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Influence of Ground Stress on Coal Seam Gas Pressure and Gas Content

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Abstract: The influence of ground stress was quantitatively analyzed on coal seam gas pressure and gas content in this paper. Mining activities in coal mine can result in stress concentration in the coal (rock) body around the mining space, but porosity of the coal seam would not change too much. Therefore, gas pressure and gas content in the coal seam are slightly affected. Studies showed that the free gas was gradually transformed into adsorbed gas, and the gas adsorption volume was small, and then gas pressure increases roughly linearly when the porosity decreased because of stress influence. Additionaly, when porosity of coal seam reduced to 40%, the amount of adsorbed gas accounted for no more than 10% of coal seam gas content, and the increase of gas pressure did not exceed 15% of the original gas pressure.

Keywords: Ground stress, coal seam porosity, gas pressure, gas content, stress concentration.

1 Introduction

Coal is the main energy in China, China's production of raw coal is 35.2 million tons in 2011, and the proportion of coal in primary energy production structure is 78.6%. According to the forecast of the national twelfth five-year plan, the demand of national coal to 2015 is 37.9 million tons. In the foreseeable decades, coal will remain the main energy in China. With the rapid development of mining production technology, mine production efficiency has been improving greatly in recent years. In conjunction with an increase in output per working face, increasing mechanization and exploitation at greater depths contribute quite substantially to deteriorating climatic conditions in underground workplaces, and the number of coal mines that suffer gas problems is rapidly increasing. With the increase of mining depth, ground stress, gas pressure and gas content has been increasing gradually, and the coal and gas outburst disaster has been becoming more and more serious.

In recent years, coal mine accidents occur frequently in China, which caused the death toll and seriously affect the safety production of the coal mine. Gas has become one of the biggest hidden dangers in coal mine safety production. Therefore, we must control the

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coal mine gas effectively, in order to reverse the situation of coal mine safety production in China and ensure that the coal industry health, sustainable development.

Variation in crustal stress will lead to variation of coal seam porosity. Porosity is an important factor deciding adsorption, permeability and strength properties of coal. By measuring porosity and gas pressure, calculation of free gas content in coal seam is possible [Wang, Cheng, Cheng et al. (2015)]. Under the influence of mining, the balance between in-situ stress field and original gas pressure of coal and rock mass is destroyed, resulting in stress redistribution of the coal and rock mass around the mining space as well as migration of gas dynamics [Li (2011)], with stress concentrated in front of the heading face as shown in Fig. 1. In this way, local coal body stress is increased, which will compress coal (rock), making osmotic volume, porosity of the coal seam decreased, coal seam gas pressure and gas internal energy increased, thus providing conditions for coal and gas outburst [Han, Zhang, Song et al. (2008)].

Gas in the voids of the coal exists in both free and adsorbed states [Wang, Cheng, Cheng et al. (2015)]. As shown in Fig. 2, free gas exists in free form in the void space of the coal body while adsorbed gas is absorbed in a molecular state by tiny particles of coal body to its surface. Gas in these two states maintains a dynamic equilibrium state at a macroscopic level, and mutual conversion is likely to be under certain condition. The increase of gas pressure in the coal seam will make partial gas convert from free state to adsorbed state. Many scholars at home and abroad have conducted extensive studies on variation law of coal (rock) porosity [Yin and Wang (2006); Lu and Pan (2010); Berryman (2011); Jasinge, Ranjith and Choi (2011)], law in effect of adsorption on coal permeability [Zhao, Wang, Zhang et al. (2018)], the effect of effective stress on coal seam gas desorption and seepage [Liu, Wang, Kong et al. (2018)], effective stress law of coal [Zhao, Hu, Wei et al. (2003)], etc. However, few scholars have studied how many changes will occur in gas pressure of the coal seam under variation of crustal stress, and how many free gases can be converted into adsorption gas. This paper will study on it through examples, which will help clarify the objective laws in coal-rock dynamic disasters and mean important theoretical significance for coal and gas outburst prevention.

