$Re = \rho VL/\eta^*$ is the Reynolds number;
ρ is the density;
F_{ij} is the deformation rate tensor.

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VARIATION OF THE RHEOLOGICAL PROPERTIES OF MULTIPHASE MIXTURES DURING THEIR PRESSURE TREATMENT

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Nonequilibrium effects in the barotreatment of non-Newtonian multiphase systems are discussed.

It has been established by a large number of investigations that when non-Newtonian systems are pressure-loaded under static conditions, one observes a slow pressure drop to some stabilized value [1].

These kinetic effects are observed under both static and dynamic conditions [2].

The "pressure-drop" effect was the basis for an examination of the possibility of regulating the rheological properties of non-Newtonian systems through their pressure treatment – barotreatment.

The effect of pressure on the properties of some non-Newtonian systems is discussed below. Proceeding from fluid-transport problems, as the models of non-Newtonian systems we chose: 1) glycerin+quartz dust (10%); 2) glycerin+quartz dust (10%)+CO_2 gas (with gas–liquid ratios $\Gamma = 5$, 10, and 25 cm^3/cm^3); 3) glycerin+quartz sand with fraction of ϕ 0.25-0.75 mm.

The tests were conducted on a specially constructed installation whose main component is the pressure chamber – an RUT cylinder (Fig. 1).

The first series of experiments was performed with a non-Newtonian system, a mixture of glycerin+quartz dust (10%), which was carefully evacuated at T = 40°C before the start of a test.

The presence of a piston in the RUT cylinder, as is known, is associated with some "shear" forces on the order of 1-1.5 atm (tech.) expended in the motion of the piston itself. In order to eliminate this effect, the experiments were conducted inside a container.

The tests were conducted in the following way: excess pressure was produced in the container 2 (Fig. 1) by depressing the piston with the press, and when the assigned pressure P_0 was reached the container was disconnected from the RUT cylinder by the valve 9, with the loading of the system taking place in a relatively short time. The time variation of the pressure was recorded with a standard manometer 6 with a scale division of 0.2 atm (tech.).

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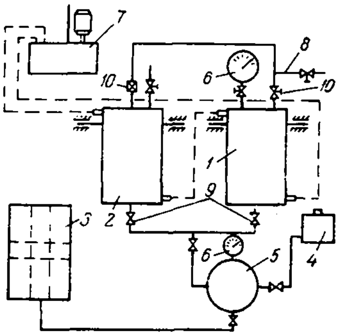

Fig. 1. Diagram of experimental installation for barotreatment of non-Newtonian multiphase systems: 1) high-pressure RUT cylinder; 2) high-pressure container; 3) hydraulic press; 4) vessel containing glycol; 5) manifold; 6) standard manometers; 7) thermostat; 8) vacuum line; 9, 10) high-pressure valves.

During a test a pressure drop from P_0 = 93.6 atm (tech.) (Fig. 2, line I) to practical stabilization at P_1 = 90.7 atm (tech.) was observed in 3.5 h. Upon the subsequent loading of the system to the original value of P_0=93.6 atm (tech.) a pressure drop was also observed but by less than the preceding value, P_2=92 atm (tech.), and stabilization of the pressure occurred in a smaller time (Fig. 2, line II). After the next compression a change in pressure was not observed: $P_3=P_0$=93.6 atm (tech.) (Fig. 2, line III).

For a comparison of the results obtained, we made control tests with Newtonian liquids (water and glycerin), which do not change their rheological characteristics during pressure loading and the amount of excess pressure does not vary with time.

In the second series of experiments we examined the possibility of reducing the barotreatment time. The initial pressure was set the same as in the preceding experiments: P_0 = 93.6 atm. (tech.). A slow pressure drop was also observed here, but the reloadings took place not after its prolonged stabilization but in periods of a relatively low rate of pressure drop. At P = 92 atm. (tech.) the system was loaded to values corresponding to line II (Fig. 2). In this case a second pressure drop was observed, no longer along the line II but somewhat below it. Without waiting for stabilization of the pressure the next compression (Fig. 2, III) was performed and a slow pressure drop was again observed. Similar actions were repeated until the pressure no longer changed after the next compression (Fig. 2, IV). With pulsed stepwise loading the process of loading and total stabilization of the pressure took about 3.5 h.

A comparison of the results of the first and second series of tests showed that the effective factor of the process of barotreatment of non-Newtonian systems is probably not the duration of the treatment but the cyclicity of the pressure loading of the non-Newtonian system. A considerable reduction in the treatment time was achieved in the pulsed cyclic barotreatment of non-Newtonian systems.

The results of these tests can be explained as follows. One of the important factors of two- and three-phase systems under the conditions of directional actions is the nonconstancy of their rheological properties, which is connected with a change in the layered structure [3]. Orientation of the particles of the disperse phase in the direction of action of the maximum stresses occurs in this case.

The next stage of the investigations was devoted to an experimental investigation of the effect of barotreatment on the rheological characteristics of three-phase systems.

In this series the first experiments were conducted with CO_2 gas inclusions, i.e., the system consisted of a mixture of glycerin + quartz dust (10%) + CO_2 gas (with gas–liquid ratios Γ = 5 and 10 cm^3/cm^3 at the corresponding saturation pressures P_s = 15 and 35 atm (tech.).

