Impact of Electro-Convection (EC) on Heat Transfer in Liquid-Filled Containers

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Introduction: Electro-convection (EC) can be caused by electric forces acting on a liquid, even in absence of space charge; thus, EC can influence heat transfer.

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

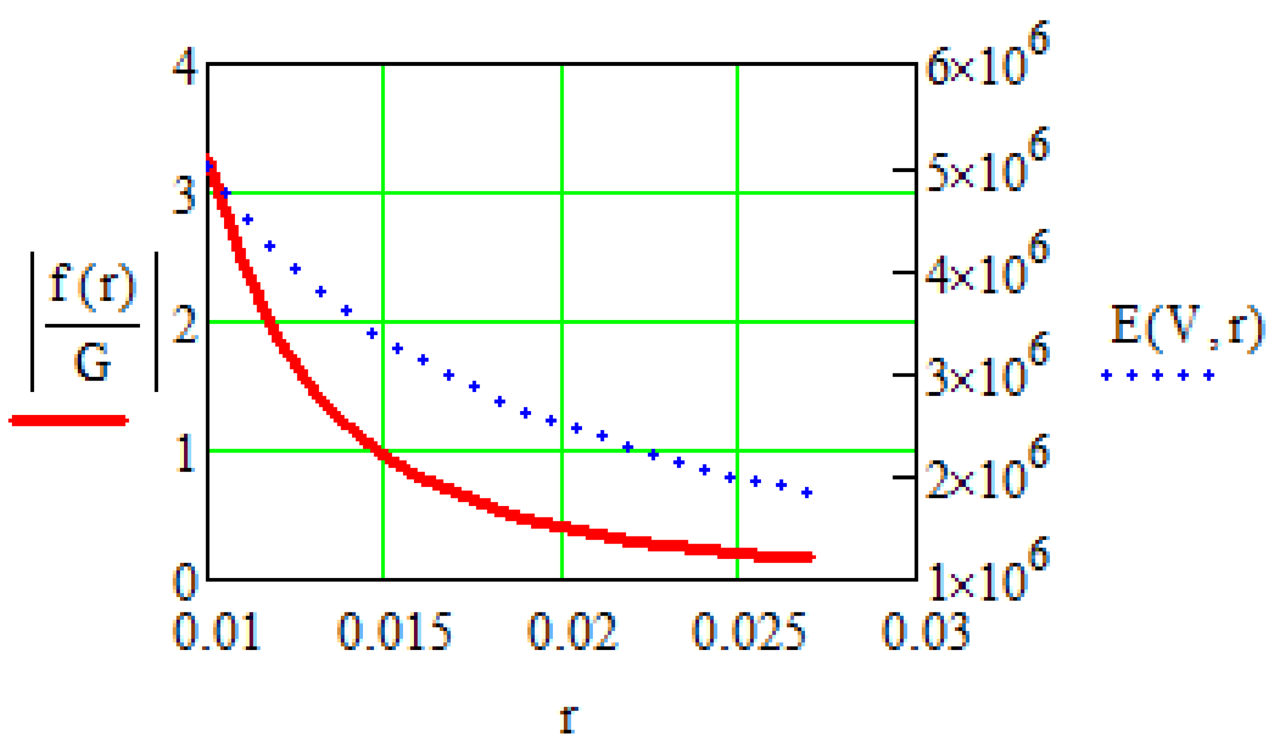

Figure 1. Ratio of electric force to specific gravity (G= $8.83\cdot10^3$ N/m^3) in oil between coaxial cylinders (red) and field E [V/m] for r_{in}=1cm, R_{out}=2.72cm, $\varepsilon_r = 2.3$, and V=50kV.

