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Research Article

Enhancement of Heat Transfer of Forced Convection for Trapezoidal Channel using Sharp Edged Wavy Plate in a Turbulent Flow

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Abstract

Heat transfer enhancement in a channel with trapezoidal bottom wall using sharp edged wavy plate has been investigated experimentally. The experiments were performed for different Reynolds numbers 17037.1, 19799.9, and 26246.3 by varying heat flux. The results shows that the channel with trapezoidal bottom wall, the average Nusselt number increases by 30-55% at different heat flux and Reynolds numbers, but by using a wavy plate the average Nusselt number increased by 40-75% as compared to plane duct. The increase in Reynolds number leads to enhancement in the heat transfer coefficient. But there is a moderate increase in the pressure drop as compared to plane plate.

Keywords: *Heat transfer enhancement, forced convection, Trapezoidal bottom wall, Channel flow.*

1. Introduction

Augmentation of heat transfer is the process of improving the thermal performance of heat transfer devices. Designing of heat exchangers is required to increase energy saving and decrease cost. The use of corrugated plates is a suitable method to augment the thermal performance and compactness of exchanger devices. These act as turbulence promoters to improve heat transfer, due to the induced breaking and destabilizing as fluid flowing through the wavy surfaces.Heat transfer improvement has developed over the years and is the main focus in the heat exchanger industry. Augmented surfaces give up superior heat transfer coefficient compared to plane surfaces. The surfaces can be enhanced, either by active enhancement which requires use of external power which is clearly high in operational and capital cost thus unviable, and passive enhancement that involves adding extended surface, or employing interrupted surface (e.g. corrugations). The compact heat exchangers compared to the traditional shell and tube heat exchangers have high thermo-hydraulic performance, small size and compact volume. These make the compact heat exchangers more attractive in different industrial applications. They find wide applications in power, process, automotive, electronics and aerospace industries. Special channel shapes, such as channel with trapezoidal bottom wall and a sharp edged wavy plate as an insert is used in current study. These Sharp edged wavy plate (SEWP) surfaces are particularly attractive for their simplicity of manufacturer, potential for superior thermal performance and simple to usage in both plate and tube type exchangers. Under steady condition of flow it yields low performance of heat transfer coefficients therefore unsteady condition or turbulence flow is being deployed to get the relevant results. However, if the flow is made unsteady (either through external forcing or through natural transitioning to an unsteady state) significant increases in heat exchange are observed.

Considerable study has been conceded on the use of passive vortex generators in the heat transfer augmentation. Nishimura *et al.* numerically investigated flow characteristics in channel with a symmetric sinusoidal wavy wall, having geometry alike the oxford membrane blood oxygenator. The flow observations were performed in the Reynolds number range 100 to 10000. Sparrow and Comb studied the effects of varying the spacing between the corrugated walls in the Reynolds number range of 2000 to 27000.Nishimura *et al.* [3] investigated mass transfer characteristics in a channel with symmetric wavy wall by the lveque theory and the electrochemical method, in the flow regime covered from laminar to turbulence. In this study mass transfer coefficient at high peclet number for laminar and turbulent flow was investigated and compared with straight wall channels. For laminar flow mass transfer

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coefficients was low for wavy channel, but for turbulent flow it was high. Brunner and Brenig calculated the scattering of molecules from the corrugated surfaces with rotational energy transfer. Sunden and Skoldheden both experimentally and numerically studied the heat transfer and pressure drop in the corrugated channels and the smooth tubes. It was found that the heat transfer obtained from the corrugated channel was 3.5 times higher than that from the smooth channel. But, the pressure drop was 5–6 times larger than a smooth channel. Wang and Vanka [6] numerically studied the rate of heat transfer for flow through periodic array of wavy passage. The flow was observed to be steady at Re number around 180, beyond this self-sustained oscillatory flow was observed, which leads to the destabilization of thermal boundary layers. Stone and Vanka studied developing flow and heat transfer in wavy passages. It was observed that the flow was steady in part of the channel and unsteady in the rest of the channel.

