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EFFECTS OF VARIABLES ON NATURAL CONVECTIVE HEAT TRANSFER THROUGH V-CORRUGATED VERTICAL PLATES

M. Hasanuzzaman[a], R. Saidur[a], M. Ali[b], H.H. Masjuki[a]
[a]Department of Mechanical Engineering,
University of Malaya, 50603 Kuala Lumpur, Malaysia
E-mail: hasan308@yahoo.com
[b]Department of Mechanical Engineering,
Bangladesh University of Engineering and Technology
Dhaka-1000, Bangladesh
Email: mali@buet.ac.bd

ABSTRACT

Natural convection is an important mode of heat transfer. Natural convective heat transfer is a common phenomenon in most of the heat transfer cases. This paper presents the natural convective heat transfer and the effect of different variables on heat transfer in the square enclosure of two V-corrugated parallel vertical plates. An experiment has been performed to investigate the effect of mass flow rate of cooling water, input heat energy and inlet water temperature on natural convective heat transfer in the square enclosure of two V-corrugated parallel vertical plates. The air inside the V-corrugated parallel vertical plates was the main media to transfer heat from the hot V-corrugated plate to cold V-corrugated plate. Mass flow rate and the inlet temperature of cooling water are considered to vary the cold plate temperature. The increase in mass flow rate of water and the input heat energy increases the heat transfer rate. On the other hand, the decrease in inlet water temperature increases the heat transfer rate. So, there is an influence of different variables on natural convective heat transfer through V-corrugated vertical plates.

Keywords: Natural convection, V-Corrugated plate, Mass flow, Heat transfer, Enclosure.

1. INTRODUCTION

Natural convection is an important mode of heat transfer. A significant number of investigations have been carried out on heat transfer problems across V-corrugated surfaces. Chinnappa [1] carried out an experimental investigation on natural convection heat transfer from a horizontal lower hot V-corrugated plate to an upper cold flat plate for a range of Grashof number 10^4 to 10^6. Author noticed a change in the flow pattern at Grashof number 8×10^4, which was a transition point from laminar to turbulent flow. Elsherbiny *et al* [2] investigated free convection heat transfer for air layers bounded by a lower hot V-corrugated plate and upper cold flat plate. A single correlation equation in terms of Nusselt number, Rayleigh number, tilt angle and aspect ratio was developed for the aspect ratio ranging from 1 to 4 and angle of inclination ranging from 0 to 60 degrees. Authors claimed that the convective heat transfer across air layer bounded by V-corrugated and flat plate was greater than those for parallel flat plates by a maximum of 40%. Zhong *et al.* [3] carried out a finite difference study to determine the effects of variable properties on the temperature and velocity field and the heat transfer in a differentially heated two-dimensional square enclosure. Ozoe *et al.* [4] performed a set of experiments for laminar convection in silicone oil and air along a rectangular channel. The aspect ratios (width/height) of the cross-section of the channel were 1, 2, 3, 4.2, 8.4 and 15.5 and the Rayleigh number was varied from 3×10^3 to 10^5. Dropkin *et al.* [5] performed an experimental investigation on natural convection heat transfer in liquid confined by two parallel plates and inclined at various angle. The range of Rayleigh number covered in the experiment was 5×10^4 to 7×10^8 and Prandtl number was varied from 0.02 to 11560. Experiments were carried in rectangular and circular containers having copper plates and insulating walls. Water, silicon oil and mercury were used as liquids.

Yao [6, 7] studied the case of uniform surface temperature laminar free convection along a semi-infinite vertical wavy surface. The author also studied Natural convection along a vertical complex wavy surface created from two sinusoidal functions, a fundamental wave and its first harmonic. The total heat-transfer rates for a complex surface are greater than that of a flat plate. The numerical results show that the enhanced total heat-transfer rate seems to depend on the ratio of amplitude and wavelength of a surface. Bianco *et al.* [8]

investigated natural convection in air in a convergent channel with the two principal flat plates at uniform heat flux with finite thickness and thermal conductivity numerically.

