CFD-Analysis of Natural Convection in A Triangular Enclosure

Noble A Manivelil
B. Tech Student
Department of Mechanical Engineering
Mahathma Ghandhi University Saintgits College of Engineering Pathamuttom. kottayam, kerala

Vishnu Ram R
B.Tech Student
Department of Mechanical Engineering
Mahathma Ghandhi University Saintgits College of Engineering Pathamuttom. kottayam, kerala

Tino V Dominic
B. Tech Student
Department of Mechanical Engineering
Mahathma Ghandhi University Saintgits College of Engineering Pathamuttom. kottayam, kerala

Mathew Jose
B. Tech Student
Department of Mechanical Engineering
Mahathma Ghandhi University Saintgits College of Engineering Pathamuttom. kottayam, kerala

Abstract

Natural convection in enclosed cavities is widely studied because of its importance in many engineering applications. The most commonly used enclosures in the industries are rectangular, cylindrical, trapezoidal, triangular etc. In recent years, natural convection in triangular shaped enclosures have received a considerable attention. The reason for considering this geometry is, it has application in various fields such as building and thermal insulation systems. In the present study natural convection inside a triangular enclosure is analyzed. The analysis is conducted as 3 different cases. For the first case the bottom wall is heated and other two sides are kept at ambient temperature. For the second case, left wall is heated and other two sides are kept at ambient temperature and for the final case right wall is heated and other two sides are kept at ambient temperature. Simulations are carried out for varying Rayleigh number. Heat transfer rate from the hot surface is obtained numerically. The fluid flow characteristics and heat transfer characteristics are analyzed using computational fluid dynamic software ANSYS FLUENT 14.0.
Keywords: Isotherm, Nusselt number, Rayleigh number, Streamline, Triangular enclosure

I. INTRODUCTION

Recently, it has been observed that there is a considerable increase in the studies of natural convection in triangular enclosures because of its applicability in various fields such as heat transfer in air filled attic spaces of houses, buildings with sloped roofs and horizontally suspended ceilings, triangular built-in-storage type solar collectors, solar stills and the electronic equipment cooling. In the summertime, the conventional attic spaces which are symmetrically heated at the two upper inclined walls and cooled at the bottom represent a triangular cavity heated from the top. In solar engineering, triangular built-in-storage type solar water heaters, which result in higher 1solar gain and enhance the natural convection, lead to better heat transfer between the absorbing surface and the water stored in the heater. Thus, they represent another practical application of triangular geometry heated from top inclined surfaces.

Natural convection has been and still remains to be a promising option in the cooling of electronic equipment due to noise free, simple and economical applications it offers in engineering design. The electronic components are usually mounted on boards, which form rectangular or triangular cavities. Another practical application of triangular enclosures arises in the miniaturization of electronic packaging, subject to strict space and weight constraints. The present work has been motivated by the need to determine the detailed flow field, temperature distributions and natural convection heat transfer in isosceles triangular enclosures for cold base and hot inclined walls.

II. LITERATURE REVIEW

Chengwang Lei and John C. Patterson in paper a numerical simulation of natural convection in an isosceles triangular enclosure heated from below, the transient flow development in isosceles triangular enclosure takes place in 3 distinct stages,

- Early stage: Growth of thermal boundary layers and initiation of primary circulation
- Transitional stage: Appearance of convective instabilities and formation of cellular structures
- Quasi steady stage: Alternating occurence of convective instabilities from 2 sides and oscillation of upwelling flow near center.

SeyedMilad Mirabedin in paper CFD modeling of natural convection in right angled triangular enclosures, the heat transfer rate increases with an increase in the Rayleigh number and aspect ratio. The Nusselt number increases by increasing the Rayleigh number in the range of 10^4 to 10^7.

