EFFECT OF A CONSTANT ELECTRIC FIELD ON THE FILM FLOW OF A LIQUID DIELECTRIC

A. G. Gagarin

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The method and results of an experimental investigation into the effect of a constant electric field on the flow of a liquid dielectric film over a vertical surface are described.

In a number of investigations the question of the effect of an electric field on the film flow of dielectric and conducting liquids has been examined theoretically [1-4]. In [1] it is noted that the electric field affects the velocity and average thickness of the film, as well as the wave parameters of its surface. The theoretical results presented in [2] indicate that the electric field has no effect on the velocity and average thickness of a conducting film, but the surface wave characteristics are shown to depend on the field strength. It is stated that similar results should be obtained for a liquid dielectric. In [3, 4] the question of the occurrence and development of wave-type instability on the surface of the liquid film was examined in relation to the electric field parameters.

The fact that an electric field can influence the transfer processes in film flow was experimentally confirmed in [5, 6], but without an analysis of the effect of the field on the film hydrodynamics.

The present paper describes the method and results of an experimental investigation into the effect of an electrostatic field on the film flow of a dielectric liquid over plane and cylindrical vertical surfaces.

The experiments were performed on an apparatus consisting of a circular loop with a system for regulating the temperature of the working fluid and interchangeable experimental sections. The conditions were created for film flow of the liquid dielectric (mineral oil) in slightly inhomogeneous and homogeneous electric fields. In the first case the experimental section was a steel tube $2.5 \cdot 10^{-2}$ m in diameter and 0.65 m long mounted coaxially in a glass cylinder $4.5 \cdot 10^{-2}$ m in diameter, to which was attached a steel mesh (mesh size $4 \cdot 10^{-3} \times 4 \cdot 10^{-3}$ m). The entire experimental section was set up vertically, and the film flow was initiated at the top of the tube by means of a special fitting.

The experimental section for investigating film flow in a homogeneous electric field was a vertical flat capacitor. The film of mineral oil flowed over one of the plates. The other plate was a sheet of plexiglas to which was attached a wire mesh (mesh size $3 \cdot 10^{-3} \times 3 \cdot 10^{-3}$ m). In this case the length of the irrigated surface was 0.9 m and the width $9 \cdot 10^{-2}$ m. In both variants the irrigated electrode was grounded. The VS-23 stabilized high-voltage source provided a voltage of up to 10 kV. In both cases the electrode spacing was $1 \cdot 10^{-2}$ m, which made it possible to obtain an electric field strength of up to 10 kV/cm in the film flow zone.

In the experiments we measured the thickness of the film and made visual observations of the state of the film surface. The film thickness was measured at six points along the flow and in investigating the flow over the surface of the vertical tube at five other points around the perimeter of each of the six sections. For this purpose we employed a contact method involving the use of a glass needle bonded with epoxy to one end of a piezoelectric crystal whose other end was attached to a micrometer. The moment at which the free end of the needle touched the surface of the film was recorded visually by means of a dioptric telescope. Further rotation of the micrometer screw caused the needle to penetrate the film, and when it made contact with the irrigated wall an electrical signal from the piezoelectric crystal was transmitted to an S1-17 oscillograph, which served as contact indicator. The

Division of Mechanics of Inhomogeneous Media, Academy of Sciences of the USSR, Moscow.
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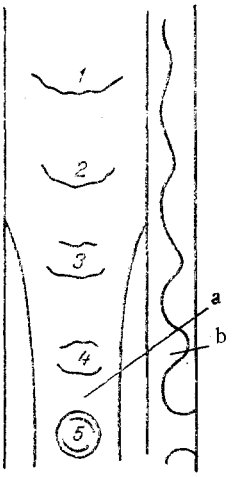

Fig. 1. Schematic representation of perturbations of film flow based on the results of photography: a) view in direction of electric field; b) view of perturbations in profile; 1) U_0 = 2 kV; 2) 4; 3) 6; 4) 8; 5) 10 kV. L = 0.45 m.

thickness of the mineral oil film was determined from the difference in micrometer readings between the moment at which the needle touched the film surface and the moment of appearance of the signal from the piezoelectric crystal.

The reliability of this method was confirmed by comparing the results of film thickness measurements in the absence of an electric field with the calculated values obtained from the knwon relation [7, 8]

$$\delta_0 = \left(\frac{3\nu\Gamma}{g\gamma}\right)^{\frac{1}{3}}. \qquad (1)$$

The experimental investigations of mineral oil film flow in a slightly inhomogeneous electric field were carried out at liquid flow rates per unit length of the perimeter of the irrigated tube ranging from $2.96\cdot10^3$ to $0.42\cdot10^3$ $m^3/m\cdot sec$. The potential difference across the electrodes was 2-10 kV with a step of 2 kV for each value of the flow rate. The viscosity of the oil under the various flow conditions was maintained at between 120 and 21 m^2/sec by means of a thermostating system. This high viscosity of the working fluid made it possible to obtain a laminar waveless flow regime in the absence of an electric field over almost the entire range of flow rates.