There are many literatures on the natural convective heat transfer from the flat surface or wavy surface to the air but there is little information about the heat transfer from the hot V-corrugated surface to cold V-corrugated surface confined in air with the variation of both hot and cold plate temperature. The natural convection from a heated corrugated surface has received a great deal of attention due to its relation to practical application of complex geometries. It is also a model for the investigation of heat transfer from a corrugated surface in order to understand the heat transfer enhancement. The main objectives of this paper are to investigate heat transfer behavior inside the square enclosure with V-corrugated vertical and insulated horizontal walls by changing the input power, varying the mass flow rate of water and the inlet water temperature.

2. RESEARCH METHODOLOGY

The experiment is conducted to investigate the effect of mass flow rate of cooling water, input heat energy and inlet water temperature on the natural convective heat transfer of the V-corrugated vertical walls.

2.1 Instrumentation

Voltmeter and ammeter were used to measure the voltage and current. Varier was used to vary the input voltage which ranges 0 to 230 volt. Temperature controller was used that was connected to the varier and the nicrome wire to control the asbestos cloth temperature. Asbestos cloth was used as insulator to reduce heat losses that can sustain up to120 ºC. The nicrome wire 26 was used to make heater. To measure the temperature of the corrugated heated and cold walls of the test unit, T-type thermocouples were used. Thermocouples were connected to the digital reader and the reader read the temperature.

2.2 Experimental setup

In this experimental investigation, water is used as coolant and air is present in the rectangular box between the two V-corrugated vertical plates. The air is the main media to transfer heat from the hot V-corrugated plate to cold V-corrugated plate. The convective heat transfer is the main mode of heat transfer through the air in the square enclosure of the V-corrugated vertical plates. The rectangular enclosure had adiabatic surroundings, therefore, it is expected that the heat transfer rate from the test plate would be unaffected by the presence of surrounding surface as there would be no loss through the surroundings from the hot plate. The experimental setup was a square enclosure with two V-corrugated vertical plates as shown in the Figure 1.

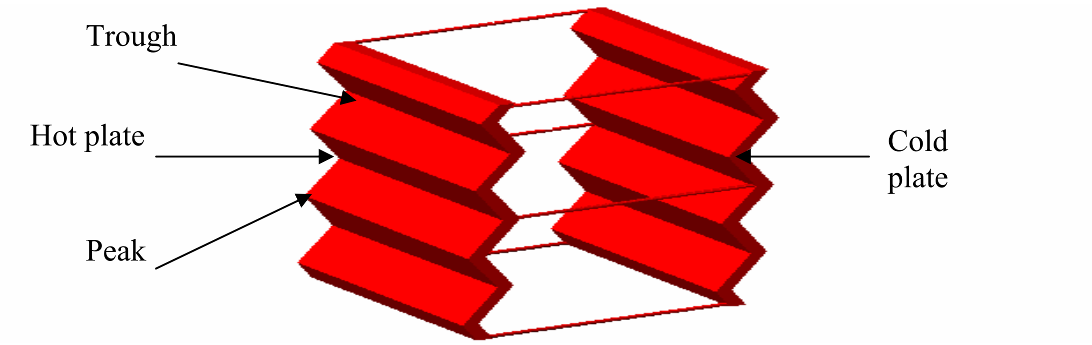

Figure 1 Assembled configuration of V-corrugated plates

One is hot plate, which is heated by electric heater and another is cold plate, which is cooled by the contact of coolant. Coolant is reserved in a tank. The experimental setup consists of four different assemblies, which are listed below:

2.2.1 Hot plate and cold plate assembly

Hot plate assembly, which is made of corrugated mild steel sheet of length 42 cm, width 42 cm and thickness 2 mm. The corrugation amplitude is fixed at 5 percent of the enclosure height throughout the experiment**,** where the amplitude is defined by a half of the horizontal distance, measured from the left extremity of the left wall to its right extremity. Therefore, the amplitude is 2.1 cm folding a plain sheet in seven stages makes this corrugation. The cold plate is similar to the hot plate and it is used to gain heat from hot plate.

