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Develop the nano scale method of lattice Boltzmann to predict the fluid flow and heat transfer of air in the inclined lid driven cavity with a large heat source inside, Two case studies: Pure natural convection & mixed convection

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HIGHLIGHTS

- Develop LBM performance to simulate the heat flux of heat source.
- Natural convection and mixed convection of inclined driven cavity by LBM.
- Modify collision operator and macroscopic velocities equations in LBM.

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ABSTRACT

Nano scale method of lattice Boltzmann is developed to predict the fluid flow and heat transfer of air through the inclined lid driven 2-D cavity while a large heat source is considered inside it. Two case studies are supposed: first one is a pure natural convection at Grashof number from 400 to 4000 000 and second one is a mixed convection at Richardson number from 0.1 to 10 at various cavity inclination angles. Using LBM to simulate the constant heat flux boundary condition along the obstacle, is presented for the first time while the buoyancy forces affect the velocity components at each inclination angle; hence the collision operator of LBM and also a way to estimate the macroscopic velocities should be modified. Results are shown in the terms of streamlines and isotherms, beside the profiles of velocity, temperature and Nusselt number. It is observed that the present model of LBM is appropriately able to simulate the supposed domain. Moreover, the effects of inclination angle are more important at higher values of Richardson number.

1. Introduction

Various particle base methods like lattice Boltzmann method (LBM) have been introduced by now to simulate the fluid flow. In general, all particle base methods like molecular dynamic (MD), direct simulation of Monte Carlo (DSMC) or LBM

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Nomenclature

e	Internal energy
f	Hydrodynamic distribution function
g	Thermal distribution function
$\mathbf{g}$	Vector of gravity
Gr	Grashof number
H	Cavity height
L	Cavity length
Nu	Nusselt number
q	Heat flux
Re	Reynolds number
Ri	Richardson number
Tc	Cold wall temperature
$\mathbf{u}$	Vector of macroscopic velocity
$U0$	Upper wall velocity
(U, V)	Velocities in dimensionless forms
(X, Y)	Coordinates in dimensionless forms

Greek symbols

ρ	Density
γ	Cavity inclination angle
υ	Kinematic viscosity
θ	Dimensionless temperature

can be implied at different flow regimes including MEMS and NEMS; however using MD and DSMC would be much time consuming at macro or even at micro scales. As a result, LBM usage has increased in recent decade; and a great number of works can be addressed to improve LBM ability at macro, micro or nanoscales [1–15].

In addition, LBM is based on first-order PDE Boltzmann equation, which makes its discretization and coding easier than using the well-known Naiver–Stokes approach. Moreover, the pressure field is directly achieved by LBM with no more need to other equations. It means LBM would be more useful to simulate the more complex or multi-phase flows in comparison with SIMPLE algorithm approach [16–33].

LBM works based on the collision and streaming between the virtual particles located on the nodes of a lattice at each time step. To do this, the Boltzmann equation is defined according to the microscopic density–momentum distribution function of "f" so that all other macroscopic variables can be achieved simply through it [34–56].

Various models of LBM have been developed to simulate the thermal domains. Among them, double population distribution functions model, showed more desired performance in both aspects of accuracy and convergence. In this way, a separate distribution function of "g", called internal energy distribution function, was introduced for the temperature field, which was defined according to density–momentum distribution function of "f" [57–71]. However, there are still several drawbacks in different presented models of LBM such as weak convergence procedure or undesired accuracy at different boundary condition models in the form of LBM approach. In addition, LBM is a compressible way for the ideal gases, which means the incompressible flows can be modeled by this way at near incompressible limit (low values of Mach number). Therefore, LBM would be encounter to compressibility error at higher values of Mach number. These mentioned facts beside some other minor ones, have made researchers to work on LBM and improve its performance in different aspects as like developing the better boundary condition models or using a suitable collision operator like BGK model or even introducing appropriate models of relaxation times to increase convergence. The last object leads to apply LBM for the fluids with higher Prandtl number as like the nanofluids [72–89].

2. Problem statement and present work novelty

Fluid flow and heat transfer of air ($Pr = \upsilon/\alpha = 0.7$) through the inclined lid driven 2-D cavity is studied by the nano scale method of LBM while a large heat source is considered inside it (Fig. 1). Upper and lower walls of the obstacle are imposed by a constant heat flux of q''_0. Moreover the aspect ratio of cavity equals to $L/H = 3$ and its sidewalls are adiabatic.