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MOVEMENT OF ANOMAL OIL IN THE ROUND CYLINDRICAL PIPE ACCORDING TO MAXWELL'S LAW OF FRICTION

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ABSTRACT

The article solves a stationary hydromechanical problem about the movement of anomalous oil in a round cylindrical pipe according to the law of friction, i.e., according to the modified Maxwell model. When solving this problem, it is assumed that the direction of oil movement will coincide with the direction of the pipe axis. Between the 1st and 2nd cross sections of the pipe, a part with a length is taken. In this part of the pipe, radius size calculations are taken from the pipe axis. The speed of oil movement depends on the radius and decreases as it increases. At : $r = R : v = 0$ *.*
From the condition of equilibrium of two forces, that is, the pressure force and the friction force, an expression was found for the radius of the flow core. Formulas are presented for the initial pressure ΔP *drop and for the shear stress* τ *. To solve the differential equation of anomalous oil, a technique was used to replace a complex differential with a simple differential. A formula has been derived for the total oil flow rate in a pipe; a formula for pressure loss in the laminar mode of movement of anomalous oil in a pipe has been extracted. When* $\Delta P \leq \Delta P_0$ *the liquid in the pipe does not move, it remains at rest.*

The article solves a new hydromechanical theoretical problem about the rectilinear stationary movement of anomalous oil in a round cylindrical model, that is, according to Maxwell’s law of friction [1].

To solve this problem, it was assumed that the direction of oil movement would coincide with the direction of the pipe axis.

In Fig. 1 shows a schematic drawing of a given oil pipe. Between the first and second cross sections of the pipe, a part of it with a length of l . In a given part of the pipe, the radius r dimensions were calculated using the pipe axes.

The speed of movement of visco-plastic oil v depends on the radius r and decreases as r it increases. In the inner surface of the pipe it reaches its lowest value. At: $r = R : v = 0$.

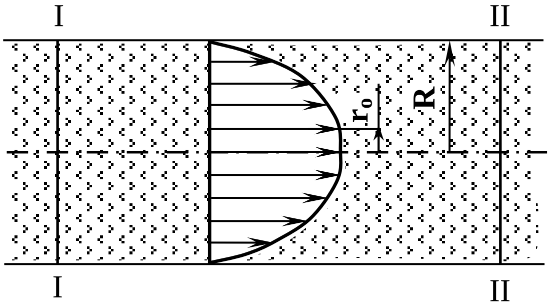

Fig.1. Schematic drawing of a round cylindrical pipe

Due to the fact that as the radius r increases, the speed of oil movement decreases, then the velocity gradient $\frac{dv}{dr}$ receives a negative value (-). Therefore, from the point of view of geometry, it represents an obtuse angle, which is known to be a negative quantity (-).

The modified model – Maxwell's law of friction has the form:

$\tau = \eta\frac{dv}{dr} + \tau_0 e^{-\frac{t}{T}}$ .... (1)

As you can see, this expression has three constant parameters, which are physical characteristics of the liquid (in this case, oil): η – coefficient of structural viscosity, τ_0 - static shear tightness, T - period of relaxation (weakening).

In formula (1) τ – tangential tightness, e – base of natural logarithm, t – flow time of the technological process.

Equation (1) at $\tau > \tau_0$ expresses the movement of the fluid. During movement, tangen-tial tightness τ must always be greater than the static shear tightness τ_0 and $\frac{dv}{dr}$ as shown abo-ve, it can be a (-) value.

When $r = R$ the tangential tightness in the inner surface of the pipe reaches its maxi-mum value. As the pipe approaches the axis, the tangential tightness decreases and at the radius $r = r_0 : \tau > \tau_0$; that's why $\frac{dv}{dr} = 0$. A flow core with a radius r_0 moves like a rigid body.

Let us determine the value of the radius of the flow core r_0 from the condition of equili-brium of two forces:

1) The pressure forces acting on the lateral surfaces of the flow core are equal to $\pi r_0^2 \Delta P$;

2) The friction forces acting on the surface of the same flow core are equal to $2\pi r_0 l \tau_0$.

Then we get:

$r_0^2 \Delta P = 2\pi r_0 l \tau_0$ .... (2)

hence we have:

$r_0 = \frac{2l\tau_0}{\Delta P}$ .... (3)

As noted above, for fluid movement in a pipe, the tangential tightness of the fluid in the pipe must be greater than the ultimate shear tightness, that is to start the movement of liquid in the inner wall of the pipe, it is necessary that $\tau > \tau_0$. At values of $\tau < \tau_0$, the liquid in the pipe does not move.

In fig. 2 shows a graph of the velocity gradient versus tangential tightness. It is part of a general curve in the form of an inclined straight line and intersects with the abscissa axis at the point τ_0 . This graph is expressed by Shulman's friction law. At $\tau < \tau_0$, as can be seen in all its values $\tau\frac{dv}{dr} = 0$. This happens when the speed in the pipe does not depend on the radius and remains constant.

