

INVESTIGATION OF THE DISPERSION OF LIQUIDS IN AN ELECTRIC FIELD

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The results of an investigation of the dependence of the dispersion potential on the liquid flow rate, distance between electrodes, and different parameters are presented.

The problem of obtaining readily controlled stable dispersive flows of high-density liquids arises in the study of the processes of heat and mass exchange on different surfaces.

In the literature [1-4], different techniques are known for obtaining dispersive flows of liquids: mechanical, ultrasonic, and electric dispersion. The first two methods are difficult to control, unstable, and require considerable additional energy consumption; besides, when dispersed by ultrasound, the temperature of the liquid varies with the energy density of the ultrasonic field. Therefore, the authors prefer to deal with the dispersion of liquids in an electric field, although this technique also has a shortcoming: it requires high potentials.

In [5, 6], the dispersion of a liquid is considered in an electric field for very low densities, which are of no practical interest. This required investigations on obtaining dispersive flows of high-density liquids. In the majority of heat exchange devices, heat and mass exchange occurs in the presence of noncondensing gases; therefore, the work is divided into two parts: the study of the dispersion flows in air and in vacuum. The present paper is a review of the results of investigations in the first part of the work.

The general view of the experimental set-up is shown in Fig. 1. Depending on the nature of the experiment, either a gauging glass tube mounted on a support that is movable in a vertical plane or a wide vessel serve as the container for the liquid. The container is connected to a capillary, the first electrode, by means of a fluoroplastic tube 2 mm in inner diameter. The capillary is mounted on a dielectric plate attached to a fluoroplastic rod that is movable in the vertical plane. The electrode toward which the flow is directed (the second electrode) is placed on a micromanipulator, type CT-12, which can be moved both vertically and horizontally. The rod and the manipulator are fastened on a special frame installed on a tripod, which provides for a precise setting of the second electrode in the

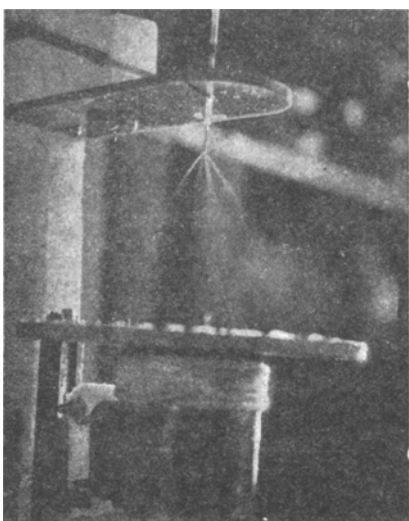


Fig. 1. General view of the set-up.

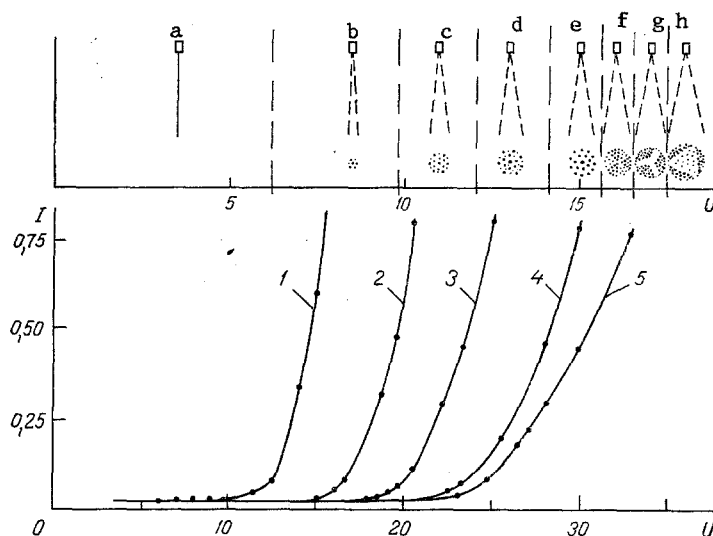


Fig. 2. Current-voltage characteristic of the flow of amyl alcohol for different distances between electrodes: 1) $\ell = 15$ mm; 2) 25; 3) 35; 4) 55; 5) 75 for $d = 0.48$ mm, $G = 1.14 \cdot 10^{-5}$ kg/sec (top). Dependence of the flow shape on the dispersion potential for $\ell = 25$ mm: I , μA ; U , kV (bottom).

