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A PROBLEM ABOUT INFLUENCE OF A WALL LAYER ON HYDRAULIC RESISTANCE WHEN LOWERING CASING

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Abstract: Due to the fact that with increasing well depth, pressure and temperature increase, the thickness of the near-wall layer, which plays a significant role in hydraulic calculations, also changes. This paper stdies the influence of the dimensions of the near-wall layer and the viscosity of the liquid in it on the magnitude of pressure losses during various technological operations.

Keywords: Wall layer, viscosity, borehole, laminar layer, friction resistance, pressure drop (loss).

Let us consider the effect of the presence of a near-wall layer on the value of hydrodynamic pressure when running casing strings into an open hole. Due to the complexity in calculations for the case of a clay solution, we will assume that a viscous liquid is used as a flushing liquid. Thus, we consider a separate movement of two viscous fluids with different physical properties in the annular space between two concentrically arranged cylindrical pipes, the inner one with a closed end moves at a given speed.

To simplify the solution, the stationary motion of fluids and the inner tube is considered. In this case, for the distribution of velocities in the laminar regime of fluid motion in the annular space, we will have [1]

$$\upsilon_i = \frac{\Delta p}{4l\eta_i} r^2 + C_{2i-1} \ln r = C_{2i} \tag{1}$$

where υ_i - liquid distribution rate; η_i -viscosity coefficient; Δp - pressure drop along the length; r - current radius; C_{2i} и C_{2i-1} - integration constants.

Integration constants C_{2i} и C_{2i-1} are defined from the following conditions:

$$\upsilon_1(R_1) = -u, \qquad \upsilon_2(R_2) = 0,$$
$$\upsilon_1(r_1) = \upsilon_2(r_1), \quad \frac{d\upsilon_1}{dr}(r_1) = \frac{d\upsilon_2}{dr}(r_1). \tag{2}$$

Here R_1, R_2, r_1 are respectively radii of drill pipes, wells and fluid interfaces; u - running speed.

The flow rate of the fluid displaced by the drill string is calculated by the formula

$$Q = \pi R_1^2 u = \int_R^{r_1} 2\pi r \upsilon_1(r) dr + \int_{r_1}^{R_2} 2\pi r \upsilon_2(r) dr. \tag{3}$$

Consdering values of $\upsilon_1(r)$ from (1) into (3) to determine the hydrodynamic pressure, we obtain

$$\Delta p=\frac{4l\eta_2 u(R_2^2-R_1^2)}{\left[\left(R_2^4+r_1^4\right)-\left(R_1^4+r_1^4\right)\frac{\eta_2}{\eta_1}+2r_1^2R_1^2\left(\frac{\eta_2}{\eta_1}-1\right)\right]\ln\frac{R_2}{R_1}-\\ -\left(R_2^2+R_1^2\right)\left[r_1^2\left(\frac{\eta_1}{\eta_2}-1\right)\left(1-2\ln\frac{R_2}{R_1}\right)+\left(R_2^2-\frac{\eta_2}{\eta_1}R_1^2\right)\right]} \tag{4}$$

From (4) it follow that at $r_1=R_2,\eta_1=\eta_2$ we obtain a well-known formula for the value of hydrodynamic pressure when lowering casing strings into a well filled with a viscous fluid, in the absence of a near-wall layer [2].

To estimate the effect of the presence of a near-wall layer on the value of the hydrodynamic pressure, consider the relation

$$\frac{\Delta p}{\Delta p_1}=\frac{\left(1-\overline{R}_1^4\right)\ln\frac{1}{R_1}-(1-\overline{R}_1^2)^2}{\left[\left(1+\overline{r}_1^4\right)-\left(\overline{R}_1^4+\overline{r}_1^4\right)\frac{\eta_2}{\eta_1}+2\overline{r}^2\overline{R}_1^2\left(\frac{\eta_2}{\eta_1}-1\right)\right]\ln\frac{1}{R_1}-\\ -\left(1-\overline{R}_1^2\right)\left[\overline{r}_1^2\left(\frac{\eta_2}{\eta_1}-1\right)\left(1-2\ln\frac{\overline{R}_1}{\overline{r}_1}\right)+\left(1+-\frac{\eta_2}{\eta_1}\overline{R}_1^2\right)\right]} \tag{5}$$

Where: $\overline{R}_1=R_1/R_2;\overline{r}_1=r_1/R_2$.

