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# INTENSIFICATION OF THE ELECTRIC CONVECTION OF WEAKLY CONDUCTING LIQUIDS BY A PULSED ELECTRIC FIELD

**Yu. M. Rychkov and A. E. Vasilevich**

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*Results of an investigation of the kinematic characteristics of the electric convection of weakly conducting liquids intensified by a pulsed electric field are reported.*

Intensification of the electric convection of weakly conducting liquids has been necessitated by the constant improvement of systems of heat and mass transfer operating under zero-gravity conditions. The traditional ways of solving of this problem by increasing the anode voltage and choosing the composition of the working fluid are inefficient at present, which has stimulated the search for other solutions. Below, as one of those solutions, a method of intensification and control of the electric convection of weakly conducting liquids by a pulsed electric field is suggested.

The method is based on the use of the regularities of the molecular structure of a near-electrode layer in liquid-state dielectrics [1, 2] and regulation of the level of injection of an emitting electrode (cathode) by a pulsed electric field of an additional initiating electrode (grid).

The additional electrode (grid) made in the form of a thin wire creating a minimum hydrodynamic resistance for a liquid flow is placed at the boundary of ionic and cluster conducting layers near the cathode (depending on the type of investigated liquid, this distance varies from 50 to 200 μm). A sequence of rectangularly shaped voltage pulses of controlled amplitude, duration, and frequency is applied to the grid. The pulse amplitude is chosen larger than the breakdown voltage of the cathode–grid section; the pulse duration is smaller than the time necessary for the breakdown to occur. As a result, a unipolar pulsed charge flux toward the near-electrode cluster layer of a liquid is formed with subsequent development of electric convection in the anode field. Control of the level of charge injection and, respectively, of the electric convection of a weakly conducting liquid is accomplished by regulation of the amplitude and repetition frequency of the pulses of voltage of the initiating electrode of the grid.

**Experimental Procedure.** An investigation of the kinematic characteristics of electric convection [3] in the entire range of its existence on a voltage scale, i.e., from the threshold of occurrence to the breakdown of an interelectrode gap, was carried out in the system of electrodes of the type "sphere (cathode) – wire (grid) – plane (anode)" in solutions of isobutyl alcohol in transformer oil.

The visualization of the electric convection of weakly conducting liquids very sensitive to impurities [3] represents a complex problem. Special investigations have shown that for this purpose gas bubbles are the best tool [4].

A block diagram of the experimental bench is shown in Fig. 1. The experimental setup allows simultaneous recording of the kinematic parameters of convection and of the corresponding electrical characteristics. To determine the kinematic parameters, we introduced air bubbles (BG is a bubble generator) of a calibrated size (1 μm) into the investigated medium via a capillary (C). Spatial visualization of bubbles was

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Ya. Kupala Grodno State University, Grodno, Belarus: email: vasil@grsu.grodno.by. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 74, No. 2, pp. 106–108, March–April, 2001. Original article submitted August 7, 2000.

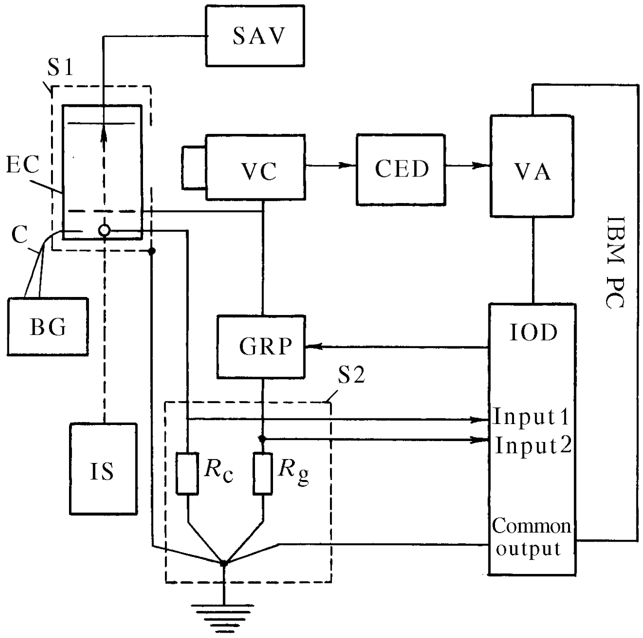

Fig. 1. Block diagram of the experimental setup used for investigation of the electric convection of weakly conducting liquids by the method of stroboscopic visualization of air bubbles.

accomplished by using an illumination source (IS) creating a light plane with a width of 1 mm in the interelectrode gap of the experimental cuvette. The coordinates of the bubbles and the velocity of their displacement are determined by recording the image of the interelectrode gap in real time by means of an MCF-468 video camera (VC) via a contrast-enhancement device (CED) [5] and a video adapter (VA) to an IBM PC computer with subsequent frame-by-frame processing in a specially developed program.

