OPTIMIZATION OF AN EHD PUMP CHARACTERISTICS

OPTIMIZAREA CARACTERISTICILOR UNEI POMPE EHD

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***Summary**. Electrohydrodynamic pumps generate flow in dielectric liquids. Two injection type electrohydodynamic pumps with blade-blade with insulation coating type electrodes and grid-grid type electrodes made of bare wires and wires covered with perforated insulation have been studied. There was a movable flow-limiting partition in the interelectrode space of the second pump. The current-voltage and pressure-flow rate characteristics of the pumps are given when using pure transformer oil, transformer oil-butanol mixtures ans polyethylsiloxane liquid. The optimal interelectrode gap distance, conductivity of the medium and position of the flow-limiting partition has been established, which ensures maximum pressure (in transformer oil, the pressure was 1.8 times higher than in polyethylsiloxane liquid).*

***Keywords**: dielectric fluid, electrohydrodynamic pump, partition, perforated insulation, pressure.*

INTRODUCTION

An electrohydrodynamic (EHD) pump is a device that directly converts the energy of an electric field into the kinetic energy of a dielectric fluid and is capable to get the fluid flow out of the interelectrode space. In EHD pumps, the force acts directly on the liquid, therefore, compared to mechanical pumps, they have a simpler design, no moving elements, no vibration and ease of control. [1]. A very important advantage of EHD pumps is the possibility of their miniaturization. Such pumps are used in cooling, hydraulic actuation and robotics devices [2-6]. The electric body force acting on a dielectric liquid has the form [7]:

$$f_e = \rho_e E - \frac{1}{2} E^2 \nabla \varepsilon + \frac{1}{2} \nabla \left[E^2 \left(\frac{\partial \varepsilon}{\partial \rho} \right)_T \rho \right].$$

Here the first term represents the Coulomb component acting on the free charges in the liquid. The second term represents the dielectrophoretic component, which arises due to the dielectric constant gradient in the liquid and the third term represents the electrostrictive component, which arises due to the change in permeability in the non-isothermal fluid. The direction of the Coulomb force coincides with the direction of the electric field lines, and the direction of the dielectrophoretic and electrostrictive forces does not depend on the direction of the electric field. For an isothermal single-phase incompressible fluid, only the first term can be taken into account.

EHD pumps based on their operating principle can be divided into three groups: injection, induction and conductive [8]. The injection mechanism is based on the direct injection of charged particles using field emission, field ionization or corona discharge. These particles move along the electric field lines, dragging along the adjacent liquid due to friction [9-11]. The induction mechanism is based on the induction of a charge in a liquid due to an electrical conductivity gradient. The traveling wave of the electric field interacts with these charges, which leads to the movement of the liquid [12-14]. The conductive mechanism is based on the phenomenon of dissociation-recombination conductivity in an asymmetrical configuration of electrodes, which leads to the appearance of an electric force directed along the channel axis and is used to pump a dielectric liquid [15-18].

This work studies the influence of the position (gap size) of a movable flow-limiting partition in an injection-type EHD pump from the point of view of obtaining maximum pressure.

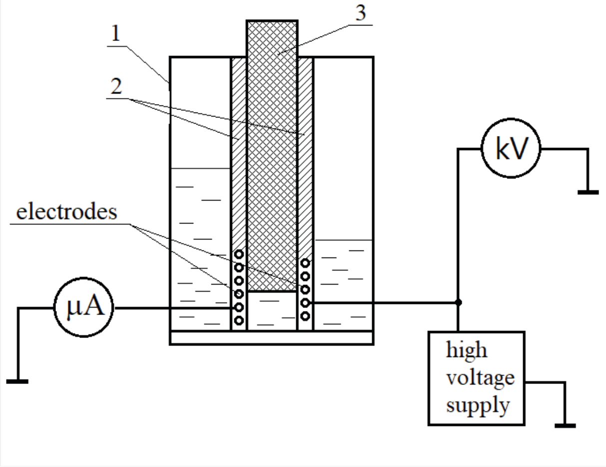

Fig. 1. Scheme of the experimental setup.
1 - cuvette, 2 - fixed partition between the compartments of the cuvette, 3 - movable partition.

EXPERIMENTAL SETUP

The investigations were carried out on an experimental setup, the diagram of which is shown in Fig. 1. The main element is a closed cell 1 (made of organic glass), which is divided by a fixed dielectric partition 2 into two compartments filled with dielectric liquid. At the bottom of the partition there is a rectangular hole for installing an EHD pump. The interelectrode space can be partially blocked by a movable partition 3. A constant voltage was supplied to the pump electrodes from a high voltage source and measured with a kilovoltmeter, and the leakage current was recorded with a galvanometer. The created pressure was measured with a piezometer at zero flow. Transformer oil and polyethylsiloxane liquid (PES-1) with electrical conductivities of $0.9 \cdot 10^{-11}$ S/m and $5.1 \cdot 10^{-11}$ S/m, respectively, were used as working fluids.

