Calculation of the coal seam natural gas content

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Abstract. A research and methodological approach to calculating coal seam natural gas content and coal methane spatial resource evaluation is introduced in the paper. The research is based on the geological survey data about inclosing massif stratigraphy and natural properties of coals. Stresses that act in a coal seam are also taken into account here. The results allow substantiating safety-on-gas-factor technological parameters of coal mining processes beforehand.

1. Introduction
It is conventional that coal seam gas content is defined as an amount of gas that a coal mass unit (m³/t) or a coal volume unit contains (m³/m³). As methane is the main gas, which a coal seam contains then the “methane content” notion can often reasonably substitute the “gas content” notion. It is the most important characteristics of the seam and its values in coal depth can reach 30-35 m³/t.

During mining (distraction of the coal seam), coal actively emits gas into the coal workings in different gas showings: starting from standard methane-release and methane bleeding (blowing) to excessive methane release and even up to sudden outbursts of gas and coal. Gas recovery factor is a negative constraining factor that influences on the development of the coal seam. A selection of such technological parameters as a mining sequence in series of strata and in mining extracted area sections, directions of stopes and development headings movement, optimal geometric sizes of the coal faces, the advance rate of a face, coal extraction volumes, air consumption rate for ventilating the workings etc. depends on the gas content volume, gas content forms and extent influence.

Reliable evaluation of a gas content allows making qualitative and quantitative evaluations of the coal methane resources on a large area of the deposit, defining the places with its high and low consistency. It influences on the selection of methods for gas content control during mine exploitation, for example, when substantiating the number and places for degassing drainage boreholes and methane extraction holes placement. In overall, it helps to plan mining processes rationally considering a gas factor and decreasing methane outbursts into the atmosphere.

However, it is still impossible to take into account all the factors, which influence on rather complex distribution of gas in a coal bearing strata or in a seam. Methods and technical devices for studying gas content are rather imperfect. As a rule, a value obtained by a geological survey at the points of exploration wells intersection with the coal seams is taken as a gas content value, though to the moment of starting the mining of the seam it can significantly differ from the natural one. Moreover, defining the gas content at the stage of geologic exploration bears irregular character. In average, only one coal sample out of five wells goes to direct gas analyses testing. Such sparse network of direct gas testing can cause unreliable gas-content determination at the place of a coal seam.
mining and consequently, it can bring about a problem of taking wrong decision on controlling gas emission in working areas. Thus, it is extremely important to increase initial data density in the limits of the studied coal deposit area and the forecasting values of gas-content should be specified. It should be done as far as new data on coal properties are being accumulated, for example, in the process of building the mine, preparing the development headings, during stoping, and on the basis of the practical and scientific researches, considering new knowledge about the coal as a coal-methane geomaterial.

2. Calculating and adjusting coal seam natural gas-content and spatial evaluation of coal methane resources

At present regulatory documents [1, 2] regulate the process of determining coal seam natural gas-content at the coal deposits of RF. Mining science and practices when evaluating gas-kinetic properties of coals (together with methane-content) continue resting on sorption theory. The drawback of this approach is in discrepancy between gas-content calculated and actual values in deep layers.

Apart from general notions, there are other notions about the coal as a substance geological processes of metamorphism of which were accompanied by formation of a significant methane volumes formation. For example, the hypotheses on liquid [3] and crystalhydrate [4, 5] state of methane in coal are developed. The models on multicomponent geo-material states together with some unique ones, such as generation of methane in coal seams [6, 7], radical synthesis while destructing coal [8] are being improved. Fundamental scientific ground in the sphere of describing a coal seam gas-content as a monophase coal-methane solution was formulated by Russian scientific researchers in 1980s [9], and in 1990s it was recognized as a scientific discovery [10] and it is being actively developed in recent years [11–13]. For correct determining of a coal seam gas-content, a technique based on the selection of coal samples out of wells drilled into a coal seam out of the workings was worked out [14]. Russian and foreign researchers are also interested in determining coal gas-content [15–17].

According to the results of the research conducted in Institute of Coal FRC CCC SB RAS an approach to calculating coal seam natural gas-content was developed. The approach do not contradict to classical concepts and ground on new knowledge about gas concentration in coals.

