Available online at www.sciencedirect.com

ScienceDirect

Natural Gas Industry B 4 (2017) 182–188

www.elsevier.com/locate/ngib

Research Article

A new method for calculating gas content of coal reservoirs with consideration of a micro-pore overpressure environment☆

Song Jinxing[a,b,*], Su Xianbo[a,b], Wang Qian[a], Chen Peihong[a]

[a] School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan 454000, China
[b] Henan Collaborative Innovation Center of Coalbed Methane and Shale Gas for Central Plains Economic Region, Jiaozuo, Henan 454000, China

Received 28 November 2016; accepted 25 January 2017
Available online 22 September 2017

Abstract

When the gas content of a coal reservoir is calculated, the reservoir pressure measured by well logging and well testing is generally used for inversion calculation instead of gas pressure. However, the calculation result is not accurate because the reservoir pressure is not equal to the gas pressure in overpressure environments. In this paper, coal samples of different ranks in Shanxi and Henan are collected for testing the capillary pressure of coal pores. Based on the formation process of CBM reservoirs and the hydrocarbon generation and expulsion history of coal beds, the forming mechanisms of micro-pore overpressure environments in coal reservoirs were analyzed. Accordingly, a new method for calculating the gas content of coal reservoirs with consideration of a micro-pore overpressure environment was developed. And it was used to calculate the gas content of No. 1 coal bed of the 2nd member of Lower Permian Shanxi Fm in the Zhongmacun Coal Mine in Jiaozuo, Henan. It is indicated that during the formation and evolution of coals, some solid organic matters were converted into gas and water, and gas–water contact is surely formed in pores. In the end, capillary pressure is generated, so the gas pressure in micro-pores is much higher than the hydrostatic column pressure, which results in a micro-pore overpressure environment. Under such an environment, gas pressure is higher than reservoir pressure, so the gas content of coal reservoirs calculated previously based on the conventional reservoir pressure evaluation are usually underestimated. It is also found that the micro-pore overpressure environment exerts a dominating effect on the CBM content calculation of 3–100 nm pores, especially that of 3–10 nm pores, but a little effect on that of pores >100 nm. In conclusion, this new method clarifies the pressure environment of CBM gas reservoirs, thereby ensuring the calculation accuracy of gas content of coal reservoirs.

Keywords: Coalbed methane (CBM); Gas content; Calculation method; Micro-pore overpressure environment; Gas pressure; Reservoir pressure; Capillary pressure; Zhongmacun Coal Mine in Jiaozuo, Henan

The determination of gas content in a coal reservoir directly affects the estimation of CBM resources, the evaluation of CBM provinces and the preparation of development plan [1–4]. Currently, the gas content of a coal reservoir can be obtained by direct or indirect methods [5,6]. Direct methods include geologic exploration method, mine method, natural desorption method and heating and desorption method, for all of which accurate calculation of escaping gas volume is a challenge [5,7,8]. Indirect methods include gravimetric method [9], isothermal adsorption method [10], Kim method [11] and well logging method [12], for all of which, the Langmuir equation is used to invert the gas content of a coal reservoir, mainly based on the coal sample analysis data, well logging data and coal reservoir temperature and pressure values, and using the reservoir pressure instead of the gas

☆ Project supported by the National Natural Science Foundation of China (No.: 41472129, 41472127, 41502158); Scientific and Technological Key Project for Coal Rank of Shanxi Province in 2014 (No.: MQ2014-01); project supported by the CBM Joint Study Foundation of Shanxi Province (No.: 2013012004).
* Corresponding author. School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan 454000, China.
E-mail address: songjinxing@hpu.edu.cn (Song JX.).
Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2017.08.003

phase pressure [6]. However, during the formation and evolution of a coal reservoir, some solid organic matters were continuously converted into gas and water [13−15], and gas−water contact was surely formed in pores; hence, capillary pressure was generated. Accordingly, the free gas pressure in micro-pores includes reservoir pressure and capillary pressure. In this paper, the study results show that the capillary pressure in 10 nm pores can exceed 10 MPa if water exists; therefore, as to a coal bed shallower than 1000 m, under the combing effect of capillary pressure and reservoir pressure, an overpressure environment is formed. Furthermore, gas pressure environment formed after gaseous hydrocarbon was generated is kept in blind pores of coals. In the course of geologic evolution, if the coal bed was uplifted, the gas pressure in the blind pores probably exceeded the hydrostatic pressure of the same burial depth, and an overpressure environment was thus formed. Therefore, gas pressure is not equal to reservoir pressure, and the gas content of coal reservoir should be calculated based on a micro-pore overpressure environment.

