

# Flow CFD Analysis of and Heat Transfer in Differentially Heated Vertical Enclosures

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**ABSTRACT:** Natural convection in vertical enclosure has been extensively studied in past few decades. This spontaneous method of heat and flow has a wide range of applications in engineering. In these research work, natural convection was numerically analyzed in a vertical square and rectangle cavity heated on one right sides and cooled on the opposite side. We assume that the temperature of heat and cold wall is constant and other two wall is perfectly adiabatic. The objective of these studies was to investigate the behaviour of flow and heat transfer under the different Rayleigh number and aspect ratio. The CFD simulation and correlation factor shows that the nature of heat flow depend upon the Rayleigh number and aspect ratio. It also verified that the Nusselt number is strongly dependent on the Aspect ratio and this dimensionless variable increases with the increase of the L/H. The CFD simulation of natural convection problems satisfactorily described the current boundary condition.

Solutions are obtained for several Rayleigh numbers with Prandtl number  $Pr = 0.70$  and aspect ratio 1,2, and 3. The Pressure-Velocity Coupling Method used with Non-Iterative Time Advancement (NITA) scheme used to solve the problem. 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.

**KEYWORDS:** CFD Computational Fluid Dynamic, 2D Two Dimensional, Ra Rayleigh Number

## I. INTRODUCTION

The natural convection flow and heat transfer in rectangular enclosures are extensively Studied due to its diverse applications. In the vertical position enclosures can acts as insulation for doors and windows of buildings, air conditioning compartment of trains, industrial furnaces, chimney and many heat transfer equipment and in an inclined position it is used in skylights, roof windows, solar collector storage and many other solar applications. The present study is concern with natural convection heat transfer in rectangle enclosures. The rectangle enclosures consist of two glass panels set in a frame and separated by a small space. The gap between the glass panels is filled with air since air acts as insulator and air being a transparent medium allows light to pass through it. The 2-D representation of vertical enclosures is shown in the figure 1.

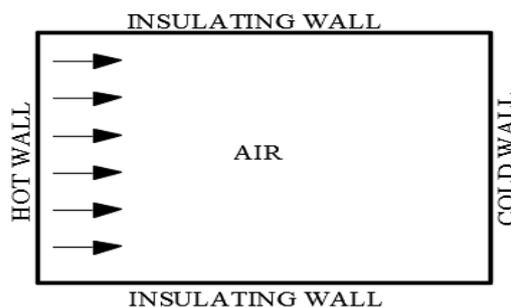


Fig. 1 Two-dimensional representation of vertical enclosure

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The figure 1 shows rectangle enclosures with two pieces of glass separated by a distance apart. In the present study a vertical enclosures is considered with side wall heating in which right wall is kept at a higher temperature and left wall is kept at lower temperature or vice-versa and top 2 and bottom walls are kept adiabatic. The space between two glasses is filled with air to reduce the rate of heat transfer. Heat transfer through vertical enclosures consists of following heat transfer mechanisms:

1. Natural convection in the air trapped inside the enclosure.
2. Forced convection on the outdoor surfaces.
3. Conduction through the solid components of the glass.
4. Radiation from both the indoor and outdoor surfaces.

## II. PROBLEM IDENTIFICATION

The present study deals with two-dimensional natural convection taking place inside enclosed Space. The enclosed cavity has differentially heated side walls and adiabatic top and bottom wall. In this problem the cavity is filled with air and the effect of conduction and radiation is neglected. The space between the enclosures is filled with air since air being transparent allows light rays to pass through it and also acts as insulator.

### ASSUMPTIONS

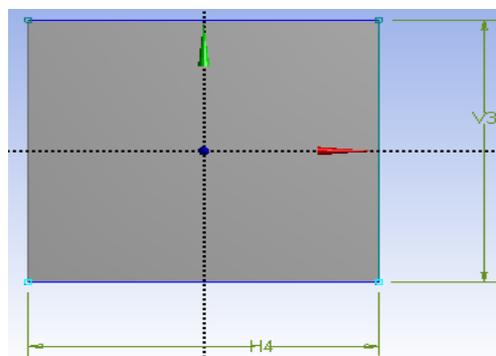
The following assumptions are made in the present work:

1. Flow is steady laminar natural convection.
2. Flow is two -dimensional.
3. The effect of conduction and radiation effects are neglected.
4. The top and bottom wall are perfectly adiabatic.

## III. METHODOLOGY

The geometry of cavity is created using Ansys 15 software by using geometry generation workbench for different Rayleigh number varying from  $10^3$  to  $10^6$  and aspect ratio at 1 , 2 & 3. The heat transfer analysis is carried out using Ansys (Fluent).

