Laws of gas draining in the massif disturbed by mining operations

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Abstract. A method for calculating gas permeability of the rock massif depending on its stress-strain state is presented. By using methods of the mine experimental studies, influence of mining operations in the adjacent longwalls on intensity of gas release from the previously worked-out long-pillar was determined, as well as impact of the massif stress-strain state on efficiency of the drainage boreholes. Formulas were obtained for calculating coefficients of the impact of zones with static and dynamic abutment pressure on intensity of gas draining in the previously worked-out long-pillar.

1 Introduction

The most effective method for mining flat coal seams in the Donbas deep mines is the long-pillar method with roof control in terms of its complete fall. Today, about 90 % of the coal seams are mined by this method [1]. The main sources of methane gas flowing into the mine roadways are coal seam and sandstones in its roof. Sandstones are characterized by the greatest natural gas content and easy gas release at their destruction. This fact should be taken into account while developing schemes for gas drainage from the massif.

With the view of the gas-drainage operations, a coal-rock massif can be conditionally divided into three zones: zone of the previously worked-out long-pillar, zone of the working long-pillar and conjugate zone between these long-pillars. Each of the zones is characterized by its own specific geomechanical processes of the rock breaking and consolidation and methane release during the mining operations.

Efficiency of the gas drainage can be improved by choosing rational parameters for the gas-drainage boreholes: their number and length, angles of their inclination to the horizon and their location around the roadway axis; besides, these parameters should be calculated with taking into account stress-strain state of the rock massif. Therefore, it is necessary to determine the laws, according to which stress-strain state of the rock massif is changed in the process of mining operations. These laws taken into account in the gas-drainage schemes will improve efficiency of degassing operations.

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2 Methods

The laws, according to which stress-strain state of the rock massif is changed in the process of mining operations, were studied by the mine experimental methods. Experimental studies were conducted in the Zasyadko Mine. Rock cracking was determined by method of electrometry at different distances from the mine roadway. Stress-strain state of the massif was studied by method of local hydraulic fracturing and by method of boreholes. Data on the methane-air mixture and methane flow rates were provided by the mine ventilation service.

3 Influence of the rock massif stress-strain state on productivity of the gas-drainage boreholes

Any rock massif is a pore-fractured structure, and its gas permeability is an important parameter, which characterizes its draining properties. This parameter takes into account geomechanical state of the massif and its ability to pass gases and their mixtures (fluids) in the presence of a pressure gradient. The rock permeability is described by the Darcy equation:

$$K_p = \frac{v_g \mu}{dP / dl_f}, \tag{1}$$

where K_p is rock permeability, m^2; dP/dl_f is pressure gradient, N/m^3; v_g is flow velocity of gas, m/s; μ is dynamic viscosity of gas, $N \cdot s/m^2$; l_f is length of the gas seepage path, m.

In terms of quantity, gas permeability of the rocks is determined by calculation by formula (1) converted for the one-dimensional laminar flow of gaseous fluids with regard to their compressibility [2]:

$$K_p = \frac{2\mu Q l_f P_b}{S(P_{in}^2 - P_{out}^2)}, \tag{2}$$

where Q is flow rate of the drainage gas, m^3/s; P_b is barometric pressure in the rock massif, N/m^2; S is area of the drainage flow, m^2; P_{in} is gas pressure in the entry to the drainage zone, N/m^2; P_{out} is gas pressure in the exit from the drainage zone, N/m^2.

From equation (2), we conclude that the drainage process can be quantitatively characterized by an informative indicator - flow rate of the drainage gas Q, which is determined by experimental studies. To this end, it is necessary to have: reference data on the dynamic viscosity of the drainage gas; given or experimentally measured geometrical dimensions of the drainage zone; value of input and output gas pressure in the drainage zone.

Conditional drainage radius r_{dr} is an important parameter for assessing change in the state of the gas-containing rock massif in zone of the gas-drainage borehole influence [3]. This parameter characterizes in time spatial distribution of the drainage zones relative to the surface of the free flow. Parameters of the drainage zone depend not only on the drainage properties of the rock massif, but also on the patterns of gas flowing to the drainage surfaces.

Gas enters the gas-drainage borehole through its walls and ends:

$$S_h = 2\pi r_h l_h + \pi r_h^2 \tag{3}$$

from the rock massif, area of which is calculated by the formula:

$$S_{dr} = 2\pi r_{dr} l_{dr} + \pi r_{dr}^2 , \tag{4}$$

where S_h and S_{dr} are areas of the borehole surface and drainage zone, respectively, m^2; r_h, r_{dr} are radius of the borehole and drainage zones, respectively, m; l_h, l_{dr} are length of the borehole and drainage zone, respectively, m.

