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Radiation Effects on Turbulent Heat Transfer Characteristics in Vertical Channel

T. Anvesh, R. Harish

***Abstract**: In this study we concentrated on the radiative turbulent air to enter into the convective vertical channel. The vertical channel is having two openings at top and the bottom. The radiation is modelled with discrete ordinates method and turbulence is modelled with computational fluid dynamics (CFD) approach using Lambremhorst turbulence model. The governing equations are solved and discretized by using Finite Difference Method (FDM). The parametric study is performed on Assisting and opposing cases by comparing both the cases with the radiation and without radiation in the channel and found that temperature and velocity characteristics have much impact when the channel is involved with radiation*

***Keywords**: lambremhorst Turbulence, Assisting flow, Opposing flow, Discrete ordinates method.*

I. INTRODUCTION

Heats transfer an important phenomenon which is benefitting the world since decades. Many scientists, scholars worked enormously for better understanding of heat transfer. Heat transfer generally arises due to temperature variations. Convection and Radiation are the two important aspects which are classified from the heat transfer by the phase changes. In this study a computational fluid dynamics approach is sued to model the turbulence and radiation.

Breuer et. al [1] worked on large eddy simulations (LES) Approach got to a point that simulation with high global mass loadings the cpu time required from the collision detection and handling took less 10% of computational result are compared with experimental measurements and received a decent match Hamimid et. al [2] worked on combined natural convection and radiation for high temperatures found that the radiation exchanges reduce the satisfaction at the cavity center and intensifies the floe near the wall. Shirvan et.al [3] performed a numerical investigation and got to a point that increasing the Rayleigh number (Ra) increases the vortices and makes the flow to clockwise direction and also by increasing surface emissivity the vortices in the streamlines become more intensive and gap between isothermal lines on the surface wall increases. Martyushev et.al [4] worked on 3 d regions of natural convection and surface radiation and got to a point that when passing from 2D to 3D problem. It has shown the growth of surface emissivity's regardless of Rayleigh number also shown that most important distinction in the structure of core of the local processing parameters are raised to higher Rayleigh number and emissivity's. Cheng et.al [5] performed work on thermal radiation and natural convection with turbulence in vertical channel concluded that the ratio of radiative to the convective heat power shows its minimum at heated a wall temperature of 80^0 C. The convective heat transfer is stronger near the channel inlet. Tkachenko et.al [6] also worked on the channel wall by introducing turbulent natural convection and radiation found in the study that turbulent statistics have changed decently by resulting in delayed transition to turbulence near the active wall of channel and increased turbulent activity near the cold wall. Andreozzi et.al [7] found that the insertion of an auxiliary plate and the two insulated plates extensions covers Optimal channel specifications. This converts into the increases of convective heat transfer. Guojun et.al [8] used discrete ordinates method two radiative heat transfer equation and concluded that the convective temperature of cooling air has less influence on dimensionless temperature distribution. Akiyama et.al [9] found that the results show the surface radiation impacted very much on flow patterns temperature distribution at higher Rayleigh number. The average Nusselt number on radiation rises quickly with increase of emissivity Kayne et. al [10] has worked to assess the modelling requirements and accuracy of computational fluid dynamics using Reynold Averaged Navier Stokes (RANS) equation and made a good comparison between the computational and experimental was obtained from velocity and temperature inside the atrium. The motto of this study is to introduce the turbulent radiative air inside the vertical channel with convection process inside it.

The motto of this work is to deal with the turbulent mixed convective flow and conjugate heat move qualities inside the heated vertical channel. The heat source is at left wall and the opposite end is cold wall and the rest of the walls are adiabatic. The problem is solved by solving the continuity equation for mass conservation and the momentum equation for capturing the velocity field and the energy equation for the temperature distribution. The turbulence is modeled with cfd approach using lambremhorst turbulence model while the radiative transport equation was solved by discrete ordinates method. The parametric study is performed on assisting and opposing flows by comparing with the radiation and with out radiation in the vertical channel.

