DEFORMATION EFFECT AND LIQUID DISPERSION KINETICS IN A MAGNETIC FIELD

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The deformation of liquid drops formed at the end of a capillary in a nonuniform magnetic field has been experimentally investigated. The nature of the effect of a nonuniform magnetic field on the kinetics of aqueous emulsion formulation is discussed.

Umov [1], in the course of investigating the free formation of drops of diamagnetic and paramagnetic liquids in a magnetic field, observed the deformation of the drops as a function of the strength and gradient of the field and offered an explanation of the effect. The change in the rate of drop formation approximately satisfied the equation $\tau_0 P = \tau P_0$, where τ_0 and τ are the times required to form identical numbers of drops without and with a field; and P_0 and P are the corresponding drop weights.

Investigations of the capillary saturation of quartz powder with 10% aqueous solutions of NaCl have revealed an increase in the rate of penetration in a nonuniform magnetic field [2]. The magnetohydrodynamic conditions affect the capillary-rise kinetics of mercury [3].

It follows that a nonuniform magnetic field may have an important influence on the kinetics of disperse system formation. We have observed the effect of a nonuniform magnetic field on the formation of drops of distilled water and surfactant solutions (Table 1) and on the formation of aqueous emulsions. The surfactant solutions were diamagnetic liquids with various electrical conductivities commonly employed as media in dispersion processes. Two of the solutions – hexyl alcohol and sodium oleate – had the same surface tension, but the kinetics of formation of the equilibrium adsorption layers at the solution–air interface were different. The deformation effect observed by Umov was estimated from the weight of the drops.

A glass capillary 0.71 mm in diameter was used to form drops at a temperature of 18-20°C along the Z axis in a pole gap of width d = 8 mm (Fig. 1) at constant hydrostatic pressure. The field strength was varied between 2000 and 11,000 Oe and recorded at the end of the capillary. The direction of the field gradient ($2 \cdot 10^3$ Oe/cm) was varied by rotating the pole pieces through 180°.

The dependence of the mean weight of the water drops on H grad H at currents of 3 and 5 A in the coils of the electromagnet is presented in Fig. 2. Curves 1 and 2 represent a slowing of drop formation (direction of gradient negative), the weight of the drops increasing by 3.5% as compared with the least value of H grad H, while curves 3 and 4 represent an acceleration of the rate of formation (direction of gradient positive) and a decrease in the weight of the drops by 2.7-5.5%. The data obtained confirmed Umov's relation (see above) to within 0.1-0.6%.

Almost linear relations (Fig. 3) were obtained for sodium oleate and hexyl alcohol solutions in the positive-gradient region. The fall in the weight of the drops for a sodium oleate solution as compared with the least value of H grad H was 2.4-3.3% (curves 1 and 2); for hexyl alcohol with the same σ the corresponding figure was 3-4.6% (curves 3 and 4), while for hexyl alcohol of higher concentration (σ = 54.3 erg/cm^2) the fall in weight was approximately the same, namely 3.5% (curve 5). The difference in the weights of the drops for sodium oleate and hexyl alcohol solutions with the same σ is evidently chiefly associated with the different kinetics of formation of the adsorption layers under nonequilibrium conditions. It may be assumed that the magnetic field also affects the adsorption layer kinetics, since the paramagnetic properties of the active OH and COOH groups are different [4].

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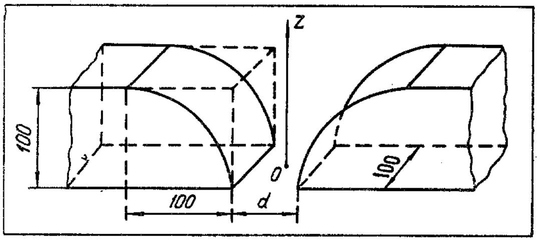

Fig. 1

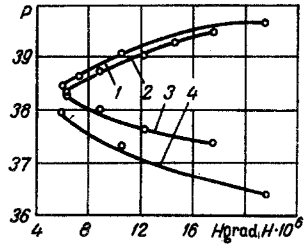

Fig. 2

Fig. 1. Diagram showing the arrangement of the magnet poles.