As the Reynolds number was progressively increased, the unsteadiness was onset at a much earlier location, leading to increased heat transfer rates. Varying the channel spacing alters the heat transfer and pressure drop characteristics. Hamza *et al.* experimentally studied effects of the operating parameters on laminar flow forced convection heat transfer of air flowing in a channel having a V-corrugated upper plate. The experiments were performed for Reynolds number and tilting angles of channel in the ranges of 750–2050, and 0–60°, respectively. Bahaidarah and Anand numerically investigated two-dimensional steady developing fluid flow and heat transfer through periodic wavy passage and compared to flow through a corresponding straight channel. In this work, sinusoidal and arc-shaped configurations were studied for a range of geometric parameters. Paisarn Naphon *et al.* numerically investigated heat transfer characteristics and pressure drop in the corrugated channel under constant heat flux. Two opposite corrugated plates with 3 different angles β = 20°, 40° and 60° degree were tested with channel height 12.5mm, experiment were performed for heat flux 0.5-1.5 KW/m^2 and Re 500-1400. The heat flux had a significant effect on the outlet air temperatures. The higher wavy angles gave lower plate temperature, due to higher surface area heat transfer from the surface to the air increases. Naphon and Kirati analyzed on the heat transfer and fluid flow developments in the channel having one side corrugated plate under constant heat flux conditions. Bahaidarah *et al.* numerically studied a two-dimensional steady developing fluid flow and heat transfer through a periodic wavy passage (sharp edge-shaped configurations), with and without horizontal pitch. Triangular wavy channel without horizontal pitch (l/L = 0) provide lower normalized pressure drop values when compared to triangular wavy channel with horizontal pitch and it keep increasing as the (l/L) increases. *Paisarn et al* numerically studied on the heat transfer and flow distributions in the channel with different geometric configurations under constant heat flux conditions and effects of geometry configuration of wavy plates. It was concluded that the sharp edges of wavy plate has significant effect on the flow structure and heat transfer enhancement as compared to trapezoidal shaped wavy plate.

Literature review shows that many experimental and theoretical attempts have been made to improve the heat transfer enhancement in the heat exchangers by use of passive techniques. No attempts so far have been made to enhance the heat transfer in the channel with trapezoidal bottom wall and using sharp edged wavy plate (SEWP) in center at the height of 10mm, in a turbulent flow. In the present study the heat transfer analysis with trapezoidal bottom wall and SEWP is made and is compared with plane channel.

2. Experimental Set Up

2.1 Experimental set-up

The experimental set up for the present study is shown in Figure 2.1.The apparatus consist of a rectangular duct. The total length of the duct is 1750 mm. The apparatus consist of four parts; first part the inlet section having length of 500 mm, width 200 mm, and height 120 mm. A straightener is used in the inlet section up to a length of 200 mm to minimize the turbulence in the air and to keep a uniform air flow before entering the test section. A port is made in the top part of the inlet section for the measurement of velocity by hot wire anemometer. Second part of the duct is the test section having the overall length of 600 mm, width 200 mm, height 120 mm. Test section consist of a rectangular plate made up of aluminum , having dimension of 300x150x6 mm. The bottom wall is trapezoidal as shown in Figure 2. The AC power supply was the source of power for the plate type heater with a capacity of 400 W used for heating the plate. Air is taken as tested fluid, was directed in to the system by a blower. To obtain the desired flow rates the operating speed of the fan can be varied by using a regulator. Hot wire anemometer (Testo-405) is used to measure the flow rate of air in the system. In order to measure the temperature distributions on the plate, six thermocouples wires of k-type are fitted to the plate at equal distance from the sides of the plate. Third part of the duct is the extended section having dimension of 200x200x120 mm, on the top of which the hot wire anemometer is placed to measure the outlet velocity of the air and to measure the temperature of the outlet air. And the fourth part of the test section is the divergent section which is inclined at an angle of 8^o and of 450 mm length. The end of the divergent section has the square part of 230x230 mm which consists of a blower of 200 mm in diameter along with a capacity of 360 cubic feet per minute. The sharp edge wavy plate (SEWP) is inserted inside the test section.