The electrodes of the EHD pump are two parallel grids installed at a distance of 3 mm from each other. Each grid consisted of six copper wires with a diameter of 0.6 mm, located with a pitch of 2 mm. On the emitter grid, in the varnish insulation of the wires on the collector side, notches 0.1 mm wide are applied with a pitch of 2 mm, and the grid used as a collector consists of bare wires. Grating dimensions 12 x 34 mm^2. A movable flow-limiting partition 2 mm thick could be inserted into the interelectrode gap, completely or partially blocking it.

Before the experiments, the cell was thoroughly washed with distilled water, ethyl alcohol and a small amount of liquid, which was used to study the EHD pump. After filling the cell with the test liquid, a gap was established using a movable partition and a constant high voltage was applied to the emitter of the pump. The collector pressure and leakage current were recorded after the pump operation had stabilized. In the experiments, the voltage was varied in steps of 2 kV, and the position of the movable partition (gap) in steps of 5 mm.

RESULTS AND DISSCUSSION

Figures 2 and 3 show the current-voltage characteristics of the EHD pump in PES-1 and pure transformer oil. At small gaps in PES-1, an almost linear dependence of the current on voltage is observed up to approximately 18 kV, then the influence of high-voltage liquid charging becomes apparent. As the gap increases, the currents increase noticeably, and the role of high-voltage liquid charging also increases. A similar picture is observed in transformer oil, but in it, with small gaps, the linear section extends to 22 kV. As the gap increases, the linear section shifts towards lower voltages and, with a gap of 10 mm, starts at 8 kV.

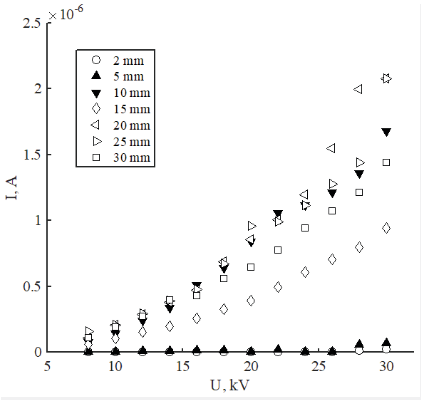

Fig. 2. Current-voltage characteristics of the EHD pump for PES-1 at various gaps

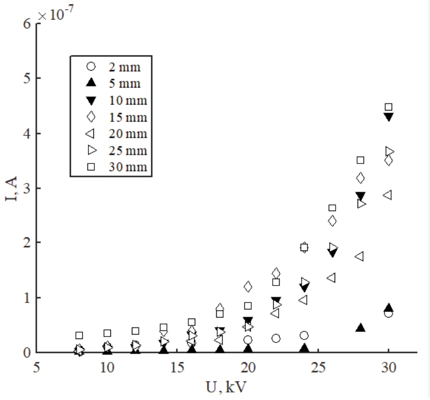

Fig. 3. Current-voltage characteristics of the EHD pump for transformer oil at various gaps

Figures 4 and 5 show the dependence of the pressure of the EHD pump on the voltage on the electrodes. As expected, for both fluids the pressure increases with applied voltage and varies with the square of the applied voltage. With increasing voltage, the density of space charges in the interelectrode gap increases, and as a result, the speed of electroconvective movement of the working medium and pressure increase. The pressure is determined by the transfer of charges by ions from the emitter to the collector, that is, the pump collector current. The maximum pressure values obtained in PES-1 and transformer oil are 321 and 618 Pa, respectively.

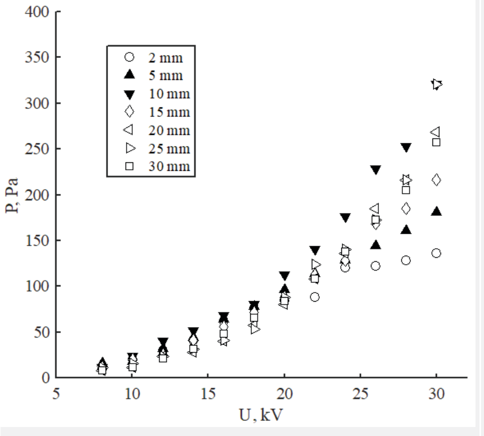

Fig. 4. Dependence of pressure on voltage on electrodes for PES-1 at various gaps

