption rate K_1 of the CSG. Together, the two indices help to predict the risk of gas outburst of mining faces. According to The Regulations for Prevention and Control of Coal and Gas Outburst, the critical values of q and K_1 are defined as 5L/min and 0.5mL/g·min$^{1/2}$, respectively. To identify the suitable values of q and K_1 under the influence of water, the author decided to perform field tests on gas desorption features using original coal seam water injection measures (Li et al., 2018).

The water injection tests can be conducted on the driving face or the work face. For the driving face, 3 to 5 holes (diameter: 42mm; depth: 10~15m) were drilled before the tunnel (Figure 5(a)); for the work face, 4 holes (diameter: 42mm; depth: 10~15m) were drilled facing the transport tunnel or return airway. As shown in Figure 5(b), the four holes were arranged at the longitudinal interval of 2m and transversal interval of 4m (Figure 5(b)), forming a rectangular area.



(a) Schematic diagram of water injection borehole layout on driving face



(b) Schematic diagram of water injection borehole layout on stope face

Figure 5: The sketch map of drill holes for water injection

The water injection tests aim to disclose the change law of q and K_1 with the growing water content of the coal sample. To this end, it is necessary to eliminate the interference of other factors. For example, the water injection pressure was kept between 3 and 5MPa, slightly greater than the CSG pressure. Otherwise, the high water injection pressure may fracture the coal seam and change the permeability of the latter, which affects the measurement of q and K_1.

The water injection time was determined in light of the designed injection volume and the actual injection volume, considering the backwater situation of coal wall. The orifice valve of the corresponding hole should be closed upon detecting a backwater phenomenon on the wall. This phenomenon was also taken into account to set the water injection rate. According to the amount of wet coal surrounding each hole, the water injection rate can be calculated as:

$$Q = \frac{KT\Delta_w \rho_w}{100} \tag{1}$$

where Q is the water injection volume of a hole (m^3); K is the extra coefficient of water injection (1.0~1.3); T is the amount of wet coal surrounding a hole (t); Δ_w is the added value of designed water content (%); ρ_w is the water density (t/m^3).

The amount of wet coal surrounding a hole can be derived from:

$$T = LSM\rho_c \tag{2}$$

where L is the length of the coal body to be injected with water in the axial direction of a hole (m); S is the interval between the holes (m); M is the mean thickness of coal seam near a hole (m); ρ_c is the coal density (t/m^3).

3.2 Test results and analysis

Figures 6 and 7 respectively depict the variation in the initial velocity q and in the desorption rate K_1 of the CSG with water contents in the work face #22071 of Yanmazhuang coal mine. Each of the two indices was measured through 3 tests.

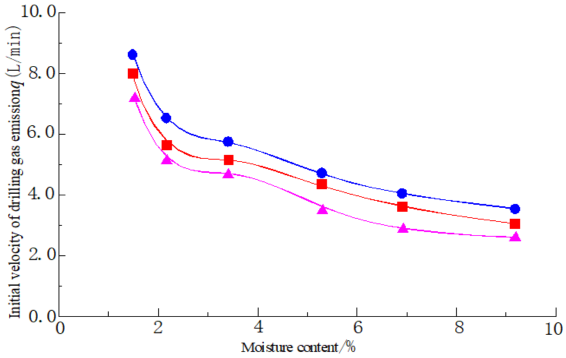


Figure 6: The change curve of drilling gas emission initial velocity q with the moisture content of coal

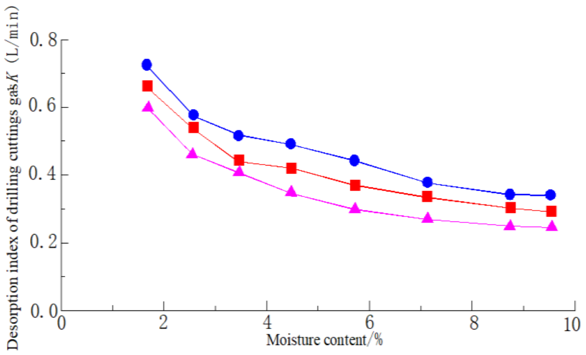


Figure 7: The change curve of drill cuttings *gas desorption index K_1 with the moisture content of coal*

It can be seen that both indices were affected by the water content of the coal body. The increase of the water content led to different levels of decline in the value of q and the value of K_1, indicating that the change of the water content affected the gas emission and migration. As shown in Figure 6, the q value varied greatly with the increase of water content when the latter was below 5%. This means the q value was highly sensitive to water content in this phase. The decrease of the q value slowed down as the water content surpassed 6%, and stabilized when the latter increased to 9%~10%. As shown in Figure 7, the K_1 value exhibited a similar trend as that of the q value. The K_1 value varied greatly with the increase of water content when the latter was below 4.5%. The decrease of the K_1 value slowed down and stabilized after the water content surpassed 6.5%. The variations in the q value and K_1 value reveal that the two indices not only reflect the coal stress, residual gas volume, and the permeability and mechanical properties of coal seam, but also indicate the water content of the coal body. From the levels of the original coal seam, the q value dropped by 63.9% at the maximum, while the K_1 value fell by 53.1% at the maximum. Through the water injection, the values of both indices moved from above the critical level to below the critical level. It can be concluded that the rising water content of the coal body can reduce the q value and K_1 value, but fail to essentially lower the gas content and pressure. Without the release of the CSG, the occurrence of coal and gas outbursts still pose a potential threat to the work safety of the coal mine.

4. Conclusions

The experiments on gas desorption under different water contents demonstrate the obvious inhibitory effect of water on gas desorption: when the equilibrium pressure and desorption time remained constant, the gas desorption is negatively correlated with the water content of the coal samples. Whichever the water content, the cumulative desorption amount increased over time, forming a monotonous increasing curve in the first 200min. In the first 5minutes, the gas desorption rate of the coal sample, whichever the water content, plunged deeply by over 70% on average. The decline started to slow down from the 10^{th} minute and stabilized after 20 minutes. The water exerted insignificant impact on the desorption rate after reaching a certain content.

In the water injection tests, the increase of the water content led to different levels of decline in the value of q and the value of K_1, indicating that the change of the water content affected the gas emission and migration. The values of both indices varied greatly with the increase of the water content, when the latter was between 4.5% and 5%. This means the two indices were highly sensitive to water content in this phase. The decrease of the values slowed down as the water content fell between 6% and 6.5%, and stabilized when the latter increased to 9%~10%.

Through the water injection, the values of both q and K_1 moved from above the critical level to below the critical level. Hence, elevating the water content of the coal body can reduce the q value and K_1 value, but cannot essentially lower the gas content and pressure. To sum up, the water injection of coal seam, i.e. using the q value and K_1 value as the indicators of outburst hazards, only partially mitigate rather than eliminate the potential threat of gas outburst.

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