# Investigation of Laminar and Turbulent Natural Convection Combined with Radiation in a Square Enclosure with a Vertical Partition

**Mariyam Ali and Anil Kumar Sharma**

**Abstract** The present research work focuses on numerical simulation of combined natural convection and radiation inside a square enclosure with a vertical partition having different heights. The distance of the partition is varied from the hot wall for establishing the results. The left wall is considered to be the hot, the right wall as the cold and the horizontal top and bottom walls are considered to be adiabatic. The analysis is done in both the laminar and in the turbulent range for the Rayleigh number in range of $10^3$ to $10^{10}$. The partition is considered to have a fixed thickness which is taken to be L/20. Also, it is assumed to be adiabatic. Air is taken as the working medium. It has been concluded from the results that an increase in radiative Nusselt number is much higher than that of convective Nusselt number for turbulent flow regime. It was found to be 379% as the Rayleigh number increases from $10^8$ to $10^{10}$. Also, the increase in $Nu_T$ is almost 352% when Ra is increased from $10^8$ to $10^{10}$. However, as the partition height is increased the value of $Nu_T$ decreases to 15 and 28% for Ra $10^5$ and $10^{10}$ respectively.

## 1 Introduction

The study of natural convection and radiation inside cavities with different orientations and boundary conditions has been a topic of interest for the past decades by the thermal engineering researchers. The heat transfer and fluid flow are the major factors studied in these researches. However, often in these studies the combined effect of natural convection and radiation is not considered. So, in this research work the combined effect of natural convection and radiation is studied in both the laminar and turbulent range. Bahlaoui et al. [1] in their research work present the results of mixed convection and radiation inside a cavity which is heated from below and consists of a vertical adiabatic partition on this horizontal heated surface. The results are shown with the help of streamline and isotherm contours. Han and Baek [2] in

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M. A. Siddiqui et al. (eds.), *Advances in Heat Transfer and Fluid Dynamics*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-981-99-7213-5_21

their paper studied the phenomenon of heat transfer and fluid flow by considering three cases, in the first case only natural convection is considered, in the second case convection along with surface radiation is considered and in the third case convection with surface/gas radiation is considered. Both the partitions were considered to be adiabatic. The results obtained showed that the surface radiation had greater effect than the gas radiation on the heat transfer phenomenon. Again, the result is presented with the help of streamlines and temperature contours along with the calculation of Nusselt number. Zemani et al. [3] carried out a numerical simulation inside a cavity having hot and cold vertical walls with a partition placed parallel to the horizontal walls on the hot wall. The Rayleigh number was considered between $10^6$ and $3.7 \times 10^9$. Finite volume method was used to solve the governing equations. Time evolutions and temperature contours were presented to demonstrate the ongoing simulation along with the calculation of Nusselt number. Also, the results show that the presence of partition highly abrupt the fluid flow and heat transfer inside the cavity. Nakhi and Chamka [4] in their research work presented the results of laminar natural convection inside a square enclosure consisting of an inclined partition attached to the vertical hot wall while the rest of the three sides of the cavity were cooled from outside. Brown and Solvason [5] performed an experimental study of the phenomenon of natural convection inside rectangular openings with two cases, in the first case considering a vertical partition and in the second case considering a horizontal partition. The Grashof number for the present study was considered between $10^6$ and $10^8$. The results were presented in the form of Nusselt number calculated from the study. Nagaraja [6] in his research work carried out a numerical simulation of natural convection in a square enclosure with partition. The Rayleigh number for the present study is considered in the laminar range i.e., $10^3$ to $10^6$. Similar to the other studies, the results in this also are presented in the form of streamline, isotherm contours and the Nusselt number. From the above studies we can see that most of the studies are done either in laminar region or in turbulent region. In the present study, the numerical computation is done both in the laminar region and in the turbulent region. Also, the cavity considered for the analysis consists of a vertical partition.