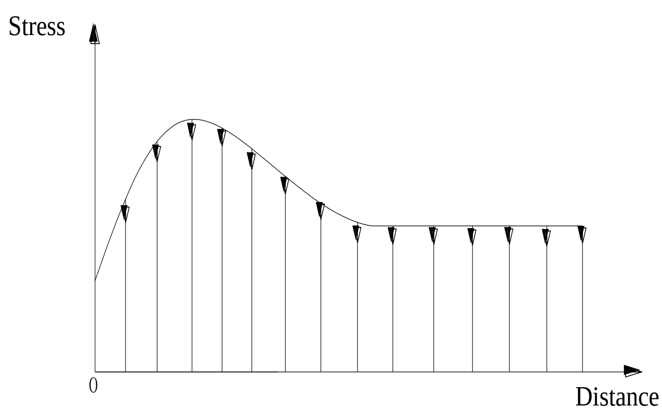

Figure 1: Stress distribution in front of the working face

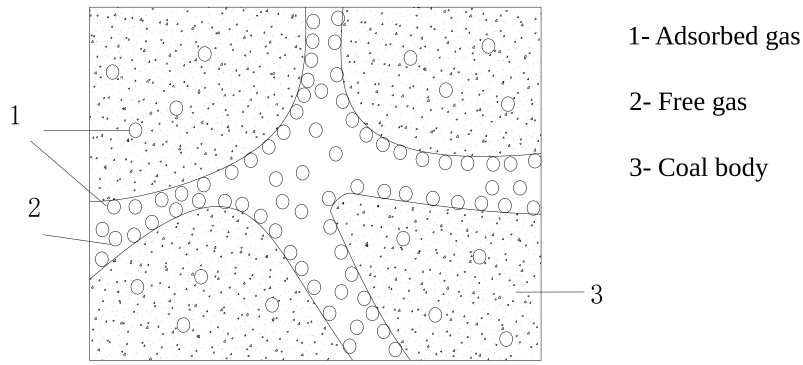

Figure 2: The state of storage of coalbed gas

2 Calculation of coal seam gas content and gas pressure

The gas content in coal seam refers to the amount of gas contained in the coal mass per unit mass or volume, that is, the sum of the amount of free gas and adsorbed gas [Wang, Cheng, Cheng et al. (2015)].

2.1 Calculation of free gas content

In general case, the free gas content of coal is calculated according to gas state equation, i.e.,:

$$X_y = \frac{npT_0}{Tp_0} \tag{1}$$

Where X_y ——free gas content of coal seam, m^3/t;

n ——porosity, %;

p ——gas pressure, Mpa;

T_0, p_0 ——absolute temperature and pressure in standard state, 273 k, 0.101325 Mpa;

T ——absolute temperature, K, T=273+t;

t ——celsius temperature, ℃.

2.2 Calculation of adsorbed gas content

We generally calculate absorbed gas content in coal seam according to Langmuir equation. The effect of temperature is ignored in the calculation, and only the moisture in the coal, the percentage of combustibles and the influence of adsorption constant are considered, that is:

$$X_x = \frac{abp}{1+bp} \cdot \frac{1}{1+0.31M} \cdot \frac{100-A-M}{100} \tag{2}$$

Where X_x——adsorbed gas content of coal seam, m^3/t;

p——gas pressure, Mpa;

a——adsorption constant, m^3/t;

b——adsorption constant, Mpa^{-1};

A, M——water and ash in the coal, %, %.

2.3 Calculation of total gas content of coal seam

The gas content in coal seam is the sum of the amount of free gas and adsorbed gas, which is obtained by Eqs. (1) and (2):

$$X = \frac{npT_0}{Tp_0} + \frac{abp}{1+bp} \cdot \frac{1}{1+0.31M} \cdot \frac{100-A-M}{100} \tag{3}$$

2.4 Gas desorption and adsorption

Gas content of coal seam is certain, but the quantity of gas in the free state and the adsorption state can be transformed into each other, which depends on the changes in pressure, temperature and moisture conditions in the coal seam. When the temperature is lower or higher pressure, part of free state gas will be transformed to the adsorption state, this phenomenon was called adsorption. Conversely, if the temperature rises or pressure reduction, part of adsorption gas will be transformed to free state, this phenomenon was called desorption. When the gas pressure of coal-bed changes from the equilibrium state to standard atmospheric condition normal, the gas released from coal-bed is desorption gas content. In the current mining depth, coal-bed gas is mainly existing in the adsorbed state, free state gas only accounted for about 10%.

3 Influence of stress on coal seam gas pressure and gas content

In general, coal seam gas content, temperature, moisture and ash change little in the mining process. Assuming that coal volume, gas content, temperature, moisture and ash content remain unchanged before and after the

variation of crustal stress, the following formula can be listed:

$$\frac{n_1 p_1 T_0}{Tp_0} + \frac{abp_1}{1+bp_1} \cdot \frac{1}{1+0.31M} \cdot \frac{100-A-M}{100} =$$

$$\frac{n_2 p_2 T_0}{Tp_0} + \frac{abp_2}{1+bp_2} \cdot \frac{1}{1+0.31M} \cdot \frac{100-A-M}{100}$$

let $c = \frac{1}{1+0.31M} \cdot \frac{100-A-M}{100}$

The above formula can be simplified as:

$$\frac{n_1 p_1 T_0}{T p_0} + c\frac{abp_1}{1+bp_1} = \frac{n_2 p_2 T_0}{T p_0} + c\frac{abp_2}{1+bp_2}$$