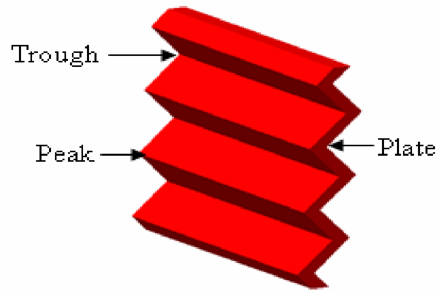

Figure 2 Hot and cold V-corrugated plate

2.2.2 The thermocouple assembly

In the experimental setup, 18 thermocouples are used to measure the temperature of the various points of the surfaces of two V-corrugated parallel vertical plates. Among them 9 thermocouples are used in hot plate and other 9 thermocouples are used in cold plate. Thermocouples are located in different points that cover the most critical section as shown in Figure 3.

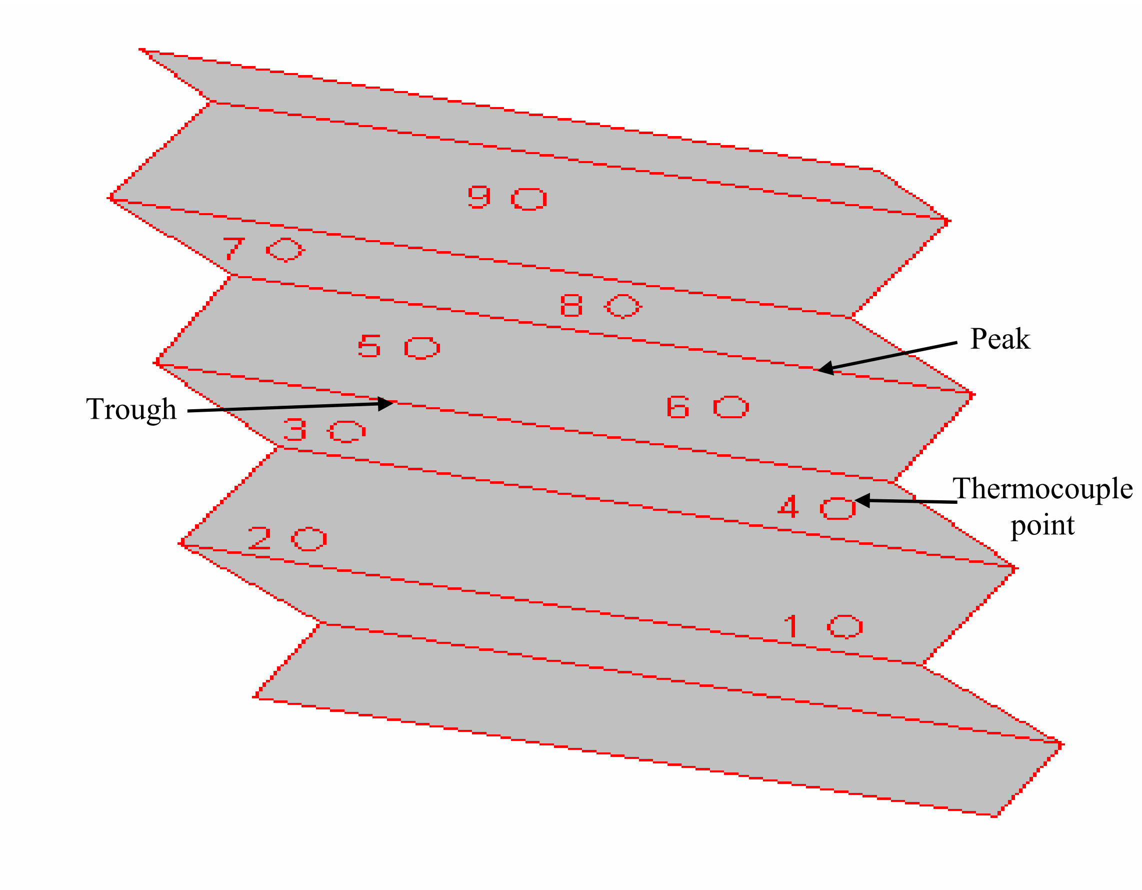

Figure 3 Thermocouple position on the V-corrugated cold plate.

2.2.3 The insulation assembly

The insulation is use to protect the heat losses from the v-corrugated plate to the ambient. The insulation assembly consists of asbestos cloth, asbestos tape, glass wool and white tape. The whole setup is covered with asbestos cloth.