Tanmay Basak, S. Roy, S. Krishna Babu and A.R. Balakrishnan in paper finite element analysis of natural convection flow in a isosceles triangular enclosure due to uniform and non-uniform heating at the side walls, at low Rayleigh numbers isotherms are smooth and monotonic .It is observed that non-uniform heating produces greater heat transfer rate at the centre of the walls than in uniform heating.

III. NUMERICAL FORMULATION

The geometric configuration of the physical system is an isosceles triangle. The enclosure is filled with a viscous, incompressible Newtonian fluid. Assumptions are made to simplify the expressions and they are:

1) A two-dimensional flow is assumed to exist; any effects occurring in the third dimension are neglected. This assumption is reasonable and acceptable for the problem under study.
2) The Boussinesq approximation is applicable; that is, the fluid is incompressible with constant density.

The analysis is carried out for 3 different cases and they are:

– Case - 1: The bottom wall alone is heated.
– Case - 2: The left wall alone is heated.
– Case - 3: The right wall alone is heated.

For all the 3 cases, the heat transfer and fluid flow characteristics are plotted for varying Rayleigh number. Rayleigh number is defined as a dimensionless parameter that is a measure of the instability of a layer of fluid due to differences of temperature and density at the top and bottom. Here, the Rayleigh number is varied by varying the temperature difference between the surface and the fluid.

The Rayleigh number is given by,

$$Ra = g\,\beta\,(T_s - T_f)\,x^3 / \nu\,\alpha$$

Where,

g - acceleration due to gravity (m/s^2)
β - thermal expansion coefficient (K^{-1})
ν - kinematic viscosity (m^2/s)
α - thermal diffusivity (m^2/s)
T_s - surface temperature (K)
T_f - fluid temperature (K)
x - characteristic length (m)

IV. METHODOLOGY

To ensure the accuracy of the numerical results, a grid independence study is performed. For each grid and aspect ratio, proportional number of elements are used for each side of the enclosure according to the side lengths. Important parameters such as the horizontal velocity component along the symmetry plane and both local and average Nusselt number is calculated at several grid resolutions and compared. The grids for the results reported in this paper are chosen, based on the percent change in Nusselt number.

To verify that the grid resolutions based on this criterion are adequate for resolving local quantities, additional grid studies are performed for each of the cases included in this study. Typical results are shown, which shows the Nusselt number along the base and the non-dimensional horizontal velocity along the mid plane of the triangle, respectively, for each of the grids used. The local values of Nusselt number and the horizontal velocity are observed to converge to one profile as the grid is refined. Similar trends are observed for all other cases considered.

Table – 1
Grid Independent Study

NUMBER OF CELLS	*AVERAGE NUSSELT NUMBER*
747	*4.204008*
2349	*4.684112*
4008	*5.067434*
7262	*5.289903*
11224	*5.432076*
15609	*5.549458*
21090	*5.627733*
25440	*5.710322*
34156	*5.784516*
42660	*5.787486*

