ELECTROCONVECTION IN GAS-LIQUID MEDIA

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Abstract: The electroconvective gas bubble movement in the field of plane-parallel capacitor is investigated both experimentally and theoretically. The evolution of a bubble on the stages of growth, separation and surfacing is considered.

Key words: gas-liquid system, electroconvection, electric field, bubbling, equations of bubble motion, Rayleigh-Lamb equation, Poisson equation, electroaerosol.

1. INTRODUCTION

A significant role is played in the development of electroconvective phenomena by inhomogeneity of the medium with respect to the electrophysical parameters ε and τ [1]. When temperature variation in the medium is insignificant, one can speak of *electromechanical convection* (EMC) in gas-liquid systems, since the phases differ in their mechanical and, thus, electrophysical composition.

It should be stressed that electromechanical convection is the fundamental but not the only form of convection in such media. The processes of charge, heat, and mass transport occur in the presence of high gradient temperature and concentration fields which increase the inhomogeneity of the ε and τ distributions: the nonisothermal state of the medium causes *electrothermal convection* (ETC), while concentration gradients cause *electroconcentration convection* (ECC). Thus, a nonisothermal medium in an electric field is located in a complex dynamic state defined by the simultaneous action of EMC, ETC, and ECC.

System reaction to stimulation by the field can be predicted by the criterion R [1], which is the ratio of the displacement current to the through-conduction current, and is proportional to τ/t_0 . For R >> 1, the system behaves like an ideal dielectric, while for R << 1 it acts as a weakly conductive medium. Even relatively good liquid dielectrics with parameter $\tau \geq 1$ s cannot be considered ideal after lengthy maintenance in a dc field (to $t_0 \to \infty$), while in hf field (0 << t_0 << 1 s) gas-liquid media with relaxation times characteristic of conductors become ideal.

2. BUBBLING OF HIGH RESISTANCE LIQUID IN AN ELECTRIC FIELD

The process of bubble flow through a high-resistance liquid within a volume exposed to the electric field of a horizontal system of planoparallel electrodes is accompanied by various electrodynamic effects, in the absence of an electric field gas bubbles detached from the lower electrode settle on the upper one, forming a multilayer structure. At low gas velocities the settling bubbles are driven by rising ones to the edges of the electrodes and are removed from the interelectrode space. Their place is taken by rising bubbles and, thus, there is a constant renewal of the foam. With increase in gas velocity the thickness of the layer of deposited bubbles increases and

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foam renewal is extended, although the intensity of renewal over layers is stabilized. In an electric field the bubble layer moves away from the upper electrode toward the lower one, a greater distance, the higher the field intensity. Simultaneously bubbles are scattered and intensely removed from the region under the action of electrical forces. The electric field also affects the hydrodynamic state of the continuous phase. With increase in field intensity electroconvection of the liquid increases, while the character of liquid flow at the lower electrode differs from that at the upper. Visual observations have shown that jets of gas escaping from capillaries in the lower electrode are the source of vortices which form about that electrode; with increase in gas velocity the intensity of electroconvection and turbulization of the layer adjoining the electrode increase. The layer of bubbles departing from the upper electrode limits the scale of liquid circulation in the interelectrode space and with increase in gas velocity at low field intensities the intensity of electroconvection at the upper electrode is less than at the lower.
Judging from the hydrodynamic pattern of bubble flow in an electric field, one would expect a strong dependence of heat liberation at each electrode on the field intensity and gas velocity. It has also been proposed that the main force acting on bubbles is caused by the electric field gradient, inhomogeneity in which reaches large values at the electrodes, as has been shown by probe measurements.
This hypothesis has been confirmed by study of the mathematical model of [2], describing evolution of a gas bubble under such circumstances. The mathematical description of the problem is based on the equations of motion [3], Rayleigh-Lamb equation (5), and Poisson equation (8) of [4].

3. EXPERIMENTAL DEVICE AND METHOD OF INVESTIGATION

The experimental device (Fig.1) consists of a transparent cell 1 in which is located a system of horizontal parallel-plate electrodes 2. The gas bubble 3 is generated at the edge of glass capillary tube 4 located in the plane of the lower electrode. The cell is filled with transformer oil 5. The gas pressure and temperature in the gas chamber 6 were measured by a standard manometer 7 and thermometer 8. The gas flow rate was regulated by the valve of the gas regulator of and was measured by rotameter 9 connected to the compressed air system. A constant potential was supplied from high voltage source 10 to the upper electrode; the lower electrode was grounded; the voltage was measured by kilovoltmeter 11.