2.2.4 The heater assembly

The nicrome wire 26 is used in the heater. The nicrome wire is placed in asbestos in a rectangular manner in loop and tape is used to hold the nicrome wire in the asbestos. Adjacent wire is placed in such a way that they do not touch each other. The nicrome wire is covered with two fold asbestos cloth and joined the upper and lower asbestos cloth. Single asbestos, which touches the plate surface, is placed in the inner side of the heater and double fold asbestos is placed in the outer side of the heater. Asbestos cloth can sustain 120 ºC. So, the temperature of heater is maintained within this range.

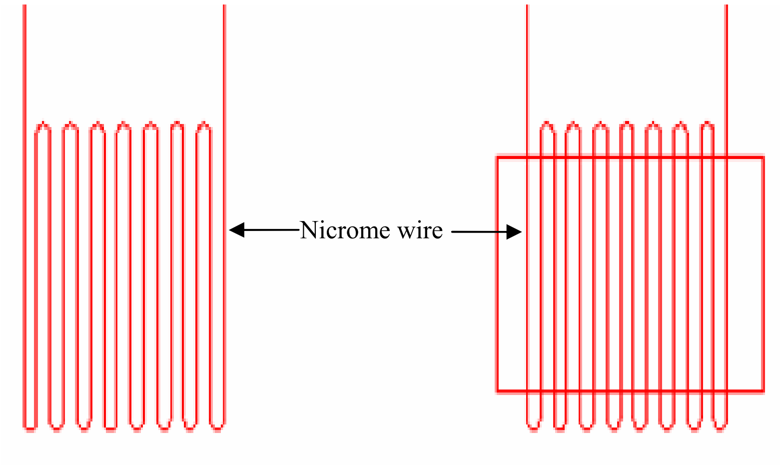

Figure 4 Nicrome Wire Loop in Heater   Figure 5 Using Heater Section

3. MATHEMATI.CAL MODELING

In this experiment the V-corrugated plate is heated by an electric heater. The equation of the input power can be written as

$$P = V \times I \times \cos\theta \qquad (1)$$

where

P =Input power, watt

V = Input voltage, volt

I = Input Current, ampere

The heat transfer from hot V-Corrugated plate to cold V-Corrugated plate by natural convection can be written as

$$Q_{hotplate} = A \times h \times \left(T_{hotplate} - T_{coldplate}\right) \qquad (2)$$

where

A = Area of hot plate, m^2

h = Convective heat transfer coefficient, W/ m^2.K

$T_{hotplate}$= Temperature in hot plate, ºC

$T_{coldplate}$ = Temperature in cold plate, ºC

The equation of heat gained by water can be written as

$$Q_{water} = m \times Cp \times dT \qquad (3)$$

where

Cp=Specific heat at constant pressure (J/kg.K)

dT = Outlet water Temp – Inlet water Temp, ºC

m=Mass flow rate of water, Kg/s

Using equations (1)-(3) the heat transfer rate is calculated by changing the input power, mass flow rate of water and the inlet water temperature.

4. RESULTS AND DISCUSSIONS

4.1 Temperature distribution of V-corrugated plates

4.1.1 Temperature distribution of hot V-corrugated plate

The temperature distribution of the hot plate is shown in Figures 6 and 7. From the Figures, it can be seen that temperature of the plate is not same at all the points. In the same plate temperature varies from point to point. Between the plate and heater, asbestos is used to prevent short circuit. As the plate is corrugated, contact between asbestos and plate surface is not perfect. The contact of the peak of the corrugated plate is perfect but the trough of the corrugated plate is not perfect. There is an air gap between the surface of the trough of the corrugated plate and the asbestos. Therefore, the temperature of the peak of the corrugated plate is greater than that of the trough of the plate. In this case, at certain points the temperatures are steady even though the overall plate temperature is not same.

