Journal of Natural Gas Science and Engineering 56 (2018) 93–106

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

Study on the characteristics of matrix compressibility and its influence factors for different rank coals*

Pei Shao[a,b,c,*], Xiao Wang[a,c], Yu Song[a,c], Yong Li[a,c]

[a] Key Laboratory of Coalbed Methane Resources & Reservoir Formation Process, Ministry of Education, China University of Mining & Technology, Xuzhou 221008, China
[b] Shanxi Key Laboratory of Coal and Coal Measures Gas Geology, Taiyuan 030001, China
[c] School of Resources and Geosciences, China University of Mining & Technology, Xuzhou 221116, China

ARTICLE INFO

Keywords:
Matrix compressibility
Coal rank
Influencing factor
Coal material
Pore structure

ABSTRACT

To thoroughly understand the mechanism of permeability change and improve production in coalbed methane development, it is important to clarify the evolution characteristics and influencing factors of matrix compressibility for various coal ranks. This paper presents calculations of matrix compressibility coefficients of different rank coals through mercury intrusion porosimetry (MIP) and N_2 adsorption. Furthermore, the evolution of coal material and pores based on coal rank is analyzed to study their effect on matrix compressibility coefficients. The results show that the relationship between matrix compressibility coefficients and coal rank is a cubic polynomial function, in which two inflection points are situated in the maximum vitrinite reflectance ($R_{o,max}$) = 1.3% and 2.5%. For coals with $R_{o,max}$ < 1.3%, matrix compressibility coefficients increase as vitrinite and volatile matter contents increase, which may be related to the lower microhardness of vitrinite and the more random structure of aromatic carbon micells surrounded or linked by carbon functional groups, such as aliphatic chains, methoxyl and carboxylic functional groups. Moreover, the regular change of moisture content with coal rank is similar to matrix compressibility coefficients and it also plays a positive role in matrix compressibility. However, the inertinite and mineral content has a rather opposite effect on matrix compressibility. For the pore structure, the larger porosity and micropore volume in coals, the greater matrix compressibility. The coals $R_{o,max}$ < 1.0%, which have a loose chemical structure and high micropore volume, can bear a greater intrusion pressure than the coals with $R_{o,max}$ > 1.0%, in which the micropore structure will be broken when pressure exceeds 150 MPa. The coals with greater fractal dimension are more sensitive to stress. The matrix compression can lead to reduction of micropore volume and can make the micropore structure more irregular. It indicates that the increasing of effective stress with gas discharge could reduce the permeability of the reservoir and enhance the adsorption of micropore.

1. Introduction

Coalbed methane (CBM) is a potential alternative to conventional gas energy, and CBM development can be effective in reducing the emission of methane and avoiding coal mine accidents. China hosts the world's third-largest amount of CBM resources, behind only Russia and Canada (Meng et al., 2011). Currently, Chinese CBM development zones have mainly been concentrated in the southern Qinshui basin (Peng et al., 2017; Zhang et al., 2016a,b; Zhao et al., 2016; Zhu et al., 2015), the eastern Ordos basin (Chen et al., 2015a; Wu et al., 2017; Xu et al., 2012; Yao et al., 2014), the western Guizhou-eastern Yunnan regions (Li et al., 2015a; Tang et al., 2016a), and the Southern Junggar Basin (Fu et al., 2016, 2017; Zhou et al., 2016, 2017). These CBM reservoirs cover low ($R_{o,max}$ < 0.7%), medium (0.7% < $R_{o,max}$ < 2.0%), and high ($R_{o,max}$ > 2.0%) rank coals (ASTM D388-18, 2018).

