Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(6) (2018) 415-418
DOI: 10.22060/mej.2017.12686.5396

Investigating the Effect of Radiation Scattering and Surface Emission on Combined Convection Heat Transfer in an Enclosure with Moving Insulation Surface

N. M. Bazzi Nasab, S. Payan*

Department of Mechanical Engineering, University of Sistan and Baluchestan, Zahedan, Iran

ABSTRACT: In most cases, the effect of radiation is not taken into account in enclosures in which convection is taking place. However, this needs to be addressed given the many applications of radiation, including nuclear reactor design, furnaces, electrical coolers, and solar collectors. The combined convection-radiation heat transfer on the moving surface of a square enclosure with laminar flow and gray surfaces, absorber, emitter, and radiation isotropic scattering was solved by the finite volume method. The effects of scattering and emissivity of the cold wall on heat transfer, streamlines, and isothermal lines were investigated. All walls were assumed to be black surfaces except for the one on right. The radiation problem was solved by the discrete ordinates method and the absorption coefficient was assumed to be fixed at 0.1. The SIMPLER method was employed in the convection problem given the correlation of velocity and pressure fields, while the power law method was used to investigate the significance of convection and diffusion terms. The results showed although scattering does not significantly affect streamlines and ambient temperature, it reduces the heat flux through the wall thus lowering the radiation flux. The major difference in surface reflection and scattering is in the temperature distribution at the center of the enclosure away from the surface which is evident despite the change in reflection. Moreover, the greater influence of scattering on local radiation and convection Nusselt number on the lower insulation surface was shown, suggesting the cooling of the insulation surface with changing of scattering at a fixed absorption coefficient.

Review History:

Received: 23 March 2017
Revised: 19 July 2017
Accepted: 6 September 2017
Available Online: 7 September 2017

Keywords:

Combined convection
Participating media
Discrete-ordinates method
Square enclosure

1- Introduction

Combined convection with fluid motion by a moving surface together with radiation has many applications, including nuclear reactor thermal hydraulic, heat exchangers, electrical equipment cooling, furnaces, lubrication technology, solar collectors, fuel cells etc. Therefore, convection and radiation heat transfer in enclosures has attracted much attention in recent years. Fiveland [1] addressed thermal radiation in rectangular enclosures by the discrete-ordinates method, concluding that the prediction of the rate of radiative heat transfer using the discrete-ordinates method yields more accurate results compared to the P3 and zone methods. Mahapatra et al. [2] investigated the interaction of combined convection in a square enclosure with two, moving, hot and cold surfaces with radiation, concluding that the effects of radiation are significant when the emissivity is increased and the scattering is decreased. Belmiloud [3] addressed the combined convection-radiation in a transparent media and claimed that convection heat transfer is reduced as the emissivity is increased. Roy et al. [4] investigated the combined heat transfer in square enclosures and the influence of moving walls on heat transfer rate and streamlines distribution. None of the previous researchers have addressed the impact of scattering in combined convection problems incorporating a moving insulated surface coupled with radiation from a participating media at small optical thicknesses. Moreover, the effect of emissivity of the cold wall on heat transfer from the enclosure was studied that was not previously addressed in the literature. The impact of scattering on the local Nusselt number of enclosure walls was also examined in this study. Although Mahapatra et al. [2] have investigated the effect of radiation scattering in an enclosure that consists of moving surfaces, the moving surfaces they considered were cold and hot surfaces and not insulated surfaces. As stated by Roy et al. [4], the movement of any of the active or inactive surfaces has a different effect on heat transfer. In addition, Belmiloud [3] focused on surface emission and did not consider the volumetric effect of radiation (participating media), hence, absorption and scattering were not examined.

Corresponding author, E-mail: s_payan_usb@eng.usb.ac.ir

2- Problem Description

A square enclosure with insulated top and bottom surfaces, hot left side (at T_h) and cold right side (at T_c) was considered (Fig. 1). The top side of the enclosure moves to the right, resulting in combined convection heat transfer. The radiative participating media in this study was assumed. The effect of scattering and the emissivity of the cold surface were investigated. The adiabatic and the hot surfaces were assumed as black bodies.

