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Optimal control of dielectrophoretic force-driven flows

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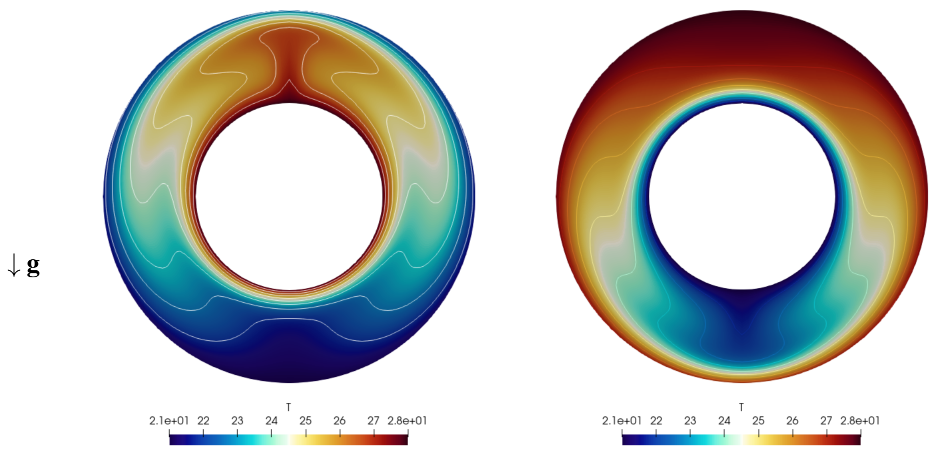
We investigate the feasibility of numerical optimal control methods to manipulate the hydrodynamical behavior of a dielectric fluid contained in a cylinder annulus under applied voltage and temperature gradient between inner and outer wall. A body force arises in this scenario, given as a superposition of the thermal buoyancy and the dielectrophoretic (DEP) force. The situation, which has diverse engineering applications in devices such as solar heaters, can be modeled by means of thermal electrohydrodynamical (TEHD) Boussinesq equations. This mathematical model is generally three-dimensional and nonlinear, requiring large computational resources. For the purposes of this study, we focus on a two-dimensional flow, which has been observed in the case of radial gravity without sufficient voltage to cause an instability [1]. Our numerical approach is based on the finite element method (FEM).

In the referenced scenario of a horizontal annulus, a stable jet forms at the top, along with a temperature increase in the same area. A similar jet forms at the bottom, where a temperature decrease is observed. The corresponding velocity magnitude of each jet increases with a voltage increase. We intend to showcase that a gradient-based boundary control algorithm derived in [2] for steady Boussinesq flows can be adapted to control this TEHD flow. Initially, we will test the method by using it to replicate a target velocity or temperature distribution. For instance, one may be interested in reversing the direction of heat transfer, as seen in figure 1. The corresponding quantity of interest to optimize in such a case is a regularized quadratic loss function. We will then extend the same approach to other theoretically and experimentally relevant quantities of interest, such as maximizing heat transfer or vorticity. We also intend to integrate a reduced-order model (ROM) into the workflow and explore its performance in terms of approximation accuracy and computational speedup.



(a) (b)

Figure 1: Temperature distributions and isolines for annular TEHD flows in a horizontal configuration with $\Delta T = 7\text{K}, V_{rms} = 7\text{kV}$. Heat transfer from inner to outer wall (a); from outer to inner wall (b).

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[1]Hamede, M.H. et al., *Physics of Fluids* **36.12** (2024).

[2]Chierici, A. et al., *Fluids* **7.6**, 203 (2022)