Benard-Rayleigh Convection In Thin Ring Layer

A. Fedotov[1], Y. Tsitavets[1], Y. Levy[2]

[1]Belarusian State University, Minsk, Belarus
[2]HiLASE Centre, Prague, Czech Republic

Abstract

Convective instability in a thin liquid layer is observed in many technical systems [1] and is of interest to the self-organization theory. To date, however, only simple problems with the convection between flat plates are well studied [2]. In real systems and devices, convective flows often happen in curved or cylindrical layers. The study of these cases will contribute to practical applications as well as basic theory.
In this work, the Benard-Rayleigh convection is addressed in 2 dimensions and in a thin ring layer with gravity perpendicular to the revolution axis. Rayleigh's numbers were kept in the range (1,5 - 4,4)·10^5. For air, these values are high enough to lead to a quick development of periodic convective cells and low enough to neglect the turbulent subgrid transport. The inner wall of the ring was overheated by ΔT in comparison to the outer wall.
COMSOL Multiphysics® provides a convenient interface for the finite-element computations suitable for solving fluid dynamics equations with heat transfer in Boussinesq approximation. For this purpose, preset equations in COMSOL Multiphysics® CFD Module and Heat Transfer Module can be used. Moreover, there is a possibility to track the movement of control fluid volumes with the idealized particles which velocity coincides with the velocity of fluid computed from Navier-Stokes equations. This allows the construction of phase portraits that provide valuable information on dynamic systems. Such functionality is implemented in the Particle Tracing Module.
The time integration of partial differential equations was performed with the 3rd order backward differentiation method and the solving of linear equations was carried out by PARDISO algorithm. Computational meshes included 10^4 - 10^5 elements condensing in the vicinity of walls.
It was established that convection in a ring layer can be separated by the character of the flow into four spatial regions: upper, transitional, lateral, and bottom. In the upper region classical Benard-Rayleigh cells are observed, in the transitional region the neighboring convective vortexes in cells become asymmetrical, in the lateral area there is a flow without the formation of stable structures. In the bottom region, there is only conductive heat transfer as the heated boundary is on top.
In the upper part of the ring layer, the phase portrait is similar to that observed in classic planar Benard-Rayleigh convection. In general, the upper, transitional and bottom regions of the ring layer are characterized by stable phase portraits with periodic envelopes. As one moves along the layer, the phase portrait becomes more chaotic with the most unstable behavior in the lateral region.

References
1. Lappa, M. Rotating Thermal Flows in Natural and Industrial Processes / M. Lappa. - 2012.
2. Borońska, K. and Tuckerman, Laurette S. Extreme multiplicity in cylindrical Rayleigh-Benard convection. II. Bifurcation diagram and symmetry classification, Phys. Rev. E 81, 036321 (2010)

Figures used in the abstract

Figure 1 : Particle positions and velocity magnitude in a stable vortex inside a classical Benard-Rayleigh cell

Figure 2 : Temperature distribution in top, transitional and lateral regions of ring layer after the establishment of a quasistationary regime

Figure 3 : Phase portrait in x, Ra = 220 000, classical Benard-Rayleigh cell

Figure 4 : Phase portrait in x, Ra = 220 000, in the different spatial regions of a ring layer: the violet color corresponds to the upper region, the blue color corresponds to the transitional region, the green color corresponds to the lateral region