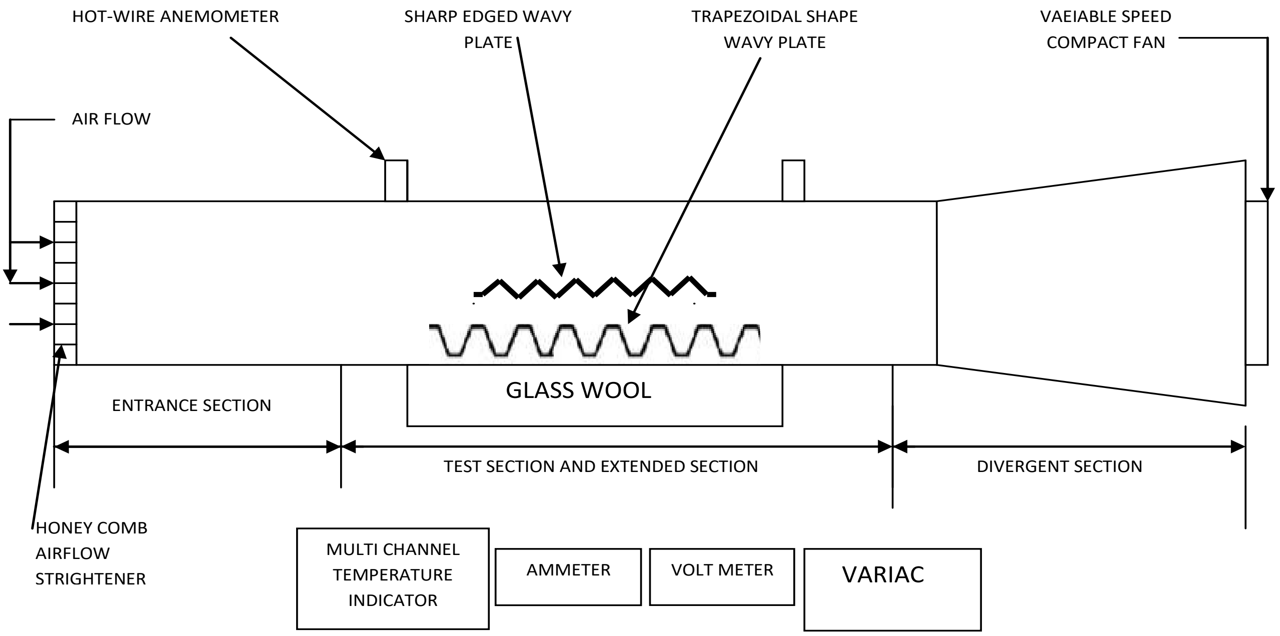

Figure 2.1 Schematic diagrams of experimental apparatus

2.2 First Step Making Plane Plat

Plane plat was prepared from aluminium having dimensions of size 300*150*6.0mm. Because aluminum has good properties of heat conductivity, machinability and availability. The bottom side of this plate was fixed with the help of a plate type heater through springs to make a good contact between plate and heater. To minimize the heat loss from bottom side of heater Glass wool insulation was packed in a box.

2.3 Second Step Trapezoidal Channel

In the second step 11mm grooves were cut on the 17mm thick alluminium plate with the help of milling machine. The total length of this plate is 300mm and 150mm width.

Figure 2.3 Trapezoidal bottom channel wall

2.4 Third Step Trapezoidal Channel with Sharp Edged Wavy Plate

In the third step a sharp edged wavy plate was fixed in hanging position over the trapezoidal channel with the wavy angle of 60°. This wavy plate was placed at the height of 10mm over the base plate in centre.

Figure 2.4

3. Table Figures and Equations

The experiments have been performed by taking three different cases plane channel, channel with trapezoidal bottom wall (TBW) and channel with trapezoidal bottom wall and sharp edged wavy plate(TBWSEWP).The experiments were performed by varying the Reynolds number and heat flux. The pressure drop was also calculated.

Fig 3.1 (a-d) shows the variation of average plate temperature with Reynolds number, at different heat flux conditions and the comparison of average plate temperature between plane channel, TBW and TBWSEWP. From Fig 3.1 (a-d) it is observed that as the heat flux is increases, the average plate temperture increases for all the cases.This may be attributed as due to the increase in power dissipation with increase of heat flux. It is also observed that at particular heat flux and Reynolds number the average plate temperature for TBW is lower as compared to plane channel. But with TBWSEWP the average plate temprature of that channel will be lowest then other two cases. The presence of wavy surface causes disturbance, induced breaking and destabilizing, recirculation, swirl flow as air flows through such surfaces in the main flow and hence the thinning of thermal boundary layer which leads to the cooling of the plate and decreases the average plate temperature. The average plate temperature decreases with increase in Reynolds number in all three cases.

