EXPERIMENTAL STUDY IN THE STRUCTURE OF WATER ELECTROLYTE SPRAYS AND DROPS UNDER THE ELECTRICAL FIELD

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Abstract

This paper gives experimental results obtained for the behaviour of thin sprays of the electrolyte and drops of different electric conductivity under the action of electric fields with high potential up to 30 kV. Procedures controlling dynamics of sprays and drops are also presented. Processes of auto oscillations of spray height as well as an effect of constant magnetic field on the spray structure are considered. Principal differences of electrohydrodynamic phenomena in dielectric fluids, water solutions and natural waters are discussed. Results obtained are valuable as concerning the problems of electromagnetic ecology and while revealing a role of atmospheric electricity in functioning of bioobjects.

1. Introduction

The objective of presented here research cycle was to study experimentally the process of origination of auto oscillation of electrolyte sprays height, the effect of generation of the glow of the drops and a series of other phenomena in electric field which are of the interest for understanding physics of natural atmospheric phenomena and for applications.

As earlier works [1-4] show, electrohydrodynamic (EHD) effects in water electrolytes are not limited by processes of electroosmosis, the spectrum of phenomena is considerably broader, and in some cases it principally differs from EHD-effects in fluid dielectrics. EHD- effects are able to originate in water electrolytes under considerably lower strengths of constant and low-frequency electric fields. Furthermore, the presence of atmospheric electric fields of different nature stipulates the interest to laboratory studies. Processes proceeding in water systems in the domain of inter-phase boundaries are deeply different by their nature that depends on electric conductivity of the fluid and is related not only to the motion or dispersion by also to the nature of electric discharges originating in gases. Thus, presence of water medium considerably changes the process of discharge, particularly, it applies to corona discharge [5].

The work concerns with peculiarities of dispersion and coalescence processes in the water sprays and solutions and also in their drops under electric fields.

Studies in the effect of reduction of dispersion of thin sprays under electric fields of rather small strengths to (1-20) V/cm are, by our opinion, of the particular interest. Since the similar phenomena have been also observed under magnetic fields [6], but their results have not been comprehensively investigated, we concluded spray dispersion under magnetic fields in our research.

2. Procedure of the experiment

In the course of studies we utilised the set-ups of different types [4]. As the general approach for all those set-ups was application of high-voltage high-stabilised power supply in voltage range of 0-30 kV. The electrodes have been fabricated from different materials. Thus, for instance, the influence on the water sprays was examined on the plates made of SRB paper-laminate (dielectric) and coated by the copper foil. Spray behaviour has been observed on set-ups with different inter-electrode distance: 250 mm, 17 mm and 2.4 mm. The voltage between electrodes has been measured by a high-voltage voltmeter. The sprays have been photographed by *Zenith* camera with transition rings. A frequency of spray auto-oscillations has been measured by the metering unit with photodiodes. Fluid has been applied under the certain pressure to capillaries of different diameters and materials (glass, steel needles). Fig. 1 shows a set-up used in studies of the influence of the magnetic field on the character of spray sprinkling. Distillate, tap water, and water solutions of NaCl of concentrations from 1% to 5% have been taken for examination.

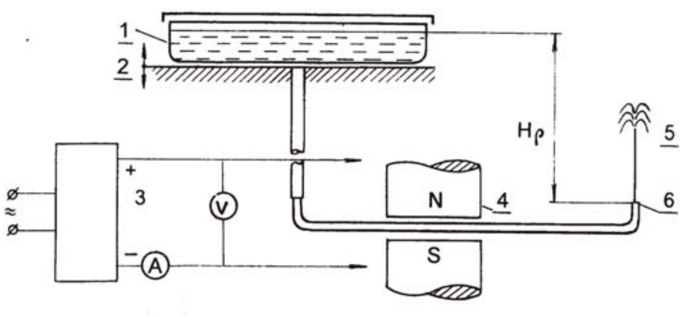


Fig. 1. Experimental set-up for registration the magnetic field effect on the water dispersion.
1 – vessel for generation the hydrostatic pressure; 2 - joint of vertical motion of the vessel;
3 – electromagnet power supply and control unit; 4 – electromagnet; 5 – free vertical spray;
6 – extension unit; H_p – pressure.