The results of the calculation from (5) to determine the dependence $\Delta p=f\left(\frac{\eta_2}{\eta_1}\right)$ at

$\overline{r}_1=0,99$, $\overline{R}_1=0,446$ $(R_1=0,06m,\ R_2=0,1345m)$

are shown in Fig.1. he values for the size of the near-wall layer were taken in accordance with the data, which range from 2 to 4 mm. From Fig. 1 it can be seen that the rate of decrease in hydrodynamic pressure due to the existence of a near-wall layer is more at $\eta_2/\eta_1\to 1$, than at $\eta_2/\eta_1\to 0$.

Calculations given for the other values of $\overline{r}_1$, specificaly at $\overline{r}_1=0,98;0,97$, showed, that the shape of the curve most coincides with the curve obtained for the case of $\overline{r}_1=0,99$. The impact of change of η_2/η_1 on $\Delta p/\Delta p_1$ is greater than the impact of change on r_1. Moreover, both for the change of η_2/η_1, and for the $\overline{r}_1$ maximum influence on the value $\Delta p/\Delta p_1$ we obtain at $\overline{r}_1\to 1$; $\eta_2/\eta_1\to 1$.

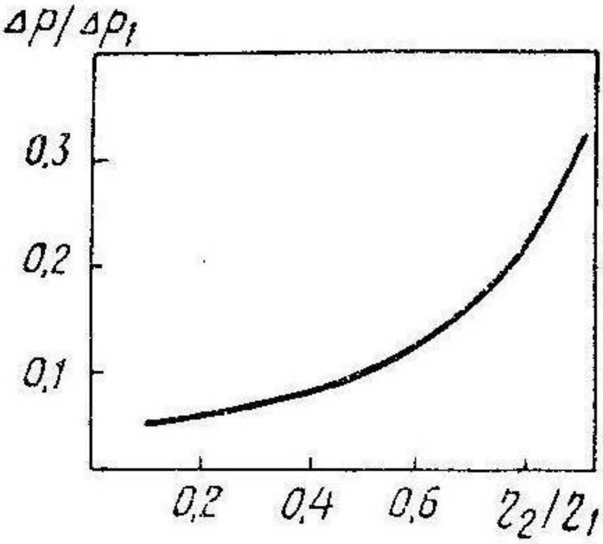

Figure 1. Dependance $\Delta p/\Delta p_1 = f(\eta_2/\eta_1)$

Thus, with an increase in the size of the near-wall layer and a decrease in the viscosity of the liquid near the wall, the hydrodynamic pressure decreases.

A similar phenomenon is also found in the case of separate rectilinear-parallel motion of two viscous-plastic fluids, when the structural viscosity of the fluid near the wall is less than the structural viscosity of the fluid moving in the center of the flow.

The particles of the dispersion medium, and hence the structural viscosity, are unevenly distributed throughout the flow.

For simplicity, let us consider a rectilinear stationary parallel motion of two viscoplastic fluids in a round cylindrical tube. The velocity distribution in this case has the form:

$$\upsilon_1 = -\frac{\Delta p r^2}{4l\eta_i} + C_{2i-1}\ln r + C_{2i} + \frac{\tau_i}{\eta_i} r \tag{6}$$

$$(i = 1,\ r_0 \le r \le r_1;\ i = 2,\quad r_1 \le r \le R).$$

Integration constants C_{2i-1} и C_{2i} are determined from the boundary conditions:

$$\frac{d\upsilon_1}{dr}(r_0) = 0;\quad r_0 = \frac{2l\tau_1}{\Delta p};\quad \upsilon_2(R) = 0;$$

$$\upsilon_1(r_1) = \upsilon_2(r_1);\quad \tau_1 - \eta_1\frac{d\upsilon}{dr}(r_1) = \tau_2 - \eta_2\frac{d\upsilon_2}{dr}(r_1). \tag{7}$$

At the same time, it is assumed that $\eta_2 < \eta_1$ и $\tau_2 < \tau_1$.