CBM development usually occurs in three stages: water single-phase flow, gas and water two-phase flow, and gas single-phase flow (Chen et al., 2009; Sun et al., 2017). During this process, the coal reservoir pressure decreases gradually as water and gas are discharged, leading to an increase of the effective stress on the coal reservoir (Lu and Connell, 2007; Meng et al., 2011; Pan et al., 2010). Multiple studies have shown that the permeability of coal reservoirs decreases exponentially as effective stress increases (Cai et al., 2014; Chen et al., 2015b; Durucan and Edwards, 1986; Li et al., 2009; Pan and Connell, 2012; Somerton et al., 1975; Zheng et al., 2012). This is because the flow of water and

* Corresponding author. Key Laboratory of Coalbed Methane Resources & Reservoir Formation Process, Ministry of Education, China University of Mining & Technology, Xuzhou 221008, China
E-mail address: spei623@cumt.edu.cn (P. Shao).

https://doi.org/10.1016/j.jngse.2018.05.035
Received 29 August 2017; Received in revised form 22 May 2018; Accepted 26 May 2018
Available online 31 May 2018

Table 1
Relevant test data for the collected samples.

Mines	Samples	$R_{o,\ max}$ (%)	Coal compositions (%)				MH (N/mm^2)	Proximate analysis (%)				TRD (g/cm^3)
			V	I	L	M		M_{ad}	A_d	VM_{daf}	FC_d	
LK	LK1	0.42	81.48	7.01	9.30	1.24	172	7.32	9.82	45.17	49.45	1.23
	LK2	0.42	81.69	5.90	8.20	1.70	203	8.03	9.26	44.64	50.23	1.24
	LK3	0.41	83.76	4.79	7.10	2.26	215	10.12	17.76	55.41	36.67	1.34
HN	HN1	1.27	67.40	23.11	0.00	9.49	244	1.27	14.55	26.58	62.74	1.55
	HN2	1.69	65.93	27.03	0.00	7.04	216	0.84	10.92	16.47	74.41	1.47
	HN3	1.07	49.61	34.48	9.92	5.99	250	1.20	9.10	27.95	65.5	1.40
	HN4	1.37	74.07	19.10	0.00	6.83	230	1.02	10.14	20.45	71.48	1.46
	HN5	1.14	66.59	24.87	2.68	5.85	267	0.92	8.74	27.72	65.97	1.42
	HN6	1.05	50.30	37.68	2.90	9.12	246	0.64	13.77	25.93	63.87	1.47
	HN7	0.99	45.93	32.12	3.21	18.74	254	0.73	27.86	30.23	50.34	1.64
	HN8	1.15	66.08	25.67	2.78	5.47	249	1.12	8.41	24.69	68.98	1.42
	HN9	1.04	65.93	30.02	0.00	4.05	253	0.80	6.34	25.14	70.11	1.38
SH	SH1	2.77	81.66	15.33	0.00	3.01	339	2.34	4.47	6.99	88.85	1.42
	SH2	2.83	77.29	19.28	0.00	3.43	348	2.30	5.42	8.56	86.49	1.38
	SH3	3.08	81.71	15.13	0.00	3.17	349	1.48	4.94	7.23	88.19	1.42
	SH4	3.10	65.23	26.62	0.00	8.15	347	2.43	12.74	8.53	79.82	1.48
	SH5	2.96	79.60	17.10	0.00	3.30	352	2.17	5.18	7.60	87.62	1.40
	SH6	2.95	60.73	33.64	0.00	5.63	300	1.90	8.83	8.39	83.53	1.44
	SH7	3.12	67.04	23.81	0.00	9.15	314	1.99	13.77	8.77	78.67	1.48
	SH8	2.99	70.89	17.98	0.00	11.13	343	2.45	16.50	8.28	76.59	1.54
SC	SC1	1.67	66.13	26.45	0.00	7.42	266	0.97	11.57	20.13	70.63	1.51
	SC2	1.32	66.12	28.28	0.00	5.60	267	0.89	8.65	25.02	68.5	1.43
	SC3	1.74	60.78	27.60	0.00	11.62	251	0.91	17.80	17.63	67.71	1.59
	SC4	2.64	74.50	22.22	0.00	3.28	248	1.64	5.22	13.57	81.92	1.40
	SC5	1.6	63.40	24.70	0.00	11.90	260	1.00	18.33	17.66	67.25	1.66
	SC6	2.01	66.27	26.30	0.00	7.43	255	0.91	11.29	14.74	75.64	1.47
	SC7	1.05	66.57	30.42	0.00	3.01	266	0.84	4.34	23.26	73.41	1.39
	SC8	0.65	59.14	28.65	3.98	8.23	253	2.07	11.77	36.39	56.13	1.41
	SC9	1.85	66.45	28.54	0.00	5.01	249	1.05	7.91	14.73	78.53	1.44

