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Using ANSYS Fluent, examine natural convection in a trapezoidal enclosure

Rajesh Kumar Behera [1*], Ajay Kumar Sahoo[2]
[1*]Assistant Professor, Department of Mechanical Engineering, Nalanda Institute of Technology, Bhubaneswar, Odisha, India
2Assistant Professor, Department of Mechanical Engineering, Nalanda Institute of Technology, Bhubaneswar, Odisha, India
*Corresponding author e-mail: rajeshbehera@thenalanda.com

Abstract:

With the aid of the commercial programme ANSYS Fluent, the heat transfer characteristics of natural convection in a trapezoidal enclosed room with air are investigated. About its vertical mid plane, the enclosure is symmetrical. Lower temperature settings are used for the two inclined side walls, whereas higher temperatures are used for the lowest horizontal wall. It is kept the upper wall adiabatic. Several inclination degrees of the enclosure are calculated (-20°, -10°, 0°, 20°, 30°, 35°, 40°, 45°, and 50°). The largest amount of air motion is discovered to be close to the vertical midplane. The corners of the cage develop stagnant areas. The rate of heat transfer declines as the slope of the wall increases.

Keywords: Enclosure; Trapezoidal; ANSYS Fluent; Rayleigh number

1. Introduction

There has been a lot of investigation into natural convection in the enclosures over the past few years. Its usability in numerous thermal engineering applications, such as air conditioning systems, cooling of electronic equipment, heating of furnaces, etc., have allowed it to draw in a sizable audience. When an enclosure is properly constructed to achieve maximum heat transfer rates, it contributes significantly to the transmission of energy. The primary barrier to improving heat transfer performance, however, continues to be the lower heat conductivity levels of the commonly used heat transfer fluids, such as glycol, water, oil, etc. Ganzarolli et al. [1] used a stream function-vortices formulation to quantitatively study the steady natural convection in an enclosure that was heated from below and symmetrically cooled from the sides. The Prandtl number is determined to have little effect on the Nusselt number, according to numerical values of the Nusselt number as a function of the Rayleigh number. Using a stream function-vorticity framework, Aydin et alnumerical .'s investigation of natural convection in rectangular enclosures heated from one side and chilled from the roof. When the enclosure is shallow, the influence of the Rayleigh number on heat transport is shown to be more important. When the enclosure is tall and the Rayleigh number is large, the aspect ratio's impact is greater. In a two-dimensional differentially heated inclined enclosure, Soong et al. [3] conducted a numerical examination of natural convection and the related mode-transition and hysteresis phenomena. We illustrate hysteresis phenomena for Ra 2000.. Hiroyuki et al. [4] conducted analysis on natural convection in an inclined square channel experimentally and numerically. The maximum rate of heat transfer was found both theoretically and experimentally to occur at about 50 degrees of inclination. The minimum heat transfer rate and a change in the orientation of the two-dimensional roll-cells were found experimentally to occur at an inclination of about 10 degrees. Oosthuizen et al. [5] considered three-dimensional natural convective flow in a rectangular enclosure with vertical sidewalls and horizontal top and bottom surfaces. Because of the application being considered, results have only been obtained for Pr=0.7. Frederick [6] conducted study on natural convection in an inclined square enclosure with a partition attached to its cold wall. At high Rayleigh numbers, the heat transfer reduction is affected by secondary buoyancy forces, generated by the partition. Lee, T. S. [7] constructed non-rectangular enclosures with 45° slanted walls (one heated and another cooled), and performed theoretical and experimental studies of fluid motion and heat transfer in those enclosures. Remaining parallel sides are insulated. To investigate the effects of the AR, Ra, and direction of the enclosure on the heat transfer properties, the enclosure is spun along the longitudinal axis. As the angle of inclination rose from 0 to 360°, a lower average and a higher average Nusselt number were seen. It was concluded that the heat transfer and fluid flow within the enclosure is greatly affected by both the cavity orientation angle and Rayleigh number or AR of 3 and 6. Varol et al. [8] in their paper wrote about the natural convection under steady state for a 2D trapezoidal enclosure with an orthogonal side wall filled with a porous medium. The parallel walls are adiabatic and the orthogonal wall is heated. The inclined wall is cooled with a cooler. The study is done for three different cases, changing the position of the cooler wall. The results are presented for aspect ratios, AR=0.25, 0.50 and 0.75 and Rayleigh number, $100 < Ra < 1000$ which indicate significant enhancement in flow and temperature patterns in comparison to those with both the wall orthogonal with similar parameters. Varol et al. [9] undertook the investigation on buoyancy-induced, steady flow for heat transfer by free convection in a trapezoidal enclosure filled with a water-saturated cold porous medium at 277K. The results are presented by applying finite-difference method with aspect ratios changing between 0.25 to 0.75 and Rayleigh number between 100-1000. The maximum density effect cause buoyancy force reversals which results in reduced strength of convection and average Nu. The convective flow strength increases for higher AR and increased Ra numbers. Varol et al. [10] focused on the growth of entropy by natural conduction and convection in a right-trapezoidal enclosure filled with a penetrable regime that is saturated with fluid. The right-angled solid wall on the left has a specific conductivity and thickness. The outer side wall is kept at an elevated temperature than the inclined wall and the remaining walls are kept adiabatic. Darcy method of finite difference is employed to solve the governing equations. They have taken Ra ($50 < Ra < 1000$), and inclination angle as 35°, 45° and 60°. Results convey that rate of heat transfer is proportional to Rayleigh number. The dimensionless thickness of the solid wall and the thermal conductivity ratio affect significantly on the temperature distribution as well as heat transfer. Saleh et al. [11] investigated for enhancing energy transfer with nanofluids in a trapezoidal geometry for different relevant parameters. They considered Water-Al2O3 and Water-Cu within the enclosure with inclined sloping walls. Considering Gr, θ and φ as the governing parameters, they noticed that heavily concentrated Cu nanoparticles with a sharply sloped wall work well to speed up heat transfer. Tiwari and Das [12] examined how nanofluids behaved in a square cavity with a two-sided cover that was driven by differential heating with finite volume approach using SIMPLE algorithm. The convection recirculation and flow processes induced by Cu-Water nanofluid were studied using constant temperature side walls and isothermal top and bottom walls for $Pr = 6.2$. It was concluded that both the Richardson number and the directions of the mobile walls have impact on the fluid motion and convection heat transfer in the square cavity. Esfe et al. [13] experimented on natural convection by carbon nano-tubes filled with ethylene glycol and water. He used SIMPLER algorithm for governing equation discretization. The geometry consisted of a trapezoid with the parallel walls at constant temperature and side walls with zero heat flux. The results convey that Nu is inversely depended on the the aspect ratio because of dominance of conduction heat factor.

