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# Natural convection and radiation in rectangular cavities with one active vertical wall

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ABSTRACT

Natural convection and radiation in rectangular cavities with aspect ratios of 1, 2.09, 3, 4, 5 and 6 has been studied. All six cavities have a height of 340 mm and a depth of 210 mm. The cavities have different lengths. The cavity is closed, filled with air, and has one active vertical wall. The opposing vertical wall is inactive. The other four walls are adiabatic. Experiments are performed to study the heat transfer in the cavity. Thermocouples are used to measure the temperature. In each cavity case, the temperature distribution between the vertical walls of the cavity is obtained at 35 positions in the length, seven positions in the height and one position in the depth directions. Temperature field is presented at the mid-depth of the cavity. In the central region of the cavity, the temperature is nearly constant, and the fluid is almost stagnant. Heat transfer correlation is obtained for the Rayleigh number range of $1.60 \times 10^5$ to $4.67 \times 10^7$, and the aspect ratio range of 1 to 6. The variations of the temperature profile and the local Nusselt number along the cavity height are presented.



## 1. Introduction

Natural convection in a closed cavity differs widely in geometries, boundary conditions, fluids and flow regimes. Aspect ratio ($A$) is the ratio of the cavity height ($H$) to cavity length ($L$). Depending on the aspect ratio, enclosures can be divided into three types: shallow rectangular, square and tall rectangular. In these types, the aspect ratio is smaller than one, equal to one and greater than one, respectively. Based on the thermal boundary conditions, enclosures can be classified into two main categories: heating from a horizontal wall and heating from a vertical wall. In the second category, two opposite vertical walls of the cavity are differentially heated while its top, bottom, front and back walls are maintained adiabatic.

Extensive studies have been conducted on natural convection in a cavity with adiabatic horizontal walls and differentially heated isothermal vertical walls at temperatures $T_h$ (hot) and $T_c$ (cold). Some researchers investigated square and cubical cavities. De Vahl Davis [1] numerically studied natural convection of air in a square cavity in the Rayleigh number range of $10^3$ to $10^6$. Markatos and Pericleous [2] numerically investigated natural convection of air in a square cavity in the Rayleigh number range of $10^3$ to $10^{16}$ and obtained heat transfer correlations. Yousaf and Usman [3] numerically investigated natural convection of a fluid in a square cavity for the Rayleigh number range of $10^3$ to $10^6$. The Prandtl number of the fluid was 1. They studied three cases: smooth hot and cold vertical walls, sinusoidal roughness elements on the hot wall and sinusoidal roughness elements on the hot and cold walls. Cordoba et al. [4] numerically and experimentally studied natural convection of mineral oil in a cubical cavity with a side length of 100 mm in the Rayleigh number range of $1.7 \times 10^8$ to $6.3 \times 10^8$. Hot and cold walls were aluminium, one wall was acrylic and other walls were glass. They presented the numerical results of the temperature distribution in the cavity at the dimensionless cavity depth of 0.5. They also presented the numerical and experimental results of the vertical temperature profile between the top and bottom horizontal walls at the dimensionless cavity length of 0.5 for the dimensionless cavity depth of 0.5. Li et al. [5] performed a numerical study on natural convection of air in a cubical cavity for the Rayleigh number range of $10^4$ to $10^5$. They provided the three-dimensional distributions of the temperature and the Nusselt number. Some other researchers investigated tall rectangular and rectangular prism cavities. Emery and Chu [6] analytically and experimentally investigated natural convection of different fluids in rectangular cavities with aspect ratios of 10 and 20. They changed the Prandtl and Rayleigh numbers from 3 to 30000 and $10^3$ to $10^7$, respectively.

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**Nomenclature**

| | |
|---|---|
| $A$ | area, $m^2$; aspect ratio, $A = H/L$ |
| $D$ | cavity depth, m |
| $g$ | gravitational acceleration, $m/s^2$ |
| $h$ | heat transfer coefficient, $W/m^2K$ |
| $h_y$ | local heat transfer coefficient, $W/m^2K$ |
| $H$ | height, m; cavity height, m |
| $k$ | thermal conductivity, W/mK |
| $L$ | thickness, m; cavity length, m |
| $Nu_{yL}$ | local Nusselt number based on the cavity length |
| $Nu_{ymL}$ | mean of the local Nusselt numbers based on the cavity length |
| $Pr$ | Prandtl number, $Pr = \nu/\alpha$ |
| $Q$ | heat transfer rate, W |
| $R$ | thermal resistance, K/W |
| $Ra_{yL}$ | local Rayleigh number based on the cavity length |
| $Ra_{ymL}$ | mean of the local Rayleigh numbers based on the cavity length |
| $T$ | temperature, °C |
| $t$ | time, min |
| $\Delta T_y$ | local temperature difference, °C |
| $w$ | weight factor |
| $x, y, z$ | coordinates, m |
| $X, Y, Z$ | dimensionless coordinates, $X = x/L$, $Y = y/H$, $Z = z/D$ |
| $\Delta y_i$ | vertical length of the point i, m |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | thermal diffusivity, $m^2/s$ |
| $\beta$ | thermal expansion coefficient, 1/K |
| $\varepsilon$ | emissivity |
| $\nu$ | kinematic viscosity, $m^2/s$ |
| $\sigma$ | Stefan-Boltzmann constant, $W/m^2K^4$ |

