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Unsteady states in non-equilibrium and non-linear two-phase flow through a porous medium

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When a two-phase mixture flows through a porous medium, oscillations in the pressure drop are observed for which there is no satisfactory explanation. It is shown below that these oscillations are associated with non-equilibrium and non-linear effects. In this paper, it is proposed to take account of the non-equilibrium effects associated with a charge in the rheological properties in micro emulsified media. Here, the two-phase fluid is in the form of a microemulsion; the particles of which possess viscoelastic properties. During the motion through the channels, which is accompanied by deformation of the particles, there is change in the seepage resistance of the flow due to restructuring of the microemulsion with a relaxation time which is characteristic for the given system.

Laboratory experiments show that, when the pressure gradient is increased, the resistance to seepage in flow of microemulsion is reduced and increases when the pressure gradient is decreased. In this sense, the rheological behavior of a microemulsion is of a non-Newtonian nature (the effective viscosity decreases with increasing applied stress). Several possible details of this process have been proposed. However, not all its special features have been fully investigated. We will therefore confine ourselves to a phenomenological approach to the description of phenomena of this kind and the specification of functions of the relative phase permeabilities (RPP) of water and oil, taking account of their non-equilibrium nature. We write the kinetic equations for the non-equilibrium RPP of water (the displacing phase) $n_1(s)$ and oil (the displaced phase) $n_2(s)$ in the form

$$n_i(s) + \tau_1 \frac{\partial n_i}{\partial t} = k_i(s)\psi(q), i = 1,2;\; q = \left|\partial p \big/ \partial x\right|,$$

where τ_1 is the restructuring time, $k_1(s)$, $k_2(s)$ are the equilibrium RPP, s is the saturation of the displacing phase and p is pressure. The introduction of the function $\psi(q)$ enables one to describe the non-Newtonian properties of the water-oil emulsion

$$\psi = \begin{cases} 1-\exp(-bq),\; \partial p/\partial t > 0 \\ 0{,}01[\exp(bq)-1],\; \partial p/\partial t < 0 \end{cases}.$$

The values of this function for the same absolute values of the pressure gradient, determined for a decreasing and an increasing pressure, are not same, that is, the phase permeabilities exhibit hysteresis. For generality, the equation of motion of the displaced phase is taken in the relaxation form. The conclusions of the asymptotic analysis are confirmed by the results numerical analysis of the mathematical model.

Hence, it has been shown that oscillations of the pressure drop with time arise during two-phase flow in a porous medium and these oscillations are the result of the combined effect of the non-linear properties of a microemulsion and the effects of a time lag in the establishment of the phase permeabilities in immiscible displacement processes.

The most brightly nonlinear behavior in hydrodynamics of emulsion is observed at its current in microchannels (micro fluidic) at experiments with constantly operating pressure difference on a channel site. It was revealed that, despite constantly operating pressure difference, a current of return water-oil emulsion in due course almost completely stops. Such phenomenon has been named by effect of dynamic blocking. It is shown at a current through the cylindrical micro channels, at plainly current in elements of a crack and at a filtration through three-dimensional capillary structure – a core. The most surprising that the sizes of micro drops of water in an emulsion 10 times less the cross-section sizes of micro channels, and, nevertheless, formed the structure from water micro drops locks not only separate micro channels, but also system from such micro channels, including cores. Thus formed structures maintain huge gradients of pressure of 6 GPa/M. The physical nature of dynamic blocking of emulsions is connected with "friction" presence between micro drops and their deformation at increase in a gradient of pressure.