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Evaluation of pore development in different coal reservoirs based on centrifugation experiment

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ABSTRACT

Pore development in a coal reservoir is closely related to the coalbed methane (CBM) occurrence. Therefore, an experimental study on the properties and characteristics of coal pores is critical for CBM exploration and production. In this paper, capillary pressure data from six coal samples with coal ranks ranging from medium volatile bituminous to anthracite were obtained using centrifugation, which is fast, convenient, non-toxic and harmless compared with other experimental methods. The centrifugation capillary pressure curves can be classified into three types. Type A refers to the medium-low volatile bituminous with a wide platform on its capillary pressure curve, indicating the pores have a good connectivity. The fractal analysis show that the fractal structure of macro- and mesopores are more complicated than that of transition pores. Thus the pore structure has a good capacity for gas seepage. Type B and C refer to the semi-anthracite to anthracite with steeper capillary pressure curves, suggesting that they both contain large numbers of micropores. However, the maximum and average pore diameters of type B are larger than those of type C, indicating that type B has more macropores than type C. Therefore, type B has both gas flow and adsorption capacities, while type C is only favorable for methane storage. Mercury porosimetry and scanning electron microscopy (SEM) were also performed on the six samples to verify the results of centrifugation. The capillary pressure curves obtained using mercury porosimetry also indicate the three types of pore structures. The pore size distributions evaluated from mercury intrusion show a consistency with those from centrifugation. As the assessment of pore development using centrifugation is limited to quantity, SEM can help to visually reveal the genesis of pores in different types of coal reservoirs.

1. Introduction

China attaches unprecedented importance to the exploration and development of coalbed methane (CBM) due to coal mining safety, greenhouse gas emissions and demand for natural gas (Luo and Dai, 2009; Tao et al., 2012). For coal reservoirs, a special porous media, the characteristics of pores (quantity, size, proportion of different type pores, and connectivity between pores), can influence not only gas transportation behavior, but also the mechanisms of gas adsorption and storage in coal seams (Clarkson and Bustin, 1996; Karacan and Okandan, 2001; Mastalerz et al., 2008). The matrix pore structure, specifically the relative abundance of micro-/transition-/meso-/macropore volume, has been demonstrated to be a function of coal composition and rank (also known as maturity or level of metamorphism which is commonly quantified by vitrinite reflectance) (Clarkson and Bustin, 1996, 1999; Gan et al., 1972). Therefore, the development of pore systems in different rank coal reservoirs is an important physical property having great influence on CBM occurrence (Meng et al., 2014; Zhao et al., 2015). Experimental studies, which aim to determine the pore size, shape, distribution, connectivity and genesis at different rank coals, are useful in understanding pore properties, gas content, porosity and permeability of coal reservoirs (Levy et al., 1997; Rahman et al., 2007).

Recently, many researchers have characterized the complex coal pore systems at different scales using mercury intrusion, N_2 adsorption/desorption analysis, low-field nuclear magnetic resonance (NMR), computed tomography (CT) and scanning electron microscopy (SEM) (Liu et al., 2009; Yao et al., 2008, 2009, 2010a, 2010b; Xu et al., 2015; Karacan and Okandan, 2001). But very few papers have discussed the application of centrifugation experiments on characterizing pore development for the study of coal reservoirs. Similar to mercury intrusion,

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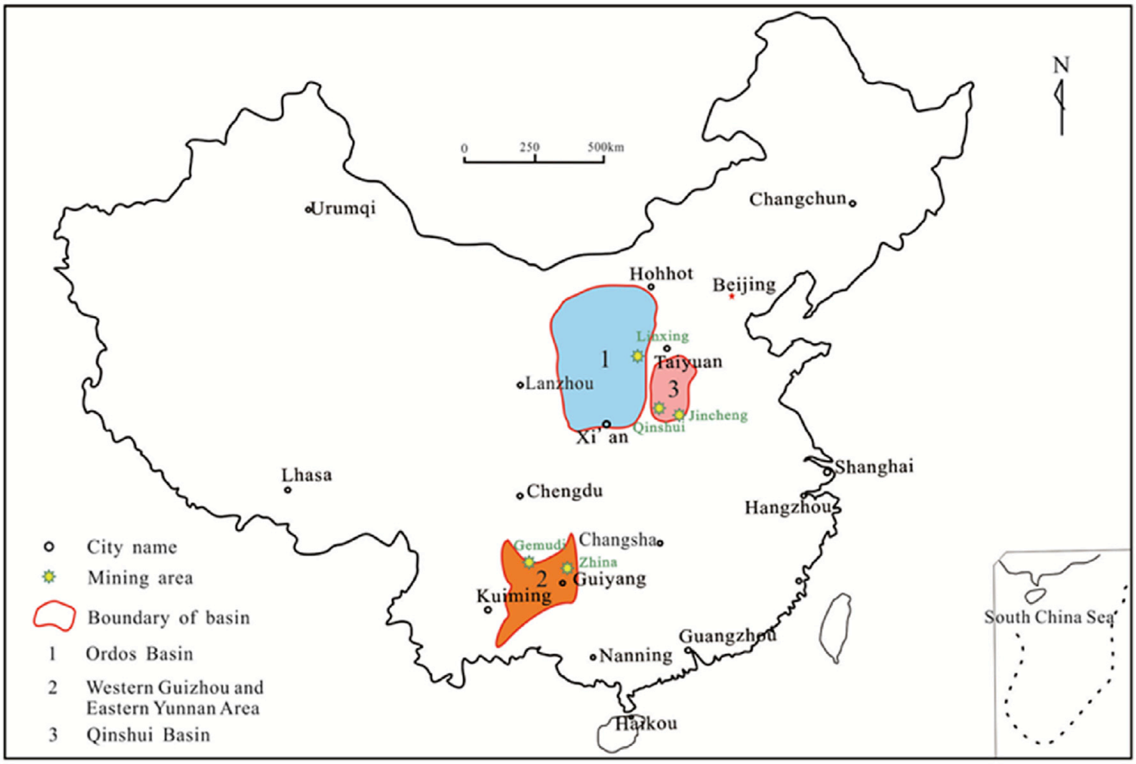

