CENTRALLY SYMMETRICAL FILTRATION OF LIQUID IN CRACKED POROUS MEDIA WITH A HEMISPHERICAL SUPPLY CONTOUR

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The motion of a homogeneous liquid in a well with a hemispherical face is studied for the case of transient, spherically radial filtration in cracked porous media comprising mutually superposed hemispherical regions with different crack permeabilities, having a supply contour in the outer hemispherical region. Using a Laplace integral transformation with respect to the time variable, the systems of differential equations describing the filtration of liquid in these media are solved for zero initial and corresponding boundary conditions. Exact solutions are obtained for the reduction in stratal pressure with time and distance, and also for the changes taking place in the output of a well operating under conditions of specified face pressure. On the basis of corresponding numerical calculations, the influence of the parameters of the cracked porous strata and the radius of the surface containing the supply contour on the indices of the production process is established.

1. Formulation of the Problem

An analysis of existing literature relating to well-drilling and the operation of oil wells in sites characterized by cracked porous collectors shows that these sites contain caverns, zones of broken rocks, and tectonic dislocations which prevent the greater part of their width from being exploited. The width of the strata, in fact, varies from tens to hundreds of meters [1, 2], so that in a number of cases we may regard the ratio of the opened region to the total width as a small quantity, and the flow of liquid to the well as centrally symmetrical. It is accordingly reasonable to assume that the face of the well has a hemispherical shape of radius R_W (Fig. 1).

Analogous hydrodynamic problems for a granular stratum were solved earlier in an approximate form [3], or in an exact form for a homogeneous stratum [4]; a number of exact solutions were obtained in a complex form in [5-7].

In order to solve the corresponding hydrodynamic problems for a cracked porous stratum, let us assume (Fig. 1) that there is a hemispherical region $R_W \leq R \leq R_0$ with a permeability k_1 around a well with a hemispherical face. Outside this zone $R_0 \leq R \leq R_1$ and the permeability of the system of cracks has the value k_2. In contrast to the previous discussion [8], we assume that a constant pressure p_0 is maintained on the surface of the hemisphere $R = R_1$ during the whole production process. It is required to determine the fall in pressure at an arbitrary point in the variable-permeability system of cracks in the cracked porous medium at any instant of operation. This form of presentation enables us to establish the part played by the skin effect in the part of the well close to the face in changing the indices characterizing working processes in the well (the removal of sand, the silling process, and other features tending to damage the well) on the basis of numerical calculations.

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In accordance with the theory of filtration of a homogeneous liquid in cracked porous media [9, 10], as applied to a centrally symmetrical flow [8], we must now integrate the following systems of differential equations:

$$\frac{\partial^2\psi_i^{(2)}}{\partial\xi^2}+\frac{2}{\xi}\frac{\partial\psi_i^{(2)}}{\partial\xi}-\frac{1-\omega}{k_i}\frac{\partial\psi_i^{(1)}}{\partial\tau}=\frac{\omega}{k_i}\frac{\partial\psi_i^{(2)}}{\partial\tau};$$
$$\frac{\partial\psi_i^{(1)}}{\partial\tau}+\Lambda\psi_i^{(1)}=\Lambda\psi_i^{(2)},\quad i=1,2 \tag{1.1}$$

subject to the initial conditions

$$\psi_i^{(1)}(\xi,0)=\psi_i^{(2)}(\xi,0)=0,\quad i=1,2 \tag{1.2}$$

and the boundary conditions

$$\psi_2^{(2)}(\xi_1,\tau)=0; \tag{1.3}$$

$$\psi_1^{(2)}(\xi_0,\tau)=\psi_2^{(2)}(\xi_0,\tau);\quad \frac{\partial}{\partial\xi}\psi_1^{(2)}(\xi_0,\tau)=k_0\frac{\partial}{\partial\xi}\psi_2^{(2)}(\xi_0,\tau). \tag{1.4}$$

