

Analysis of Free Natural Convection Flow through Enclosure Cavity by Computational Fluid Dynamic (CFD) Analysis

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Abstract— In CFD approaches, the partial differential equations are converted into algebraic equations by discretization methods (i.e. finite difference, finite volume and finite element method). The algebraic equations are modified to incorporate boundary conditions. The large set of algebraic equations so obtained, is then solved by iterative numerical procedures to obtain the Unknown flow variables like pressure, velocity, temperature etc. at all grid points in the domain of interest. The solution can then be visualized in the form of velocity vector plot, contour plots of pressure, temperature or any other derived quantity. Important engineering quantities like heat flux, drag force, lift force; pressure drop etc. can be calculated from the solution.

Keywords: heat transfer, Computational Fluid Dynamics CFD, convection, Rayleigh number, Nusselt Number

- 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.

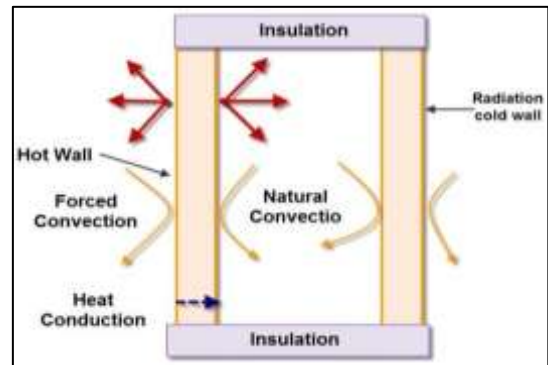


Fig. 2: Modes of heat transfer in Vertical enclosure

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 equipments 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 vertical enclosures. The vertical 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).

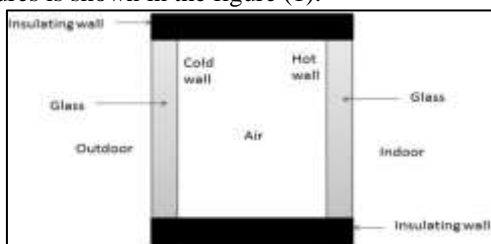


Fig. 1: Two-dimensional representation of vertical enclosure

The figure (1) shows vertical 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 glass is filled with air to reduce the rate of heat transfer.

Heat transfer through vertical enclosures consists of following heat transfer mechanisms shown in figure (2):

- 1) Natural convection in the air trapped inside the enclosure.

II. OBJECTIVE

The objective of the present study is to employ CFD methodology for computing laminar natural convection flow and heat transfer in two-dimensional vertical air cavities.

The Nusselt number is a function of Rayleigh number, Aspect ratio, Inclination and Prandtl number. In the present study the Prandtl number and inclination are constant so the Nusselt number is the function of Rayleigh number and Aspect ratios.

In the present study Nusselt number is computed for steady, laminar natural convection in vertical enclosures using commercial Computational Fluid Dynamics code for wide range Rayleigh number varying $103 \leq Ra \leq 106$ and aspect ratios vary from 1 to 10 at the rate of 2.5.

The details of flow features is studied with the help of stream function and temperature Distribution is studied to understand the heat transfer trends in vertical enclosures with side wall heating.

In the present study Nu-Ra correlations are proposed for wide range Rayleigh number varying $103 \leq Ra \leq 106$.

III. PROBLEM FORMULATION

A. 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.

H is the height of the cavity and L is length of the cavity along which the heat transfer takes place. Th is the hot-wall temperature and Tc is the cold-wall temperature and the upper wall and the lower wall are assumed to be adiabatic.

B. Assumptions

The following assumptions are made in the present work:

- 1) Flow is steady laminar natural convection.
- 2) Flow is two-dimensional.
- 3) The fluid properties are constant except that the variation of density with temperature is accounted for in the formulation of buoyancy term (Boussinesq approximation).
- 4) The effect of conduction and radiation effects are neglected.

Range of Parameters Investigated

Rayleigh number = $10^3, 10^4, 10^5, 10^6$
 Aspect ratio A = 1, 2.5, 5, 7.5, 10
 Inclination $\theta = 90^\circ$
 Prandtl number (Pr) = 0.7

IV. METHODOLOGY

A. Geometry

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 constant at 1. aspect ratio 1 means we are using the square geometry for analysis. The heat transfer analysis is carried out using Ansys (Fluent).

The geometry of the enclosed space, meshing and boundary identification is carried out in Ansys software.