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To simulate the turbulent flow in the rectangular open-ended channel an in house Fotron 90 code was used.in this code a finite difference method is adopted to discretize the governing differential equation

II. MATHEMATICAL MODELING AND NUMERICAL METHOD

The vertical channel taken in our work is having H, W, B. There are two openings at the top and base of the channel for air flow, the hot wall is considered to left side and the cold wall is on the right. The rest of the walls are treated as adiabatic. Governing equations are worked by utilizing Finite Difference Method (FDM). The Problem is concentrated in two cases 1. Assisting case with and without radiation and 2. Opposing case with and without radiation as appeared in the figure 1

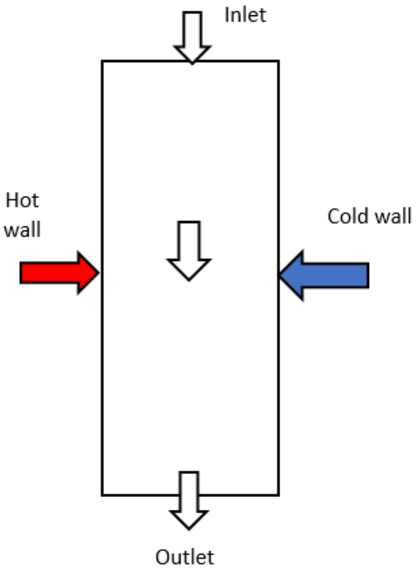

Figure.1. Assisting flow

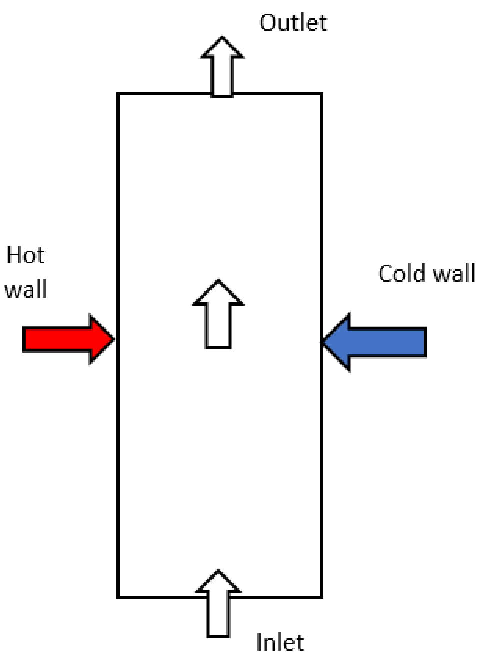

Figure.2. Opposing flow

This investigation depends on computational fluid dynamics approach utilizing lambremhorst turbulence model. Radiative forces are assessed utilizing discrete ordinates method (DOM). It changes over radiative transport equation (RTE) into set of halfway differential conditions. The Radiative transport condition is determined in each step of computational space to get the radiation intensity the turbulent flow of the problem is detailed by explaining the Reynolds Average Naiver – Stokes conditions (RANS). The investigation utilizes a simplified marker and cell algorithm (SMAC) for pressure-velocity decoupling. The time averaged governing conditions are as per the following:

$$\frac{\delta \rho}{\delta t} + \frac{\delta(\rho u_j)}{\delta x_j} = 0 \quad (1)$$

$$\frac{\delta(\rho u_i)}{\delta t} + \frac{\delta(\rho\, u_i u_j)}{\delta x_j} = \frac{-\delta p}{\delta x_i} + \frac{\delta \sigma_{ij}}{\delta x_j} + \frac{\delta\, M_{ij}}{\delta x_j} + (\rho - \rho_{\,ref}) \quad (2)$$

$$\rho c_p \frac{\delta T}{\delta t} + \frac{\delta(\rho c_p u_i T)}{\delta x_j} = \frac{\delta}{\delta x_j}\left(k \frac{\delta T}{\delta x_j}\right) + \frac{\delta q_j}{\delta x_j} + S_r \quad (3)$$

$$\xi_j \frac{\delta I_j}{\delta x} + \eta_j \frac{\delta I_j}{\delta y} + \zeta_j \frac{\delta I_j}{\delta z} = k_a(E_b - I_j) \quad (4)$$