horizontal position. The potential is applied to the capillary with the help of a wire passing inside the rod. The tests were conducted on capillaries with inner diameters (d) of 0.25, 0.48, and $0.65 \cdot 10^{-3}$ m. The set-up provided for smooth variations in the distance between the electrodes in the interval $0-130 \cdot 10^{-3}$ m. As a high-voltage power source, we used the power pack from the B242 electron microscope with an additional device that allowed us to vary smoothly the potential in the interval 3.5-60 kV. The capillary potential was measured by an electrostatic kilovoltmeter, type C96, while the value of the current carried by the dispersion flow was measured by a microampere, type M136, calculated for a measurement limit of 10^{-6} A. In order to reduce the effect of the external fields on the flow, the dimensions of the frame were sufficiently large: 520×410 mm.

When conducting the experiments, the liquids were chosen in such a way that their density ρ , viscosity η , and coefficient of surface tension σ had large dispersions; their isomers, cooling agents, and distilled water were also included. In the course of the investigation we tested the dependence of the capillary potential U on the flow rate G of the liquid, current-voltage characteristics $I = f(U)$, the effect of the distance ℓ between the electrodes on the potential, and the relationship between the flow rate and the capillary potential. The flow rate of the liquid was varied by changing the height of the level. The dependence of the flow rate on the level height was determined both in the absence and in the presence of a potential on the capillary. The tested liquids, some of their physical parameters, and the dispersion potentials are given in Table 1. The values for the dispersion potential are obtained for a capillary of diameter $0.25 \cdot 10^{-3}$ m for a distance between electrodes equal to $76 \cdot 10^{-3}$ m. In this case, the flow rate of the liquid remained constant. All the tested liquids dispersed in the electric field within a large range of the apex angles of the cone-shaped flow. Ethyl ether, which has relatively small values of viscosity and coefficient of surface tension, carbon tetrachloride, ethyl benzene, chloroform, and water dispersed at very small flow rates and relatively large potentials.

The investigation of the dependence of the flow structure on the capillary potential is conducted on amyl alcohol. This structure is typical for almost all liquids except for the five enumerated above, for which the potential practically does not affect the structure at flow rates exceeding 10^{-6} kg/sec. The relationship between the structure of the flow and the capillary potential is depicted qualitatively on the current-voltage characteristic of the flow for different distances between electrodes (Fig. 2). The entire current-voltage characteristics can be divided into different regions in which the flow structure changes from finely dispersed to flow with large particles. The replacement of one flow by the other one occurs in an unstable zone within a narrow interval of potential change of the order of 0.1 kV. The flow structure is depicted for a distance between electrodes equal to

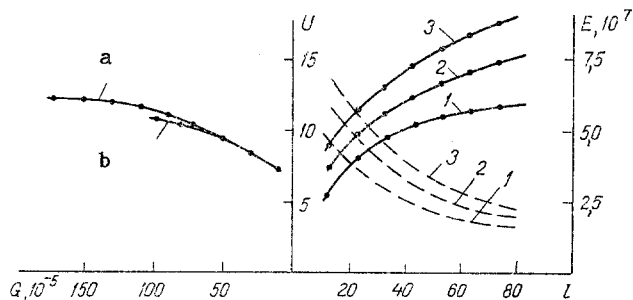


Fig. 3. Dependence of the dispersion potential U (kV) on the liquid flow rate G (10^{-5} kg/sec) for $d = 0.25$ mm (a) and $d = 0.48$ mm (b) and on the distance between electrodes l (mm) for different flow rates: 1) $G = 5.2 \cdot 10^{-6}$ kg/sec; 2) $9.1 \cdot 10^{-6}$; 3) $2.04 \cdot 10^{-5}$ ($d = 0.48$ mm). Dashes show the dependence of the electric field intensity on distance between electrodes. E , V/m.

