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DETERMINATION OF SURFACE TENSION AT THE PHASE INTERFACE

Ye. I. Dobychin

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16. Abstract

Theoretical study of a method for determining the surface tension coefficient at the interface of two immiscible liquids or a gas and a liquid. Basic in this method is the measurement of the capillary rise of a droplet of one of the phases placed on the surface of the other phase. It is shown that the capillary rise is a function of the surface energy of the droplet and the viscous friction of the phases. A mathematical description is given to the dynamics of a liquid droplet. The description is supported by experiments.

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separated from the end of the pipe, and others, has satisfied the requirements of laboratory and educational studies for many years.

However, a number of publications of recent years [5,6] have covered a study of the coefficient of surface tension. It is necessary to continue these studies, as S. S. Kutateladze and M. A. Styrikovich note [7] because until now there have not been any accurate data on surface tension at the interface of a number of media. Knowledge of these data is necessary to study questions associated with the possibility of controlling the interface of phases and to control the change in shape of this boundary under the influence of different perturbing factors.

This work discusses the possibility of measuring the coefficient of surface tension on the interface liquid-liquid, liquid-liquid metal, liquid-gas.

We will imagine a drop, for example, of liquid metal, that is submerged into a transparent vessel filled with a liquid on whose interface it is necessary to measure the surface tension. This drop will adopt the shape of a round tablet with radius R and height h that lies freely on the flat bottom of the vessel (fig. 1). The surface energy of the drop in this case can be defined from the formula

$$W_1 = 2\pi\alpha R(R+h), \tag{5}$$

where α--coefficient of surface tension on media interface.

If conditions of weightlessness are suddenly created for the drop, then at the moment these conditions develop, it will be compressed and will jump up from the bottom of the vessel, moving vertically at a rate of V. During its movement, the drop makes damping fluctuations, and then acquires a spherical shape and stops (fig. 2). The surface energy of the spherical drop in the state of rest equals

$$W_2 = 4\pi\alpha a_0^2, \tag{6}$$

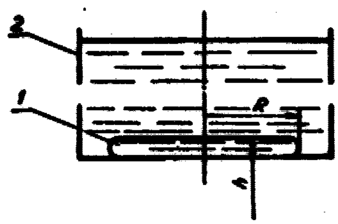

Figure 1. Shape of Drop (1) Which Lies Freely on Bottom of Vessel (2)

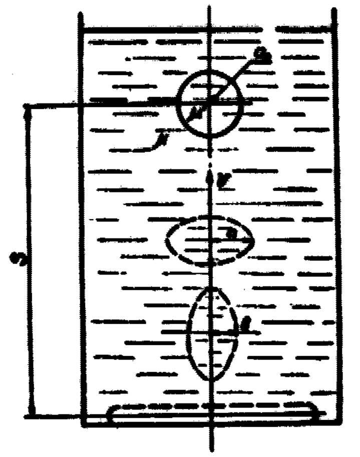

Figure 2. Transition of Drop from Condition of Known Overload to Condition of Weightlessness

where a_0--radius of spherical drop.

The surface energy W_1-W_2 that is released as a result of the capillary jump is consumed for the drop to complete fluctuations and forward movement upwards. Since the period of fluctuations of the drop is T<<t--time of its movement, then the potential energy of the drop $\alpha S_{el} < W_1$, and consequently, the kinetic /69

$$W_3 = W_1 - \alpha S_{el} \quad (7)$$

where S_{el}--surface of drop with maximum extension immediately after the jump, i.e., the surface of extended rotation ellipsoid. The energy that is spent to complete the fluctuations equals

$$W_4 = \alpha S_{el} - W_3. \quad (8)$$

Thus,

$$W_3 + W_4 = W_1 - W_2 = W \quad (9)$$

--this is all the energy that is released during movement of the drop that equals

$$W = 2\pi\alpha(R^2 + Rh - 2a_0^2). \quad (10)$$

The drop is stopped as a result of the effect of the viscous friction force which is expressed by the following formula for a liquid spherical body according to Adamra-Rybchinskiy [8]:

$$F=2\pi a_0\mu V\frac{2\mu+3\mu'}{\mu+\mu'}, \tag{11}$$

where μ and μ'--viscosities of surrounding liquid and liquid of drop.