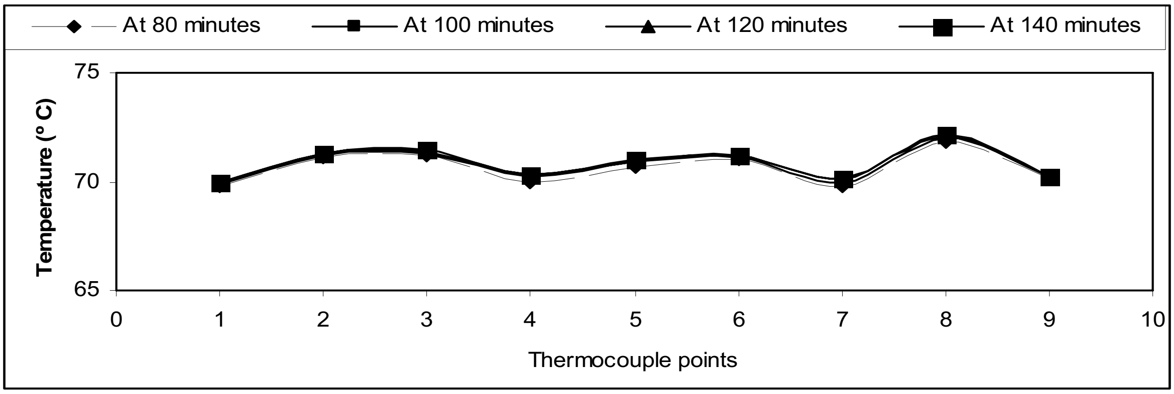

Figure 6 Temperature distribution of hot V-corrugated plate (Input power 70 watt)

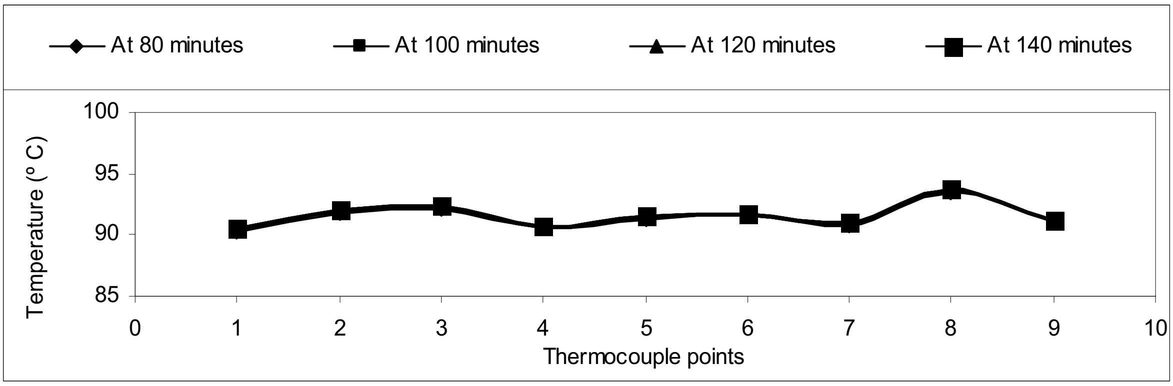

Figure 7 Temperature distribution of hot V-corrugated plate (Input power 110 watt)

4.1.2 Temperature distribution of cold V-corrugated plate

The temperature distribution of the cold plate at different input power is shown in Figures 8 and 9. The temperatures of the plate are not uniform from point to point. However, the temperature of the overall plate should be same. Water is flown through the cold plate. During water flow, the trough of the corrugated plate is in close contact with flowing water and the peak of the plate is not in close contact with flowing water. The still water is in contact with the peak of the plate. In this case, temperature of the trough of the plate is less than that of the peak of the plate. For this reason, temperatures are varied from point to point. When the mass flow rate is increased, the temperature difference is also increased because the peak is in contact with still water and the trough with flowing water that why heat transfer rate increase from the trough. When the input power increases, the temperature difference from point to point also increases. The temperature difference from point to point increase when the inlet water temperature decreases.