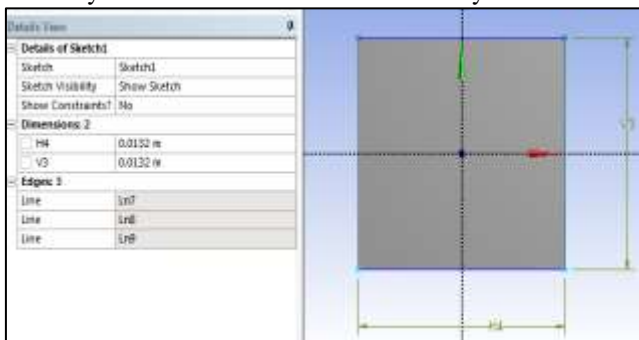


Fig. 3.1: Geometry of Square enclosed space

B. 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 results as compared to unstructured grid. Here we were using the minimum size of node $1e-04$ m for mesh generation of square cavity.

C. Solution Method

In order to solve the given boundary condition in ansys fluent workbench we were using the Pressure-Velocity Coupling Method. ANSYS Fluent provides four segregated types of algorithms: SIMPLE, SIMPLER, PISO, and (for time-dependant flows using the Non-Iterative Time Advancement option (NITA) Fractional Step (FSM)). These schemes are referred to as the pressure-based segregated algorithm. Steady-state calculations will generally use SIMPLE or SIMPLER, while PISO is recommended for transient calculations. PISO may also be useful for steady-state and transient calculations on highly skewed meshes. In

ANSYS Fluent, using the Coupled algorithm enables full pressure-velocity coupling, hence it is referred to as the pressure-based coupled algorithm.

V. RESULT & DISCUSSION

A. Validation of Present Results

The thermal conditions and dimensions of the enclosures are permit to cover wide range of Rayleigh number varying from 103 to 106. 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 shown in the table 4.1.

S No	Rayleigh Number Ra	Present Study (Nu)	Byong-Hoon Chang [1] (Nu)	De Vahl [8] (Nu)
1	10^3	1.17	1.118	1.118
2	10^4	2.08	2.241	2.243
3	10^5	4.48	4.532	4.519
4	10^6	8.86	8.848	8.799

Table 4.1:- Validation of results for square enclosure

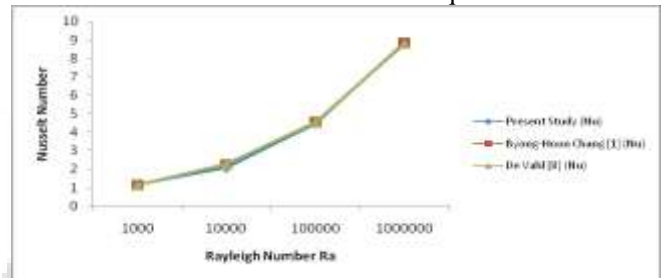


Fig. 4.1: Validation of Nusselt number for square enclosure at different Rayleigh number

B. Result of Heat transfer for square cavity and different Rayleigh No.

In order to find out the result in ansys fluent we perform 200 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 defines function. The result tabulated below in table 4.2

Rayleigh number	Nusselt Number (Nu)
10^3	1.17
10^4	2.08
10^5	4.48
10^6	8.86

Table 4.2: Nusselt number of Square cavity for different Rayleigh number

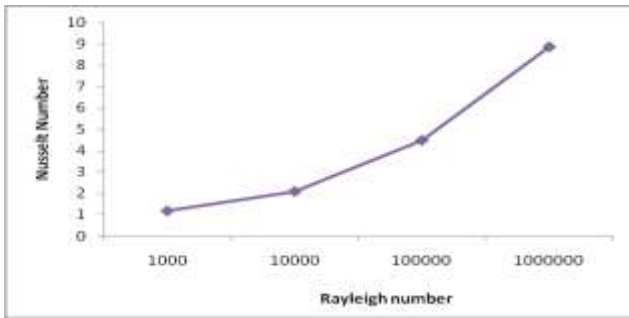


Fig. 4.2: Variation of Nusselt number with Rayleigh number at A=1

C. Stream Function Plot for Square Enclosure

The stream function plot is used to visualize the flow of air in square cavity for different Rayleigh number varying from 10^3 to 10^6 shown in fig.4.3