V = vitrinite; I = inertinite; L = liptinite; M = mineral; MH = microhardness; M_{ad} = moisture on the air dry basis; A_d = ash on the dry basis; VM_{daf} = volatile matter on the dry ash-free basis; FC_d = fixed carbon on the dry basis; TRD = true density.

gas can induce deformation of the coal, leading to volumetric changes of the coal matrix and cleat (Li et al., 2013; Ju and Li, 2009). Essentially, a volumetric change of the coal matrix is a comprehensive result of both the matrix compression response to increasing effective stress and matrix shrinkage due to gas desorption (Harpalani and Schraufnagel, 1990; Peng et al., 2017, 2017; Shi and Durucan, 2005). The mechanism of matrix shrinkage and its influence on permeability is well understood (Connell, 2016; Gray, 1987; Harpalani and Chen, 1995; Levine, 1996; Mazumder et al., 2012; Pan and Connell, 2012; Shi and Durucan, 2004). However, coal matrix compressibility has not been investigated thoroughly.

Coal, a porous medium, consists of coal matrix and cleat network. The matrix is characterized as solid grains, micropores (< 10 nm), and transition pores (10–100 nm) (Yao et al., 2009). Matrix compression under pressure is due to volumetric changes in the coal matrix skeleton and pores (Li et al., 1999). Therefore, coal matrix compressibility coefficients are the result of the integrated effects of lithology, material composition, pore structure, and tectonic deformation (Guo et al., 2014; Okolo et al., 2015). The common methods to study matrix compressibility include mercury intrusion porosimetry (MIP) and nuclear magnetic resonance (e.g., Friesen and Mikula, 1988; Han et al., 2015; Li et al., 2013; Suuberg et al., 1995; Xu et al., 1999; Zhou et al., 2017). Li et al. (1999) combined MIP and gas adsorption to calculate matrix compressibility coefficients. Guo et al. (2014) suggested a simple analysis for the influence factors of matrix compressibility coefficients for low-, medium-, and high-volatile bituminous coals. However, due to lack of lignite, subbituminous and anthracite coals, the change characteristics of matrix compressibility based on coal rank are still not clearly understood. Further analysis is needed to better understand the mainly influence factors of matrix compressibility.

Here, MIP and N_2 adsorption were combined to calculate coal matrix compressibility coefficients. Correlation analysis of matrix compressibility coefficients with coal materials and pore structure was performed to investigate the change characteristics of matrix compressibility as coal rank rises and to confirm its influence factors. This research regarding the mechanism of coal matrix compressibility is of great significance for controlling coal reservoir permeability and enhancing CBM production.

2. Collecting and processing samples

The samples were collected in the Longkou (LK), Huainan (HN), Sihe (SH), and Shuicheng (SC) mines, China, as listed in Table 1. The collected coal samples were primary structure coals, which were immediately sealed to prevent oxidation.

Proximate analysis was conducted using ASTM Standard D3173-11, D3175-11, and D3175- 02. For determining $R_{o,max}$, measurements were conducted on a Zeiss Imager Mim microscope at 50 points for all samples. Maceral contents were determined on a mineral-matter basis by petrographic analysis, which was conducted with a Zeiss Imager Mim microscope equipped with white light photometer, and 500 points were recorded and assigned to the corresponding maceral according to the new classification-ICCP System 1994. Microhardness (MH) of bituminous and anthracite samples was achieved using the China coal industry standard MT 246–1991, and 20 points were counted under the test force of 0.9807 N. The true density of samples was determined by a helium pycnometer (Ultrapyc 1000). The results were listed in Table 1.

The pore structure of samples was detected by mercury intrusion measurements and N_2 adsorption experiments. MIP was performed with a Micromeritics Porosimeter (Autopore IV 9500), which permits the mercury filling at as low as 3.45×10^{-2} MPa, up to 206 MPa. To evaluate the pore diameter using the Washburn equation, a surface tension of 485 dynes/cm and a contact angle of 130° were used. The diameters of coal particles were 7–10 mm, and weights were 8–10 g.