Hot plate

Numerical investigation of dielectric heating

F. Zaussinger, *Lehrstuhl für Aerodynamik und Strömungslehre, BTU Cottbus-Senftenberg*

In Short

- Electro-hydrodynamics
- Dielectric/Volumetric heating
- Power law for convection

Rayleigh-Benard (RB) convection has become one of the most important types of fluid-dynamical instabilities in the past century. The simple setup of a confined fluid layer between two thermalized plates allows the study of non-linear transport processes which occur in a variety of geophysical, astrophysical and industrial applications. Thermal convection occurs by temperature-induced differences in the buoyancy force, which also depends on the gravitational acceleration. In the absence of gravity other external body forces can be used to trigger convective flows. Electric and magnetic fields applied to dielectric and magnetic fluids are common candidates for that purpose. Especially electro-hydrodynamics (EHD) has become an important field in the last decades,[3]. Applying electric fields on dielectric fluids induce a directional acceleration field, also known as electric gravity $\mathrm{g_e}$. The strength of this acceleration depends on the electric field, fluid properties and geometrical aspects. It is used to manipulate fluids in the absence of the Earth's gravity and in many industrial applications e.g. in EHD thrusters and pumps,[1]. The triggering force in EHD is the dielectrophoretic force $\mathbf{F}_{\mathrm{DEP}} = 0.5\rho^{-1}\mathbf{E}^2\nabla\epsilon$, where ρ is the density of the fluid, $\mathbf{E}$ is the electric field and ϵ is the electric permittivity. This force is non-zero when the electric permittivity is not constant, but e.g. temperature dependent. A non-constant temperature field can be imposed by the boundaries, which represents the classical RB convection or by volumetric heating. The latter case is of special interest as many dielectric fluids are sensitive to dielectric heating, a volumetric heat source induced by the a.c. field. The principle of dielectric heating is used in microwave stoves and in many industrial applications like glass melting, foot processing and drying. However, dielectric heating may also lead to unpredictable hot spots and damages. In this study we focus on a generic setup in the plane capacitor, where dielectric heating and induced convection is investigated by means of direct numerical simulations.

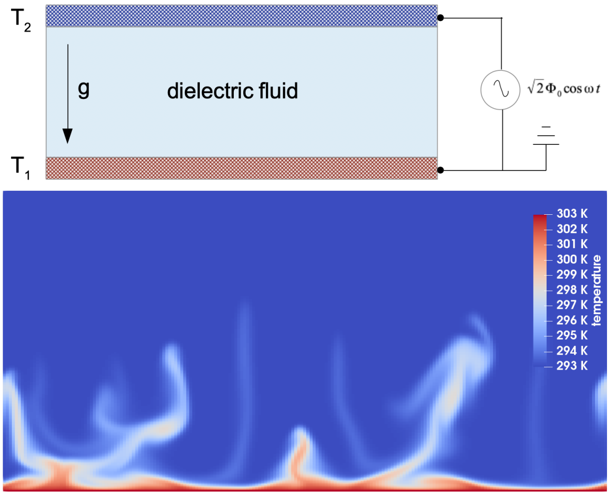

Figure 1: *(top) sketch of the dielectric heating model in the plane capacitor. (bottom) numerical simulation of EHD (without dielectric heating) with* $\mathrm{Ra_e} = 14.000$, *performed at the HLRN Berlin MPP1. The depicted value is the temperature after 5 seconds.*

Numerical tool

The governing thermo-electro hydro-dynamic equations are solved with the ANTARES (A Numerical Tool for Astrophysical RESearch) code, [2],[4]. Among several options it can solve the equations on an equidistant, three dimensional rectangular grid. It can also perform compressible hydrodynamic simulations with radiative transfer in all three spacial dimensions (HLRN project bbi00008). The source code is written in Fortran90 and In order to avoid high computational costs for global high resolution simulations, a local grid refinement is implemented, too. The order of spatial and temporal discretisation can be chosen arbitrarily. However, a 5^{th} order weighted essentially non-oscillatory scheme (WENO5) is favoured for the mentioned type of simulations. This scheme guarantees stable upwinding. The turbulent subgrid scales are modelled with a Smagorinsky subgrid scale model with a constant of 0.2. The parallel output is realised with HDF5 in version 1.8.16 on the HLRN Berlin MPP1, which is based on cray-MPI.

Open research questions and goal of the project

The main goal of this project is the investigation of a power law, which describes the Nusselt number as function of the Rayleigh number, $\mathrm{Nu} = \alpha \mathrm{Ra}_{\mathrm{T}}^{\beta}$, for EHD driven convection. Hereby, an alternative definition of the Rayleigh number is used, $\mathrm{Ra_e} = \frac{\epsilon_0(\epsilon_\mathrm{r}(\mathrm{T}_0)-\epsilon_\mathrm{r}(\mathrm{T}_2))^2}{\epsilon_\mathrm{r}(\mathrm{T}_0)}$, where ϵ_0 is the vacuum permittivity and ϵ_r is the relative permittivity. This definition differs from the classical RB convection, but fulfills the same requirements. Such a law is known for the classical RB, but not for the special case of EHD and dielectric/volumetric heating. Knowing a power law helps to extrapolate into Rayleigh number regimes, which are not achievable by recent numerical simulations. A coarse scan of the parameter space, which is spanned by the properties of the electric field, the fluid properties and geometrical properties will bring first insights. Two scenarios are foreseen: a) dielectric heating induced convection under micro-gravity conditions and b) dielectric heating induced convection under 1g conditions. Both cases represent important geophysical and industrial applications.

WWW

`www.b-tu.de/las`

More Information

[1] F. Zaussinger et al., Phys. Rev. Fluids, 3, 093501, 2018

[2] F. Zaussinger et al., Adv. Space Res., 60,6,1327-1344, 2017

[3] Mutabazi et al., Fluid dyn. Res., 48,6,061413,2016

[4] F. Zaussinger, PhD thesis, 2011