## 2 Physical Model and Problem Description

In the present study, a square cavity is considered with vertical walls as hot and cold walls while the horizontal walls are assumed to be adiabatic as shown in Fig. 1. The vertical partition considered in the present research work is assumed to be adiabatic. Air is taken as the working fluid having a Prandtl number of 0.71 and also the Boussinesq approximation is adopted. All other physical parameters are assumed to be constant. The present study is carried out for Rayleigh number $10^3$, $10^5$, $10^8$ and $10^{10}$ resulting in the analysis in both the laminar and turbulent regions. In order to study the effect of partition height, the length of partition is varied as L, 3L/4, L/2 and L/4 as in Cases 1, 2, 3 and 4 respectively. Likewise, the partition distance is varied as L/4, L/2 and 3L/4 respectively as in Cases a, b and c.

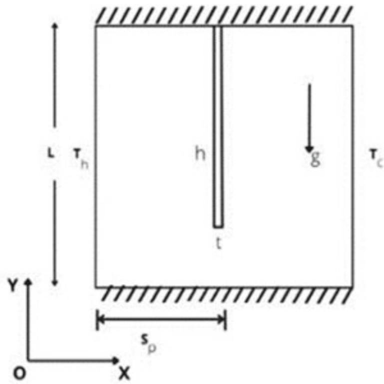



**Fig. 1** Computational domain

## 3 Solution Methodology

The numerical simulation for the present study is done using ANSYS FLUENT 2022R1 which is a finite volume-based solver. The pressure velocity coupling is done using Coupled algorithm. Also, the pressure interpolation is done by Second order scheme. For solving momentum and energy equation Second order Upwind is used. The surface emissivity value for all the general cases is considered to be 1 and Discrete Ordinate is used as the radiation model. SST K-Ω model is adopted as the turbulence model after detailed model sensitivity analysis beyond 80 × 80.

## 4 Grid Sensitivity Test

The grid sensitivity analysis has been carried out for Ra $10^5$ for case 1b. Grid sizes 80 × 80, 100 × 100, 120 × 120 and 140 × 140 have been chosen for the analysis. Table 1 shows that the changes in the Nu values are almost negligible. Therefore, 100 × 100 has been chosen for further analysis for all the cases. Also, the test is done for turbulent flow in the enclosure.

**Table 1** Grid sensitivity study for different grid sizes for Rayleigh number $10^5$

| Grid | Nu (numerical) | % Change with numerical results |
|---|---|---|
| 80 × 80 | 5.910 | – |
| 100 × 100 | 5.902 | −0.135 |
| 120 × 120 | 5.906 | 0.067 |
| 140 × 140 | 5.905 | −0.016 |

# 5 Results and Discussion

## 5.1 *Effect of Rayleigh Number*

Heat transfer and fluid flow characteristics in the enclosure are studied in both the laminar and turbulent regimes. The variation of total Nusselt number with Rayleigh number is depicted in Fig. 2. It can be seen that as the Rayleigh number is increased from $10^3$ to $10^5$ i.e., in the laminar range the total Nusselt number increases to a value of around 202%. Again, when the Rayleigh number is increased from $10^8$ to $10^{10}$ i.e., in the turbulent range the percentage increase in total Nusselt number is 343%. Thus, we can see that as the Rayleigh number is increased either in the laminar or in the turbulent region, the value of $Nu_T$ increases with it in the direct proportion.

## 5.2 *Effect of Partition Height*

In the research work in order to study the effect of partition height on the overall heat transfer and fluid flow, different cases of partition height are considered. In case 1 the height of the partition is taken as L, in case 2 it is taken as 3L/4, in case it is considered as L/2 and for the 4th case it is taken as L/4. It is observed that as the partition height is increased from L/4 to L, the value of total Nusselt number decreases to 15% for Rayleigh number $10^5$ and 28% for Rayleigh number $10^{10}$ as shown in Fig. 3. Thus, it leads us to the observation that both the stature of partition and $Nu_T$ are inversely proportional to each other.

