International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:14, No:3, 2020

Numerical Study of Natural Convection in a Triangular Enclosure as an Attic for Different Geometries and Boundary Conditions

H. Golchoobian, S. Saedodin, M. H. Taheri, A. Sarafraz

***Abstract*—**In this paper, natural convection in an attic is numerically investigated. The geometry of the problem is considered to be a triangular enclosure. ANSYS Fluent software is used for modeling and numerical solution. This study is for steady state. Four right-angled triangles with height to base ratios of 2, 1, 0.5 and 0.25 are considered. The behavior of various parameters related to its performance, including temperature distribution and velocity vectors are evaluated, and graphs for the Nusselt number have been drawn. Also, in this study, the effect of geometric shape of enclosure with different height-to-base ratios has been evaluated for three types of boundary conditions of winter, summer day and one another state. It can be concluded that as the bottom side temperature and ratio of base to height of the enclosure increases, the convective effects become more prominent and circulation happened.

***Keywords*—**Enclosure, natural convection, numerical solution, Nusselt number, triangular.

I. Introduction

THE natural convection flows are complicated due to the coupling of the hydrodynamic and thermal fluid flow field. Various types of natural convection heat patterns can be mentioned in many engineering applications, including cooling electrical equipment [1], lubrication systems [2], heat exchangers [3], solar energy collectors [4], electric cookers [5], solar desalination systems [6], and melting and solidification processes [7], [8].

Natural convection in a square and rectangular enclosure has been investigated in many studies and most of these studies have focused on the effect of boundary conditions, size ratio and average Natural convection [9]-[11].

A number of studies have focused on natural convection in enclosures with complex applications due to their engineering applications [12]-[14]. The coupling between the hydrodynamic and thermal fields in a complex geometry through buoyancy forces makes mathematical modeling difficult. As a result, researchers have interested significantly in the investigation of natural convection in non-rectangular enclosures with various type of walls.

H. Golchoobian is with the Faculty of Mechanical Engineering, Semnan University, Semnan, Iran and ChatrEnergy Research & Development Company, Tehran, Iran (corresponding author, e-mail: h.golchoobian@gmail.com).

S. Saedodin, is with the Faculty of Mechanical Engineering, Semnan University, Semnan, Iran (e-mail: s_sadodin@semnan.ac.ir).

M. H. Taheri and A. Sarafraz are with the ChatrEnergy Research & Development Company, Tehran, Iran (e-mail: hasan.taheri@gmail.com, sarafraz.d@gmail.com).

Lee [12] has evaluated the numerical and experimental investigation of fluid flow and heat transfer in a non-rectangular enclosure with different heat. The effects of the Rayleigh number, the size ratio, and the slope of the enclosure on flow and temperature characteristics have been reported. One of the results highlighted was the maximum mean Nusselt number that occurred at a slope angle of 180 degrees and the minimum size at the slope of 270 degrees. A complete review of natural convection in triangular enclosures has been carried out by Kamiyo et al. [14]. Their study has focused on the entire range of induced current regime by floating damping in a triangular enclosure. In addition, the effects of step angle, Rayleigh number and different temperature boundary conditions on fluid and heat flow fields are studied in detail. Numerical research has been carried out to evaluate the heat transfer and fluid flow due to natural convection in a porous triangular enclosure with a conductive object centrally located by Varol [15]. The center of the object is at the center of gravity of the triangle. The Darcy's law model is used to write the governing equations and the finite difference numerical method is used to solve. The results are expressed as flow lines, isothermal lines, mean and local Nusselt number, thermal conductivity ratio, and height and body width. It was observed that the ratio of thermal conductivity, both height and body width, play an important role in fluid flow and cavity heat transfer.

The increase in natural convection in the equilateral triangular enclosure containing Nano fluids was carried out by Aminossadati and Ghasemi [16]. A heat source is located on the bottom wall and Nano-fluids are ethylene glycol and copper. In this study, the effect of relevant parameters such as Rayleigh number, solid volume fraction, heat source location on enclosure thermal performance is investigated. By increasing the Rayleigh number and the solid volume fraction, the thermal performance of the enclosure is increased. The results show that the variations in the heat transfer vary slightly with respect to the tip angle and location of the heat source and the dimensions of the Rayleigh numbers. The results of this study were compared with the results of Maxwell model and, it was observed that heat transfer is more than Maxwell model.