This article presents a study of free convection fluctuations in a trapezoidal container. A trapezoidal chamber with an internally heated and cooled sloping wall was evaluated using a 2-D static model created in ANSYS DesignModeler. The factors being examined are the distance between the parallel sides and the slope of the slanting walls. In order to investigate the heat transfer properties of the average heat transfer rate along the hot walls and the cold walls as well as the maximum velocity of the fluid inside the enclosure, ANSYS Fluent was used with air as the working fluid. The flow pattern and structure of the energy distribution inside the enclosure, which are modelled using stream functions and isotherms, are investigated.

2. Analysis

The schematic diagram of the trapezoidal enclosure with heated bottom wall is shown in Figure 1. The analysis has been carried out using ANSYS Fluent workbench. The modeling of the trapezoidal geometry is done in the ANSYS Design Modeler.

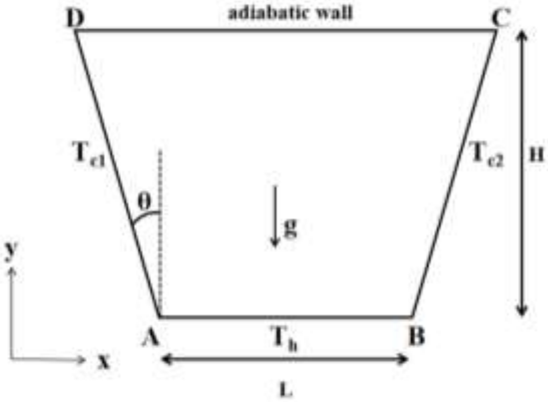


Figure 1: Schematic diagram of the enclosure

Face meshing and edge sizing method was done in commercial software ANSYS 2022 R2 (Fluent). For edge sizing the edges of the geometry were divided into 100 equal divisions. In the scoping method, the meshing was further refined with refinement level set to 1 for a smoother and finer mesh. Meshing of two dimensional geometry of the trapezoidal enclosure is shown in Figure 2.