*Subscripts*

| | |
|---|---|
| a | ambient |
| c | cold, cooled |
| conv | convection |
| f | fluid in the cavity |
| h | hot |
| i | running index |
| insl | insulation |
| iw | inner wall |
| L | based on L |
| m | mean |
| o | outside |
| ow | outer wall |
| rad | radiation |
| y | at the measurement position y, local |
| 1, 2 | surfaces 1, 2 |

They reported a heat transfer correlation. Hot and cold walls were metal. MacGregor and Emery [7] carried out numerical and experimental studies on natural convection of different fluids in rectangular cavities with aspect ratios of 1, 10, 20 and 40. They varied the Prandtl and Rayleigh numbers from 1 to 20000 and $10^4$ to $10^9$, respectively. They proposed heat transfer correlations for different ranges of aspect ratio, Prandtl number and Rayleigh number. Schinkel et al. [8] numerically studied natural convection of air in rectangular cavities with aspect ratios of 1, 2, 3, 4, 6, 8, 11 and 18 for the Rayleigh number range of $10^4$ to $10^6$. Mahdavi et al. [9] numerically and experimentally investigated natural convection of air, water and mixture of ethylene glycol and water in rectangular prism cavities with aspect ratios of 0.94 and 3.76. Hot and cold walls were copper. In the case of $A = 0.94$, the investigation was carried out for all three fluids. The cavity was 96 mm high, 102 mm long and 120 mm deep. For air, the Rayleigh number was varied between $1.70 \times 10^6$ and $4.52 \times 10^6$. In the case of $A = 3.76$, the fluid was water. Cooper et al. [10] carried out an experimental study on natural convection of air in a rectangular prism cavity with an aspect ratio of 28.6. The cavity was 2180 mm high, 76.2 mm long and 520 mm deep. The Rayleigh number was changed between $0.86 \times 10^6$ and $1.54 \times 10^6$. Hot and cold walls were aluminium, top and bottom walls were natural rubber, and front and back walls were plexiglass. The cavity angle of inclination was varied for 15° and 60°.

Some authors studied natural convection of air in a cavity with partially active vertical walls at temperatures $T_h$ and $T_c$. The active part was half height of the cavity wall and the inactive part was adiabatic. Horizontal walls were adiabatic. Nithyadevi et al. [11] performed a numerical study on rectangular cavities with aspect ratios of 0.5, 1, 2, 3, 5, 7 and 10. The active part was located at the top, middle and bottom for each vertical wall and thus, nine cases were studied. The Grashof number was varied from $10^3$ to $10^5$. Corvaro et al. [12] conducted an experimental study on a square cavity. Active parts were aluminium, inactive parts and other walls were plexiglass. They fixed the location of the hot active part at the middle and changed the location of the cold active part for positions of top, middle and bottom. They obtained different heat transfer correlations for each position in the Rayleigh number range of $5.5 \times 10^4$ to $2.3 \times 10^5$. Valencia and Frederick [13] carried out a numerical study on a square cavity. The active part was positioned at the top, middle and bottom. Five cases were investigated. They proposed separate heat transfer correlations for each case in the Rayleigh number range of $10^3$ to $10^7$.

Some researchers investigated natural convection in a cavity with one active vertical wall. Opposing vertical wall and horizontal walls were adiabatic. Nicolette et al. [14] numerically and experimentally studied convection in a square cavity in transient regime for air and water. The active vertical wall was cooled. The Grashof number was changed between $10^5$ and $10^7$. Cold wall was aluminium and other walls were plastic. Hall et al. [15] numerically investigated convection of water in a square cavity in transient regime. The active vertical wall was cooled. The Rayleigh number was varied from $1.4 \times 10^3$ to $1.4 \times 10^6$.

On the other hand, few researchers have focused on combined natural convection and radiation in square and rectangular prism cavities with adiabatic horizontal walls and differentially heated isothermal vertical walls at temperatures $T_h$ and $T_c$. Akiyama and Chong [16] studied natural convection and radiation of air in a square cavity for the Rayleigh number range of $10^4$ to $10^6$ numerically. Surface emissivity of all surfaces was changed from 0.02 to 1. They reported a heat transfer correlation for combined convection and radiation. Mezrhab et al. [17] numerically investigated natural convection and radiation of air in a square cavity for two cases. In the first case, they studied flow in an empty cavity for the surface emissivities of 0 and 1 at the Rayleigh number of $10^6$. In the second case, they investigated flow in a cavity with a square body at its center for the surface emissivity range of 0 to 1, and for the Rayleigh number range of $10^3$ to $10^8$. Ibrahim et al. [18] numerically investigated natural convection and radiation of air in a square cavity