The experimental scheme considered above, based on the stability conditions obtained in Sec. 2 within an exact formulation, possesses the same range of applicability as the method of [7]. We only note in addition that the critical pressure in the scheme suggested can, in principle, be measured more reliably than drop height at the moment preceding breakup.

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CHARACTERISTICS IN THE INITIAL STAGE OF THE SPREADING OF A DROP ON A SOLID SURFACE

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A study of the process of the spreading of a drop on a solid surface has been the subject of many investigations (see, e.g., [1, 2]). In all of these investigations the process of spreading was considered from the instant of time when the drop could already be regarded as a liquid body, having the form of a spherical segment with an angle of wetting on the order of 90°. However, for a precise formulation of the problem concerning the spreading of a spherical drop it is necessary to have some idea of how the boundary of wetting behaves from the instant the drop makes contact with the solid surface. This is the problem we address in the present paper.

To study the initial stage in the spreading of a spherical drop on a solid plane surface we employed the experimental setup shown in Fig. 1. The principle involved here is the following. When air is admitted into the pipette 1 a spherical drop 2 is formed; upon separating from the pipette, the drop acquires the requisite speed u_0 and falls onto the plane surface 3. But before striking the surface it intersects a light ray in the optical system consisting of the light source 4 and the photocell 5; consequently, after a requisite time delay, the device 10 energizes the high-voltage RC-oscillator 9, which furnishes a series of high-voltage pulses to the hydrogen flashtube 6. Periodic flashes of light from the latter pass through the shadowgraph 7 in whose field of view the drop appears, spreads out on the solid surface, a recording of which is made by the photoregister 8 (a transparent rotating drum with a film). Thus, the process to be studied is recorded frame by frame. Moreover, with the aid of the two mirrors 11 (see Fig. 1a), a record is obtained of the spreading of the drop 2 on the transparent plate surface 3, in two projections simultaneously: from the side (rays *a*–*a*) and from below (rays b–b).

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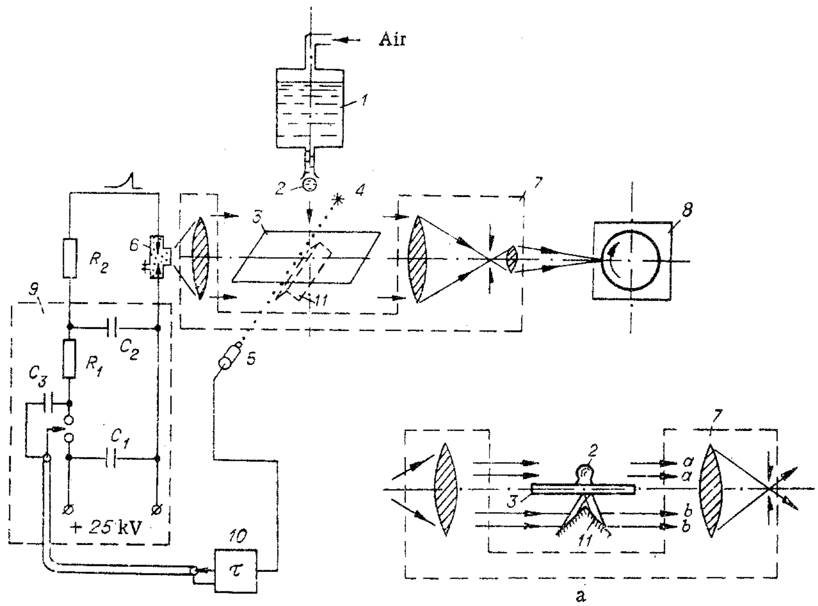

Fig. 1

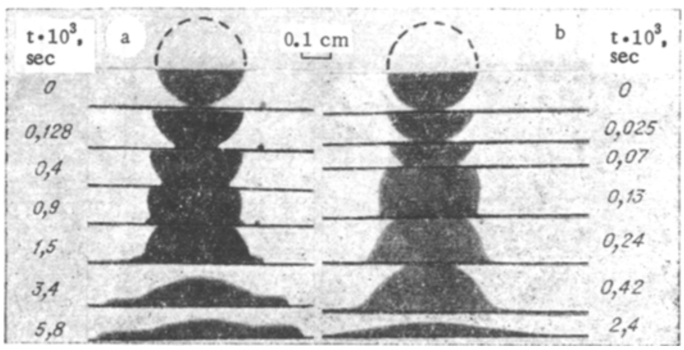

Fig. 2

The maximum exposure rate was 40,000 frames/sec; the time interval involved in the study was approximately 10^{-2} sec; the drop radii were $r_0 = 1.5$ mm and 3 mm; the drop materials were H_2O and C_2H_5OH; and, finally, the materials composing the solid surface consisted of glass and fluorite.