The electrical part of the setup consists of a high-voltage source of anode voltage (SAV) (0–40 kV) and a programmed generator of grid high-voltage pulses of rectangular shape (GRP) ($U_{out}$ = 0–20 kV). The duration and the period of repetition of the formed high-voltage pulses are prescribed by the program ($\tau = 1 \cdot 10^{-6}$–10 sec, $T = 1 \cdot 10^{-6}$–10 sec, and $\tau_b$ = 100 nsec). To measure the currents of the cathode and the grid, use is made of the reference resistances $R_c$ and $R_g$. The currents are recorded by an analog-to-digital converter (ADC) of the input–output unit (IOU) ($L$ = 783, ADC 12 bits, 3 MHz, $R_{out}$ = 1 MΩ, 16 digital TTL input/outputs) installed in the IBM PC computer. The same unit generates rectangular pulses which control the GRP. To eliminate electrical noises, the experimental cuvette (EC) and the reference resistances were placed in metallic screens S1 and S2.

The setup makes it possible to record a velocity field within the range $10^{-4}$–10 m/sec. The measurement error for the velocity does not exceed 10%; the accuracy of the current measurement is 0.1%.

**Measurement Results.** All the conducted measurements involved three stages. The first stage was aimed at determination of the optimum location of the initiating electrode. Results of measurement of the velocity of the central convection jet in relation to the distance cathode–grid are given in Fig. 2.

It turned out that for the case of a constant grid voltage (Fig. 2a) this dependence has a pronounced maximum near 100 μm. In the case of a pulsed voltage, from this distance one can observe saturation. Since, according to the results of [1, 2], this distance corresponds to the boundary of the ionic and cluster layers of conduction, it is the optimum one for intensification of the injection current from the cathode surface. Thereafter, the cathode–grid distance was chosen within the limits 100–200 μm.

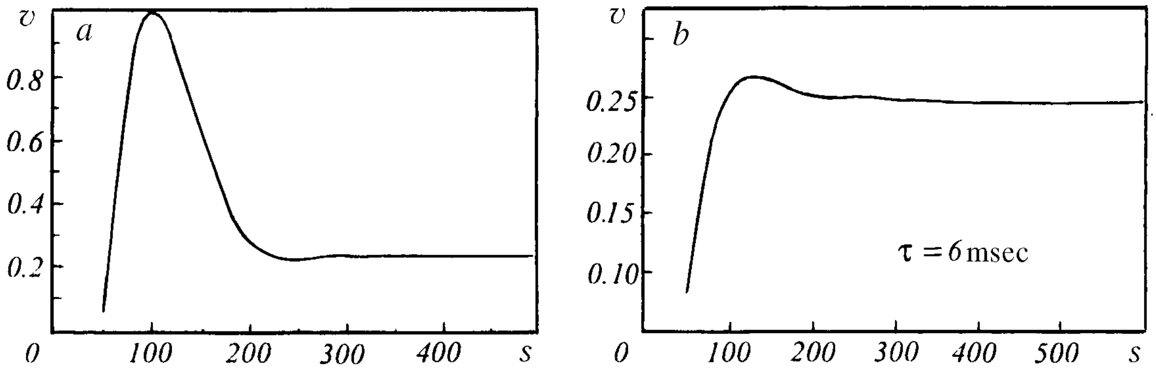

Fig. 2. Velocity of the central jet of electric convection vs. cathode–grid distance at constant (a) and pulsed (b) voltage on the grid (a 10% solution of isobutyl alcohol in transformer oil, $U_a$ = 10 kV): a) $U_g$ = 2 kV; b) 6 kV; $T$ = 30 msec. $v$, m/sec; $s$, μm.

