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Abstract

Introduction
It is known that electric field can bring liquid in motion and thus influence heat transfer. One of early patents [1] depicts using this effect for power transformer cooling. There are two basic mechanisms:
Related to formation of charged species (similar to electric wind in corona discharges);
Electric forces acting on a polar or nonpolar liquid; related to relative permittivity which must be greater than unity for this effect to take place.
We will disregard ionization. Thus, the term EC is applied here only to the second mechanism.
Volumetric electric force acting on an incompressible linear dielectric is given by a formula (see [2]-[4]), in SI units:
f=((ε _r-1)ε_0)/2 ∇E^2 [N/m3]
The physical meaning of (1) is that the dielectric is pulled towards strong field. In the case of a liquid, the physics involved are fluid dynamics and electrostatics. This effect was observed in [5].
On the first sight, EC is always favorable for better cooling. However, to bring liquid in motion, energy from external source needs to be invested. This energy eventually transits to heat, which is explored in this work.

USE OF COMSOL MULTIPHYSICS®
We calculate heat transfer in a metal vessel filled by oil. Heat Q0 is generated by an internal body (an ellipsoid of revolution) sitting at a high potential V0 relative to the grounded vessel. The electrostatic problem is first solved using the Electrostatic interface. Electric field components determine the volume forces (1), in addition to gravitational forces. Then Laminar Flow with Heat Transfer interface is used. Thus, the problem is studied for low Reynolds numbers. The external cooling conditions are natural convection in air and radiation.

Results
Heat transfer was analyzed without electric field. Then V0=1V was applied. Both transient and steady-state solutions have been obtained for the above cases. The results were identical. Then HV was applied. Figure 1, Figure 2 show velocity profiles and temperature distribution for the cases without and with electric field, respectively. It is seen that electric field generates intense flow, while increasing maximum temperature. In absence of field, experiments show fair agreement with calculated temperatures.

Conclusions
The described method can be useful for understanding of electrohydraulic phenomena in liquids and gases. Turbulent flow and the mechanism of electrical energy conversion to heat as indicated by this study can be a subject of further modeling with COMSOL Multiphysics.

Reference

[1] F. J. Kaehni, Electro-Convection Cooling of Transformers and the Like", US Patent 2,748,356, Filed July 26, 1951.

[2] I.E. Tamm, "Fundamentals of the Theory of Electricity", 2003, p. 147 (11th ed., in Russian, 1st ed. 1929; multiple English translations available).

[3] J.D. Jackson, "Classical Electrodynamics", Wiley, 3rd ed., 1999.

[4] J. A. Stratton, "Electromagnetic Theory", McGraw-Hill, New York and London, 1941.

[5] E. Sher, A. Pokryvailo, E. Yacobson, and M. Mond, "Extinction of Flames in a Nonuniform Electric Field", Combust. Sci. and Tech., 1992, Vol. 87, pp. 59-67.

Figures used in the abstract

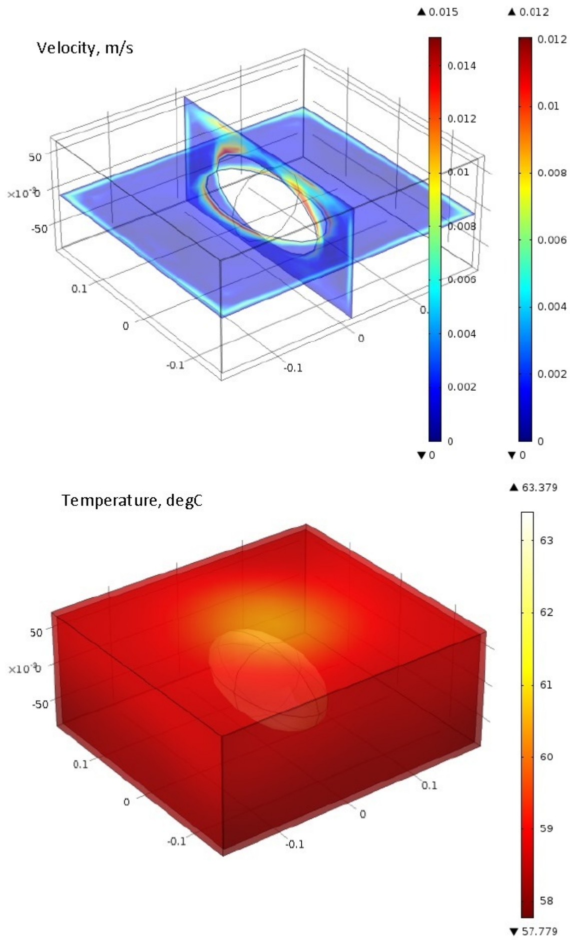

Figure 1. V0=0, Q0=150W. Ambient T0=23degC. Transient solution, Time=50000s.

Figure 1

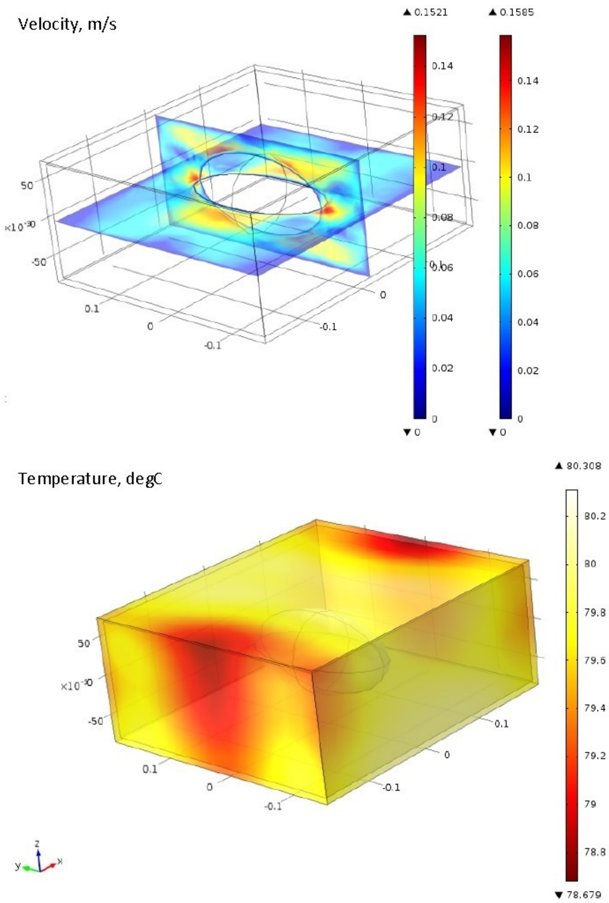

Figure 2. V0=80kV, Q0=150W. Ambient T0=23degC. Transient solution, Time=50000s.

Figure 2

$$f = \frac{(\varepsilon_r - 1)\varepsilon_0}{2} \nabla E^2 \text{ [N/m}^3\text{]} \quad (1)$$

Figure 3: Eq. (1)