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Submitted via email to Карпова Наталья n.karpova@spbu.ru and Чирков Владимир Александрович v.chirkov@spbu.ru

Regarding: Review of PhD thesis prepared by Vasilkov Sergei Andreevich
Thesis Title: Structure and Properties of Electrohydrodynamic Flows Caused by the Wien Effect
Specialization 01.04.13 — Electrophysics, electrophysical installations

The PhD Thesis is devoted to the computational modeling and experimental study of EHD flows in a dielectric medium. Specifically, the research focuses on the Wien effect, a flow mechanism caused by charge formation based on the field enhanced dissociation process. Although studied for almost 100 years since first identified by Max Wien, previous research was primarily theoretical based with several more recent studies focusing on computationally modeling the effect, more often the Wein effect is typically neglected in experimental research programs. The current research focuses on the coupling of the charge formation mechanisms with the induced electrohydrodynamic flow. Further, the study acts to help understand how the Wien effect can influence the injections charge formation process. The research undertaken was an elegant integration of computer simulation of the space charge distribution due to the Wien effect and the subsequent effect on the EHD flow. This was complimented by a novel experimental study that isolated the Wein effect for the more commonly researched electrode injections mechanisms. Combining the experimental and numerical findings, the candidate quantified the applicability of the Onsager theory through comparison of the flow structure and current-voltage characteristics of the system. The research has direct applicability in a number of engineering applications that can take advantage of the benefits of the EHD effect including EHD pumps, controllable EHD heat exchanger and atomizers and non-thermal food drying applications.

The introduction of the thesis outlines the relevance of the topic and clearly presents the research objectives and proposed contributions of the research. The literature review is sufficiently detailed to identify the current state of the art in experimentally measuring EHD flows and computer simulation methods used to model EHD including a detailed summary of the injection charge formation and the Wien effect. A summary of the challenges of using PIV to measure EHD flow and the potential of particles affecting the flow was briefly discussed. The critical review clearly presents the relevance of the thesis and scientific novelty of the work it defends. Chapter 2 reviews the mathematic models that describe the EHD phenomena including the EHD body force, charge, injection and dissociation and recombination theory with a focus on field enhanced dissociation. In addition, background in the computer simulations such as the commercial software package COMSOL used in the current research is discussed.

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Mr Andreevich discusses the stability criteria using the Peclet number <1 that is satisfied by the quality of mesh or by using a heightening of the diffusion. Although it is mentioned that when studying the Wein effect, the solutions are normally stable using the real diffusion coefficient in some cases the discussion coefficient "was heightened up to a hundred times to provide stability of the solution". The author states that this was verified but no details were provided regarding when the diffusion was heightened and how it was verified. The COMSOL calculation algorithm, boundary conditions and mesh design and mesh verification was well documented, however there was no mention of laminar or turbulence models (and coefficients) used in the flow simulation.

In Chapter 2.3 the complementary experimental research program is described in detail. The PIV method was discussed and noted that Borosilicate glass hollow microspheres (diameter of 10 μm) and the density of 1000 kg/m^3 were used as visualizing particles. Further, concentrations not exceeding 0.15 g/l based on the work of Daaboul [86] (who used SiO2) were selected. I recommend more detail regarding the selection of the seed particle and size be included in the manuscript. How did the density and dielectric constant (ε~4.6) of the seed particles compare with the liquid transformer oil (ε~2)? How were gravitational effects and dielectrophoretic determined to be negligible? Was a study done on the effect of particle concentration in transformer oil?

The results on the numerical simulations are presented in Chapter 3. Initially, the simulation focus on the more typically studied electrode geometry and EHD flow that is created in the near vicinity of the electrode via injection type flows, including or neglecting the Wien effect model to analyse the interdependence of the two mechanisms. In Chapter 3.2, a novel geometry that isolates the Wien effect is studied. This is accomplished by creating a region of increased electric field strength at a hole in a dielectric barrier between two plate electrodes. The simulations show that the Wien effect leads to EHD flows of the same velocity ranges as injection type flow mechanisms and that a transition region base on the liquids conductivity exists. The study revealed the transition region where the EHD flow is dominantly created by the charge-formation mechanism induced by injection changes to the regime where the EHD flow is primarily driven by the Wien effect, which for the transformer oil and cyclohexanol mixture was at the conductivity range from 10^{-10} S/m to 10^{-8} S/m. The EHD flow results from the CFD simulations in Chapter 3.2, which are caused the Wien effect, are compared to the experimental findings in Chapter 4 and are in general agreement. Comparing the velocity contours and streamlines from the simulation and the experiment show that the flow structure is similar and both show the interesting two oppositely charged jets that propagate along the dielectric barrier. Generally, the numerically predicted velocity values and currents are greater than experimentally measured ones by approximately ~10% in high-voltage regions, (Note: units legend in Figure 61). I believe that Mr Andreevich has successfully proven that for weak electrolytes the theoretical description of the Wien effect based on Onsager theory is applicable of the EHD flows. Although further work is needed to understand the flow differences in the low-voltage regions of the system.

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The thesis overall is clear and without shortcomings. Mr Andreevich has presented new and relevant information regarding EHD flows induced by the Wein effect and has successfully defended his primary thesis statements presented on page 7 of the thesis. I believe that this work has scientific novelty and provides an original contribution to knowledge and should thus be considered acceptable for publication and the partial fulfilment of the Ph.D degree completion of Mr. Vasilkov Sergei Andreevich. The thesis and published peer reviewed journals present evidence of rigour and introduced the appreciation for the wider field of scholarship. The thesis was well written and provides a clear and concise examination of important scientific and engineering phenomena relevant to the Specialization 01.04.13 — Electrophysics, electrophysical installations. The degree should be awarded for the thesis with some very minor revisions as suggested in the letter and that we can discuss during the defence.

Yours Sincerely,

James S. Cotton, Ph.D., P. Eng.,
Professor