Our principal aim in the experiments was to study the initial stage in the spreading of a drop on a plane surface subject to the action of surface-tension forces. For this study we chose the speed of contact u_0 of the drop with the surface to be 1 cm/sec.

Figures 2a and 3a display typical ciné records of the process of spreading of a spherical water drop of radius $r_0 = 1.5$ mm on a plane fluorite surface. It is quite evident from the first few frames that a film of liquid is formed in a neighborhood of the point of contact of the drop with the surface; and that this film apreads rapidly over the fluorite surface. A similar phenomenon is observed also when a drop of alcohol C_2H_5OH falls onto a surface of glass or fluorite; it is also observed when drops of water fall onto a surface of glass. After a time of $0.12 \cdot 10^{-3}$ sec the radius of the liquid film attains a value of $r_0 = 0.6$ mm; during this time the center of the drop is lowered by only $0.12 \cdot 10^{-2}$ mm. Thus, one can assume that during this time interval the drop is stationary whereas formation of the liquid film (shown shaded in Fig. 3a) depends only on the wetting forces, subject to whose action there occurs a displacement of the particles of the liquid from the surface layer of the drop on the fluorite (glass) surface.

The mirrors (see Fig. 1) enabled us to view the expanding drop simultaneously across its lateral projection and across the area of the spot, the latter being the trace of the liquid film on the surface of the glass plate. This method allowed us to determine, fairly accurately, the values of the radius of the wetted region on the surface of the glass. Radius values obtained during the initial stages of the spreading of the liquid film ($t \lessdot 10^{-4}$ sec) proved to be higher when determined from measurements of the spot size than when determined

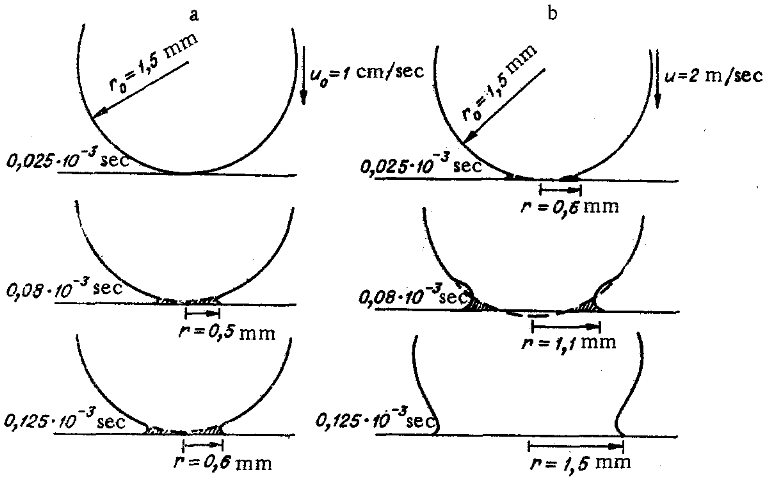

Fig. 3

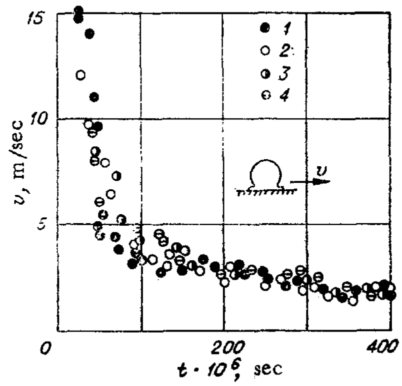

Fig. 4

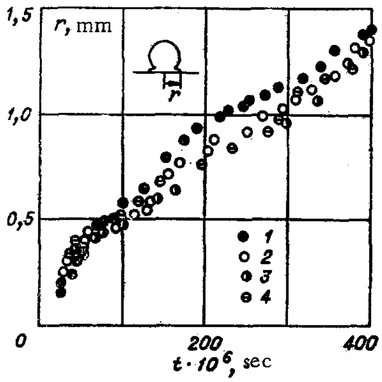

Fig. 5

from measurements on the lateral projection of the drop. From this it follows that for the time interval indicated for spreading of the drop, the leading edge of the liquid film is very thin and is not scanned on its lateral projection.

