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The lattice Boltzmann method for Mixed Convection in a Cavity

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Abstract

In this work, a numerical study of the laminar mixed convection in a opened square cavity is presented. Two opposite and staggered openings distributed over the two lateral walls are proposed with 20% size of the height of the cavity. The bottom wall being hot and all others are considered adiabatic. The lattice Boltzmann method with the double population thermal model was used. A computer code was developed with the D2Q9 model for the velocity field and D2Q5 for the temperature field to determine the whole structure of the flow. The results are presented in the form of hydrodynamic and thermal fields for the Richardson number Ri = 10, and are compared with results computing with one conventional method especially finite volume. The obtained results show good agreement between the two methods.

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Keywords: Lattice Boltzmann method, mixed Convection, opened square cavity, finite volume method

1. Introduction

The mixed convection heat transfer is by definition the coupling of two convection modes: natural and forced. This mode has received considerable interest from several researches, for technological applications such as: building ventilation, chemical deposition of thin films, the cooling of electronic parts, heat sinks in solar collectors and nuclear reactors.

Due to the practical importance of the study of heat transfer by convection mixed in the enclosures has attracted remarkable attention over the last decades. A large number of numerical studies based on conventional methods, were conducted on ventilated enclosures. The different configurations of the position of the openings are studied with an isothermal wall [1, 2] or a wall heated with a heat flux [3].

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Other numerical and experimental studies [4, 5] treated the effect of the geometry of an obstacle like the source of heat inside the cavity in order to maximize the total conductance. The position of the air entry and the exit has a great effect on the hydrodynamic and thermal structures [6]. One cavity that has several entries [7] improves its ventilation. In this work, a numerical contribution with a thermal lattice Boltzmann method in this domain is proposed.

The lattice Boltzmann method (LBM) [8] is a relatively new and original numerical method that has emerged in last years. Its interested, neither at the macroscopic quantities: velocity, pressure and density resolved by Navier-Stokes equations, but directly by the distribution of different particles constitute a fluid in the study domain. This approach is called a mesoscopic representation. What makes it competitive with other conventional methods such as finite volumes, finite elements and finite difference. This method is based on the lattice gas method with the theory of cellular automata [9] and on the formalism of statistical physics. It is important to situate its performance compared to conventional numerical methods to simulate and reproduce the isothermal or thermal fluid flows.

The thermal lattice Boltzmann model (TLBM) [8] with Bhatnagar, Gross and Krook (BGK) approach [10], In general, can be categorized into two types [11]. The first one is the multi-speed approach and the second one is the passive scalar model. The major advantage of the passive scalar model over the multi-speed approach is the enhancement of numerical stability, and this last is commonly adopted. In the passive scalar thermal lattice Boltzmann models [11, 12], a separate distribution function is used to solve the temperature distribution.

The study presented in this work, is a numerical contribution of mixed convection flow in a square cavity with two openings. The inner walls of the latter are assumed adiabatic except for the one on the down side, it is considered isothermal. The thermal model of the Lattice Boltzmann method on double population in two dimensions is applied. The nine-speed lattice (D2Q9) is used to reproduce the dynamic field, and the five-speed lattice (D2Q5) is used for the temperature field. Thus, a rigorous comparison of the velocities fields and temperature should be conducted between: the conventional approach specially the finite volume method (FVM) and that of Boltzmann method. This will allow us to determine the performance of this new numerical method in this area.

2. Physical description of the problem

The model chosen is a square cavity of height H with two ventilation openings, the first located in the lower left corner side L1 and the second located in the upper right side L2= L1= L=20% H. The walls of this cavity are adiabatic except the lower wall which is maintained by a source of heat at a constant temperature Th. The air enters through the left wall opening with a temperature T0 and a uniform velocity U_{inlet} as fig.1 shows it. The assumptions used are summarized in the case of an incompressible and Newtonian fluid. The flow is laminar, stationary and in two dimensions satisfying the Boussinesq assumption. We neglect a heat transfer by radiation and the heat dissipation by effect of viscosity.

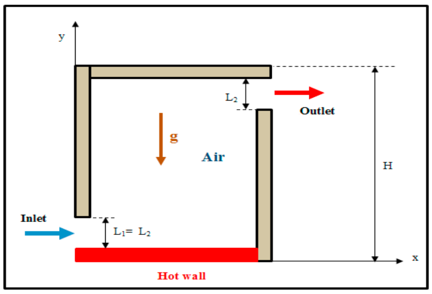

Fig.1. Configuration of the physical problem

The classical equations governing the flow are the continuity equation, the momentum equation and the energy equation. The characteristic parameters for the flow are the Prandlt number $Pr=\nu/\alpha$, the Richardson number $Ri=Gr/(Re)^2$, with Grashof number $Gr=(\beta\Delta tgH^3)/\nu^2$ and Reynolds number $Re=LU_{inlet}/\nu$. In this work, the mesoscopic description is used with lattice Boltzmann method.