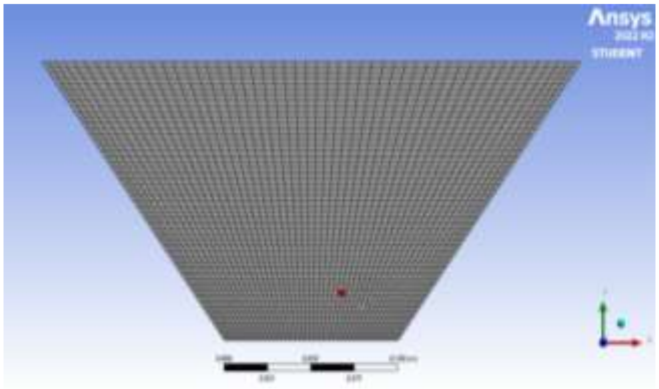


Figure 2: Meshing of geometry

2.1 Boundary Conditions

The lower horizontal wall of the enclosure is maintained at a constant hot temperature (T_h) of 315K, while the sloping side walls are kept at a constant cold temperature (T_c) of 298K. By setting the top wall's heat flux to zero, the top wall is kept adiabatic. In the negative Y-direction, the fluid inside the container experiences a gravitational acceleration of 9.81 m/s^2.

2.2 Material Properties

Table 1: Default properties of air from Fluent database

Sl. no.	Description	Symbol	Value	Units
1.	Thermal conductivity	K	0.0242	*W/m K*
2.	Density	ρ	1.1405	kg/m^3
3.	Specific heat	C_P	1006.43	*J/kg K*
4.	Dynamic viscosity	μ	1.7894×10^{-5}	*kg/ms*
5.	Thermal expansivity	β	0.003263	K^{-1}

2.3 CFD Setup and Solutions

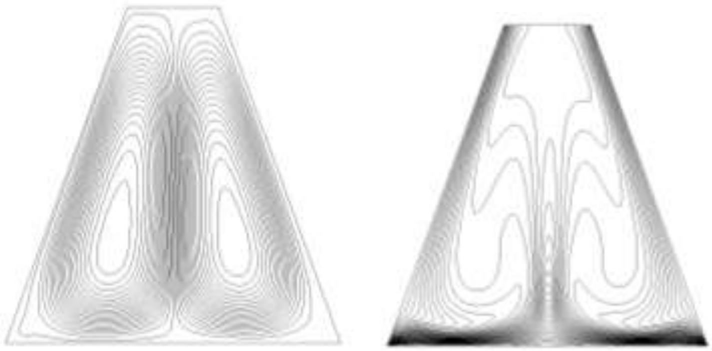
Table 1 describes the default properties of air from Fluent database. In the CFD analysis default air properties from the ANSYS Fluent database are used to for calculations. Boussinesq approximation is used for density to account for the buoyancy driven flow and the thermal expansion coefficient (β) is calculated for the temperature range of 278 K - 315 K. The solver is set to pressure-based with the time parameter set to steady. The viscosity of the fluid is set to laminar and the gravitational component has been added to negative Y-axis. The energy is switched on to account for the heat transfer in the fluid and between the walls and the fluid. Since the problem is supposed to hail in a general environment, hybrid initialization is used. SIMPLE solution method is applied for pressure-velocity coupling while spatial pressure discretization is performed by PRESTO! discretization.