Here we have used the notation

$$\xi_\nu=R_\nu/R_W;\quad \tau=\frac{k_1^2 t}{\mu R_W^2 B};\quad \Lambda=\lambda(1-\omega)^{-1};$$
$$\lambda=\alpha R_W^2 k_i^{(1)}/k_i^{(2)};\quad \omega=\frac{1}{B}m_i^{(2)}\beta_i^{(2)};$$
$$1-\omega=\frac{1}{B}m_i^{(1)}\beta_i^{(1)};\quad B=m_i^{(1)}\beta_i^{(1)}+m_i^{(2)}\beta_i^{(2)};$$
$$\psi_i^{(j)}(\xi,\tau)=\frac{1}{p_0}[p_0-p_i^{(j)}(\xi,\tau)];$$
$$k_i=\begin{cases}1, & i=1\\ k_0=k_2^{(2)}/k_1^{(2)}, & i=2,\ j=1,2,\end{cases}$$

where α is a parameter of the cracked porous medium characterizing the exchange of liquid between the systems of low-permeability blocks and high-permeability cracks; p_0 and $p(\xi,\tau)$ are the initial and current pressures respectively; k is the permeability coefficient; μ is the dynamic viscosity of the filtering liquid; m is the porosity; β is the compressibility of the medium; R is the radial coordinate; t is the time. The upper indices 1 and 2 in the functions of pressure and the parameters of the stratum, respectively, relate to the systems of blocks (matrices) and cracks in the medium, and the lower indices relate to the hemispherical regions of the stratum.

Conditions (1.4) signify the constancy of the fall in pressure and the flow velocity in the system of cracks on the hemisphere $R=R_0$, which constitutes the boundary between regions with different degrees of permeability. Analogous conditions are not specified for the systems of blocks in the medium, since it is the cracks in the medium which serve as channels, taking the liquid to the well, while the low-permeability blocks of rock simply feed these with liquid as the pressure drops.

Conditions (1.2)-(1.4) must be supplemented by specifying the pressure or output (flow) at the hemispherical surface of the well. We shall now give the solution to the problem for various working conditions of the wells.

2. Pressure Field of a Cracked, Porous Stratum for a Specified Well Flow Equal to $q(\tau)$

The condition specifying the flow of a well with a hemispherical face for a spherically radial filtration may (according to the Darcy filtration law) be written in the form

$$\left[\xi^2\frac{\partial}{\partial\xi}\psi_1^{(2)}(\xi,\tau)\right]_{\xi=1}=-q(\tau); \tag{2.1}$$

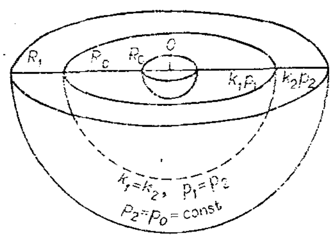

Fig. 1

$$\psi_i^{(j)}(\xi,\tau) = 2\pi k_1^{(2)} R_W(\mu q_0)^{-1}\left[p_0 - p_i^{(j)}(\xi,\tau)\right], \quad i,j=1,2. \tag{2.2}$$

If we apply a Laplace transformation in the time variable to the system (1.1) (using a transformation parameter s) and eliminate the function $\psi_i^{(1)}(\xi, \tau)$ from the transformed systems, we obtain (subsequently omitting the index 2):

$$\frac{1}{\xi^2}\frac{d}{d\xi}\left[\xi^2\frac{d}{d\xi}\Psi_i(\xi,s)\right] - \frac{S(s)}{k_i}\Psi_i(\xi,s)=0, \quad i=1,2; \tag{2.3}$$
$$S(s)=s(\omega s+\Lambda)(s+\Lambda)^{-1}.$$