2- 1- The governing equations and boundary conditions

The equations governing combined convection coupled with radiation from the participating media are presented in dimensionless form assuming Newtonian, incompressible fluid in two-dimensional steady-state laminar flow, using the Boussinesq approximation. Eqs. (1-4) are conservation of mass equation, momentum equation in the X direction, momentum equation in Y direction and energy equation, respectively.

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \tag{1}$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \tag{2}$$

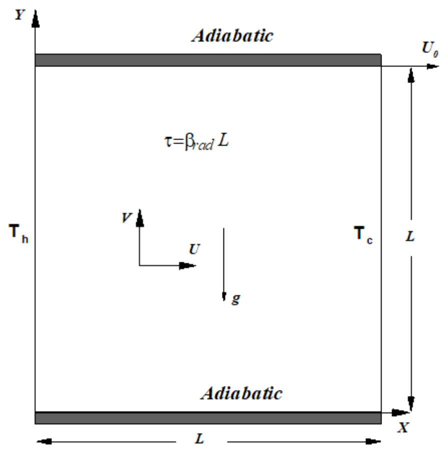

Fig. 1. Schematic figure of a lid driven square cavity

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+Ri\times\theta \tag{3}$$

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{1}{\mathrm{Re}\times\mathrm{Pr}}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right)-\frac{1}{\mathrm{Re}\times\mathrm{Pr}\times Pl}\nabla^*\bullet Q^*_{rad} \tag{4}$$

The energy and momentum equations will be linked by the Boussinesq approximation.

$$\rho=\rho_0(1-\beta(T-T_0)) \tag{5}$$

In order to solve Eq. (4), it is necessary to calculate the thermal source term from Eq.(6).

$$\nabla^*\bullet Q^*_{rad}=\tau(1-\omega)((\theta/\theta_0+1)^4-G^*) \tag{6}$$

where $G^*=\int_{4\pi} I^* d\Omega, \omega=\frac{\sigma_s}{\beta_{rad}}$

$$I_p^m=\frac{\mu^m A_x I_W^m+\xi^m A_y I_S^m+(S_{bp}+S_p^m)V_p}{\mu^m A_x+\xi^m A_y+\gamma\beta_{rad}V_p} \tag{7}$$

It is evident that, in order to solve the radiation source term, it is necessary to calculate the radiation intensity which is done by solving the two-dimensional radiation equation in a gray medium under steady-state conditions using the discrete ordinates method [1], yielding Eq. (7). Where μ and ξ are directional cosines with respect to X and Y axes.

Heat flux (zero at the moving (top) surface and the bottom (insulated) surface) on enclosure surfaces is nondimensionalized as follows. Moreover, θ is 0.5 on the hot (left) wall, and -0.5 on the cold (right) wall.

$$Q^*_{tot}=-\nabla^*\theta+\frac{\theta_0}{Pl}Q^*_{rad} \tag{8}$$

3- Results and Discussion

A square enclosure with adiabatic surfaces at the top and bottom was considered (Fig. 1). All surfaces were assumed to be black bodies except for the cold surface which was assumed to have a different emission coefficient. The top adiabatic wall moves to the right at a fixed velocity of U_0. The effect of combined convection coupled with radiation from the participating media was investigated in this enclosure. Fig. 2 shows the impact of the emissivity and scattering on the mean Nusselt number of the cold wall at a Richardson number of 10. Increasing the emissivity from 0.1 to 1.0, and reducing the scattering from 0.4 to 0, the mean Nusselt number is increased on the cold wall. Moreover, increasing the Richardson number (increasing the natural convection effect), the mean Nusselt number on the cold wall is significantly reduced.

