Evaluation of safe (by gas criterion) process parameters for longwalls and gateways based on operational gas content measurement in coal seams

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Abstract. The article describes the effect exerted by variability of gas content of coal seam on its mining process parameters: geometry of longwalls, directions and velocities of face advance in longwalls and gateways, as well as overmining and (or) undermining of close-spaced seams. The results are applicable in efficient mine layout and safe mining design.

1. Introduction
Gas safety is of concern at any stage of mineral mining: geological exploration and acquisition of data on natural properties of coal seams; mine field layout; selection of mining sequence at maximum allowable face output in gateways and longwalls; advanced selection of gas control patterns for gateways and longwalls; actual mining with undertaking operational measures of ground control. Such challenges are overcome by Russian and foreign researchers [1–14. The background for handling problems connected with gas risk reduction is reliable information on kinetic characteristics of gas desorption and natural gas content of coal seams. Gas content per unit mass of coal prior to mining and variation in gas content of coal seams in the course of mining belong to the key indicators involved in selection of efficient integrated gas release control in longwalls and gateways.

The field and analytical studies implemented by the Institute of Coal, FRC CCC SB RAS and by mining practitioners in extraction panels at the Chertinskoe deposit prove the following inference. During undermining of a coal seam (with a parting 40 cm thick), the natural coal seam gas content drops to 50 % as a consequence of reduction in elastic energy of enclosing rock mass and owing to gas release. The data on natural gas content were updated by direct measurements of gas volume in the formation samples taken in underground excavations. The comparative results of the natural and residual gas content in a partly degassed seam laid foundation for barrier degassing in gateways and for coal seam degasification within the limits of influence exerted by the undermined zone on the lower lying longwalls [15, 16].

2. Modeling of geomechanical process and amendment of geological exploration data
Modeling of geomechanical structure of rock mass with regard to its stratigraphy made it possible to optimize gas drainage parameters for adjacent undermined and overmined coal seams. The
optimization aims at designing gas drainage patterns, namely, number of boreholes, their lengths, turn angles and drilling sites towards maximum possible reduction in methane content of a future longwall.

The field research and analytical studies were performed in mines at the Leninskoe and Chertinskoe deposits. The scope of works included: adjustment of natural gas content by geological exploration data; geomechanical assessment of change in the stress state of rock mass and the related reduction in coal seam gas content; determination of mechanism of gas desorption. As a result, the integrated gas release control circuit was substantiated for longwalls alongside with conditions of joint use of ventilation, gas outlet via mined-out area and degassing techniques [17].

Furthermore, with regard to variability of natural coal gas content and dynamics of methane release under different geotechnical conditions in mines at the Alarda and Baidai deposits, relations were obtained, which allowed methane content control in gateways and longwalls using such parameters of mining technology as advance rates of headers and shearsers, as well as face output [18].

For more than 20 mine sites in Kuzbass, 3D modeling (mapping) of natural properties of coal seams is implemented, including natural gas content and adsorption capacity [19]. The calculation of gas desorption (prediction of gas release) is complicated by to effect of coal self-destruction under the energy of gas when coal is unloaded from confining pressure. Considering nonlinear dependence of gas release rate from broken coal on natural gas content of coal seam, the found self-destruction property of coal is determined as gas-dynamic activity. This energy-based indicator integrates the cumulative effect of gas content, occurrence depth and volatile yield, and makes it possible to identify the boundary between gas hazard and gas-dynamic hazard. Thanks to the accomplished zoning of coal–methane seams by the criterion of their gas-dynamic activity, the degassing ratios meant to eliminate coal self-destruction using energy of gas contained in coal are calculated. Such degassing prevents spontaneous rise of the initial outgassing rate from broken coal with increasing gas content [20].

Using the parameter model of geomechanical structuring of enclosing rock mass with regard to its potential energy during longwall advance, based on the new knowledge on nonlinearity of geomechanical processes, it is found that the length of a longwall should equal an aliquot part of the length of an extraction panel. Adherence to this condition can help avoid such adverse phenomena as rock bursts, floor swelling and sidewall squeezing, including increased gas releases.

Gas content of coal seam is a base characteristic in detection of mine areas with increased gas–coal ratio, which may be promising from the viewpoint of coal seam methane production and utilization. These feasibility studies of safe (by gas criterion) process parameters for gateways and longwalls were accomplished using methods developed at the Institute of Coal, FRC CCC SB RAS. These methods extend and amend standards currently effective in the coal industry [21–24].