After applying the Laplace transformation to the boundary conditions (1.3) and (1.4), these retain their form with respect to the functions $\Psi_i(\xi, s)$, while condition (2.1) becomes

$$\left[\xi^2\frac{d}{d\xi}\Psi_1(\xi,s)\right]_{\xi=1} = -q(s).$$

The solution of the system of equations (2.3) for the boundary conditions indicated takes the form [11]

$$\Psi_i(\xi,s)=\frac{q(s)}{\xi}\cdot\frac{U_i[\xi,S(s)]}{V[\xi_0,\xi_1,S(s)]}, \quad i=1,2; \tag{2.4}$$
$$U_1(\xi,x)=\left(1+\sqrt{k_0}\right)\operatorname{sh}(X_1-\xi)\sqrt{x}+\left(1-\sqrt{k_0}\right)\operatorname{sh}(X_2+\xi)\times$$
$$\times\sqrt{x}+\frac{1-k_0}{\xi_0\sqrt{x}}\left[\operatorname{ch}(X_2+\xi)\sqrt{x}-\operatorname{ch}(X_1-\xi)\sqrt{x}\right];$$
$$U_2(\xi,x)=2\operatorname{sh}(\xi_1-\xi)\sqrt{x/k_0};$$
$$V(\xi_0,\xi_1,x)=\left(1-\sqrt{k_0}+\frac{1-k_0}{\xi_0}\right)\operatorname{sh}(X_2+1)\sqrt{x}+$$
$$+\left[\left(\sqrt{k_0}-1\right)\sqrt{x}+\frac{1-k_0}{\xi_0\sqrt{x}}\right]\operatorname{ch}(X_2+1)\sqrt{x}+\left(1+\sqrt{k_0}-\right.$$
$$\left.-\frac{1-k_0}{\xi_0}\right)\operatorname{sh}(X_1-1)\sqrt{x}+\left[\left(1+\sqrt{k_0}\right)\sqrt{x}-\frac{1-k_0}{\xi_0\sqrt{x}}\right]\operatorname{ch}(X_1-1)\sqrt{x};$$
$$X_{1,2}=\frac{\xi_1-\xi_0}{\sqrt{k_0}}\pm\xi_0. \tag{2.5}$$

In order to transform from the images (2.4) to their originals we must specify the change in the well flow by means of an analytical expression. Let the well flow diminish in accordance with the law

$$q(\tau)=q_0\exp(-\nu\tau) \doteqdot q_0(s+\nu)^{-1}, \tag{2.6}$$

where q_0 is the constant well flow before the inflow starts diminishing; $\nu \geq 0$ is a dimensionless parameter defining the rate of diminution.

We see from Eqs. (2.5) and (2.6) that the functions $\psi_i(\xi, s)$, (i = 1, 2) are meromorphic, having simple poles with respect to the argument S(s); they may therefore be expanded into an infinite series with respect to the roots $-p_m^2$ of the equation

$$V\ [\xi_0,\ \xi_1,\ S(s)]=0. \tag{2.7}$$

If we then transform to the original by the second expansion theorem [12] we obtain

$$\psi_i(\xi,\tau)=\frac{\Lambda-\nu}{\xi}\exp(-\nu\tau)\sum_{m=1}^{\infty}\frac{U_i(\xi,p_m)}{W_1(\xi_0,\xi_1,p_m)}\left[\Lambda p_m^2+\right. \tag{2.8}$$
$$\left.+\left(\nu\omega-\Lambda-p_m^2\right)\nu\right]^{-1}+\frac{1}{\xi}\sum_{m=1}^{\infty}\frac{U_i(\xi,p_m)}{\delta_m W_1(\xi_0,\xi_1,p_m)}\times$$
$$\times\left[\frac{\Lambda-s_{1m}}{\nu-s_{1m}}\exp(-s_{1m}\tau)-\frac{\Lambda-s_{2m}}{\nu-s_{2m}}\exp(-s_{2m}\tau)\right], \quad i=1,2;$$

$$W_1(\xi_0, \xi_1, x) = \left[\left(\sqrt{k_0} - 1 + \frac{1-k_0}{\xi_0}\right)(X_2 - 1) + (1 - k_0) \times \right. \tag{2.9}$$