The motion equation of the drop can thus be written in the form:

$$m\frac{dV}{dt}+2\pi a_0\mu V\frac{2\mu+3\mu'}{\mu+\mu'}=0, \tag{12}$$

from which

$$\ln V=-\frac{2\pi a_0\mu}{m}\frac{2\mu+3\mu'}{\mu+\mu'}t+C$$

and

$$V=e^c e^{-\frac{2\pi a_0\mu}{m}\frac{2\mu+3\mu'}{\mu+\mu'}}.$$

With $t\to\infty,\ V\to 0;\ t=0,\ V_0=e^c,$ but $\frac{mV_0^2}{2}=W_3$, consequently $V_\theta=\sqrt{\frac{2W_3}{m}}$

and

$$V=\sqrt{\frac{2W_3}{m}}e^{-\varkappa t}, \tag{13}$$

where the following designation is introduced

$$\varkappa=\frac{2\pi a_0\mu}{m}\frac{2\mu+3\mu'}{\mu+\mu'}.$$

After integrating the latter expression for time, we obtain the path traversed by the drop: /70

$$S=\int_0^t V\,dt=\sqrt{\frac{2W_3}{m}}\frac{1}{\varkappa}(1-e^{-\varkappa t}).$$

With $t \gg \varkappa$

$$e^{-\varkappa t} \to 0$$

and

$$S = \sqrt{\frac{2W_3}{m}} \frac{1}{\varkappa}. \qquad (14)$$

By substituting into (14), the value W_3 from (7), we obtain

$$\alpha = \frac{m\varkappa^2}{2(2\pi R^2 + 2\pi Rh - S_{el})} S^2. \qquad (15)$$

Here all the quantities, with the exception of S, are known or can be easily measured beforehand, therefore, the expression for the coefficient of surface tension can finally be written in the form

$$\alpha = KS^2. \qquad (16)$$

The presented technique for determining α was experimentally verified with different liquids and gas bubbles in the liquids. The experiments were set up in a container that freely fell from aheight of ~ 20 m [9]. Figure 3 presents the frames of a movie of the dynamics of a mercury drop in a solution of hydrochloric acid.

Experiments were initially set up with vapors of liquids, whose surface tension on the interface is known from reference books , and a good coincidence was obtained. Then the coefficients of surface tension were found on the interfaces of media for which there are no data in the literature known to us. Thus, for example, for a mercury drop with R=1.2 cm, h=0.35 cm (fig. 3), the surface tension on the interface with a 20% solution of hydrochloric acid was ~ 340 dyne/cm. The coefficient of surface tension for mercury that is in certain other media (in dyne/cm):

mercury and benzene--364
toluene--387

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aniline--323 /71

carbon tetrachloride--398

20% solution of sulfuric acid--371

kerosene T-1--314

air--471

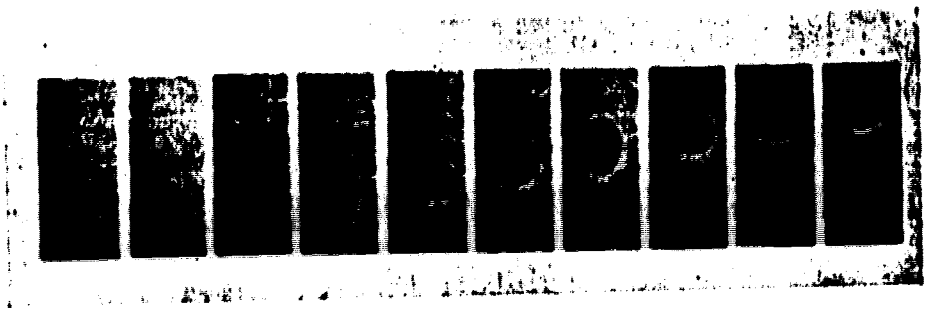

Figure 3. Experimental Verification of Technique of Measuring α.

First frame from the left: drop in state of overload. Subsequent frames: fluctuations and forward movement of drop in transition to conditions of weightlessness. Extreme right frame: halting of forward motion of drop, moment of measurement of S. Photographic frequency: 12 frames per second.

The error in determining the coefficient of surface tension will depend on the accuracy of measuring the height of elevation of the drop S with given K. Since the quantity S is determined by movie film, the accuracy of its values will be higher, the greater the frequency of the frames. With an interval between the frames of 0.083 s which occurs in experiments, the greatest error in determining S was about 1%. The weight of the drop and its geometric dimensions which are included in formula (15) were determined with accuracy to 0.1%. The total relative error in the coefficient of surface tension computed from the experimental results was ~ 3%. As compared to the known methods, this is quite a lot. In addition, an important factor that influences the accuracy of the measurements is the quality of simulation of weightlessness and the sound data on the overload in the testing container. In the described experiments, the overload was changed and taken into consideration according to the graph presented in publication [10]. The advantage of this method is expanded potentialities for determining the coefficient of surface tension of the liquid and liquid-gas interface. When more accurate instruments are used to measure the quantities that comprise the coefficient K, and with an increase in the rate of photography, the measurement accuracy may be diminished several times.

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