Oztop et al. [17] numerically and experimentally investigated the heat transfer and fluid flow induced by gravitational force in a triangular enclosure. The enclosure was made of a wall of heat and the side wall is insulated. The Hypotenuse temperature is constant and cold.

Numerical and experimental tests have been performed for different Rayleigh numbers. The local and mean Nusselt numbers are presented for different angles of the triangle. The numerical code is written in a FORTRAN finite difference numerical method and the governing equations are solved. Numerical and experimental results show good agreement. It can be seen that the angle gradient can be used to control heat transfer.

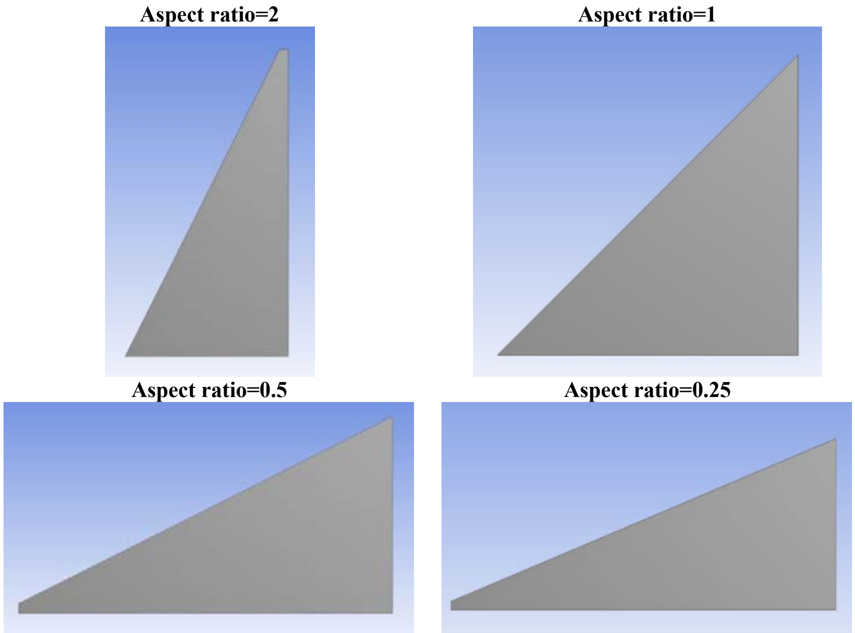

Fig. 1 Problem Schematic

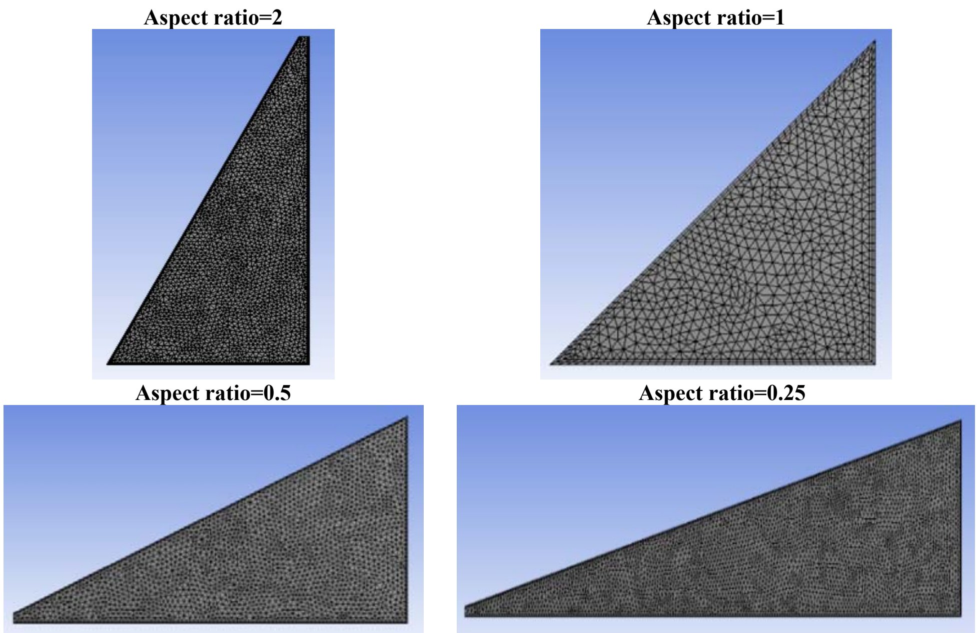

Fig. 2 Meshing for different geometries

The enhancement of nanofluid heat transfer in a triangular enclosure has been numerically performed by Billah et al. [18]. The proposed model is developed to analyze the