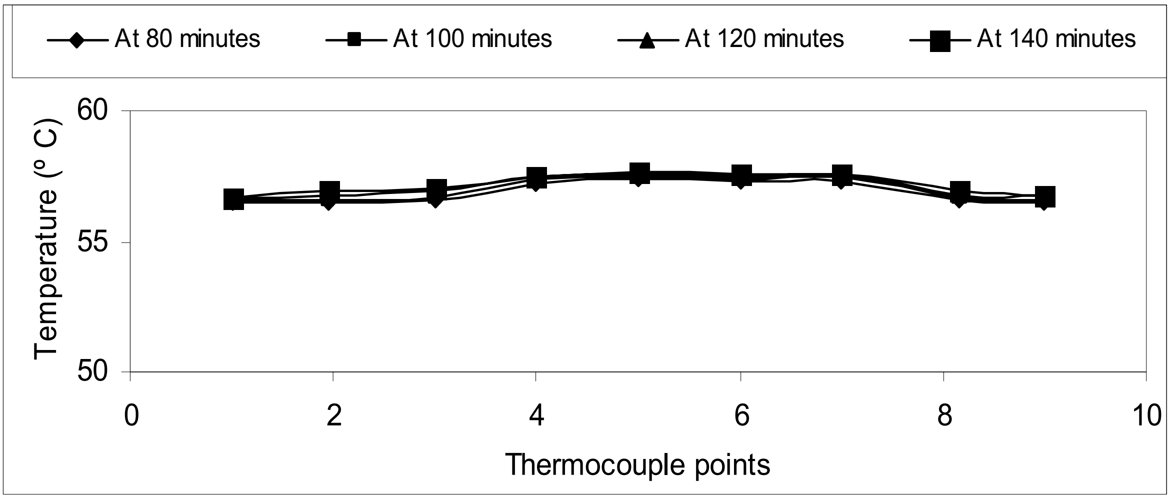

Figure 8 Temperature distribution of cold V-corrugated plate (Input power 70 watt)

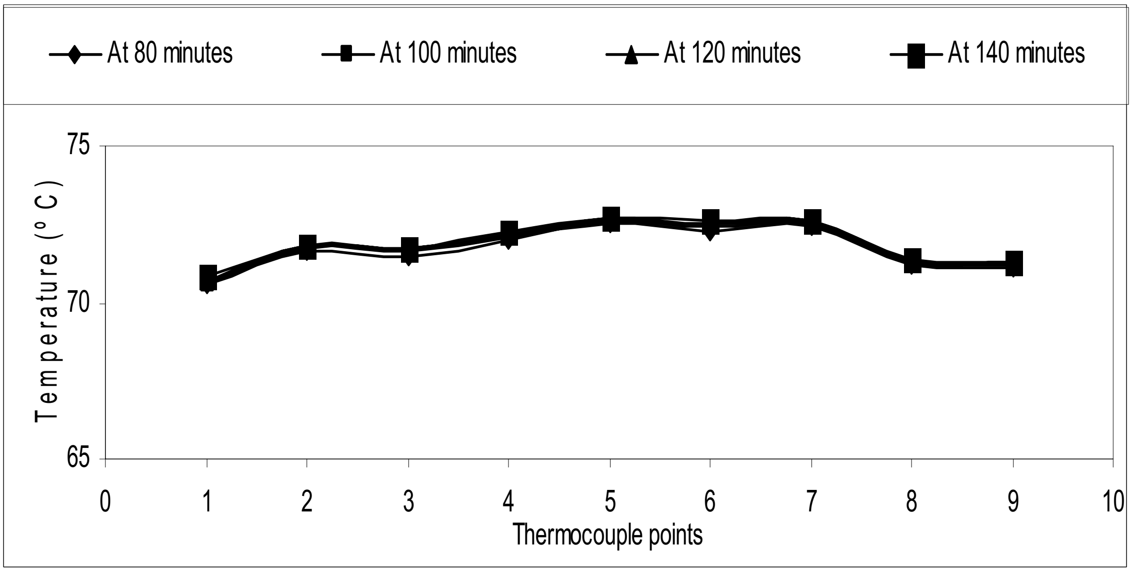

Figure 9 Temperature distribution of cold V-corrugated plate (Input power 110 watt)

4.2 Heat Transfer

It is a natural phenomenon that heat is transferred from higher temperature to lower temperature. Heat is transferred from hot plate surface to the cold plate surface through the air due to the temperature difference. The heat transfer system is purely natural convection.

The heat transfer in between the parallel plate is investigated on the theory of natural convection through the air. In the heat transfer analysis, the rate of heat transfer through a medium is normally calculated under steady conditions and surface temperature. The heat transfer rate is shown in the Table 1 and Table 2 for input power 70 Watt and 110 Watt respectively.