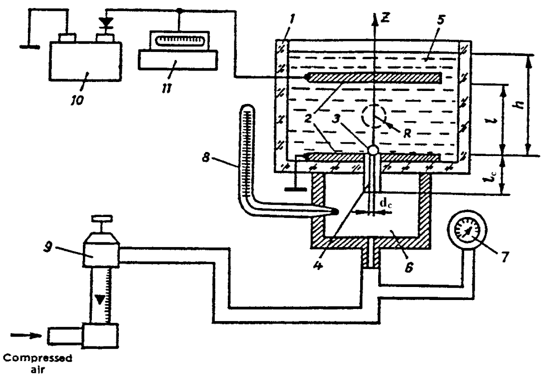

Fig. 1. Schematic diagram of experimental device (explanation in text)

The method of investigation consisted in the following. The bubbles were photographed at two exposure values (1/500 and 1/60 or 1/125 *s*). The first exposure value made it possible to fix the diameter of separation of the bubbles and the second the tracks of their motion, from which the velocity was determined. Magnifying rings were used for changing the photography scale. The investigations were conducted at a field strength up to 40 *kV/cm* and various air pressures before the capillary tube.

4. RESULTS AND DISCUSSION

The phases of bubble growth, separation, detachment, and free ascent in the interelectrode space of a horizontal planoparallel capacitor were studied. Numerical calculations were compared to experimental data obtained by the trajectory method. Calculations showed that a bubble nucleus begins to grow slowly at first due to the influence of all the retarding factors, especially surface tension (Fig. 2). The duration of this period is very brief and is determined mainly by gas pressure ahead of the capillary. Soon the effects of surface tension and liquid velocity become negligibly small in comparison to the gas pressure and liquid inertia, and the bubble growth rate increases rapidly, reaching a maximum. With increase in gas pressure the maximum growth velocity increases significantly. For example, at 0.11 *MPa*, v_{ra}' =0.17 m/s, while at 0.16 MPa, v_{ra}' = 3.23 m/s.

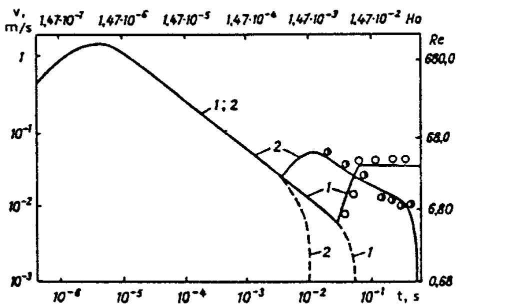

Fig. 2. Dynamics of growth and motion of an air bubble in transformer oil (v_{ra}', v_2' [m/s]; t, [s]): P_g = 0.13 MPa; E', kV/cm: 1-0; 2-30. Solid lines - calculation of bubble linear velocity; dashes - radial velocity calculation; points - experiment.

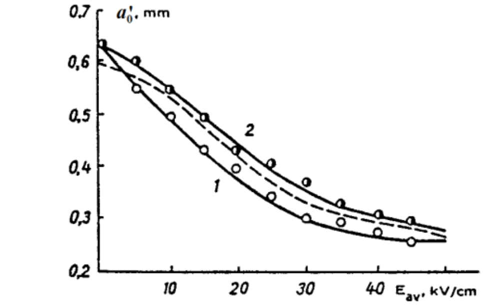

Fig. 3. Field intensity E', [kV/cm] vs bubble detachment radius a_0', [mm]: Gaspermeable electrode polarity: 1- positive; 2- negative; solid lines along points - experiment; dashes - calculation.

At the maximum the effect of inertial forces decreases, the growth rate falls off, and the process enters an asymptotic stage. The growth curves in this phase are qualitatively analogous to corresponding dependences for boiling. With increase in field intensity the bubble detachment diameter decreases (Fig. 3), this dependence being determined by the polarity of the lower electrode, due to the asymmetry of the field distribution. The effect of the field on bubble growth and detachment dynamics reduces to earlier completion of these stages as compared to the absence of a field. However, in the free bubble ascent stage the bubbles rise more rapidly in the absence of a field (curve 1, Fig. 2), but then are braked, not reaching the upper electrode in an electric field (curve 2). Thus, the results obtained indicate the validity of the propositions presented above regarding the nature of the electrical force.