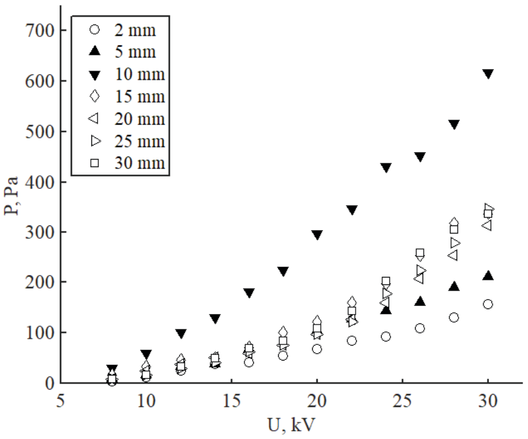

Fig. 5. Dependence of pressure on voltage on the electrodes for transformer oil at various gaps

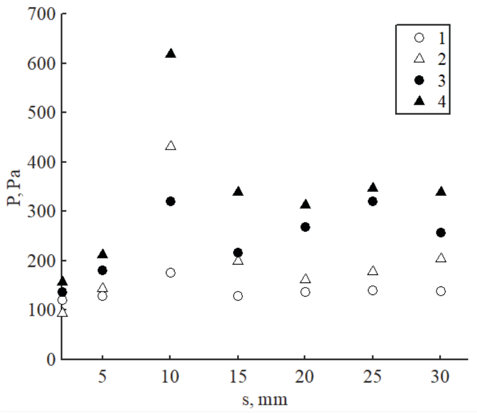

Fig. 6. Dependence of the pressure of the EHD pump on the height of the gap: PES-1: 1 - U = 24 kV; 3 - U = 30 kV. Transformer oil: 2 - U = 24 kV; 4 - U = 30 kV.

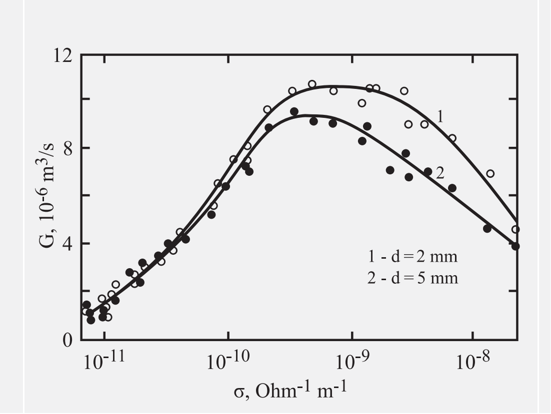

Fig. 7. The dependence of flow rate on conductivity of medium at different distances between electrodes

The dependences of the created pressure on the gap size for voltage values of 24 and 30 kV are presented in Fig. 6. At a gap of 10 mm, a well-defined maximum is observed both in PES-1 and in transformer oil, which is apparently due to the maximum suppression of reverse flows in the interelectrode gap.

Previously [19], we studied an EHD pump with electrodes of the “blade - blade with an insulating coating” type using pure transformer oil ($\sigma = 10^{-12}$ Ohm^{-1}·m^{-1}) and solutions of butanol in transformer oil with concentration 1-20% as a working fluid. It was found that the optimal width of the interelectrode gap, providing maximum flow, lies in the range of 3.3-5 mm. When the interelectrode gap is narrowed to 2 mm, the liquid flow rate decreases from 1.67 to 0.11 cm^3/s at a voltage across the electrodes of 30 kV. With an interelectrode gap width of 1.2 mm, there is practically no pumping. With an increase in conductivity to $\sigma = 5{\cdot}10^{-10}$ Ohm^{-1}·m^{-1} (13% butanol solution in transformer oil), the pumping speed first increases (Fig. 7) and then decreases.

CONCLUSIONS

The pressure and current-voltage characteristics of an EHD pump with a movable partition between the electrodes were experimentally studied. The electrodes are made in the form of grids (copper wires with a diameter of 0.6 mm). Notches were applied in the varnish insulation of the emitter with a certain pitch. Polyethylsiloxane liquid PES-1 and transformer oil were used as working fluids. The maximum static head was obtained in transformer oil. At the gap of 10 mm, a pronounced maximum pressure is observed in both liquids, which is apparently a consequence of the maximum suppression of reverse flows. This effect requires further study.

The narrowing of the canal in the interelectrode gap and applying the insulation coating leads to the change of return flow structure and, consequently, to the increase of the throughput rate. It is preferable to use the investigated electrode system in the transformer oil having conductivity $\sigma \sim 10^{-10}$ Ohm^{-1}·m^{-1}, in which the maximum efficiency was achieved.

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