RAMAZANOV T.K, ATAYEV G.N.

DETERMINATION OF THE PARAMETERS OF THE DELATONSION-PLASTIC SEAM AROUND THE ACTING BOREHOLE AND THE PROBLEM ON THE CARRYING OUT OF THE SAND

Abstract

In the work on the base of the equations of mechanics of the saturated porosity mediums the more effective solution of the stationary problem on filtration of the fluid into the borehole in the plastic seam is obtained. The mechanism of expansion of the plastic zone around the acting borehole is determined and the connection between the discharge of the fluid and solid phases is found.

The elastic-plastic skeleton of seams at loading-off don't restore completely their primary condition. Some weak grouted seams are characterised by non-reversible rigid-plastic deformations which influence much on the filtration properties of the seams. Oil-gas deposits consists of porosity rock with the extracted fluids the solid rock comes into the borehole. Coming of the broken rock complicates and fails the normal working regime of the borehole and also it reduces to formation of sand plugs in the borehole, to early amortisation and disexploitation of the borehole equipment.

One of the problems of the rational exploitation of deposits complicated by the weak-grouted porosity rocks is the prevention of coming of the seams into the borehole, decrease of the service time of sand boreholes. So the purpose of the present work is to obtain on the base of the equations of mechanics of saturated porosity mediums the more effective solution of the stationary problem on the filtration of the fluid into the borehole in the plastic seam.

Let one central borehole with the radius a work in the rigid-plastic dilatation plane radial seam $r \in (a, R_k)$. On the contour of feed R_k (supply) the effective radial stress σ_k and the flowing pressure P_k are given. In this case the equation of continuity of phases and the dilatonsion correlation have the form [1,2].

$$\frac{d}{dr}(1-m)r\rho_s v = 0,\ \frac{d}{dr}\left(rm\rho_f w\right) = 0,\ \frac{dv}{dr} + n\frac{v}{r} = 0, \tag{1}$$

where ρ_s, ρ_f and v, w are the real density and velocities of the solid and fluid phases, m is the porosity of the seam, Λ is the velocity of dilatonsion,

$$n = 1 + \frac{2\Lambda\left(3\Lambda - \sqrt{3\left(3-\Lambda^2\right)}\right)}{3-4\Lambda^2}.$$

The first integrals (1) will be

$$r(1-m)\rho_s v = C_s,\ rm\rho_f w = C_f,\ v = br^{-n} \tag{2}$$

we determine the constants of integration from the conditions of mass flow rate of the solid and fluid phases on the wall of the borehole

$$C_s = -\frac{q_s}{2\pi h},\ C_f = -\frac{q_f}{2\pi h}, \tag{3}$$

$$q_s = -2\pi a h\rho_s(a)(1-m_a)v(a),\ q_f = -2\pi a h\rho_f(a)m_a w(a),$$

where $m_a, \rho_s(a), \rho_f(a)$ are the values of the porosity and density of the phases on the wall of the borehole.

On the other hand, using from the condition in the borehole and the third formula (2) and (3) we obtain

$$b=-\frac{q_s}{2\pi ah\rho_s(a)(1-m_a)},\quad v=-\frac{q_s}{2\pi ah\rho_s(a)(1-m_a)}\left(\frac{a}{r}\right)^n. \tag{4}$$

For determination of the porosity we substitute (4) into the first formula (2)

$$m=1-\frac{(1-m_a)\rho_s(a)}{\rho_s}\left(\frac{r}{a}\right)^{n-1}. \tag{5}$$

This formula is simplificated for $\rho_s=const$

$$m=1-(1-m_a)\left(\frac{r}{a}\right)^{n-1}. \tag{6}$$

Hence we estimate the asymptotic values of the porosity:

$$\begin{aligned}&\text{if}\quad n>1, r\to\infty, m<1,\ \text{ then }\ m_a\to 1;\\ &\text{if}\quad n<1, r\to\infty, m_a<1,\ \text{ then }\ m\to 1;\\ &\text{if}\quad n=1,\ m=m_a=m_0=\cos t\end{aligned} \tag{7}$$

However the theoretic and practice investigations show that such asymptotic values of the porosity don't correspond to their real values, because $m\le m_{\max}\sim 0{,}4$. In spite of that the formula (5) doesn't describe completely the change of the porosity of the seam, the first condition corresponds to the loosening of the dense seam $(n>1)$ and the second condition corresponds to the compacting of the porosity seam $(n<1)$ and the third - non-compressibility of the skeleton of the seam $(n=1,\Lambda=0)$. The formulas (5) or (6) are fulfilled in some area of the seam $r\in(a,R)$, denoting porosity for the gush zone of the borehole. Therefore, in the rigid-plastic plane-radial seam $r\in(a,R_k)$ two zones form (appear) around the acting borehole where porosity in the first zone $r\in(a,R)$ is determined by (6) and in the second zone $r\in(a,R_k)$ the skeleton is in the critic condition $(n=1,\Lambda=0)$ and $m=m_0=const,\ k=k_0=const$.

