Framework for innovative determination of natural gas content in coal seams

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Abstract. The article discusses the development framework of the method and device for high-accuracy measurement of coal seam gas content. It is proposed to design a device ensuring full measurement of gas content of coal core from the moment of coring (drilling at a distance of 4 – 6 m from coal boundary in the gateway face) to sealing of a core in the thermobaric flask (chips reception container). The results obtained using thermobaric flasks are essential. For another thing, the authors consider the requirements imposed on a portable flow rate meter and on the device for gas measurement and recording during drilling in coal seam. The anticipated difficulties in determination of volume of gas release from borehole walls in the total volume of gas measured during drilling are described. Alongside with the production benefits, the device being developed will provide determination of up to 20 gas-kinetic and gas-dynamic characteristics of coal, which can offer new knowledge on the nature of coal-and-methane substance.

1. Introduction

Modern practices of underground gas-bearing coal mining both in Russia and in the world are faced with the problem of increased methane content of mine air, which gets even worse with increasing occurrence depth of coal seams. Adequate ventilation design to ensure required gas content of mine needs forecasting volume of gas release during mining. In this regard, the forecast quality depends directly on determination of the natural coal seam methane content.

When developing methods to determine safe mining conditions, of concern is the order of accuracy of parameters included in the algorithm. Lower accuracy calls for higher safety factor. The governing value in determination of volume of gas release in coal mines is natural coal seam gas content. The value of gas content needs regular updating as gas criterion is the major constraint of buildup in output rate of coal mines.

In connection with this, operational determination coal seam gas content to adjust geological exploration data can be a complimentary background for optimal process solutions, or design of mine ventilation and gas drainage systems.

According to [1], in Russia gas content is mostly determined using direct [2] and indirect methods [3]. The difficulty of indirect determination consists in maintenance of thermodynamic conditions conformable with the natural conditions of coal seams.

Reliability of the direct gas content determination largely depends on the time between coring and core sealing. In [4] it is emphasized that the common method of direct natural gas content...
determination using special core barrel offers no decrease in losses as rapid decrease of efficient stresses in cores alongside with growth of free gas pressure results in propagation of micro- and macro-cracks followed by the related increase in the rate of methane emission. Furthermore, the time between coring and core sealing is higher by an order of magnitude than the time of drilling-out of the same mass of coal. As a result, a considerable volume of gas is missed (not measured), and the accuracy of gas content determination worsens.

The foreign procedures of coal gas content determination include, for example, the desorption method approved by the U. S. Bureau of Ming [5] and Gas Research Institute [6], or the direct desorption method by the Australian AS 3980 1999 [7].

DMT GmbH & Co suggests determining gas content of coal seams using drilling equipment fitted with air-powered drive AND HOLLOW RODS [8]. Coal is sampled from a certain depth in a borehole by suction via hollow drilling rods.

Suction is carried out by an ejector pump installed between the drill column and compressed air source. Travel of drill fines from the borehole bottom to the collecting chamber of the ejector takes a few seconds. The use of this equipment allows sampling at a distance more than 20 m from the bottomhole, which enables sampling of coal with undisturbed gas content.

On the other hand, this method lacks direct measurement of gas lost between coal destruction up to core sealing. Coal gas content is determined using data obtained in laboratory tests after sealing of a damaged coal sample. This method allows operational assessment of gas-dynamic risk based on identification of anomalous zones in longwalls.

### 2. Model of gas content change in coal seams during mining

The model of change in coal seam gas content and in residual gas content of broken coal versus time between the start of seam degassing up to the moment of broken coal removal from a longwall section (figure 1) is borrowed from [9]. This model correlates well with the modern understanding of coal seam methane [10]. It is thought that methane rapidly releases due to decrease or complete relief of geostatic stresses in the course of coal seam mining and owing to initiation of decomposition of solid coal–gas soliton. In the model, the time interval $t_1$ characterizes reduction in natural gas content due to pre-mine drainage. It is worthy of mentioning that such reduction can also result from undermining and overmining of coal seam, or due to other methods of timely or advanced isolated extraction of methane from coal. The time $t_2$ relates with decrease of the coal seam gas content due to approach of longwall face and considerable relief of rock mass from rock pressure under heavy fracturing in the face zone. During $t_3$ coal gas content rapidly lowers down to residual gas content of broken coal. In the time $t_4$ gas content decreases within longwall during haulage of broken coal. The time interval $t_5$ describes further insignificant decrease in coal gas content beyond the longwall. The key parameters of gas release from coal in the face zone is coal gas content in the face area and residual gas content of broken coal–$X_f$ and $X^{\prime}_I$, respectively.

