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Experimental study of negative pressure gas drainage influences on coal moisture content

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ABSTRACT
In light of water loss phenomena of coal by negative pressure gas extraction, the relationship between time and coal moisture content, and the rate of water loss in special conditions of temperature and negative pressure were studied in the laboratory, and the water loss mechanism of coal was analyzed. Results show that the moisture content of three coals decreased as the negative pressure reaction time increased. In the initial phase, the moisture content of coals descends quickly. Afterwards, the decrease trend slows, and finally the moisture content of coals trends to a constant value. The maximum saturated water loss rate reaches 82.19% and the water loss of coal in experimental conditions is larger. The negative pressure by gas extraction reduces the coal pore gas pressure, and the boiling point and the saturated vapour pressure of water decrease; the free water vapourization (no boiling) rate of coals increases. Adsorption water and liquid water can change from a liquid to a gas, and be extracted by negative pressure. This action reduces the coal moisture content. The moisture of coal has great affects on dust quantity by mining. A long and continuous gas extraction will result in water loss of coal, and it is of great disservice to the prevention of coal mine dust, so it is necessary to perform water injection into coal seams or to take enhanced dust prevention measures after gas extraction.
Keywords: dust; gas extraction; negative pressure; coal moisture content; water loss mechanism

1. INTRODUCTION

At present, China's coal mine safety production situation is improving significantly. However, coal mine dust prevention is still a prominent problem, and it leads directly to high pneumoconiosis cases for operators (Fang H. et al., 2011; Tong R. et al., 2013). Occupational safety and occupational health should be equally important for workers. Great importance should be attached to gas disasters as well as dust control. Aimed at low permeability coal seams, closed drilling and long time gas drainage is the main measure to control disasters, especially in high gas mines and coal and gas outburst mines. Gas drainage can lead to the loss of coal moisture content, drying out the coal seam (Bao Q. et al., 2013). The amount of dust produced in mining is directly related to the moisture content of coal. The smaller the coal moisture content, the more dust generation. Some scholars have studied the water vapourization of coal in natural environments (Jin L. et al., 2000; Cong X. et al., 2010). In order to quantitatively study the effects and mechanism of negative pressure drainage on coal moisture content, the relationship between time and coal moisture content, and the rate of water loss in special conditions of temperature and negative pressure, three coal samples were studied in the laboratory, and the water loss mechanism of coal was analyzed.

2. EXPERIMENTS

2.1 Coal samples

Three representative coal samples were taken as the study and experiment object, and the samples were collected from 6-2# coal seam of Kaida mine, 15# coal seam of Jiarui mine, and 8# coal seam of Xinjing mine. The three coal samples were numbered 1#, 2#, and 3#, respectively. The coal samples were not influenced by gas drainage, and the sealed coal samples were taken to the laboratory. The proximate analysis and rank of coal samples are shown in table 1.

Table 1: Proximate analysis and rank of coal samples.

Sample ID	Moisture content (%)	Volatile component (%)	Ash component (%)	Coal rank
1#	14.16	19.66	22.47	Nonstick coal
2#	1.90	14.05	9.83	Meager coal
3#	0.98	8.81	12.76	Anthracite coal

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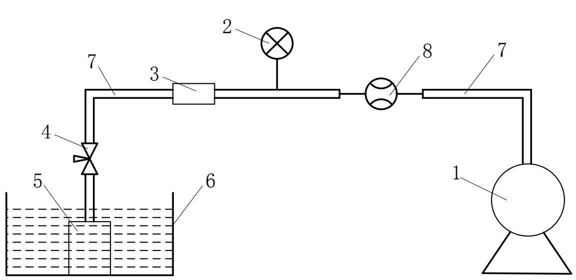
The 300 g coal samples with the particle sizes of 0.1-0.18 mm of three coals (1#, 2#, and 3#) were prepared by crushing and screening by proximate analysis standard. The prepared coal samples were enclosed in Ziploc bags to prevent water vapourization in air. The samples are shown in Figure 1.

Figure 1: Experimental coal samples.