Table 1 Heat Transfer rate at Input power 70 Watt

Expt	Mass flow rate, m (kg/s) * 10^{-3}	Inlet Temp (ºC)	Outlet Temp (ºC)	ΔT_{water} (ºC)	T_{avg}, Hot Plate (ºC)	T_{avg}, Cold Plate (ºC)	$T_{hot\ plate} - T_{cold\ plate}$ (º C)	$Q_{hotplate}$ (Watt.)	Q_{water} (Watt.)	Efficiency of Heater (%)	Heat transfer from Hot to Cold Plate (%)
1	1.165	17.3	28.3	11	62.67	42.67	20	60.01	53.82	85.72	89.69
2	1.15	17.3	27.9	10.6	62.29	42.59	19.7	59.10	51.19	84.44	86.61
3	1.138	17.3	27.5	10.2	61.89	43.49	19.2	57.60	48.75	82.29	84.62
4	1.117	17.3	27	9.7	61.56	43.16	18.4	55.20	45.50	78.87	82.42
5	1.11	17.3	26.3	9.0	61.21	43.31	17.9	53.70	41.95	76.72	78.12
6	1.09	17.3	25.9	8.6	60.59	43.19	17.4	52.20	39.69	74.58	76.03

Table 2 Heat Transfer rate at Input Power 110 Watt

Expt	Mass flow rate, m (kg/s) * 10^{-3}	Inlet Temp (ºC)	Outlet Temp (ºC)	ΔT_{water} (ºC)	T_{avg}, Hot Plate (ºC)	T_{avg}, Cold Plate (ºC)	$T_{hot\ plate} - T_{cold\ plate}$ (º C)	$Q_{hotplate}$ (Watt.)	Q_{water} (Watt.)	Efficiency of Heater (%)	Heat transfer from Hot to Cold Plate (%)
1	1.22	16.8	29.8	13	89.61	65.41	24.2	72.57	66.61	90.71	91.78
2	1.18	16.8	29.5	12.7	88.76	64.86	23.9	71.67	62.94	89.58	87.81
3	1.15	16.8	29.2	12.4	88.19	64.79	23.4	70.17	59.82	87.71	85.35
4	1.12	16.8	28.7	11.9	87	64.1	22.9	68.67	55.97	85.84	81.51
5	1.10	16.8	28.4	11.6	86.5	64.2	22.3	66.87	53.78	83.59	80.43
6	1.06	16.8	28.2	11.4	85.4	63.5	21.9	65.67	50.75	82.09	77.28

4.3 Parametric influence on heat transfer

In this study the heat transfer through V-corrugated vertical walls are investigated for the variation of (a) Mass flow rate of cooling water (b) Input heat energy and (c) Inlet water temperature. The effects of these variables are discussed below.

4.3.1Effect of mass flow rate of cooling water

Figures 8 and 9 show the change of heat transfer rate with respect to mass flow rate of water. If mass flow rate of water increases, heat transfer rate increases linearly up to a certain limit. If the mass flow rate is increased cooling water takes more heat from contact surface. The temperature difference between the two surfaces of cold plate one contact with cold water another with confined air also increased which causes more internal conduction of the cold plate. Further increase in mass flow rate of water decreases the rate of change of heat transfer because of the effect of viscous dissipation.

4.3.2 Effect of input power

Figures 10 and 11 show the change of heat transfer rate with respect to input power. If input power increases, heat transfer rate also increases**.** The heat transfer between the walls of enclosed space depends on the temperature difference of walls. If the input power is increased the temperature of the hot plate also increased which causes more heat transfer.

4.3.3Effect of inlet water temperature

Heat transfer rate depends on the inlet water temperature. Figure 10 shows that for constant input power 70 watt, heat transfer rate increases with decreasing of water inlet temperature. For a constant mass flow rate of water, heat transfer rate is greater at inlet water temperature 17.3°C than at inlet water temperature 27.2°C. Figure 11 also shows that for a constant input power 110 watt heat transfer rate is more at inlet water temperature 16.8°C than 26.3°C for same mass flow rate of water. Heat transfer rate depends on various operating conditions as well. From the above information, it can be stated that with the increase of both input power and mass flow rate of water, heat transfer rate can be increased. Heat transfer rate also increases with decreasing of inlet water temperature. When the inlet temperature of the water is decreased the convective heat transfer from the cold plate to the water increased and thus increases the convective heat transfer from hot plate to cold plate.

