PERMEABILITY OF A COAL SEAM WITH RESPECT TO FRACTAL FEATURES OF PORE SPACE OF FOSSIL COALS

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The present study is aimed at demonstration of possible calculation of permeability of coal beds with respect to their depth that is based on the measurement of coal porosity taking into account their hierarchical structure. The characteristics of pore space obtained by small-angle neutron scattering (SANS) with the use of fractal theory allow explanation of the regularities of coal permeability evolution within the frameworks of a model differing from the traditional concepts of the theory of deformation of an elastic and plastic solid.
Now we shall analyze the data available for coals of Donets basin [1]. Coals of Lean baking rank have been selected (volatile content is V^{daf} = 15-20%). All the samples are related to the same geological conditions of mine named after A.I. Gayevoy, Ukraine, but of different beds. The total porosity was found by uniaxial deformation of cylindrical samples in a high-pressure chamber [2]. Surface fractal dimension, specific pore surface with respect to fractality were calculated on the basis of neutron scattering curves registered by a spectrometer of small-angle scattering of YuMO pulse reactor IBR-2, Frank laboratory of nuclear physics, JINR, Dubna, Russia. For this uniform series of coal samples, the dependences of surface fractal dimension on the occurrence depth, and specific surface S/V have been calculated (Table 1).

Table 1. Basic data about coals

Number of the sample	Occurrence depth, m	Fractal dimension (SANS)	A, m^2/g	S/V,10^6 m^2/m^3	Total porosity	Open porosity
1	680	2.98	3.38	4.48	0.220	0.034
2	820	2.92	2.51	3.57	0.240	0.061
3	975	2.93	3.62	5.02	0.194	0.027
4	975	2.84	0.95	1.44	0.187	0.143
5	1080	2.75	0.192	0.60	0.189	-
6	1090	2.66	0.033	0.26	0.188	-

Note: A, S/V are specific surfaces of pores related as $A = (S/V)/\rho_c$, where ρ_c is coal mass density (kg/m^3).

The last column contains the data about the open porosity obtained by the standard analysis of adsorption curves of nitrogen at 77 K. Note that contrary to open porosity, other parameters are of conventional occurrence depth dependence. Here we use the data about the samples of mine named after A.I. Gayevoy in order to provide calculation of permeability at the same conditions of rock massif. The modified Kozeny-Carman equation [3] is aplied to calculate the permeability.
Results. The result is that the total porosity is slightly decreased at the depth increase, but the specific pore surface is reduced substantially (Table 1). It means that micropores are “healed” at a depth. Thus, the average pore size increases when the fractal dimension is reduced with the depth rising. So, a consequence is a sharp increase in permeability that cannot be explained by conventional formula for reduced relative permeability k/k_0 that employs the change in stress (rock pressure) and the pressure of adsorbed gas [4]. At real values of elastic and plastic characteristics of rock massif at the depth of 500 - 1000 m, permeability is not modified significantly as follows from estimates of real parameters of the tested samples taken under almost the same geological conditions of mine named after A.I. Gayevoy .

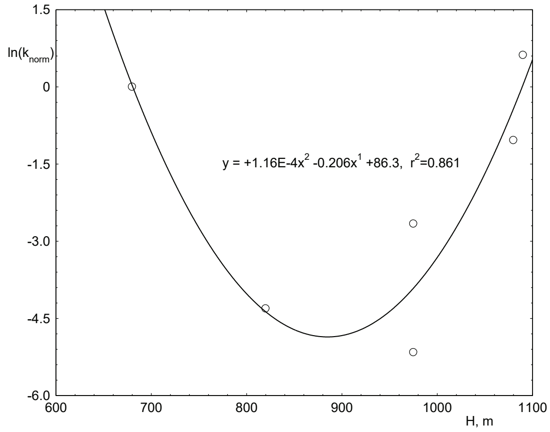

Fig. 1. *Depth dependence of reduced relative permeability (to H = 680 m), coal mine named after A.I. Gayevoy.*

Non-linear behavior of permeability (Fig. 1) can be explained by changes in the specific surface of pore space calculated with account of fractality on the basis of SANS curves. Actually, value of $(S/V)^{-2}$ in eq. for permeability [3] is changed substantially at depths close to H = 1000 m. So, the depth dependence of permeability is parabolic due to changes in pore parameters.

Reduction of permeability down to a certain level is a result of deformation of pores and cracks under rock pressure. At the next stage, under a higher loading, larger agglomerates of the matrix of coal substance are formed and the related increase in the permeability of the beds formed at large depth. This conclusion is also confirmed by depth dependence of the specific surface of pores found by SANS. Reduction of $S/V \sim r^{-1}$ is associated with an increase in size of pores formed by consolidation due to plastic deformation of large aggregates that are characterized by a lower surface fractal dimension. Similar regularities have been observed when calculating fractal dimension of the coal samples exposed to uniaxial loading in a chamber of high pressure up to 2 GPa [5].

Conclusions. Permeability of coal beds determines the processes of gas transfer with in their porous structure. When methane is extracted in the vicinity of the holes or coal excavation proceeds at large depth, fractured porous structure of a coal bed and surrounding rocks be substantially changed. The present study demonstrates that the hierarchical size distribution of fractured porous structure of coals provides explanation of a change in permeability when the occurrence depth of a coal bed is increased. A substantial advantage of this study is the use of SANS that accounts for both open and closed porosity of coal when analyzing the reservoir properties of coal beds.

An important fact is that the depth dependence is derived without invoking the data about the gas pressure in coal beds. Only laboratory data about the structural characteristics of coal samples have been used.

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