The research is done for coal seams occurring in all Kuzbass coal deposits. Basic initial data served as the informative basis for the research are: total number of coal seams – 250; coal-bearing strata series – Balakhonskaya, Kol’chuginskaya; coal seam depth at the points of intersection with exploration wells – 75 ÷ 925 m; gas-content – 3 ÷ 36.7 m3/t dry ash-free mass; content of volatile agents – 10 ÷ 49.5 %.

To calculate and bettering the reliability of coal seam gas-content forecasting a method, which includes eight basic stages is offered.

1. Forming electronic geological surveys databases.

On the basis of geological and surveying documentation (geological, geological and gas cuttings along exploratory lines, direct gas testing data, isogas maps, coal technical analysis indices) data bases in the form of electronic spreadsheets are formed. These spreadsheets contain information about well top markings in the limits of the mining extracted area, stratigraphy of the deposit: thickness, depth and natural gas-content values, ash-content, coal humidity, content of volatile agents.

2. Applying basic principal provisions of the sorption theory specifying limit methane-bearing capacity values and methane-bearing capacity constant.

Sorption theory is based on the notion that coal-methane seam is a “sorbent–sorbate” system. The theory postulates that to determine methane content an indirect method can be applied. The method is based on determining the quantity of occluded methane in coal under the most approximate real coal seam condition (rock temperature, coal humidity, gas pressure) and free methane situated in filtering volume of coal under the same condition.

However, this is the way to determine coal potential gas-content, its ability to occlude (adsorb) gas under certain thermal-dynamic conditions. As a result of numerous researching experiments the
discrepancies between coal gas-content values determined in laboratory conditions and actual, measured coal gas-content situated in natural conditions (in seams) are marked. To eliminate the discrepancy the following corrections into the basic equation for gas-content calculation are introduced.

\[ x_L = \frac{abP}{1 + bP}, \]  

(1)

where \( x_L \) is sorbate methane-bearing capacity (according to Langmuir equation) sm\(^3\)/gr dry ash-free mass.; \( a \) – limit methane-bearing capacity, sm\(^3\)/gr; \( b \) is methane-bearing capacity constant, 1/MPa; \( P \) – gas pressure, atm.

Instead of the equations for calculating \( a \) and \( b \) according to the catalogue, published in 1968 which contain the data on 728 coal samples, selected at the basic coal deposits of Kuzbass [18] modern technical capabilities and formed data bases of the developing coal deposits of Kuzbass (over 15000 seam intersections) allowed setting the equations [18]:

\[ A = -0.102V^2 + 4.98V + 11 \]  

(2)

\[ B = 0.00013V^2 - 0.0069V + 0.12, \]  

(3)

where \( A \) is a limit methane-bearing capacity (for Kuzbass coals), m\(^3\)/t; \( B \) is a methane-bearing capacity constant (for Kuzbass coals), 1/MPa; \( V \) is a content volatile agents, %.

The received equations for calculating \( A \) and \( B \) indicators are approximated to conditions and properties of coal-bearing series seams of Kuzbass for each coal deposit.

3. Using the dependency of gas-content changes on acting stresses (geo-static and hydro-static pressures).

Contemporary knowledge about the coal properties facilitates the explanation of the discrepancies between methane-bearing capacity of coals and methane content of seams; for example, it can be explained by the change in sorbate potential of coals in the process of solid solution decomposition. The property of the coal organic matter to form, together with gases, some metastable monophase systems on solid solution type was discovered. They appear as a result of coal metamorphism or as a result of introduction of gas into intermolecular space of coal under combined effect of gas pressure and mechanic load [10]. As a result of solid solution decomposition new sorbate surface is formed, methane evolves out of the solid solution blocks into fractured porous system forming a free gas pressure gradient in fractures and filtering flow respectively, herewith a free gas pressure overlaps hydrostatic one. It is revealed that gas-content change according to the forms in which methane exists in a coal seam depends on acting stresses in gas infiltrating zones and zones of outrunning discharge during the stopes and development headings movement [19, 20].

Considering the revealed peculiarities, gas pressure value included into Langmuir equation (1) is supplemented by natural stresses values in a rock massif evaluated according to traditional equations:

\[ \sigma = \sigma_0 + P_0, \]  

(4)

where \( \sigma \) is a stress in a seam, MPa; \( \sigma_0=0,025H \) – geostatic stress, MPa; \( P_0=0,01H \) – hydrostatic pressure (in-situ gas pressure), MPa; \( H \) – the coal seam depth, m.