Visual observations showed that an electric field has a strong influence on the nature of the mineral oil film flow over the surface of a vertical tube. Thus, in the laminar waveless film flow regimes obtained in the absence of an electric field the film had a smooth surface. When voltage was applied to the outer mesh electrode, perturbations in the form of sinusoidal waves with wave front oriented along the flow developed on the surface of the film in the lower part of the tube. However, these waves did not become stable immediately, but only after the voltage reached 2 kV. Up to that point the wave instability of the film surface was almost periodic in character and took the form of individual groups of 5-6 sinusoidal waves. These groups were generated at a distance of 0.15-0.20 m from the point of formation of the film flow and were damped in the lower part of the flow, i.e., over a distance of 0.45-0.50 m. With further increase in voltage the surface of the film became covered with stable waves whose amplitude increased correspondingly. At the same time as the amplitude of the waves increased, their profile changed, and in particular the leading edge became steeper. It should be noted that with increase in voltage the zone of wave formation rose higher up the tube and at 10 kV the waves appeared immediately beyond the zone of formation of the film flow.

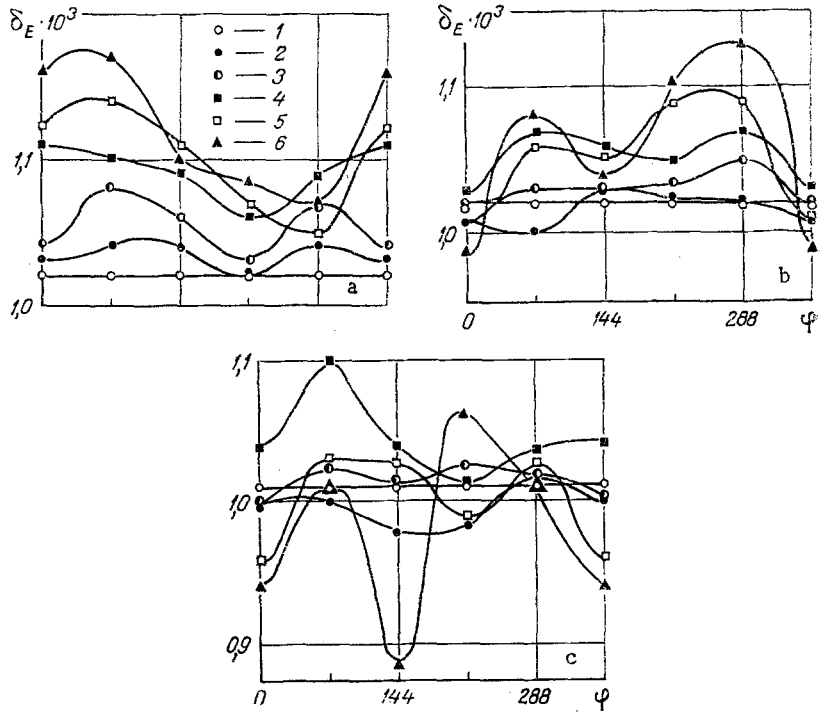

Fig. 2. Distribution of film thickness δ_E, m, over circumference of tube in various cross sections: L = 0.05 m (a); 0.15 m (b); 0.35 m (c); 1) U_0 = 0; 2) 2 kV; 3) 4; 4) 6; 5) 8; 6) 10 kV, φ, in degrees.

In the case of a coaxial configuration wave formation was not the only form of flow instability created by the application in an electric field. Raising the voltage to 5-6 kV resulted in the film contracting into separate streams. In this case the irrigated tube was nonuniformly wetted by the liquid, and here and there liquid splashed onto the surface of the glass tube to which the mesh electrode was attached. The nature of the perturbations of the film surface at a distance of 0.45 m from the point of formation of the flow, based on visual observations, is shown shcematically in Fig. 1 for various voltages. In view of this nonuniformity of the film surface around the perimeter of the irrigated tube, we measured the film thickness at five points on the circumference of each section investigated. These measurements revealed a complex pattern of redistribution of the liquid over the irrigated surface under the influence of the slightly inhomogeneous electric field (Fig. 2). From the data obtained we conclude that this nonuniform distribution of liquid over the surface is primarily associated with the fact that the electric field promotes the development of the slightest flow instabilities up to disintegration of the film on the irrigated surface. Averaging the film thickness values over the perimeter for each section investigated showed that under the influence of an electric field the average film thickness increases in the upper flow zone, but decreases in the lower third of the experimental section. It should be noted that along the zones of increased thickness (streams) the decrease in thickness is less marked than between streams.

In investigating mineral oil film flow in a flat capacitor field, the conditions were so maintained as to reduce as far as possible uncontrolled perturbations of the film surface. This made it possible to obtain a certain dependence of film thickness on electric field strength. Figure 3 shows the results of measuring the film thickness at various flow rates and voltages for one of the viscosity values. It is clear from these data that the electric field causes a substantial increase in the thickness of the liquid dielectric film. On the basis of an analysis of the structure of expression (1) for calculating the film thickness, we conclude that the most probable mechanism affecting the film thickness is the electrorheological effect [9]. Since in the experiments we used technical mineral oil containing a certain amount of impurities, the electric field could influence the film thickness by way of the electroviscosity mechanism.