Each symbol meaning was same as the above. The finishing formula can be:

$$\frac{n_2 b T_0}{T p_0} p_2{}^2 + (abc + \frac{n_2 b T_0}{T p_0} - \frac{n_1 p_1 b T_0}{T p_0} - \frac{ab^2 c p_1}{1+bp_1}) p_2 - (\frac{n_1 p_1 T_0}{T p_0} + \frac{abcp_1}{1+bp_1}) = 0$$

let $A = \frac{n_2 b T_0}{T p_0}$ $B = abc + \frac{n_2 b T_0}{T p_0} - \frac{n_1 p_1 b T_0}{T p_0} - \frac{ab^2 c p_1}{1+bp_1}$ $C = -\frac{n_1 p_1 T_0}{T p_0} - \frac{abcp_1}{1+bp_1}$

$$p_2 = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \tag{4}$$

Gas pressure and gas content under different porosity conditions caused by variation in crustal stress can be calculated via Eq. (4).

4 Example analysis of stress's influence on coal seam gas pressure and gas content

The existing coal seam I has a gas pressure of 0.45 Mpa and gas content of 2.17 m^3/t including 0.35 m^3/t of free gas and 1.82 m^3/t of absorbed gas content. The coal seam II has a gas pressure of 1.38 Mpa and gas content of 9.67. M^3/t including 0.40 m^3/t of free gas and 9.27 m^3/t of absorbed gas. Other relevant parameters are shown in Tab. 1.

Table 1: Coal seam gas parameter table

	A **(m^3/t)**	***b*** **(Mpa^{-1})**	***p_1*** **(Mpa)**	***A*** **(%)**	***M*** **(%)**	***n_1***
Coal seam I	17.639	0.415	0.45	27.59	0.31	0.078
Coal seam II	38.517	0.564	1.38	9.53	1.91	0.029

When the gas content, temperature, moisture and ash content of the coal body remain unchanged, the variation of gas content and gas pressure of the coal body with porosity is shown in Figs. 3-6.

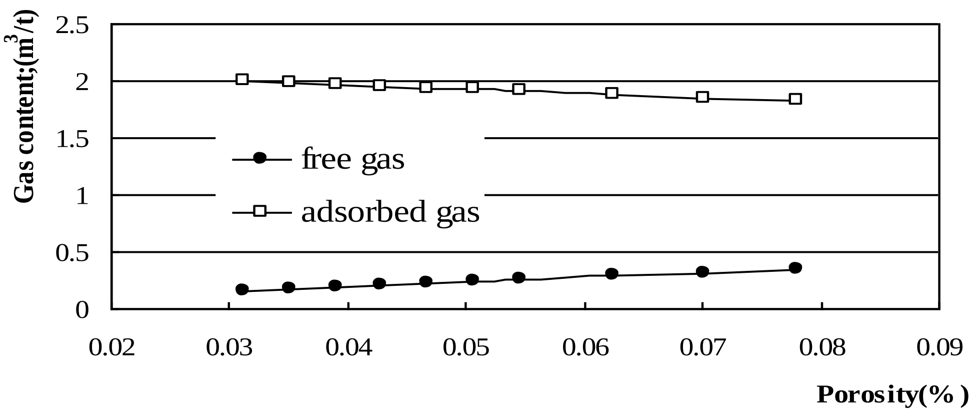

Figure 3: Effects of porosity on gas content (Coal seam I)

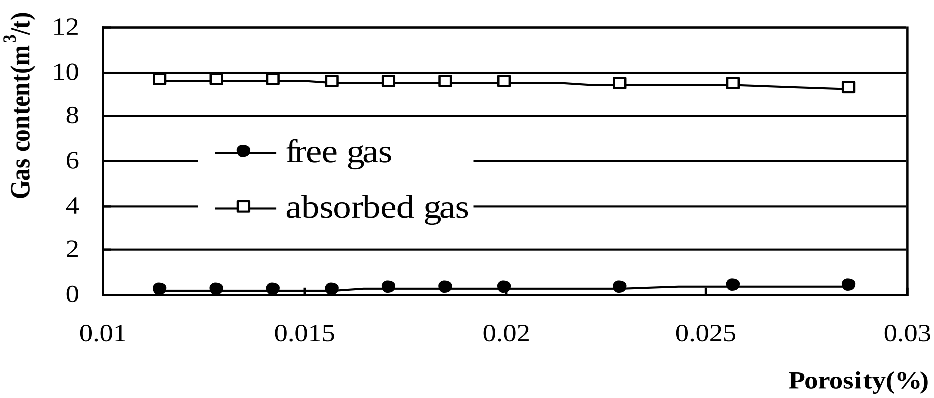

Figure 4: Effects of porosity on gas content (Coal seam II)

It can be seen from Fig. 3 and Fig. 4 that as porosity decreases, the absorbed gas content of the coal body increases gradually while the free gas content gradually decreases. That is, free gas is gradually converted into absorbed gas, and the amount of adsorbed gas varies less with the decrease in porosity. When porosity is reduced to 40% of the original, in coal seam I, only 0.19 m^3/t free gas is converted into adsorbed gas, accounting for only 8.29% of the total gas content of coal seam; in coal seam II, only 0.23 m^3/t free gas is converted into adsorbed gas, accounting for only 2.37% of the total gas content of the coal seam.