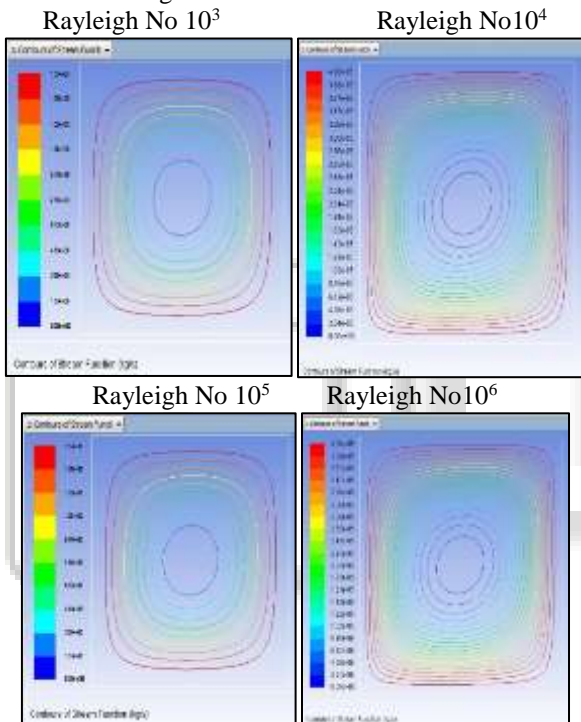


Fig. 4.3: Stream function plot for square cavity at different Rayleigh number

D. Contours for Square Cavity

The temperature contour plots are used to study the temperature distribution of air in square enclosures for different Rayleigh numbers varying from 10^3 to 10^6 shown in fig.4.4. The detailed study of temperature contours shows that the path of the contour becomes irregular with increasing Rayleigh number.

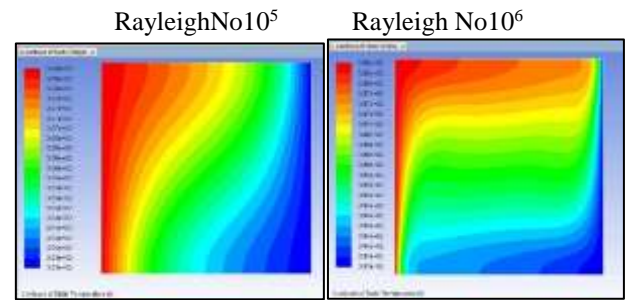
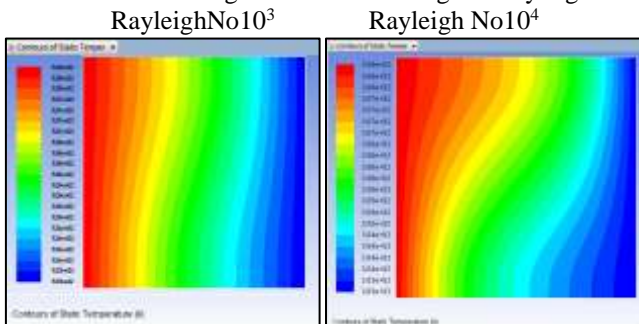


Fig. 4.4: Temperature contour plot for square cavity at different Rayleigh number

E. Comparison of Present Correlations for Medium Aspect Ratios and Lower Rayleigh Number

The present correlation for heat transfer in enclosed spaces for medium aspect ratios ($2.5 \leq A \leq 10$) and lower Rayleigh number ($10^3 \leq Ra \leq 10^6$) is validated with the correlations given by Byong-Hoon Chang [1] and is shown in table (12) to (15). The present correlations under-predict the correlations given by Byong-Hoon Chang [1] and deviate by about 1 to 10%. The deviations seem to be quite high but the heat transfer correlations are only the best possible curve fit of a large amount of data. The fig. 4.3 to 4.6 shows the variation of Nusselt number with Aspect ratio for different Rayleigh numbers i.e. $10^3, 10^4, 10^5, 10^6$.

Aspect ratio (A)	Nusselt Number (Nu) Present Work	Nusselt Number (Nu) Byong-Hoon Chang [1]
1	1.07	1.34
2.5	1.14	1.21
5	1.08	1.13
7.5	1.06	1.08
10	1.04	1.04

Table 4.3:- Comparison of Present correlation at $Ra=10^3$ and $A=1$ to 10

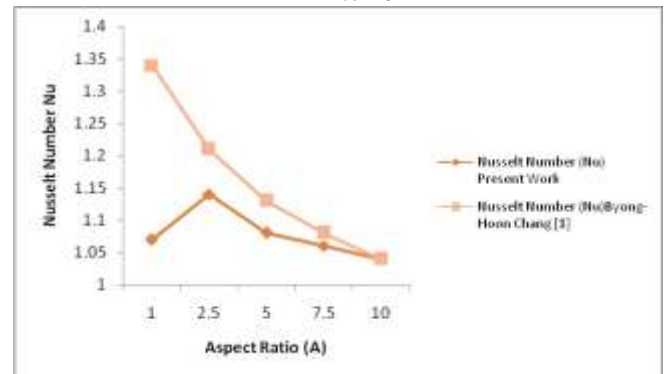


Fig. 4.5: Comparison of Present correlation for different aspect ratios at $Ra=10^3$