![Figure 1. Model of change in gas content X of coal seam and broken coal in time t [9].](image)

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According to this model, for determination of natural gas content, coal is to be sampled beyond the influence zone of longwall face, in the interval between X and X1 free from the impact of pre-mine drainage. Otherwise, it is only possible to determine technical gas content of coal seam.

An optimal place for natural gas content determination is face zone of gateway (figure 2) for:
1. The distance between the face and coal with natural gas content is comparatively small (from 4 m);
2. It is possible to analyze gas-kinetic characteristics of coal in the face zone before the abutment zone, which is important for handling problems connected with gas-dynamic phenomena.

3. Method to determine coal seam gas content
Direct gas content measurement needs special equipment capable to measure full gas from the moment of reduction in natural stress in coal samples until sealing.

Figure 3 and 4 demonstrate the layout and pneumatic circuit of the device for measurement of full volume of gas release during drilling.

**Figure 2.** Model of variation in natural Xn and technical Xt gas contents along the length of gateway: 1 – determination of natural (technical) gas content; 2 – estimation of gas-kinetic and gas-dynamic characteristics of coal face zone; 3 – efficient degassing; 4 – active decrease of gas potential; 5 – broken coal.

**Figure 3.** Layout of device for operational gas determination in coal: 1 – seal; 2 – quick disconnect coupling; 3 – screw rod; 4 – drill bit; 5 – sealer; 6 – air lines; 7 – benchboard; 8 – drill; 9 – chips reception container or thermobaric flask; 10 – portable measurement instrumentation; 11 – gateway face.
Samples are taken during drilling in the face of a gateway, at a distance of 4–6 m from the coal seam boundary, given the face advance is not more than 3.5 m/day in the last 5 days.

Basic stages of coal seam gas measurement include:
1. Preparation;
2. Sampling;
3. Laboratory analysis;
4. Calculations.

3.1. Preparation
This stage consists of such operations as selection of a sampling point on the face surface; drilling-out of a niche for equipment installation, as well as connection and tuning of electrics.

3.2. Sampling
When equipment is installed, hole 4 m drilled without sampling and with measurement of gas-kinetic response parameters of coal via the new surface of the hole walls. Then, two cycles of stage-wise drilling each 1 m long are carried out with sampling and sealing, as well as with recoding of gas release parameters during drilling.

Drilling chips are sampled into the dedicated thermobarometric flasks (figure 5) or chips reception container [11], the time from coal sampling to sealing is 40–100 s. For the research, more than 100 samples of coal are taking in mines of Kuzbass, the research findings [12] are comparable with the foreign studies [13–15].

3.3. Laboratory analysis
After sampling, TBF with samples are delivered to laboratory and placed in thermostat. Then, residual gas content of the samples is determined with stage-by-stage releases of gas from the flasks and with proximate analysis of the samples.

![Figure 5. TBF (chips reception container) knocked-down and profile.](image)

### 3.4. Calculations

The most difficult stage in the developed procedure is determining volume of gas release during coal destruction as the considerable volume of gas measured by flow rate meter is methane from the borehole surface. Separation of flows in the calculations is planned to perform based on the modern knowledge on state of a coal seam in the face zone [16, 17] and on gas-kinetic coal characteristics obtained in development of the borehole prediction method [18, 19].

Coal seam gas content (coal sample) is calculated from the formula

\[
\chi_{\text{nst}} = \left( \frac{V_1 - V_2}{m_n} \right) + \chi_{\text{npd}}, \text{ cm}^3/\text{g ash-free dry weight},
\]

where \( V_1 \) is the total volume of gas release in a drilling interval, cm\(^3\); \( V_2 \) is the volume of gas release from the borehole walls during sampling, cm\(^3\); \( m_n \) is the mass of a sample, g ash-free dry weight; \( \chi_{\text{npd}} \) is the residual gas content after sample sealing, cm\(^3\)/g ash-free dry weight.

