Assessment of Relationship Between Mechanical States of the Solid and Gas-Dynamic Factors in Relation to Development of Methods for Calculating Parameters of Methane Drainage Boreholes in Coal Deposits Exploitation

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Technology of degassing coal beds and carboniferous massifs is an essential component of coal production in modern coal mines, ensuring both intensity of stock mining and mining safety. In turn, methane is a valuable energy feedstock, therefore in degassing operation it should be regarded not only as a necessary component for effective coal deposits development, but also as a source of hydrocarbons industrial production.

Production of coal bed methane requires development of special technologies, it is a complex process consisting in “fragmentation” (creating fractured zones) of coal beds by hydraulic and pneumatic methods with use of water, acids, surface-active substances, pulp, using hydraulic fracturing, pumping special solutions into the well [1-3]; in the US, new technology of methane extraction from undeveloped coal beds have been developed (Enhanced CoalBed Methane - ECBM), consisting of injecting CO₂ into the coal bed to be absorbed by the coal and displace methane [4]; one of the most effective ways is tapping of a carbonaceous massive, resulting in sharp increase of its permeability and filtration capacity.

Theoretical and practical issues of managing methane release and methane removal in course of working bedded deposits have been considered by many scientists and experts [5-8], The projects of extracting coal bed methane is characterized by considerable geological and technological risks, especially at an early stage, and one of the most volatile and difficult to forecast parameters of it is production rate of methane wells [9, 10]. Its forecast is based on results of experimental work on the adjacent plot and (or) on the analysis of coal mining experience with similar geological and mining characteristics, making it difficult to design effective degassing (gas production) technologies, in particular in the conditions of massive man-induced impact in course of coal mining and changing its gas-dynamic characteristics in specific mining-and-geological and mine engineering conditions.

For the purpose of predictive appraisal (or engineering calculations) of methane production rates (or volumes of its extraction) in a differentiated way by gas-emission sources it is necessary to develop a method based on current understanding of the stress-strain state (SSS) of technology-perturbed rock mass (RM) and its displacement. The method should consider mechanical and gas-dynamic properties of the massif in question, their time-to-time change, as well as the surface of filtering area (borehole wall, strata surface outcropping, etc.) and permeability of fractured porous (block-fractured) environment.

Thus, one of the main objectives of research is to establish relation between mechanical state of overworked / underworked massif (i.e. RM SSS) and its gas-dynamic characteristics (reservoir, filtrating characteristics).

Most often developed are series of strata, or rather the most productive layers of the series. With this, geologic-mechanic gas-dynamic influence of developed beds largely determines recovery (extraction) of
methane from all strata, which depends on parameters that characterize environment gas-dynamic characteristics at the "point" of the massif, and, in turn, is functionally interrelated with SSS parameters at this "point". This method envisages development of quantitative approaches to coordination of the above indicators: Massif SSS parameters and its gas-dynamic characteristics [11]. Obviously, such information makes it possible to develop corresponding rational technological solutions in undermined areas for methane extraction.

Stages of deformation and displacement of an undermined massif can be schematized within the framework of the model shown in Fig. 1. This model is based on classical concepts of displacement of underworked stratified rock massif. In conventional theory, it is believed that after performing a long-bore highwall mining, immediate mine roof stone caves in, with fragmentation index of 1.1 to 1.35. After lava recoil by the value of main roof-caving increment, the main roof caves in large blocks (fragmentation index 1.05 to 1.1). Overlying rock masses hang in the goaf for a certain time and then collapse (or slowly descend), loading with their weight worked-out strata bedrock. Overlying rocks, respectively, collapse in larger blocks with a lower fragmentation index. But even in case of slow descent of thick layers, their cleavage is greatly increased.

![Fig. 1: Scheme overlying rock collapsing in the goaf.](image)

Vertical collapse speed of undermined layers is 50-100 m/month. I.e., aqueous rock mass over 100 m thick, except for the immediate roof (IR) and main roof (MR), remains hanging over 1-2 months. This, in turn, determines filtration time (with constant parameters of medium permeability) of IR and MR broken-down rock complex and poroelastic (unloaded from rock pressure) bedrock and soil roof.

In the А zone, broken-down are IR and MR, and overlying bedrock is stratified, detached part of the roof bedrock is deformed according to the elastoplastic law, and gradually moves its weight onto the goaf. Thereby, the goaf bedrock are loaded, compacted, their thickness and permeability decrease. This increases permeability of bedrock roof due to creation of stratification planes that act as filtering areas (free surface through which methane can be filtered) and gas "delivery channels" from location of its desorption to the well. It should be emphasized that stratification area increases gradually, then at some point it intersects the bore, and the gas is flush-released into the wellbore. Dimensions of such areas are comparable to the wall length.