performance of unsteady nanofluid heat transfer in an enclosure taking into account solid volume fraction, variable velocity and variable thermal boundary conditions. The governing equations include momentum and energy equations and the Galerkin finite element method is used. The results are obtained for wide ranges of Grashof number and in time steps. Saha and Gu [19] investigated the unsteady natural convection in a triangular enclosure with non-uniform cooling on a sloping surface and uniform heat at the bottom. Numerical simulations of Rayleigh numbers and ratios of different sizes were performed using the finite volume method.

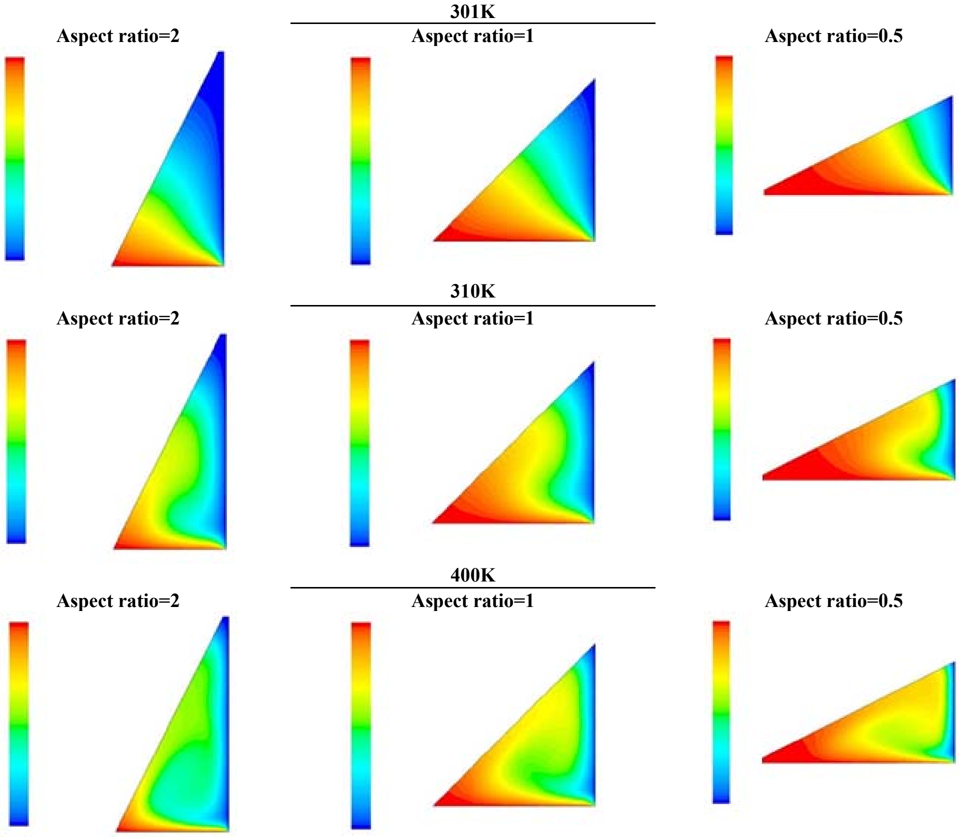

Fig. 3 Temperature contour for different aspect ratio

Numerical simulations show that transient flow development is divided into three categories and stages: the initial phase, the transient phase and the steady state. The flow inside the enclosure is significantly dependent on the governing equations, the Rayleigh number, and the size ratio.

