MONODISPERSED DECOMPOSITION OF CHARGED JETS OF DIELECTRICS

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The conditions under which a corona discharge in air can be used to obtain a series of charged monodispersed drops of a dielectric liquid are studied. The charge on the drops, which is characterized by the output current, can be varied over wide limits depending on the position of the jet in the interelectrode space and the voltage of the electrodes. It was confirmed experimentally and numerically that it is best to precharge the cylindrical part of the jet in the field of the corona and then to separate the jet into charged drops by the method of induced capillary decomposition.

Flows of a dispersed material, controlled with the help of electric fields, are being increasingly used in modern technologies and the required uniformity of the particles employed is constantly increasing [1]. The analysis performed in [2] and experiments performed by many experimenters show that the best results, regarding monodispersity, are achieved by means of induced capillary decomposition of a jet of liquid, the theoretical basis for which was first given by Rayleigh [3]. Many investigators and designers of an entire class of devices referred to generally as "jet printers" [4, 5] employ this method to separate jets of liquid into drops while at the same time electrifying the drops by the method of induction charging. This method obviously presupposes the use of electrically conducting liquids and is completely inapplicable to dielectrics. The formation of a charged flow of drops of a dielectric liquid presupposes that the jet is separated into drops and charging is performed by irradiating the drops with electron—ion flows produced by various techniques [6]. However, the indicated sequence of actions can be changed, and a new problem then arises — charging of the jet and separation of the charged jet of dielectric liquid by the method of induced capillary decomposition. This method was developed to separate charged drops of cryogenic liquids [7]. The jets were charged by means of poorly studied methods of electron field emission or field ionization — these terms denote the appearance of uncompensated volume charge in a liquid dielectric when electrodes, which create a strong highly nonuniform field, are submerged in it. The details of the study of the conditions of electrification of jets, the drops formed, and the characteristics of the decomposition of charged electric jets were not presented.

In this work we studied the conditions of charging of a jet in the field of a corona discharge in air in order to produce monodispersed drops by the method of induced capillary decomposition. The corona discharge is a good source of ion flows for electrifying neutral objects and it appears under comparatively high pressures in all cases when the field in the discharge gap is strongly nonuniform [8]. Ionization and excitation of neutral particles of gas as they collide with electrons accelerated in the field occur in a thin layer near the electrode with a small radius of curvature; as a result of this a glowing halo — the "corona" — appears around the electrodes. Under the conditions of a constant voltage there exist two types of coronas: 1) unipolar, when an electrode of only one sign displays a corona and ions of this sign flow in the outer zone (if the cathode displays the corona, then negative ions flow in the external zone in an electronegative gas and electrons move in an electropositive gas), and 2) bipolar, when electrodes of both signs display coronas and oppositely charged ions flow in the outer zone toward one another. The main processes involved in the generation of electrons, which give rise to the production of avalanches and therefore allow the corona discharge to be self-maintained, are the photoelectric effect on the surface of the electrodes and volume photoionization by the characteristic radiation of the discharge.

The purpose of our experimental investigation was to study the conditions of electrification of jets of dielectrics and some characteristics of the formation of charge on drops formed as a result of induced capillary decomposition of a charged jet. The jet was electri-

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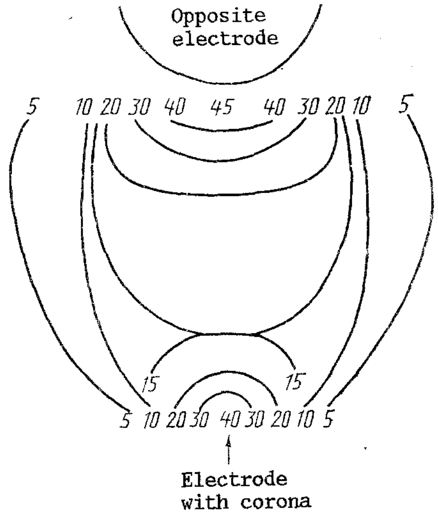