Fig. 1. Locations of coal samples studied in this paper.

centrifugation obtains capillary pressure data by discharging the liquid in different size pores at different rotation speeds. It is derived from Hassler's assumption based on the gravity drainage principle (Hassler and Brunner, 1945). This method has advantages of short-cycle and fast-speed, and is also non-toxic. Yi (1998) applied capillary pressure curves derived from centrifugation of conventional reservoirs to confirm that the centrifugation method is equivalent to mercury intrusion for evaluating characteristics of pore structures, but is better than mercury intrusion due to the limited damage to the pore structures. Que and Lei (2003) identified influencing factors on oil recovery and the saturation of residual wetting and non-wetting phase via a series of centrifugation experiments on the Berea sandstone and Texas Cream limestone. Such studies have not been performed on coals. Hence, there is a need to seek contributions that uses centrifugation for pore system characterization of CBM reservoirs.

The purpose of this work is to characterize the pore development and evaluate the gas storage/flow behavior in different coal reservoirs using capillary pressure data from a centrifugation experiment. In order to validate the results, mercury porosimetry and SEM experiments were also carried out for comparison and to further reveal the genesis of pore development in different coal reservoirs, respectively. The results may be applicable in developing strategies in exploration, well completion and drainage of CBM.

2. Samples and experiments

2.1. Sample collection and description

A total of six coal samples were collected directly from the sub-seams of the working faces of coal mines in three main coal-bearing basins in China. All of the samples were carefully sealed with plastic wrap to prevent weathering and oxidation and then shipped to the laboratory for analysis. The geographical locations for the six samples are shown in Fig. 1, including one from the eastern margin of the Ordos basin, two from the western Guizhou and eastern Yunnan and three from the southern margin of the Qinshui basin.

Vitrinite reflectance (R_o) of coals increases with the increase of coal rank. In this study, we tested the mean random, maximum and minimum R_o of coal samples and chose the mean random R_o to describe the coal's metamorphism. Based on the ASTM D 388-05 (2005a), sample PPT and YS are medium-low volatile bituminous with R_o of 1.34% and 1.89%, sample NF and YA are semi-anthracite to anthracite with R_o of 2.51% and

Table 1
Basic information for coal samples.

Location	Mining area	Sample number	R_o (%)	Coal organic maceral composition (%)			Proximate analysis (%)				Contact angle (°)
				V	I	E	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	
Eastern margin of Ordos basin	Linxing	PPT	1.34	71.2	25.8	0	0.35	18.73	18.74	56.18	61.580
Western Guizhou and eastern Yunnan	Gemudi	YS	1.89	75.8	21.2	0	0.20	16.94	13.89	65.97	68.980
	Zhina	NF	2.51	77.4	19.9	0	1.06	12.84	5.78	70.32	67.840
Southern margin of Qinshui basin	Qinshui	YA	3.04	80.5	16.3	0	1.59	13.58	5.57	73.26	74.852
	Jincheng	TA	3.12	81.4	17.3	0	0.71	16.05	4.34	77.9	72.993
	Jincheng	BF	3.15	80.1	17.8	0	0.34	10.83	4.18	79.28	73.618

Note: R_o = Mean random vitrinite reflectance; V = Vitrinite content; I = Inertinite content; E = Exinite content; M_{ad} = Moisture content (wt. %, air dry basis); A_{ad} = Ash yield (wt. %, air dry basis); V_{ad} = Volatile matter (wt. %, air dry basis); FC_{ad} = Fixed carbon content (wt. %, air dry basis).