Measurement 121 (2018) 47–56

Contents lists available at ScienceDirect

Measurement

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

On factors affecting coalbed gas content measurement

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ARTICLE INFO

Keywords:
CH_4
Desorption
Diffusion
Coalbed methane

ABSTRACT

Coalbed gas content measurement is important for both unconventional gas recovery and mining safety. This study experimentally discussed factors affecting coalbed gas content measurement. It is found that small coal particles demonstrated high desorption rate at the early stage of desorption tests. However, the difference in methane desorption rate reduces when the coal particle size is more than 1.0 mm, indicating that a threshold of coal particle size exists in methane desorption in coal. Also, the particle size distribution tends to be stable when coal sample mass is over 15 g, stabilizing at around 1.75 mm. Therefore, the coal sample over 15 g is recommended to use in desorption tests of coalbed gas content measurement. The temperature and gas pressure can enhance the desorption rate, especially at the early stage of desorption. This temperature effect, however, mainly occurred in the first 15 min of desorption test. After 30 min, the desorption rate tends to be stable, slightly changing from around 0.35 mol/kg/min to 0.75 mol/kg/min. Due to endothermic process, absolute isothermal condition does not exist in desorption test, but this temperature variation mainly occurred in the first 15 min. The results also show incorporating the desorption data from the time of exposure to 13 min of desorption tests is essential to typically reflect methane desorption kinetics in coal. The study also shows that the measurement difference in gas content between the case with sample being air-puffed and -flushed and the case with sample exposed to the air is small. Therefore, the air-puffing and flushing during the sample collection has an insignificant effect the gas contact measurement result. This study can help to advance the understanding of impact factors on coalbed gas content measurement method.

1. Introduction

Coalbed methane (CBM) had been recognized as mine hazard threatening the safety of coal mining, but today it has been considered as an unconventional gas resource attracting increasing research interest [1,2]. CBM recovery can be conducted from underground coal deposits before, during or after coal mining. Prior to gas drainage, the bulk gassy coal contains both adsorbed and free methane under a three-dimensional stress state prior to mining and gas recovery, where the methane is held in coal matrix and cleats by pore water. Once water is pumped out, the adsorbed methane transforms to the free state. CBM management is important for mining safety. In mining, slow methane release from coal seam and bounding rock strata may lead to a high risk of gas explosion when meeting explosive concentration limits of 5–15% [3], and sudden methane release can lead to coal and gas outburst [4]. From the viewpoint of hazard mitigation and economic recovery, determination of gas content in a coal deposit is critical [5].

Two kinds of gas content measurement methods have been developed: direct and indirect methods [6]. In direct methods, the methane emitted from a coal sample is firstly measured and then the methane lost during the sample preparation process is assessed. Residual gas that remains in coal matrix after desorption test is estimated. In indirect methods, the gas content is estimated based on sorption isotherm or established empirical curves. In this study, the factors affecting the CBM content measurement technique are systematically discussed.

Coal is heterogeneous with pore size varying from sub-nanometer to millimeters containing closed and open porosity [7,8]. The coal contains both micropores and macropores [9,10], where the micropores are part of coal matrix and provides massive surface area to adsorbate, while the macropores provides flow pathway and is called the cleat system. The methane adsorption/desorption behavior of coal correlates with the surface coverage of coal and depends significantly on micropores [11]. Macropores decrease with the coal rank while micropores increase with it [12]. In composition, coal is a complex organic porous rock and it can be of variable purity and moisture content even for coal

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https://doi.org/10.1016/j.measurement.2018.02.026
Received 4 January 2017; Received in revised form 10 June 2017; Accepted 14 February 2018

Table 1
Coal sample characteristic of Yanmazhuang coal mine and Sihe coal mine (30 °C).

Proximate analysis (%)			Sorption constants		Density		Porosity (%)	Note
A_{ad}	W_{ad}	V_{daf}	V_L (cm^3/g)	P_L(MPa)	Real relative density (t/m^3)	Apparent density (t/m^3)		
22.52	2.01	8.74	39.6850	0.5998	1.57	1.65	4.85	Yanmazhuang coal mine
20.64	1.22	6.93	40.0168	0.5176	1.53	1.69	–	Sihe coal mine

samples of the same basin. Therefore, the sorption between gas molecule and coal matrix is a complex process and it is influenced by coal rank [13], maceral [14], porosity [15], moisture [16], temperature [2] and gas pressure [13].

The measurement technique of gas content involves the process of methane desorption and diffusion, where gas initially desorbs from the walls of micropores and diffuses through the matrix to the cleat [17]. The dissociation of methane from coal over the van der Waals force among molecules is an endothermic process [18–20]. In terms of mean free path of methane molecule, there are three distinct diffusion mechanisms. For macro pore or high gas pressure conditions, collisions among methane molecules dominates in the Fickian diffusion. For the case of mean free path of methane molecules larger than pore size, the collisions of methane molecules against pore walls dominate and is called Knudsen diffusion. Surface diffusion denotes the adsorbate moves along pore wall surface typically for a thermally promoted process [21,22]. As coal is a heterogeneous organic rock with variable pore size, these three diffusion mechanisms play important roles in methane diffusion in coal matrix.

