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MODELING OF THE NATURAL COAL DESTRUCTION DUE TO SORBED METHANE

Odintsev V.N., Trofimov V.A., Shipovskii I.E.

*Institute of Comprehensive Exploitation of Mineral Resources RAS, Moscow*

Catastrophic events in coal mines are often associated with the sudden appearance of a huge amount of gas (methane) during the development of a coal seam. The most famous events are the instantaneous outbursts of coal and gas. There are various theories of coalbed methane participation in the destruction of coal. In a new field of research, developed in our works, the catastrophic destruction of coal is associated with bound methane, absorbed inside the coal, as well as being in the coal substance in the state of solid solution. The reason for this approach is the fact that the share of bound methane in coalbed can reach 90% of the total amount of methane.

This paper considers the mechanisms of destruction of gas-bearing coal at the micro- and macro-levels due to methane passing from the natural bound state to the free state under man-made impact on coal. The emphasis is placed on the possible destruction of virtually impenetrable natural (crushed and pressed) coal, which is most prone to coal and gas outbursts. The research is based on the analysis of experimental studies and computer modeling.

The models of the development of a tensile crack in a coal due to the pressure of free methane are considered. This methane appears in the crack due to the transition of methane molecules from the dissolved state in the coal to the free state on the crack surfaces. The yield of dissolved methane molecules in the crack is described by a diffusion mechanism. The appearance of the initial crack is associated with the effect of man-made mechanical impact on coal, in particular, the blast wave [1].

Step-by-step calculations were carried out for the diffusion of dissolved methane into the crack in view of adsorption of the molecules on its surfaces, and the growing pressure of free methane in the fracture was evaluated. The beginning of crack growth was estimated using the Griffiths-Irwin criterion for the crack under compression conditions [2]. The developed model took into account the processes of pressure drop of free methane with an increase in the crack length and pressure growth due to the continued diffusion and release of dissolved methane molecules into the crack. The crack was considered as a smooth cut in an elastic medium.

The dependence of the crack growth rate on the diffusion and adsorption parameters of the model is obtained. It is established that the crack growth rate under the most favorable conditions, in particular, with a diffusion coefficient in an intact coal of the order of  $10^{-13}$  m<sup>2</sup>/s, cannot exceed 1 mm/s, which calls into question the applicability of the concept of crack development due to the classical diffusion of methane in fast-flowing processes of coal and gas outbursts.

Another model was also considered – the model of "instantaneous release" of methane into the crack. Two following specific factors were taken into account: the complex geometry of the crack surface (fractality) and the presence of the induced pre-fracture zone of coal, i.e. the fracture process zone at the crack tip. This zone covers the entire crack surface if the crack grows. According to estimates this zone has a thickness of about 100nm and a very high induced permeability.

The system of equations of the second model included the Henry equation, which allows us to link the amount of methane released from the coal substance and the gas pressure in the crack [3]. The possibility of dynamic crack development was determined by the energy required for the formation of a free surface. The energy condition for dynamic crack development was transformed to the form  $F(a/\varepsilon) > C$ , where  $F(a/\varepsilon)$  is a known dimensionless function of the dimensionless crack length. The dimensionless parameter  $C$  included the energy of free surface formation in addition to geometric and deformation parameters.

The article uses notation:  $a$  – non-fractal crack length;  $\varepsilon$  – step of crack length measurement,  $D$  – fractal dimension,  $d_0$  – methane content in a cubic meter of coal;  $\sigma_3$  – coal compressive stress,  $R$  – gas constant,  $T$  – temperature,  $E$  – Young's modulus,  $\nu$  – Poisson's ratio,  $p_0$  – methane "saturation pressure",  $\gamma$  – specific surface energy;  $k = \sigma_3/p_0$ ;  $C = \gamma DE / [\pi(1 - \nu^2)p_0^2\varepsilon]$ ;  $q =$

**Секция 13. Мезомеханика, флюидодинамика, сейсмичность и триггерные эффекты в геосредах**

$[d_0 \rho_0 ERT] / [8\pi(1 - \nu^2)\epsilon p_0^2]$ . Parameter values:  $\epsilon \sim 10$  nm;  $\rho_0 \sim (10 - 100)\epsilon$ ;  $d_0 \sim (10 - 100)$  kg/m<sup>3</sup>;  $E \sim (10 - 100) \cdot 10^3$  MPa;  $\gamma \sim (0,1-10)$  N/m;  $p_0 \sim 10$  MPa;  $T = 293^\circ\text{K}$ .