TABLE 1. Physical Parameters and Dispersion Potentials of Tested Liquids

Liquid	ρ kg/m ³	η , 10^{-3} N·s/m ²	T_H , K	r , 10^3 J/kg	U , kV
Ethyl ether	713,5	0,233	308,75	361,52	6,0
Alcohol:					
isopropyl	785,10	2,390	355,55	671,00	7,8
isobutyl	805,00	3,950	380,50	593,30	7,2
butyl	809,80	2,950	390,50	593,30	5,7
amyl	816,20	2,990	391,00	593,20	5,4
Ethyl benzene*	886,90	0,230	409,30	339,42	12,0
Ethylene chloride	1257,60	0,832	356,85	326,80	7,1
Carbon tetrachloride*	1633,95	0,969	350,00	195,79	17,4
Chloroform	1498,45	0,570	334,30	245,00	8,8
Ethyl alcohol	789,30	1,200	361,40	201,50	7,4

*Dispersed weakly.

$25 \cdot 10^{-3}$ m. In the same figure, the cross sections of the central parts of the flows are schematically given. Although there are no anomalies in the initial region of the current-voltage characteristic, the sizes of the flow particles and the flow shape vary.

In the top of Fig. 2, in the region of the potential a , the frequency of the drops increases, and the flow is converted into an uninterrupted flow; b) flow with a central single stream or several streams ("stems"); c) uniform flow, but with relatively large particles; d) finely dispersed flow; e) coarse flow; f) finely dispersed, unsteady flow, which can break up into several flows; g) conversion into a coarse flow with the flow forced outward toward the periphery; h) coarse, unstable peripheral flow. Such flow structure is observed only for small liquid flow rates. For liquids dispersing at high potentials, only regions a , b , c , and d can be distinguished; the other regions are difficult to differentiate. This is also observed for other liquids at high flow rates.

As the distance l between the electrodes increases, the regions a - g expand; when l decreases, certain regions merge and it becomes difficult to distinguish transient zones. Variation in the value of l results also in a change of flow shape. For small distances (up to $4\text{-}5 \cdot 10^{-3}$ m) the flow has the shape of a cone; when l increases further, the generating line of the cone bends; and, in the limit, at large distances, the flow converts into the shape of cylinder, as depicted in Fig. 2.

When the flow rate of the liquid increases, the dispersion potential also grows (Fig. 3) due to the increase in the number of particles in the flow. If, when the flow rate increases, the dispersion potential does not change, then the diameter of the particles increases, and the flow structure changes. The dependence of the dispersion potential and the electric field intensity on the distance between the electrodes for different flow rates for

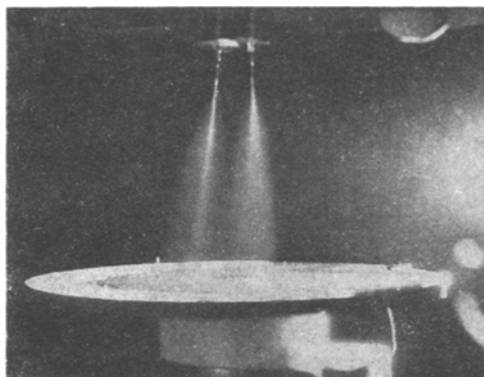


Fig. 4. Two flows of amyl alcohol from capillaries of diameter 0.25 mm, placed at a distance of 4 mm at $G = 1.5 \cdot 10^{-6}$ kg/sec, $U = 8.8$ kV, $t = 40$ mm.

a capillary diameter $d = 0.48 \cdot 10^{-3}$ m is shown in Fig. 3. The experimental data on all the curves are shown by points. All the measurements have been repeated not less than 13 times to verify their reproductibility. It might be well to point out that the variation in liquid temperature results in a variation of quantitative characteristics shown in Fig. 2, while qualitatively they remain unaltered.