The dimensions of the length (L) of the cavity for different Rayleigh number varying from  $10^3$  to  $10^6$  is calculated by substituting the values of properties of fluid in the formula of Rayleigh Number. The height (H) of the cavity is found by multiplication of length (L) and aspect ratio (A) for a given Rayleigh number.



*Fig. 2 Geometry of vertical enclosed space for  $Ra=10^3$*

### MESH GENERATION

After creating the geometry it is required to divide the control volume into smaller number of Nodes and element of finite size, therefore it is called finite volume method. The method of splitting the Control volume into small finite size volume is known as meshing of the control volume. As Geometry is simple structured grid is preferred as it gives better

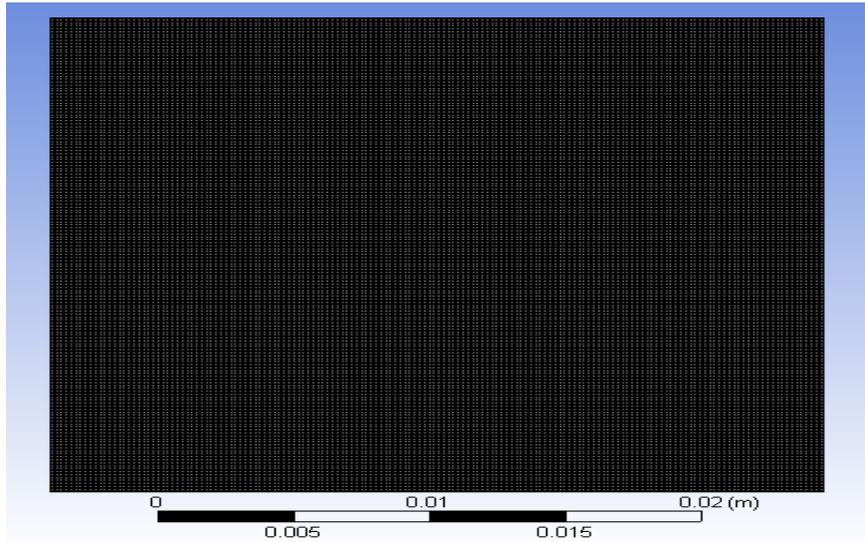
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results as compared to unstructured grid. Here we were using the minimum size of node 10e-04 m for mesh generation of square cavity.



*Fig.3 meshing of vertical enclosed space for  $Ra=10^3$*

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

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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

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## BOUNDARY CONDITION

The enclosed cavity has differentially heated side walls and adiabatic top and bottom wall which is shown in table 5.3 below.

*Table 4.3 Boundary condition of vertical cavity*

<i>BOUNDARY</i>	<i>TYPE</i>	<i>VALUES</i>
Left Side wall	Isothermal	T=308 K
Right Side wall	Isothermal	T=303 K
Top wall	Adiabatic	q= 0 W/m <sup>2</sup>
Bottom wall	Adiabatic	q= 0 W/m <sup>2</sup>

## IV. RESULT & DISCUSSION

In order to validate the code two-dimensional, laminar, steady natural convection of air with differentially heated side walls and adiabatic top and bottom walls of vertical cavity was solved. The thermal conditions and dimensions of the enclosures are permit to cover wide range of Rayleigh number varying from  $10^3$  to  $10^6$ . The temperature difference between side walls was kept at constant for all the cases. The property of air is obtained at mean temperature of hot wall and cold wall. The computed results of heat transfer for average Nusselt number are obtained by using commercial Computational Fluid Dynamics software and compared with results available in the literature.

*Table 3 Validation of results for vertical square enclosure*

<i>S No</i>	<i>Rayleigh Number Ra</i>	<i>Aspect Ratio</i>	<i>Present Study Nu</i>	<i>Vahl (Nu)</i>	<i>Byong-Hoon Chang [2] (Nu)</i>
1	1000	1	1.05	1.118	1.118
2	10000	1	2.15	2.243	2.241
3	100000	1	4.11	4.519	4.532
4	1000000	1	7.97	8.799	8.848

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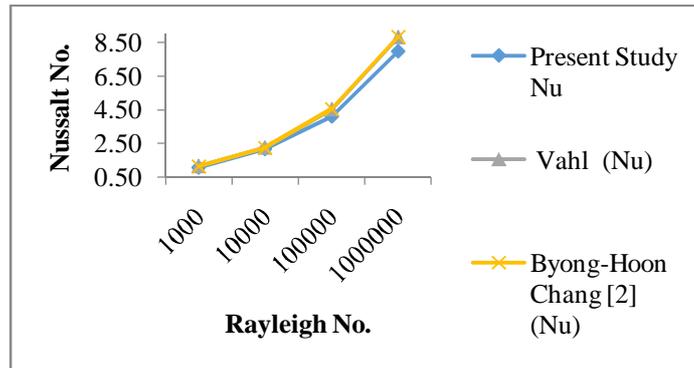


