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Undesorbable residual gas in coal seams and its influence on gas drainage

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ABSTRACT

The definition of "residual gas" can be found in different scenarios, such as the "fast" and "slow" desorption methods of measuring gas content and the sorption hysteresis test and gas management of coal mines, however, its meaning varies a lot in different contexts. The main aim of this paper is to discuss the existence of truly undesorbable residual gas in coal seam conditions and its impacts on sorption model and gas drainage efficiency. We believe the undesorbable residual gas does exist due to the observation of the extended slow desorption test and the sorption hysteresis test. The origin of undesorbable residual gas may be because of the inaccessible (closed or semi-closed) pores. Some gas molecules produced during coalification are stored in these inaccessible pores, since the coal is relatively intact in the coal seam condition, these gas molecules cannot escape during natural desorption and then create the undesorbable residual gas. Based on the existing adsorption models, we propose the improved desorption versions by taking into consideration the role of residual gas. By numerically simulating a gas drainage case, the gas contents after different drainage times are studied to understand the influence of residual gas content on gas drainage. The results indicate that the influence starts to be obvious even when the total gas content is at a high level, and the impact becomes more and more apparent with increasing drainage time. Our study shows that the existence of residual gas will impede the gas drainage and the total amount of recoverable coal seam methane may be less than expected.

1. Introduction

The adsorption isotherm of coal reflects the relationship between gas pressure and the adsorbed gas content. Because both the gas pressure and the gas content are very important in order to accurately predict gas outburst, coal seam gas (CSG) drainage and coalbed methane (CBM) production, much attention has been given to improving the adsorption models which can reproduce the adsorption isotherms. In this regard, the Langmuir model is the simplest and most widely used, and it can provide a reasonable fit in most cases [1]. Based on the assumption that gas sorption in coal includes not only adsorption but also an absorption process, an additional absorption coefficient k is introduced in the dual sorption model. In consideration of the heterogeneous characteristic of the coal surface, the Dubnin-Radushkevich (D-R) model incorporates the parameters of temperature, pore size distribution and coal-gas affinity. The general form of the D-R model is called as the D-A model, in which an extra integer is included in order to account for pore size distribution [2]. As the original D-R and D-A models cannot be used to describe supercritical gas sorption, Sakurovs et al. proposed a modified version using gas density rather than gas pressure [3].

The above adsorption models represent different sorption mechanisms. They are accurate in describing the pure gas adsorption process in coal, but both CSG drainage and CBM recovery are depressurization processes rather than pressurization processes. Our previous study has found that: in addition to the different paths between desorption and adsorption isotherms, an obvious feature of desorption isotherms is the existence of residual gas content [2]. In other words, part of the gas content in coal cannot be released even when the ambient gas pressure is very low. In previous field practices "residual gas" also plays a significant role in determining the total gas content using the direct method, but the meaning varies according to different determination methods. In this paper, the definitions of "residual gas" in different scenarios are discussed. The existence and origin of undesorbable residual gas are analysed. New desorption models are proposed which considers the amount of residual gas. Using the improved desorption

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model, the impact of residual gas content on gas drainage is analysed through numerical simulation.

2. Concepts of residual gas in different scenarios

Taking residual gas content into consideration was first put forward in the "direct method" to determine the desorbable gas volume of raw coal by Bertard et al. [4]. This method involved crushing the sample for 20–30 min in a metal cup and before crushing, the air in the cup is replaced by pure CH_4. A "declined curve method" was proposed by McCulloch et al. to estimate the residual gas instead of crushing, but this method has not been widely used [5]. Two important concepts regarding the measurement of residual gas were suggested by Diamond and Levine, where the residual gas is defined as the volume of gas left in the coal after desorbed volumes have decreased to insignificant levels, and a sealed ball mill is used to crush the coal sample [6]. The measurement of gas content with a rigorous definition of residual gas is called as the "slow" desorption method, in which the determination of the "insignificant level" is important. Ulery and Hyman proposed a termination level range from 0.05 cc/g/day over a one-week period up to 10 cc/day per sample, and other definitions such as "any reading must be less than 1% of the cumulative gas desorbed" can also be found [7,8].

Although given the same name, the essence of residual gas determined from 'fast' desorption methods differs from that of "slow" desorption methods. Fast desorption methods were developed for a number of reasons. These include: (1) the relatively long time of natural desorption required by a slow desorption method may not be acceptable when the results are urgently demanded for mine safety purposes; (2) when a CO_2-mixed gas condition is encountered, the slow desorption method may induce CO_2 dissolution in the measuring water; (3) low-rank coals have the tendency of producing their own gas during long periods of time [8,9]. In fast desorption method, the collected coal sample will be immediately, in some cases with a short time of delay, crushed after being transferred to the laboratory.