The results of investigations show that the density of the dispersion flow depends on ℓ , G , U , d , physical parameters of the liquid, and geometric dimensions of the second electrode, and for practical usage it is necessary to obtain data on the quantitative influence of different parameters. One of the important characteristics from the point of view of practical use is the problem of the determination of the dependence of the size of flow particles on different factors. The precision of the measurement on sizes of particles is small when using known methods [2]. Besides, the known measurement methods introduce perturbations in the flow shape, and, consequently, affect the density. In this connection, a high-precision method has been developed for measuring particle sizes and the density of the dispersion flow. Since the problem of the determination of the sizes of flow particles is related to application problems, it will be considered in a separate publication.

Of great practical interest is the problem of increasing the area of coverage of the flow when its density is high. To do this, investigations were conducted on the interaction of flows incident on a common second electrode from several capillaries (Fig. 4). It can be accomplished by sliding apart the electrodes, with the cross sectional area being increased while the flow density is simultaneously decreased.

The investigation of the interaction of two flows of amyl alcohol has shown that the flows do not practically influence each other at distances between the capillaries up to the minimal values of $4 \cdot 10^{-3}$ m for the values of ℓ in the interval $15-75 \cdot 10^{-3}$ m and flow rates from $3 \cdot 10^{-7}$ to $9 \cdot 10^{-6}$ kg/sec, as is shown in Fig. 4. The capillary diameters in the study were equal to $0.25 \cdot 10^{-3}$ m. When conducting this experiment, the liquid flow rates in both capillaries should be equal, i.e., the capillary potentials should be regulated independently from each other; otherwise, the potentials of the capillary dispersion do not correspond to the flow rates in them, and, consequently, it can be shown that the change in the flow structure is due to their interaction. The dispersion potential for amyl alcohol is equal to 8.8 kV.

The study of the dispersion mechanism has shown that for relatively small flow rates the separation of particles takes place from the edge of the liquid [2], while for flow rates reaching 10^{-6} kg/sec, the dispersion occurs by means of disintegration of the liquid flow [1, 6]. The latter can be readily discovered if the flow disperses far from the end of the capillary.

The investigation of the dependence $G = f(U)$ has shown that for liquids dispersing at high capillary potentials, the flow rate does not practically depend on the potential. For other liquids the effect is very weak and can be neglected.

As a result of the experiments conducted, it has been found that practically all the investigated liquids disperse, provided that the appropriate conditions are observed, while the flow density and sizes of particles for liquids with low viscosity and high density are very small, which can restrict their practical usage. The application of the principle of superposition allows one to avoid this disadvantage. A high degree of dispersion, homogeneity of the constitution of particles, and negligibly small energy consumption of the technique provide for expanding the field of its practical application.

The electroconductive liquids disperse with more difficulty than the organic liquids with high specific resistances. The impurities of different organic liquids dissolving in water and solutions of salts improve the conditions of their dispersion. Thus, for example, small impurities of acetone and methyl alcohol in water and aqueous solutions of sodium chloride reduce the dispersion potentials by 27%.

NOTATION

d , inner diameter of the capillary; ρ , liquid density; η , coefficient of dynamic viscosity; σ , coefficient of the surface tension; U , capillary potential; G , liquid flow rate; ℓ , distance between electrodes; I , current between the electrodes; T_H , capillary temperature.

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HYSTERETIC BEHAVIOR AND INERTIAL CHARACTERISTICS OF A FLAME OF DROPS OF HYDROCARBONS

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The results of an experimental investigation of the kinetics of the displacement of a flame, surrounding a drop of hydrocarbon fuel, accompanying an instantaneous change in the flow around the drop from zero to the detachment value are presented.

It is well known that when a burning drop is placed in a flow of oxidizer the thermo-physical characteristics of the burning and the shape and size of the flame are closely related with the flow rate. When the flow rate is changed hysteretic behavior of the flame surrounding a drop of hydrocarbon is observed; this behavior is associated with the existence of two critical velocities: The first one is determined by the maximum value of the flow rate for which the flame is located on any point of the drop and the second one characterizes the reestablishment of the flame on the bow point as the flame moves out of the wake of the drop [1].

The separation of a flame from burning drops has been studied in detail for stationary flow velocities. The reestablishment of the flame from the wake of the drop on the bow point

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