Mahian and colleagues [20] evaluated the average Nusselt number value and heat transfer coefficient rate for natural convection of silica nanofluid water in a square and triangular enclosure using theoretical equations. The relationships used to calculate the enclosure heat transfer characteristics are subject to the thermophysical properties of nanofluids. To avoid error, thermophysical properties have been obtained experimentally and conventional models have not been used because of the possibility of error. Heat transfer rates in square and triangular enclosures at different Rayleigh numbers, different nanofluid volume fractions were investigated, and local and intermediate Nano silver numbers were extracted.

The purpose of the present study is to investigate triangular enclosure numerically and obtain the temperature, velocity and Nusselt number distribution for three normal conditions, summer and winter day's boundary conditions with different aspect ratio. The effect of aspect ratio on the temperature distribution and velocity vectors of the triangular enclosure as well as the effect of ambient temperature (summer or winter) will be discussed.

II. Problem Statement

In the present study, a natural convection heat transfer in a triangular enclosure is investigated. The fluid is considered air. For more accurate and better understanding of the problem, four triangular enclosure with different aspect ratio are considered. As can be seen in Fig. 1, four triangular enclosures with aspect ratio 2, 1, 0.5 and 0.25 are selected for investigation of the problem.

A. Governing Equations

The governing equations including continuity, momentum and energy for a laminar, steady and incompressible fluid are introduced as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\rho u\frac{\partial u}{\partial x}+\rho v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