The coefficient of the penetrability of the seam can be given by the power function of the porosity [1]

$$\frac{k}{k_0}=\left(\frac{m}{m_0}\right)^l, l=\frac{a_k}{a_m}, \tag{8}$$

$$k=\frac{k_0}{m_0^l}\left[1-(1-m_a)\left(\frac{r}{a}\right)^{n-1}\right]^l, \tag{9}$$

where k_0, m_0 are the values of the penetrability and porosity for the initial seam pressure, a_k, β_m are the coefficients of change of the penetrability and porosity.

By I.Fatta's data [1,3] l changes $l=2\div 15$. For example, for sandstone $l=10$, for sand space in the form of a set of plane channels $l=3$, for the non-compressible seam $l=0$.

Write the equation of motion of the non-compressible fluid phase [1] with help of (2) and (3) in the convenient form:

$$\frac{2\pi h}{\mu}\frac{dP}{dr}=\frac{1}{rk}\left(Q_f-\frac{m}{1-m}Q_s\right), a\le r\le R. \tag{10}$$

Here $Q_f = q_f / \rho_f(a)$, $Q_s = q_s / \rho_s(a)$.

Substituting (6) and (9) in (10) and integrating it we have:

$$P = \frac{\mu m_0^l Q_f}{2\pi h k_0} \int_1^{r/a} \frac{dx}{x\left[1-(1-m_a)x^{n-1}\right]^l} - \frac{\mu m_0^l Q_s}{2\pi h(1-m_a)k_0} \int_1^{r/a} \frac{dx}{x^n\left[1-(1-m_a)x^{n-1}\right]^{l-1}} + P_a, \quad (11)$$

where P_a is the pressure on the walls of the borehole, $x = r/a$.

The seam in front of the delatating zone $r \in (R, R_k)$ is in the compacted critic condition and so $\Lambda_1 = 0$, $n_1 = 1$, $\sin\varphi_1 = \alpha_1$, $\alpha_1 \neq 0$. So in the delatating and rigid-plastic zones the radial effective stress by analogy [2] will have the form:

$$\sigma_{rr}^f = \left(\sigma_a + \frac{K}{N-1}\right)\left(\frac{r}{a}\right)^{N-1} - r^{N-1}\int_a^r \rho^{N-1}\frac{\partial P}{\partial \rho}d\rho - \frac{K}{N-1}, \ a \le r \le R, \quad (12)$$

$$\sigma_{rr}^f = \left(\sigma_k + \frac{K_1}{N_1-1}\right)\left(\frac{r}{R_k}\right)^{N_1-1} - r^{N_1-1}\int_{R_k}^r \rho^{N_1-1}\frac{\partial P}{\partial \rho}d\rho - \frac{K_1}{N_1-1}, \ R \le r \le R_k,$$

where σ_a is the value of the radial effective stress on the wall of the borehole, K, K_1 are correspondingly the coefficients of adhesion in the dilatating and rigid-plastic zones, $N = \frac{1+\sin\varphi}{1-\sin\varphi}$, φ is the angle of the internal friction.

Solution of the equation of dilatonsion in $r \in (R, R_k)$ (1) for $n = 1$ is simplificated

$$v_1 = \frac{b_1}{r}. \quad (13)$$

The parameter of integration b_1 is found from the condition of equality of radial velocities of solid participles (4) and (13) on R

$$b_1 = -\frac{Q_s a^n R^{1-n}}{2\pi a h(1-m_a)}. \quad (14)$$

As for as $m_0 = const, k_0 = const$, then the equation of motion of the fluid phase (10) with help of (13) and (14) takes the form

$$\frac{dP}{dr} = \frac{\mu}{2\pi h k_0 r}\left(Q_f - \frac{m_0}{1-m_0}\left(\frac{R}{a}\right)^{1-n} Q_s\right), R \le r \le R_k, \quad (15)$$

$$P = \frac{\mu}{2\pi h k_0}\left(Q_f - \frac{Q_s m_0}{1-m_a}\left(\frac{R}{a}\right)^{1-n}\right)\ln\frac{r}{R_k} + P_k. \quad (16)$$

