Combined Natural Convection and Surface Radiation Inside Vented Triangular Enclosure - An Experimental Study

Rahul Raj[1]*, *Pradyumna K. C.*[2], *Rakshith B. R.*[2], *Nithin R. B.*[2] and *Karthik S. R.*[2]

[1]*Department of Mechanical and Manufacturing Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal – 576104, Karnataka, India*
[2]*Department of Mechanical Engineering, B.N.M. Institute of Technology, Banashankari, Bengaluru - 560 070, Karnataka, India*

Abstract. In the present experimental study, the influence of Opening ratio on the chamber temperature in case of vented triangular enclosure with hot base plate has been undertaken. Due to more flow passage, the average air temperature in the enclosure decreases by 12% for OR of 0.25 and 13% for OR of 0.5 compared to OR of 0.125. Similar trend is observed for Rayleigh number with a rise of 73% in OR 0.5 compared to OR of 0.125. Further, the influence of radiation heat transfer in the natural convection based enclosure is also studied. This kind of investigation is useful in the design and analysis of electronic cooling systems.

Keywords: Natural Convection, Triangular Enclosure, Opening Ratio, Radiation heat transfer

1 Introduction

When a fluid or any matter is surrounded on all sides by solid walls, it forms an enclosure. It might be desired to improve or slow down heat transfer by using enclosures depending on the type of application. In electronic enclosures, it is required to increase heat transfer in the enclosure to make sure the electronic components are operating at temperatures lower than the critical temperature of the component. But when we consider a double paned glass window, which is an enclosure trapping air between two glass panes, the heat transfer decreases from the interior. Triangular cavities have a wide range of applications in solar collectors and electronic devices as well as heating and ventilation in buildings with inclined roofs [1].

The geometry of the enclosure used also has an effect on the heat transfer. Use of different shaped enclosures / variation in aspect ratio and changing the inclination of the enclosure influences the heat transfer rate. It has been found that increasing the inclination angle of a rectangular enclosure reduces the heat transfer [2]. Changes in geometry varies the amount of surface area available for convective heat transfer from the enclosure to the surroundings. The convection with respect to the inside walls greatly depends on the geometry of the enclosure especially when only natural convection heat transfer is available.

* Corresponding author: rahulraj2894@gmail.com

The thermal analysis of an enclosure irrespective of its geometry involves finding the temperature and velocity variation of the fluid within the enclosed space. It is important to analyse the flow of the fluid inside the enclosure and its interaction with the enclosure walls. The temperature variation describes the temperature gradient pattern set up inside the enclosure which leads to buoyancy driven flow of the fluid.

Many researchers have studied the natural convection phenomena in enclosures. Mirabedin[3] formulated a correlation for Nusselt number in terms of its aspect ratio and Rayleigh number in case of a triangular enclosure and found that the Nusselt number increased with increase in aspect ratio. Kamiyo et al.[4] studied the heat transfer in an asymmetric triangular enclosure with a hot isothermal base wall. They varied the pitch angle (angle between the hot isothermal wall and cold inclined wall) and found that the heat transfer from hot base wall to inclined cold wall is high at low pitch angles and reduces with increasing pitch angle. This was due to the formation of a multi-cellular flow structure at low pitch angles. With increase in the pitch angle, the number of cells reduced, thereby reducing the heat transfer. Anderson et al.[5] determined the heat transfer coefficient for various aspect ratio in an attic shaped enclosure. They suggested a correlation for Nusselt number in terms of the Grashof number as well as the aspect ratio of the attic shaped enclosure. This correlation covers a wide range of Grashof number than the earlier correlation. Sieres et al.[6] carried out numerical computations for laminar flow in a triangular enclosure with a vertical hot wall by varying the aperture angle. They obtained the maximum temperature at the upper edge of the heated vertical wall and concluded that Nusselt number increases with Rayleigh number till critical state and then reduces with increase in Rayleigh number. Kuznetsov et al.[7] studied the radiative-convective heat transfer in an enclosure. They found that when radiation heat transfer was taken into account, the temperature of the gas cavity increased on average by 11% while measuring temperatures below 200°C. Dubovsky et al.[8] analysed the temperature and flow inside a rectangular enclosure with two openings. Flow visualisation was done by using smoke of incense sticks. He also carried out numerical simulations with the bottom wall as hot wall and found good agreement with the experimental results.

