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Determining the Gas Content of Coal Beds

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Abstract—Direct methods of measuring the gas content of coal beds, including calculation of the lost gas, are reviewed. In determining the gas content of the coal in productive beds within the Kuznetsk Basin, the distinctive properties of the coal must be taken into account: specifically, its high natural gas content; and hazardous dynamic gas releases in mine workings. That is especially common for valuable coking coal.

Keywords: coal beds, natural gas content, lost gas, direct methods, Kuznetsk Basin

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In assessing coal, the characteristics taken into account include the strength, moisture content, ash content, yield of volatiles, sulfur content, phosphorus content, calorific value, ease of enrichment, clinkering properties, and coking properties. These characteristics are important since they directly affect product quality, whether coke or coking byproducts. However, equally important is the natural gas content of coal: the content of gas (mainly methane) in the coal structure within the bed. Correct determination of the natural gas content affects the productivity and safety of coal extraction, especially in the case of valuable coking coal (G, GZh, Zh, KZh, K, KO, and OS coal). The extraction of such coal is dangerous on account of dynamic gas releases into the mine workings, as noted in [1, 2]; sudden rock falls are possible in such events. Given the growing demand for coking coal in Russia and around the world, it is of great importance to ensure safe coal extraction despite these characteristics.

In planning the introduction of new coal mines, the first step is surveying and geological analysis of the bed, including measurement of the gas content. However, at the stage of mine construction, the actual gas content of the bed may differ greatly from the value measured in surveying, because of work already done on the bed or nearby beds. In addition, refinement of the gas content is recommended for coal beds in which the value established in geological assessments is 13 m^3/t of dry ash-free mass or more, according to standard [3].

For production purposes, we need reliable and effective methods of determining the gas content in coal beds [4, 5]. One option is to use the experience gained in developing the existing direct methods and standards now current outside of Russia. However, the reliability of this approach is questionable. Another option is to develop a new method of determining the gas content. In the present work, attention focuses on the inaccuracy of existing direct methods.

EXPERIENCE IN DEVELOPING DIRECT METHODS

Existing direct methods of determining the gas content in coal beds were developed outside of Russia. These methods are based on measurement of the total gas removed on desorption. As a rule, the total gas content in the sample (core) is subdivided into three components: 1) the lost gas; 2) the desorbed gas (measured after sealing the sample; 3) the residual gas. Special equipment may be used for precise measurement of the desorbed and residual gas. The lost gas is the component that leaves the sample on drilling, before it is sealed in a special container. The lost gas is regarded as the least reliable component of the coal's gas content. After developing methods of determining the gas content in coal beds for around half a century, the goal is still to improve their accuracy [6].

In 1970, the Bertard method was proposed. This direct method was developed in France to assess the gas concentration from coal samples at different stages of extraction. The method is based on experimental data indicating that the volume of gas lost in the initial stages of desorption is proportional to the square root of the desorption time. Subsequently, this method was adapted and refined during an extensive research on methane leakage from coal by the United States Bureau of Mines (USBM). The outcome of this research was the USBM method [7]. Its fundamental

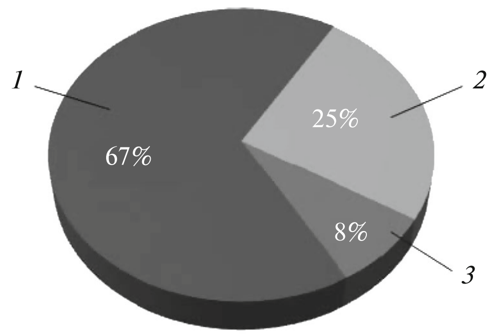

Fig. 1. Components of the coal bed's gas content at a depth of 300 mm in the Chertinsk field (Kuznetsk Basin): (*1*) dissolved methane; (*2*) sorbed methane; (*3*) free methane.

principle is that the volume of gas liberated from the coal sample is proportional to the square root of the desorption time, up to a limit of 10 h. It may be used for coal samples extracted from vertical boreholes drilled immediately before sampling. The theory of lost-gas assessment associated with the USBM method is widely used in modified methods of determining the gas content in coal beds. On that basis, Standards Australia published a procedure for determining the gas content of coal beds in 1991 (Australian Standard AS 3980).

In 1995, the United States Gas Research Institute developed an expanded version of the USBM method: the GRI method [8]. This method improves the accuracy in determining the lost gas by extrapolating desorption data measured in conditions resembling those in the coal bed. Only those desorption data measured after stabilization of the sample temperature to the bed temperature in laboratory conditions are extrapolated in the GRI method. Another refinement is that the time when sample desorption begins (time zero) is determined; this is the actual core (sample) extraction time when the pressure of the drilling solution matches the hydrostatic pressure in the bed.

In China, a specialized standard for assessing the gas content of coal was developed in 2008 (GB/T 19559–2008). This is a modification of the USBM and GRI methods.

In other methods, the gas content is determined from breeze: for example, the Smith–Williams method [9] and the DMT method [10]. In contrast to direct methods of measuring the gas content from coals, these methods are of lower accuracy, because the volume of lost gas is greater.