$$\times \left.\left(1 - \frac{1}{\xi_0 x}\right)\right] \frac{\cos(X_2 + 1)x}{2x} + \frac{X_2 - 1}{2x^2}\left[(1 - \sqrt{k_0})x^2 + \right.$$

$$\left. + \frac{1-k_0}{\xi_0}\right] \sin(X_2 + 1)x + \left[\frac{1-k_0}{\xi_0 x^2} - 1 - \sqrt{k_0} - \left(1 + \sqrt{k_0} - \right.\right.$$

$$\left.\left. - \frac{1-k_0}{\xi_0}\right)(X_1 - 1)\right] \frac{\cos(X_1 - 1)x}{2x} + \frac{X_1 - 1}{2x^2}\left[(1 - \sqrt{k_0})x^2 + \frac{1-k_0}{\xi_0}\right] \sin(X_1 - 1)x;$$

$$s_{(1,2)m} = \frac{\Lambda + p_m^2 \mp \delta_m}{2\omega};$$

$$\delta_m = \left[(\Lambda + p_m^2)^2 - 4\Lambda\omega p_m^2\right]^{1/2}.$$

The resultant equation (2.8) is an exact solution of the problem formulated, and describes the change in pressure taking place at arbitrary points of the inhomogeneously permeable system of cracks in the cracked porous medium at any instant of time during well operation when the well flow varies in accordance with the law (2.6). In particular, if we put $\nu = 0$, the equation giving the fall in pressure may, on the basis of Eq. (2.8), be written in the following form for the case $q = q_0 = \text{const}$:

$$[\psi_i(\xi, \tau)]_{\nu=0} = \frac{1}{\xi} \sum_{m=1}^{\infty} \frac{U_i(\xi, p_m)}{p_m^2 W_1(\xi_0, \xi_1, p_m)} \left[1 - \omega s_{2m} \frac{\Lambda - s_{1m}}{\Lambda \delta_m} \times \right. \tag{2.10}$$

$$\left. \times \exp(-s_{1m}\tau) + \omega s_{1m} \frac{\Lambda - s_{2m}}{\Lambda \delta_m} \exp(-s_{2m}\tau)\right], \quad i = 1, 2.$$

In view of the linearity of the Laplace transformation the difference between the right-hand sides of (2.10) and (2.8) will correspond to the law governing the change in well flow, expressed in the form

$$q(\tau) = q_0[1 - \exp(-\nu\tau)].$$

In order to find an expression for the face pressure we must put $i = 1$, $\xi = 1$ in Eqs. (2.8) and (2.10). The form of these equations then remains exactly the same, only the function $U_i(\xi, p_m)$ transforms into $U_1(1, p_m)$.

It may be shown that when $\omega = 1$, $\lambda \to \infty$ Eq. (2.10) transforms into the well-known solution of the corresponding problem for a granular medium [4]

$$[\psi_1(\xi, \tau)]_{k_0=1} = [\psi_2(\xi, \tau)]_{k_0=1} = \frac{\xi_1 - \xi}{\xi_1 \xi} + \frac{2}{\xi} \sum_{m=1}^{\infty} \frac{1}{p_m} \frac{\sin(\xi_1 - \xi) p_m \exp(-p_m^2 \tau)}{\left[\xi_1 - (\xi_1 - 1) p_m^2\right] \cos(\xi_1 - 1) p_m}, \tag{2.11}$$

where p_m are the roots of the equation

$$[V(\xi_0, \xi_1, x)]_{k_0=1} = 0 \quad \text{or} \quad x^{-1} \operatorname{tg} x = (1 - \xi_1)^{-1}.$$

