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Desorption Behavior of Coalbed Gas and its Anisotropy Within High Rank Coal Reservoir in the Zhengzhuang Block of the Southern Qinshui Basin, China

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1 Introduction

With the exploration and development of coalbed methane (CBM), there has been a growing interest in the coalbed gas desorption behavior and its geological controls. To date, two primary species including the desorption rate and desorption velocity of the coalbed gas have been studied widely (e.g. Pollard and Aydin, 1998; Chen et al., 2008; Liu et al., 2012). Some evidences have shown that the gas desorption from coals is dependent upon multiple factors, such as coal metamorphic grade, maceral composition, gas concentration and degree of fracture development etc., which usually result in a intensely lateral and vertical anisotropy of coalbed gas desorption within individual coal reservoir. In this paper, the main effort was devoted to study the desorption behavior (including desorption rate and desorption velocity) of coalbed gas in the No. 3 coal seam from the Zhengzhuang block of the southern Qinshui basin, China. It is meaningful to the effective recovery of the CBM from high rank coals.

2 Geological Settings

The Qinshui Basin is one of the most prospective CBM development districts in China where some pilot wells have achieved commercial CBM production (Li et al., 2011; Lv et al., 2012). Located in the southern Qinshui Basin, the Zhengzhuang block studied in this paper is rich in CBM resource (proved reserves ac. 843×10^{8} m^{3}) and covers an coal-bearing area of about 980 km^{2}. Tectonically, the study area is located in a “horseshoe-shaped” slope characterized by a trend of geographical low in northwest and high in southwest. It is bounded by the Sitou fault zone in the east and southeast. Geologic structures, including a variety of folds and faults of different scales, are developed throughout the study area. In the study area, the primary coal-bearing sequences occur in the Pennsylvanian Taiyuan Formation (No. 15 coal seam) and the Lower Permian Shanxi Formation (No. 3 coal seam). The Nos. 15 and 3 coal seams are for the most part minable. The No. 15 coal seam was deposited in a delta plain which was strongly influenced by the marine environment and has a thickness of 3–6 m and a maximum thickness of 6.7 m. The No. 3 coal seam was deposited in swamp environments between distributary channels in a terrestrial delta plain. The thickness of the No. 3 coal seam is 3.0–6.9 m, averaging 5.6 m. Both coal seams are laterally stable but slightly thicken from south to north and from west to east. Due to the influence of the Middle Yanshanian magmatic intrusion, the two coal seams have a high metamorphic grade that even reaches anthracite rank. The maximum vitrinite reflectance ($R_{o,\ max}$) of the No. 3 coal seam is 3.24–4.04 %.

3 Primary Measurements and Methods

A cumulative gas measurement approach following the Chinese standard of GB/T 19559-2004 was employed to investigate the coalbed gas desorption behaviors of 93 cores from the 13 wells located in the Zhengzhuang block. The primary procedure consists of four steps, i.e. core sampling, natural desorption, measurement of residual gas and estimation of lost gas. During core sampling, the time interval from elevating the core to the surface was strictly controlled by the following standard: (1) coal burial depth (D) $\leq$ 500 m, time interval (T) < 10 min; (2) D ranges from 500–1000 m, T < 20 min; (3) D > 1000 m, T< 30 min. When reaching the surface, the core (> 800 g) was immediately sealed in the desorption canister within 10 min. Following the procedure of placing the canister in the thermostat (adjusted at coal reservoir temperature) and

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connecting the canister and volumenometer with a plastic tube, the natural desorption test was started. Then a series of data was generated on the desorbed gas volume and were recorded by the method from the Chiese standard. The natural desorption test will be stopped when the desorbed gas volume is less than 10 cm^3 per day within continuous 7 days. Subsequently, the core samples of about 400–500g were selected and crushed to 2–3 cm fragments. These fragments were further shattered using a sealing ball mill for 2–4 h. Desorption test for residual gas was then carried out adopting the same method as that used during the natural desorption test. The only difference is that the desorption canister was replaced with a sealing ball mill. Need to note that the weight (in air dried basis or dry ash-free basis) of the cores were accurately measured at the end of desorption tests. Lastly, the volume of the lost gas was estimated by plotting the cumulative gas desorbed for the first few measurements from field desorption test as a function of square-root of time. The intercept of the straight line plotted is believed to be the lost gas volume (Diamond and schatzel, 1998). A significant parameter of adsorption time reflects the velocity of gas desorption, and is defined as a time at when the natural desorption gas content accounts for 63.2 % of total natural desorption gas content.

The volumes obtained from field and laboratory desorption tests need to be converted into the standard temperature (293.15 K) and pressure (101.33 KPa), which is expressed as:

$$V_{STP} = \frac{293.15 \times P_m \times V_m}{101.33 \times (273.15 + T_m)} \quad (1)$$

Where V_{STP} is gas volume (cm^3) at standard temperature and pressure; P_m and T_m are atmospheric pressure (KPa) and atmospheric temperature (K) measured along with desorption tests; V_m is desorbed gas volume (cm^3) obtained directly from volumenometer.

