Natural convection from a horizontal plate built in a vertical variable height duct

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Abstract: Natural convection from flat plate built in variable height duct was investigated experimentally. With air as the working liquid the impact of variable height duct on the heat transmission of the flat panel were studied. Duct was with Square section of (300x300) mm$^2$ and the elevation of the duct H was various as 100, 200 and 300 mm. square flat plate (300×300) mm$^2$ which heated surface facing upwards, was built in the bottom of the duct and exposed to different input power which represent a heat flux of (423, 660 and 830 W/m$^2$. The experimental results showed that the variable height duct deteriorate the heat transmission. heat transmission of the flat panel built in a variable height duct become lower than those do not have a channel and heat transmission are significantly reduced in the circumference of the duct. at circumference of variable height duct, heat transmission for flat board become 27% smaller than heat transfer for flat panel that do not have a duct owing to that the perpendicular duct hinders airflow from the top of the perpendicular duct this causes decrease of heat transmission.

Key Words: convection from a duct, four-sided hollow, channel heat transfer

1. Introduction

The transmission of natural thermal heat and liquid flow in the cavity are a major problem in everyday lifetime applications as requirements of heating and cooling, sources of renewable energy and devices of electronic cooling[1]. Numerous investigators studied normal convection in cavities, some of which are listed below. Elton Fontana et. al [1]. Numerically fixed buoyancy air flow was examined in a two-dimensional, partly open cavity with an interior heat source. The lowest and upper walls of the cavity are adiabatic, and the vertical walls are kept at dissimilar constant temperatures. The perpendicular right wall of the cavity was opened with three shapes of H/4, H/2 and 3H/4a. A small heat source of 2% of the cavity size is located on In the middle of the lower wall. The consequences showed that the thermodynamics of the liquid strongly affected by having a heat source, by opening the volume and changing the temperature among the vertical walls..V.S.M.R.Bhushan et. al [2]. Study experimentally Thermal convection heat transfer of square slanted channels. With air still in the channel directed at a 45° angle Experiments were carried out .two channels have a dissimilar area ratio, and uniform heat flow conditions are kept. Result show that the contrast of experimental results with those in the literature on vertical cylinders was fully consistent. Tatsuo Nishimura et. al [3]. Experimentally and numerically study for Normal convection heat transmission in four-sided container having several perpendicular portions. The parts were evenly spaced in the four-sided container and the thickness of the sections was negligible the casing was surrounded by equal-temperature perpendicular walls at dissimilar temperatures and fixed flat walls. The result showed that the temperature of the parts and the core temperatures increased almost in the perpendicular direction excepting nearby the higher and inferior walls of the four-sided container in the border layer area. For an odd number of portions, The Nusselt number is unchanging at the central portions while the heat flow across the sections varies in the perpendicular direction in generality cases.Fumiyoshi Kimura et. al [4]. Experimental Examined of Normal convective movements about flat hot panel with a perpendicular panel at the edge. By color
and a fluid crystal imagine the movement and temperature fields adjacent to the flat panel. It was found that the non-heated perpendicular panel destroys the heat transmission, but the hot perpendicular panel promotes heat transmission from the flat panel. M. Arici et al [5]. Studied the influence of the elevation ratio along with the Riley number and the tilt angle on the properties of the flow and heat transmission in a hollow Confined by two isothermal wavy walls and two insulated straight walls. Results show that aspect ratio has a considerable effect on the flow structure and heat transfer. Increasing aspect ratio enhances the heat transfer. Inclination angle has also very significant effect on the flow field and heat transfer depending on the Rayleigh number and aspect ratio. The inclination angle where the heat transfer reaches a maximum decreases as aspect ratio increases. After reviewing the previous studies and researches, it has seen that all of their study the case of thermal boundary layer over the heated surfaces basically the experimental studies. Therefore, the present work will study experimentally the case of natural convection for flat plate built in variable height duct and including the influence the variable height duct on the heat transfer. Experiments begin with heat transmission across the flat plate without a variable height channel; we carried out flat panel heat transmission measurements then the effect of the variable height channel on heat transfer from the flat panel.

2. Experimental Facility

Study is made on heated flat plate built in a vertical height-changing channel made of wooden blocks. The heated flat panel is installed at the bottom of the channel. The channel is designed at a different height (100, 200, 300 mm). The flat plate was electrically heated using a horizontal heater installed at the bottom of the flat plate.