The strength of the heat source is denoted by a dimensionless number called Grashof number (Gr). When the Grashof number increases Thermal expansion following temperature difference increases and Kinematic viscosity decreases. The Grashof number is represented as follows

$$G_r = \frac{g\beta\Delta T L^3}{v^2} \quad (5)$$

Were,

$$\beta = \frac{1}{(T_h + T_\infty) + 273\,(k)} \quad (6)$$

For understand the patterns in a fluid's behavior a dimensionless number is used called as Reynolds number (R_e). The Reynolds number is mathematically represented as follows

$$R_e = \frac{\rho v l}{\mu} \quad (7)$$

Were,

ρ is the density, v is velocity, l is the length, μ is viscosity. As Grashof number and Reynolds number are dimensionless we can change the characteristics by altering the Richardson number

$$R_i = \frac{G_r}{(Re)^2} \quad (8)$$

Boundary conditions for the vertical rectangular channel is velocity inlet and pressure outlet

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III. RESULT AND DISCUSSION

Figure 1 and 2 indicates the assisting flow with and without radiation. In the present study turbulent mixed convective air goes into the channel were free and constrained air goes into the channel according to the particular cases were free air goes in the assisting flow and forced goes in the opposing flow because of the gravitation.

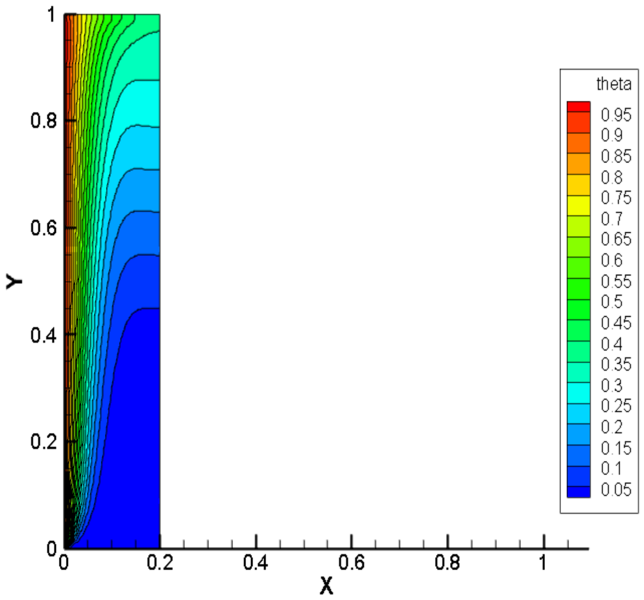

Figure. 3. Temperature contours of Assisting flow with radiation at Gr=10^6

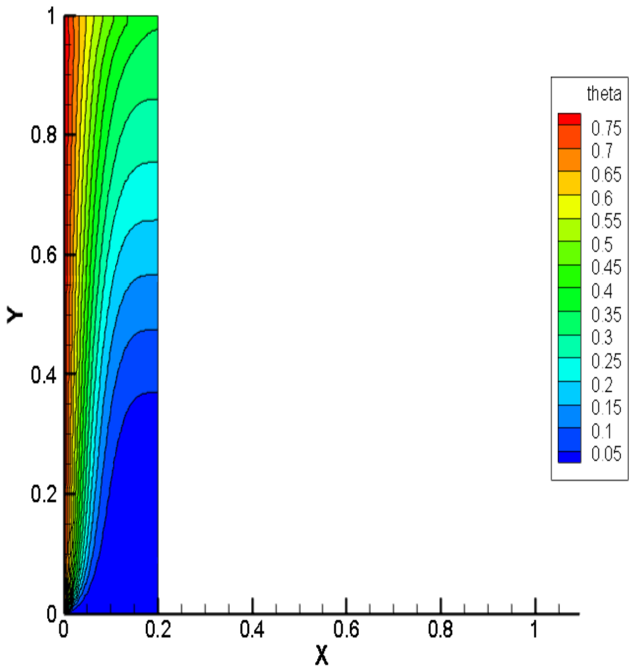

Figure. 4. Temperature contours of assisting flow without radiation at Gr=10^6

Figure.3 and 4 indicates evolution of temperature contours of with and without radiation inside the enclosure at (Gr) of 10^6. As in the assisting case the turbulent free convective air enters into the channel, we can see the temperature drop in the flow. The flow enters into the channel at Re=10^2