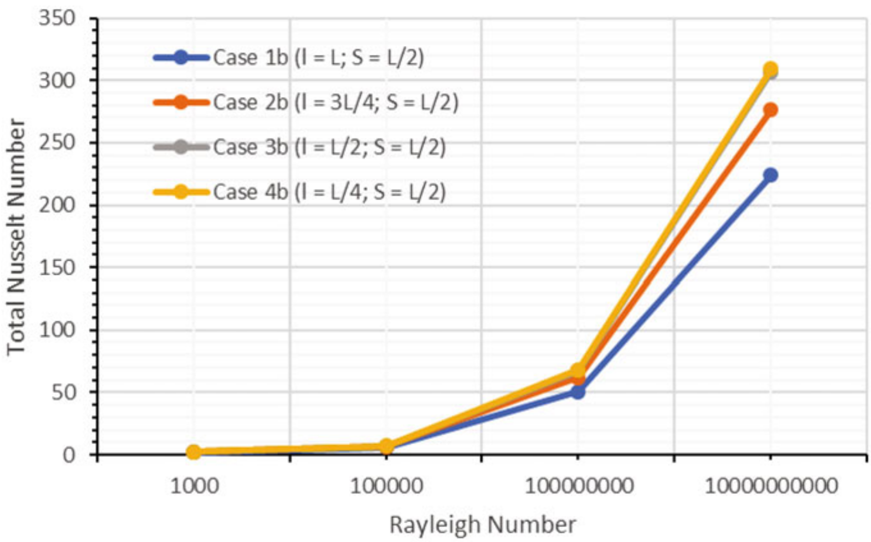
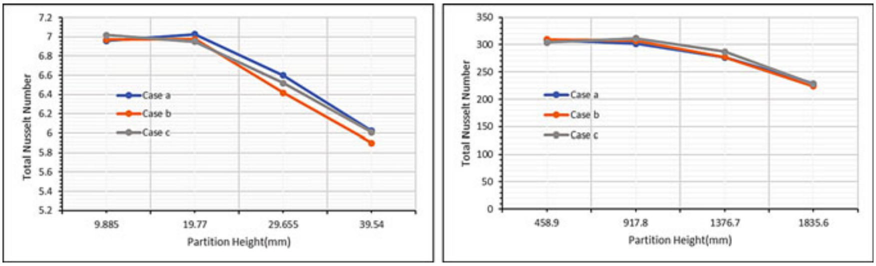



**Fig. 2** Variation of total Nusselt number with Rayleigh Numbers along the hot wall for central position of partition wall and different partition height




(a)Graph of h versus $Nu_T$ for Ra $10^5$ (b) Graph of h versus $Nu_T$ for Ra $10^{10}$

**Fig. 3** Variation of total Nusselt number with partition length for different partition distance from hot wall for Rayleigh number $10^5$ and $10^{10}$ respectively

## *5.3 Combined Radiation and Natural Convection*

The study of natural convection and radiation is done inside a square cavity with a vertical partition. All these analyses are done both in the laminar and turbulent range for Rayleigh number $10^3$ to $10^{10}$ and as such the results are presented in the form of isotherm and streamline contours as shown in Figs. 4, 5, 6 and 7 respectively. For all the Rayleigh number and for all the considered cases the value of surface emissivity is taken as 1 i.e., $\varepsilon = 1$. In the laminar range i.e., for Ra = $10^3$ and $10^5$ it can be observed from the streamline contours for Case 'a' when the partition is close to the hot wall, that the fluid flow is in the clockwise direction with the fluid rising from the bottom of right side of the partition, rising above than after coming in contact with the top adiabatic wall flows along the left wall in the downward direction thus forming uniform flow of the fluid. When the partition is present at the center, the fluid flows on both the side of the partition as in Case 'b'. While when the partition is present near the cold wall in Case 'c' the fluid flow occurs on the right side of the partition. Also, from the temperature contours for Ra $10^3$ we can observe the contours are almost parallel to the vertical walls. However, for Ra $10^5$ the isotherms are observed to be disrupted. Similarity is breaking and unsymmetrical flow behavior is seen along the vertical sides.