Ratio of areas of the wall and end surfaces of gas drainage borehole and drainage zone allows neglecting the second term in the formulas (3) and (4). Then, volume of the rock massif contoured by the drainage surface and surface of the gas drainage borehole, will be:

$$V_{dr} = \pi r_{dr}^2 l_{dr} - \pi r_h^2 l_h . \tag{5}$$

With the known reservoir properties of the rock massif and volume of gas released during time t, volume of the drainage zone can be calculated by the well-known gas state equation:

$$V_{dr} = \frac{\alpha V_g P_b}{m_w P_{av}} , \tag{6}$$

where α is coefficient of gas compressibility under the given temperature and pressure conditions; V_g is volume of gas released during time t, m^3; m_w is coefficient of pore-fractured structure of rocks with regard to their humidity; P_{av} is average pressure equal to half-sum of input P_{in} and output P_{out} pressures in the rock massif on the drainage surface, N/m^2.

From equation (5) and with considering of (6), it follows that:

$$r_{dr} = \sqrt{\frac{\alpha V_g P_b}{\pi l_{dr} m_w P_{av}} + \frac{r_h{}^2 l_h}{l_{dr}}} . \tag{7}$$

At various distances from the gas-drainage boreholes, rock massif permeability can be estimated by numerical values of the rock massif permeability coefficient K_p. In the massif undisturbed by mining operations, this coefficient is calculated by the known dependence for the flat-radial pattern of gas flowing [2]:

$$K_p = \frac{2.3\mu Q \alpha P_b}{\pi l_h (P_{in}{}^2 - P_{out}{}^2)} \cdot \frac{T_m}{T_0} \lg\left(\frac{r_{dr}}{r_h}\right), \tag{8}$$

where Q is rate of gas flow at atmospheric pressure, m^3/s; T_m is temperature in the rock massif, °C; T_0 is atmospheric temperature, °C.

4 Results and discussion

It is known that gas flows from zones with high rock pressure to zones with low rock pressure. In order to drain gas from the coal-rock massif with the help of gas-drainage boreholes, it is important to determine direction and intensity of methane flows. Methane moves as a result of the stresses redistribution in the massifs of previously worked-out and working long-pillars under the influence of technological processes of the coal mining operations [4, 5].

In the previously worked-out long-pillar, broken rocks were partially compacted. Degree of the rock compaction significantly depends on location of the worked-out massif under the consideration. The mine experimental studies showed that process of the rock compaction was much more intense in the lateral parts of the previously worked-out long-pillar than in its middle part. This phenomenon significantly influences gas permeability of the underworked (overworked) rocks.

It is experimentally established that methane drains to the previously worked-out long-pillar and its conjugate zone with the working long-pillar under the action of the front abutment pressure caused by the adjacent working longwall. This pressure is formed ahead of the longwall and can extend to the distance up to 100 m from the longwall face. Methane comes from the previously underworked massif as a result of the stress redistribution due to the shrinkage of the rock massif or under the influence of mining operations.

Rate of methane flow from the previously worked-out long-pillar is described by logarithmic dependences (Fig. 1). Nature of their change significantly depends on the front abutment pressure created by the working longwall.

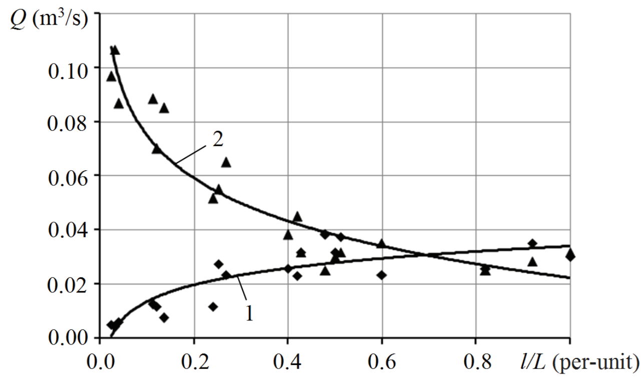

Fig. 1. Dependence of rate of methane flow from the previously worked-out long-pillar on distance to the adjacent longwall edge: 1 – methane flow rate outside the zone of influence of front abutment pressure created by the working long-pillar, m^3/s; 2 – methane flow rate in the zone of influence of front abutment pressure created by the working long-pillar, m^3/s.

