NUMERICAL MODELING OF HYDROFRACTURING IN A MULTILAYER COAL SEAM

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The mathematical model of the process for hydrodynamic fracturing in a multilayer coal seam is proposed. The model is based on the equation of continuity and Darcy’s law. The filtration – temperature analogy allows solving the obtained non-linear, non-stationary problem in an axisymmetric statement for the pressure function as the heat-conductivity problem, by the finite-element method. The calculation results yield estimation of the radius of degassing borehole influence zone.

Coal seam, methane recovery, filtration, porous medium, finite-element method

INTRODUCTION

The high gas content and outburst hazard existing in coal seams greatly complicate the operation of mines. Thus, preliminary methane recovery is of prime importance when preparing a coal deposit to a safe and efficient development. At present, coal methane is considered as a significant non-traditional power hydrocarbonaceous source, probable reserves of which are evaluated as 50 – 60 trillion m$^3$ in the main coal regions in Russia. In USA, production of coal methane is as high as 40 billion m$^3$ a year and continues growing [1]. The appreciable advance is made in the Donetsk Basin (Ukraine), Karaganda Coal Basin, in the Federal Republic of Germany, China, Australia, and other countries; the analogous work has been initiated in the Kuznetsk and Eastern Donetsk Basins since 1995 [2 – 4].

The process for methane recovery from coal seams differs from that for natural gas production, as methane in a coal substance is in a bound occluded state. To break the coal — gas system, it is required to exert special actions on the carboniferous massif. There are several techniques to control gas release. One of them is the coal seam degassing by hydrofracturing. The technology is as follows: through a special-drilled borehole, a working fluid is pumped under high pressure. The fluid front, moving deep into the seam, displaces and compresses methane in pores. When the pressure reaches the hydrofracturing pressure value, the seam fracturing occurs and methane in the porous space is set free from the bound state. Failure of the coal seam structure results in the gas recovery in the degassing zone.

As methane in the coal substance is in the bound state, the developed mathematical models consider filtration factors of a weakly compressible fluid rather than gas, as it would be reasonable in the case when methane is in the “free” state. One of these models is an analytical model of the coal seam hydrofracturing proposed in [5]. The basic parameter of the model is the pressure of fluid pumped into a borehole. The equation of fluid filtration is derived based on the equation of continuity and Darcy’s law. The obtained one-dimensional axisymmetric problem is solved numerically by the finite-difference method.

In the present paper, a more generalized, two-dimensional axisymmetric model of non-stationary filtration for a multilayer coal seam, with the variable filtration and porosity factors is considered. To continue the study [6], the finite-element approximation of the problem is given. ANSYS software is used in the calculations.
The initial data correspond to a coal seam of the Krasnodonetsk deposit, in the Eastern Donets Basin, and to the performed experiment characteristics. The experiment is based on a barogradient effect exerted on coal seam and coal-hosting rocks, during fluctuation filtration of a water solution fed in a pulse mode by a unit CA-320 to the well bottom [7]. Carboniferous thickness in the deposit area is the main coal seam \( m_1 \), the associated seams \( m_0 - m_0^0 - m_0^1 \) and alternate sandstone, argillite, and limestone beds, in other words, the rocks with quite different physical and mechanical properties. This is taken into account in the mathematical model, where three basic layers are considered: coal, sandstone, and shales. The problem formulated in this way is of practical importance to the perfection of the hydrodynamic effect produced on the gas-bearing seams.

The calculated model results allow finding the values of pressure function. The curve of the pressure variations along the radial coordinate aids in determination of the radius the influence zone of the degassing borehole has.

**EQUATION FOR FLUID FILTRATION IN HETEROGENEOUS MEDIUM**

The basic parameter of the mathematical model is the pressure of working fluid pumped into a borehole, that is the function of coordinates and time. Deformation of a porous body is not taken into account, so, the equation for a medium movement is not considered in the present paper. It is known that filtration is described by different empirical laws relating the vector of the fluid filtration velocity and the pressure field. In the common case of low velocities, Darcy’s linear law is:

\[
v = -\frac{k}{\mu} \nabla P ,
\]

where \( P \) is the fluid pressure; \( k \) is the permeability of a porous medium; \( \mu \) is the fluid viscosity. In hydraulic engineering, along with (1), another version of Darcy’s law takes place, where a filtration factor \( K \) is used instead of the permeability:

\[
v = -\frac{K}{\rho g} \nabla P ,
\]

where \( K = k \rho g / \mu \); \( \rho \) is the fluid density; \( g \) is the gravitational acceleration. One more constitutive relation is the equation of continuity, written for the filtration velocity and density, related to the total volume of the porous medium:

\[
\frac{\partial (m \rho)}{\partial t} + \nabla \cdot (\rho v) = 0 ,
\]

where \( m \) is the porosity. By using (2) and (3), we derive the filtration equation:

\[
\frac{\partial (m \rho)}{\partial t} = \nabla \cdot \left( \frac{K(P)}{g} \nabla P \right).
\]

The filtration regime is characterized by the fact that the fluid density \( \rho \) and porosity \( m \) depend on the pressure. During hydrodynamic fracturing, the treatment proceeds in elastic mode, under which the fluid and porous medium compressibility is taken into account due to the high pressure gradients. According to [5], the following relationships are used for the density and porosity under the pressure of the order of \( 10^7 \) Pa:

\[
\rho = \rho_0 (1 + \beta_1 (P - P_0)) ,
\]

\[
m = m_0 + \beta_2 (P - P_0) ,
\]

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