INSTABILITY AND DYNAMIC CHAOS OF NON-EQUILIBRIUM FILTRATION OF GASEOUS LIQUID

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Oil filtration with the pressure head below the bubble point is a classical problem, widely covered due to efforts of many scientists (Wyckoff & Botset 1936; Muskat 1949; Efros 1969; Rosenberg *at al.* 1969). However, experimental data that were recently obtained fall into controversy with the established physical concepts of the process studied (Bolotov *at al.* 1988; Martos 1978). In last papers it is reported that there is an abnormal increase in discharge of gaseous liquid within bubble point pressure ranges, while discharge decreases with further pressure decreasing. Observed phenomenon cannot be explained in the frames of classical approaches. Authors (Bolotov *at al.* 1988; Buyevich 1987) are attributing this effect to the subcritical bubbling (processes of accumulation and discharging of micro gas bubbles in porous media), that results in decreasing of the volumetric viscosity of a gas liquid mixture. However, with the viscosity to decrease up to 10-15%, flow rates have grown up to 2.5-3 fold. From analysis of gas saturation with time, Martos (1978) came to the conclusion of the heterogeneity of flow. On the general background of the gas saturation growth with the throughput volumes, there are observed sporadic fluctuations of the saturation in different sections of the sample.

Experimentally shown (Churaev 1990) that in micro capillaries due to gas absorption, decrease of cohesion forces between a liquid and the inner surface of capillary takes place. With the absorption layer to be about 10 nm only, markedly slippage is registered resulting in a non-monotonous behavior of the relative phase permeability (RPP) of the liquid phase. In this context, it is of great interest to give qualitative, if not quantitative, evaluation of the filtration characteristics of the gaseous liquid flow accounting for a non-monotonous behavior of the RPP.

Let us consider the non-stationary filtration of gaseous liquid in porous medium using the concepts of the theory of filtration of multi component systems. We will focus here on the filtration of oil with dissolved gas.

As a rule, there are considered models of equilibrium filtration of gaseous liquid, with the inter phase mass transfer being described by the known isoterm of the gas solubility in liquid. In particular, Genry solubility isoterm is accepted: $g = g_e = ap$, $a = const$, $g_e(p)$ – equilibrium phase concentration.

On the contrary, we are assuming non-equilibrium phase transitions. In this case, we have the following non-equilibrium model to describe the dependence of the mass concentration of the dissolved gas on the pressure:

$$\frac{dg}{dt} = -\frac{g - g_e(p)}{t},$$

where $\frac{dg}{dt}$ – substantial derivative, $\frac{dg}{dt} = \frac{\partial g}{\partial t} + u_1 \frac{\partial g}{\partial x}$. Velocity u_1 is derived by the Darcy law, t – relaxation time.

From the analysis of the experimental data it follows that the effect of slipping of the liquid is responsible for the nonmonotonic behaviour of the relative permeability of the liquid phase.

We assume that the phase permeability function for the liquid phase has the form shown in Fig. The relative permeability is given by $f_i = k_i / k_{i0}$, where k_{i0} is the permeability measured for the phase *i* when it completely fills the pore volume and k_i is phase permeability.

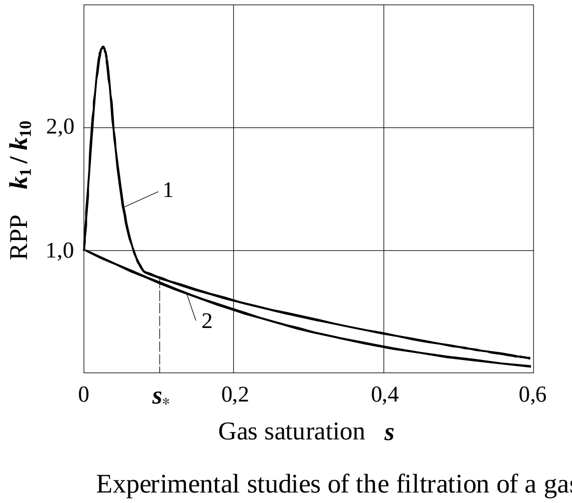
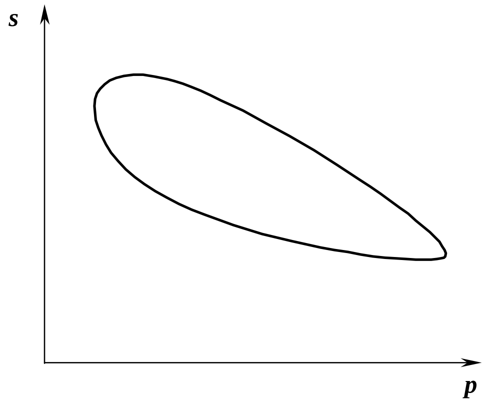


Fig.1. Relative phase permeability versus gas saturation: curves 1 and 2 corresponds to calculations using the method proposed herein and the method of Wyckoff and Botset, respectively.

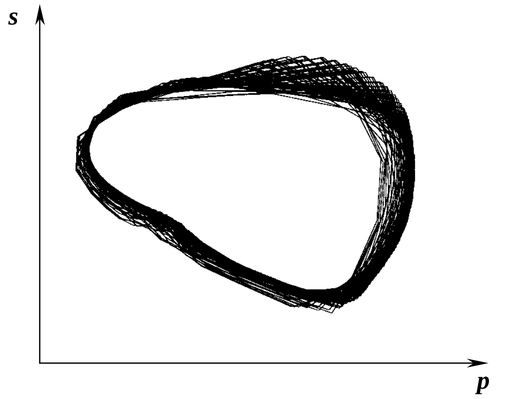
Experimental studies of the filtration of a gas-liquid mixture through a porous medium show that once the pressure difference becomes critical, steady filtration regimes lose stability and undamped time variation in the flow rate of the filtrated liquid are observed. Therefore, we study the stability of steady filtration regimes for the gas-liquid mixture taking into account the nonmonotonic behaviour of the phase permeability for the liquid phase.

The relative permeability of the liquid phase is chosen in such a way that the maximum of the function corresponds to tha gas saturation value *s* for which the involved gas is entirely absorbed by the pore walls. The gas involved acquired mobility, forming a bound phase, at mean gas saturation $s = s_* = 0{,}1$.

By means of numerical investigations it was found out that transition to chaos in the considered system is evolved through destruction of the quasiperiodical movement. Attractor's evolution in the phase plane (p,s) from finite cycle to the strange attractor for the oscillatory regime given on Fig.2.



(a) $\Delta p = 3MPa;\ t = 20\sec;\ m_0 = 0{,}01$



(b) $\Delta p = 5MPa;\ t = 2000\sec;\ m_0 = 0{,}001$

CONCLUSIONS

1. We offer a model of non-equilibrium filtration of gaseous liquid within bubble point pressure ranges in the case of non-monotonous dependence of relative phase permeability of fluid on gas saturation.
2. It is shown that in this case two things are possible: stability violation of stationary behaviour of gaseous liquid filtration and regular and stochastic auto oscillations. Oscillations behaviour is determined by pressure drop parameter in a reservoir model, degassing degree, and oil filtration viscosity.
3. We give a numerical solution of oil degassing in a model of porous media taking into account non-equilibrium behaviour of gas releasing and nonmonotonic dependence of relative phase permeability of liquid phase on gas saturation. Calculations show increase in discharge within bubble point pressure ranges and decrease in charge with further pressure decay. The results of numerical investigations satisfactorily coordinate with laboratory experiments data.
4. Numerical solution also shows pressure and gas saturation oscillations during periods of time in particular reservoir section.

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