In Figs. 4 and 5 we show, respectively, how the rate v at which the liquid film spreads out varies with the time, and also how the radius r of the region of wetting varies with the time, for various liquids and solid surfaces [1) water on glass, $r_0=3$ mm; 2) water on glass, $r_0=1.5$ mm; 3) water on fluorite, $r_0=1.5$ mm; 4) alcohol on fluorite, $r_0=1.5$ mm]. In Fig. 4 it is evident that in the time interval considered the rate at which the liquid film spreads decreases very rapidly from values of $v>15$ m/sec to values of v in the range from 1 to 2 m/sec. (In an initial time interval less than $25 \cdot 10^{-6}$ sec, the spreading rate is obviously greater than 15 m/sec; however, we could not record this since our maximum frame rate was at most 40,000 frames/sec.) With a decrease in v the film thickness increases rapidly (see Fig. 2a), with the result that the angle of wetting increases towards 90°. Based on the experimental data shown in Fig. 5, we can say that in the time interval $0.1 \cdot 10^{-3}$ sec $<t<0.4 \cdot 10^{-3}$ sec the radius of the region of wetting increases approximately in accordance with the law $r \sim t^{0.6}$.

In the last stages ($t>0.6 \cdot 10^{-3}$ sec) in the process of spreading of the drop, surface tension plays the dominant role, leading to a noticeable distortion in the spherical shape of the drop. The angle of wetting, at least up to $13 \cdot 10^{-3}$ sec, remains approximately equal to 90°.

It should be noted that, according to the results displayed in Fig. 4, the materials we employed for the drop and for the solid surface have no essential influence on the rate of spreading of the drop. Consequently, based on these results, we cannot determine to what degree the effect of wetting influences the dynamics of formation of the liquid film.

We investigated the matter of how the rate at which the drop falls influences the mechanism of its spreading on the solid surface. In Figs. 2b and 3b we display typical ciné records showing the spreading of a drop of water ($r_0=1.5$ mm) after falling onto a solid fluorite surface at a speed of $u_0=2$m/sec. It can be observed that an increase in the rate of fall by two orders of magnitude leads to new results, both qualitatively and quantitatively. Thus, the rate of spreading of the liquid film $25 \cdot 10^{-6}$ sec after the instant of contact is equal to 27 m/sec. This, obviously, may be explained by the fact that an increase in the rate of fall of the drop leads to the development of a cumulative flow at the point where the spherical drop surface impacts the solid surface; that is, in this case the initial rate of spreading of the liquid film is determined not only by the capillary effect but also by the cumulative effect. Because of this, the process of deformation of the drop manifests itself much earlier (approximately 10^{-4} sec after the instant of impact).

The angle of wetting at the start is equal to zero, after which it increases slowly, remaining less than 90° for at least $13 \cdot 10^{-3}$ sec. In our series of experiments it was not possible to determine with sufficient accuracy the angle of wetting owing to the very small thickness of the forward edge of the liquid film.

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INVESTIGATION OF THE FRICTION STRESS ON A WALL IN A MONODISPERSED GAS – LIQUID FLOW

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Despite the fact that a large number of papers (see [1]) is devoted to the measurement of the pressure drop in two-phase gas-liquid flows, at present there are no universal methods of computing the friction stress in such systems which would yield satisfactory results in the whole range of variation of the flow parameters. The bubble flow mode with low gas contents has been investigated least in this respect. Data on the measurement of the friction stress in this mode are presented in [2-5]. At the same time, investigations performed recently of the velocity profiles and local gas content [3, 6, 7] show that the flow configuration in the bubble mode is quite complex, which should naturally be reflected in the behavior of the friction coefficient. As has been shown in [4, 5], at high fluid velocities (more than 3 m/sec) the friction stress at the wall differs slightly from the value computed by means of the homogeneous model [1]. At low flow velocities an anomalous growth in the friction stress occurs in the bubble mode [2, 8, 9], where the measured values differ essentially from the values given by all the known computational methods [8]. In addition to the sharp growth in the tangential stress at the wall, the lack of a unique dependence of the friction stress on the Reynolds number and the discharge gas content is observed at low velocities [8, 9]: the experimental points disclose a significant spread.

A two-phase stream with shallow gas bubbles is a particular case of the flow of a suspension. For small bubble sizes, the gas bubbles can be considered nondeformable in a first approximation; their behavior will hence be analogous in certain respects to the behavior of spherical solid particles in suspensions. Investigations of the effects of solid-particle migration in a fluid flow [10, 11] show that the particle size is an important parameter characterizing the properties of such systems. It is natural to assume that the size of the gas bubbles will exert substantial influence on the flow characteristics in definite modes in gas–liquid flows. At the same time, there are no experimental data in the literature in which the size of the gas bubble was a controllable varying parameter. The purpose of this paper is the experimental investigation of the influence of the gas-bubble size on the characteristics of a monodispersed ascending two-phase flow.

The experiments were performed in the apparatus of [9]. The working section was a vertical tube with a 15-mm inner diameter and 6-m length. The reduced fluid velocity varied between 0.006 and 0.3 m/sec, and the

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