From the above literature review, the concluding remarks are: There has been substantial work done on triangular enclosures with respect to aspect ratio/apex angle/Rayleigh number. The effect of having openings in a triangular enclosure and its size, as well as the influence of variation of the internal hot wall emissivity of the enclosure in the heat transfer has not been studied. Hence the present study is focused on the above mentioned objectives.

2 Methodology

A right angled triangular enclosure was taken with an aspect ratio of 1 as shown in Figure 1. The opening ratio (OR) is the ratio of the sum of the length of the two vents to the length of the vertical edge. The inclined wall and the vertical wall containing the vents were insulated while the bottom wall was maintained at 60°C. The effect of change in the opening ratio was studied experimentally. Further, the hot base plate was blackened and compared to the results when the base was not blackened.

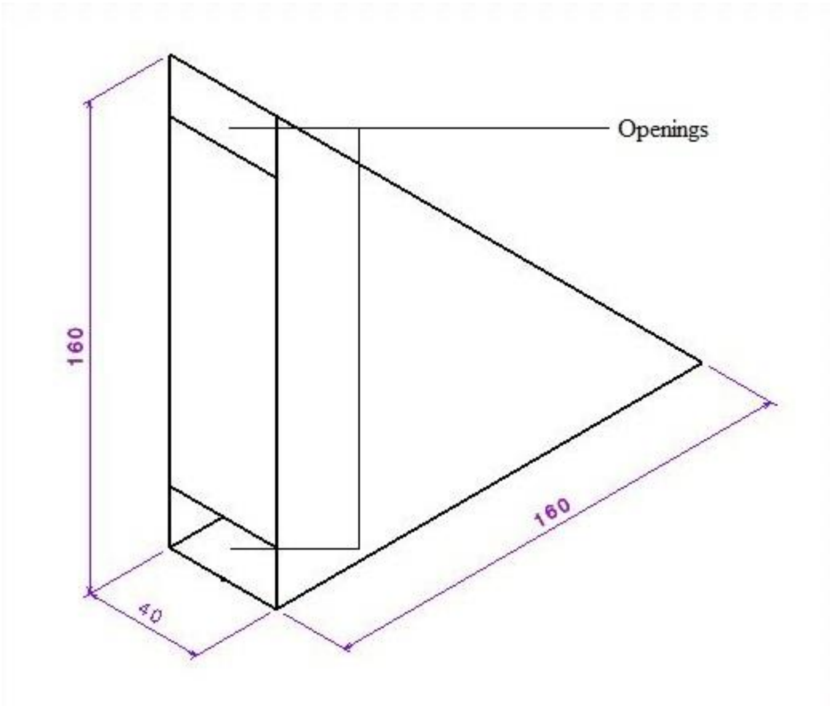

Fig. 1. Schematic of triangular enclosure with openings (dimensions in mm)

3 Experimental setup

As a heat source, a copper plate (160mm×40mm×3mm) was attached to two small 30W heaters through regulators at its ends. Thermal paste was applied between heater and the plate to minimize the thermal contact resistance. This arrangement ensures better heating and a variable uniform temperature system as shown in Figure 2.