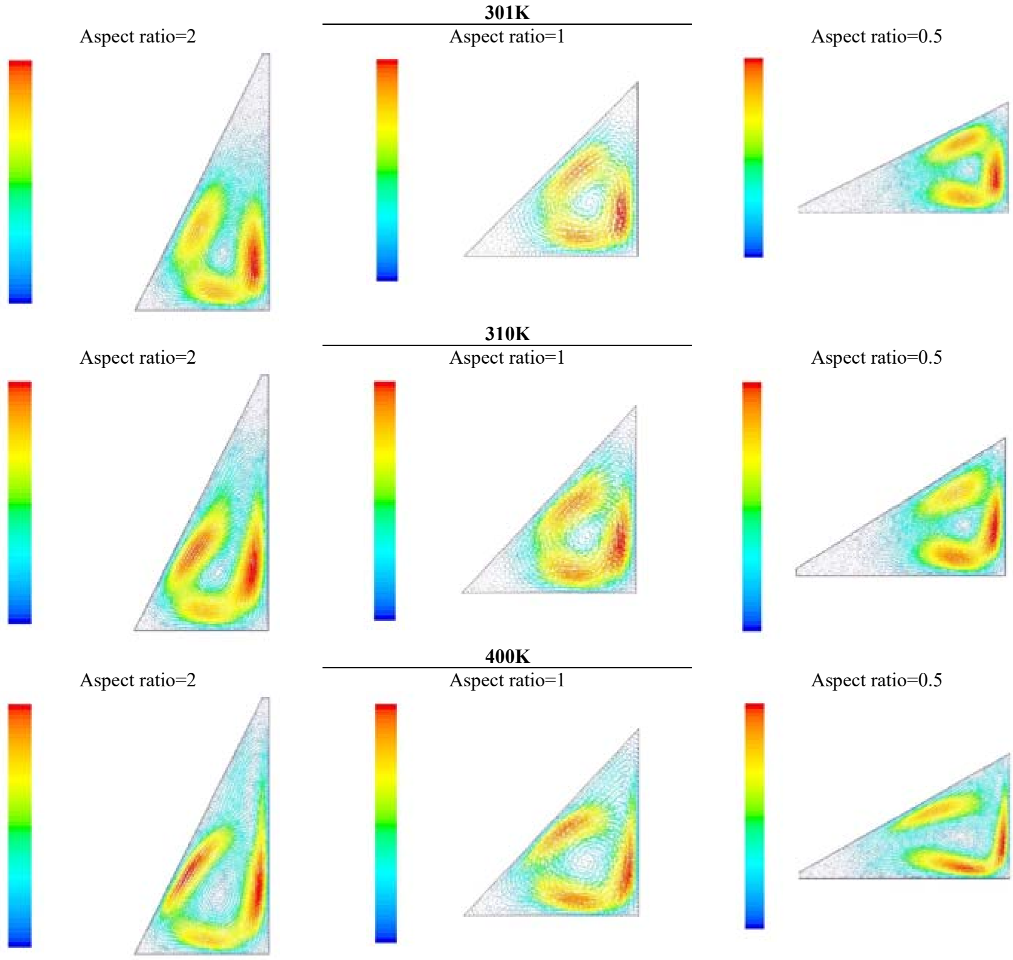

Fig. 4 Velocity vector for different aspect ratio

$$\rho u\frac{\partial v}{\partial x}+\rho v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+g\beta\rho\left(T_h-T_c\right) \tag{3}$$

$$\rho c_p\frac{\partial (uT)}{\partial x}+\rho c_p\frac{\partial (vT)}{\partial y}=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) \tag{4}$$

x and y are the distances along the horizontal and vertical directions, respectively, u and v are the velocity components in the x and y, respectively, T is the temperature, g is the gravitational acceleration, μ the dynamic viscosity, p pressure, T_h and T_c are the hot and cold wall temperatures, respectively, and ρ is the density. Thermophysical properties, except the density which is dependent to temperature, are considered constant. In addition, Boussinesq approximation is considered for the natural convection heat transfer. The radiation heat transfer is neglected.

B. Boundary Conditions

Three boundary condition types are considered as follows:

- *Type 1:* Vertical side with constant temperature of 300K and hypotenuse is considered as thermally insulated. For the horizontal side which is the higher temperature side, different temperatures are determined and the results will be investigated.
- *Type 2:* Winter simulation in which the hypotenuse has a constant temperature of 0 °C, a bottom side with a constant temperature of 27 °C and a vertical side is insulated.
- *Type 3:* Simulation of a summer day with a constant flux of 100 W/m^2, a bottom side with a constant temperature of 27 °C and a vertical side is insulated.

III. Numerical Solution

In the present study, the ANSYS Fluent Software is used for the problem geometry simulation and the governing equations solution. The finite volume method is used. Central differencing is used for the diffusive terms, while the second-order upwind scheme is applied for the convective terms. In order to avoid round-off errors, double precision is used for all calculations. The SIMPLE algorithm is employed for the pressure-velocity coupling and the momentum and continuity equations are solved using the steady-state iterative algorithm. Furthermore, to have the converged results, the residual error is selected 10^{-5}.