3. Results and discussion

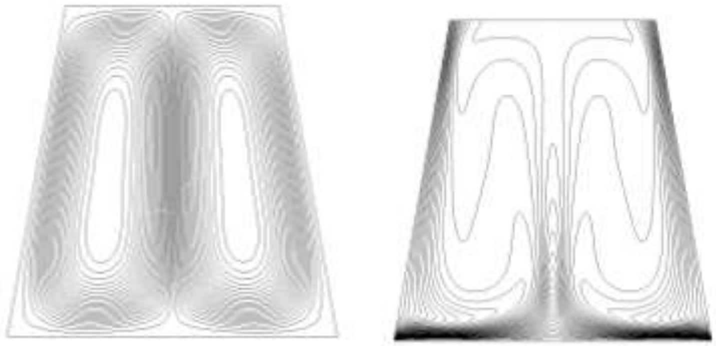
Within this study, inclination angle (θ) is varied from -20° to 50°. Between this range, 9 different inclination angles has been taken for each of 5 different heights of the enclosure (75 mm, 100 mm, 125 mm, 150 mm and 200 mm) to study the variations in its temperature distribution, flow pattern and energy transfer. The contours of stream function and isotherm are in obtained for analysis. Further the total surface heat transfer coefficient is considered.

3.1 Flow patterns and energy distribution

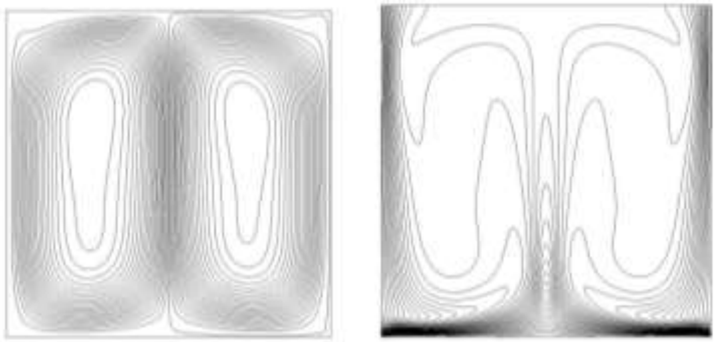
Since the domain and the boundary conditions of the geometry are symmetric about the vertical mid-plane, so the temperature distribution and flow field are also symmetric with reference to that plane. Figure 3(a-f)shows the isotherm contours and the stream function contours for different inclination angles,θ = -20°, 10°, 0°, 20°, 30° and 40°. The distribution of isotherms shows that thermal stratification occurs near the hot bottom wall.