3. Results

3.1. Drops

In case of the distillate, when a potential U grows on the upper electrode, the drop stays motionless despite the deformation up to U= 7 kV. At U ≥ 7 kV, the fluid starts its flowing away from the drop, by the way, its volume W is increasing with increase of U (Fig.2). In this case, the surface tension forces are insufficient to preserve the drop. Otherwise, in case of the absence of the fluid on the electrode, corona discharge starts nearby electrode at U= 14-15 kV, by the way the area of illumination is very small. Thus, the spark discharge has not been observed up to the value of U=30 kV. However, in case of filling the electrode by the water, strong corona discharges has been originated at considerably small values of a potential U. The colour of the glow changes from white-blue to violet (Fig. 3). The glow is similar to St.Elm's fires [5]. Considerable contribution to the illumination of a photo-film is apparently performed by the ultra-violet part of the glow. Intensive odour of the ozone has been felt. In case of the distillate the glow nearby electrodes started at U=6 kV, while for the tap water at U=10 kV, respectively. In both cases with potential growth spark break-down of the inter-electrode gap could be observed. In the break-down the structure of the glow is different: in case of the tap water (Fig. 3a) it is of stream type, thus resembling the typical lightening, while in case of the distillate it is featured by plain, spatially localised character (Fig.3b). Duration of the shooting in the darkness has been selected by the empirical way (t = 60 s).

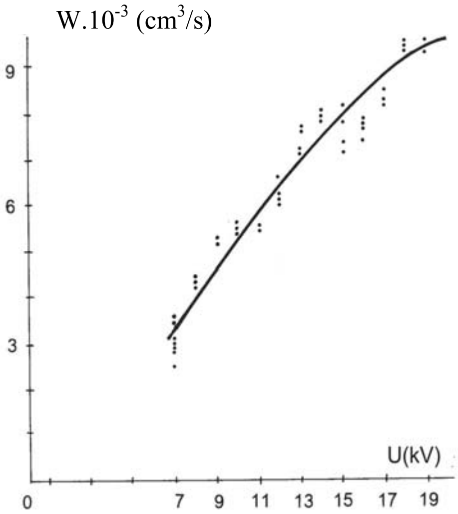
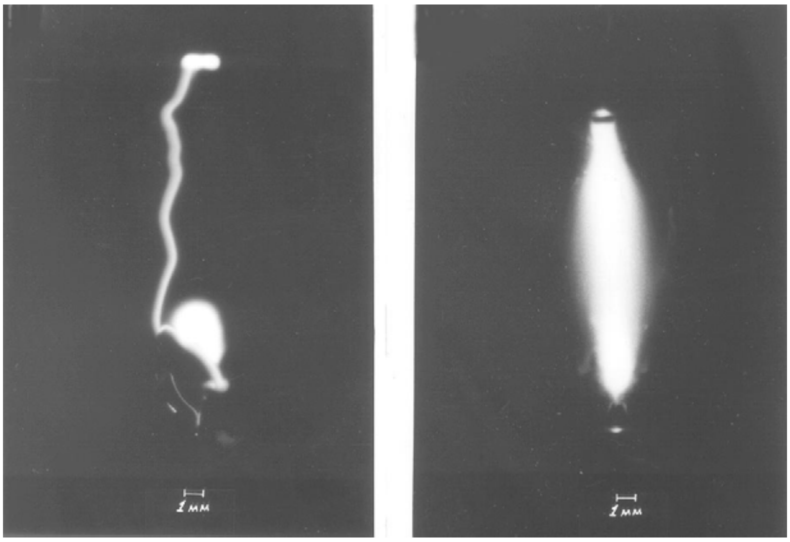


Fig. 2. Dependence of the fluid amount flowing out of the capillary W on the potential U (the distillate)



a) b)

Fig. 3. Photo of the inter-electrode gap on the break-down condition. U = 4 kV. The lower electrode is filled by the water, and supplied by a high potential. Exposure of 60 s. Shooting is performed in the darkness: a – tap water, b – distillate.

Consequently, the presence of the drops and vapours reduces the discharge threshold and also changes the structure of the glow, obviously owing to reduction of the break-down gap.