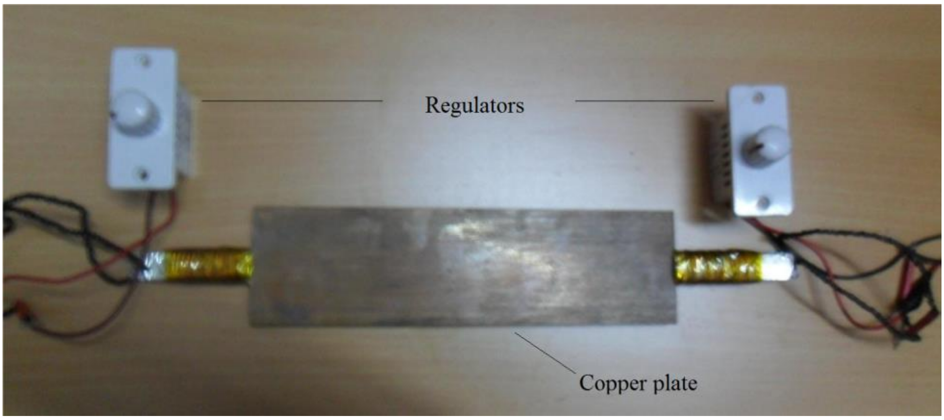

Fig. 2. Heater used in experimental setup

The triangular enclosure was fabricated from galvanised steel sheet. The length of the horizontal and the vertical edge were taken as 160 mm. Two cut-outs were provided, one at the top and the other at the bottom of the vertical wall to act as the openings of the enclosure with a provision for changing opening ratio. 3 different models with opening ratios of 0.125,0.25 and 0.5 were studied. Both inner and outer walls (other than hot wall) were insulated (using glass wool) so that the heat transfer by conduction from the base plate to the triangular vertical sides do not affect the convective heat transfer inside the enclosure. One side of the triangular enclosure is made transparent by using an acrylic sheet to examine the location of thermocouples as shown in Figure 3.

In total, eight K-type thermocouples were used. Two thermocouples were placed on the base plate at equal distances from either edges so that a uniform temperature throughout the base plate can be ensured. The remaining six thermocouples were suspended from the inclined edge of the enclosure and are positioned within the enclosure as shown in Figure 4.

