NON-STATIONARY FLOW OF FLEXIBLE CHAIN POLYMER SOLUTIONS IN POROUS MEDIUM

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Summary. Theory of elastic deformation effects for the flow with stretching of flexible chain polymer solutions predicts a higher degree of porous medium inclusion to be achieved by non-stationary flooding of polymer solution into it. In order to justify this prediction water solutions of polyethylene oxide were studied under conditions of non-stationary flow with stretching. Conducted experiments proved the accuracy of theoretical prediction.

INTRODUCTION

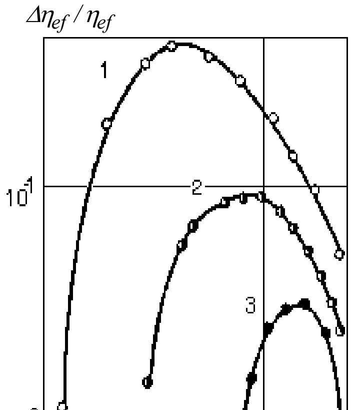
Experiments mentioned in this work were conducted with the prospect to clarify the question on the mechanism of “abnormally” high degree of seam inclusion with a polymer solution. There have been expressed the most conflicting judgments as to some deviations from Darcy's law. Further on we shall describe experiments to test some theoretical conclusions based on the knowledge about a strong deformation impact of a hydrodynamic field on macromolecular coils in a filtration flow.

Theory of elastic deformation effects for the flow with stretching of flexible chain polymer solutions [1] predicts a higher degree of porous medium inclusion to be achieved by non-stationary flooding of polymer solution into it. In order to justify this prediction water solutions of polyethylene oxide (PEO) were studied under conditions of non-stationary flow with stretching.

OUTCOMES AND THEIR DISCUSSION

During a modeling mode of solution flooding into a porous medium (seam) the examined solution was forced by a constant pressure difference through a flow chamber (module) with two capillaries located at inlet and outlet ends. That chamber had a diaphragm connected to electromagnet fed by an AC generator. Amplitude of diaphragm vibrations was constant and was chosen so that the rate of polymer solution flow through capillaries caused by diaphragm vibrations was less than flow rate due to constant pressure difference. The last flow rate went over a critical limit [2]. Capillaries had a diameter of $0.2\cdot10^{-3}$m.

Experiment results are given in Figure 1, where η_{ef} - a value of solution effective viscosity in a stationary flow; $\Delta\eta_{ef}$ – an additive resulted from non-stationary effect caused by oscillating influence on the main flow; ω' - frequency of diaphragm vibrations. Curves correspond to different velocities of the main flow through capillaries.



$M_{PEO} = 4{,}5\cdot10^6$, $C_{PEO} = 0{,}02$ %,
$\bar{U}$:1-0,3 m/s, 2-0,5 m/s, 3-0,7m/s

Figure 1. Influence of outer frequency effect on effective viscosity changes in water PEO solution.

It is seen that there is some critical frequency effecting on a stationary flow due to which the latter becomes more dissipative. An average flow velocity being increased gives way to ω'_{cr} to grow, while $\Delta\eta_{ef}$ is reduced. The critical frequency value is higher in case of smaller concentrations of PEO solutions and the same flow velocity.

Under deformation of polymer systems, just PEO solutions in our case, values of deformation ε and tension σ undergo changes at different stages [3]. Angle δ' that characterizes this difference is a composite function of vibration frequency ω'. Here deformation took place under tension effects reflected in the law:

$$\sigma(t) = \sigma + \sigma_0 exp\,(i\omega' t), \qquad (1)$$

where σ – stationary tension, t – time.

Taking into account that $\sigma(t) = \sigma_0 cos(\omega' t)$ and $\varepsilon = \varepsilon_0 cos(\omega' t - \delta')$, and excluding time from these equalities we got the equation:

$$\left(\frac{\sigma}{\sigma_0}\right)^2 + \left(\frac{\varepsilon}{\varepsilon_0}\right)^2 = \varepsilon\delta' + \left(\frac{\sigma}{\sigma_0}\right)\cdot\left(\frac{\varepsilon}{\varepsilon_0}\right) cos\,\delta' \,. \qquad (2)$$

The expression (2) is an equation of ellipse with the area equaling performance A_0, done within a cycle of harmonic vibrations and irreversibly lost (dissipated) under deformation.

Then dissipation function W is calculated as A_0 multiplied by a number of cycles per time unit:

$$W = A_0 \frac{\omega'}{2\pi} = \frac{\varepsilon_0 \sigma_0 \omega'}{2} sin\,\delta'. \qquad (3)$$

It is understood from (3) that dissipation function under identical deformation conditions depends only upon polymer characteristics expressed in the value δ'.