The streamline and isotherm contours for turbulent range are shown in Figs. 6 and 7 for Rayleigh number $10^8$ and $10^{10}$ respectively. For all the cases of partition height and distance it can be observed that the fluid flows very close to the enclosure walls and the partition wall in the clockwise direction. The isotherm contours for Ra $10^8$ are almost parallel to the horizontal walls but as the Ra number is increased to $10^{10}$ the contours get disturbed.

Figure 8 shows the variation of $Nu_C$, $Nu_R$ and $Nu_T$ with Rayleigh number. It can be observed that there is a slight variation in $Nu_C$ as the Ra varies from $10^3$ to $10^5$ however beyond that the change is significant to a value of almost 290% as Ra changes from $10^8$ to $10^{10}$. For $Nu_R$ the percentage change from $10^8$ to $10^{10}$ is extremely high similar to a value of 379%. Also, it can be observed that the value of $Nu_R$ is greater than the value of $Nu_C$. The increase in $Nu_C$ and $Nu_R$ results in the increase of $Nu_T$ with the increase in Rayleigh number.

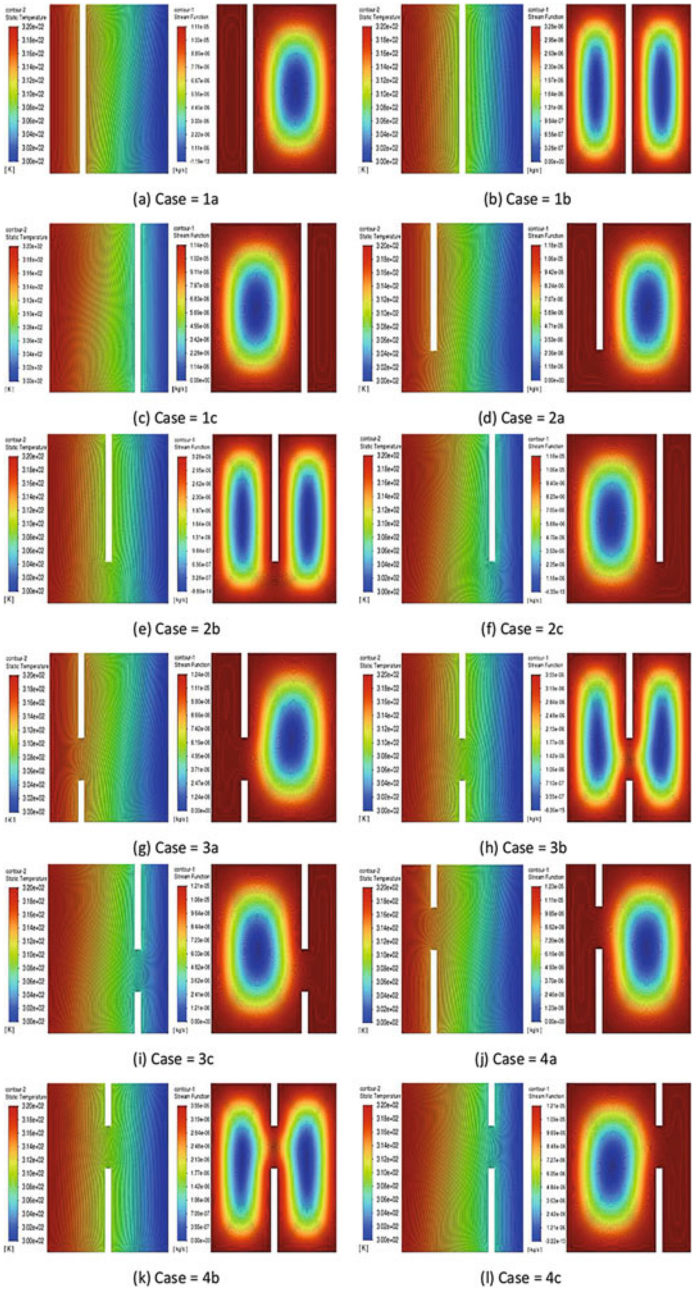



**Fig. 4** Temperature and streamline contours for natural convection and radiation for Rayleigh number $10^3$ for all cases of partition height and distance from hot wall