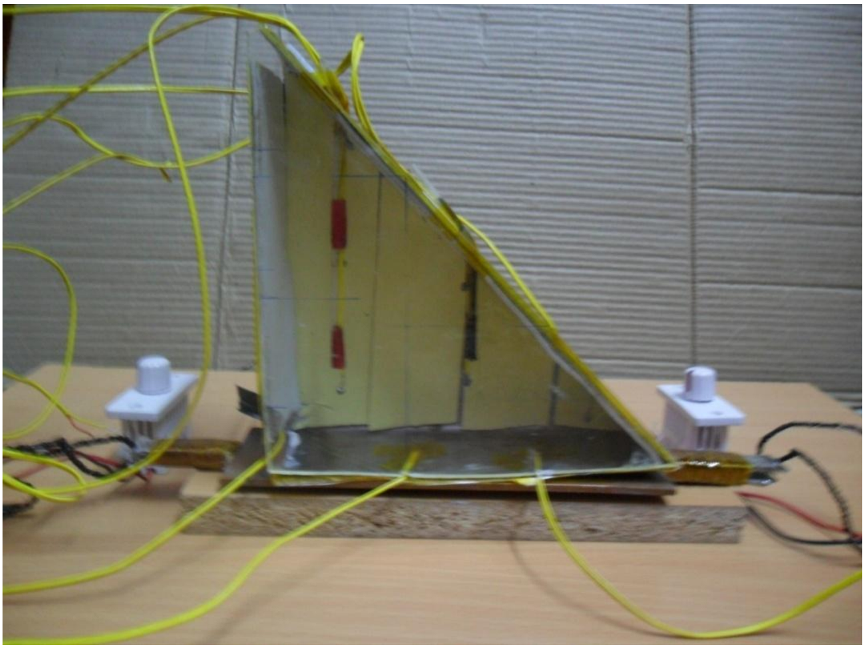

Fig. 3. Experimental Setup

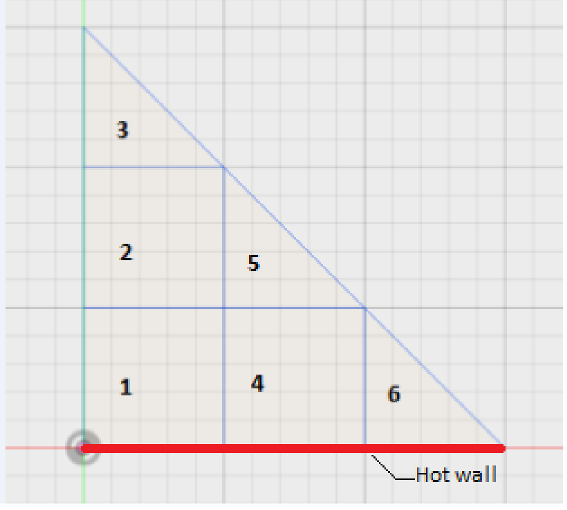

Fig. 4. Triangular enclosure divided into 6 parts

A data acquisition system was used to simultaneously record the temperature readings of all 8 thermocouples. The schematic of the entire arrangement is shown in Figure 5.

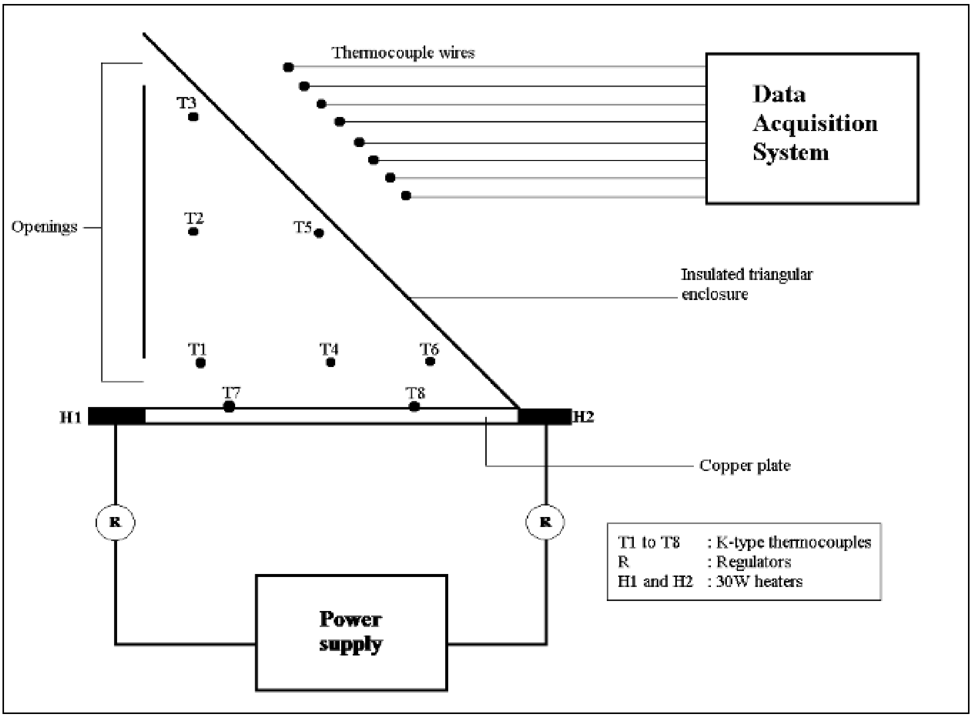

Fig. 5. Schematic of experimental setup

4 Experimental analysis

Rayleigh number is a very important parameter in natural convection heat transfer and affects the Nusselt number. To experimentally determine the Rayleigh number, the bulk mean temperature was taken by the average of the 6 thermocouple readings.

$$Ra = \frac{g\beta(T_s - T_m)L^3}{\nu\alpha} \tag{1}$$

The base plate is initially heated till it reaches a constant temperature, say 60°C. This process is then repeated for different opening ratios. The emissivity of the hot base plate was also altered by blackening the base plate. This increases the radiative heat transfer within the enclosure. It was found that the heat transfer rate is quicker compared to an untreated base. It was seen that the thermocouple readings in the case of the blackened base were much lower due to increased radiative heat flux.