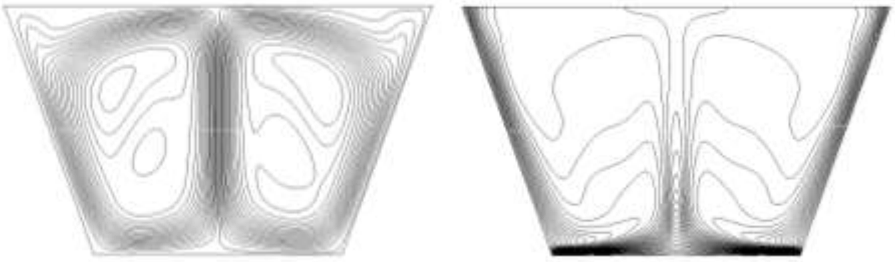
(a) θ = -20°



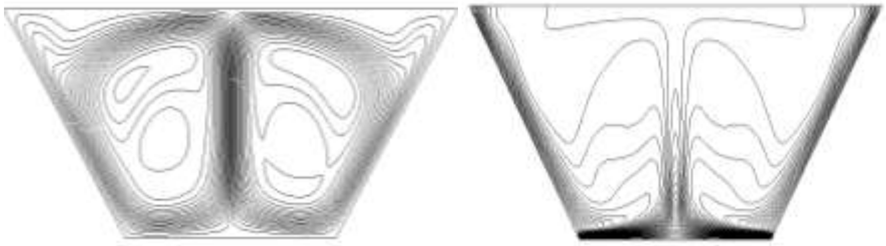
(b) θ = -10°



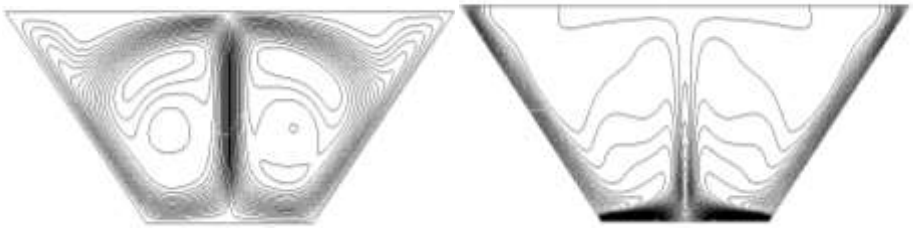
(c) θ = 0°



(d) θ = 20°



(e) θ = 30°

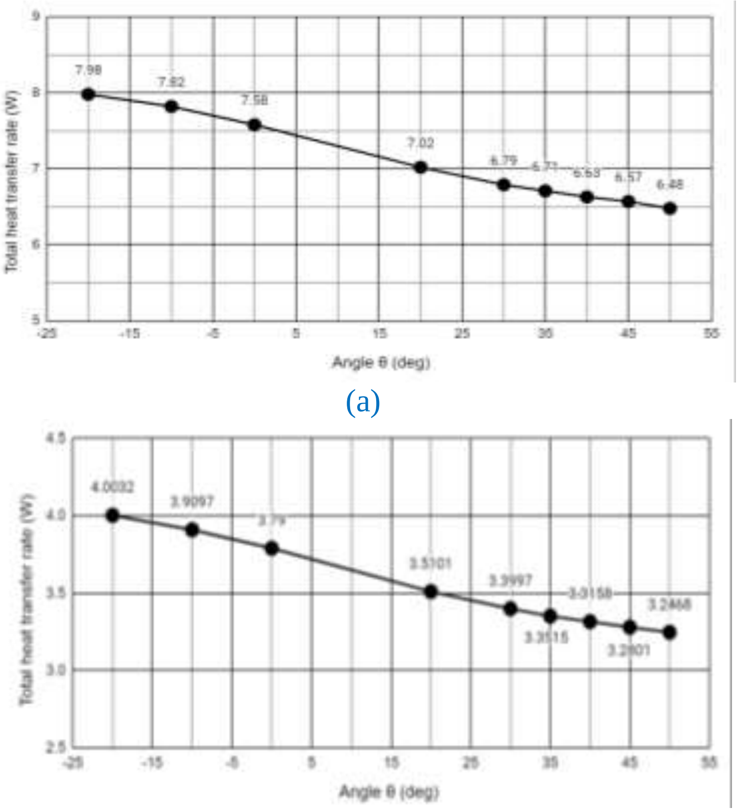


(f) θ = 40°

Figure 3: Contours of stream function and isotherm for different inclination angles (θ)

It is observed that maximum of the stream function is centralized towards the central mid plane due to the superposition of streamlines, so the flow rate is more in this region. This indicates that most of the internal heat exchange occurs through thermal conduction. However, around the centre on both sides of the mid plane, the streamlines are more apart from each other. Therefore the flow rate is less. The density of the streamlines at the symmetrical centres becomes lesser for higher positive angles. From the contours, it is evident that hot air starts moving up from the hot bottom boundary and divaricates near the top insulated wall. This is because when the hot fluid moves up it creates a vacuum on the sides inducing motion of the fluid towards the side walls. When the fluid touches the cold side walls it begins to cool and runs along them, creating two symmetrical concentric rolls about the vertical axis. While the fluid moves down, the fluid moves away from the wall. There are stagnant regions at the corners of the geometry. The size of the stagnant region at the bottom is more for higher negative angles. For positive θ, the hot walls face upwards and the fluid moving downwards flow along the wall filling up the bottom corners while creating larger areas of stagnant fluid corners at the top. The size of the stagnant region at the top corners increases with higher positive angles. In the isotherms most of the contour appears at the lower half of the regime. As air moves upward, the contour lines diverge and open up at the top adiabatic wall. Near the inclined cold walls the contours lines are parallel to the sloping walls and with increase in angle of inclination, the lines become more and more parallel.

3.2 Heat transfer characteristics



(a)

(b)

Figure 4: Variation of total heat transfer rate with inclination angle at (a) hot wall and (b) cold wall

Figure 4(a) and 4(b) show the changes in heat transfer rates with angle of inclination of side wall along the hot and the cold wall. For negative θ, the cold walls are facing downwards. Thus, the surface heat transfer coefficient decreases as it moves towards the bottom along the cold side wall. But, as θ increases, the cold walls face upward and the area of interaction between the fluid and the cold side wall becomes lesser and lesser due to the formation of stagnant regions in the top corners. So, the total heat transfer rate along the walls decreases with increase in angle θ. Thus it can also be said that acute sloping of the side walls of the structure enhances heat transfer rates.

