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Natural convection in rectangular cavities with one active vertical wall

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ABSTRACT

Natural convection in rectangular cavities has been studied. One of the vertical walls of the cavity is active. The opposing vertical wall is inactive and insulated from the back. The other four walls are adiabatic. Heat transfer is by convection only because surface emissivities of the walls have been reduced. Experiments are performed on rectangular cavities with aspect ratios of 1, 2.09, 3, 4, 5 and 6. All six cavities have a height of 340 mm and a depth of 210 mm. The cavity length is changed to obtain different rectangular cavities. The cavity is closed and filled with air. Thermocouples are used to measure the temperature. For each cavity, the temperature distribution between the vertical walls of the cavity is obtained at 35 positions in the length, three positions in the height and one position in the depth directions. Three regions are observed along the cavity length. In the central region, the temperature changes slightly. The isotherms are concentrated near the active wall. The variation of local Nusselt number along the cavity height is obtained. Heat transfer correlations are presented for the Rayleigh number range of 2.16×10^5 to 5.06×10^7, and for the aspect ratio range of 1–6.

1. Introduction

Many efforts have been made to investigate natural convection heat transfer in closed cavities. Most of the work focuses on two-dimensional and steady state solution of the problem. Natural convection in a closed cavity differs widely in boundary conditions, geometries, fluids and flow regimes. 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. Aspect ratio (A) is the ratio of the cavity height (H) to cavity length (L) for a two-dimensional cavity. 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. Many researchers studied natural convection in a cavity with adiabatic horizontal walls and differentially heated isothermal vertical walls at temperatures T_h and T_c. Isothermal vertical walls are called hot and cold walls.

Some researchers investigated natural convection in a square cavity with differentially heated side walls. 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}. They obtained heat transfer correlations for different Rayleigh number ranges. Ramesh and Venkateshan [3] experimentally investigated natural convection of air in a square cavity in the Grashof number range of 5×10^4 to 2×10^6. They fixed the surface emissivities of hot and cold walls at 0.05 and studied the effect of surface emissivity of top and bottom walls for values of 0.85 and 0.05. They concluded that the emissivity of top and bottom walls did not affect the Nusselt number. They obtained a heat transfer correlation. Bairi [4] numerically and experimentally studied natural convection of air in a square cavity. The Rayleigh number was varied from 10^3 to 10^{10}. Hot and cold walls were copper and other walls were polyurethane. He varied the angle of inclination of cavity from 0° to 360° and proposed heat transfer correlations for different angles of inclination.

Some other researchers investigated rectangular cavity with differentially heated side walls. Eckert and Carlson [5] experimentally studied natural convection of air in rectangular cavities with aspect ratios of 2.5, 10, 20 and 46.7. They obtained a heat transfer correlation for the boundary layer region. Hot and cold walls were polished, nickel plated copper and other walls were wood. 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 30,000 and 10^3 to 10^7, respectively. They reported a heat transfer correlation. Hot and cold walls were metal. MacGregor and

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Nomenclature

A	aspect ratio, $A = H/L$
D	cavity depth, m
g	gravitational acceleration, m/s^2
h	average heat transfer coefficient, W/m^{2}K
h_y	local heat transfer coefficient, W/m^{2}K
H	cavity height, m
k	thermal conductivity of fluid, W/mK
L	cavity length, m
Nu_H	average Nusselt number based on the cavity height
Nu_L	average Nusselt number based on the cavity length
Nu_{yL}	local Nusselt number based on the cavity length
Pr	Prandtl number, $Pr = \nu/\alpha$
Q	heat transfer rate, W
R	total thermal resistance, K/W
Ra_H	average Rayleigh number based on the cavity height
Ra_L	average Rayleigh number based on the cavity length
T	temperature, °C
ΔT	average temperature difference, °C
ΔT_y	local temperature difference, °C
x, y, z	coordinates, m
X, Y, Z	dimensionless coordinates, $X = x/L$, $Y = y/H$, $Z = z/D$

Greek symbols

α	thermal diffusivity of fluid, m^2/s
β	thermal expansion coefficient of fluid, 1/K
ν	kinematic viscosity of fluid, m^2/s
θ	dimensionless temperature, $\theta = \dfrac{T - T_c}{T_h - T_c}$

Subscripts

a	ambient
c	cold, cooled
h	hot
H	based on H
L	based on L
m	mean
y	at the measurement position y, local

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. Yin et al. [8] experimentally studied natural convection of air in rectangular cavities with aspect ratios from 4.9 to 78.7. The Grashof number was changed between 1.5×10^3 and 7.0×10^6. Hot and cold walls were aluminium and copper with surface emissivities of 0.09 and 0.07, respectively. Other walls were polyurethane. They subtracted radiation from total heat transfer and used natural convection in results. They proposed a heat transfer correlation. Schinkel et al. [9] 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. They proposed a heat transfer correlation for the aspect ratio range of 8–18 and separate heat transfer correlations for each aspect ratio. Inaba [10] conducted an experimental study on natural convection of air in rectangular cavities with aspect ratios of 5, 10, 29, 58 and 83. The Rayleigh number was varied from 1.2×10^3 to 2.0×10^6. Hot and cold walls were polished copper with a surface emissivity of 0.06. They subtracted radiation from total heat transfer and used natural convection in results. He changed the angle of inclination of cavity from 0° to 180° and proposed heat transfer correlations for two different ranges of angle. Betts and Bokhari [11] experimentally studied natural convection of air in a rectangular cavity with an aspect ratio of 28.7 for the Rayleigh number range of 0.86×10^6 to 1.43×10^6. Hot and cold walls were polished aluminium and top and bottom walls were aluminium foil. Lartigue et al. [12] numerically and experimentally investigated natural convection of air in a rectangular cavity having an aspect ratio of 40 in the Rayleigh number range of 3.55×10^3 to 17.75×10^3. Hot and cold walls and top and bottom walls were aluminium and PVC, respectively.

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. [13] 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. [14] 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 5.5×10^4 to 2.3×10^5. Valencia and Frederick [15] 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.

A few researchers numerically investigated natural convection of air in a square cavity with discrete heat sources on vertical walls. Horizontal walls were adiabatic. Dias and Milanez [16] studied a cavity in the Rayleigh number range of 10^2 to 10^6. One vertical wall was heated by discrete heat sources and opposing vertical wall was isothermally cooled. Sources were flush mounted on an adiabatic vertical wall. They studied one or two heat sources and varied the dissipation rates of the sources. Deng [17] investigated a cavity in the Rayleigh number range of 10^2 to 10^6. Vertical walls were heated and cooled by two or three discrete source-sink pairs. He maintained two source-sink heights and investigated six cases.

Some researchers investigated natural convection in a cavity with one active vertical wall. Opposing vertical wall and horizontal walls were adiabatic. Poulikakos [18] numerically studied convection of air in rectangular cavities for two cases. In the first case, the active vertical wall was heated from its upper half and cooled from its lower half for the aspect ratios of 1/8, 1/6, 1/5, 1, 2 and 4. In the second case, the active vertical wall was cooled from its upper half and heated from its lower half for the aspect ratios of 1 and 4. The Rayleigh number based on the cavity height was between 10^2 and 10^5. Nicolette et al. [19] numerically and experimentally studied convection of air and water in a square cavity in transient regime. 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. [20] numerically investigated convec-