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STUDY OF THE OPERATING REGIMES OF A THREE-ELECTRODE ELECTROHYDRODYNAMIC PUMP

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The results of studying the electrical and head-flow-rate characteristics of a single-stage electrohydrodynamic pump with an additional ignitor electrode have been presented.

The efficient use of electrohydrodynamic (EHD) pumps is hindered by a number of its inherent drawbacks, primarily, low level of efficiency and head pressure [1]. Therefore, the search for new solutions enabling one to improve the head-flow-rate characteristics and efficiency of EHD pumps is topical.

The intensity of electric convection of low-conducting fluids may be increased by introducing an additional electrode (grid) into the structure; this electrode is manufactured in the form of a thin wire creating only a low hydrodynamic drag for fluid flow. The grid is placed at the boundary of the ionic and cluster conductivity layers near the cathode (this distance ranges from 50 to 200 μm depending on the type of fluid under study) [2]. A train of rectangular pulses of adjustable amplitude, duration, and frequency is applied to the grid. The pulse amplitude is selected to be larger than the breakdown voltage of the cathode–grid portion; the pulse duration is shorter than the time it takes for the breakdown to be established. This creates a unipolar pulsed flow of charge into the electrode cluster layer of fluid followed by the development of electric convection in the anode field. The level of injection of the charge and accordingly the electric convection of the low-conducting fluid are controlled by adjusting the amplitude and frequency of repetition of voltage pulses of the ignitor electrode of the grid.

The electrical and head-flow-rate characteristics of a three-electrode EHD pump compared to the classical two-electrode pump are given below.

Experimental Procedure. A needle–ring electrode system possessing the best experimental results in efficiency and also in volt-ampere and head-flow-rate characteristics was selected as the operating structure of a single-stage EHD converter [3]. An additional ignitor electrode in the form of a thin (0.1 mm) copper wire located at a distance of 0.1 mm from the point of the cathode needle was used to ensure the regime of unipolar injection (Fig. 1).

The characteristics of a single-stage EHD pump were studied on a test bench enabling us to record the electrical and head-flow-rate characteristics on a real-time basis (see Fig. 2). Purified transformer oil (ρ = 876 kg/m^3 and $\sigma = 1.7 \cdot 10^{-10}$ S·m^{-1}) was used as the working fluid.

The single-stage EHD pump 4 is in a vessel with working fluid 6. The anode-voltage source 5 ensures adjustable voltage in the range 0–40 kV. The value of the anode current is monitored by measuring the voltage drop on the resistor R_c connected in series to the EHD-converter cathode. An input/out device for analog signals (L-783, ADC 12 bits, 3 MHz, R_{in} = 1 MΩ, and 16 TTL inputs-outputs), which is installed in the IBM personal computer 3, is used as the recording device. The grid-voltage source 7 ensures direct-current or rectangular output voltage with an amplitude of 0–30 kV. The parameters of a rectangular signal (τ = 0–100 msec and T = 0–100 msec) are controlled via the input-output device. The value of the grid current is monitored by measuring the voltage drop on the resistor R_g connected in series to the grid-voltage source. The analog pressure transducer 1 is intended for continuous conversion of the value of the excess or absolute pressure to the analog output voltage in the range 0–2.5 kPa. The flow rate of the working fluid is monitored by the electron sensor 2.

Measurement Results. We recorded the anode and grid currents, the static pressure, the efficiency, and the flow rate of the working fluid during the experiments. For correct comparative characteristics of the two- and three-electrode EHD pumps the measurements were carried out in structures uniform in size.

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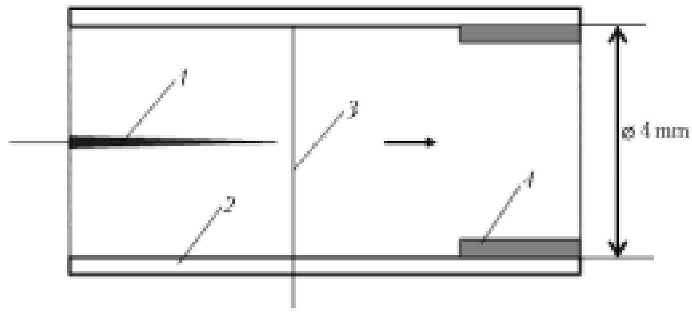

Fig. 1. Single-stage needle–ring EHD pump with an additional ignitor electrode: 1) emitter; 2) dielectric casing; 3) additional injector electrode; 4) collector.

