JUSTIFICATION OF RHEOTECHNOLOGICAL METHODS OF CONTROL OF COLMATAGE

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UDC 539.30+622.244+517.9

Theoretical and experimental investigations of localized structures appearing in filtration of nonlinear viscoplastic drilling fluids are reported. The depth of penetration of mud into a porous medium is shown to be dependent on the rate of change of the pressure on the boundary. This fact has been suggested for use in creation of colmatage barriers that prevent penetration of drilling mud into strata.

Introduction. Penetration of drilling fluids into a stratum (upon its opening) and their filtration can result in a sharp reduction in the stratum permeability due to colmatage processes (cluttering of the pores with disperse particles suspended in the fluid). Investigations show that this phenomenon serves as a basic cause of reduction in well output. Sometimes, due to colmatage, well output is reduced by tens of times. Colmatage taking place in close vicinity to a well can play a positive role as well, since it leads to formation of a low-permeability layer of the porous medium that limits penetration of drilling mud into the stratum. This effect can be purposefully employed to protect the near-bottom zone when technological techniques enabling the creation of colmatage barriers of sufficiently small thickness near the well walls are available.

In the present paper it is shown that rheotechnological methods can be used to control colmatage processes. These methods are based on the use of specific features of the rheology of drilling mud (the structural viscosity of the fluids is strongly dependent on their shear rate [1-4]). An analysis of certain exact solutions of filtration equations for a nonlinear viscoplastic fluid is performed. On the basis of the analysis it is shown that the intrusion depth of the fluid into a stratum can be regulated by controlling the rate of pressure change at the porous medium boundary. Experimental results on investigation of filtration of water-polymer drilling fluids in a laboratory model of a stratum are given that confirm qualitative conclusions made in an analysis of mathematical models.

Localization of Boundary Regimes. The rheology of drilling fluids is determined by the interaction of molecules and supramolecular aggregates that tend to form a spatial structure, which provides the fluids with viscoplastic properties. Viscoplasticity means that the fluids start to move only when the absolute value of the pressure gradient exceeds a certain critical value (the starting pressure gradient). In movement the behavior of the structured fluid also differs substantially from the behavior of an ordinary viscous (Newtonian) fluid, since an increase in the shear rate leads to further degradation of the structure. Therefore, drilling fluids should be included in the class of nonlinear viscoplastic media whose structural viscosity depends on the velocity of movement.

Equations describing the transient radially symmetric filtration of a nonlinear viscoplastic medium are of the form [5, 6]:

\[
\frac{m \beta}{\partial t} = -\frac{1}{x^2} \frac{\partial}{\partial x} \left( x^2 \nu \right); \quad x \in (x_1, +\infty), \quad t \in (0, +\infty);
\]

\[
\nu = \begin{cases} 
-\frac{k}{\mu (|\nu|)} Z \text{sgn} \left( \frac{\partial P}{\partial x} \right), & Z > 0, \\
0, & Z \leq 0,
\end{cases}
\]

where \( m, \beta, \) and \( k \) are the porosity, compressibility, and permeability of the porous medium; \( P \) is the pressure; \( \mu = \mu(1/v) \) is the fluid viscosity, which depends on the filtration rate \( v \):

\[
Z = \left| \frac{\partial P}{\partial x} \right| - \Theta
\]

(\( \Theta \) is the initial pressure gradient; \( S = 0, 1, \) or \( 2 \) for flat, flat-radial, and spherical filtration, respectively). If we restrict ourselves to consideration of solutions monotonically decreasing in \( x \) and replace the variables by the dimensionless ones

\[
\bar{P} = P/P_0, \quad \bar{\Theta} = \Theta/\Theta_0, \quad \bar{Z} = Z/\Theta_0, \quad \bar{\nu} = \nu/\nu_0,
\]

where \( P_0, \Theta_0, \) and \( \mu_0 \) are certain characteristic values of the pressure, initial pressure gradient, and viscosity;

\[
l_0 = P_0/\Theta_0; \quad \nu_0 = k/\mu_0 \Theta_0; \quad l_0 = x_0^2/a;
\]

\( a = k/m\beta\mu_0 \) is the piezoconductivity coefficient, then by differentiating with respect to \( x \) we obtain from (1) the equation

\[
\frac{\partial \bar{Z}}{\partial \bar{t}} + \frac{\partial \bar{\Theta}}{\partial \bar{t}} = \frac{\partial}{\partial \bar{x}} \left[ \frac{1}{\bar{x}^\lambda} \frac{\partial (\bar{x}^\lambda \Phi (\bar{Z}))}{\partial \bar{x}} \right], \quad \bar{x} \in R, \quad \bar{t} \in (0; + \infty), \tag{3}
\]

where \( R \) is the domain in which \( Z > 0; \bar{\nu} = \Phi(\bar{Z}) \) is the function inverse to the function \( \bar{Z} = \bar{\nu}_1(\bar{\nu}) \). We will consider that the function \( \Phi(Z) \) is a monotonically increasing one, and

\[
\Phi'(0) = 0. \tag{4}
\]

Hereinafter, we will use only dimensionless quantities, and therefore the bars will be omitted.

First of all we consider solutions of (3) corresponding to a constant \( \Theta: \Theta = \Theta_1 \). By virtue of (4) Eq. (3) is degenerate: at \( Z = 0 \) the condition of its parabolicity is violated. As is known [7, 8], such equations can have generalized solutions describing propagation of disturbances with a finite penetration depth (as mentioned above, precisely these solutions are of interest to us). In order to study the behavior of localized regimes in more detail, we approximate the function by a power dependence

\[
\Phi(Z) = Z^\lambda, \quad \lambda = \text{const} > 1.
\]

By making the replacement

\[
u = x^{\lambda} \bar{Z}, \quad y = x^\sigma, \quad \tau = \sigma^2 \bar{t},
\]

we obtain from (3) (for \( \Theta = \text{const} \))

\[
\frac{\partial u}{\partial \tau} = y^\sigma \frac{\partial}{\partial y} \left( \frac{1}{y^\sigma} \frac{\partial u^\lambda}{\partial y} \right), \tag{5}
\]

where

\[
\sigma = 1 + \frac{S}{2} \left( \frac{\lambda - 1}{\lambda} \right), \quad \delta = \frac{S}{2\sigma^\lambda} (\lambda + 1).
\]