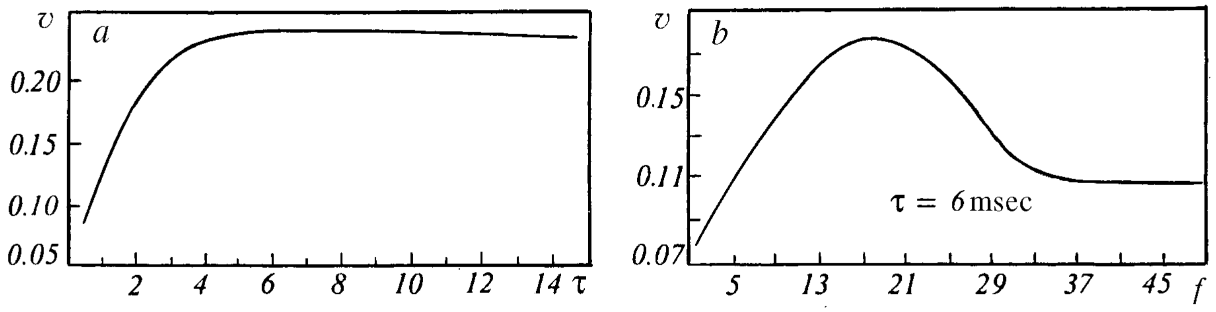

Fig. 3. Velocity of the central jet of electric convection vs. duration of the driving pulse (a) and the repetition frequency of pulses on the control electrode (b) (a 10% solution of isobutyl alcohol in transformer oil, $U_a$ = 10 kV, $U_g$ = 6 kV, and $s$ = 100 μm): a) $T$ = 30 msec; b) τ = 6 msec; τ, msec; $f$, Hz.

In the second stage, we determined the velocity of the central jet of electric convection in relation to the duration and to the repetition frequency of pulsed voltage pulses on the grid. The results of measurements are given in Fig. 3.

It is established that the dependence of the flow velocity on the pulse duration (Fig. 3a) has saturation starting from a pulse duration of 5–10 μsec. An increase in the pulse duration of the grid voltage to 20 μsec or more leads to breakdown of the cathode–grid gap. Thereafter, the pulse duration was chosen within the limits 5–10 μsec.

The dependence of the flow velocity on the repetition frequency of the pulses of the grid voltage (Fig. 3b) exhibits a maximum near 15–23 Hz. In our opinion, this corresponds to the optimum relationship between the Maxwell relaxation time and the time of absence of the voltage pulse, during which the liquid in the cathode–grid gap must return to its initial preionization state. Thereafter, the frequency of pulse repetition was chosen within the range 17–19 Hz.

In the third stage, we studied the dependences of the flow velocity of the central jet of electric convection on the pulse amplitude of the grid voltage. The results of the measurements are given in Fig. 4.

It turned out that the rate of electric convection for amplitudes of the pulsed grid voltage lower than 4 kV slightly differs from the values attained in the traditional two-electrode system [4]. When the voltage amplitude becomes higher than 4 kV, the velocity of flows abruptly increases as compared to the two-electrode system (up to 2 orders of magnitude), till attaining 5 kV. Here, the saturation level corresponds, appar-

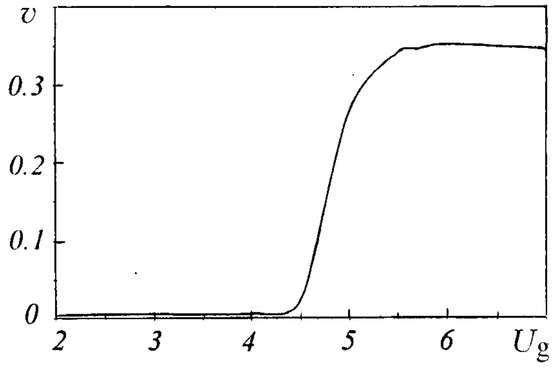

Fig. 4. Velocity of the control jet of electric convection vs. amplitude of pulses on the control electrode (a 10% solution of isobutyl alcohol in transformer oil, $U_a$ = 10 kV, $T$ = 30 msec, $\tau$ = 6 msec, and $s$ = 100 μm). $U_g$, kV.

ently, to the maximum capacity of a weakly conducting liquid for molecular structurization and convective transfer of a charge injected into it. Despite the fact that the theory of this process is still under development [6], the discovered effect already provides the possibility of the creation of new (pulsed) electrohydrodynamic converters (ionic-convective pumps, devices of adaptive optics, actuators of microhydromechanics, and so on), which substantially exceed the existing analogs in characteristics.

Thus, the use of an initiating pulsed electric field allows substantial (by two orders of magnitude for the flow velocity) intensification of the electric convection of weakly conducting liquids and control of its parameters.

## NOTATION

$U_{out}$, amplitude of the output voltage of the GRP; $U_a$, anode voltage; $U_g$, voltage amplitude on the grid; $f$, frequency; $v$, flow velocity; $s$, distance from the cathode; $\tau_b$, time of buildup of the leading edge of a high-voltage pulse; $\tau$, duration of a high-voltage pulse; $T$, repetition period. Subscripts: out, output; b, buildup; p, pulse; a, anode; g, grid.

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