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Numerically investigation of Flow and Heat Transfer in differentially heated enclosures

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Abstract: In this research work natural convection in two dimensional cavity is studied numerically for differently heated air filled square and rectangular cavity. Vertical cavity with two adiabatic and hot and cold wall with different aspect ratio of 1, 2.5, 5, 7.5 and 10 has taken for investigation. the heat transfer was investigated over the wide range of Rayleigh number from 10^3 to 10^6. Solutions are obtained for several Rayleigh numbers with Prandtl number Pr = 0.70 and aspect ratio 1, 2.5, 5, 7.5 and 10. The Pressure-Velocity Coupling Method used with Non-Iterative Time Advancement (NITA) scheme used to solve the problem. Flow patterns and isotherm plots were used to display the results, and for every case, local and mean Nusselt values were also produced. The results show that an increase in Rayleigh numbers greatly increases heat transfer, natural convection intensity, and average Nusselt number at a particular aspect ratio. The distribution of temperature and stream function are taken as a function of thermal and geometrical output parameter for given problem. Two stage investigations have been performed to find out the variation in the result between different approaches.

Keyword: ANN (average Nusselt number), AR (aspect ratio), LNN (local Nusselt number), Nu (Nusselt number), Pr (Prandtl number), Ra (Rayleigh number).

1. Introduction

Due to its many applications, the natural convection flow and heat transfer in rectangular enclosures are intensively studied. Enclosures are used in a variety of heat transfer equipment, including industrial furnaces, chimneys, skylights, roof windows, solar collector storage, and doors and windows of buildings. They can also serve as insulation for doors and windows of trains, air conditioning compartments, air conditioning units in automobiles, and many other heat-transfer devices when they are in a vertical position. The current work is concerned with the transmission of heat by natural convection in vertical enclosures. The vertical enclosures are made up of two glass panels that are separated by a short space and mounted in a frame. Since air is an insulator and a transparent substance, it fills the space between the glass panels so that light can travel through.

2. Problem Identification

All the researchers has focused on the analysis of natural convection in single enclosure but only few researchers has considered the comparative study between the cavity. The scope of the present study is to employ CFD methodology for computing laminar natural Convection flow and heat transfer in two-dimensional vertical square and triangular air cavities. The dimensionless Parameter i.e. Nusselt number depends upon Rayleigh number, Aspect ratio, Inclination and Prandtl number. In the present study the Prandtl number and inclination are fixed in all the cases, so the Nusselt number is the function of Rayleigh number and Aspect ratios. In the present study the Nusselt number is computed for the range of Rayleigh number and Aspect ratios is vary from 1 to 10.

3. Methodology

The Fluid analysis process involve geometry creation and meshing process to form the required boundary condition so it's one of the important process which greatly influence the end result of CFD. The two dimensional plain geometry of triangular and square profile is created by using geometry workbench in ANSYS. The geometry of the enclosed space, meshing and boundary identification is carried out in Ansys software.

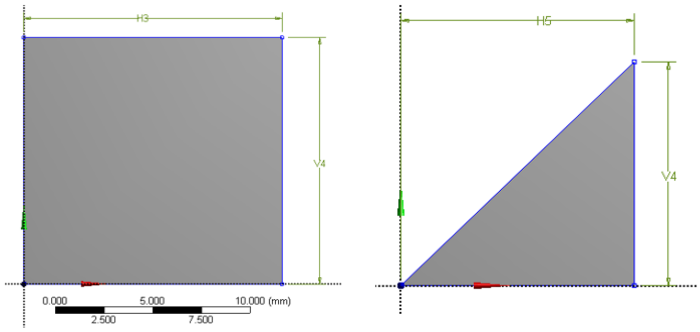


Fig. 1 Geometry of Square enclosed space for Ra=10^3

Mesh Generation

The term "finite volume method" refers to the process of dividing the control volume into smaller numbers of Nodes and elements of finite size after the geometry has been created. The process of meshing the control volume involves dividing the control volume into smaller finite-sized volumes.

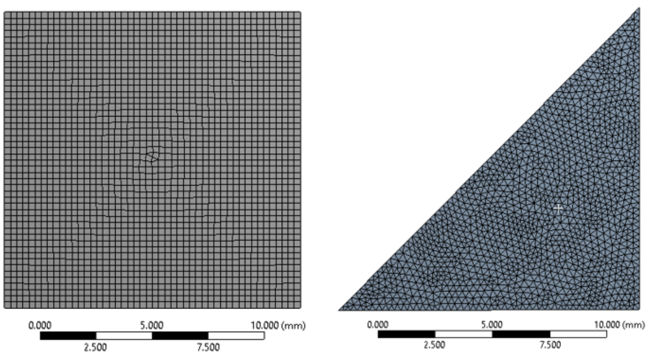


Fig. 2 Meshing of Square & Triangular Enclosed Space

Boundary condition

The properties of fluid are obtained at a mean temperature of differentially heated side walls, which is kept at temperature of 30^0C and 35^0C. The properties of air are calculated at 32.5^0C.