From the equalities of pressure (11), (16) and effective radial stresses (12) on R we find the connection between the pressure differential $\Delta P = P_k - P_a$ and discharge of phases Q_f, Q_s.

$$\overline{Q}_f\left(m_0^l \int_1^{R/a} \frac{dx}{x\left[1-(1-m_a)x^{n-1}\right]^l} + \ln\frac{R_k}{R}\right) -$$
$$- Q_s\frac{m_0}{1-m_a}\left(m_0^{l-1}\int_1^{R/a} \frac{dx}{x^n\left[1-(1-m_a)x^{n-1}\right]^{l-1}} - \left(\frac{R}{a}\right)^{1-n}\ln\frac{R_k}{R}\right) = P_k - P_a, \quad (17)$$

$$\overline{Q_f}\left\{m_0^l\left(\frac{R}{a}\right)^{N-1}\int_1^{R/a}\frac{dx}{x^N\left[1-(1-m_a)x^{n-1}\right]^l}+\frac{1}{N_1-1}\left[1-\left(\frac{R_k}{R}\right)^{1-N_1}\right]\right\}-$$

$$-\frac{m_0 Q_s}{1-m_a}\left\{m_0^{l-1}\left(\frac{R}{a}\right)^{N-1}\int_1^{R/a}\frac{dx}{x^{n+N-1}\left[1-(1-m_a)x^{n-1}\right]^{l-1}}+\frac{1}{N_1-1}\left[1-\left(\frac{R_k}{R}\right)^{1-N_1}\right]\left(\frac{R}{a}\right)^{1-n}\right\}+$$

$$+\left(\sigma_k+\frac{K_1}{N_1-1}\right)\left(\frac{R_k}{R}\right)^{1-N_1}-\left(\sigma_a+\frac{K}{N-1}\right)\left(\frac{R}{a}\right)^{1-N}+\frac{K}{N-1}-\frac{K_1}{N_1-1}=0,$$

where $\overline{Q_f}=\frac{Q_f\mu}{2\pi hk_0}$, $\overline{Q_s}=\frac{Q_s\mu}{2\pi hk_0}$.

If the system of equations (17) $\overline{Q_f}$, P_k-P_a and the parameters of the problem are given then hence we find the unknown variables $\overline{Q_s}$ and R/a.

The calculations have been carried out by (17) for the compacted sands for the following data: $m_0=0{,}16$, $m_a=0{,}16$, $N=3$, $N_1=2$, $l=4;4{,}5$, $n=1{,}2$, $R_k/a=10^3$, $K=4\cdot10^5 Pa$, $K_1=5\cdot10^5 Pa$, $\sigma_k=10^8 Pa$, $\sigma_a=0$.

In (17) the orientation values P_k-P_a and $\overline{Q_f}$ are determined from the problem on the rigid-plastic regime of filtration for $R=R_k$, $\Lambda=0$,

$$P_k-P_a=\frac{\ln\frac{R_k}{a}}{1-\left(\frac{R_k}{a}\right)^{1-N_1}}\left[(N_1-l)\sigma_a+K_1-((N_1-1)\sigma_k+K_1)\left(\frac{R_k}{a}\right)^{1-N}\right],\quad \overline{Q_f}=\frac{P_k-P}{\ln\frac{P_k}{a}}.$$

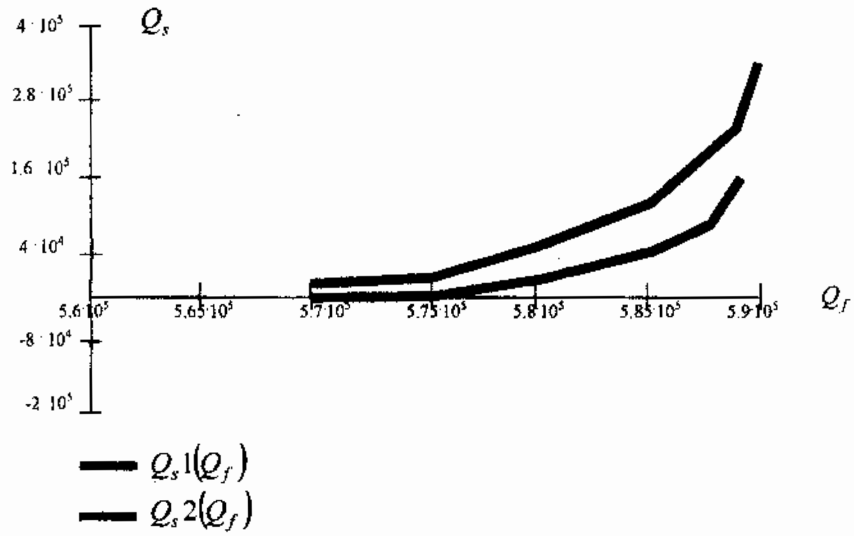

Fig.1. Correlation of the intensivity of discharge of the fluid $\overline{Q_f}(Pa)$ and the intensivity of carrying out of sand $\overline{Q_f}(Pa)$ for the stationary work of the borehole in the seam of dense sand. The curve 1 corresponds to $l=4$, the curve 2 - to $l=4{,}5$.

