БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ

ИНСТИТУТ ПО МЕХАНИКА

София 1113, ул. "Акад. Г. Бончев", бл. 4, тел: +359 2 717186, факс:+359 2 870 74 98,
E-mail: director@imbm.bas.bg

Review

on the PhD thesis of Mr. 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

This study is dedicated to the development of experimental investigation and numerical simulations of the coupling between hydrodynamics and the electric field, phenomena which fall within the electro-hydrodynamique. It is a topical area and since a few years, there is a growing interest in the studies not only from a fundamental point of view but also because of potentially technological advantages that may result of them (the flow control, EHD pumps, atomizer, for example).

Actuality of dissertation

Up to now there not such a systematic and completed theoretical and experimental study of the different mechanism of charge creation in dielectric liquids, in different geometry of the electrode, which mechanism is dominant, at what electric field strength. Most of the authors working in Electrohydrodynamic (EHD) field have been studied the convection and instability problem in plane horizontal geometry. There are a few studies in point plane geometry, which is more complicated, but more useful for the practice.

The English version of dissertation contains 2 chapters, being the first a comprehensive introduction and the main part, where is stating the conclusions. It also contains more than 14 figures and graphics that are very helpful to understand the text. It is well structured and well written.
The list of publications presented by the author includes: 4 articles, published in journals, 2 - in press; and 14 articles – in conference proceedings (4 – in English and 10 - in Russian).

Short description of the dissertation:

The *first* introductory chapter presents a detailed discussion of the Electrohydrodynamics basic concepts and equations. The candidate has made an extensive and comprehensive bibliographical search, which is *sufficient and logical* connected with the aim of the present study. It results in about 86 bibliographic references (more than 150 – in Russian version).

- The first paragraph is devoted to a presentation of the physical theory describing the EHD flows of dielectric liquids of low conductivity. For such a liquid the magnetic field effects could be neglected and mathematical model is considerably simplified. The two different conceptions of the mechanism of charge formation in the bulk of dielectric liquids of very low conductivity, existing in the literature, are discussed. The space charge induces the EHD flow can be created by ion injection, which occurs at liquid–metal interface for high enough electric potential and by the intensification of dissociation rate under the influence of the electric field. In the dissertation this basic problem is clarified by numerical experiments.

– In the following paragraphs are considered: the governing equations; different numerical techniques for solving EHD problems, presented by another authors (like the particle-in-cell method, the flux corrected transport one; the finite volume method (FVM) with different algorithms of discretization) and the finite element method, using by the candidate, as well as the experimental technique (particle image velocimetry and particle tracking velocimetry).

- The studies of EHD flows for different symmetry of the electrode system (symmetrical systems like plane–plane and wire–wire and non-symmetrical ones with highly non-uniform electric field distribution) are also briefly mentioned throughout the work already achieved.

- In the last paragraph the **main contributions** of the is presented.

Scientific novelties of the investigation of EHD flows in the dielectric liquids of low conductivity when the both mechanisms of charge formation (injection and dissociation one) take place, are clearly written. Here, the theoretical significance and the practical value of the present work, as well as its application in the education on EHD is also explained.

Chapter *two* is the main part, devoted to the experimental investigation and computer simulation of EHD flows in a needle–plane electrode system.

In the following paragraphs are presented: The governing equations, the two models of charge formation (the injection and dissociation one), the geometry of the computer model (needle–plane electrode system), respective boundary conditions as well as the simulation technique are explained. In the numerical simulation the 2D axisymmetric finite element model is used. I found that this method and using software is adequate and suitable for the axial symmetry of the system under consideration.

Special care is taken on the experimental technique. In the present study the PTV (Tracking Velocimetry method) is used and it is described in details.

The following general problems are considered:

1. The the behavior of EHD flows at unipolar injection into non-conducting liquid without recombination in the bulk. The structure of electrohydrodynamic (EHD) flows in a needle–plane electrode system using a numerical simulation and experimental analysis is carried out. All the characteristics of the flow (the velocity field with acceleration and deceleration zones, pressures, band structure, etc.) are calculated. The results obtained experimentally and numerically are in very good agreement.

2. The features of the formation of EHD) flows of low conducting liquids in nonuniform electric field in the needle–plane electrode system. The both mechanisms of charge creation, the injection (weak and strong) and dissociation ones are considered. The current–time characteristics of the transient process of stabilization of EHD flows are calculated.

3. The experimental study of EHD flows in pure Vaseline oil at highly non-uniform electric field, obtained by needle electrode. The current–voltage characteristics are resented. The most interesting results is a hysteresis of dynamic current–voltage characteristics at high voltage is found.

4. The numerical simulations of the current time characteristic in a cell of low-conducting liquid in the needle plane electrode system, taken into account the injection and dissociation mechanisms of charge creation.

Results

All the result of this complex investigation of the EHD flows subjected to electric field with created electric charge in the needle–plane geometry are very well presented in the dissertation. The numerical results show the complex structure that results from the coupling of the both, injection and dissociation mechanism of charge creation. They are in excellent agreement with the experimental observations done by the author.

The author presents many interesting, satisfactory and original results, which will be very helpful for those who are interested in experimental and numerical simulation of EHD problems. I would like to point out only someones. The candidate is succeeded to obtain very good agreement between experiment and calculations of the flow structure (see the stream function given in Fig.14).

It is notable the current-voltage and current-time characteristics have been obtained numerically taking into account the convective and ion drift mechanisms of charge transport as well as the Wien effect.

Contributions

The contributions of are clearly written in the first part of the dissertation and I'm agree with them. It is noteworthy the problems of: the dominant mechanisms of charge creation in the dielectric liquids of low conductivity in the needle–plane geometry, the comparison of convective and ion drift mechanism of charge transport as well as the conditions for simplified approaches of the models are clarified.

Some critical remarks:

The language is understandable, but some expressions are not well structured or not grammatically correct (the verb is missing).

For example: "The following confirms the dependability expressions of the obtained results", should be: "The dependability of the obtained results is confirmed by the ...". I think also that it is better to use "numerical simulations" instead of "computer simulations".

In my opinion the reference to the article A1 and A2 , which are in press, should not be used in the text. The critical notes do not change my positive evaluation of the present work.

Questions:

How and where in the simulations (see article P1) the electric Reynolds number - Re_{el} is used?

Conclusion

The the thesis work of Mr. **Vladimir A. Chirkov** is complete, comprehensive and rigorous, includes innovative aspects. The good knowledge of literature in the field is demonstrated and the adequate and suitable numerical method and experimental technique is used.

The scientific results are published in the journals and proceedings of specialized conferences in the field of *Electrohydrodynamics and Dielectric liquids.*

For all these reasons, and because of the quality of the presented work, I give **very favorable opinion to the dissertation to be defended** in order to obtain the degree of Doctor of Philosophy in Physics.

30.09.2013
Sofia, Bulgaria

Dantchi Koulova, *PhD, assoc. professor*
Institute of Mechanics
Bulgarian Academy of Sciences