Table 1 Properties of fluid air at 32.5^0C

PROPERTY	UNIT	METHOD	VALUES
Temperature	K	Constant	305.5
Density	Kg/M3	Boussinesq	1.15575
Specific heat	J/kgK	Constant	1005
Thermal conductivity	W/mk	Constant	0.02634
Viscosity	Kg/ms	Constant	1.87E-05

Thermal expansion	1/K	Constant	0.003273
Gravitational acceleration	m/s2	Constant	9.801
Dynamic viscosity	Kg/ms	Constant	0.00002074
Beta	1/k	Constant	2.87E-03

4. Result

Table 2:- Nusselt number of Square & Triangular cavity

S No	Rayleigh Number Ra	Square Cavity (Nu)	Triangular Cavity (Nu)
1	1000	1.23	3.18
2	10000	2.08	3.49
3	100000	4.48	5.56
4	1000000	8.86	10.1

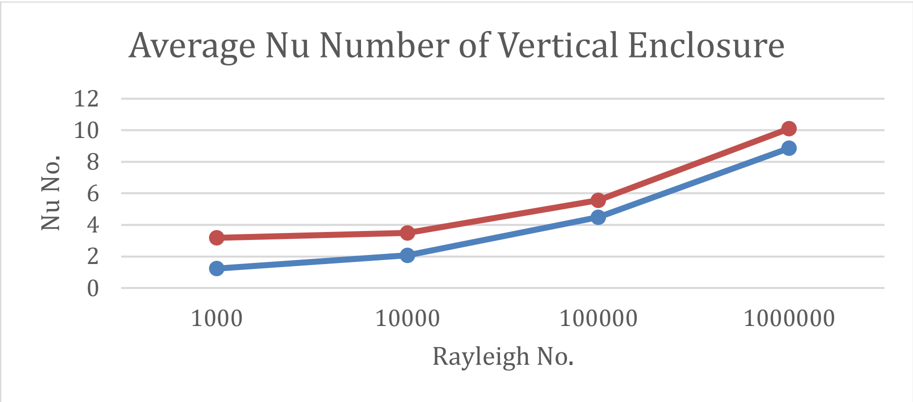
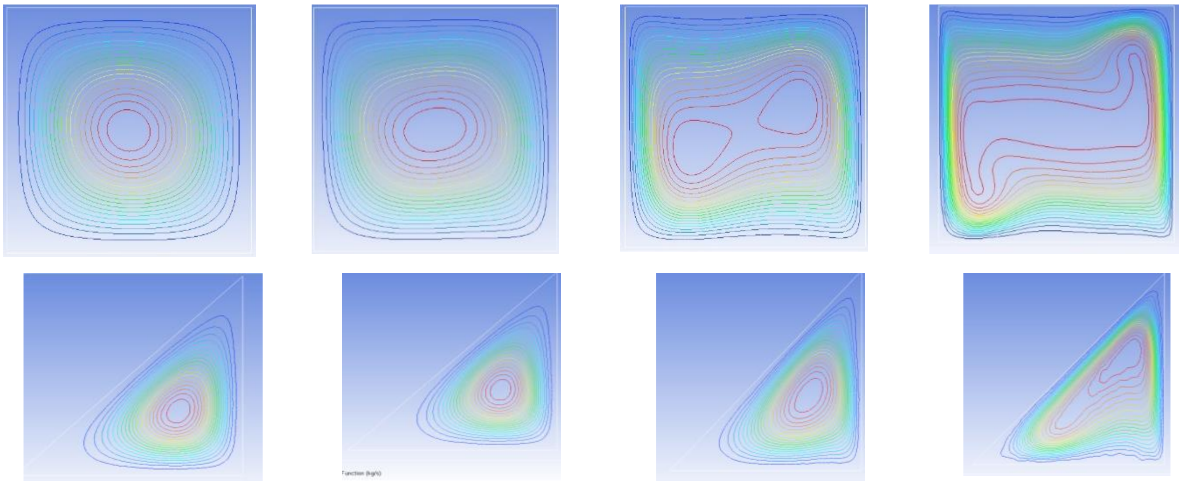
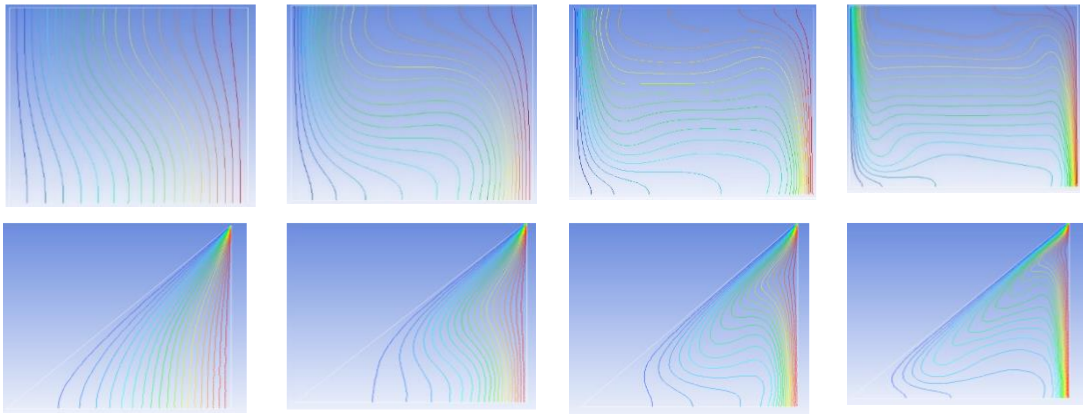