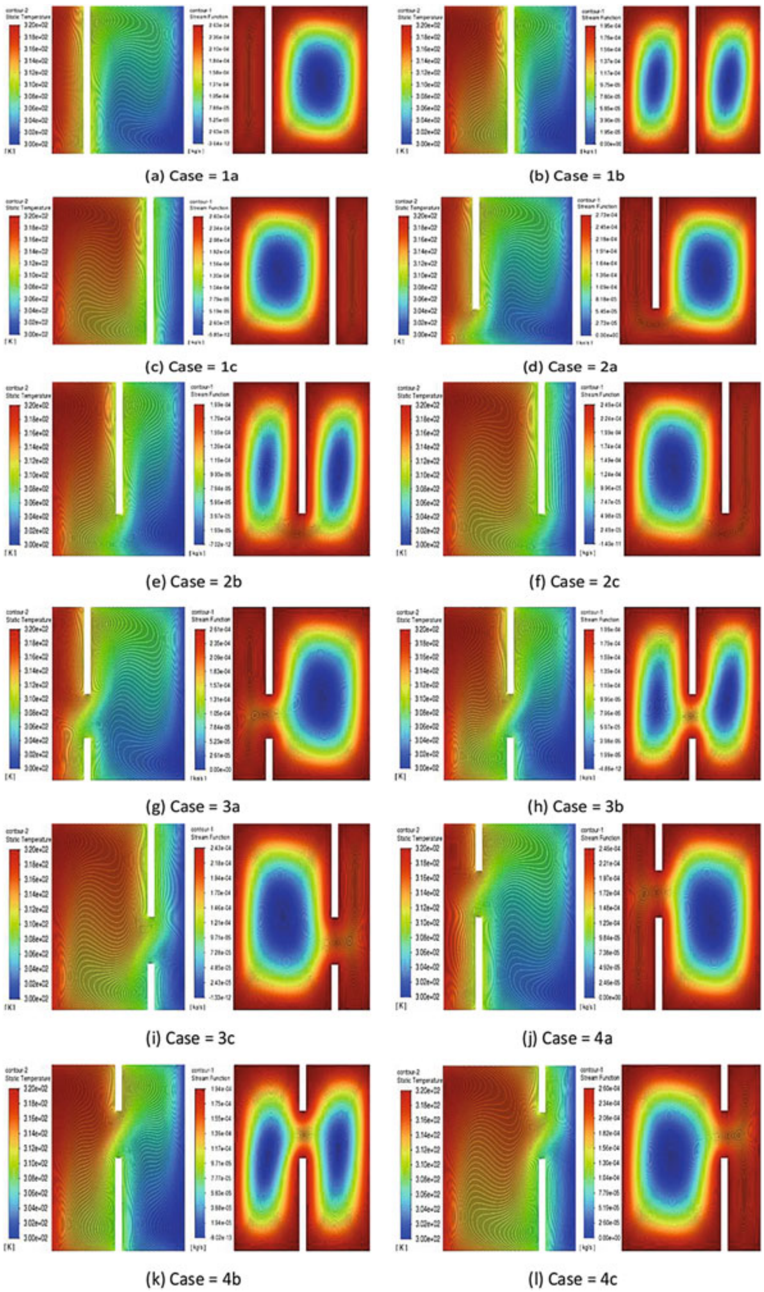



**Fig. 5** Temperature and streamline contours for natural convection and radiation for Rayleigh number $10^5$ for all cases of partition height and distance from hot wall