Many studies have been conducted on desorption and diffusion characteristics in coal and shale. The gas diffusion is driven by concentration difference, driving the gas diffuses from high concentration region to low concentration region. This diffusion process can be described by Fick's Second Law [23], differing from fluid flow through coal cleats or rock fractures that is driven by pressure head difference [24]. Based on Fick's Second Law, two well-examined models to describing diffusion kinetics have been developed for coal and shale. One is the unipore model postulating that the diffusion is through the spherically porous media matrix of uniform pore size [25]. Even though the unipore model could not reflect the variable pore size characteristics of coal matrix but it can meet the first-order approximation of engineering estimation. The other is bidisperse model assuming that porous media matrix contains micropores among spherical particles and inter-particle macropores [26]. Note that the concepts of micropore and macropore of bidisperse model only represent pore size difference, different from pore size definition of coal matrix. Either unipore or bidisperse models reveal that the gas diffusion coefficient is bi-modal with regards to gas pressure change rather than a constant [11,27,28]. The matrix moisture has a significant impact on diffusion kinetics of coal. Compared to unipore model, the bidisperse model is more suitable to describe such moisture effect [22,29]. Alternatively, Staib et al. [30] developed a stretched exponential model to describe the gas diffusion in coal.

This study mainly discussed the factors affecting the accuracy of gas content measurement technique, rather than adsorption/desorption behavior and diffusion kinetics of coal matrix. Therefore, the coal rank, moisture, maceral, porosity and proximate analysis of used coal samples were not investigated. Instead, the effects of particle size, exposure time in sample collection, required desorption test period as well as other environmental factors were experimentally studied, aiming to improve the understanding of impact factors of coalbed gas content measurement technique.

2. Experimental methods

2.1. Sample preparation

The freshly collected coal samples were prepared and firstly pulverized. Then the particle size in the range of 0.17–0.25 mm was sieved to measure Langmuir sorption isotherm constants:

$$\mathrm{V}=\mathrm{V}_L\frac{P}{P+P_L} \tag{1}$$

where V is gas content in unit of cm^3/g, V_L is Langmuir volume constant in unit of cm^3/g, P is gas pressure in unit of MPa, P_L is Langmuir pressure constant in unit of MPa. For coal sample from Yanmazhuang coal mine and Sihe coal mine, China, the results of proximate analysis, adsorption constants and density are given in Table 1. In Table 1, A_{ad} represents ash, W_{ad} represents water content and V_{daf} represents volatile matter, and sorption constants are of the same representation with Eq. (1).

For methane sorption tests, the freshly collected coal samples from field sites were pulverized and sieved into different particle size groups. Prior to the tests, the prepared coal samples were stored in reagent bottle with individual mass more than 300 g.

2.2. Experimental setup and procedure

In order to accomplish this research task, the experimental set-up should be capable of simulating coalbed gas content measurement technique at different reservoir temperatures and gas pressures. More importantly, it should be capable of measuring the lost gas in sample exposure. Here, an automated Sieverts instrument PCTPro-Evo is used as the gas sorption measuring unit. The PCTPro-Evo sorption measuring instrument is based on the volumetric sorption measurement technique, where the amount of sorption gas can be determined by the difference in actual measured pressure and calculated pressure. It can accurately measure the sorption quantity of many adsorbates, such as methane, nitrogen and carbon dioxide, under the temperature from −269 °C to 400 °C and the gas pressure from 0 to 20 MPa. The accuracy of pressure, volume and temperature measurement of PCTPro-Evo instrument can be 0.5%, 5%, and 1%, respectively. The PCTPro-Evo instrument mainly consists of thermostated unit, degas unit, gas pressure control unit and data acquisition unit as shown in Fig. 1.

An isolation valve is used to control the connection between the sample reservoir for adsorption equilibrium and desorption units. Therefore, the quantity of desorbed gas due to exposure in sample collection process can be evaluated to discuss the lost gas. Meanwhile, the testing system can investigate gas desorption characteristic in coal after some exposure time. In order to study the temperature variation during the methane adsorption and desorption and its impact on coalbed gas content measurement, two thermostated water baths were used to simulate the gas desorption condition under non-isothermal condition.

It is known that moisture content of coal sample plays a role in adsorption capacity. In order to reduce the effect of moisture content on sorption capacity and test result, the coal sample was firstly placed in the oven and heated to 100–105 °C for 6 h under vacuum condition prior to the adsorption equilibrium. In the process of adsorption, the