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UDC 539.3

DEVELOPMENT OF CRACKS IN CONFINED POROUS VOLUME

ABSTRACT. Theories of development and formation of oil reservoir hydraulic fracturing are considered by a number of Russian and foreign scientists. This technology is used to increase the wells production rate. Unintended fracturing is possible when injection wells are under intensive operation. This paper deals with the process of fluid displacement from a porous medium by injecting some other fluid into the hydraulic fracturing crack. The formation geometry is a cuboid of unlimited length. The hydraulic fracture is led along the center. The reservoir was initially saturated with a viscous fluid, hydraulic fracturing is performed with a less viscous fluid. It was once believed that the pore pressure at the sides of the cuboid is constant and equal to the original value. This may be due to the change of the hydraulic geometry of rock layers. It is now shown that in some cases cracks expand and subsequently contract during intensive pumping.

KEY WORDS. Porous medium, filtration, fluid.

Mathematic formulation of the problem

The scheme of the problem is given in Figure 1.

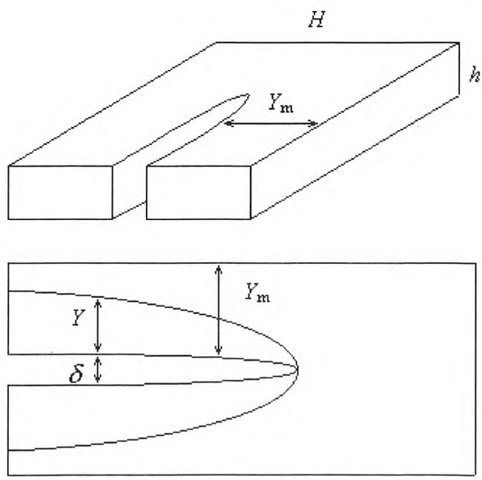

Fig. 1. The scheme of the problem about fracture development in a limited-size formation

Perkins's hypothesis [1] and flat facture patterns in the elastic medium [2] let introduce the co-relation between excess pressure and average fracture opening width. The process of hydraulic fractures formation is defined by equations [3, 4]

$$\frac{\partial \delta}{\partial t}+\frac{\partial q}{\partial x}=-2\beta v_r,$$
$$q=-\frac{b}{12\eta_1}\delta^3\frac{\partial \delta}{\partial x}, \qquad (1)$$
$$\frac{\partial Y}{\partial t}=v_r;$$

where Y — invaded section depth, $q = \delta u$, u — speed along the fracture (X-line), $\eta_{1,2}$ — viscosity of displacing and displaced fluids, β — soil porosity, b — constant.

Filtration equations [5–7]

$$\frac{\partial p_r}{\partial y}=-\frac{\eta_1}{k}v_r,\ 0<y<Y;$$

$$\frac{\partial p_r}{\partial y}=-\frac{\eta_2}{k}v_r,\ Y<y<Y_m;$$

with boundary conditions

$$p_r(0)=P=b\delta,\ p_r(Y)=0;$$

let define the fluid speed in soil, as

$$v_r=\frac{kb}{\eta_1}\frac{\delta}{Y\left[1+\frac{\eta_2}{\eta_1}\left(\frac{Y_m}{Y}-1\right)\right]}$$

When function Y reaches Y_m, it stops.

The dimensionless form

Let us introduce dimensionless variables [8–10]

$$\bar{x}=\frac{x}{L^*},\ \bar{t}=\frac{t}{t^*},\ \bar{\delta}=\frac{\delta}{\delta^*},\ \bar{q}=\frac{q}{q^*},\ \bar{v}=\frac{v_r}{v^*},\ \bar{Y}=\frac{Y}{Y^*};$$

supposing

$$L^*=\frac{1}{4\beta}\sqrt{\frac{k}{6}\frac{P_0^2}{kb^2}},\ t^*=\frac{1}{4\beta^2}\frac{\eta_1 P_0}{kb^2},\ \delta^*=\frac{P_0}{b},$$

$$q^*=2\beta\sqrt{\frac{k}{6}\frac{P_0^2}{\eta_1 b}},\ Y^*=\frac{1}{2\beta}\frac{P_0}{b},\ v^*=2\beta\frac{kb}{\eta_1}.$$

Here P_0 —parameter, expressing a characteristic excess pressure at the fracture jaws, this pressure will have the equivalent of $\bar{\delta}(0, t) = 1$.

The system of motion equations will have the following dimensionless form (no bar)

$$\frac{\partial \delta}{\partial t} + 2\frac{\partial q}{\partial x} = -v,$$

$$q = -\delta^3 \frac{\partial \delta}{\partial x}, \qquad (2)$$

$$\frac{\partial Y}{\partial t} = v;$$

The fluid current speed in soil

$$v = \frac{\delta}{Y + \frac{\eta_2}{\eta_1}(Y_m - Y)}, \quad 0 \le Y \le Y_m.$$

Let us look at the process of fracture growth when the fluid injection rate is constant. The initial and boundary conditions are as follows

$$\delta(x, 0) = q(x, 0) = Y(x, 0) = 0;$$

$$q(0, \mathrm{t}) = q_0, \; q_0 = const.$$

Some resulting estimates

Figure 2 shows a solution for the system of equations (2) when $q_0 = 0.5$, $Y_m = 2$, $\eta_2/\eta_1 = 10$. The fracture form changes extraordinarily. For a while the fracture grows wide and long getting narrower towards the tip.

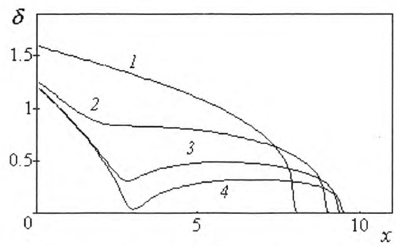

Fig. 2. Dimensionless width distribution along the fracture at certain times $t = 15, 20, 25, 30$ — curves 1, 2, 3, 4.

Further the fracture width abruptly decreases till 0 in its middle. The fluid drains from the newly formed closure into the soil, and vanishes. It results in forming a stable fracture profile, with its open tip being much less that its whole length. The following fluid injection leads neither to the fracture growth nor to its form change.

With bigger values of Y_m the motion character repeats. This effect is explained by a gradual increasing rate of the fluid from the fracture into soil resulting from the widening depth of the soaked zone, and perhaps by nonlinear differential coefficients in motion equations. When $Y_m < 0.5$, it is not observed.

Conclusion

There has been described the process of fluid displacement from a porous medium of a limited width by injecting some other fluid into the hydraulic fracturing crack. It has been shown that the fracture can stop growing. In some cases the fracture can experience closing under intensive injection.

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