Fig. 3: Variation of Nusselt number with Rayleigh number at A=1



Rayleigh No 10^3 *Rayleigh No 10^4* *Rayleigh No 10^5* *Rayleigh No 10^6*

Fig.4: Stream function plot for square cavity at different Rayleigh number



Rayleigh No 10^3 Rayleigh No 10^4 Rayleigh No 10^5 Rayleigh No 10^6

Fig. 5: Temperature contour plot for square cavity at different Rayleigh number

S.No.	Rayleigh	Aspect ratio (A)	Nu Square Cavity	Nu Triangular Cavity
1	1000	2.5	1.14	3.08
2	1000	5	1.08	2.97
3	1000	7.5	1.06	2.81
4	1000	10	1.04	2.65
5	10000	2.5	2.25	3.88
6	10000	5	2.03	2.66
7	10000	7.5	1.82	2.57
8	10000	10	1.69	2.41
9	100000	2.5	4.18	5.19
10	100000	5	3.74	4.93
11	100000	7.5	3.45	4.57
12	100000	10	3.2	4.22
13	1000000	2.5	7.6	8.18
14	1000000	5	6.65	7.84
15	1000000	7.5	6.21	7.53
16	1000000	10	6	7.01

Table 3: Change in Nu. Square and triangular cavity in different Rayleigh no. and aspect ratio.

5. Discussion

Result of Heat transfer for square & triangular cavity

The computation fluid dynamic analysis in Ansys fluent workbench has performed to find out the Nusselt number and natural convection or nature of heat transfer from hot medium to cold medium. To find out the result in Ansys fluent we perform 1000 iteration for each combination of aspect ratio and Rayleigh No. Fluent provide wide range of solution in terms of continuity, energy, and velocity in x and y direction with respect to the time. On the basis of each result we calculate the average Nusselt number by maximum and minimum range by using user define function. The result tabulated below in table 2 and fig 3.

Stream Function Plot for Square Enclosure

The stream function plot is use to visualize the flow of air in square and triangular cavity for different Rayleigh number varying from 10^3 to 10^6 shown in Fig.4. It is observed that for all Rayleigh number circulation of air takes place from upward to downward. The circulation pattern exists due to density difference between side walls maintained at different temperature. It is observed that flow is unicellular for $10^3 \leq Ra \leq 10^4$ and multi-cellular for $10^5 \leq Ra \leq 10^6$.

Temperature Contours for Square Cavity

The temperature contour plots is used to study temperature distribution of air in square enclosures for different Rayleigh number varying from 10^3 to 10^6 shown in the fig.5 the detail study of temperature contour it is found that the path of contour becomes irregular with increasing the Rayleigh No.

Table 3 shows the change in Nusselt square and triangular cavity with respect to change in aspect ratio of 2.5, 5, 7.5, and 10.

6. Conclusion

The important conclusion can be summarized as follows:-

- The Nusselt Number is directly proportional to the Rayleigh Number.
- The stream function plot is circular for aspect ratio 1 and 2 for both cavity and it goes deformed for higher aspect ratio and Rayleigh Number.
- The average Nusselt number of the cavity rises for the same Rayleigh number as the aspect ratio falls, but the rate of increase also isn't determined. When the state of heat transfer is close to conduction, decreasing AR has a substantial impact on enhancing ANN; however, when convective heat transfer dominates, the effect is minor.

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