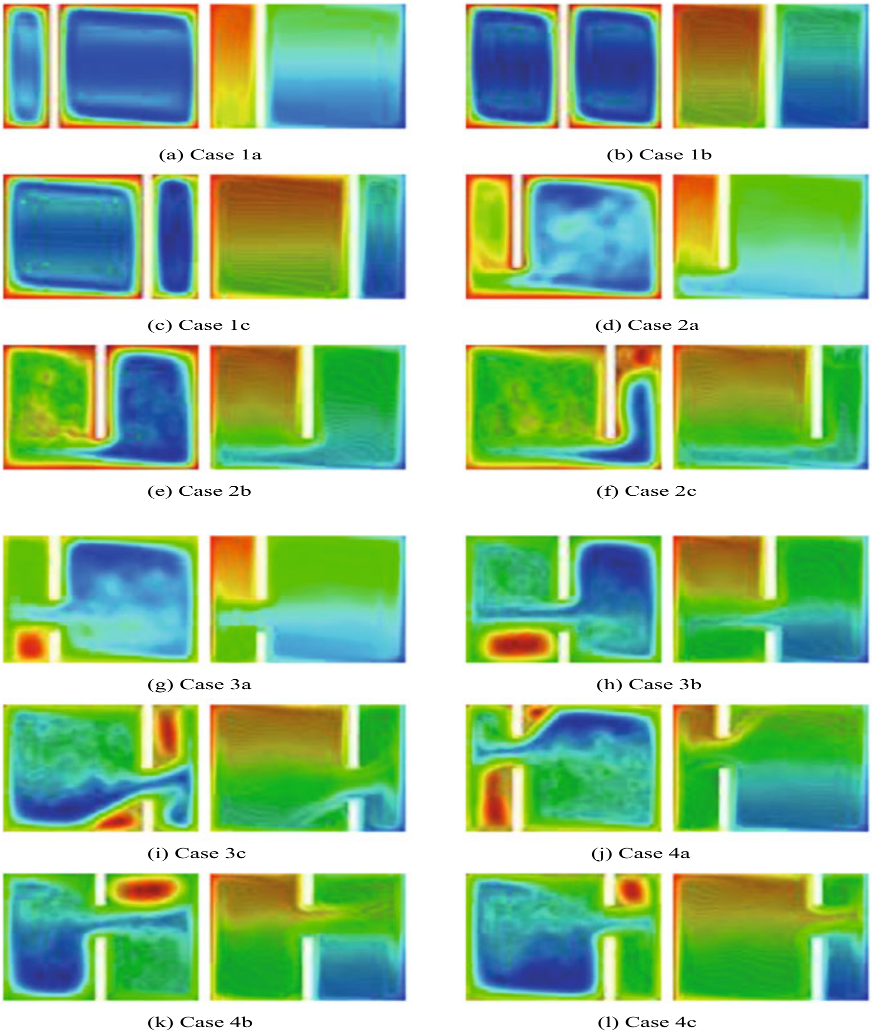



**Fig. 6** Temperature and streamline contours for natural convection and radiation for Rayleigh number $10^8$ for all cases of partition height and distance from hot wall