In zone B, bedrock that was deformed after bedrock stratification in zone А, fully transfers its weight into the goaf, and stratification occurs in the next "packet" of the roof bedrock. It should be emphasized that boundaries of "bedrock packets" of the bedrock roof will be the weakest (by deformation and strength characteristics) layers. These are typically coal beds or carbonaceous mudstone.

Thickness of the packets will be determined by thickness of parting in the underworked massif and composing lithotypes of roof bedrock. More solid and thick homogeneous layers will be stable over a longer period. In zone В, stratification planes occur in roof bedrock at a greater distance from developed bedrock, as compared to zone А, and is characterized by smaller size along the wall length, but greater size along the length.
of extraction column. After full transfer of hanging "bedrock package" weight onto the seat earth, goaf bedrock is compacted, and separation occurs in the bedrock further away from the goaf roof (zone C). In this, thickness of goaf broken-down rock has increased, and thickness of hanging roof bedrock has decreased.

In zone C cleavage of next bedrock package occurs, wherein its geometry is determined by full displacement angle (along the wall length) and stable flow along excavation column (which depends on thickness of the cleaved bedrock package and its mechanical characteristics). Thus, undermined bedrocks subside, this decreasing cleavage span along the wall length and reducing cleavage cracks. Conditionally, for each of the stages in question, one can distinguish stable states in this bedrock complex and estimate the time during which gas will be filtered through the bedrock with stable parameters of gas permeability in all zones in question (collapsed and stable). When less solid bedrocks are located under thick strong roof layers (e.g., sandstone), they will crumble (sag) immediately after collapse of roof bedrocks. Such "packages" will include all layers until the moment the settlement reaches the layers with deformation characteristics defining their steady state for a certain time interval.

With that, in order to calculate the gas flow rate into the well, it is most appropriate to use the following equations [12].

In order to calculate the flow rate (m3/c) of area filtration (filtration from free exposed surface), in accordance with Darcy's law:

$$I = k \cdot F \cdot \frac{\Delta P}{\mu}$$

(1)

whereas $k$ is collector permeability, Darcy; $F$ is filtration area (free surface); $\Delta P$ - pressure difference in the way of gas filtration, Pa; $L$ is the path (distance) of gas filtration, m; $\mu$ is dynamic viscosity of methane, cP.

In a situation where stratification crack propagates not along the coal bed, it is necessary to take into account permeability of bedrocks between coalbeds and the plane of cleavage (see Figure 2, a).

In this case, permeability of bedrocks will be determined by the following expression:

$$k_{cp} = \frac{L_{\text{total}}}{\sum_{i=1}^{n} \frac{L_i}{k_i}}$$

(2)

whereas $L$ is gas filtration path, $k_i$ is permeability of the $i$-th bed.

Assuming that the crack (plane) of the stratification intersects the drilling location, all gas that is desorbed and filtered into the stratification cavity will be delivered to the well at minimum pressure difference.

This dependence can also be used for calculating gassing from destroyed (fractured) bedrock, but in this case filtration area is the total surface area of all cracks, which grows exponentially with increasing of fragmentation rate (decreasing average size of a characteristic piece).

Since the well will not only cross the stratification plane, but elastically hanging bedrocks and caved in bedrocks in the goaf that also contain gas, calculation of production rate in these bedrocks can be made by the equation for calculating filtration into the well (see Figure 2, b).
where \( (p_c - p_k) \) is pressure difference at the borehole surface and the surface of filtering circuit, \( r_c \) and \( r_k \) are the radii of the well and the filtering circuit, respectively.

On the above diagrams, highlighted are the main stages of overlaying massif displacement along the length of the excavation column. This approach makes it possible to estimate the exposed (filtering) areas of the coal-bearing strata in case of their strata-by-strata caving-in with highwall mining shift. Obviously, time parameters of selected zones existence will be determined by the average rate of overlaying bedrock shift. Assessment of these parameters makes it possible to estimate the volume of the filtered gas and to predict total volumes (depending on time of existence of the areas in question) of captured methane.

The main parameter in the above dependencies that need justification is permeability of the filtration environment (hanging bedrocks, surface coal beds, caved-in bedrocks into the goaf). Since this parameter greatly depends on the SSS of the filtration environment and its state (caved-in or hanging bedrocks), it should be determined separately for selected characteristic zones.

The studies made are the basic part of developing an algorithm for calculating parameters of degassing (gas production) wells, including design of integrated coal mining and methane production in promising areas with flat bedrocks with high gas content. The algorithm developed should include methods for calculating flow rates of methane drainage boreholes located in various specific zones or underworked or overworked coal-containing rock massif and predictive assessment of efficiency (technical and economic parameters) of the options under consideration.

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I = \frac{2\pi r \mu k_{mp} (p_c - p_k)}{r_c \ln \frac{r_k}{r_c}}
\]

(3)

**REFERENCES**