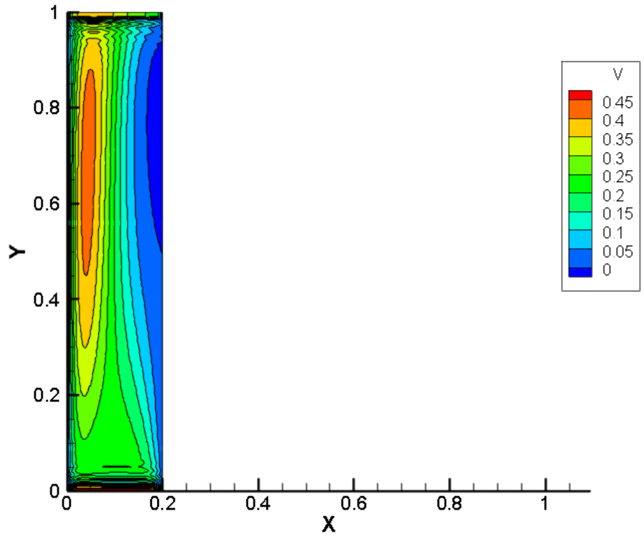

Figure. 5. velocity contours of Assisting flow with radiation at Gr=10^6

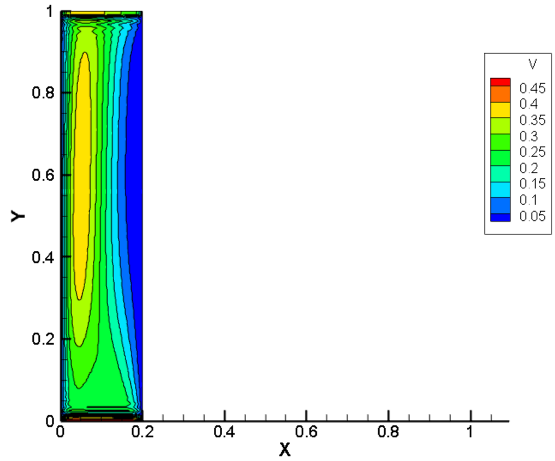

Figure.6. Velocity contours of Assisting flow without radiation at Gr=10^6

Figur.5 and 6 indicates evaluation of velocity contures for assisting case with and without ration.the flow velocity of with radiation is higher than the without radiation

