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FILTRATION IN THE FACE ZONE OF AN OIL POOL WITH ABNORMALLY HIGH SEAM PRESSURE

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The problem of the filtration to a well in a thin strained clay-containing seam with an abnormally high initial seam pressure is solved. The rheological behavior of the seam is described by the Kelvin–Voigt model. The drop in the flow rate of the well and the decrease and rate of decrease in the seam pressure are calculated for different parameters of the model.

In many cases, the abnormally high seam pressure in oil pools can be due to clay compaction and dehydration [1]. In modeling filtration in these pools, the substantial dependence of the permeability of the medium on the stressed-strained state (SSS) should be allowed for in the initial step of their working [2]. This dependence is due not only to contracting of the initially undercompacted seam by the weight of overlying rocks [2] but also to the clay redistribution in pores in contraction. In accordance with this, the permeability of the network of channels along which a liquid moves can be represented as the product $k(\varepsilon) = k_0(m)f(\sigma)$. We will give some estimations of the range of change for $k(0)/k(\varepsilon)$.

If it is assumed that the strain that is experienced by the seam in operation is pure transverse, it will be equal to a relative change in the medium volume. In straining, the volumes of the solid phase and clay are preserved, in practice; therefore $(m - m_0) = (1 - m_0)\theta$ and $ms = m_0 s_0$. Let us assume that $\varepsilon = -0.05$, $m_0 = 0.3$. Then $m = 0.265$ and, in accordance with the Kozeni formula, $k_0(m)/k_0(m_0) = (m/m_0)^3 = 0.69$. We note that, from the data of [2], this ratio is 0.67. The effect of the clay redistribution on $k(\varepsilon)$ can be estimated by the cubic relative permeability

$$f(\sigma) = \max\left\{0\,,\ \left(\frac{\sigma - \sigma_*}{\sigma_0 - \sigma_*}\right)^3\right\}.$$

Let the loss of the hydraulic connectivity of the conducting network occur for $\sigma_* = 0.2$. Then, after straining, the function $f(\sigma)$, for $s_0 = 0.3$, 0.4, 0.5, and 0.71, takes on values of 0.78, 0.65, 0.47, and 0, the corresponding values of $k(0)/k(\varepsilon)$ being 1.85, 2.23, 3.05, and ∞. Thus, a strain change in the hydroconductivity of the seam with an abnormally high steam pressure depends strongly on the clay content in it and can be very significant. In what follows, the dependence $k(\varepsilon)$, similarly to [2, 3], is taken as $k(\varepsilon) = k(0)\exp(\alpha\varepsilon)$.

We consider a horizontal liquid-saturated uniform seam within the thickness of rocks at a distance from the free surface, which is much larger than the seam thickness. Let us consider that the seam is clay-containing and the liquid in it is under high pressure. In accordance with the above, when this seam is opened with the well with the prescribed lower pressure, in the vicinity of the well, a distinct compaction of the porous matrix can occur, and the clay redistribution will be initiated in the pores. This will result in a substantial and, what is more, irreversible increase in the filtration resistance and a viscoelastic behavior of the porous matrix.

To further analyze the pressure fields in a seam and the well flow rate as functions of time, we state an axisymmetric interrelated problem of the SSS of rocks and filtration seam consolidation in well operation. The rocks are modeled by a uniform elastic half-space, which is characterized by the Young modulus and Poisson coefficient, while the seam is modeled by the section parallel to its roof and floor [4, 5]. The well axis coincides with the

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vertical axis of a cylindrical coordinate system. The SSS of the elastic half-space obeys the equations of a linear theory of elasticity, which are written in displacements from the initial state. On the banks of the section, with allowance made for the filtration consolidation of the seam, there are conjugation conditions, the rheological properties of the seam being described by the Kelvin–Voigt model with its Young modulus and coefficient, which are responsible for the viscous component of seam strains. Thus, the boundary conditions of the problem take the following form:

$$z = h: \ \sigma_z = \tau_{rz} = 0 ,$$

$$z = 0: \ [\sigma_z] = [\tau_{rz}] = 0 , \ \ [u_r] = 0 ,$$

$$\left(E_1 + \mu_1 \frac{\partial}{\partial t}\right) \varepsilon = \sigma_z + p .$$