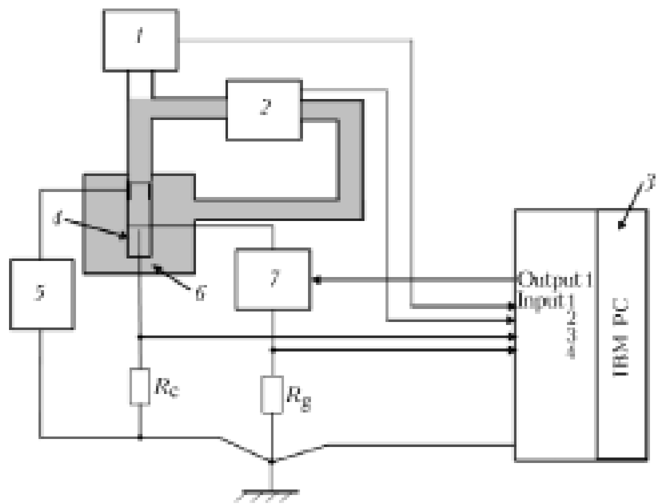

Fig. 2. Diagram of the test bench for studying the characteristics of a single-stage EHD pump.

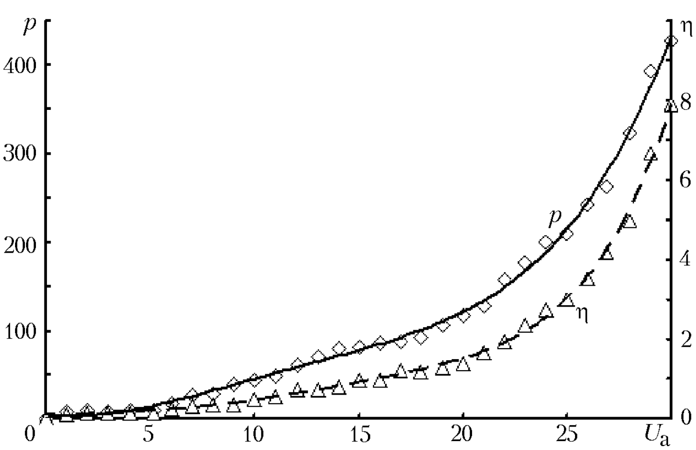

Fig. 3. Static pressure p and efficiency η of a two-electrode EHD pump vs. anode voltage U_a. p, Pa; η, %; U_a, kV.

Figure 3 gives the static pressure and the efficiency as functions of the anode voltage for the two-electrode structure of an EHD converter.

The use of a pulsed grid voltage enables us to substantially increase the static pressure and the efficiency of the EHD pump (Fig. 4). A shift of the maximum efficiency and its reduction are due to the "choking" of pumping at high levels of injection of bulk charge induced by the electric field and by the hydrodynamic drag of the pump.