2.1. The Duct

It is made of wood with cross section of (300x300) mm and 25 mm thickness with variable height of (100, 200, 300 mm) is connected with the test section from bottom and the other side opened to the surrounding air. Dimensions of the used ducts are presented in Table 1. Photos of the duct and Schematic diagram for the of the duct with test section are shown in Figures (1).

| Table1. Dimensions of the used ducts |
|-------------------------------------|
| Duct no | Duct width (W) | Duct length (L) | Duct height (H) |
|--------|----------------|-----------------|-----------------|
| 1      | 300 mm         | 300 mm          | 100 mm          |
| 2      | 300 mm         | 300 mm          | 200 mm          |
| 3      | 300 mm         | 300 mm          | 300 mm          |
2.2. Test Section:

It consists of square steel (300x300) mm² flat plate and (1) mm thickness. This forms the top of the test section set. The flat board is heated from the bottom by a Constant thermal flow generated by a flat electric heater with cross section of (300x300) mm². To safeguard a regular distribution of heat flow from the plate, aluminums panel is placed among the flat panel and the flat electric heater. A non-silicone thermal composite is used among flat panel, aluminums panel and flat electric heater, to ensure reliable thermal coupling and heat transfer. Foam layer of 90 mm thickness used to minimize the hotness loss owing to transmission from the bottom surface of hot panel. To measure the surface temperature of the horizontal panel, Ten K-type thermocouples are installed on the hot panel along the middle line with distance of 3 cm on a flat panel through the holes drilled at the lowest surface of the foam layer and are joined by epoxy resins to a hot plate, these thermocouples are inserted. The previous parts were installed inside a wooden frame (with low thermal conductivity). And to measure the temperature of the air surrounding of the test surface was used thermocouple to amount it. Power is supplied to the heater by a variable transformer (Variac) to control the voltage supply and the possibility of providing a wide range of values of thermal flux. The value of the current it is measured by the ammeter and a voltmeter is connected in parallel to the measured voltages of the heater. For measuring the temperature the temperature recorder was used. Figures (2) and (3) demonstrations a details of test section and a picture of the test rig instrument.

Figure 1. (a) The Schematic diagram for the of the duct with test section and (b) the Photo of the duct
**Figure (2)** a detail of test section assembly
3. Analysis of experimental data

The amount of heat generated in the heater:

\[ Q_{\text{spec}} = IV \] \quad (W) \quad (1)

Net convection heat transfer is calculated as follows:

\[ Q_{\text{conv}} = Q_{\text{input}} - Q_{\text{rad}} - Q_{\text{cond}} \quad \text{ (W)} \quad (2) \]

Where \( Q_{\text{rad}} \) and \( Q_{\text{cond}} \) heat losses owing to radiation from are test section and heat losses due to conduction from the heater through the insulation (foam layer), it can be calculated as

\[ Q_{\text{rad}} = \varepsilon \sigma A_s (T_s^4 - T_a^4) \] \quad (W) \quad (3)

\[ Q_{\text{cond}} = K_p A_s \frac{\Delta T}{\Delta x_p} \] \quad (W) \quad (4)

By Newton's law of cooling the heat transfer through convection it can be stated as:
\[ Q_{\text{conv.}} = hA_s(T_s - T_f) \quad (W) \quad (5) \]

Calculated the constant heat flux on the plate from following equation

\[ q_r = \frac{Q_{\text{conv}}}{A_s} \quad (\text{W/m}^2) \quad (6) \]

Then we calculated the local heat transmission coefficient from following equation:

\[ h_x = \frac{q}{T_x - T_f} \quad (\text{W/m}^2 \cdot ^\circ \text{C}) \quad (7) \]

The relation among the buoyancy force and the viscid strength is demarcated as The Rayleigh number

\[ Ra = Gr \cdot Pr \quad (8) \]

Where Gr: Grashof number founded on the board length, Pr: prandtl number

The Grashof number can be calculated from the next equation;

\[ Gr = \frac{g\beta(T_w - T_x)L^3}{v^2} \quad (9) \]

4. Results and Discussions

Conduct of cooling rate of a model in the form of square horizontal flat plate built in a vertical variable height duct was deliberated in the current work. Based on the radial distance from the front edge of the board to the end of the board the local heat transfer coefficients are calculated. We started to flow on the flat panel to get inclusive info on airflow on flat panel which do not have of a perpendicular channel. Temperature distribution over the horizontal plate with the distance from the foremost edge of the board to the end of the board at various locations for different power inputs is represented in Figure (4). Temperature distribution of the flat hot board appears symmetrical with the plate's midline is obvious from this figure. Owing to a low temperature peripheral air coming from open edges, air flows from the ends lengthways the hot surface and collides with both in the middle of the board as a column. The maximum temperature is in the middle of the plate while at the minimum at both ends of the plate. Figure (4) also showed that the difference between the temperature at the center and at the end increases with an increased heat flux.
Figure 4. Variation of Temperature distribution over the horizontal plate with the distance from the front edge of the panel to the end of the panel.