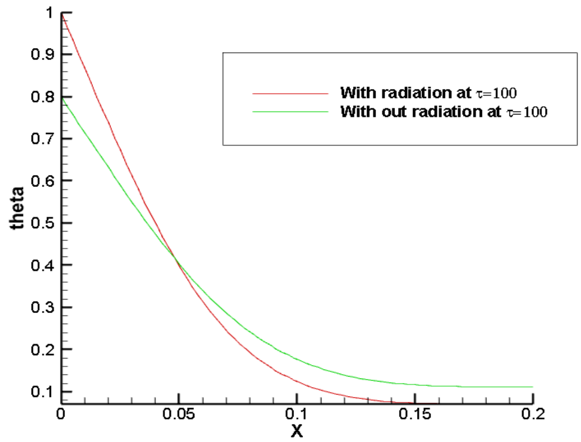

Figure.7. Comparison of temperature contours with and without radiation

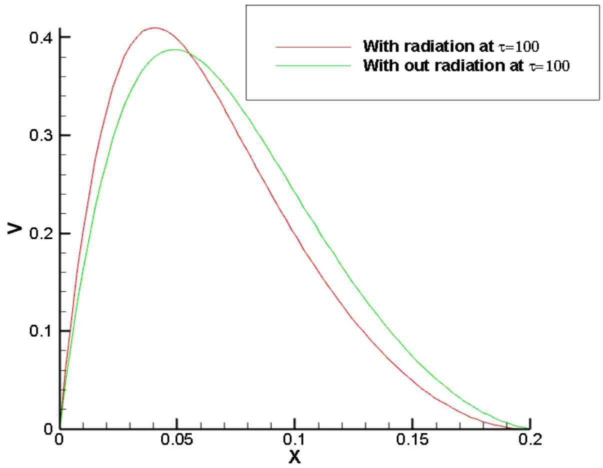

Figure.8. Comparison of velocity contours with and without radiation

In the above two graphs 7 and 8 it is very evident that the temperature flow of assisting case with radiation is higher than the assisting case of without radiation. The velocity graph shows that in assisting case the flow velocity without radiation is higher than the without radiation.

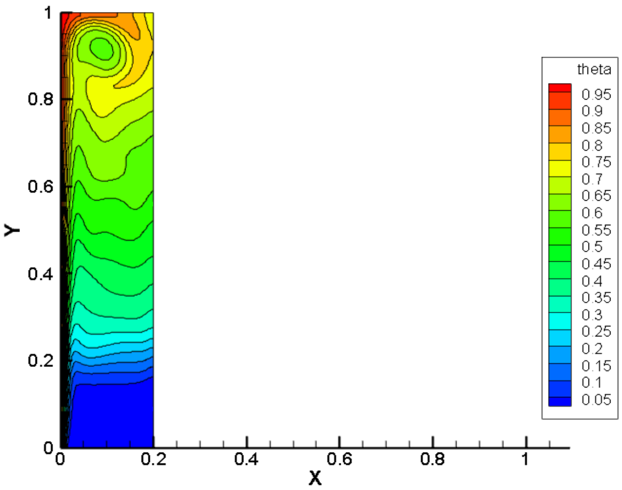

Figure. 9. Temperature contours of opposing flow with radiation at Gr=10^6

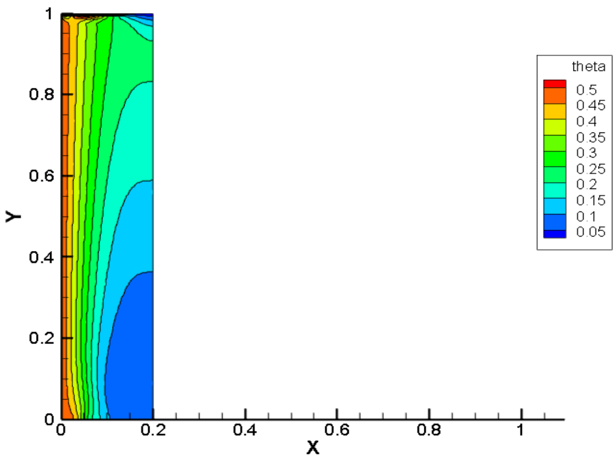

Figure. 10. Temperature contours of opposing flow without radiation at Gr=10^6

The temperature variation of with radiation flow is higher than the without radiation.