The case of initial dense pack of sand in the seam corresponds to the results of the calculations when around the exploitation borehole loosening of the $\Lambda > 0$ sand happens. The critic value Q_f which is the messenger of reveal of sand in the borehole, is determined by the complex parameters of the seam, generally by adhesion, the angle of the internal friction, the velocity of delatansion, external and internal loadings and etc.

Some cast of the initial data of the real data can reduce to the wrong result. According to the considered model, solution of the system (17) exists only for certain connection between the parameters and in this case, between the intensivity of sand $\overline{Q_s}$ and R/a is found in dependence on the intensivity of the discharge of the borehole (fig.1 and fig.2).

From fig.1, it is seen that the connection between $\overline{Q_f}$ and $\overline{Q_s}$ is non-linear and a little decrease of $\overline{Q_f}$ reduces to much increase of $\overline{Q_s}$. The dilatonsion zone of loosening doesn't penetrate into depth of the seam and immediately arises in the neighbourhood of the borehole (fig.2).

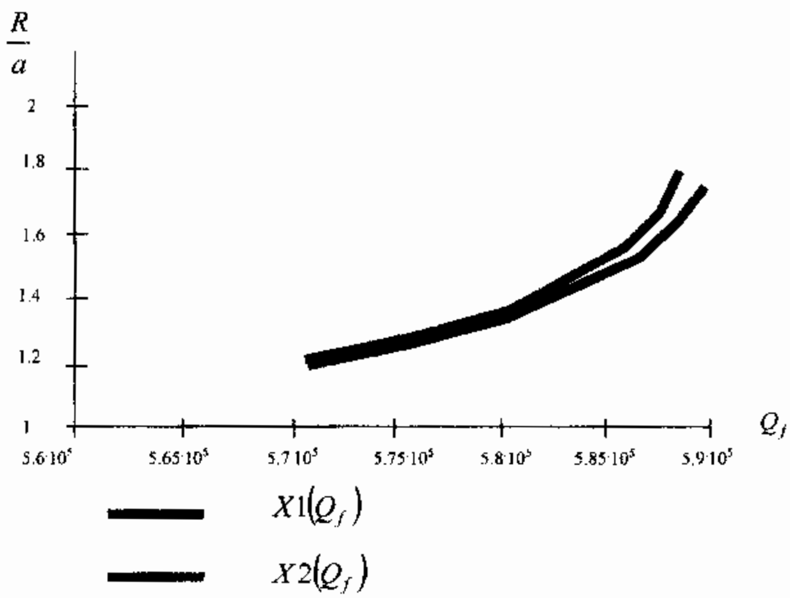

Fig.2. The dependence of the dimensionless radius of the intensivity of the discharge of the borehole $\overline{Q_f}(Pa)$. The curve 1 corresponds to $l = 4$, the curve 2 corresponds to $l = 4{,}5$.

Distribution of the pore pressure along the seam is determined by (11) and (16). In the dilatonsion-plastic zone $\bar{r} \in [1, R/a]$ the pressure P_a is from (17) and the above pointed out data for the minimal and maximal values of $\overline{Q_s}$ and $P_k = 1{,}5 \cdot 10^7\,Pa$. In difference form the rigid-plastic zone $\bar{r} \in [R/a, R_k/a]$ the curves of pressure in $\bar{r} \in [1, R/a]$ will be bent.

References

[1]. Николаевский В.Н. *Геомеханика и флюидодинамика.* М.: Недра, 1996, с.447.

[2]. Атаев Г.Н. *Возникновение неустойчивых зон вокруг действующей скважины.* Вестник Бакинского Университета, 1999, №1, с.164-180.
[3]. Горбунов А.Т. *Разработка аномальных месторождений.* М.: Недра, 1981, с.237.

Ramazanov T.K., Atayev G.N.
Institute of Applied Mathematics.
Baku State University named after M.Rasul-zadeh.
23, Z.I.Khalilov str., 370148, Baku, Azerbaijan.

Received January 6, 2000; Revised March 19, 2000.
Translated by Soltanova S.M.