For the described statement of the problem, with the constraints $\mu_1 = 0$ the integral operator, which makes it possible to efficiently calculate the strain $\varepsilon = \varepsilon[p(r)]$ with the prescribed distribution of the pressure $p = p(r)$ in the seam-section, was obtained in [5]. In a similar manner, we can relate transverse strains of the section boundaries to the indicated pressure distribution in the case $\mu_1 \neq 0$, also.

Let us set the initial pressure in an undisturbed seam equal to zero. We introduce the following dimensionless quantities:

$$P = \frac{p}{p_0}, \ \ \rho = \frac{r}{R}, \ \ \tau = \frac{\kappa t}{R^2}, \ \ \varepsilon^0 = \frac{\varepsilon E}{p_0}, \ \ \beta = \frac{\mu_1 \kappa}{E_1 R^2},$$

$$a = \frac{4R(1-\nu^2)}{\delta} \frac{E_1}{E}, \ \ K(\varepsilon^0) = \frac{k(\varepsilon^0)}{k(0)} .$$

Then we obtain the following integrodifferential equation to determine the transverse seam strains as functions of pressure:

$$\varepsilon^0(P) + \beta \frac{\partial \varepsilon^0}{\partial \tau} = \frac{aE}{E_1} \int_{\rho_0}^{1} \xi P(\xi, \tau) A(\xi, P) \, d\xi , \tag{1}$$

$$A(\xi, \rho) = \begin{cases} \dfrac{2}{\pi \xi} K\left(\dfrac{\rho}{\xi}\right) - \dfrac{2a^2}{\pi} \displaystyle\int_0^{\infty} \dfrac{I_0(\rho y) K_0(\xi y)}{y^2 + a^2} dy , & \rho < \xi , \\ \xi \leftrightarrow \rho , \ \ \xi < \rho , \end{cases} \tag{2}$$

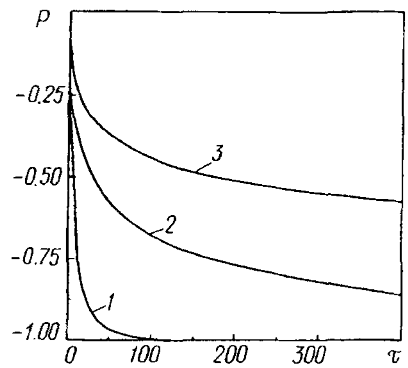
with the initial condition

$$\varepsilon^0(\rho, 0) = 0 . \tag{3}$$

Plane-radial filtration in the strained seam is described by the nonlinear parabolic equation [6]

$$\frac{1}{\rho} \frac{\partial}{\partial \rho} \left\{ \rho K[\varepsilon^0(P)] \frac{\partial P}{\partial \rho} \right\} = \frac{\partial P}{\partial \tau} . \tag{4}$$

Let the external boundary of the seam be impermeable to a liquid. Then Eq. (4) corresponds to the initial and boundary conditions:



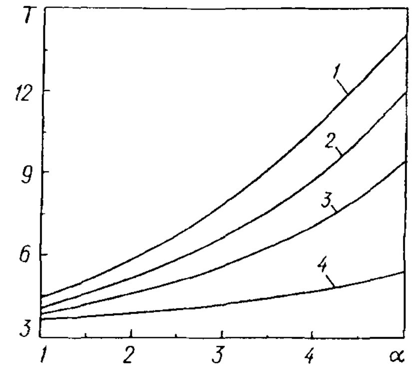


Fig. 1. Dimensionless pressure at an impermeable boundary of a seam vs. dimensionless time [1) $\alpha = 1$; 2) 3; 3) 5] for $\rho_0 = 10^{-3}$; $a = 20$; $\beta = 1$.