This review indicates the development of new approaches and models for calculating the lost gas from core samples at the moment of sample sealing [11]. What we do not see is detailed methods for measuring the gas content with calculation of the lost gas.

SPECIFIC FEATURES OF KUZNETSK BASIN COAL BEDS

In Russia, in the preparation of the coal field for mining, the gas content of the beds must be determined at the prospecting stage by means of sealed core-sampling devices when drilling boreholes from the surface, according to the relevant Russian standard [12]. The determination of the gas content in coal beds is governed by State Standards GOST R ISO 18871–2018 (on methane determination in coal beds) and GOST R 55955–2014 (on standard determination of the gas content in coal) [13, 14]. With minor changes of wording, these are translations of the corresponding international standards. The method in [3] is analogous to the USBM method, with the important difference that the USBM method was developed for the sampling of cores through boreholes from the surface.

Summing up, national and international methods of determining the gas content in coal beds that are derived from the USBM method are based on large-scale research. However, Russian methods must take account of the distinctive characteristics of the country's coal fields.

In direct methods of determining the gas content, the approach adopted in assessing the lost gas is erroneous, as noted in [6]. The error is that desorption of the lost gas is assumed, in accordance with Fick's second law, and the same assumption is made for all the measured gas volumes used in extrapolation. However, coal beds may contain a considerable quantity of free gas. As a rule, the content of free gas declines with increase in bed depth.

On the other hand, with increase in depth and natural gas content of the bed, the methane content and methane capacity of the bed diverge. At a depth of 500 m, the actual gas content of the bed exceeds the limiting sorption capacity of the coal in laboratory conditions by a factor of 1.5–2.0, even if we correct for the free gas.

To address such shortcomings of sorption theory, it has been proposed that methane exists in coal in both liquid [15] and crystal hydrate [16] states. Models have been proposed to describe the state of this multicomponent geological material. Some are highly original: for example, regarding the generation of methane in coal beds [17]; and the synthesis of radicals on coal disintegration [18]. The fundamental principles in describing gas-bearing beds as coal–methane geological materials (a coal–gas solid solution) were formulated by Russian scientists in the 1980s [19]; were granted scientific recognition in [20]; and were actively developed in subsequent years.

For example, in discussing whether the state of methane could correctly be described as a coal–methane solution, Etinger noted [19]:

The concept of a solid solution of methane in coal beds does not imply a simple terminological replacement of "absorption" by "solid solution," since the physical structure of the coal–methane solid solution includes not only the characteristics of the structural elements but also their morphology—that is, their mutual configuration—and in addition, finally, the characteristics of the solute particles' motion.

The natural gas content of a coal bed may be determined as the sum of three components, on the basis of the law of mass conservation for the gas and the hypothesis of a coal–gas solid solution [20]: sorbed methane, free methane, and dissolved methane (Fig. 1).

The bed's content of dissolved methane (m^3/t) may be calculated as follows

$$x_p = \frac{\sigma_d A(x - x_s - x_c)}{\sigma_0 (A - x_s)},$$

where x is the natural gas content of the bed, m^3/t; x_s is the sorptional methane content of the coal, m^3/t; x_c is the free methane content, m^3/t; σ_d is the active stress in the bed, MPa [21]; σ_0 is the aggregate stress in the bed, determined as the sum of the lithological pressure and hydrostatic pressure, MPa; and A is the bed's limiting gas content, m^3/t.

It is difficult to study coal. Assessment of its gas content and gas-kinetic characteristics on the basis solely of sorption theory may lead to considerable error, especially if the gas content of the coal beds is high. The state of the methane in the coal bed under omnidirectional compression must be taken into account, while the decrease in gas content of the bed (the gas liberation) is determined as a function of the decrease in stress within the field. These considerations are especially important for the Kuznetsk Basin, where much of the coal is extracted from beds with high gas content. The same problems arise in the Vorkuta, Donetsk Basin, and Kazakhstan coal fields.

CONCLUSIONS

Analysis of existing methods of determining the gas content in coal beds suggests that measurement of the gas content in the bed without the lost gas is promising. Such research is underway at the Institute of Coal, Federal Research Center of Coal and Coal Chemistry, Siberian Branch, Russian Academy of Sciences.

Analysis, field experiments, and laboratory experiments are based on current concepts regarding the state of methane in the coal bed and the gas-kinetic processes at the perimeter of the bed. An innovative method has been developed for determining the gas content of a coal bed without the lost gas by means of a special instrument that permits measurement of the total gas volume liberated in drilling a sampling borehole and removal of the sample without atmospheric access [22].

The basic advantages of this approach in relation to the USBM method are as follows.

1. Precise determination of the sample location over the height of the bed.

2. Elimination of the lost gas. That improves the accuracy in determining the gas content of coal beds.

3. Elimination of the aqueous drilling solution. As a result, samples with natural moisture content may be obtained.

Disadvantages of the method include its laboriousness; and difficulty in transporting the equipment.

It may be expected that, on the basis of practical experience, the method will be refined, and its disadvantages will diminish. The proposed method is recommended in measuring the gas content of any coal, including coking coal with high gas content that poses the risk of dynamic gas releases.

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