In the inner cylindrical surface $r = R$ (at $\tau < \tau_0$), that is $v = 0$, as a result, the speed does not depend on the radius, in the inner wall of the pipe, the speed is zero at all points. On the surface $r_0 = R$ when $\tau = \tau_0$ the limit equilibrium is not observed and in this case the corresponding value ΔP_0 is determined by the following formula:

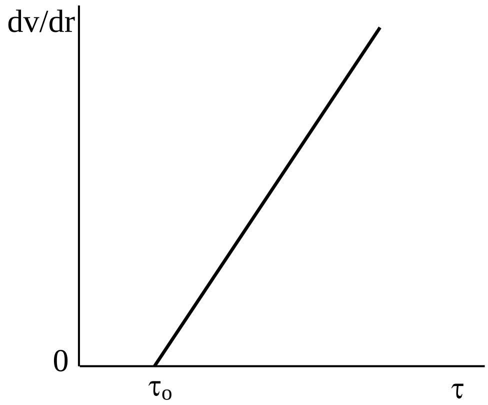

Fig. 2. Gradient modulus graph speed from tangential tightness

$$\Delta P_0 = \frac{2l\tau_0}{R} \quad \text{.......} (4)$$

To start the movement of liquid in a pipe, the following condition must be met $\Delta P > \Delta P_0$.

Inside the pipe, we select an annular space with an outer radius r and an inner radius r_0 and create a condition for the equilibrium of the tangential forces that act in the surface of the selected space:

$$2\pi r l\tau - 2\pi r_0 l\tau_0 = \pi(r^2 - r_0^2)\Delta P_0 \quad \text{.......} (5)$$

From formula (3), we substitute the value r_0 in the equilibrium equation (5) and obtain:

$$2\pi r l\boldsymbol{\tau} - \pi r_0^2\Delta P = \pi r^2\Delta P - \pi r_0^2\Delta P \quad \text{.......} (6)$$

Thus, the equilibrium condition takes the form:

$$\pi r_0^2\Delta P = 2\pi r l\tau$$

From here we have:

$$\tau = \frac{r\Delta P}{2l} \quad \text{.......} (7)$$

From formula (7), we substitute the value τ into Maxwell's equation (1) and obtain:

$$\frac{r\Delta P}{2l} = \eta\frac{dv}{dr} + \tau_0 e^{-\frac{t}{T}} \quad \text{.......} (8)$$

We divide the differential equation (8) into variables and obtain:

$$\frac{\Delta P}{2l\eta} r dr + \frac{\tau_0}{\eta} e^{-\frac{t}{T}} dr = dv \quad \text{.......} (9)$$

We integrate equation (9) within the limits from v to v_0 and from r to r_0 before r and we obtain:

$$\frac{\Delta P}{2l\eta}\int_r^{r_0} rdr + \frac{\tau_0}{\eta}e^{-\frac{t}{T}}\int_r^{r_0} dr = \int_v^{v_0} dv \;;$$

$$v_0 = v - \frac{\Delta P}{4l\eta}(r^2 - r_0^2) - \frac{\tau_0}{\eta}e^{-\frac{t}{T}}(r - r_0) \;................. (10)$$

From formula (10) we can derive the formula for the pressure drop in the form:

$$\Delta P = \frac{1}{r^2 - r_0^2}\left[(v_0 - v)4l\eta + 4l\tau_0 e^{-\frac{t}{T}}(r - r_0)\right] \ldots\ldots (11)$$

The total flow of abnormal oil in the pipe consists of two parts:

1) fluid flow in the flow core: $Q_1 = \pi r_0^2 v_0$,

2) fluid flow in the annular space around the flow core, that is, in the gradient layer: $Q_2 = \int_{r_0}^{R} 2\pi r dr$.

The total oil consumption will be:

$$Q = Q_1 + Q_2 = \pi r_0^2 + 2\pi\int_{r_0}^{R} rdr \;\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Substituting the value v_0 from formula (10) in formula (12), we get:

$$Q = \pi r_0^2\left[v - \frac{\Delta P}{4l\eta}(r^2 - r_0^2) - \frac{\tau_0}{\eta}e^{-\frac{t}{T}}(r - r_0)\right] + \pi(R^2 - r_0^2) \;............ (13)$$

When $\Delta P \le \Delta P_0$ the oil in the pipe does not move.

Thus, the solution to the problem posed in the article is completed.

CONCLUSIONS

1. The article solves a stationary hydromechanical problem about the movement of anomalous oil in a round cylindrical pipe according to the law of friction i.e. according to the modified Maxwell model.
2. When solving this problem, it is assumed that this direction of oil movement will coincide with the direction of the pipe axis.
3. Between the 1st and 2nd cross sections of the pipe, a part of the pipe with a length of l .
4. In this part of the pipe, radius r size calculations are taken from the pipe axis.
5. The speed of movement of anomalous oil depends on the radius r and with its increase it decreases, at $r = R$; $v = 0$.
6. From the condition of equilibrium of two forces, that is, the pressure force and the friction force, an expression was found for the radius of the flow core.
7. Formulas are presented for the initial pressure drop ΔP_0 and for the tangential tightness τ.
8. To solve the differential equation of motion of anomalous oil in a pipe, a technique was used to replace a complex differential with a simple differential.
9. A formula has been derived for the total oil flow in the pipe.

10. The formula for pressure loss in the laminar mode of movement of anomalous oil in a pipe has been extracted.
11. At $\Delta P \leq \Delta P_0$ the liquid in the pipe does not move, it remains at rest.

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