Fig. 1

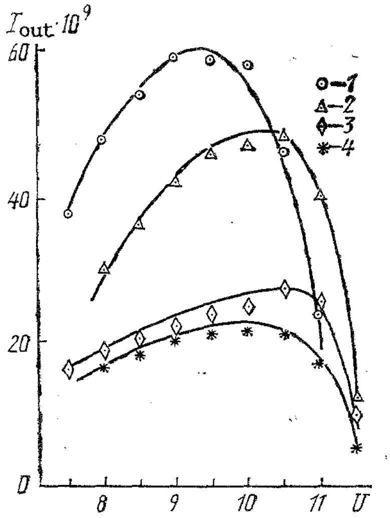

Fig. 2

Fig. 1. Interelectrode space of the needle-sphere charging system in a 10:1 scale. The lines correspond to points with the same values of the output currents and the numbers denote the values of I_{out}, nA.

Fig. 2. Output current versus the voltage on the electrodes for different positions of the jet relative to the opposite electrode: 1) ℓ_1 = 1 mm; 2) 2; 3) 3; 4) 4. I_{out}, A; U, kV.

fied with the help of a system of electrodes [4], which formed in air a steady flow of ions toward the object being charged. The experimental apparatus included a generator which generated monodispersed drops, a power supply, an excitation system, a system for monitoring the amplitude of the oscillations and the outflow velocity of the jet, a charging system, and a system for measuring the charge and its fluctuations on separate monodispersed drops [5]. The following characteristics were measured for diagnostics of the charge on the drops: an integral characteristic — the output current — and a differential characteristic — the magnitude of the charge on each drop. The measurements were performed with the help of a V7-30 electrometer and an induction meter. The electrification of a jet and of monodispersed drops of VM-1 vacuum oil was studied. The properties of the oil at t = 40°C were as follows: the surface tension $\sigma = 36.22\cdot10^{-3}$ N/m; the viscosity $\eta = 111.2\cdot10^{-3}$ Pa·sec; the density ρ = 868.18 kg/m³; and, the dielectric constant $\varepsilon = 2.1$.

The systems needle—sphere and needle—cylinder were used for the electrode systems. Since for such configurations there are no exact mathematical solutions of the equations for the potential and distribution of the volume charge, the characteristics of the field were studied experimentally. It turned out that it is convenient to study the field of the corona discharge, in particular, the field of the needle—sphere electrode system, with the help of thin jets of dielectric liquid. Induced capillary decomposition made it possible to measure with high accuracy the velocity of outflow of the liquid based on the repetition frequency of the monodispersed drops and the distance between the drops, and the significant (of the order of 5-10 m/sec) outflow velocities of thin jets (jet diameter $D = 3.8\cdot10^{-4}$ m) made it possible to obtain signals that significantly exceeded the sensitivity threshold of the electrometer. The distortions introduced by the jet in the field of the corona discharge were evaluated experimentally. To this end the current in the circuit of the discharge electrodes without the jet (I_c) and after the jet was introduced into the discharge gap (I^*_c) was measured. It was found that the quantity $\Delta I = I_c - I^*_c$ is an order of magnitude greater than the output current; this could be a consequence of the changes made by the jet in the field of the corona. Each point in the interelectrode space can be characterized by the relative change in the field by means of the quantity $\Delta I/I_c$, which for the measurements presented below was equal to 15% on the average.

In the experiments a negative corona with a voltage of 9 kV was used; the corona current was equal to about 5 μA and the current carried by the jet of vacuum oil (the diameter of the jet $D = 3.8\cdot10^{-4}$ m) was equal to 40-50 nA. The results obtained by scanning the interelectrode space under conditions of a corona discharge are presented in Fig. 1. Interpola-

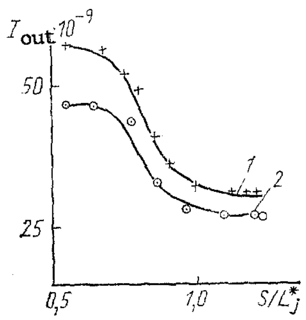

Fig. 3

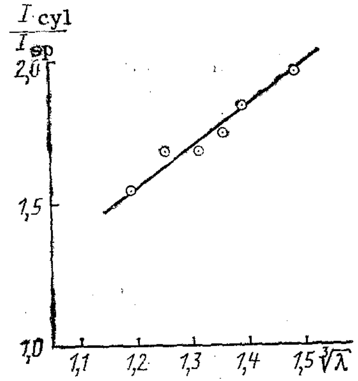

Fig. 4

Fig. 3. Output current as a function of the position of the axis of the electrode system relative to the point of decomposition: 1) v = 6.75 m/sec, f = 2500 Hz; 2) 4.88 and 2000.