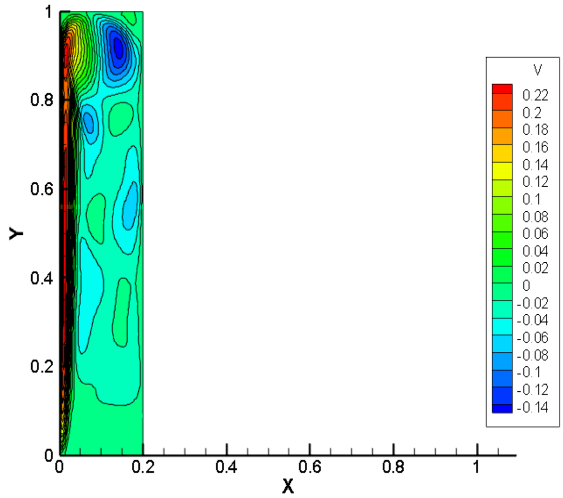

Figure. 11. velocity contours of opposing flow with radiation at Gr=10^6

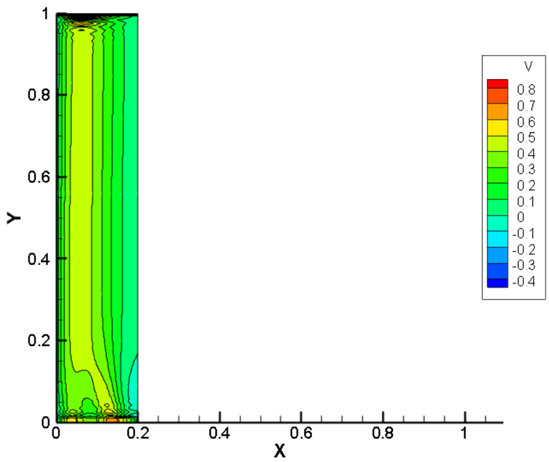

Figure. 12. velocity contours of opposing flow without radiation at Gr=10^6

Figure.11 and 12 shows that the velocity variations between the with radiation flow and with out radiation flow. The velocity variation in without radiation is higher than the with radiation.

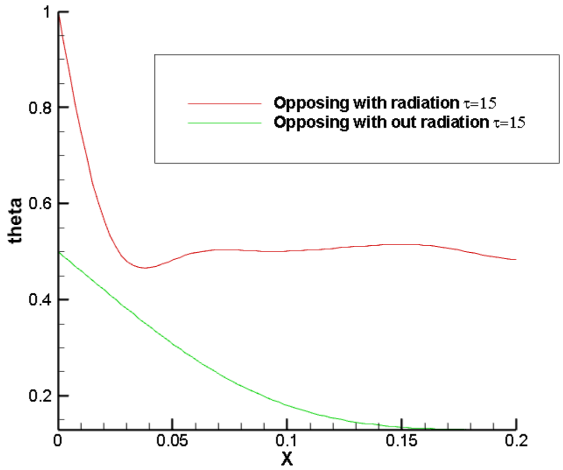

Figure. 13. Temperature comparison

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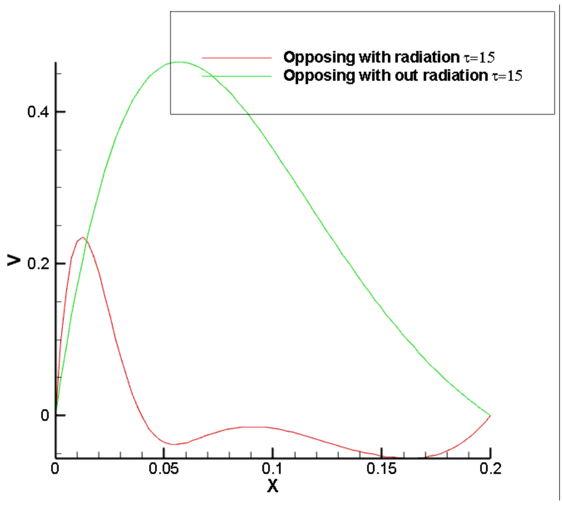

Figure.14. velocity comparison

In the above two graphs 13 and 14 it is very evident that the temperature flow of opposing case with radiation is higher compared to opposing case without radiation. The velocity graph shows that in opposing case the flow velocity without radiation is higher than the without radiation.

IV. CONCLUSION

The mixed convection of turbulence inside a vertical rectangular channel with a hot and cold wall inside the channel is settled numerically by altering the stream and stream course. The violent stream is demonstrated by the computational liquid elements (CFD) approach utilizing the Lambremhorst model were the governing equations are solved in every step. The boundary conditions for this work is velocity inlet and pressure outlet. It was found that in assisting case the flow with radiation is having 20% higher characteristics with comparing of case without radiation. While the velocity of Assisting case with radiation is having 4% higher characteristics than without radiation. In the opposing case the temperature is 47% higher in opposing with radiation case and the velocity is 23% higher in the opposing without radiation.

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