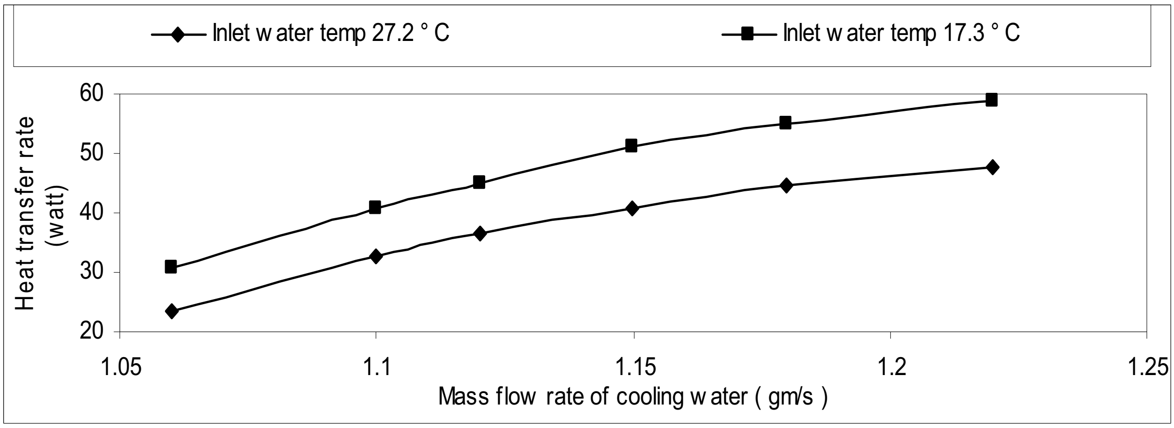

Figure 10 Heat transfer rate with mass flow rate of water (Input power 70 watt)

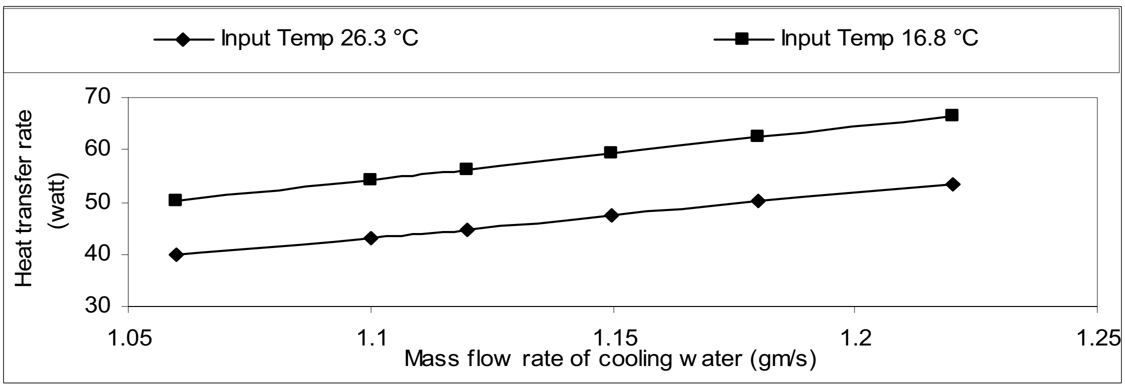

Figure 11 Heat transfer rate with mass flow rate of water (Input power 110 watt)

5. CONCLUSION

It has been found that the temperature of the peak is higher than the trough in the hot plate on the other hand; the temperature of the trough is higher than the peak in the cold plate. Overall temperature is almost same in both hot and cold plates. Heat is transferred from hot plate to cold plate and from cold plate to cooling water. Heat transfer rate increases with the decrease of inlet water temperature. Heat transfer rate increases with increase of input power. Heat transfer rate increases with the increase of mass flow rate of water. The increment of heat transfer is high for low mass flow rate of water. The increment of heat transfer is low for high mass flow rate of water

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