The figure explains some of the calculation results. The curves drawn at different values of the defining parameters. Dashed lines indicate possible values for the criteria dimensionless parameter C. The higher the position of the curve in the figure, the more favorable the conditions for the dynamic development of the crack. With the exception of two cases, the function  $F(a/\epsilon)$  is monotonously increasing. This means that if the crack starts to grow dynamically, it will grow "indefinitely" and may grow into an object of significantly larger scale.

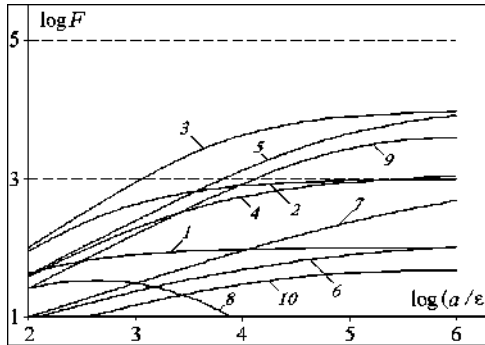


Fig. 1. Graphs of the criterion function of crack development: 1 –  $k = 0, D = 1, q = 100$ ; 2 –  $k = 0, D = 1, q = 1000$ ; 3 –  $k = 0, D = 1, q = 10000$ ; 4 –  $k = 0, D = 1.2, q = 1000$ ; 5 –  $k = 0, D = 1.2, q = 10000$ ; 6 –  $k = 0, D = 1.5, q = 100$ ; 7 –  $k = 0, D = 1.5, q = 1000$ ; 8 –  $k = 0.2, D = 1, q = 100$ ; 9 –  $k = 0.2, D = 1.2, q = 10000$ ; 10 –  $k = 0, D = 1.5, q = 100$

Thus, it was found that under certain conditions, a situation is possible when the considered tensile crack in the coal can develop in a self-sustaining mode only due to the transition of methane from bound state in the local pre-fracture zone to free state in the crack. The amount of bound methane in the coal substance and the amount of surface energy are the main physical factors that affect the possibility of crack growth. The crack development also depends on the stress state of the coal and the fractal dimension of the crack surface.

It should be noted that the second model fully corresponds to the case of crack development along the initially closed contacts of natural structural fragments of coal [4]. This model allows us to explain the rapid development of cracks in coal from an initial size of about ten microns to the size that corresponds to pieces of destroyed coal in sudden outbursts of coal and gas. Apparently, both mechanisms of crack development in natural coal (slow and fast) are possible under natural conditions due to dissolved methane, and their different combination can explain the observed difference in gas-dynamic phenomena in coal seams.

*The work was carried out with the financial support of the RFBR grant 18-05-00912.*

1. Odintsev V.N., Shipovsky I.E. Simulating explosive effect on gas-dynamic state of outburst-hazardous coal band // Journal of Mining Science, 2019, vol. 55, no 4, pp. 556-566.
2. Nikitin L.V., Odintsev V. N. Dilatancy model of tensile macrocracks in compressed rock // Fatigue & Fracture of Engineering Materials & Structures, 1999, vol. 22, no 11, pp. 1003-1009.
3. Odintsev V. N. Modeling of methane release from intact coal // Journal of Mining Science, 2005, vol. 41, no 5, pp. 407-415.
4. Trubetskoy K.N., Ruban A.D., Viktorov S.D., Malinnikova O.N. et al. Fractal structure of deformed coal beds and their susceptibility to gas-dynamic failure // Doklady Earth Sciences, 2010, vol. 431, no 2, pp. 538-540.

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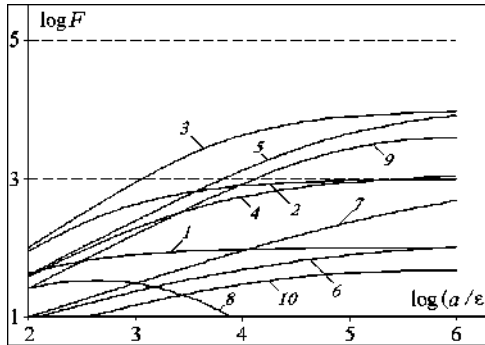


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