Finally, total coalbed gas content can be obtained, and was given as:

$$C = \frac{V_D}{m_T} + \frac{V_R}{m_R} + \frac{V_{lost}}{m_T} \quad (2)$$

Where C is total gas content (cm^3/g or m^3/t); V_D is total gas volume (cm^3) obtained by natural desorption test; V_R is residual gas volume (cm^3) obtained by laboratory desorption test; V_{lost} is lost gas volume (cm^3); Mt and Mr are the weight (in gram, air dried basis) of cores used for natural and residual desorption tests respectively.

As the natural desorption stops, the fracture characteristics of cores were timely investigated by the Chinese coal industry standard of MT/T 968-2005, including the density of primary and secondary fractures (i.e. face and butt cleats), fracture connectivity, and degree of fracture development etc. In this study, 83 cores were carried out on the description of macroscopical fractures. In addition, a total of 61 cores were prepared into coal slabs with three polished surfaces, which used for observing micro-fractures.

CH_4 isothermal adsorption measurements of 13 cores from 13 wells were performed using the *capacity method* from the standard of GB/T 19560-2004. Experimental results include Langmuir volume (as received basis and dry air-free basis) and Langmuir pressure, which were used for calculating CH_4 critical desorption pressure (P_{CD}). The CH_4 P_{CD} of coal was estimated by the equation:

$$P_{CD} = \frac{C \times P_L}{V_L - C} \quad (3)$$

Where P_{CD} is critical desorption pressure (P); C is coalbed gas content (m^3/t); V and P_L are Langmuir volume (m^3/t) and Langmuir pressure (MPa) respectively obtained from CH_4 isothermal adsorption analysis.

4 Results and Discussion

4.1 Desorption behavior of coalbed gas

Coalbed gases are all the gases stored in coal reservoirs including CH_4, CO_2, O_2, H_2, N_2 and C_2^+ etc. Generally they are dominated by CH_4, and are thus often called as coalbed methane. In the study area, the CH_4 content of the coalbed gases averages 92.28 %, while the other components such as N_2 and CO_2 just account for 6.68 % and 1.05 % respectively. The C_2^+, was completely decomposed into gases of small molecular weight such as CH_4, CO_2 and N_2 etc. The total content of the gases stored in the No. 3 coal seam ranges from 0.84–31.44 m^3/t with an average of 20.57 m^3/t. In addition, it was found that the

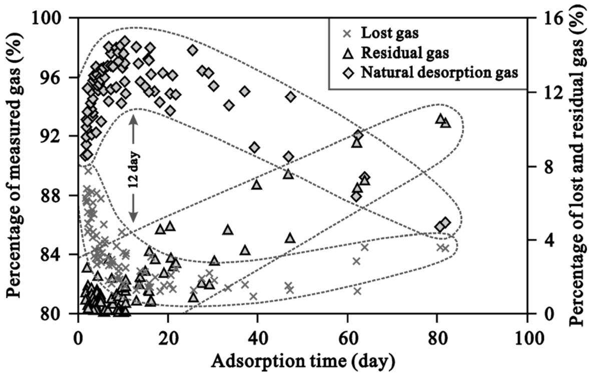

Fig. 1. Results of gas desorption from the high rank coals.

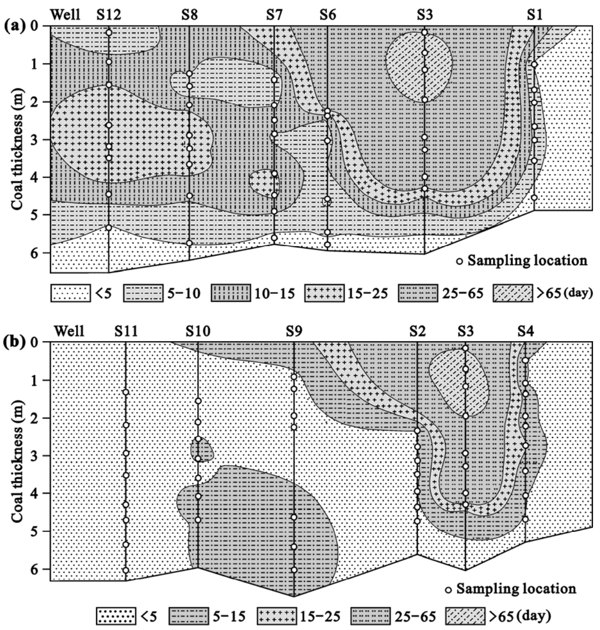

Fig. 2. Distribution of adsorption time within coal reservoir.