4. Conclusion

The length of the heated bottom wall is kept constant while studying free convection phenomena inside a trapezoidal enclosure with modifications in enclosure height and side wall inclination angles. The following conclusions are reached during the course of the study:

Towards the centre of the loops on both sides of the vertical mid plane, when flow from both sides caused it to be at its highest, the air flow rate was lowest. The distance between the streamlines at these centres grows as the inclination of the sloping wall rises. In the enclosure's corners, stationary zones began to form, and their sizes grew larger towards the top corners for higher positive angles.

The creation of stagnant areas causes the area of contact between the fluid and the cold walls to decrease as the angle of the sloping wall increases. As a result, heat transport also slows down.

References

[1] Ganzarolli, M. M. and Milanez, L. F., “Natural convection in rectangular enclosures heated from below and symmetrically cooled from the sides”, *Int. J. Heat Mass Transfer,* Vol. 38, 1995, pp. 1063-1073.

[2] Aydin, O., Unal, A. and Ayhan, T., “Natural convection in rectangular enclosures heated from one side and cooled from the ceiling”, *Int. J. Heat Mass Transfer,* Vol. 42, 1999, pp. 2345-2355.

[3] Soong, C. Y., Tzeng, P. Y., Chiang, D. C. and Sheu, T. S., “Numerical study on mode-transition of natural convection in differentially heated inclined enclosures”, *Int. J. heat and Mass Transfer,* Vol. 17, 1974, pp. 2869-2882.

[4] Hiroyuki, O. S. and Churchil, S. W., “Natural convection in inclined square channel”, *International Journal of Heat and Mass Transfer,* Vol. 17, 1974, pp. 401-406.

[5] Oosthuizen, P. H., Kalendar, A. and Simko, T. M., “Three dimensional natural convective flow in a rectangular enclosure with a rectangular heated section on one vertical wall and with the other vertical walls cooled”, *Proceedings of the ASME Summer Heat Transfer Conference,* 2008, pp. 491-497.

[6] Frederick R. L., “Natural convection in an inclined square enclosure with a partition attached to its cold wall”, *International Journal of Heat and Mass Transfer,* Vol. 32, January1989, pp. 87-94.

[7] Lee, T. S. (1984). Computational and experimental studies of convective fluid motion and heat transfer in inclined non-rectangular enclosures. *International journal of heat and fluid flow*, *5*(1), 29-36.

[8] Varol, Y., Oztop, H. F., & Pop, I. (2009). Natural convection in right-angle porous trapezoidal enclosure partially cooled from inclined wall. *International Communications in Heat and Mass Transfer*, *36*(1), 6-15.

[9] Varol, Y., Oztop, H. F., & Pop, I. (2010). Maximum density effects on buoyancy-driven convection in a porous trapezoidal cavity. *International communications in heat and mass transfer*, *37*(4), 401-409.

[10] Varol, Y., Oztop, H. F., & Pop, I. (2009). Entropy analysis due to conjugate-buoyant flow in a right-angle trapezoidal enclosure filled with a porous medium bounded by a solid vertical wall. *International Journal of Thermal Sciences*, *48*(6), 1161-1175.

[11] Saleh, H., Roslan, R., & Hashim, I. (2011). Natural convection heat transfer in a nanofluid-filled trapezoidal enclosure. *International Journal of Heat and Mass Transfer*, *54*(1-3), 194-201.

[12] Tiwari, R. K., & Das, M. K. (2007). Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids. *International Journal of heat and Mass transfer*, *50*(9-10), 2002-2018.

[13] Esfe, M. H., Arani, A. A. A., Yan, W. M., Ehteram, H., Aghaie, A., & Afrand, M. (2016). Natural convection in a trapezoidal enclosure filled with carbon nanotube–EG–water nanofluid. *International Journal of Heat and Mass Transfer*, *92*, 76-82.