Giving tensions that are being changed according to a harmonic law it is possible to watch deformation velocity changes $\dot{\varepsilon}$ that is related to ε in the following way:

$$\dot{\varepsilon} = \frac{d\varepsilon}{dt} = \varepsilon_0 i\omega\, exp\left[i\left(\omega' t - \delta'\right)\right] = i\omega'\varepsilon \qquad (4)$$

It allows then to use the ratio $\sigma / \dot{\varepsilon}$ as solution characteristics which is called complex dynamic viscosity η^*. This value can be presented in the form of both real and imaginary components: $\eta^* = \eta' - i\eta''$ *(5),* where $\eta' = (\sigma_0/\varepsilon_0\omega')\cdot sin\delta'$, and $\eta'' = (\sigma_0/\varepsilon_0\omega')\cdot cos\delta'$ (η' - dynamic viscosity). After introducing η' into formula (3) and making necessary transformations we get:

$$W = \eta' \cdot \frac{\varepsilon_0^2 \omega'^2}{2}\ . \qquad (6)$$

Dynamic viscosity appears in the system only under deformation that's why the studied growth of effective viscosity $\Delta\eta_{ef}$ in case of harmonic effects being applied to the main flow should be justified by the occurrence of η'. As the value of amplitude deformation ε_0 remained constant during the experiment it is possible to use scaling and re-write (6) in the following form:

$$W(\omega) \approx \Delta\eta_{ef} \cdot \omega'^2. \qquad (7)$$

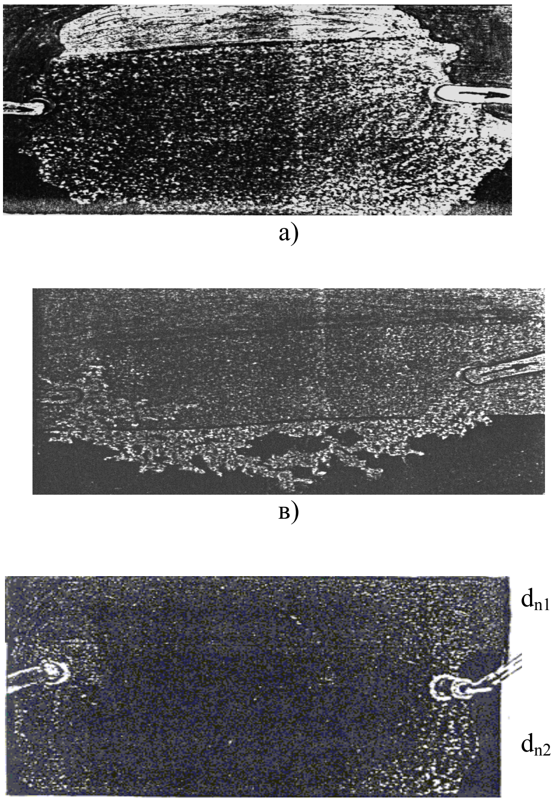


Figure 2. The picture of PEO solution flooding of the porous medium with stratified heterogeneity (d_{n1}/d_{n2} = 4): stationary mode of flooding at supercritical velocities - a) and subcritical - в); c)-under frequency effect on filtration flow at super critical velocities.

Dissipation function curves were obtained for experimental curves of Figure 1 using (7). Analysis of these curves shows that in case of increase of an average outflow velocity of a water PEO solution through capillaries, i.e. with the increased share (due to molecular-and-mass distribution) of macromolecular coils undergone deformation [4] and having a higher degree of stretching, which causes induction of macromolecule stiffness [1], energy dissipation of a pulsation flow is being reduced. Threshold frequency value that makes dissipative character of a flow noticeable increases for less "flexible" and stretched molecules. The form of dissipative curve acquires more expressed extremal character with the growth of the induced molecular stiffness.

Passing from a model on to real filtration flow and coming from the obtained results it is possible to state: non-stationary filtration flow of polymer solutions ensures higher degree of flooding and seam inclusion (Fig. 2c) than stationary flow (Fig. 2a); increase of polymer macromolecule stiffness (in identical conditions) results in decrease of their hydrodynamic activity, and, hence, of the degree of seam inclusion. Figure 2c proves the accuracy of prediction of the theory of elastic deformation effects for the polymer solution flow with stretching.

CONCLUSIONS

Thus effects stipulating highly dissipative mode under non-stationary polymer solution flow through porous media must play a very important role while optimizing the process of underground seam flooding with polymer solutions.

References

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