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INFLUENCE OF DISSOLVABLE GAS BUBBLES ON FILTRATIONAL PROPERTIES OF FLUID

Abstract

In the article, different aspects of influence of microbubbles of liquid-dissolved gas on a filtration of gas-liquid medium are discussed. The offered method allows to receivie mathematical description of nonequilibrium extraction of gas with regard to non-stationary stute of gas bubbles growth process. It is received self-model solution of behavior of a bubble in supersaturated by gas liquid. Influence of parameter of Jacob on speed of gas extraction is obtained.

Experimental and theoretical investigations carried out recently with gas-containing fluids show that in pre-transient state (i.e. in the field of pressures exceeding the saturation pressure, but close to it) rheological and relaxation properties of gas-fluid systems in great degree are determined by the availability of "micro-germs" - the smallest gas bubbles whose cooperative action becomes apparent while approaching to saturation pressure [1].

Notice some latest developments brought about by foreign specialists, that have direct relation to the considered problem.

In the articles enumerated below, mainly different properties of gas micro-germs are used for solving concrete technological problems.

It is known that shaking is necessary for mixing water and oil, in order to overcome forces retaining oil to interact with water. However, chemist Reek Peshley from Australian National University in Canberra affirms that if at first any water-dissolved gases will be removed, then oil will mix with water without outside assistance [2].

Though many scientists couldn't believe it, but Pashley submitted convincing arguments. We speak on so-called long-range hydrophobic force that compels oil drops to attract each other even in long distances. This force obstructs oil dissipation in water and leads to the fact that hydro emulsion may be created only by means of shaking and addition of stabilizing agents.

Pashley studied the behavior of drops of oil-like hydrophobic (water-repellent) agents when they break into parts. He paid a special attention to microscopic pockets appearing on their surface. The air-contacting water contains some quantity of dissolved gas, and Pashley supposed that just the pockets contain gas bubbles that are "taken away" from water, possible by the same hydrophobic force of long-range. In order to verify this assumption, Pashley removed the gas from water and oil mixture, repeatedly freezing and thawing with simultaneous pumping out evaporated gas. As the result there happened spontaneous emulsification. This allows considering that water-dissolved gas is subjected to the action of hydrophobic force.

It is more interesting that emulsion was not decomposed even if gas was again pumped after its formation. Pashley assumed that gas may interact with hydrophobic force most effectively if oil drops are very close to each other as in the beginning of emulsification process. But when mixture is already created, hydroxyl groups of water, possibly, attach to the oil drop surface, make them equally loaded and interference to draw together each other. Creation of such emulsions may have a great value for medicine and chemical industry.

It is necessary to remark influence of microbubbles on gas-fluid medium filtration. A number of experiments testify the existence of stable bubbles in pretransient phenomena, and also show that filtration of gas-fluid systems in a porous medium near the saturation pressure is always accompanied by no equilibrium affects.

It is experimentally established and theoretically stipulated that in magnetic treatment the quantity of hard microparticles in fluid (iron containing particles) that may be crystallization centers and gas bubbles, may increase. Investigations show that such micro bubbles posses electric charge and high absorption activity with regard to organic and mineral deposits. After magnetic treatment such bubbles give washing properties to fluid similar to ones that arise in adding detergent or soap to water. Colliding with the walls, the bubble pull off the particles of sediments and take them away on their surface to the fluid's flow, and clean the walls of pipelines, pores. Owing to availability of electric charge, a micro bubble arisen as a result of magnetic treatment becomes stable to collapse even under ten and hundred atmosphere pressure.

For revealing influence of gas micro-germs on filtration process theoretical methods of investigation were used in the paper [1]. Experimental investigation hesitates for lack of reliable methods allowing predicting straightly the availability of new phase embryos. Volume methods by which on beginning of embryo formation is judged by change of angle of slope of graph of dependence of system's volume change on pressure change.

In eighties, when nanotechnologies were not developed as today, while carrying out investigations the authors of the papers [5,6] didn't use the terms of nanotechnologies. However, by the essence, the elaborated methods in many respects were based on nano effects.

So, in particular, as a result of experiments carried out in a laboratory installation containing a system simulating a homogeneous oil stratum it was shown that availability of iron and aluminum particles reduces to significant increase of gas liberation and pressure intensity in porous medium.

Chromatographic analysis of generated gas showed that it represents 90-95% hydrocarbon. Since the hydrocarbon is the least adsorbing gaseous component, its intensive release in carried out experiments reduced to double increase of pressure in porous medium [8].

Let's consider behavior of solution near saturation pressure $p/p_s\,\tilde{}1$, when gas is liberated from fluid. Generated gas bubbles from the solution partially clog the pores of medium, partially are filtered through large pores and go out of porous sample. Volume consumption of fluid here is very little.

This process is accompanied by gas liberation from oversaturated solution to free state. Free gas liberation leads to generation and growth of gas bubbles in solution.

Since gas liberation is controlled by the same diffusion mechanism as redistribution of concentration in solution, the process of free gas bubbles growth will have not in equilibrium character.

Let's consider a problem on growth of a single bubble in unbounded domain with the given gas concentration remote from it c_∞ $(r = \infty)$, exceeding not in equilibrium value for pressure p_∞.