V. RESULT

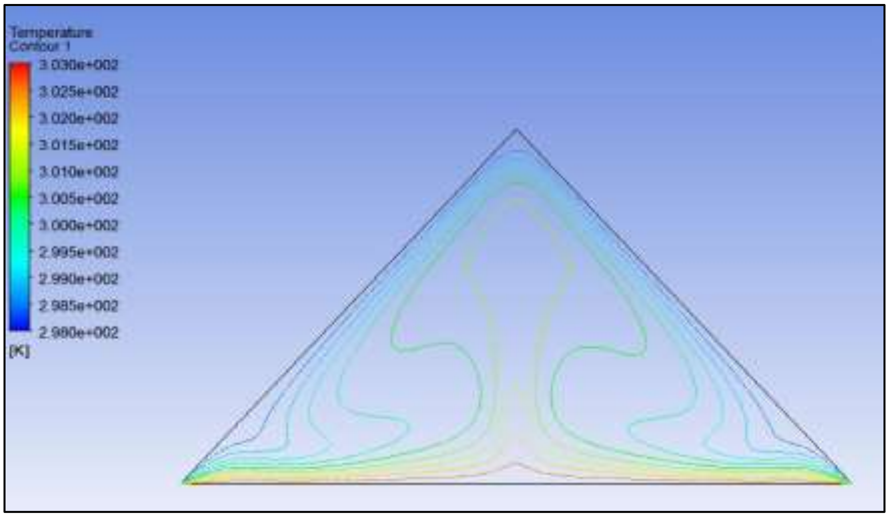

Fig. 1: Isotherm for bottom wall temperature 30°C

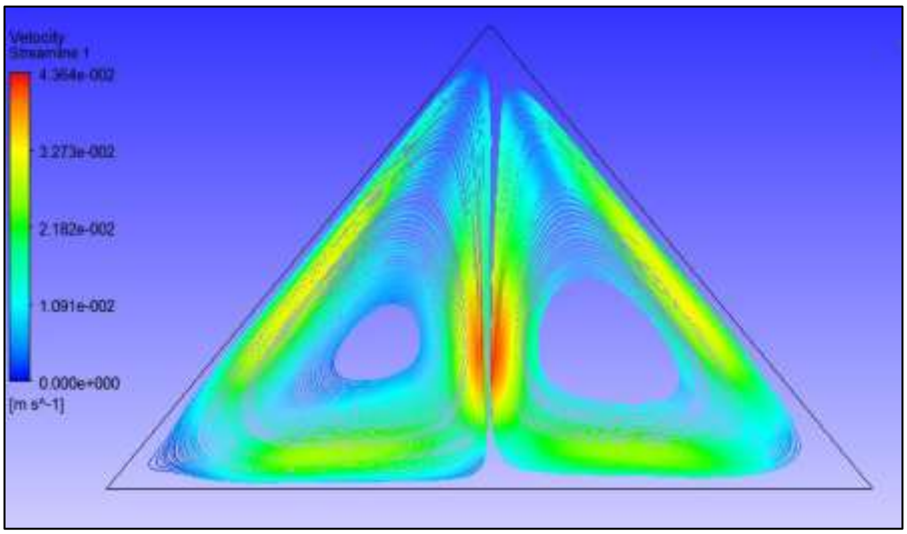

Fig. 2: Streamline for bottom wall temperature 30°C

From the isotherm contour it can be seen that, hot thermal plume starts generating from the hot wall. The hot thermal plume is found to develop at the middle. A nearly symmetrical double cellular streamline pattern is obtained.