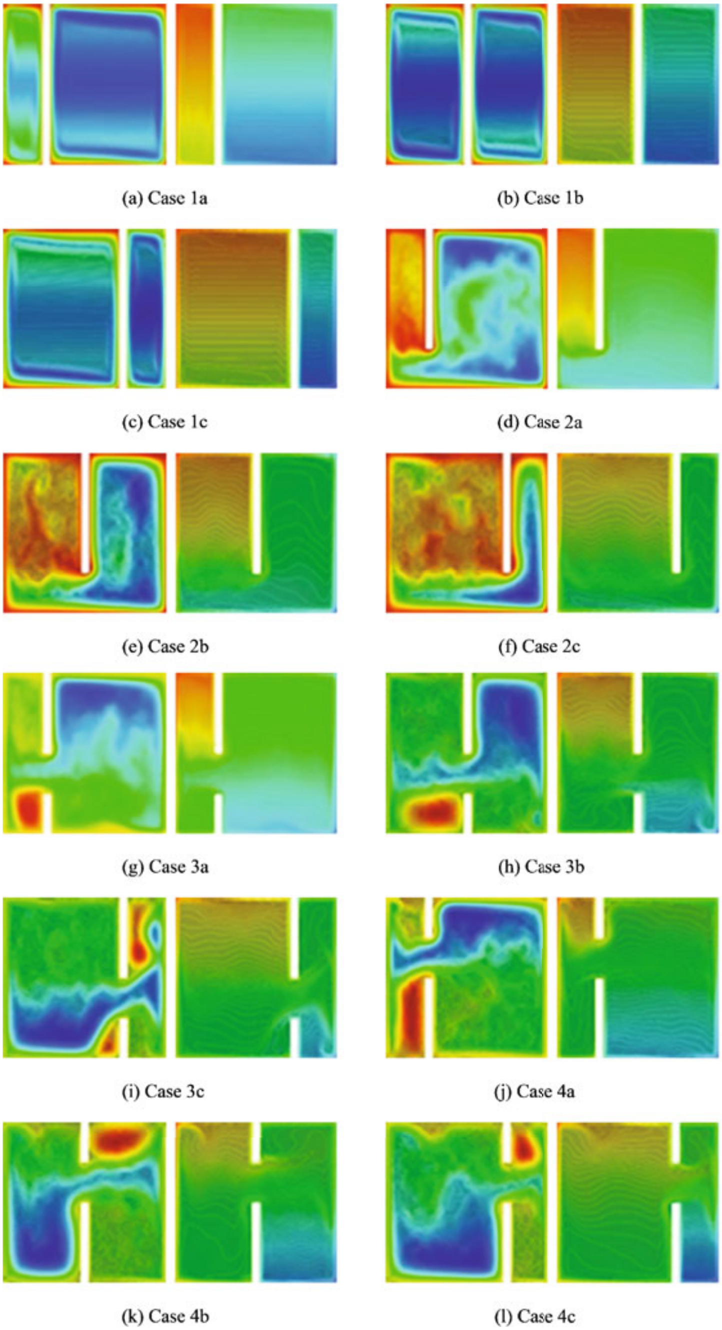
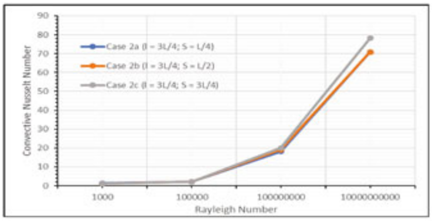
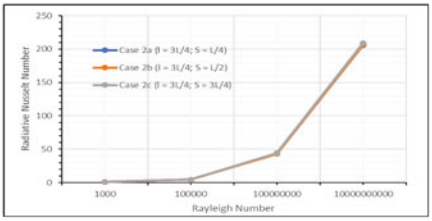


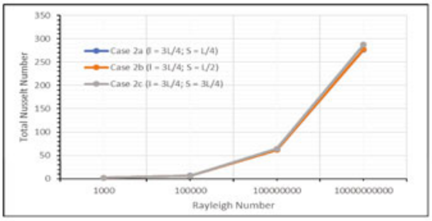

**Fig. 7** Temperature and streamline contours for natural convection and radiation for Rayleigh number $10^{10}$ for all cases of partition height and distance from hot wall




(a) Variation of $Nu_C$ along Ra for Cases 2a, 2b and 2c




(b) Variation of $Nu_R$ along Ra for Cases 2a, 2b and 2c




(c) Variation of $Nu_T$ along Ra for Cases 2a, 2b and 2c

**Fig. 8** Variation of convective, radiative and total Nusselt number for combined natural convection and radiation for hot wall for $\varepsilon = 1$ in r case 1 for Rayleigh number $10^3 - 10^{10}$

## 6 Conclusion

This paper presents the interaction of natural convection and surface radiation in partitioned enclosure for laminar and turbulent flow regimes. More than 70 cases were analyzed and the following systematic inference from the investigation were addressed. It can be concluded from the study that the increment in radiative Nusselt number is much higher than that of convective Nusselt number for higher Rayleigh number. When Ra number increases from $10^8$ to $10^{10}$ the percentage increase in $Nu_C$ and $Nu_R$ are observed to be almost 290% and 379% respectively. Thus, radiation plays a major role in net heat transfer from the enclosure. It has been observed from the decrease in the values of about 15% and 28% for Ra $10^5$ and $10^{10}$ as the partition height is increased from L/4 to L respectively. Hence, this leads to the conclusion that as the partition stature is decreased, the heat transfer and fluid flow increase thus resulting in an increase in the $Nu_T$.

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