Values \( \sigma_0 \) and \( P_0 \) in equation (4) correspond to the condition of a seam, which is situated in an unmined massif. In case when it is necessary to specify gas-content of the seam in the process of its mining equation (4) is used taking into account acting stresses in partially relived from the rock pressure massif.

The equation for calculating a part of gas-content in occlude condition is expressed as:

\[ x_c = AB\sigma/(1 + B\sigma), \]  

(5)
where \( x_c \) is calculated sorbate methane content, \( \text{sm}^3/\text{gr} \) dry ash-free mass.

However, values \( x_c \), calculated according to the equation (5), surpass real natural gas-content determined during geological surveys to 40 per cent. That is why the search of factors that influence on the indicated surpasses and allow its elimination was made.

4. Determining the dependency of gas-content change on a seam depth at the estimated section of the coal deposit.

The search of empirical dependences of natural gas-content change on the parameters of occurrence mode and coal properties using geological surveys data base is made. Applying pair correlation method expressed in a graphic manner a sustainable connection of a seam natural gas-content with a seam depth is determined. The character of the determined connection for each coal deposit is expressed in the form of exponential function with the coefficient of a mean-square deviation not less than 0.97.

In equation (5) for more accurate calculation of gas-content, a multiplier, which provides the curving of the graph according to actual data approximation rule, was introduced. The multiplier expressed in the form of exponential function was found in the result of norming of the revealed deviations according to a seam depth.

5. Calculating gas-content.

The obtained expressions for finding \( A \) and \( B \) indicators, introducing into empirical dependencies calculation the influence of acting stresses and seam depth on gas-content allowed receiving the expression for calculating natural gas-content for Kuzbass coals. It is seen in general form as:

\[
X_p = \alpha H^\beta \frac{Ab\sigma}{1+B\sigma},
\]

where \( X_p \) is a calculated seam gas-content, \( \text{m}^3/\text{t} \) dry ash-free mass; \( H \) is a seam depth, m; \( \alpha, \beta \) – empirical coefficients set for each coal deposit; \( A=\varphi(V) \) – limit methane content, \( \text{m}^3/\text{t} \); \( B=\varphi(V) \) – methane content constant, \( 1/\text{MPa} \); \( V \) – content of volatile agents, \% ; \( \sigma \) – stress in a seam, it is determined as a sum of geo-static stresses and hydro-static pressure (in-situ gas pressure), MPa.

Further, when calculating the parameters connected with relative methane release it is important to recalculate the values of gas-content found using equation (6) on dry mineral matter free, taking into account coal humidity and ash-content of coal [1].

It is found that for a coal seam mode of occurrence at the studied coal deposit the parameters values of equation (6) vary within the limits of: \( A: 7.6 \div 58.1 \text{ m}^3/\text{t} \), \( B: 0.028 \div 0.097 \text{ 1/MPa} \), and the values of \( \alpha \) and \( \beta \) indicators equal 0.2063 and 0.2199, respectively.

Equation (6) is adapted for coals of Kuznetskey Coal Basin and allows calculating a seam natural gas-content for any section of a coal deposit at a given point.

6. Numerical simulation of initial and calculated data, interpolation of the required parameter in the limits of the reviewed panel mine section.

Initial data and calculated parameters at determining gas-content are introduced as a fragment in table 1.

Table 1. Initial geological survey data and calculating parameters at determining gas-content of Kuzbass coal seams.

| Well No. | Initial data | Calculated data |
|---------|-------------|-----------------|
|         | \( H, \text{m} \) | \( X, \text{m}^3/\text{t dry ash-free mass} \) | \( V_r, \% \) | \( A_c, \% \) | \( W, \% \) | \( A, \text{m}^3/\text{t} \) | \( B, 1/\text{MPa} \) | \( \sigma, 1/\text{MPa} \) | \( X_p, \text{m}^3/\text{t} \) |
| 1153    | 223         | 11              | 38.8   | 8.5    | 2.5   | 51     | 0.048   | 8.0     | 10     |
| 1159    | 180         | n/a             | 38.6   | 6.3    | 3.2   | 51     | 0.047   | 6.5     | 9      |
| 1148    | 291         | 13              | 38.4   | 6.0    | 3.2   | 52     | 0.047   | 10.4    | 13     |
The calculations are done for each coal seam separately or for series of strata in the depth intervals given by a user. The results of the numerical experiments using equation (6) for Badayevskey Coal Deposit in Kuzbass in the form of graphical data are introduced in figure 1.