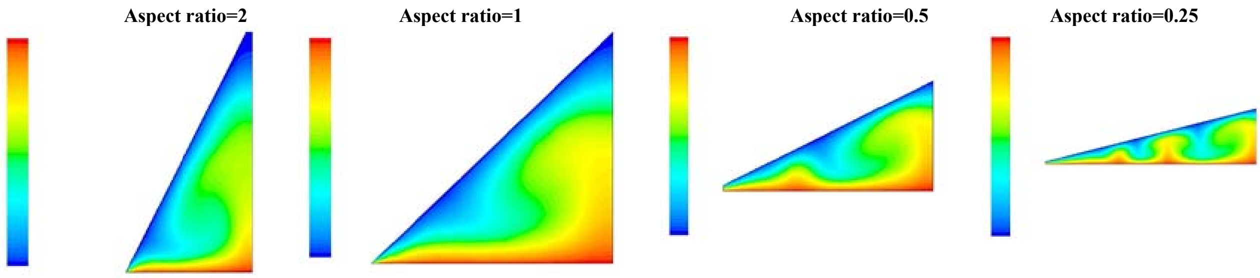

Fig. 5 Temperature contour in winter day

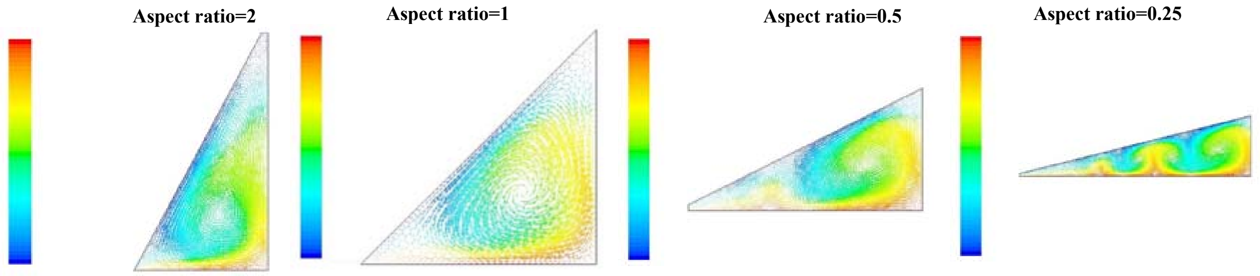

Fig. 6 Velocity vector in winter day

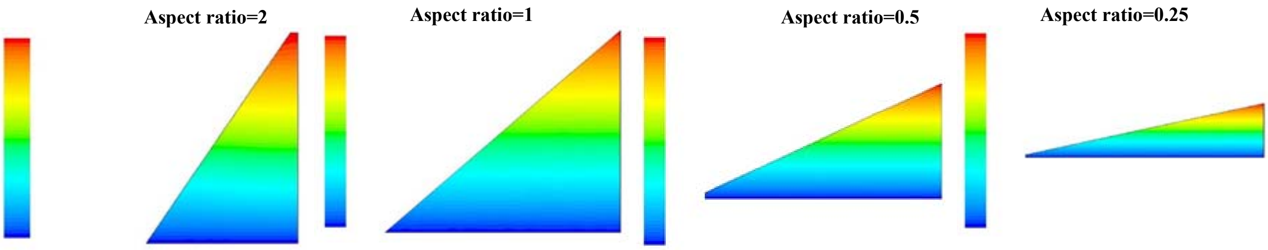

Fig. 7 Temperature contour in summer day

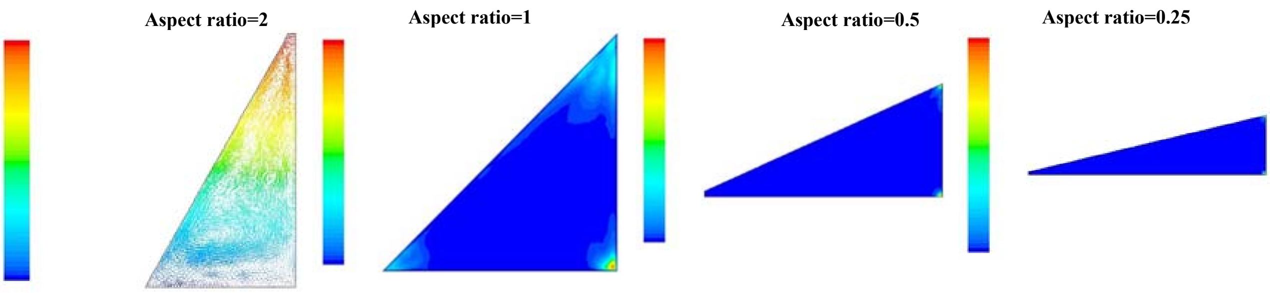

Fig. 8 Velocity vector in summer day

Due to the problem geometry and the difficulty in meshing the corners, especially at small angles, the areas near the wall have meshed separately with boundary layer mesh and for the other area, the triangular mesh is used. The meshing is illustrated in Fig. 2.

IV. Results

A. First Type of Boundary Condition

The influence of bottom side temperature augmentation and aspect ratio reduction on temperature contour and velocity vector is shown in Figs. 3 and 4. It can be observed that the augmentation of temperature leads to an increase in buoyancy effect. When the temperature is low, the temperature distribution is symmetric due to the low velocity, which is insufficient to circulate the fluid (air) within the enclosure. However, as the temperature increased, the convective effects become more prominent leading to the distortion of isotherms. This also resulted in the formation of multiple fluid circulation cells.