3. Determination of the Flow from a Well Working in a Cracked Porous Stratum for a Specified Face Pressure p_c = const

In contrast to condition (2.1) for the normalized fall in pressure,

$$\psi_i(\xi, \tau) = [p_0 - p_i(\xi, \tau)](p_0 - p_c)^{-1}, \quad i = 1, 2$$

we must now specify a condition in the form

$$\psi_1(1, \tau) = 1. \tag{3.1}$$

The set of conditions (1.3), (1.4), and (3.1) enables us to find a solution to the problem in the Laplace transform as follows:

TABLE 1

m	$10^4\ p_m$	$\lambda=0{,}005$		$\lambda=1$			
		$\omega=0{,}1$		$\omega=0\ 1$		$\omega=0{,}5$	
	from (2.7) $k_0=1$	$10^6 s_{1m}$	$10^3 s_{2m}$	$10^4 s_{1m}$	$10^3 s_{2m}$	$10^4 s_{1m}$	$10^3 s_{2m}$
1	2 863	5 234	870	768	11 853	803	4083
2	5 761	5 472	3 368	2602	14 167	3 045	4359
3	8 708	5 519	7 633	4631	18 232	6 194	4897
4	1 1703	5 536	13745	6894	24 177	9 456	5793
5	1 4734	5 543	21758	7522	32 066	12 192	7122
6	1 7791	5 547	31703	8386	41 923	14 211	8909
m	from (3.3) $k_0=1$						
1	3 141	5250	1 037	913	12 006	962	4 101
2	6 283	5485	3 998	2971	14 761	3 592	4 433
3	9 425	5520	8 932	5064	19 487	6 999	5 077
4	12 566	5545	15 841	6688	26 234	10 309	6 127
5	15 708	5546	24 724	7832	35 002	12 912	7 643
6	18 850	5547	35 580	8223	45 779	14 758	9 630
7	21 991	5548	48 411	9177	58 554	16 028	12 069
8	25 133	5549	62 146	9704	72 123	16 909	14 942

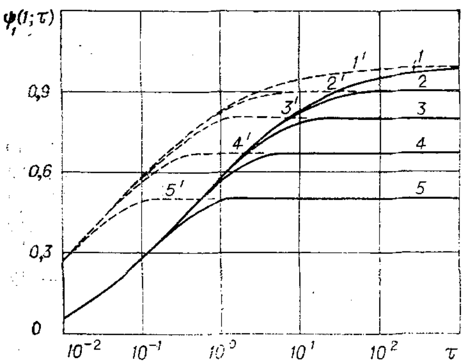

Fig. 2

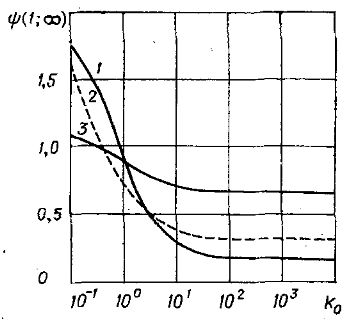

Fig. 3

$$\Psi_i(\xi, s) = \frac{1}{\xi_s} U_i[\xi, S(s)]/U_1[\xi, S(s)], \quad i = 1, 2. \tag{3.2}$$

Expanding the right-hand side of (3.2) into an infinite series with respect to the roots $-p_m^2$ of the equation

$$U_1[\xi, S(s)]=0, \tag{3.3}$$

we obtain the final solution to the problem in the form

$$\psi_i(\xi, \tau) = \frac{\omega}{\Lambda\xi} \sum_{m=1}^{\infty} \frac{U_i(\xi, p_m)}{\delta_m p_m^2 W_2(\xi_0, \xi_1, p_m)} \frac{\Lambda\delta_m}{\omega} - s_{2m}(\Lambda - s_{1m}) \times$$
$$\times \exp(-s_{1m}\tau) + s_{1m}(\Lambda - s_{2m}) \exp(-s_{2m}\tau)], \quad i = 1, 2; \tag{3.4}$$
$$W_2(\xi_0\ \xi_1, x) = \frac{k_0 - 1}{2x}\left(\frac{1}{\xi_0 x} + X_2 + 1\right)\cos(X_2 + 1)x -$$
$$-\frac{1}{2x}\left[\frac{k_0-1}{\xi_0 x} + (1 + \sqrt{k_0})(X_1 - 1)\right]\cos(X_1 - 1)x +$$
$$+\frac{k_0 - 1}{2\xi_0 x^2}[(X_2 + 1)\sin(X_3 + 1)x - (X_1 - 1)\sin(X_1 - 1)x].$$