The flow rate of the liquid is found by the formula:

$$Q = \pi r_0^2 \upsilon_1(r_0) + \int_{r_2}^{r_1} 2\pi r \upsilon_1(r)dr + \int_{r_1}^{R} 2\pi r \upsilon_2(r)dr. \tag{8}$$

Substituting values $\upsilon_1(r)$ and $\upsilon_2(r)$ from (7) into (8), after transformations we get:

$$\Delta p = \frac{Q + \frac{\pi\tau_2}{\eta_2}\left(R^3 - r_1^3\right)}{\frac{\pi}{24l\eta_1}\left(r_0^4 - 4r_0 r_1^3 + 3r_1^4\right) + \frac{\pi}{24l\eta_2}\left(3R^4 + 8r_1 R^3 - 11r_1^4\right)}. \tag{9}$$

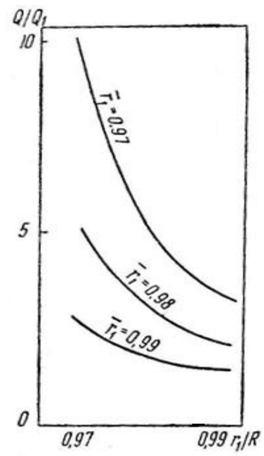

Figure 2. Dependance $Q/Q_1 = f(r_1/R)$

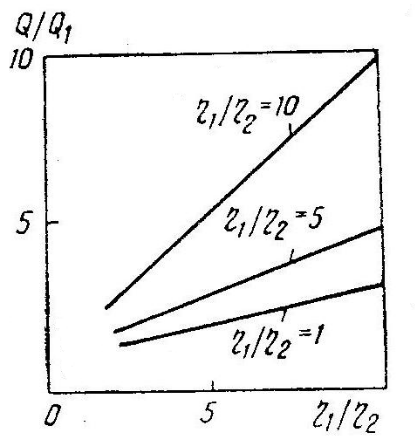

Figure 3 Dependance $Q/Q_1 = f(\eta_1/\eta_2)$

From (9) at $r_1 = R,\ \eta_2 = \eta_1 = \eta$ weg et:

$$Q_1 = \frac{\pi R^4 \Delta p}{8 l \eta}\left(1 - \frac{4}{3}\frac{r_0}{R} + \frac{1}{3}\frac{r_0^4}{R^4}\right). \tag{10}$$

From formulae (9) and (10) weh ave:

$$\frac{Q}{Q_1} = \frac{\bar{r}_0^4 + 4\bar{r}_0\bar{r}_1^3 + 3\bar{r}_1^4}{3 - 4\bar{r}_0 + \bar{r}_0^4} + \frac{\frac{\eta_1}{\eta_2}\left(3 + 8\bar{r}_1 - 11\bar{r}_1^4\right)}{3 - 4\bar{r}_0 + \bar{r}_0^4} - \frac{24\frac{\eta_1}{\eta_2} L^{"}a\left(1 - \bar{r}_1^3\right)}{3 - 4\bar{r}_0 + \bar{r}_0^4}, \tag{11}$$

$$L^{"}a = \frac{\tau_2 l}{\Delta p R}, \qquad \bar{r}_0 = \frac{r_0}{R}, \qquad \bar{r}_1 = \frac{r_1}{R}.$$

The results of calculations using formula (11) are shown in Figs. 2 and 3. From Fig. 2 it can be seen that at the value of $\bar{r}_1 \to 1$ the value of $Q/Q_1 \to 1$.

From (11) it follows that the value of Q/Q_1 ccording to a rectilinear law increases with a decrease in the limiting shear stress of viscoplastic fluids moving near the pipe wall. It is obvious that the degree of influence of η_1/η_2 on the value Q/Q_1 is stronger than the influence of the Lagrange parameter $L^{"}a$ т.е. τ_2. At $L^{"}a = 0$ coincides with the formula derived in [1].

Thus, from the above calculations it follows that by changing the viscosity coefficient of the liquid near the pipe wall, pressure losses can be controlled.

Calculations from [1,2] showed that the aeration of the laminar boundary layer in water reduces the friction resistance by approximately 10 times, and the aeration of the turbulent boundary layer in water by 130 times.

So, if a certain amount of liquid with a lower viscosity coefficient than that of the environment is introduced into the boundary layer, then pressure losses can be reduced, which is achieved by introducing a small amount of polymer additives into the liquid (clay mud) flow. Small additions, as studies in [2] showed, form a near-wall layer of a viscous liquid with a lower viscosity coefficient near the wall, which is the reason for the decrease in friction resistance.

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