The tests were conducted in the following sequence. The mixture of glycerin + quartz dust (10%) was distilled from the container into the RUT cylinder, in which the gassed mixture was then prepared. The assigned

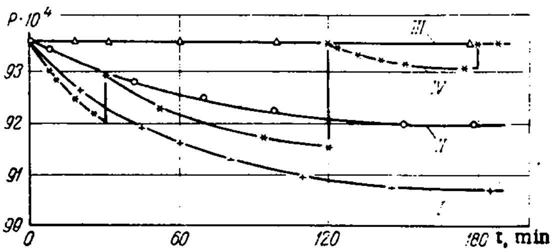

Fig. 2

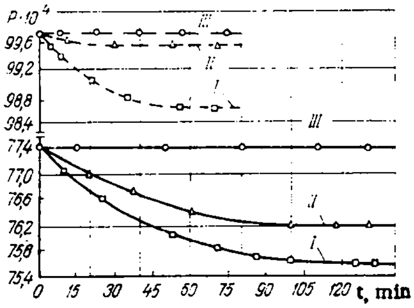

Fig. 3

Fig. 2. Pressure variation: I) after first loading; II) after second; III) after third; IV) stepwise loading. $P \cdot 10^4$, N/m^2; t, min.

Fig. 3. Barotreatment of a mixture of glycerin + quartz dust (10%) + CO_2 gas. Solid lines) at $\Gamma = 5\ m^3/m^3$ and $P_s = 15 \cdot 10^4\ N/m^2$; dashed lines) at $\Gamma = 15\ m^3/m^3$ and $P_s = 70 \cdot 10^4\ N/m^2$. Pressure variation after: I) first loading; II) second; III) third loading.

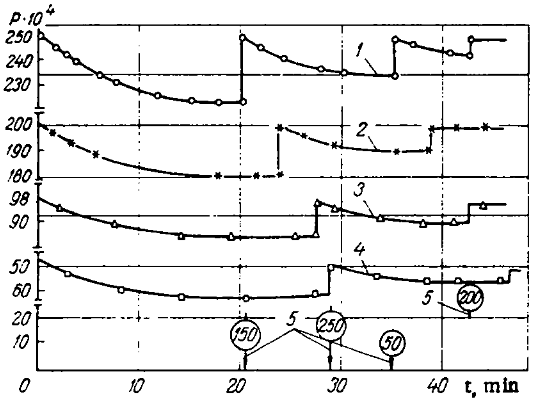

Fig. 4. Barotreatment of a mixture of glycerin + quartz sand of $0.25\text{-}0.75 \cdot 10^{-3}$ mm (15%): 1) $P_0 = 250 \cdot 10^4\ N/m^2$ (initial pressure); 2) $200 \cdot 10^4$; 3) $98 \cdot 10^4$; 4) $51 \cdot 10^4\ N/m^2$; 5) unloading of the system. $P \cdot 10^4$, N/m^2; t, min.

gas–liquid ratio (Γ) was monitored by taking samples from the RUT cylinder with their subsequent measurement. The tests were run at pressures above the saturation pressure. Then the system was pressure loaded to the assigned value of P_0 and the container was disconnected with the valve 9. The pressure drop in the RUT cylinder was monitored from readings of a standard manometer. It should be noted that the tests were conducted at a constant temperature $T = 30 \pm 0.05°C$.

Curves of the pressure drop upon loading of a system of glycerin + quartz dust (10%) + CO_2 gas [$\Gamma = 5\ cm^3/cm^3$, $P_s = 15$ atm (tech.)] are presented in Fig. 3.

Complete pressure stabilization [$P_0 = P_3 = 77.4$ atm (tech.)] was achieved with three compressions in a space of 3 h.

To refine the influence of the gas–liquid ratio on the barotreatment process, we conducted experimental investigations of the above-indicated mixtures with different gas–liquid ratios.

The results of a test on the barotreatment of a non-Newtonian system of glycerin + quartz dust (10%) + CO_2 gas ($\Gamma = 25\ m^3/m^3$, $P_s = 70 \cdot 10^4\ N/m^2$) are presented in Fig. 3 (dashed curves I, II, and III).

As seen from Fig. 3, after three compressions the initial pressure level does not vary with time, with each cycle of compression and pressure stabilization taking place in 1 h. The entire barotreatment process occupies somewhat less than 2 h.

From the test results presented in Figs. 2 and 3 it is seen that with gas inclusions the relative pressure decrease is less than for a degassed mixture. The "pressure-drop" effect decreases with an increase in the gas–liquid ratio, which is evidently explained by the negative influence of the dissolved gas on the redistribution of the disperse phase.

The results of tests on the barotreatment of a mixture of glycerin + quartz sand (15%) with fractions of 0.25-0.75 mm are presented in Fig. 4. In this series of experiments three tasks were set: first, to clarify the influence of the pressure level on the rheological characteristics of non-Newtonian systems, and also to investigate the "memory" of a treated system.

From a comparison of the "pressure-drop" curves of Figs. 2 and 4 it follows that the higher the sand concentration in the system, the larger the "pressure-drop" effect, and one also observes a strengthening of the effect with an increase in the fraction sizes of the disperse phase.

From curves 1-4 of Fig. 4 it is seen that the pressure level of the barotreatment has an important influence on the "pressure-drop" effect, i.e., with an increase in the initial pressure level P_0 the "pressure-drop" effect is considerably higher.

Special tests conducted by the method of [1] showed the absence of a "memory" for the systems investigated (Fig. 4, lines 5).

An analysis of the results presented above showed that "pressure-drop" effects lead to a change in the rheological properties of non-Newtonian multiphase systems, in particular, to a marked decrease in the limiting shear stress τ_0.

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