If we put $k_0 = 1$ in Eq. (3.4), for a homogeneous cracked porous stratum we obtain the equation

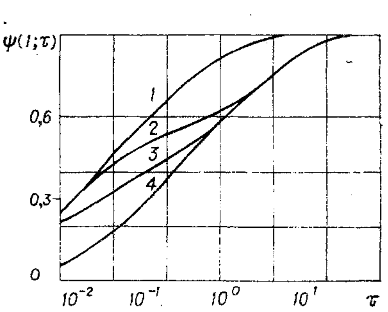

Fig. 4

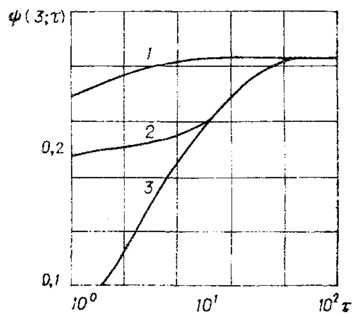

Fig. 5

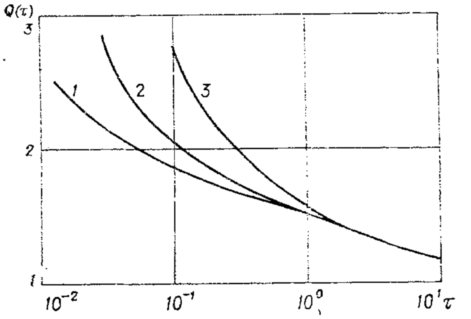

Fig. 6

$$[\psi_1(\xi,\tau)]_{k_0=1} = [\psi_2(\xi,\tau)]_{k_0=1} = \frac{1}{\xi}\frac{\xi_1-\xi}{\xi_1-1} + \frac{2\omega}{\pi\Lambda\xi}\sum_{m=1}^{\infty}\frac{(-1)^m}{m\delta_m}[s_{1m}(\Lambda - s_{2m})\exp(-s_{2m}\tau) - s_{2m}(\Lambda - s_{1m})\exp(-s_{1m}\tau)]\sin\frac{\xi_1-\xi}{\xi_1-1}m\pi,$$

in deriving which we have used Eq. (1.441.3) taken from [13].

Using a relation taken from operational calculus,

$$\int_0^{\infty} a_0 \exp(-s\tau)\,d\tau = \frac{a_0}{s}$$

and assuming that a_0 is the term independent of τ (the free term) in the time expansion of the function $\psi_i(\xi, \tau)$, Eq. (3.4) may be given a form convenient for calculation:

$$\psi_i(\xi,\tau) = \frac{1}{\xi}\frac{\xi_1 - \xi\sqrt{k_0}}{\xi_1 - \sqrt{k_0}} + \frac{\omega}{\Lambda\xi}\sum_{m=1}^{\infty}\frac{U_i(\xi, p_m)}{\delta_m p_m^2 W_2(\xi_0, \xi_1, p_m)} \times [s_{1m}(\Lambda - s_{2m})\exp(-s_{2m}\tau) - s_{2m}(\Lambda - s_{1m})\exp(-s_{1m}\tau)], \quad i = 1,2. \tag{3.5}$$