Redistribution of concentration $c(r,t)$ in oversaturated solution and liberation of gas to free phase will be described by means of diffusion equation in Euler coordinates for spherical symmetric motion of fluid around soluble gas bubble

$$\frac{\partial c}{\partial t} + v_l \frac{\partial c}{\partial r} = \frac{D}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial c}{\partial r}\right), \tag{1}$$

in which D is a coefficient of gas diffusion in water, ν_l is radial velocity of fluid around the bubble. For incompressible fluid we have [11]:

$$\nu_l = \dot{R}\frac{R^2}{r^2}, \tag{2}$$

where $R(t)$ is bubble's radius.

Usually, when a bubble grows under fixed conditions remote from it there is a regime when the parameters interior to a bubble become homogeneous and don't change in time [5,11]:

$$r < R(t):\ T = T_0,\ p = p_\infty,\ \rho = \rho_s,\ c = c_s \tag{3}$$

Here T is temperature, ρ is gas density.

Self-model solution of a problem on growth of a single bubble is suggested to use for simulating intensity of free gas phase formation. Such a solution is established in the course of long term when the system "forgets" input conditions and depends only on dimensionless variable $\eta = r/R(t)$, i.e we'll look for the solution of equation (1) of the form $c(r,t) = c(\eta)$. Introducing dimensionless concentration $\overline{c} = c/c_s$, we rewrite (1) in the form

$$R\dot{R}\left(1-\eta^3\right)\frac{d\overline{c}}{d\eta} = D\frac{d}{d\eta}\left(\eta^2\frac{d\overline{c}}{d\eta}\right), \tag{4}$$

Self-model solution of type $\overline{c}(\eta)$ may exist only, if

$$R(t)\,\dot{R}(t) = const, \tag{5}$$

Use the boundary condition [4,10]:

$$D\frac{\partial c}{\partial r}\bigg|_{r=R(t)} = \frac{\dot{m}}{4\pi R^2},\ \ (m(t)\ \text{ massa is bubble}) \tag{6}$$

that may be reduced to the form

$$\frac{Dc_s}{\rho_s}\frac{d\overline{c}}{d\eta}\bigg|_{\eta=1} = R\dot{R}, \tag{7}$$

Hence it is seen that condition (6) is fulfilled. Let's introduce a dimensionless parameter

$$\chi = \frac{c_s}{\rho_s}\frac{d\overline{c}}{d\eta}\bigg|_{\eta=1} = \frac{R\dot{R}}{D} \tag{8}$$

Allowing for (8), equation (4) and boundary conditions will take the following form:

$$\frac{d^2\overline{c}}{d\eta^2}+\left(\frac{2}{\eta}-\chi\frac{1-\eta^3}{\eta^2}\right)\frac{d\overline{c}}{d\eta}=0, \qquad (9)$$

$$\eta=1:\ \overline{c}=1,\ \eta=\infty:\ \overline{c}=c_\infty/c_s=\overline{c}_\infty$$

This is an equation with some different form of notation of boundary conditions for $\eta=1$, but for heat inflow equation it was obtained by Scriven [11]. This solution is of the form:

$$\overline{c}\left(\eta\right)=\frac{\overline{c}_\infty-1}{\int\limits_0^1\exp\left[-\chi\left(\frac{1}{2\xi^2}+\xi\right)\right]d\xi}\int\limits_1^\eta\frac{\exp\left[-\chi\left(\frac{1}{\xi}+\frac{\xi^2}{2}\right)\right]}{\xi^2}d\xi+1 \qquad (10)$$

$$\left.\frac{d\overline{c}}{d\eta}\right|_{\eta=1}=e^{-\frac{3}{2}\chi}\frac{\overline{c}_\infty-1}{\int\limits_0^1\exp\left[-\chi\left(\frac{1}{2\xi^2}+\xi\right)\right]d\xi} \qquad (11)$$

By (8) and (11), the parameter χ contained in the solution is a root of the equation

$$\chi e^{-\frac{3}{2}\chi}\int\limits_0^1 e^{-\chi\left(\frac{1}{2\xi^2+\xi}\right)}d\xi=Ja,\ Ja=\frac{c_s\left(\overline{c}_\infty-1\right)}{\rho_s} \qquad (12)$$

The roots of (12) may be determined by approximation for different values of Jacob parameter Ja. For small drops of concentration we get $\chi\approx Ja$.

Thus, bubble's growth is determined from the expression (8)

$$\overline{R}=\sqrt{1+2\chi\tau},\ \overline{R}=R/R_0 \qquad (13)$$

The solution of the problem allows to get from the equations (6), (10) and (11) a differential equation for determining bubble's mass at the expense of dissolved gas inflow through the interface:

$$\frac{d\overline{m}}{d\tau}=3\overline{R}\chi e^{-3\chi},\ \overline{m}=m/\left(\frac{4}{3}\pi R_0^3\rho_s\right),\quad \tau=tD/R_0^2 \qquad (14)$$

The solution of equation (14) allowing for (13) and initial conditions $\overline{m}=1$ for $\tau=0$ is of the form:

$$\overline{m}=1+e^{-3\chi}\left[\left(1+2\chi\tau\right)^{3/2}-1\right] \qquad (15)$$

In the figure the dependences of dimensionless size of bubble (a) and gas mass in a bubble (b) on time for different values of Jacob parameter are shown.

Intensive growth of bubble (respectively, mass of bubble) happens due to high level of oversaturation of fluid by gas.

Thus, we can speak on cardinal influence of nanoeffects on character of fluids filtration in the course of application of microembryos technology in oil-recovery.

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