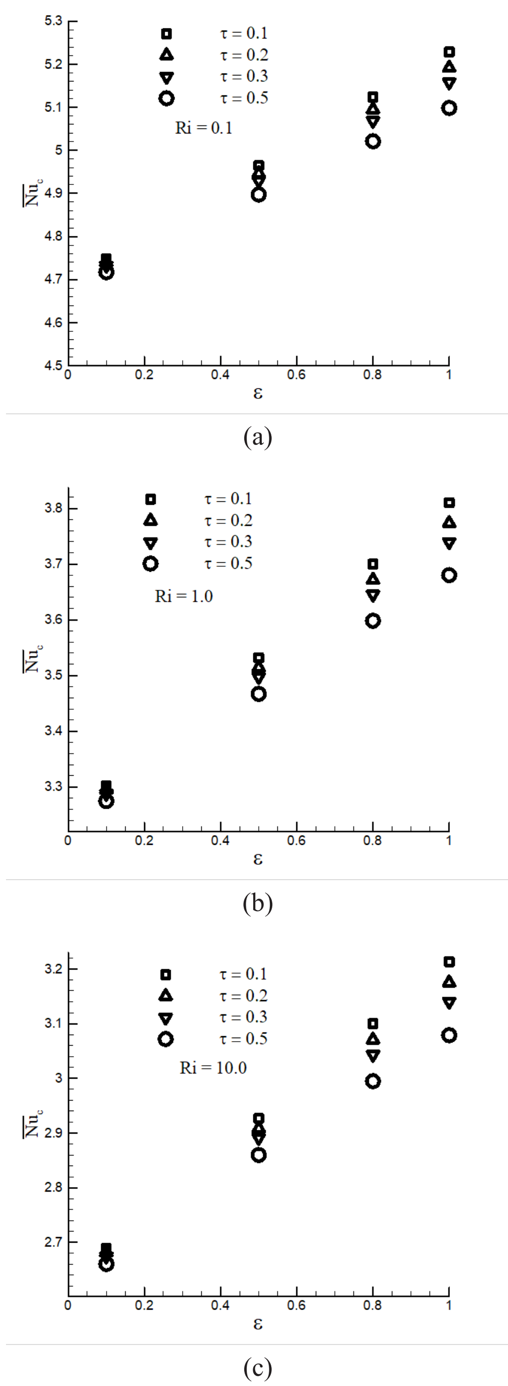

Fig. 2. Effect of scattering and emissivity on cold Nusselt number; a) *Ri*=0.1 , b) *Ri*=1.0 , c) *Ri*=10

4- Conclusions

1. The mean Nusselt number of the enclosure is reduced by increasing the Richardson number, reducing the emission coefficient, and increasing the scattering.
2. The impact of scattering at the Richardson number of 10 is more compared to the case with Richardson numbers of 1.0 and 0.1. The impact of scattering on heat flux is intensified as the emissivity is increased.
3. Surface reflection is more effective on the distribution of temperature at the center of the enclosure compared to scattering.

References

[1] W. Fiveland, Discrete-ordinates solutions of the radiative transport equation for rectangular enclosures, *Journal of heat transfer*, 106(4) (1984) 699-706.

[2] S. Mahapatra, P. Nanda, A. Sarkar, Interaction of mixed convection in two-sided lid driven differentially heated square enclosure with radiation in presence of participating medium, *Heat and Mass Transfer*, 42(8) (2006) 739-757.

[3] M.A. Belmiloud, N.E.S. Chemloul, Numerical Study of Mixed Convection Coupled to Radiation in a Square Cavity with a Lid-Driven, *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, 9(10) (2015) 1815-1821.

[4] M. Roy, S. Roy, T. Basak, Role of various moving walls on energy transfer rates via heat flow visualization during mixed convection in square cavities, *Energy*, 82 (2015) 1-22.

Please cite this article using:

N. M. Bazi Nasab and S. Payan, Investigating the Effect of Radiation Scattering and Surface Emission on Combined Convection Heat Transfer in an Enclosure with Moving Insulation Surface, *Amirkabir J. Mech. Eng.*, 50(6) (2018) 1289-1302.

DOI: 10.22060/mej.2017.12686.5396