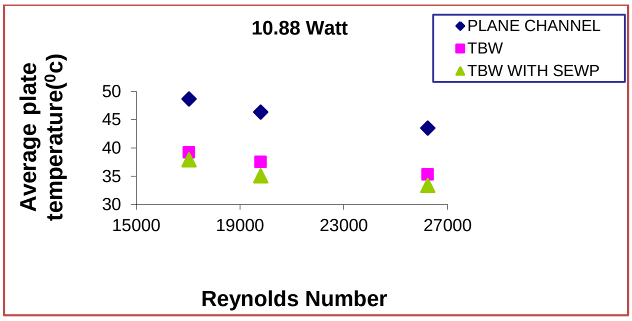

Figure 3.1 (a)

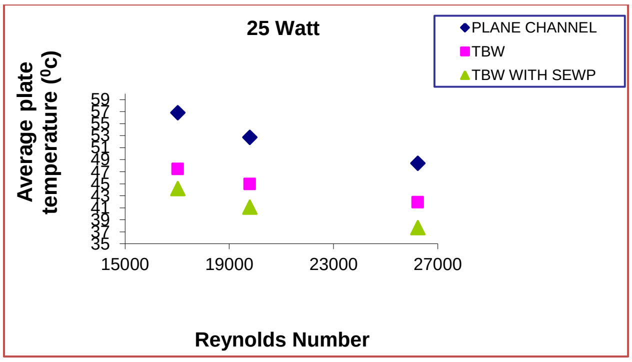

Figure 3.1 (b)

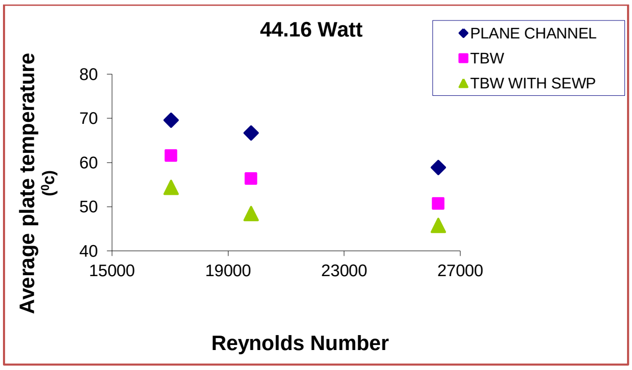

Figure 3.1 (c)

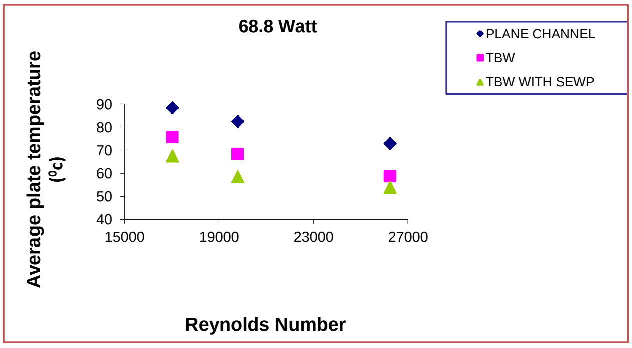

Figure 3.1 (d)

Fig 3.2 (a-d) shows the variation of outlet air temperature with Reynolds number at different heat flux. It is observed that the outlet air temperature decreases with increase in Reynolds number. This is due to the increased mass flow rate with the increase in the Reynolds number. The outlet air temperature for TBW is more than plane channel, and the outlet air temperature is highest for TBWSEWP.

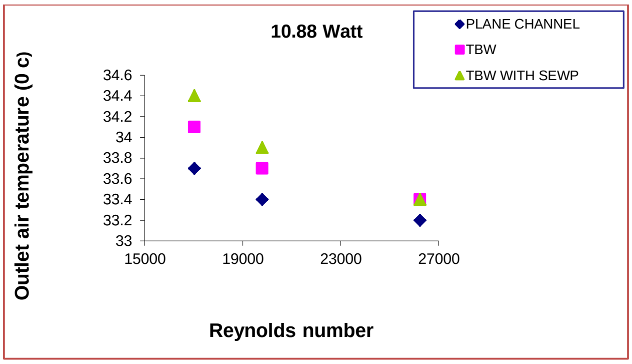

Figure 3.2 (a)

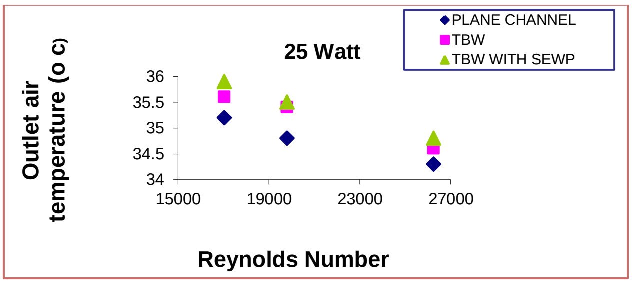

Figure 3.2 (b)