5 Results and discussions

After steady state was reached the temperature readings were obtained. The effect of varying opening ratio on the heat transfer rate is studied. It was found that the Rayleigh number increases with increasing opening ratio and hence leading to better cooling. The temperature at six different locations inside the enclosure is plotted for different opening ratios as shown in Figure 6. As can be observed from the plot, the opening ratio 0.125 has the highest temperature in each zone due to lower natural convection as the opening is very small. The trend of the line plots of the other two opening ratios are similar in the regions away from the openings. Although there is some discrepancy in the thermocouples closer to the vents, this can be due to flow reversal or other errors.

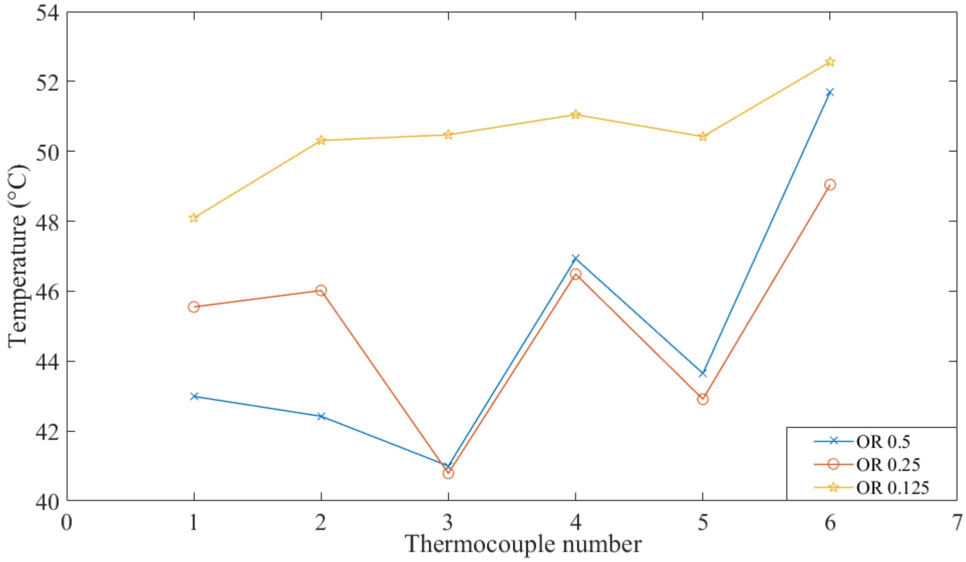

Fig. 6. Temperature variation with opening ratios

The Rayleigh number for the three opening ratios were determined and are shown in Figure 7. From OR 0.125 to 0.25, the Rayleigh number increases steeply. But the variation of Rayleigh number from an OR of 0.25 to 0.5 is very small. This shows that the heat transfer rate increases rapidly when the OR is changed from 0.125 to 0.25 and that it increases insignificantly when the OR is changed from 0.25 to 0.5. Hence, having an OR of 0.5 will give the highest heat transfer rate but similar heat transfer rate can be obtained with a much lower OR of 0.25.