Obviously, the measured residual gas content contains a certain amount of gas which can naturally desorb. Using the fast desorption method developed by the CSIRO, we measured about 500 total and residual gas contents from two adjacent longwall working faces in the Bulli coal seam in the Sydney Basin [10]. The result is shown in Fig. 1. As all the sampling locations have been impacted more or less by gas drainage (up to 3 years), the total gas content varies greatly and the volume of residual gas decreases as total gas content decreases. This indicates that a large amount of residual gas can be drained from a coal seam by providing a long leading time. However, the proportion of residual gas appears to increase as the total gas content decreases and this means the easy-to-release gas (Q1 and Q2) is depleting and the residual gas would be "stubborn".

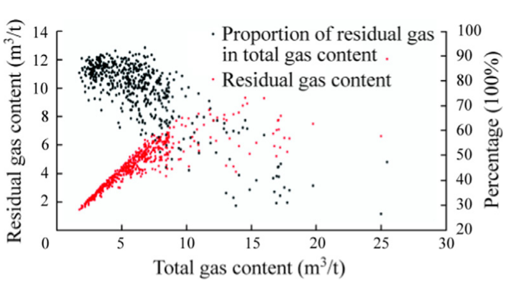

Fig. 1. Change of residual gas content (red dots), the proportion of residual gas to total gas content (black dots) with respect to total gas content measured using the fast desorption method.

The hysteresis phenomenon between adsorption and desorption isotherms has been found extensively, which indicates the adsorbed gas molecules are trapped in the coal during desorption. When the samples are exposed to atmospheric conditions or the gas pressure becomes vacuum, the amount of gas remaining in the coal can be seen as residual gas, as shown in Fig. 2.

The concept of residual gas can also be found when discussing the effect of gas drainage, for example: "CMM did not appear economic under the considered conditions due to slow recovery rates and high residual gas content"; "(see if) pre-drainage of methane from a coal seam can be accelerated and the residual gas content reduced to negligible levels" [12,13]. In these contexts, the residual gas content refers to the volume of gas adsorbed in a unit of coal after a period of gas drainage, rather than the residual gas content measured by the direct method.

From the above discussion, we can see that in a broad sense, residual gas is the amount of gas, no matter whether it is adsorbed, absorbed or dissolved after a certain time of gas release. While for a rigorous definition, residual gas is the undesorbable gas in coal after complete natural desorption in the atmosphere, such as the measurements using the slow desorption method and the desorption isotherm experiment.

3. Existence and origin of residual/undesorbable gas

An important question is whether the undesorbable residual gas really exists or is due to experimental error, such as insufficient waiting time. We believe the residual gas does exist and cannot desorb during CSM drainage or CBM production.

The first evidence is found from the work of Black, who measured the residual gas content of Sydney Basin Coal using both fast and slow desorption methods [14]. During the slow desorption test, extended desorption time (more than 200 days) was used and the results showed the extra waiting time had little effect on the residual gas content. In other words, the measured residual gas is truly undesorbable. Table 1 shows the component percentages of lost gas, desorbed gas and residual gas from fast and slow desorption test results, and the true residual gas content ranges between 0.7 and 1.0 m^3/t of methane and 1.5–1.9 m^3/t of CO_2.

Full sorption equilibrium has a large influence on the accuracy of the experimental results in gas isotherm tests. In order to measure the amount of residual gas content in an isotherm test, we carried out several adsorption and desorption tests at the University of Wollongong and a long equilibrium time was used. The coal samples are from the Sydney Basin and three different sample sizes (0.15–0.50 mm, 0.50–1.13 mm, and 1.13–2.36 mm) were selected. The main experimental procedure was similar to the normal sorption test, except that the samples were exposed to a dry atmosphere for at least 72 h at the end of desorption process [11]. Equilibrium was only assumed to be reached when the change of gas content was less than 0.001 mol/g during the last 24 h. The measured residual gas content is shown in Fig. 3.

It can be seen that residual gas exists in all experimental groups and this indicates that part of the adsorbed gas cannot desorb from the coal sample even when there is an extended waiting time. Similar to the results of the slow desorption method, the residual gas content of the methane (about 1 m^3/t) was less than that of the CO_2 sorption (2–3 m^3/t). No apparent trend of residual gas content can be found when the average sample size, both for methane and CO_2 sorption, is increased.

As discussed above, results from the slow desorption test and the sorption isotherm test both confirm the existence of residual gas. Since physical sorption is normally considered to be reversible, the origin of the residual gas needs to be understood. Mercury intrusion and adsorption methods, such as 77 K nitrogen sorption