The scatter of actual data at a certain depth can reach 10 m³/t. Applying equation (6) gives the opportunity for more accurate calculation of a gas-content value. It can help in taking a decision whether to conduct some actions, for example, early degassing of the seams. It also negates the need to take a decision on the selection of gas-content if there are different gas-content values at the same depth.

Presented in figure 1 results allow deducing that calculated gas-content shows satisfactory convergence with actual data received during geological surveys.

The changeability of coal seam position environment and coal properties obligate taking them into account as in large areas in the limits of the deposit so as in the limits of an extraction area or along the mine working route. To prevent largescale averaging of the parameters, interpolation of gas-content values or another parameter out of geological survey data base is fulfilled in the limits of the area, set by the user.

![Figure 1](image_url)

**Figure 1.** The change of coal seams natural gas-content with growing of their occurring depth (Badayevskoye Coal Deposit in Kuzbass):
For interpolation, a geo-statistic method of kriging is applied. It helps to build a supposed surface using a set of points with z-values.

7. Mapping natural (specified) gas-content of coal seams or another parameter out of geological survey database.

Mapping method allows visualizing the spatial changeability of coal seam position mining-geological environment and their properties. On the bases of exploration well mouth coordinates \((x; y)\) a computer-based map is built, and its \((z)\) coordinate corresponds to a required parameter taken out of geological survey database, for example to gas-content, as it is shown in figure 2. The analysis of the map which, reflects significant changeability of the gas-content, allows revealing massif areas with high gas potential. South-east part of the mining section can be taken as an example, precisely from this part of the massif the most part of gas can be released in the process of mining. Therefore, this part has a potential attraction for methane extraction on industrial scale.

Taking into account the changeability of the gas-content the substantiation of safety on gas factor technological parameters is fulfilled and it is done before starting mining works, at the stage of making mine layout. They are coal seams development order, their geometric sizes, directions of stopes and development headings movements. The perspective assessment of the designed areas for mining coal and extracting gas is also fulfilled.

![Figure 2. The map of calculated coal seam natural gas-content (Baydayevskoye Coal deposit in Kuzbass).](image)

- \(x\) – direction to the North, m; \(y\) – direction to the East, m; 1 – coal seams isogases, \(\text{m}^3/\text{t}\); 2 – provisional working route

8. Building profiles for coal depth property and conditions.

Computer-based map data allow receiving changeability profile (graph) of the required parameter at a given section, on axes of the extraction areas or on development headings routes automatically.
The example of the coal seam gas-content changeability graph \(X_n\) obtained along the length \(L\) of the provisional working shown in the map of figure 2 is introduced in figure 3.

![Figure 3. Coal seam gas-content profile along the provisional mine working route.](image)

Profile analysis serves as a ground for early selection of a gas release control scheme at the extraction area or along the preliminary heading route. It can be also employed during mining process when applying methods and means for controlling coal seam state on an operational base.

In the Institute of Coal FRC CCC SB RAS additionally to the above-described indirect method for coal seam gas-content determination an innovative direct mining experimental method for coal seam gas-content determination is being worked out. The idea of the method is in the selection of a coal seam samples directly out of the mine working; it is selected out of the coal, which do not undergo oxidation and degassing processes due to man-induced impact. Then, these coal and gas samples are tested in a research laboratory using sophisticated equipment and the captured data are analytically estimated. To apply this method special device for measuring coal seam gas-content and monitoring its gas-dynamic (energetic) indicators has been designed. The device is equipped with electronic sensors and autonomous microprocessor-based system that allows making a full measuring of gas which is released during selecting the sample starting from the moment of decreasing natural stresses in a seam and finishing with sealing the coal into pressure-and-temperature sample vessel. The device allows getting up to 20 gas-kinetic indices for researching coal gas recovery ability, defining new dependences of gas-release on coal properties with the purpose of substantiating a complex of measures for providing safety (on gas factor) and effective conditions for stoping and preliminary works.

3. Conclusion

To correct the scarcity of information about the gas bearing capacity of seams (at the studied section of a coal deposit) an empirical dependence of coal seams natural gas-content change on their properties, occurrence depth, geo-static stress and hydrostatic pressure has been found. The described approach to spatial estimation of coal methane resources allows early substantiation of safety (on gas factor) technological parameters of coal mining processes.

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