We will consider electromechanical convection for the case where there acts upon the dispersed phase from the direction of the electric field a Coulomb force, which is typical for droplet removal upon bubbling through low-resistance liquids [5]. It is known that upon destruction of bubbles on the free surface of the bubble layer droplets are produced by dispersion of the bubble domes and secondary fountaining. In the absence of an electric field the main mass of droplets moves inertially against the force of gravity, and under the action of the latter returns into the liquid or is carried off by the same, contaminating it, so that measures are required to separate the droplets. In an electric field the droplets take on excess charge and become capable of being controlled, depending on the field configuration, intensity, and frequency. In a dc field fine droplets are carried off to the seed electrode along force lines; dispersed phase motion in ac fields is characterized by two regimes: impulsive and oscillatory. If the characteristic time of droplet motion is greater than the electric field oscillation period, but less than the droplet charge relaxation time, such drops perform an oscillatory motion in some intermediate region of the interelectrode space at the external field frequency. The opposite relationship of characteristic times leads to impulsive motion of the dispersed phase. If the characteristic times are comparable to each other, droplet motion is unstable and represents a spontaneous transition from the one regime to the other.

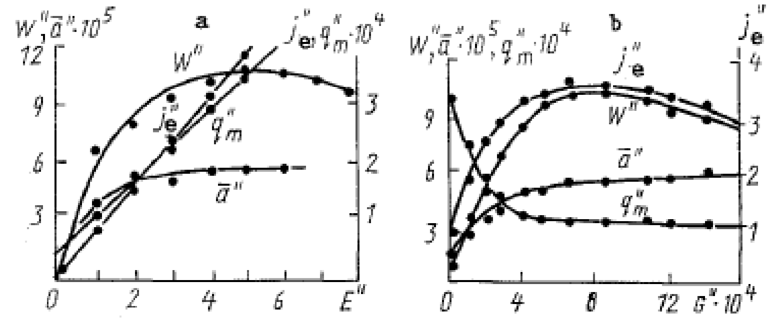

Fig. 4. Transport current density j_e'', [A/m^2], mass removal W'', [g/(m^2·s], mean mass charge q_m'', [C/kg], and mean droplet size $\bar{a}$'', [m], vs field intensity E'', [kV/cm] (a), and gas velocity G'', [m/s] (b), for bubbling through water: a) G'' = 0.68·10^{-3}; b) E'' = 5

The basic parameters of the electroaerosol removed depend basically on the gas velocity and field intensity; their characteristic dependences are shown in Fig. 4.

With consideration of the equations of droplet motion, conservation of their volume concentration in the steady state, Eq. (3), and the Poisson equation (8) [4], a mathematical model was developed for generation and electroconvective removal of droplets [I0], describing dynamic removal regimes observed experimentally.

Summarizing, we note that analysis of the problem of Eqs. (3)-(15) of [4], the particular models of [2,6], and experimental results permit determination of limits of dispersed phase concentration and electric field parameters at which the effect of collective processes begins to appear: scattering, coagulation, particle breakup, hydrodynamic inheritance effects, etc.; these should be considered at volume dispersed phase concentrations greater than 0.0001 in gas-dispersed and greater than 0.001 in liquid-dispersed media. There also exists a "threshold" for field effect on such collective phenomena.

5. CONCLUSION

The results obtained permit us to summarise that the force effect of the field on the dynamics of bubble growth and separation consists in earlier completion of these stages in comparison with those in the absence of the electric field. However, at the stage of free emergence the character of bubble motion changes qualitatively. This is related to the accumulation in the liquid phase of a free space charge leading to a redistribution of the electric field, whereas the surface effects at the interface are less substantial, especially at the stage of preasymptotic growth.

The promise of studies in this direction has resulted in wide application of results in practical problems. Thus, use of an electric field, aside from the traditional struggle with loss phenomena in chemical technology and vapor-based energy production, has permitted development of new technical approaches for effective generation of liquid electroaerosols.

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