The same behavior can be observed for the velocity vector.

Because of the low air velocity as the below side temperature is small, the circulation does not occur. But as the bottom side temperature increased, the circulation happened. Also, it can be seen that as the aspect ratio decreases simultaneously with bottom side temperature increase, the buoyancy effect increased.

B. Second Type of Boundary Condition

The effect of winter day boundary condition on the temperature contour and velocity vector for different aspect ratio is depicted in Figs. 5 and 6, respectively. By the aspect ratio augmentation, the buoyancy effect in the enclosure increased and the multiple fluid circulation can be observed.

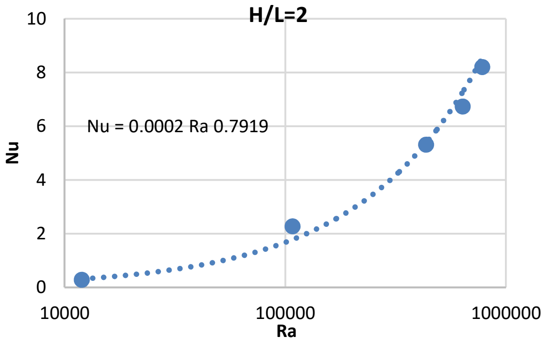

Fig. 9 Nusselt number as a function of Rayleigh number (first case)

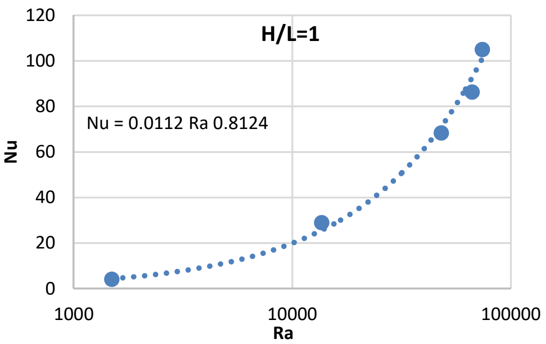

Fig. 10 Nusselt number as a function of Rayleigh number (second case)

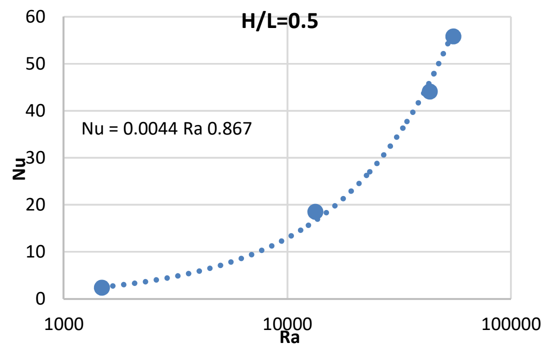

Fig. 11 Nusselt number as a function of Rayleigh number (third case)

C. Third Type of Boundary Condition

The effect of summer day boundary condition on the temperature contour and velocity vector for different aspect ratio is depicted in Figs. 7 and 8, respectively. In addition, the Nusselt number diagrams as a function of Rayleigh number for aspect ratio are plotted in Figs. 9-11.

V. Conclusion

In this study, an attic was considered as a triangular enclosure and numerically studied. ANSYS Fluent software is used for modeling and analysis. Four triangles with different aspect ratio (2, 1, 0.5 and 0.25) were considered and the including temperature contour, velocity vector and Nusselt number were plotted and discussed. The results were illustrated for three different types of temperature boundary conditions, i.e. normal, summer day and winter. As the bottom side temperature increased and aspect ratio of enclosure decreased, the natural convective effects become more dominated. This can be led to the formation of multiple fluid circulation cells.

References

[1] H. Chiang and C. Kleinstreuer, "Analysis of passive cooling in a vertical finite channel using a falling liquid film and buoyancy-induced gas-vapor flow," International Journal of Heat and Mass Transfer, vol. 34, pp. 2339-2349, 1991.

[2] P. Payvar, "Laminar heat transfer in the oil groove of a wet clutch," International Journal of Heat and Mass Transfer, vol. 34, pp. 1791-1798, 1991.