Using the expression for $\psi_1(\xi, \tau)$ from (3.5) we may determine the well flow in accordance with the linear Darcy filtration law in the form

$$Q(\tau) \equiv \frac{\mu q(\tau)}{2\pi k_1^{(2)} R_W (p_0 - pc)} = \frac{\xi_1}{\xi_1 - \sqrt{k_0}} + \frac{\omega}{\Lambda} \times \sum_{m=1}^{\infty}\frac{U_3(1, p_m)}{\delta_m p_m^2 W_2(\xi_0, \xi_1, p_m)}[s_{1m}(\Lambda - s_{2m})\exp(-s_{2m}\tau) - s_{2m}(\Lambda - s_{1m})\exp(-s_{1m}\tau)]; \tag{3.6}$$

$$U_3(1, p_m) = \left(\frac{1-k_0}{\xi_0 p_m} - 1 + \sqrt{k_0}\right)\cos(X_2+1)p_m + \left(1 - \sqrt{k_0} - \frac{1-k_0}{\xi_0}\right)\sin(X_2+1)p_m - \left(\frac{1-k_0}{\xi_0 p_m} - 1 - \sqrt{k_0}\right)\cdot\cos(X_1 - 1)p_m + \left(1 + \sqrt{k_0} - \frac{1-k_0}{\xi_0}\sin(X_1-1)p_m\right).$$

As the particular case in which $\omega = K_0 = 1$ we may than derive the corresponding solution for a granular medium [4],

$$Q(\tau) = \frac{\xi_1}{\xi_1 - 1} + \frac{2}{\xi_1 - 1}\sum_{m=1}^{\infty}\exp\left[-m^2\pi^2(\xi_1 - 1)^{-2}\tau\right], \tag{3.7}$$

where p_m are the roots of Eq. (3.3) for $k_0 = 1$, i.e.,

$$p_m = m\pi(\xi_1 - 1)^{-1}.$$

4. Numerical Calculations

In order to carry out numerical calculations (on the basis of the equations derived in the preceding sections) for the indices representing the working of cracked porous strata, we must know the values of s_{1m} and s_{2m} in relation to the roots $-p_m^2$ of Eqs. (2.7) and (3.3). We accordingly calculated the first six roots of Eq. (2.7) and the first eight roots of Eq. (3.3) for a hypothetical layer (stratum) with $\xi_1 = 11$ and $k_0 = 1$, (Table 1), and on the basis of these calculated the values of s_{1m} and s_{2m} from Eq. (2.9) for various values of the parameters ω and λ of the cracked porous stratum.

For convenience in calculating with Eq. (2.10) it is desirable to replace the time-independent sum in this equation by the residue of the function (2.4) at s = 0, as justified in the foregoing discussion. Equation (2.10) then becomes

$$\psi_i(\xi,\tau) = \frac{\xi_1 + (k_0-1)\xi_0 - \xi k_0}{\xi_1 + (k_0-1)\left(\xi_0 + \frac{\xi_1-\xi_0}{\xi_0}\right)} + \tag{4.1}$$

$$+ \frac{\omega}{\Lambda\xi}\sum_{m=1}^{\infty}\frac{U_i(\xi,p_m)}{\delta_m p_m^2 W_1(\xi_0,\xi_1,p_m)}[s_{1m}(\Lambda - s_{2m})\exp(-s_{2m}\tau) -$$