3. Research methods
The developed research methods include:

- Creation of databases of geological exploration information and gas adsorption capacity calculation;
- Updating and mapping of natural gas content of coal seams depending on their lithology, hydrostatic stresses, occurrence depth and natural properties;
- Zoning of coal seams by the criteria of gas hazard and gas-dynamic activity, as well as identification of limits of technologically feasible mining safety, including gateway routes;
- Modeling of geomechanical structuring of enclosing rock mass with regard to liberation of its potential energy during longwall advance;
- Prediction of methane dynamics in gateways and longwalls;
- Designing of integrated gas release control in longwalls;
- Operational gas measurement and determination of gas kinetics in coal seams using coal samples (chips) taken in underground excavations.

The backbone for all these method is, first, reliable value of natural gas content of coal seam, or its updated value from effective relations or direct measurements, and, second, variability of gas content
horizontally and vertically within the limits of a mining lease, or within an extraction panel, or along a longwall.

4. Results and discussion

Figure 1 shows the map of gas content (iso-gases 1) of a coal seam, plotted by coordinates of mouths of exploration holes 2 on a site of a deposit in Kuzbass. In the map, the gradients of gas content are shown as vector values 3 arrowed in the direction of growth. Roman numerals I—IX mark the extraction panels colored in accordance with advisability and inadvisability of mining at these locations.

Let us discuss various location sites of extraction panels. At the stage of mine layout, it is recommended to arrange the extraction panels and gateways with respect to the gas content gradient. The expedient direction of a panel is in perpendicular to the gradient vector, the inexpedient direction is along the gradient.

Extraction panels I and II. Though close-spaced, the seams have such natural properties that in the former case (panel I), in perimeter drilling and in longwall advance perpendicularly to the gas content gradient vector, metastable states of the seams change gradually. In the latter case (pane l II, along the gradient), the metastable states jump (10 m³/t per 500 m). In the zones of progressing geomechanical and gas-kinetic processes, coal seam structure is broken, i.e., energy releases and is spent for propagation of dislocations and initiation of microcracks. Fast buildup of energy can induce hazardous dynamic gas release – up to coal and gas outbursts (at high values of gas content and formation gas pressure). It is impermissible to extend the length of longwall I as it falls in the zone with different direction of the gas content gradient in this case.
An illustration of potential hazardous gas-dynamic situations is extraction panels III and IV. At the same time, as against with longwall II, the increment in gas content by 10 m³/t occurs in the interval of 1500 m, and, given proper gas release control, it is possible to abate gas-dynamic hazard in hazardous areas (with high gas content). Such control can involve in-seam degasification, decelerated advance of longwall face, or quantity input of ventilation air.

Although extraction panels V and VI are arranged in perpendicular to the gas content gradient, such ground conditions are hazardous in terms of gas-dynamic situation along longwall face as the natural gas content changes by 10 m³/t within this small distance of round 300 m (length of longwall face). The hazard can be mitigated through optimization of degassing and ventilation patterns, or by cutting the longwall face length, which can be economically inadvisable. Another feature of extraction panel VI is considerable variability of gas content along its axis. Adjustment of maximum allowable velocity of a shearer, as shown in the bottom right of the figure, can ensure safe mining by gas criterion along the whole extraction panel.

Extraction panel VII is arranged in the zone either overmined or undermined earlier with panels VIII and IX. In case that panel VII, partly or in full, falls in the influence zone of undermining or overmining, natural gas content of coal in this zone lowers by coefficient k governed by thickness of the parting and by displacement angles as shown in the top left of the figure. In this case, the site with gas content Xk, against the site X, will require smaller expenditures connected with gas hazard control.

### 5. Conclusions

The examples in the figure prove relevance of reliable and real-time information on natural gas content of coal, including seams after partial in-seam degasification. The values of gas content of a coal seam under mining can be updated by directional measurements of gas quantity in samples taken in mines [25, 26]. In this case, gas lost in sampling (core or chips) is calculated by extrapolation of measurements taken at long time spans (to 20 min) between sampling and sample sealing.

To innovate operational determination of gas content, R&D is currently in progress to engineer a device capable to measure full gas in coal sample, from the moment of drilling-out (4–6 m away from the face of gateway) to the moment of sealing in thermobaric flask (chips receiver). Moreover, this device will provide up to 20 gas-kinetic and gas-dynamic characteristics of coal.

Thus, the developed methods, basic conditions and arrangements of extraction panels in the figure take into account the influence exerted by variability of coal seam gas content on mining process parameters. Integration of these methods offers an algorithm for comprehensive assessment of natural properties of coal and for calculation of process parameters to ensure safe (by gas criterion) operation of longwalls and gateways. The list of such process parameters includes: geometry of longwalls, direction and velocity of face advance in longwalls and gateways, presence of overmining and (or) undermining of close-spaced seams.

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