By processing the experimental results we were able to obtain a simple empirical expression for calculating the increase in the thickness of a liquid dielectric film under the influence of an electric field:

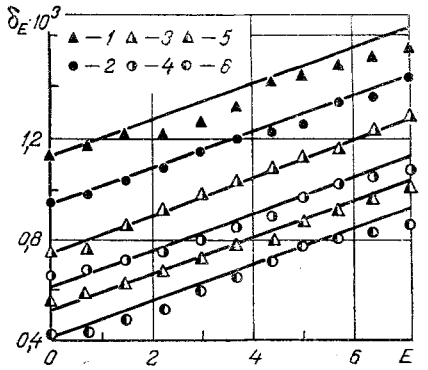

Fig. 3. Film thickness as a function of electric field strength for various values of the liquid flow rate: 1) $\Gamma = 4.7 \cdot 10^{-2}$ $m^3/m \cdot sec$; 2) 2.6×10^{-2}; 3) $1.3 \cdot 10^{-2}$; 4) $0.7 \cdot 10^{-2}$; 5) $0.4 \cdot 10^{-2}$; 6) $0.2 \cdot 10^{-2}$. The continuous lines are the results of calculations based on (1) with correction (2). δ_E is in m; E is in kV/cm.

$$\Delta = 0.068E, \tag{2}$$

where $\Delta = \delta_E - \delta_0$ is the difference in film thickness with and without an electric field, in mm; E is in kV/cm.

In Fig. 3 the continuous lines are the calculated values of the mineral oil film thickness obtained using relation (2). A comparison of the calculated and experimental results reveals good agreement, the maximum discrepancy being not greater than ±8%.

The results obtained in the experiments described above point to the possible mechanisms of action of an electric field on the transfer processes in film flow. Thus, the results obtained in [6] give reason to suppose that the fall in film temperature in the presence of an electric field is a result of a decrease in the heat-transfer coefficient consequent upon the retardation of the film associated with an increase in film thickness in the field at constant liquid flow rate.

NOTATION

δ_0, thickness of the film flowing over the vertical surface in the absence of an electric field; ν, kinematic viscosity of the fluid; ν, volumetric fluid flow rate per unit length across the direction of flow; Γ, specific weight of the fluid; U_0, potential difference across the electrodes; δ_E, film thickness in the presence of an electric field; E, electric field strength; L, distance from the investigated cross section to the point of film formation.

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EXPOSURE OF THE FLUX OF A MEDIUM TO A REGULAR SYSTEM OF LIGHT SOURCES

Yu. A. Kashin, G. Yu. Kashina, and L. G. Kravchenko

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An analysis is performed of the stationary distribution of the specific dosage of radiation energy absorbed by a medium from a regular system of tubular light sources submerged in an infinite flux of the medium.

One of the fundamental characteristics in the photochemical and radiation kinetics of molecular and biological systems simulated in the form of continuous media is the specific dosage of the radiation energy absorbed by the medium (exposure dose) which is determined by the relationship

$$q = \lim_{\Delta V \to 0} \Delta E / \Delta V,$$

where ΔE is the quantity of radiation energy absorbed by a volume element of the medium. In conformity with the definition, the local value of the exposure dose $q(\mathbf{r}, t)$ for volume elements of the flux being exposed continuously in the space of a fixed domain Ω bounded by the surface $d\Omega$ is found from solution of the problem

$$\frac{\partial q}{\partial t} + \mathbf{v} \cdot \nabla q = kI, \tag{1}$$

$$q(\mathbf{r}, 0) = \varphi_1(\mathbf{r}) \text{ on } \Omega, \tag{2}$$

$$q(\mathbf{r}, t) = \varphi_2(\mathbf{r}, t) \text{ in part, where } \mathbf{n} \cdot \mathbf{v} \leqslant 0. \tag{3}$$

Solutions of this problem are known for one-dimensional or axisymmetric stationary processes proceeding in tubular photoreactors with a single light source [1-4]. The process of exposing a flux of absorbing medium by a regular system of tubular lamps similar to the process of exposing a water stream in casette bactericidal apparatus of the type OV-PK-RKS [5] is analyzed in this paper. Since the presence of light-absorbing impurities in water results in attenuation of the light flux, it is then interesting to estimate the influence of such impurities on the exposure efficiency, and also to investigate the optimization condition for this process.

Let us consider the following steady-state two-dimensional process. An unlimited flux of medium reaches a certain system of identical tubular light sources whose axes are mutually parallel and perpendicular to the vector $\mathbf{v}_0$ of a flux of particles at infinity. We consider this system of light sources regular in the sense that adjacent projections of the lamp axes on the plane perpendicular to $\mathbf{v}_0$ are separated by the same distance 2b which we call the lattice spacing of the lamps. Assuming the interaxial spacing c between any adjacent lamps to be considerably greater than their radius a ($c \gg a$), we can assume that the perturbations in medium flux by adjacent lamps exert no substantial influence on the hydrodynamic situation

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