Before working longwall influence begins, and with increasing distance to its edge, rate of methane flow increases by logarithmic dependence (curve 1, Fig. 1):

$$Q = k_{dr}\left[0.27\ln\left(\frac{l}{L}\right)+1\right]; \quad R^2 = 0.75, \tag{9}$$

where Q is rate of methane flow from the previously worked-out long-pillar, m^3/s; l is distance from the edge of the working longwall, m; L is length of longwall, m; R^2 is accuracy of approximation; k_{dr} is coefficient of influence of abutment pressure zones on intensity of gas drainage, m^3/s*;* outside the zone of working longwall influence, this coefficient is equal to $k_{dr} = 0.03$ m^3/s.

This phenomenon occurs under the influence of static abutment pressure zone created by the edge of the coal seam. Outside this zone, methane emissions are more than doubled.

Different trend is observed in zone of mining operation influence: methane flow rate increases when approaching the working longwall edge (curve 2, Fig. 1):

$$Q = k_{dr}\left[1-\ln\left(\frac{l}{L}\right)\right]; \quad R^2 = 0.89. \tag{10}$$

In zone of working longwall influence, coefficient of influence of abutment pressure zone is equal to k_{dr} = 0.02 m^3/s. This factor is associated with two main processes: intensification of fracture formation in zone of previously worked-out long-pillar, which is adjacent to the working long-pillar, and enforcement of methane to drain from the working long-pillar into this zone under the action of front abutment pressure of the working longwall. As a result, gas release from the roof in the conjugate zone between the previously worked-out and working long-pillars increases by more than 10 times.

Under conditions when front abutment pressure zone created by the face of the working longwall does not yet influence the drainage area of the previously worked-out long-pillar, static pressure zone created by the conjugate zone between the long-pillars engenders the most influence on the process of gas draining into the boreholes. Due to the rock compaction, this zone presents a barrier for the methane drainage from the long-pillars prepared for mining operations to the previously worked-out long-pillar. In such conditions, gas is drained from the rock layer broken by preliminary underworking into the previously worked-out long-pillar.

Then, taking into account the empirical dependence described by us in (9), outside zone of influence of mining operations in the adjacent longwall, the equation (8) is transformed as follows:

$$K_p = k_{dr} \cdot \left[0.27\ln\left(\frac{l}{L}\right)+1\right] \cdot \frac{2.3\mu\alpha P_b}{\pi l_h (P_{mass}{}^2 - P_{des}{}^2)} \cdot \frac{T_m}{T_0} \lg\left(\frac{r_{dr}}{r_h}\right), \tag{11}$$

where P_{mass} is gas pressure in undisturbed massif above the boundary with the disturbed zone, N/m^2; P_{des} is gas pressure in the rock massif of the previously worked-out long-pillar, N/m^2.

Under the influence of mining operations in the adjacent longwall, stresses redistribution and rock movements occur in the previously underworked massif. Rate of methane flow from the underworked massif and its conjugate zone with the working long-pillars changes drastically under the combined influence of zones with static and front abutment pressure. In such conditions, and with taking into account (8) and (10), permeability of the previously worked-out long-pillar is determined by the equation:

$$K_p = k_{dr} \cdot \left[1-\ln\left(\frac{l}{L}\right)\right] \cdot \frac{2.3\mu\alpha P_b}{\pi l_h (P_{mass}{}^2 - P_{des}{}^2)} \cdot \frac{T_m}{T_0} \lg\left(\frac{r_{dr}}{r_h}\right), \tag{12}$$

Therefore, formulas have been obtained for calculating coefficient of rocks permeability in the previously worked-out long-pillar. They take into account influence of static abutment pressure on the conjugate zone between the previously worked-out and working long-pillars, as well as influence of mining operations in the adjacent longwall. These coefficients make it possible to determine permeability of the rock massif at different distances from the gas-drainage boreholes and conjugate zone between the previously worked-out and working long-pillars.

Conclusions

1. Conjugate zone between the previously worked-out and working long-pillars is a concentrator of static abutment pressure. Therefore, in the previously worked-out long-pillar and with increased distance to its conjugate zone with the working long-pillar, methane flow rate increases by logarithmic dependence.

2. In the massif of previously worked-out long-pillar, processes of fracture formation are intensified under the influence of mining operations in the adjacent longwall. Rock

breaking is observed above the conjugate zone between the long-pillars. Front abutment pressure forces the gas to drain from the underworked (overworked) rocks and working long-pillar into the previously worked-out long-pillar. With decreased distance to the conjugate zone between the long-pillars, rate of methane flow into the gas-drainage boreholes increases by more than 10 times according to the logarithmic law.

3. Equations are obtained for determining coefficient of influence of static and dynamic abutment pressure zones on intensity of gas drainage. This coefficient characterizes rock massif permeability in the previously worked-out long-pillar and takes into account volume of drainage rocks and influx of methane under the influence of mining operations in the adjacent longwall.

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