### 4. Measurement equipment for natural gas content

Gas determination is suggested to perform by joint R&D of the Institute of Coal (FRC CCC SB RAS) and the Institute of Semiconductor Physics (SB RAS) – portable measurement instrumentation (PMI). The instrumentation is designed to measure and record methane flow rate from a borehole using electronic transducers and an independent microprocessor. The feature of PMI is adjustability to various ranges of gas flow rate, which eliminates influence of errors on measurement results. The other singularity is option of simultaneous independent measurement of two gas flows: from the sample in TBF and from the borehole walls.

Figure 6 shows the experimental prototype of the device for coal sampling and gas content measurement. The device consists of a sampling unit (figure 6a), measuring unit (figure 6b) and a drill (figure 6c). By the time of this article preparation, a test bench is under design to be in accordance with the program and procedure of laboratory testing.
5. Conclusion

Summarizing, the implemented studies, alongside with the production benefits in the form of the procedure and device for high-accuracy gas content measurement in coal seams, are useful for science. The device enables determination of up to 20 gas-kinetic and gas-dynamic characteristics of coal, which can provide with new knowledge on the nature of coal-and-methane substance.

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References

[1] Coal Mine Degassing Guidelines Series 05 Issue 22 Approved by Rostekhnadzor (Federal Service for Environmental, Technological and Nuclear Supervision of Russia), Order No 797 as of Aug 24, 2006

[2] Guidelines on Coal Seam Gas Content Determination Series 05 Issue 48 Approved by Rostekhnadzor (Federal Service for Environmental, Technological and Nuclear Supervision of Russia), Order No 797 as of Aug 9, 2016

[3] Potokina R R, Zhuravleva N V and Ismagilov Z 2013 Chemistry for Sustainable Development 21(5) 485–489

[4] Polevshchikov G Ya, Kozyreva E N, Ryabtsev A A, Todin R I, Nepeina E S and Tsuran E M 2016 Vestnik Nauchnogo Tsentra po Bezopasnosti Rabot v Ugolnoi Promyshlennosti 16–24

[5] Diamond W P and Levine J R 1981 Procedures and Results: U.S. Bureau of Mines Report of
Investigations

[6] McLennan J D, Schafer P S and Pratt T J 1995 A Guide to Determining Coalbed Gas, Gas Research Institute Report GRI-94/0396 (Chicago, Illinois)

[7] Standards Association of Australia 1999, Australian Standard AS. 3980–1999: Guide to the Determination of Gas Content of Coal Seams. Direct Desorption Method (North Sydney, NSW)

[8] Imgrund T and Bauer F 2013 Mining Report 159–66

[9] Guidelines on Ventilation Design in Coal Mines Approved by the Ministry of Coal Industry of the USSR on Aug 15, 1989

[10] Alekseev A D, Airuni A T, Vasyuchkov Yu F, Zverev I V, Sinolitskii V V, Dolgova M and Ettinger I L Discovery Diploma No 9. Property of an organic substance to generate metastable one-phase systems with gases by the type of solid solutions (Moscow)

[11] Polevshchikov G Ya, Ryabtsev A A, Nepeina E S, Tsuran E M, Titov V P, Vanin E A, Melgunov M S, Nazarova L A and Nazarov L A 2014 RF Patent No 2526962

[12] Kozyreva E N, Nepeina E S and Shinkevich M V 2018 Coke and Chemistry 3 112–115

[13] Liu S and Harpalani S 2013 AAPG Bulletin 97(7) 1033–49

[14] Li Bo, Wei Jianping, Wang Kai, Li Peng and Wang Ke 2014 International Journal of Mining Science and Technology 5(24) 637–41

[15] Espinoza D N, Pereira J-M, VANDAMME M, Dangla P and Vidal-Gilbert S 2015 International Journal of Coal Geology 142–51

[16] Murashev V I 1980 Scientific framework for safe coal mining based on geomechanical studies. Dr Eng Dissertation Synopsis (Moscow)

[17] Kurlenya M V and Oparin V N 1999 Journal of Mining Science 3 216–230

[18] Zykov V S 2010 Coal and Gas Outbursts and Other Gas-Dynamic Phenomena in Coal Mines (Kemerovo)

[19] Polevshchikov G Ya, Kozyreva E N and Kiryaeva T A 2004 GIAB 8 81–7