Computational Methods: Laplace equation is solved using the Electrostatic interface. Electric field components determine volume forces (1), in addition to gravitational forces. Then Laminar Flow with Heat Transfer interface is used.

$$\rho\frac{\partial \mathbf{u}}{\partial t}+\rho(\mathbf{u}\cdot\nabla)\mathbf{u}=$$
$$\nabla\cdot\left[-p\mathbf{I}+\mu\left(\nabla\mathbf{u}+(\nabla\mathbf{u})^T\right)\right]+\mathbf{F}$$
$$\frac{\partial\rho}{\partial t}+\rho\nabla\cdot(\mathbf{u})=0$$

$$\rho C_p\frac{\partial T}{\partial t}+\rho C_p\mathbf{u}\cdot\nabla T=\nabla\cdot(k\nabla T)+Q+Q_{vd}+Q_p$$

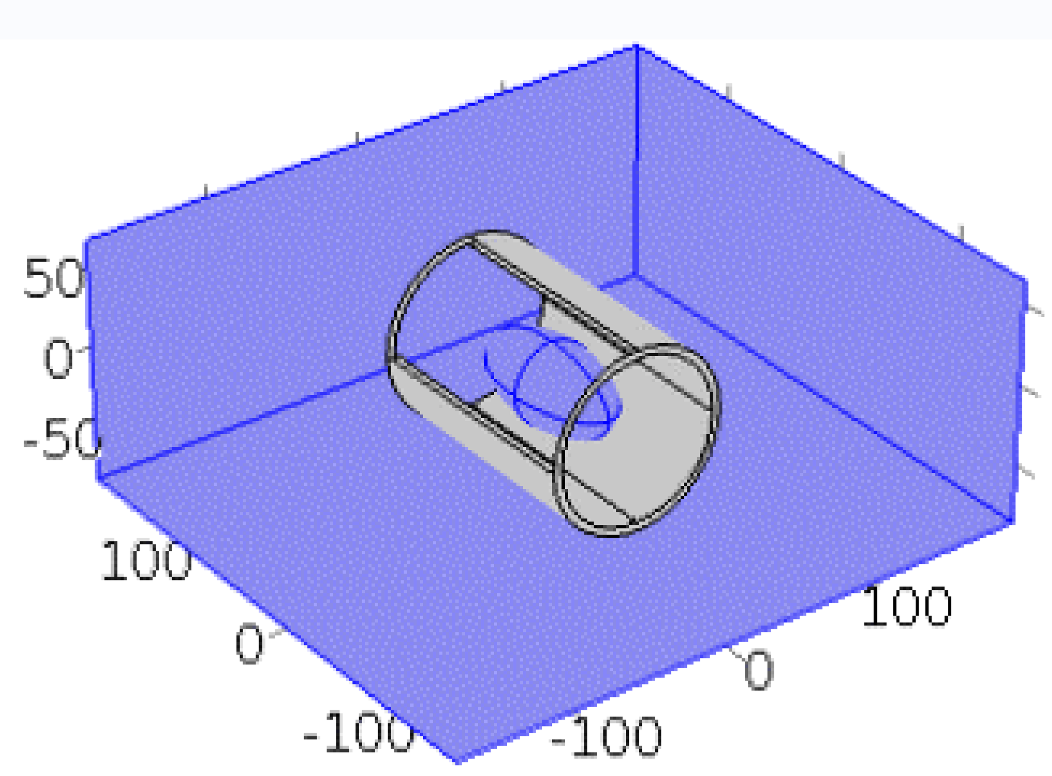

Figure 2. Metal vessel filled by transformer oil. Heat *Q0* is generated by ellipsoid sitting at a high potential *V0*. Optional dielectric cylindrical shell. Vessel cooled by natural convection and radiation.

Results: Electric field generates intense flow. Stronger flow is where HV electrode has larger curvature. ***Overall overheat MAY be larger in the presence of field (***depends on the HV electrode size and surroundings). The physical meaning is that losses are generated by viscous heating; energy for that must be supplied by the voltage source. Model experiments in absence of field show fair agreement with calculated temperatures.