Distribution of local heat transfer coefficients at different locations and heat inputs on a flat plate without a perpendicular channel with the distance from of the front edge of the board to the end of the board is shown in Figure (5). The local heat transfer coefficients of the flat plate without perpendicular channel appear symmetrical with board midline. The highest coefficient is achieved at the edges of the flat board and then gradually drops towards the center of the board. This is owed to the big difference within the hot board temperature and the surrounding air temperatures. This work was definite by the author [7]. These figure Also demonstration that the heat transition at each site higher for bigger heat flow. Increased board hotness compared to surrounding air hotness led to the high speed of the induced air, which leads to higher heat transfer coefficient.
Figure 5. The variety of local thermal heat transfer with the distance from the front edge of the panel to the end of the plate.

Figure 6 shows the variation of local heat transfer coefficients with Rayleigh number for horizontal plate in the style of natural convection. Owing to higher temperature differences that give greater intensity leading to higher convection speeds that transmit higher temperatures the Consequences was showed the local heat transfer coefficients usually increases with Rayleigh number as shown in figure (6). This behavior is observed with many researchers such as [3]
Figure 6. Variation of local heat transfer coefficients with Ra number for flat plate.

We deliberate local heat transfer coefficients for a flat panel with a variable height channel from Figure (7). This figure represents the influence of duct on the local heat transfer coefficients. Figure declares that heat transmission of the flat panel built in a variable height channel become lower than those do not have a variable height channel and heat transmission of the flat panel less at circumference of the variable height channel. Low heat transmission owing to that the perpendicular channel delays the airflow from above the perpendicular channel. This behavior predicted by numerous researchers such as [4].
Figure 7. Variation of heat transfer coefficient with the distance from the front edge of the panel to the end of the panel.

A figure (8) represents the change of hotness transmission to channel height. Shape shows that the more higher the channel height, the ambient fluid cannot enter from the top of vertical channel, and this reasons the more decrease of heat transfer. When the vertical channel is relatively small, the surrounding airflow may happen from the top of vertical channel.

Figure 8. Deviation of heat transfer coefficient with channel height.
Conclusions

In this work Natural convection from a flat plate built in a perpendicular variable height duct were investigated experimentally. With air as the working fluid, the experimental study had been made on model of square flat plate (300×300) mm and (1 mm) thickness made of steel. The altitude of the vertical channel H varies as follows: H = 100, 200 and 300 mm, respectively. The following are the abstracting conclusions from the present investigation.

1. The vertical variable height duct hinders the airflow from above the perpendicular channel and this causes the decrease of the heat transition of the flat panel are significantly reduced near perpendicular channel
2. The more height of vertical duct the more heat transfer coefficient decreased. for a perpendicular channel height of H = 300 mm, the surrounding air cannot enter from above perpendicular channel, but airflow of surrounding from the perpendicular channel may happen when the perpendicular channel is comparatively low

Nomenclature

| Symbol | Description |
|--------|-------------|
| As     | cross sectional area of plate (mm²) |
| g      | gravitational acceleration (m/s²) |
| Gr     | Grashof number |
| h      | local heat transmission coefficient (W/m²K) |
| H      | duct height (millimeter) |
| I      | intensity of Current (ampere) |
| K      | material thermal conductivity (W/m.K) |
| L      | board length (mm) |
| q      | Input power (w) |
| Ts     | board Surface temperature (K⁰) |
| Ta     | temperature of surrounding air (K⁰) |
| V      | voltage provided (volt) |
| Δxₚ   | thickness of Foam layer |
| ΔT     | change of temperature amid the two sides of Foam layer (K⁰) |
| β      | volumetric expansion thermal coefficient (1/K⁰) |
| ν      | Air kinematic viscosity (m²/s) |

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