Samples were collected for coal pore capillary pressure testing, including light coal from the Yongdingzhuang Coal Mine of Datong Coalfield, coking coal from the Shaqu Coal Mine in the Liulin area of Hedong Coalfield, lean coal from the Tunlan Coal Mine of Xishan Coalfield, meager coal from the Xinyi Coal Mine of Xin'an Coalfield, and anthracite from the Zhongmacun Coal Mine of Jiaozuo Coalfield. Combined with the forming process of CBM and the dynamic theory of bubbles, the micro-pore overpressure forming mechanism of coal reservoir was analyzed. Then, a CBM content computation method with consideration of micro-pore overpressure environment was established. Beyond the traditional CBM exploration and development concept, this method will provide a theoretical guidance for the exploration and development of coal measure unconventional gas in China.

1. Micro-pore overpressure forming mechanism of coal reservoirs

The formation of micro-pore overpressure environment of coal reservoir is closely related to the processes like reservoir formation and hydrocarbon generation of coal over geologic history. The aquatic environment in open micro-pores is the most important reason for forming an overpressure environment, whereas a gas pressure environment kept in blind pores is affected by such factors as temperature, pressure, porous volume, and gas and fluid component and proportion in the pores when it was formed, as well as the change in temperature and pressure fields during the evolutionary process of the blind pores.

1.1. Coexistence of gas and water in coal pores

Coal is a solid fossil fuel formed by plant remains through peatification, diagenesis and metamorphism. Peatification occurs in a swamp water environment, and the moisture content in generated peat is usually sky-high. At diagenetic stage, peat suffers from compaction, dehydration and carburetion still in an aquatic environment, and primary biogenic methane is formed [16].

As the burial depth further increases, the temperature and pressure become higher, and coalification enters a metamorphism stage. At this stage, after the coal has experienced a complicated physical and chemical change, CBM, a kind of thermogenic gas, is generated. CBM is dominated by methane, and also contains trace of heavy hydrocarbon, with inorganic gas mostly composed of CO_2, N_2 and trace of hydrogen sulfide. In the coalification process, some liquid products are also generated, including liquid hydrocarbon and water [17,18]. The existence of these fluent materials has laid a foundation for the formation of capillary pressure, which, together with burial depth, decides the existence of overpressure. Aquatic environment objectively exists in coal, with just the water content being different, which has been confirmed by industrial analysis results of coal (Table 1).

1.2. Coal pore capillary pressure test

Coal samples at different ranks were collected for coal pore capillary pressure test (Table 1). JC2000D contact angle survey meter was used to measure the surface tension of distilled water to be 73.55 mN/m, and it was also used to measure the contact angle of distilled water and given coal samples (Table 2). After the measured surface tension and contact angle were substituted by the Laplace equation, the capillary pressure under certain pore sizes was obtained.

$$p_c = \frac{2\sigma \cos\beta}{r} \quad (1)$$

where, p_c is capillary pressure, MPa; σ is surface tension of liquid, mN/m; β is contact angle of liquid and coal, (°); and r is capillary radius, nm.

Table 1
Sample data analysis.

Sample source	Horizon	Formation	Industrial analysis			Coal rank	$R_{o.max}$
			M_{ad}	A_{ad}	V_{ad}		
Yongdingzhuang Coal Mine in Datong	No. 14	J_2d	7.25%	14.66%	31.07%	Light coal	0.7%
Shaqu Coal Mine in Liulin	No. 4	P_1s	0.47%	11.12%	26.59%	Coking coal	1.3%
Tunlan Coal Mine in Xishan	No. 2	P_1s	0.53%	14.62%	18.33%	Lean coal	1.9%
Xinyi Coal Mine in Xin'an	No. II_1	P_1s	0.57%	16.44%	12.17%	Meager coal	2.2%
Zhongmacun Coal Mine in Jiaozuo	No. II_1	P_1s	0.43%	9.64%	8.28%	Anthracite	4.2%