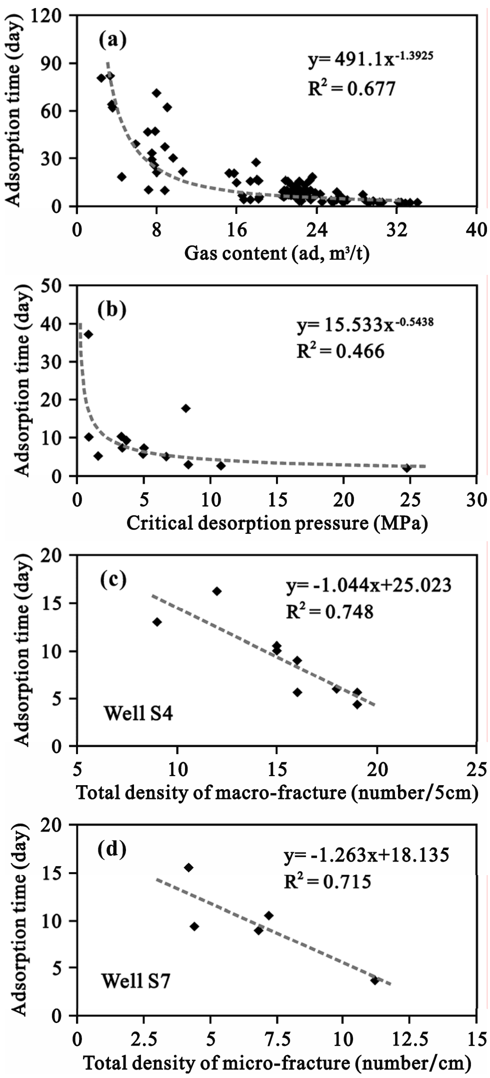

Fig. 3. Primary factors influencing the adsorption time.

CH_4 content of the coalbed gases is very high (> 90%) when coalbed gas content is larger than about 9.5 m^3/t but reduces linearly with the decrease in coalbed gas content ranging from 9.5–0 m^3/t (Li et al., 2012).

As shown in Fig. 1, the percentage of natural desorption gas is very high (> 85 %) and mainly ranges from 90.6–98.4 %. Overall, the percentages of lost gas and residual gas are relatively low, and are of 0.9–8.5% (mean 3.3%) and 0.0–10.5% (mean 1.9 %), respectively. With the increase in the adsorption time, the variation tendencies of natural desorption gas, lost gas and residual gas are distinct (Fig. 1). As the adsorption time is about of 12 days, the percentage of natural desorption gas (lost gas) exhibits a maximum (minimum) value. However, the percentage of residual gas increases with increasing adsorption time. It also can be concluded that the coals with a adsorption time of 12 days will be favorable for the CBM extraction.

4.2 Anisotropy of the desorption behavior and its primary controls

Generally, coalbed gas reservoirs with a short adsorption time will have a high gas production and a early occurrence of maximum gas production. Liu et al. (2000) reported that the curve of gas production will be obviously impacted by the adsorption time as the adsorption time is larger than 30 days. Thus, the adsorption time of coalbed gas plays a significant role on the gas production. In this study, it was found that the adsorption time of coalbed gas is lateral and vertical anisotropy within coal reservoir, as presented in Fig. 2. This also reveals that the desorption velocity is varied at different location within the coal reservoir. Comparatively, the distribution of adsorption time shown in Fig. 2a has a stronger spatial anisotropy than that presented in Fig. 2b and is not beneficial to the CBM recovery.

In this study, primary factors influencing the adsorption time were considered to be gas content, critical desorption pressure, and total densities of micro-and macro fracture. (1) The adsorption time decreases with increasing coalbed gas content (Fig. 3a). This is because that a high gas concentration, corresponding to a larger diffusion velocity, will result in a short adsorption time. In this study, the impact of gas content on the adsorption time is intense as the coalbed gas content is less than about 10 m^3/t. Then, the impact will weaken at the coalbed gas content range of about 10–25 m^3/t. The impact is very slight as the coalbed gas content is larger than about 25 m^3/t. (2) CH_4 critical desorption pressure reflects the potential of CBM recovery. For the coal with a high critical desorption pressure, it is much easier to desorb the CBM during the dewatering, which leads to a high gas production. Similar to the impact manner of coalbed gas content, the adsorption time decreases with increasing critical desorption pressure in a power exponent manner (Fig. 3b). The adsorption time is relatively low (< 4.44 days) as the critical desorption pressure is larger than about 10 MPa. (3) A great density of cleat (fracture) within coals causes a large diffusion velocity of coalbed gas, which resulting in a short adsorption time of gas. Additionally, the aperture, length and connectivity of cleat (fracture) also affect the diffusion velocity of coalbed gas (Li and Si, 2004), and further impact the gas adsorption time. As shown in Fig. 3c and Fig. 3d, the adsorption time is negatively related to the densities of micro-and macro fracture when the micro-or macro fractures have a good connectivity within coals.

5 Conclusions

In this paper, the desorption behavior (desorption rate and desorption velocity) of coalbed gas from the high rank coals were studied. Results show that: (1) natural desorption rate of the high rank coalbed gas is high (>85 %) and mainly ranges from 90.6–98.4 %; (2) the adsorption time (desorption velocity) is comprehensively influenced by gas content, critical desorption pressure, and total densities of micro-and macro fracture, and exhibits a strong anisotropy within coal reservoir.

Acknowledgments

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