Fig. 4. Ratio of the output current with charging of the undisturbed section of the jet to the output current with charging of a series of drops versus $\sqrt[3]{\lambda}$.

tion was performed between the experimental points (not shown in the graph), after which points with the same value of the output current were connected by lines, which can be called equicurrent lines.

It is known that arbitrarily shaped particles placed in the field of a corona discharge can acquire a limiting charge that is proportional to the intensity of the field E_c at the location of the particle. For example, the limiting charge on a dielectric sphere can be calculated from the formula [9]

$$q_{lim} = 4\pi\varepsilon_0 R_{sp}^2 E_c \left(1 + 2\frac{\varepsilon - 1}{\varepsilon + 2}\right). \tag{1}$$

However, the experimental study of the dependence of the output current on the voltage on the electrodes for a fixed position of the jet relative to the opposite electrode revealed the existence of anomalous regions where an increase in the voltage of the corona discharge results in a decrease of the output current I_{out}. One can see from the curves in Fig. 2 that for all curves the anomalous charging of the jet starts at voltages on the electrodes exceeding 9.5 kV. Taking this fact into account, Fig. 1 shows the results obtained with voltages U not exceeding 9 kV, when the linear dependence of the charge on the voltage is confirmed experimentally. The anomalous sections of the curves (see Fig. 2) can be explained by formation of a corona on the opposite spherical electrode or the jet itself. Both phenomena result in a reduction of the output current, but to determine the validity of one or another mechanism an additional investigation is required.

The results presented in [10] showed that with the help of a corona discharge it is possible to obtain a series of identically charged monodispersed drops of a dielectric liquid using the following scheme: 1) a jet of liquid dielectric is formed; 2) the jet is excited mechanically, for example, with the help of a piezoelectric element, in the frequency range of induced capillary decomposition; 3) the jet is electrified in the field of the corona discharge; and, 4) the charged jet separates into monodispersed drops. The relative spread in the charge on the drops may not exceed 1% with an absolute charge of the order of 10^{-11} C. The magnitude of the acquired charge depends on a number of factors (Figs. 1 and 2), one of which is the position of the electrodes displaying coronas relative to the location of outflow and decomposition of the jet. We denote by S the distance from the point of outflow to the axis of the needle–sphere system and by L^*_j the length of the undecomposed part of the charged jet. By varying these quantities with a constant voltage on the electrodes and for a fixed position of the jet we obtain a sharply nonlinear dependence of the output current (magnitude of the charge on the drop) on the ratio of S and L^*_j; this dependence is presented in Fig. 3.

To explain this dependence we shall assume that the kinetics of charging of an element of the volume of a cylindrical jet is identical to that of a spherical particle [8]:

$$q(t) = q_{\mathrm{lim}} \frac{en_0kt}{4\varepsilon_0 + en_0kt}. \tag{2}$$

Starting from the exact solutions for q_{lim} of spherical particles and particles with other shapes, we assume by analogy that for some distinguished volume of the cylindrical jet

$$q_{\mathrm{lim.cyl}} = A\varepsilon_0 S_{\mathrm{cyl}} E_{\mathrm{c}}. \tag{3}$$

Assuming that the position of the jet is identical to that of the series of drops relative to the electrodes, we find that

$$\frac{q_{\mathrm{cyl}}}{q_{\mathrm{sp}}} = \frac{q_{\mathrm{lim.cyl}}}{q_{\mathrm{lim.sp}}} = \frac{AS_{\mathrm{cyl}}}{\left(1 + 2\frac{\varepsilon - 1}{\varepsilon + 2}\right) S_{\mathrm{sp}}}. \tag{4}$$