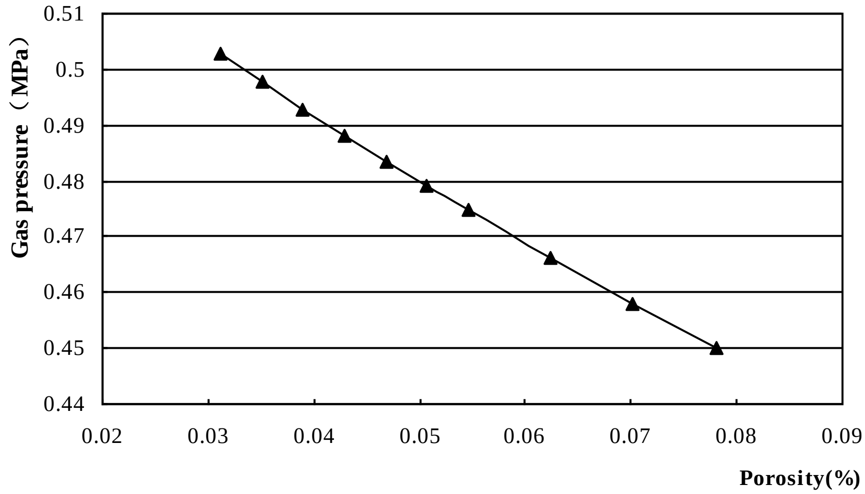

Figure 5: Effects of porosity on gas pressure (Coal seam I)

It can be seen from Fig. 5 and Fig. 6 that, as coal seam porosity decreases, gas pressure of the two coal bodies increases linearly, but the increase is small. When the coal seam porosity decreases to 40% of the original, for coal seam I, gas pressure increases from 0.45 Mpa to 0.50 Mpa, an increase of 11.1% (0.05 Mpa) compared to the original pressure. For coal seam II, gas pressure increases from 1.38 MPa to 1.44 MPa, an increase of 4.3% (0.06 Mpa) compared to the original pressure.

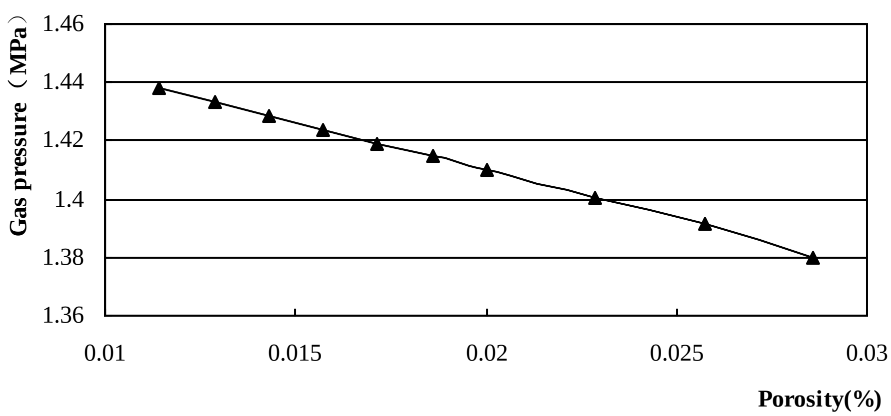

Figure 6: Effects of porosity on gas pressure (Coal seam II)

It can be seen from the literature [Qin and Wang (2010)] that as the axial stress increases, porosity first decreases and then increases. In the initial loading phase, as the load increases, voids and cracks of the coal body are gradually compacted, with porosity gradually decreased. However, when the load increases to a certain extent, internal cracks begin to form, nucleate, penetrate and expand, with porosity gradually increased. Therefore, mining activities in coal mine can result in stress concentration in the coal (rock) body around the mining space, but porosity of the coal seam would not change too much. Therefore, gas pressure and gas content in the coal seam are slightly affected. This is consistent with the statement in literature [Wang, Cheng, Cheng, et al. (2015)] that crustal stress has little effect on coal adsorption.

5 Conclusions

The influence of ground stress was quantitatively analyzed through examples on coal seam gas pressure and gas content in this paper. Mining activities in coal mine can result in stress concentration in the coal (rock) body around the mining space, but porosity of the coal seam would not change too much. Therefore, gas pressure and gas content in the coal seam are slightly affected. When the porosity decreased affected by change of stress, the free gas was gradually transformed into adsorbed gas, the gas adsorption volume was small, and gas pressure increases roughly linearly.

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