3.2. Sprays

In the course of sprinkling thin sprays of the water, with growth of the potential on the upper electrode there could be observed little-investigated but repeatedly observed earlier effect of amalgamation of the drops, then stabilisation of the spray till complete termination of its sprinkling [1, 3-4]. Thus, in our experiments, a macrodrop was formed on the spray's top so that its diameter exceeded a diameter of the original spray. Fig.4 shows an example of such macrodrop. At U=4 kV, the drop diameter was equal to 1.8 mm, i.e. approximately 6-fold larger than the nozzle diameter (0.26 mm). In the natural environment, the effect of rain drops broadening is broadly known in the storms [7]. One more interesting effect should be noted that can be observed only for the water and water solutions. At potential U (in our case at $U \leq 1$ kV), the spray auto-oscillation is observed, i.e. time variation of the spray height h_S, $h_S < h$, where h – distance between electrodes. Simultaneously with growth of the drop diameter its mass (weight) increases, the spray «sinks», the drop runs off and the spray is rises again. Fig. 5 shows dependencies for auto-oscillation frequency f_0, calculated in accordance with experimental data for periods T at various values of potential (U) and concentrations (c). The general character of the curve can be evaluated f_0=F(U, c) for different concentrations *c*, it has clearly definite maximum, followed by the sharp drop. The spray with the drop on its top begins to take its form just at U=0,5 kV, that corresponds to not more than E≈20 V/cm.

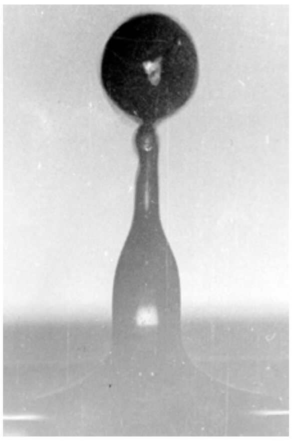


Fig. 4. Photo of the water spray (distillate) under a small pressure. The upper electrode is under 4 kV. The drop diameter is 1.78 mm, nozzle diameter is 0.26 mm. Exposure 1/250 s. Diameter of electrode discs is 9.4 cm. Inter-electrode distance is 2.4 mm.

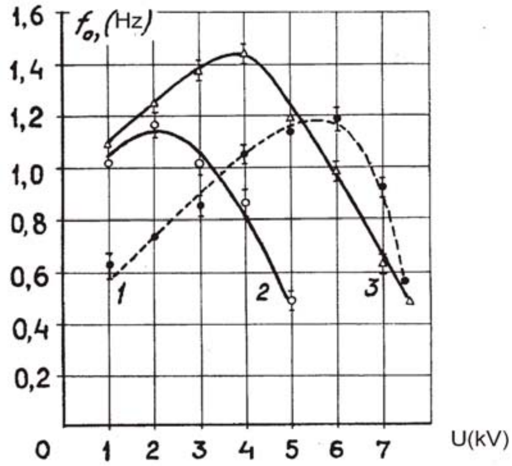
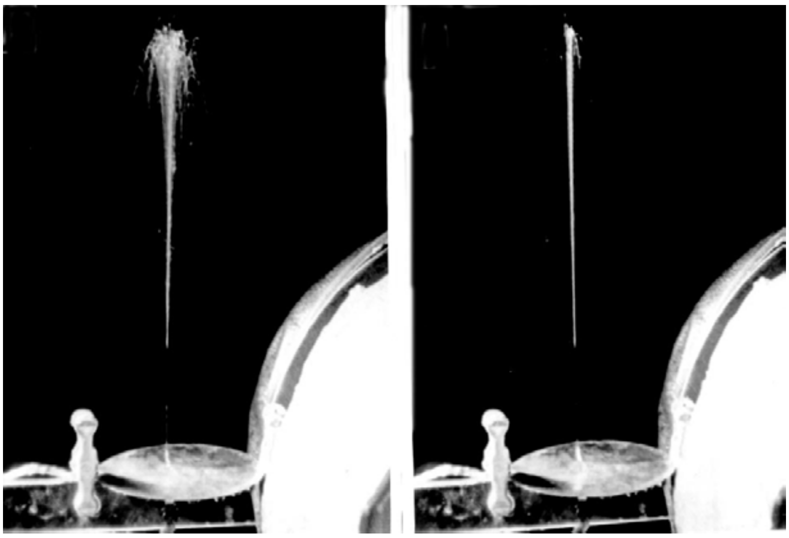


Fig. 5. Auto-oscillation frequency f_0 of the spray height h_S for the water and its solutions versus the value of high-voltage potential of the upper electrode.

1 – distillate, 2 – tap water, 3–5% solution of NaCl.