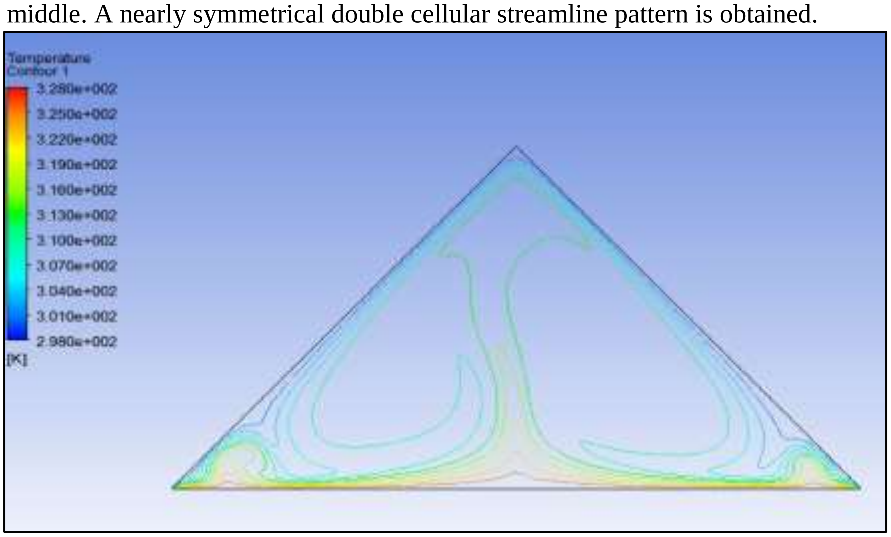

Fig. 3: Isotherm for bottom wall temperature 55°C

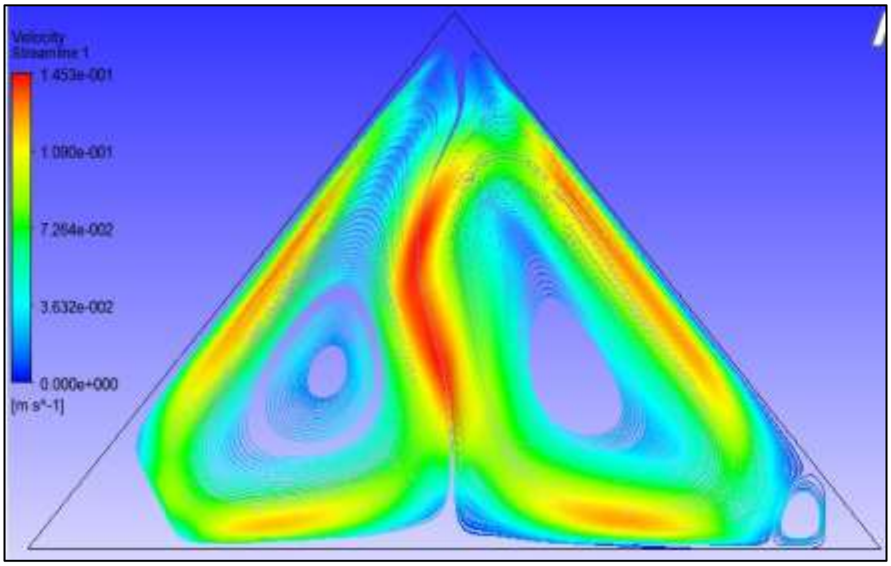

Fig. 4: Streamline for bottom wall temperature 55°C

Gradually, when the bottom wall temperature is increased from 30°C to 55°C , the flow patterns become nonlinear. The symmetry in temperature distribution is destroyed which indicate onset of turbulence. The transition of laminar to turbulent state of flow inside the enclosure occurs.

VI. Conclusion

Numerical results for laminar natural convection in an isosceles triangular enclosure heated from below, considering the complete physical domain i.e., using no symmetry assumptions, are presented. The current investigation has analyzed the flow field and temperature distribution effects with detailed emphasis on heat transfer evaluation for natural convection in isosceles triangular enclosures. Stratified temperature distributions are formed in triangular enclosures. Two symmetrical recirculating streamline cells are observed. As the Rayleigh number increases, the effect of convection also increases for all base angles. Two counter-rotating symmetrical cell structures can be seen and asymmetrical multi-cellular streamline patterns and isotherms are obtained. The isotherms are deteriorated with the increase of the Rayleigh number. These multi-cellular flow structures and deteriorated thermal fields enhance the heat transfer and the mean Nusselt number. Finally, the flow characteristics changes from laminar to turbulent, as the Rayleigh number increases.

References

[1] Gautam Biswas, "Introduction to Finite Element Methods," in Computational Fluid Dynamics, Narosa Book Distributors Pvt Ltd, 2014.

[2] G. A. Holtzman, R. W. Hill, Assoc. Mem. ASME and K. S. Ball, Mem. ASME , "Laminar Natural Convection in Isosceles Triangular Enclosures Heated From Below and Symmetrically Cooled From Above," J. Heat Transfer 122(3), 485-491 (Jan 06, 2000).

[3] R. D. Flack, "The Experimental Measurement of Natural Convection Heat Transfer in Triangular Enclosures Heated or Cooled from Below," J. Heat Transfer 102(4), 770-772 (Oct 20, 2009).