In the case of monodispersed decomposition of a jet with a diameter D, flowing out of a die with a linear velocity v and separating into drops, following one another with a frequency f, the radius of the spherical drops formed can be determined from the relation

$$\frac{4}{3}\pi R_{\mathrm{sp}}^3 f = \frac{\pi D^2}{4} v.$$

Writing $\lambda = v/f$ we obtain

$$R_{\mathrm{sp}} = \sqrt[3]{\frac{3}{16}\lambda D^2}. \tag{5}$$

Taking for the distinguished volume of the cylindrical section of the jet a cylinder of height λ we find that

$$S_{\mathrm{cyl}}/S_{\mathrm{sp}} = 0.76\sqrt[3]{\frac{\lambda}{D}}, \tag{6}$$

and then $q_{\mathrm{cyl}}/q_{\mathrm{sp}} = A^* \sqrt[3]{\frac{\lambda}{D}}$.

The obtained dependence was checked experimentally for a jet of oil with diameter $3.80 \cdot 10^{-4}$ m, and from the slope angle of the straight line presented in Fig. 4 we found that $q_{\mathrm{cyl}}/q_{\mathrm{sp}} = 1.3\sqrt[3]{\lambda}$. To obtain results of high accuracy we used in the experiment the dependence of the length of the undecomposed part of the jet on the amplitude of the oscillations of the nozzle of the generator; this guaranteed that the mutual position of the jet and the series of drops relative to the electrodes is stable. Thus, together with a high degree of uniformity of the charge of the particles obtained by means of monodispersing of charged jets [10], in the proposed geometry the corona discharge is much more effective.

The data presented make it possible to select the optimal geometry of the charging electrodes and the parameters of the corona charge in electrifying jets of dielectric liquids and to determine the magnitudes of the charges under conditions of monodispersed decomposition. In its turn, the possibility of obtaining a series of charged drops of dielectrics greatly expands the applications of devices employed in cryodispersion and electrodrop-jet technologies, microdispensing of coatings, etc.

NOTATION

R_{sp}, radius of a spherical particle; E_{c}, intensity of the field of a corona discharge at the location of a particle; ε, relative dielectric constant of the particle material; $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m; n_0, ion flux density in the interelectrode space; e, electron charge; k, ion mobility; S_{cyl}, area of the cylindrical surface of a jet of height λ; v, outflow velocity of the liquid; f, repetition frequency of the drops; λ, wavelength; S_{sp}, surface area of a drop; ℓ_1, distance from the opposite spherical electrode to the edge of the jet; q_{lim}, limiting charge of a spherical particle; L^*_j, length of the undecomposed part of the charged jet; S, distance from the location of outflow to the axis of the needle–sphere system; and D, diameter of the jet.

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INVESTIGATION OF THE KINETICS OF SELF-PROPAGATING SYNTHESIS BY THE METHODS OF COMPUTATIONAL IR THERMOGRAPHY

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The methods, techniques, and results of investigations of the kinetics of self-propagating synthesis of organic reagents performed in order to improve self-propagating high-temperature synthesis (SHS) are described. Data on the structure of the combustion wave are presented; the data were obtained using a system for computational IR thermography, IR spectroscopy of scattering media, contact thermometry and microscopy, and thermogravimetric analysis, all of which made it possible to obtain information about the physical and chemical processes occurring in a wave of SHS.

In the last few years methods for synthesizing refractory compounds and materials based on oxygen-free combustion – self-propagating high-temperature synthesis (SHS) – have been widely used. Wave regimes in which the chemical transformation is concentrated in a zone propagating along a mixture of powders have been obtained with the help of local initiation [1]. The characteristic features of the process are that virtually no gas is released, the reaction product is in the condensed phase, the temperature in the reaction zone is high, the energy consumption is low, the equipment is simple, and the product is pure. In SHS processes surface and layerwise combustion, wave localization, splitting and reflection of waves, self-excited and spin combustion, and wave stratification of the medium are realized.

It is of greatest interest to clarify the mechanism of SHS processes, to model SHS numerically, and to develop efficient technologies. The solution of this problem will make it possible to realize the direct synthesis of multicomponent solid solutions of high purity and the synthesis of metastable phases. It is difficult to study directly the chemical and physical processes occurring in a combustion wave and primarily at the combustion front in classical SHS of systems of the type metal-oxidizer. The short reaction time in the wave

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