2.2 Experimental device and process

Place the 40 g coal samples into a sealed tank and fix a constant temperature water bath at 30℃. Connect the sealed coal samples tank to a vacuum pump, and then turn on the vacuum pump. The sealed tank was opened after 0.5 h, and the vacuum coal samples were rapidly enclosed in the Ziploc bag and numbered on the outside. According to the above procedure, the coal samples were separately vacuumed at 1 h, 2 h, 3 h, 4 h, and 5 h, and the moisture content of six coal samples of different negative pressure action times (including the original coal sample) were acquired. The different moisture content of coal samples was tested by TGA-2000 automatic industrial analyzer, and the date was analyzed. The three coal samples were tested based on the above experimental method. The experimental apparatus is sketched in Figure 2.



1- vacuum pump；2-vacuum gauge；3-desiccator；
4-needle valve；5- sealed tank；6-waterbath；
7-sebific duct；8-flowmeter

Figure 2: Diagram of Experimental apparatus.

The water loss rate of coals at different time under constant temperature and negative pressure were calculated by Eq. (1).

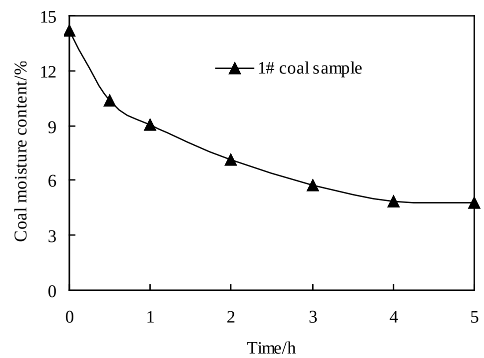
$$\delta=(W_0-W_t)/W_0 \quad (1)$$

Where δ is the water loss rate of coal sample, %, W_0 is the original moisture content, %, W_t is the moisture content at certain time after negative pressure, %.

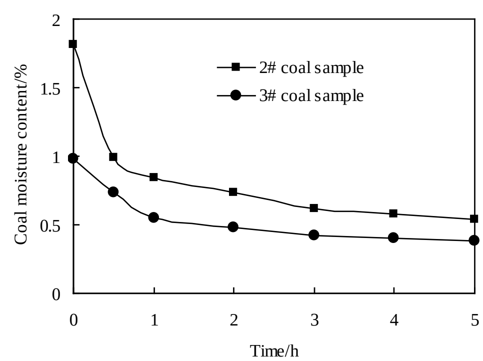
3. RESULTS AND ANALYSIS

3.1 Relationships between moisture content and time

Under particular a experimental temperature and negative pressure, the relationship between moisture content of the three coal samples and time are shown in Figure 3.



(a) 1# coal sample



(a) 2# and 3# coal samples

Figure 3: Relationships between moisture content and time.

From Figure 3, the moisture content of the three coal samples decreases as the negative pressure action time increases. In the initial phase, the moisture content of the coal samples descends quickly. Afterwards, the decrease trend slows and finally the moisture content of coal samples tends to a constant value. For the low metamorphic 3# coal sample, the original moisture content is 14.16%, and the moisture content changes to 4.77% after 5 h negative pressure action time. The water loss phenomena of coals by negative pressure were serious.

3.2 Relationships between water loss rate and time

The relationships between the water loss rate of the three coal samples and time are shown in Figure 4.

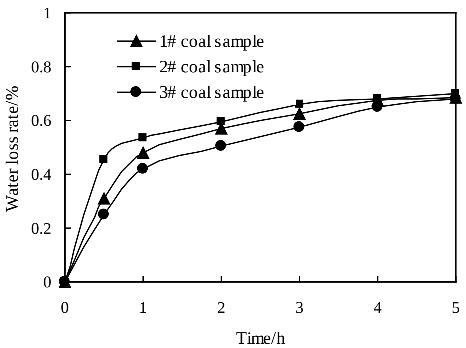


Figure 4: Experimental coal samples.