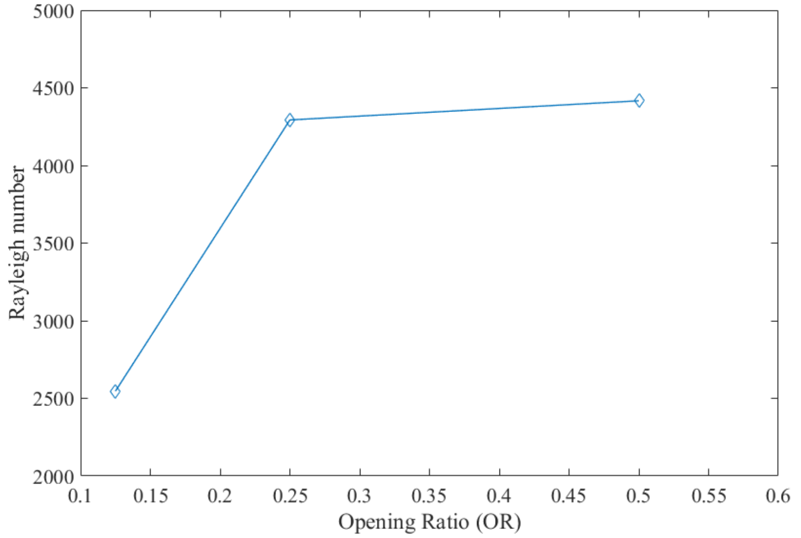

Fig. 7. Rayleigh number variation with Opening Ratio

The effect of change in radiation heat transfer was also considered during experimentation. Hence to increase the radiative heat transfer, the emissivity of the hot base plate was increased. This was done by blackening the top surface of the hot base plate. Figure 8 shows the variation of temperature at different locations of the enclosure with a normal hot base surface as well as with a blackened hot base plate. It was observed that the variation trend was similar in both the cases and the temperature readings inside the enclosure with the blackened base was found to be lower than the one with normal base. The lower temperatures inside the blackened base enclosure is due to the increase in radiative heat transfer between the surfaces.

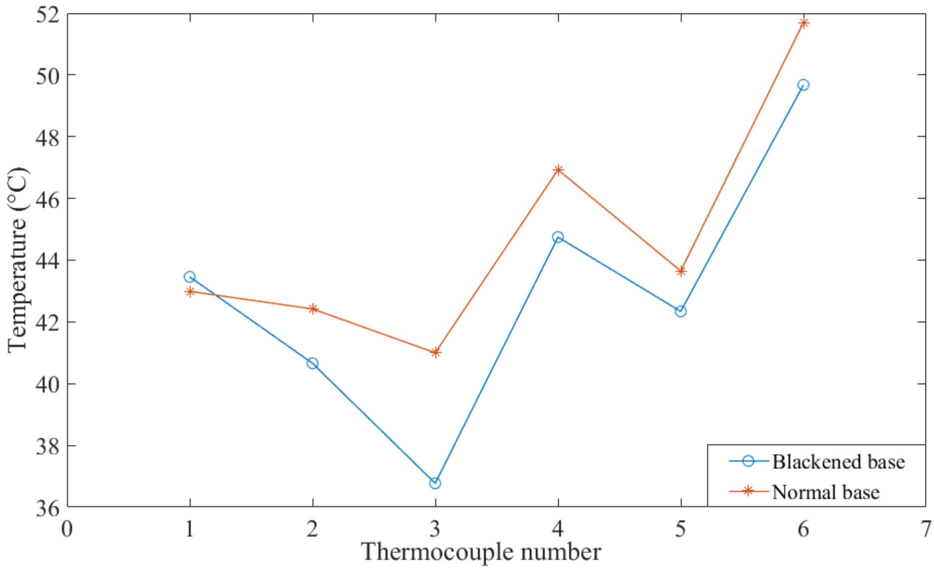

Fig. 8. Enclosure temperature comparison of blackened and normal base plate

6 Conclusions

The outcome of the experimental investigation and analysis is as follows:

1. As natural convection current is directly proportional to the opening ratio, the overall temperature of air in the enclosure is high for opening ratio 0.125, similarly, the optimum opening ratio is 0.25 as no appreciable variation in temperature is observed as in the case of 0.5
2. Since the driving potential is temperature in Ra, OR is proportional to Ra, as a result of this OR of 0.25 maybe optimized
3. The conjugate heat transfer phenomena has been studied which indicates a maximum drop of 10% in temperature locally. This is due to the dominance of radiation heat transfer as the hot surface has been blackened.

7 Nomenclature

g	Gravitational acceleration [m/s^2]	T_m	Mean Temperature [°C]
L	Characteristic length [m]	T_s	Surface temperature [°C]
Nu	Nusselt number	OR	Opening Ratio
Pr	Prandtl number	α	Thermal diffusivity [m^2/s]
Ra	Rayleigh number	β	Thermal expansion coefficient [1/K]
T_a	Ambient temperature [°C]	ν	Kinematic viscosity [m^2/s]

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