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The investigation of thermal radiation and free convection heat transfer mechanisms of nanofluid inside a shallow cavity by lattice Boltzmann method

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HIGHLIGHTS

- The new case study on the nanofluid thermal radiation using LBM.
- Nanofluid thermal radiation together with free convection in cavity.
- Emissivity effects while walls are gray diffuse radiation emitter & reflector.

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ABSTRACT

This paper aims to simulate the interaction between thermal surface radiation and nanofluid free convection in a two dimensional shallow cavity by lattice Boltzmann method. The supposed nanofluid is generated by a homogeneous mixture of water and nanoparticles of Al_2O_3. The upper and lower walls of cavity are maintained at cold and hot temperature, respectively; while the side walls are kept thermally insulated. The cavity aspect ratio is chosen as 5 which indicates a shallow one. The cavity all inner surfaces are considered as the gray diffuse emitters and reflectors of radiation. The computations are performed for the wide range of parameters as $\mathrm{Ra} = 10^4$ and $\mathrm{Ra} = 10^5$; $\varepsilon = 0.5$ and $\varepsilon = 0.9$ while nanoparticles volume fraction changes between $0.0 \leq \varphi \leq 0.04$ at each case. As a result, the effects of emissivity and Rayleigh number are studied on the total heat transfer of radiation and free convection of nanofluid. The suitable validations are examined beside the useful grid study procedure. The results are presented as the profiles of velocity and temperature and also the streamlines and isotherms. Moreover the local and averaged Nusselt numbers are provided for the coupled and uncoupled states of radiation and free convection heat transfer mechanisms. It is seen that Nu_m of total free convection and radiation would be more at higher Ra and ε; which indicates that radiation heat transfer coupled with free convection might affect the flow field and improve the Nusselt number.

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Nomenclature

AR	Cavity aspect ratio (=L/H)
B_c	Boltzmann constant (=1.3807×10^{-23} J K^{-1})
c_p	Specific heat (J/kg K)
d_f	Molecular diameter of the base fluid (nm)
d_p	Nanoparticles diameter (=10 nm)
E	Emissive power (W m^{-2})
f	Hydrodynamic distribution function of LBM
F	Configuration factor
g	Thermal distribution function of LBM
H	Cavity height (m)
k	Thermal conductivity (W/m K)
L	Cavity length (m)
L_{BF}	Mean free path of the base fluid (nm)
Nu	Nusselt number
Pr	Prandtl number
q	Heat flux (W m^{-2})
Ra	Rayleigh number
T	Temperature (K)
u	Horizontal velocity (ms^{-1})
U	Dimensionless horizontal velocity
v	Vertical velocity (ms^{-1})
V	Dimensionless vertical velocity
x	Horizontal Cartesian coordinate (m)
X	Dimensionless horizontal Cartesian coordinate
y	Vertical Cartesian coordinate (m)
Y	Dimensionless vertical Cartesian coordinate

Greek symbols

α	Thermal diffusivity (m^2 s^{-1})
ε	Emissivity
σ	Stefan Boltzmann constant (=5.67×10^{-8} W m^{-2} K^{-4})
φ	Volume fraction of nanoparticles
μ	Dynamic viscosity (N s m^{-2})
θ	Dimensionless temperature
ρ	Density (kg m^{-3})
υ	Kinematic viscosity (m^2 s^{-1})

Subscripts

con	Convection
f	Fluid
j	jth element
k	kth element
m	Averaged
nf	Nanofluid
out	Outgoing
rad	Radiation
s	Solid
x	Local value in X-direction

1. Introduction

Fluid flow and heat transfer in cavities play important roles in several applications such as solar collectors which attract many researchers. Therefore many works can be addressed for the convection heat transfer in enclosures at various