[3] P. M. Haese and M. D. Teubner, "Heat exchange in an attic space," International Journal of Heat and Mass Transfer, vol. 45, pp. 4925-4936, 2002.

[4] K. A. Joudi, I. A. Hussein, and A. A. Farhan, "Computational model for a prism shaped storage solar collector with a right triangular cross section," Energy Conversion and Management, vol. 45, pp. 391-409, 2004.

[5] H. Mistry, s. Ganapathi, S. Dey, P. Bishnoi, and J. L. Castillo, "Modeling of transient natural convection heat transfer in electric ovens," Applied Thermal Engineering, vol. 26, pp. 2448-2456, 2006.

[6] A. M. A. Dayem, "Experimental and numerical performance of a multi-effect condensation–evaporation solar water distillation system," Energy, vol. 31, pp. 2710-2727, 2006.

[7] S. Wang, A. Faghri, and T. L. Bergman, "A comprehensive numerical model for melting with natural convection," International Journal of Heat and Mass Transfer, vol. 53, pp. 1986-2000, 2010.

[8] S. Kalaiselvam, M. Veerappan, A. Arul Aaron, and S. Iniyan, "Experimental and analytical investigation of solidification and melting characteristics of PCMs inside cylindrical encapsulation," International Journal of Thermal Sciences, vol. 47, pp. 858-874, 2008.

[9] T. Fusegi and J. M. Hyun, "Laminar and transitional natural convection in an enclosure with complex and realistic conditions," International Journal of Heat and Fluid Flow, vol. 15, pp. 258-268, 1994.

[10] S. Ostrach, "Natural Convection in Enclosures," Journal of Heat Transfer, vol. 110, pp. 1175-1190, 1988.

[11] C. Hoogendoorn, "Natural Convection in Enclosures Proc. 8th Int," in Heat Trans-fer Conf. San Francisco, 1986.

[12] T. S. Lee, "Computational and experimental studies of convective fluid motion and heat transfer in inclined non-rectangular enclosures," International Journal of Heat and Fluid Flow, vol. 5, pp. 29-36, 1984.

[13] L. Iyican, Y. Bayazitoğlu, and L. C. Witte, "An Analytical Study of Natural Convective Heat Transfer within a Trapezoidal Enclosure," Journal of Heat Transfer, vol. 102, pp. 640-647, 1980.

[14] O. Kamiyo, D. Angeli, G. Barozzi, M. Collins, V. Olunloyo, and S. Talabi, "A comprehensive review of natural convection in triangular enclosures," Applied Mechanics Reviews, vol. 63, p. 060801, 2010.

[15] Y. Varol, "Natural convection in porous triangular enclosure with a centered conducting body," International Communications in Heat and

Mass Transfer, vol. 38, pp. 368-376, 2011.
[16] S. M. Aminossadati and B. Ghasemi, "Enhanced natural convection in an isosceles triangular enclosure filled with a nanofluid," Computers & Mathematics with Applications, vol. 61, pp. 1739-1753, 2011.
[17] H. F. Oztop, Y. Varol, A. Koca, and M. Firat, "Experimental and numerical analysis of buoyancy-induced flow in inclined triangular enclosures," International Communications in Heat and Mass Transfer, vol. 39, pp. 1237-1244, 2012.
[18] M. M. Billah, M. M. Rahman, M. A. Razzak, R. Saidur, and S. Mekhilef, "Unsteady buoyancy-driven heat transfer enhancement of nanofluids in an inclined triangular enclosure," International Communications in Heat and Mass Transfer, vol. 49, pp. 115-127, 2013.
[19] S. C. Saha and Y. T. Gu, "Natural convection in a triangular enclosure heated from below and non-uniformly cooled from top," International Journal of Heat and Mass Transfer, vol. 80, pp. 529-538, 2015.
[20] O. Mahian, A. Kianifar, S. Z. Heris, and S. Wongwises, "Natural convection of silica nanofluids in square and triangular enclosures: Theoretical and experimental study," International Journal of Heat and Mass Transfer, vol. 99, pp. 792-804, 2016.