Thermoconvective instabilities of a non uniform Joule-heated liquid enclosed in a rectangular cavity

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Abstract

The heating by Joule dissipation is employed in glass industry mainly for production of potentially volatile, polluting glasses, high added-value products and also for wool insulation. In this work, a numerical study is focused on a simplified model to mimic an electric glass furnace. Our investigation is limited to a two-dimensional enclosure with an aspect ratio equal to two. The energetic source is due to Joule dissipation produced by an electric potential applied with two electrodes corresponding of a fraction of the vertical walls.
The system of conservative equations of mass, momentum, energy and electric potential is solved with a finite element method. Three parameters are involved in the problem: the Rayleigh number Ra, the Prandtl number Pr and the electrode length Le normalized by the enclosure height.

The numerical method has been validated in a case where electrodes have the same length as the vertical walls leading to a uniform source term. The cutting of the electrodes from the bottom leads to a disappearance of the threshold of convection. At moderate Rayleigh number, the flow structure is mainly composed by a left clockwise rotation cell and a right anticlockwise rotation cell.
Numerical simulations have been achieved for a specific Le = 2/3 with Ra ∈ [1; 10 5] and Pr ∈ [1; 10 3]. Four kinds of flow solutions are established characterized by a two-cell symmetric steady-state structure with down-flow in the middle of the cavity for the first one. A first instability occurs for which a critical Rayleigh number depends strongly on the Prandtl number when Pr < 3. The flow structure becomes asymmetric with only one steady-state cell. A second instability occurs above a second critical Rayleigh number quasi-constant when Pr > 10. The flow above the second critical Rayleigh number becomes periodic in time. When Pr < 3, a fourth steady-state solution is established when the Ra is larger than the second critical value characterized by a steady-state structure with up-flow in the middle of the cavity.

Keywords: electric furnace, natural convection, instabilities, numerical simulation

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