Fig. 2. Mean weight of water drops P (mg) as a function of H grad H (Oe^2 / cm): 1, 2) direction of gradient negative; 3, 4) direction of gradient positive; curves 2 and 3 correspond to a current of 3 A and curves 1 and 4 to a current of 5 A.

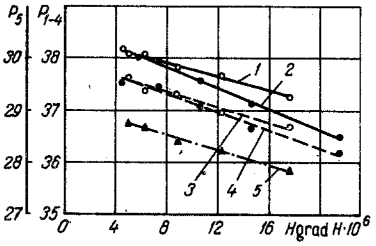

Fig. 3

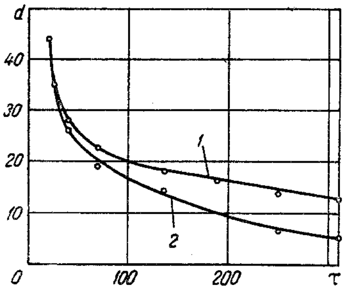

Fig. 4

Fig. 3. Mean weight of drops (mg) as a function of H grad H (Oe^2 / cm) for a positive direction of the gradient: 1, 2) for sodium oleate solutions; 3, 4) for hexyl alcohol at σ = 69.6 erg/cm^2 [1, 2) current 5 A; 3, 4) 3 A]; 5) for a hexyl alcohol solution at σ = 54.3 erg/cm^2, current 5 A.

Fig. 4. Mean diameter of emulsion droplets (μ) as a function of formation time (sec): 1) without a magnetic field; 2) with a field.

TABLE 1. Properties of the Solutions at 20°C

Solution	Concentration $c \cdot 10^3$, mole/liter	Surface tension σ, erg/cm^2	Electrical conductivity $\varkappa$, 10^{-6} ohm^{-1}·cm^{-1}
Water	—	72,8	1,99
Hexyl alcohol	1,0	69,6	2,1
The same	9,1	54,3	—
Sodium oleate	0,04	69,5	7,8

The difference in the drop weight curves obtained for different values of the current in the coils, but the same H grad H may be attributable to the Quincke effect on a column of water in a capillary located in a field. Accordingly, Umov's equation [1] for equilibrium drop formation in a magnetic field can be supplemented and represented in the form

$$V\rho g - \frac{V}{4\pi}(\mu - \mu_1) H \operatorname{grad} H - \mu_0 \chi H \operatorname{grad} H \pi r^2 Z$$
$$= \pi \frac{2\sigma \cos\Theta}{r} R^2 \left(\frac{1}{R} + \frac{1}{R_1}\right).$$

If a drop of hydrocarbon – normal tetradecane or a mixture of toluene and hexyl alcohol – is placed on the surface of a glass wetted with water, then in a gradient magnetic field its spreading perimeter is observed to increase.

When emulsions are formed by mixing in a nonuniform magnetic field it is obvious that under turbulent conditions the magnetic field is one of the important components of the deformations [5]. In this case the effect of the magnetic field was estimated from the emulsion kinetics. For this purpose we took a mixture of toluene and hexyl alcohol (1 : 1), which was added to an aqueous solution of sodium oleate (concentration 0.83%) in accordance with the method described in [6]. The emulsion was prepared by mixing in a field with a gradient of 600 Oe/cm. The concentration of the dispersed phase was 45.4%. The mean size of the emulsion droplets was determined in accordance with the procedure of [7]. The dependence of the droplet diameter on the emulsification time with and without a field is shown in Fig. 4. Clearly, the reduction in the size of the droplets, which tends to a certain limit, is more intense in the magnetic field, as a result of which the droplet diameter is only half as great as when no field is present.

NOTATION

V is the drop volume;
μ, μ_1 are the permeabilities of the liquid and air, respectively;
H is the field strength;
μ_0 is the permeability of free space;
Z is the coordinate of the end of the capillary;
Θ is the contact angle;
R, R_1 are the positive values of the radii of curvature of the drop at points on its neck.

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