$$- s_{2m}(\Lambda - s_{1m})\exp(s_{1m}\tau)],\quad i = 1, 2.$$

The results of our calculations based on Eq. (4.1) with $k_0 = 1$ for the face pressure ($\xi = 1$) are shown as a set of curves in Fig. 2. The broken curves 1'-5' correspond to cracked porous strata with supply contour radii of $\xi_1 = 100, 10, 5, 3, 2$ and parameters $\omega = 0.1$; $\lambda = 0.005$. The continuous curves correspond to granular strata ($\omega = 1$, $\lambda \to \infty$) with the same values of the supply contour radius ξ_1; they are plotted on the basis of Eq. (2.11) [4]. An analysis of the curves in Fig. 2 shows that stabilization of the fall in the face pressure of the well in a homogeneously permeable system of cracks in a cracked porous stratum ($k_0 = 1$) occurs much earlier than in the granular stratum for equal distances of the hemispherical supply contour from the hemispherical surface of the well. The normalized stabilization $\psi_1(\xi, \tau)$ defined by Eq. (2.2) depends on the radius of the supply contour surface. Analogous conclusions will also hold for cracked porous strata with inhomogeneously permeable crack system ($k_0 \neq 1$). It follows from Eq. (4.1), however, that in the case when $k_0 \neq 1$ stabilization will depend on the ratio of the permeabilities of the mutually superposed hemispherical regions k_0, as indicated by the nomogram curves of Fig. 3. The continuous lines in this figure correspond to the value $\xi_0 = 2$ and the broken lines to $\xi_0 = 5$. Curves 1 and 3 are plotted for $\xi_1 =$ 10, 4, and curve 2 for $\xi_1 = 10$.

In order to discover the role of the parameters ω and λ in the stabilization of the pressure at the face of a well in a cracked porous stratum with $\xi_1 = 11$, we plotted the curves in Fig. 4 for the following data: $\lambda = 0.005$;2) $\omega = 0.1$, $\lambda = 1$; 3) $\omega = 0.5$, $\lambda = 1$; 4) $\omega = 1$, $\lambda = \infty$. It follows from an analysis of these curves that, as the parameter of the crack capacity ω approaches unity, and as the value of λ increases, curves 1-3, representing the change in the face pressure of a well in a cracked porous stratum, approach the corresponding curves of a granular stratum. This is due to the fact that for $\omega = 1, \lambda \to \infty$ the actual systems of equations (1.1) transform into the ordinary system of piezoconductivity equations.

The curves of Fig. 5 express the time dependence of the pressure drop on the surface of the hemisphere $\xi = 3$ in homogeneous ($k_0 = 1$) cracked porous (1.2) and granular (3) strata worked with a constant face pressure and with a supply contour on the hemisphere $\xi_1 = 11$. The calculations were based on Eq. (3.5), using the following initial data: 1) $\omega = 0.1$, $\lambda = 1$; 2) $\omega = 0.5$, $\lambda = 1$. Curve 3 was plotted from the data of an earlier paper [4], using an equation derived from Eq. (3.5), with $\omega = 1$, $k_0 = 1$,

$$\psi(\xi,\tau) = (\xi_1 - \xi)\xi^{-1}(\xi_1 - 1)^{-1} + \frac{2}{\pi\xi}\sum_{m=1}^{\infty}\frac{(-1)^m}{m}\sin\frac{\xi_1-\xi}{\xi_1-1}m\pi\exp\left[-m^2\pi^2(\xi_1-1)^{-2}\tau\right].$$

It follows from the curves of Fig. 5 that the influence of the parameters ω and λ on the pressure stabilization process is analogous to the case in which a constant well flow is specified (Fig. 4). Furthermore, the curves representing the fall in face pressure in the cracked porous stratum exhibit a point of inflection in both figures; the position of the inflection varies with the values of the parameters ω and λ. This behavior of the curves representing the fall in pressure with time also appears in other forms of liquid flow [14-20]. This indicates that the existence of an inflection point on the time-dependence curve of the drop in face pressure for wells in cracked porous strata is independent of the geometry of the filtration flow.

Figure 6 illustrates the change in well flow as a function of time, calculated by means of Eq. (3.6) for $k_0 = 1$, and Eq. (3.7) for strata having a supply contour surface $\xi_1 = 11$. The curves are plotted for the following initial data: 1) $\omega = 0.1$, $\lambda = 1$; 2) $\omega = 0.5$, $\lambda = 1$; 3) $\omega = 1$, $\lambda \to \infty$. Analysis of the curves shows that the well flow in cracked porous strata depends mainly on the elastic capacity of the crack system in the presence of a hemispherical supply contour.

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