Fig. 4 Validation of Nusselt number for vertical enclosure

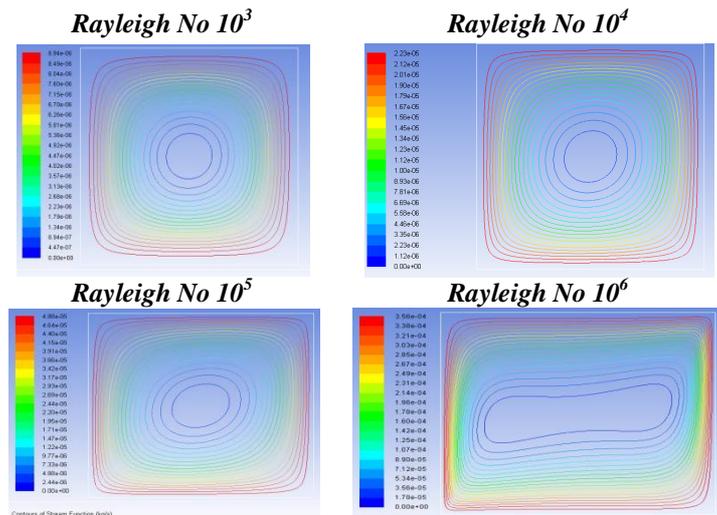
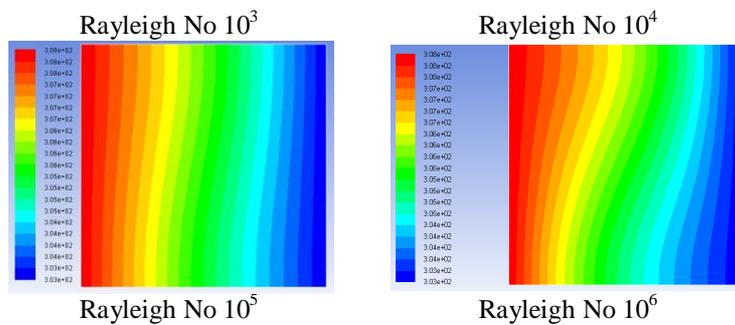


Fig. 5 Stream function plot for vertical cavity at AS 1 and different Rayleigh number

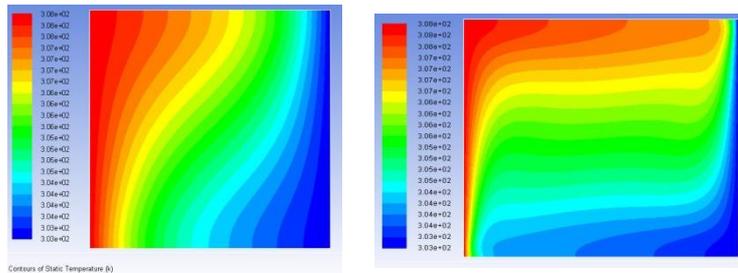


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**Table 4 Nusselt number of CFD Study at AR 2 for different Rayleigh number**

S No	Rayleigh Number Ra	Aspect Ratio	Present Study (Nu)	Correlation
1	1000	1	1.05	1.16
2	1000	2	1.14	1.04
3	1000	3	1.09	0.98
4	10000	1	2.15	2.37
5	10000	2	2.17	2.12
6	10000	3	1.95	1.99
7	100000	1	4.11	4.31
8	100000	2	3.48	3.86
9	100000	3	3.77	3.62
10	1000000	1	7.97	8.64
11	1000000	2	8.19	7.74
12	1000000	3	7.84	7.26

## V. CONCLUSION

The important conclusion can be summarized as follows:-

- The Nussalt Number is directly proportional to the Rayleigh Number.
- The stream function plot is circular for aspect ratio 1 and 2 and it goes deformed for higher aspect ratio and Rayleigh Number.
- The temperature distribution of air inside enclosed spaces is obtained with the help of temperature contours.
- The present results of heat transfer for two-dimensional, laminar, steady natural convection flow is obtained by using Computational Fluid Dynamics Software and compared with the results of Chang and Vahl. The present results show very good agreement with results of Chang & Vahl.
- Based on computational results of Nusselt number obtained by Computational Fluid Dynamics software, the correlations of heat transfer is proposed using least square curve fitting.

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