From Figure 4, the water loss rate of the three coal samples enlarges as the negative pressure action time increases. The water loss rates of the three coal samples are all more than 70%. The relationships between water loss rate and time are analogous to the Langmuir equation, and it has a saturated water loss rate that can be expressed by Eq. (2).

$$\delta=abt/(1+bt) \tag{2}$$

Where δ is the water loss rate of coal sample, %, a is the saturated water loss rate, %, b is the water loss constant, h^{-1}, t is the negative pressure action time, h.

The water loss rate curve equations of three coal samples are shown in Table 2. Under the specific conditions of the experiment, the maximum saturated water loss rate reached 82.19%. When the water loss rate reached saturation, the coal moisture content no longer reduced under increasing negative pressure action time. This was primarily connected to the existing water form, where the free water in coal was easily lost but the combined water was not.

Table 2: Water loss rate curve equations of coal samples.

Sample ID	Fitting equation	Correlation coefficient	Saturated water loss rate (%)
1#	δ=1.02t/(1+1.27t)	0.9786	80.65
2#	δ=2.36t/(1+3.29t)	0.9701	71.81
3#	δ=0.74t/(1+0.90t)	0.9668	82.19

4. WATER LOSS MECHANISM ANALYSIS

Coal is a porous medium, and water exits in two main forms: free water and combined water. Free water exists in the coal mass pore in the form of liquid water, and it includes the adsorption water which exists in coal interior particles in the form of physical absorption. Combined water (also called crystal water) binds with the mineral substance of coal in the form of combination. Combined water needs a high temperature to separate out. The micro-mechanism of coal adsorbing water is the result of the attraction between water molecules and coal molecules. These attractions include van der Waals forces and hydrogen bonds (Nie B. et al., 2004).

The water saturation vapour pressure is the pressure when the gas phase water and liquid phase water reaches equilibrium. There is a dynamic balance between liquid water and vapourous water under a particular pressure at the same temperature, and the molecular quantitative mutual transformation of the liquid water and vapourous water are equal in unit time. The water saturation vapour pressure is relative to the escape of water molecules from liquid water trend. The vapour pressure of liquid reflects the evaporation rate. According to the Clausius-Claperon equation, the relationship between the boiling point of water and the vapourization pressure can be represented as follows:

$$\lg p=A+B/T \tag{3}$$

Where p is the vapour pressure, Pa, T is the boiling point, K, A and B is the constant.

The formula shows that decreasing coal pore gas pressure (gas extraction) can lead to a decrease in the boiling point for free water and it can speed up the evaporation of the free water. If the gas drainage negative pressure is 13 Kpa, the temperature of the coal seam is 30℃, and the boiling point of water is 51℃, the vapourization pressure of water is 4.24 Kpa. At this point the boiling point of water is still higher than the temperature of the coal seam, and the vapourization pressure of water is still lower than the gas drainage negative pressure, so the water loss process is vapourization rather than boiling. Compared with the boiling point of water under normal pressure, it has reduced 49% under negative pressure. If we continue to improve the gas drainage negative pressure, the boiling point of water can be lower than the temperature of the coal seam, and the water loss process changes to boiling.

For the actual gas drainage project in mines, the negative pressure affected area around the borehole widens as time goes on. Inside the negative pressure affected area, coal pore gas pressure decreases. The water vapourization is accelerated on account of the water boiling point unloading, and the coal moisture content has a marked loss.

5. CONCLUSIONS

The coal moisture content decreases as the negative pressure action time increases. The saturated water loss rate of three coal samples reaches 82.19% and the water loss phenomena of coal by negative pressure gas extraction are serious. The gas drainage negative pressure reduces the coal pore gas pressure, and the boiling point and the saturated vapourization pressure of water decrease; it increases the water vapourization (no boiling) rate of coal. Free water (including adsorption water and liquid water) can change from a liquid to a gas and be extracted by negative pressure. This action would reduce the coal moisture content. The moisture of coal has a great affect on dust quantity in mining. Long and continuous gas drainage will result in water loss of coal, which is of great disservice to coal mine dust prevention, so it is necessary to perform water injection into coal seams or to take enhanced dust prevention measures after gas drainage.

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