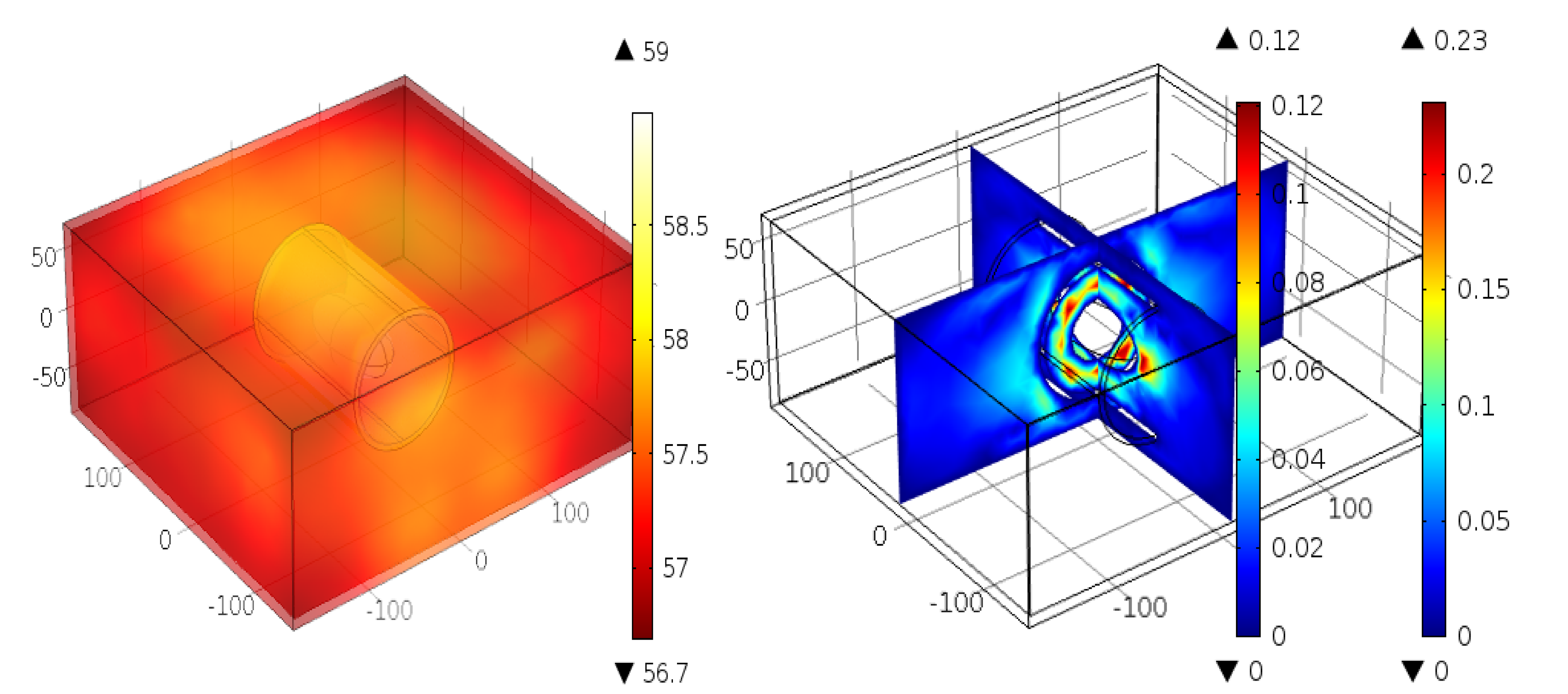

Figure 3. Temperature and velocity. Stationary solution. *V0*=80kV, *Q0*=150W. Dielectric cylinder ε_r=2.3.

Conclusions: EC in absence of ionization was simulated with multiphysics tools. The described method can be useful for understanding and simulating electrohydraulic phenomena in liquids and gases. Turbulent flow and mechanism of electrical energy conversion to heat can be a subject of further modeling. Experimental work can include measuring temperature and velocity, as well as consumed power.

References:

1. I.E. Tamm, "Fundamentals of the Theory of Electricity", 2003, p. 147 (11th ed., in Russian, 1st ed. 1929; multiple English translations available).
2. J.D. Jackson, "Classical Electrodynamics", Wiley, 3rd ed., 1999.