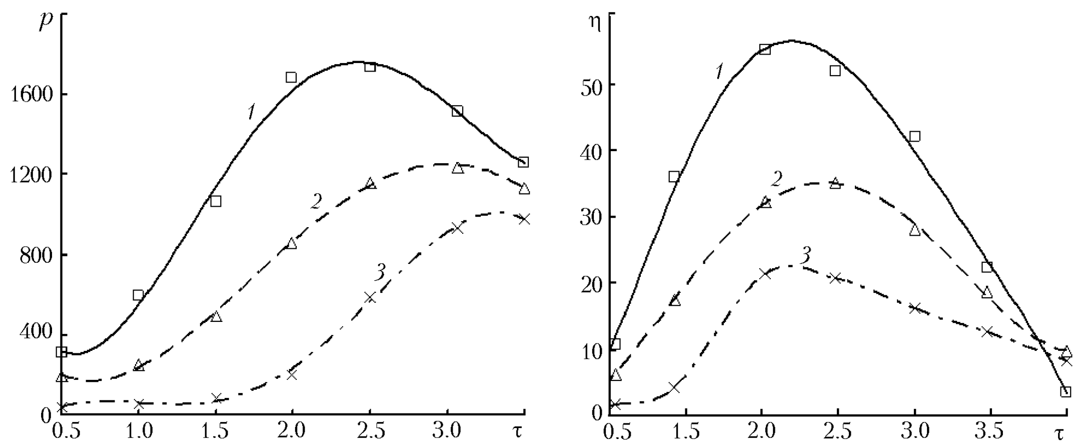

Fig. 4. Static pressure p of a three-electrode EHD pump (a) and its efficiency (b) vs. duration of the controlling pulse τ at a constant anode voltage (U_a = 30 kV): 1) U_g = 29; 2) 15; 3) 10 kV.

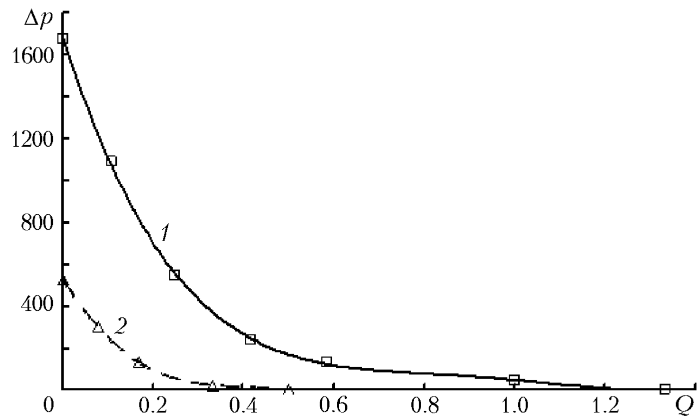

Fig. 5. Head-flow-rate characteristics of EHD pumps (U_a = 30 kV): 1) three-electrode system; 2) two-electrode system.

The head-flow-rate characteristics in the three-electrode structure are also substantially higher than the results obtained in the two-electrode system. The corresponding plots are presented in Fig. 5.

Thus, an analysis of the head-flow-rate characteristics of a three-electrode EHD pump shows its undeniable advantages over the traditional two-electrode structure. It is precisely in the proposed needle–ring structure with an additional ignitor electrode that we were able to obtain, in transformer oil, a static pressure of 1680 Pa and an efficiency of 55% (for an anode voltage of 30 kV). This is much higher than the values obtained in the existing prototypes of two-electrode structures in single- and multistage modifications. Furthermore, a three-electrode structure of an EHD pump requires lower operating voltages, which considerably simplifies its structural design, reduces cost, and extends the range of practical application.

NOTATION

p, static pressure, Pa; R, resistance, MΩ; T, pulse-repetition period, msec; U_a, anode voltage of the EHD pump, kV; U_g, grid voltage of the EHD pump, kV; Δp, difference of the pressures created by the EHD pump, Pa; η, efficiency, %; ρ, specific density, kg/m^3; σ, specific conductivity, S/m; τ, duration of a grid-voltage pulse, msec. Subscripts: a, anode; in, input; c, cathode; g, grid.

REFERENCES

1. G. I. Bumagin, Methods for improving the efficiency and unit power of the stage of EHD converters of energy, *Izv. Vyssh. Uchebn. Zaved.*, *Énergetika*, No. 3, 66–71 (1990).
2. Yu. M. Rychkov and A. E. Vasilevich, Intensification of electric convection of weakly conducting liquids by a pulsed electric field, *Inzh.-Fiz. Zh.*, **74**, No. 2, 106–108 (2001).
3. J. E. Bryan and J. Seyed-Yagoobi, Experimental study of ion-drag pumping using various working fluids, *IEEE Trans. Ind. Appl.*, **2**, 950–955 (1983).