Aspect ratio (A)	Nusselt Number (Nu) Present Work	Nusselt Number (Nu) Byong-Hoon Chang [1]
1	2.03	2.45
2.5	2.25	2.21
5	2.03	2.05
7.5	1.82	1.96
10	1.69	1.89

Table 4.4: Comparison of Present correlation at $Ra=10^4$ and $A=1$ to 10

Fig. 4.4: Comparison of Present correlation for different aspect ratios at $Ra=10^4$

Aspect ratio (A)	Nusselt Number (Nu) Present Work	Nusselt Number (Nu) Byong-Hoon Chang [1]
1	4.52	4.44
2.5	4.18	4.02
5	3.74	3.73
7.5	3.45	3.56
10	3.2	3.45

Table 4.5: Comparison of Present correlation at $Ra=10^5$ and $A= 1$ to 10

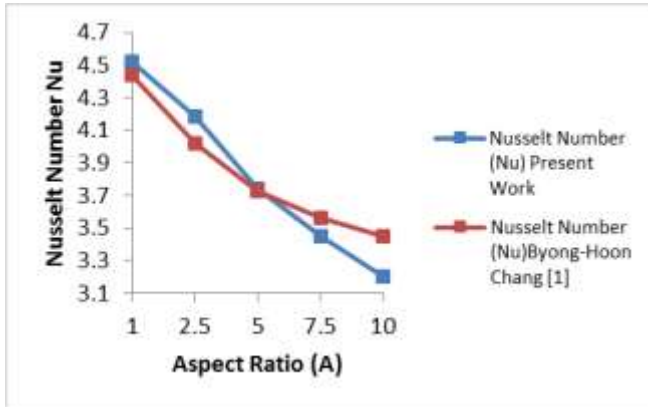


Fig. 4.5: Comparison of Present correlation for different aspect ratios at $Ra=10^5$

Aspect ratio (A)	Nusselt Number (Nu) Present Work	Nusselt Number (Nu) Byong-Hoon Chang [1]
1	8.89	8.1
2.5	7.6	7.32
5	6.65	6.78
7.5	6.21	6.49
10	6	6.28

Table 4.6: Comparison of Present correlation at $Ra=10^6$ and $A= 1$ to 10

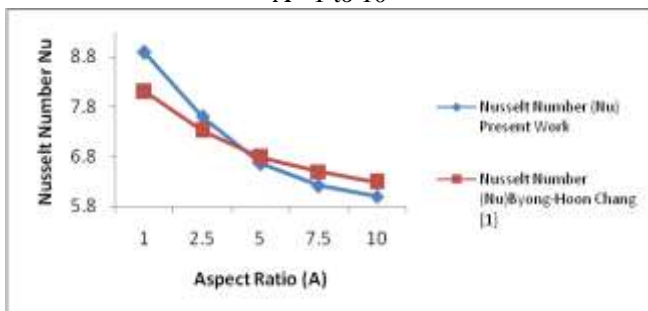


Fig. 4.6: Comparison of Present correlation for different aspect ratios at $Ra=10^6$

VI. CONCLUSION

The important conclusion can be summarized as follows:-

- It is observed that the Nusselt number increases with increase in Rayleigh number.
- It is investigated from stream function plot that for all Rayleigh number, circulation pattern exist and number of circulation cells increase with an increase in 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 Byong-Hoon Chang [1]. The present results show very good agreement with results of Byong-Hoon Chang.
- 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 for Small aspect ratio or square cavity and lower Rayleigh number.

$$Nu=0.1225 (Ra)^{0.31}$$

For Medium aspect ratios and lower Rayleigh number

$$Nu=0.23 (Ra)^{0.2625}(A)^{-0.159}$$

VII. FUTURE SCOPE

- 1) The present work is concerned with two-dimensional flow inside square enclosed space. The work can be further extended for three-dimensional Flow.
- 2) In the present work air is used as working fluid. The work can be extended for different fluid.
- 3) The present work is concerned with laminar natural convection flow. The work can be further extended for Turbulent Flow.
- 4) In the present work the dependency of Rayleigh number is taken into consideration. The work can be further extended for varying aspect ratio, Prandtl number and inclinations of plate.
- 5) In the present work the natural convection flow inside enclosed space is considered and the effect of radiation and conduction are neglected.
- 6) The present work is concerned with aspect ratios one means for a square cavity. The work can be further extended for large Rayleigh number.
- 7) The present work is concerned with vertical air cavity. The work can be further extended for various inclinations.

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