After time of growth of oscillation frequency, chaotic movement begins that is followed at large values U by the phenomenon of crushing of the drops also typical for fluid dielectrics. In our conditions periods of auto-oscillation were equal to T=(0.6-2) s. The frequency range f_0 can be seen in Fig. 5. When the fluid flowed through the electromagnet, phenomena of both spray stabilisation, and generation of auto-oscillation could by observed likely to above mentioned. Further experiments have demonstrated that observed experimental data in the considerable degree were apparently stipulated by not direct action of the magnetic field, but by the electric field induced. It should be noted that the phenomena observed are similar to those described in [6].



a) b)

Fig. 6. Form of dispersive fluid spray under a magnetic field
a) B = 0
b) B = 0.05 T.
Exposure 1/30 s.
Distillate.

4. Discussion of results

In the general case, the unit of fluid volume under the constant electric field of the strength $\vec{E}$ is subjected to the effect of pondermotive electrohydrodynamic force $\vec{f}_{EHD}$, whose density without consideration of the «strictive» component is equal to

$$\vec{f}_{EHD} = \rho_{VC}\vec{E} - \left(\frac{E^2}{8\pi}\right) grad\varepsilon, \tag{1}$$

ρ_{VC} - density of volume charges, ε - dielectric constant.

Then, let us concern the peculiarity of manifestation of (1) for the water electrolytes. As distinct from fluid dielectrics, they can be characterised by larger values of the density ρ_{VC} and strength E compared to the value E_0=U/h. High concentration of low molecular ions even in the distillate and the tap water is dozen-fold larger than ion concentrations in the fluid dielectrics, thus resulting in the growth of volume charge density ρ_{VC}, originating in electrolytes both in the domain of inter-phase boundaries (volume charge of double electric layer) and owing to electrostatic induction (sprays, drops, films). In the essence, the charges are the dipole structures with charge density $^+\rho_{VC}$ and $^-\rho_{VC}$, they are attracted to each other by the dipole ends under Coulomb forces, that is with the following force:

$$\vec{F}_C = -\rho_{VC}^2 / \varepsilon\, r^2. \tag{2}$$

These forces define both spray stabilisation and drop coalescence. On this phase the attracting forces dominate over repelling forces, that is, the drop acquire only charges of the same sign in the higher fields. In this case, Coulomb forces increase with the growth of electrolyte concentration, and the drop starts to form itself at lower U. Then, the relaxation time decreases that can be seen from the character of the curves, for instance, for distillate and 5% NaCl solution. At U=1 kV, a frequency of spray oscillation reaches 1.1 Hz and 0.6 Hz for the solution and distillate, respectively, on the same conditions. It should be noted, that with the growth of concentration, EHD-effects increase instead of decrease as is considered usually in the area of conventional ideas about the character of electrokinetic processes.

Another peculiarity is the fact that the real magnitude of the electric field strength nearby the spray, or drop surface as has been already noted by J.I.Frenkel [3], is significantly higher than according to the usual assessment for E_0= U/h, where E_0 is a mean value of a homogenous electric field. This phenomenon is stipulated by that introduction of conductive element (water spray), linked to one of the electrodes, yields to increase of the strength E, and generating grad E of a significant value. Peculiarity of water sprays and drops linked to the main mass of the fluid or to the grounded electrode, is the fact of increasing the field in proportion to the value h_S/d_0, where h_S is a spray height, d_0 – its diameter, respectively. Such increase may be very considerable and allows to expect the air break-down. By estimates performed in [8]:

$$E_{\max} / E_0 = (h_c / h_0)^2 [\ln(h_c / d_0) - 1]^{-1}. \tag{3}$$

5. Summary

Unfortunately, our experiments did not concern detailed studies in composition of the water and solutions after electric discharges. However, considerable changes in the fluid properties are expected due to its enrichment by nitrogen oxides, ozone, absorption of various discharge products, as well. Such ideas allow to estimate direct action of electric discharges in the atmosphere in storms on the composition of natural waters (rain, fog, dew, sea and river water) due to their enrichment by nitrogen oxides and other substances as necessary consideration in the real balance of feeding the plants and other living objects. Moreover, those ideas about considerable contribution of nitrogen compounds, originating in the storms in the soil balance are confirmed by multiple analytic and experimental data [9].

In accordance with above mentioned, the concepts of electromagnetic ecology and the problem of electromagnetic contamination seems as the most important not only due to infringement of information electromagnetic links in the living systems, but also due to the fact that these fields directly effect processes of electroexchange, mass and electrotransfer in the living systems and also in the system soil-plant-atmosphere, that can yield to unpredicted consequences.

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