Review
of the Ph. D. thesis of Vladimir A. Chirkov
entitled "Influence of Charge Formation Mechanism on the Structure of Electrohydrodynamic Flow in Highly Non-Uniform Electric Field"
submitted for the degree of Doctor of Philosophy in Physics
at the St. Petersburg State University

The dissertation of Vladimir A. Chirkov consists of 86 pages, including four original papers, introduction, the discussion of the results, conclusions, and acknowledgements.

The **aim** of the research is the comprehensive investigation of EHD flows in low-conducting liquids and revealing the peculiarities of their kinematic, force, and electric current structures under the injection and dissociation mechanisms of charge formation.

The heightened interest to EHD flows is explained by the fact that they present the method of the direct transformation of the electric field energy into the kinetic one. EHD flows are widely used in up-to-date knowledge-intensive technologies, and a number of applied devices (e.g., EHD pumps, heat exchangers, atomizers, and filters) are designed on the base of EHD phenomena. The possibility of using EHD flows both to practical purposes and as an object for fundamental research defines the **topicality** of the present work.

Owing to using up-to-date programs for numerical calculation of differential equation and carrying out computer simulation on the base of the aggregate of Poisson, Navier–Stokes, and Nernst–Planck equations, Vladimir A. Chirkov have managed to obtain a number of **new scientific results**. Solving the set of partial differential equations in COMSOL Multiphysics® is performed using the finite element method. The latter means, in particular, that all decision variables are described in the continuum approximation. It is the systems with highly non-uniform electric field distribution, which have become the focus of most part of works on computer simulation, since theoretical research for them is complicated. The validity of the results is provided by employing of proven software and methods for numerical calculations, high quality of the finite element grid, and the application of adaptive time step when solving time-dependent tasks. The choice of the numerical method for calculating non-linear unsteady equations is justified. The developed **new efficient technique** for simulation of EHD flows makes it possible to carry out the computer-aided design of applied EHD devices and substantially improve their characteristics.

The major results of the research:

- both the injection and dissociation mechanisms of charge formation can lead to the emergence of EHD flows that have the same direction, qualitatively similar structure and intensity;
- the structure of EHD flows caused by the Wien effect strongly depends on the voltage unlike the case of the injection charge formation;
- intensive EHD flows are steadier when they are caused by the dissociation mechanism of charge formation as opposed to the injection one when fluctuations of the lateral boundary of the charged area takes place;

- EHD flows can in fact emerge at a higher level of low-voltage conductivity due to the Wien effect unlike the case of injection.

The author showed that the zone of quasi-uniform flow in the central jet of EHD flow is specific only for the injection model, while the corresponding distribution in the field-enhanced dissociation model is non-uniform with the EHD flow structure strongly depending on the voltage.

The **theoretical value** of the results is as follows. The computer simulation data are compared with the experimental ones. The method of flow visualization with help of small particles was used for the investigation of the structure of EHD flow. The presence of a strong electric field (about 10 kV/cm) in the experimental cell and high non-uniformity of fluid velocity distribution are the main difficulties that impose a number of constraints on instruments and investigation methods to be used. The experimental study of EHD flows was carried out using a special test bench that makes it possible to visualize electroconvective flows, conduct their video recording and measure current–voltage characteristics. Recording of all data is carried out using the computer equipped with a video capture device and an analog-to-digital converter. The author has observed a satisfactory qualitative and quantitative agreement between the computer simulation results and the experimental data by the velocity distributions and the integral current characteristics. The numerical calculations let the author acquire a considerably greater amount of data, obtain distributions of unknown quantities in the entire domain, and to investigate both kinematic and dynamic structures in compare with the experimental research. Besides, it made it possible to study in succession the effects of various factors on the EHD flow structure.

The conducted research of EHD flows in a super non-uniform electric field showed that the emergence of the flows is interconnected with steep increase in the electric current, passing through the liquid. The analysis of obtained current–voltage characteristics let the author come to the conclusion that the corresponding growth of the current is both independent of the introduction of special impurities into the liquid and the voltage polarity. In turn, it allow making the conclusion that the steep increase in the electric current is independent of the injection and takes place due to the Wien effect. It is also indirectly indicated by the qualitative agreement between the dynamic current–voltage characteristic obtained in the experiment and in the simulation under the dissociation mechanism of charge formation.

The dissertation brought to a close the issue of the prevailing mechanism of charge formation leading to the emergence of EHD flows, and it was shown that both injection and dissociation mechanisms of charge formation can prevail depending on conditions. It should be especially noted that actually every significant statement or conclusion is thoroughly substantiated and justified in real experiments. The results of most actual and numerical experiments are presented graphically, which led to quite a large amount of figures in the work.

I acquainted with the contents of the dissertation during its implementation when it was presented on the a lot of scientific workshops, I was the department reviewer and took part in the preliminary presentation of the thesis. The following **remarks** should be noted. Firstly, the author presented no comparison in details between his results and those of the other researchers. And secondly, the design of actual EHD devices is absent from the thesis.

I consider that the dissertation on the whole unquestionably merits the positive assessment. It was performed on the topical subject, possesses considerable scientific novelty and practical value, and is distinguished by validity of the conclusions. The breadth of touched upon the issue in the dissertation and high level of their study let me come to the conclusion that Vladimir A. Chirkov is a highly skilled specialist in the field of electrophysics. The dissertation complies with the international standards for Ph. D. thesis in the corresponding field.

Vladimir A. Chirkov merits the awarding the PhD degree of Doctor of Philosophy in Physics at the St. Petersburg State University.

Professor Valeriy A. Pavlov
Department of Radiophysics
Faculty of Physics
St. Petersburg State University, Russia

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