Fig. 2. Dimensionless time of a $1/e$ decrease in the external-boundary pressure relative to the well pressure as a function of the strain sensitivity of the permeability of a seam [1) $\beta = 0$; 2) 1; 3) 2; 4) 5] for $\rho_0 = 10^{-3}$, $a = 80$.

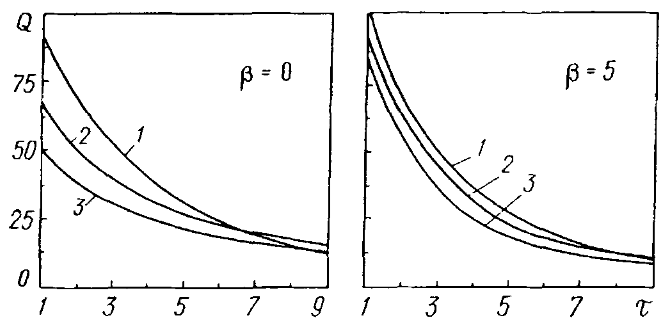


Fig. 3. Dimensionless flow rate of a well vs. dimensionless time [1) $\alpha = 1$; 2) 3; 3) 5] for $\rho_0 = 10^{-3}$; $a = 80$.

$$P(\rho, 0) = 0, \; P(\rho_0, \tau) = -1, \; \left.\frac{\partial P}{\partial \rho}\right|_{\rho=1} = 0. \tag{5}$$

The nonlinear boundary problem (1)-(5) was solved numerically. Calculations were performed using a difference scheme with a weight of 0.6 [7] for the fixed ρ_0 and $a = 40E_1/E$. Their results are presented below in Figs. 1-3.

According to Fig. 1, the larger the α and hence the sensitivity of the permeability of the seam to its strains, the more slowly the pressure at its external boundary drops.

Let $\tau = T$ be the time from the instant $\tau = 0$, in which the pressure attains the value $p = -1/e$. Figure 2 illustrates how the indicated time varies as a function of the parameter α for fixed values of β. A growth in strain sensitivity for the seam leads to an increase in the time T, the increase in β (i.e., "viscosity" of the seam) decreasing the growth rate for T.

Figure 3 shows the behavior of the dimensionless flow rate of the well

$$Q = \exp(\alpha\varepsilon^0) \left.\frac{\partial P}{\partial \rho}\right|_{\rho=\rho_0}$$

with time. It is evident that, for fixed α, the well flow rate increases with the viscous component of seam strains.

NOTATION

k and K, dimensional and dimensionless permeability of the channel network; k_0, absolute permeability of the porous medium; f, relative permeability of conducting channels; m, total porosity; m_0, porosity in the absence of strains; $\sigma = 1 - s$; s, clay saturation of pores; s_0, initial clay saturation of pores; σ_*, critical value of the parameter σ which corresponds to the loss of the hydraulic connectivity of the conducticting channel network; ε, transverse strain of the seam; θ, relative change in the medium volume; E and ν, Young modulus and Poisson coefficient of the elastic half-space; r and ρ, dimensional and dimensionless longitudinal coordinates of the cylindrical system; z, vertical coordinate; μ_1 and β, dimensional and dimensionless coefficients on the viscous component of the seam strains; h, depth of seam occurrence; δ, seam thickness; σ_z and τ_{rz}, components of the stress tensor; u_r, component of the displacement vector; [ ], symbol of an abrupt change in the quantity in crossing the section; t and τ, dimensional and dimensionless times; p and P, dimensional and dimensionless pressures; p_0, modulus of pressure on the well contour; ρ_0, dimensionless radius of the well contour; R, radius of the external boundary of the seam; $K(\rho/\xi)$, total elliptic integral; $I_0(\rho y)$ and $K_0(\xi y)$, modified Bessel functions; κ, piezoconductivity of the seam; T, dimensionless time of an $1/e$ pressure drop at the external boundary of the seam relative to the well pressure; Q, dimensionless flow rate of the well; α, sensitivity coefficient for the permeability of the seam to its strains.

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