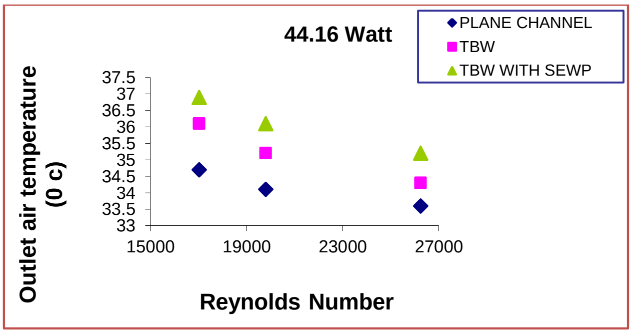

Figure 3.2 (c)

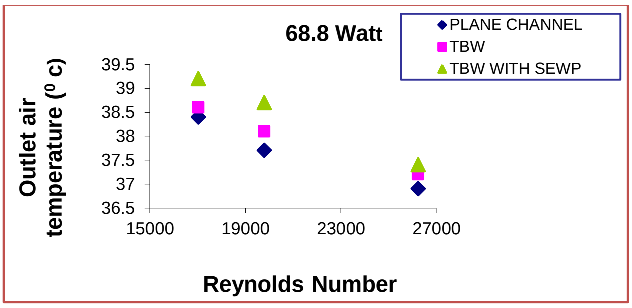

Figure 3.2 (d) Outlet temperature Vs Reynolds number

Fig 3.3 (a-c) shows the variation of Nusselt number (w.r.t plane channel) Nu/Nu_o with Reynolds number. It can observed that the Nu for TBW at different heat flux enhanced by 40-55% at 10.88 Watt, 30-50% at 25 Watt, 30-45% at 44.16 Watt, and 25-35 % at 68.8 Watt in the Reynolds number range of present study. Due to the presence of waviness causes disturbance, induced breaking and destabilizing, recirculation as air flows through such surfaces in the main flow and hence the thinning of thermal boundary layer which leads to the enhancement in the Nusselt number. The Nusselt number increases with increase in Reynolds number. When a sharp edged wavy plate is introduced over trapezoidal bottom wall at the hieght of 15 mm from the base wall then the Nusselt number for such channel is enhanced by 60-75% at 10.88 Watt, 55-70% at 25 Watt, 45-55% at 44.16 Watt, and 30-50% at 68.8 Watt in the Reynolds number range of present study. The presence of converging and diverging type of wavy channel in the form of SEWP accelerates and decelerates the air flow over the trapezoidal bottom wall along the length of duct and disturb the flow, generates vortex shedding effect and act as turbulence promoter in the flow, which leads to heat transfer augmentation i.e. increase in Nusselt number.

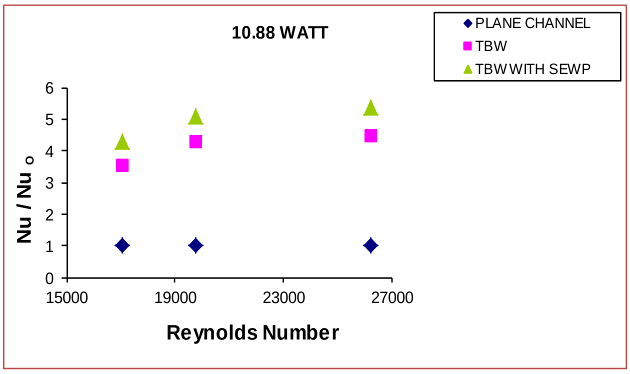

Figure 3.3 (a)

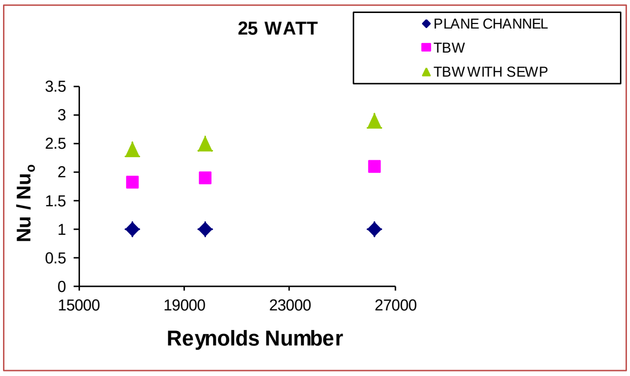

Figure 3.3 (b)

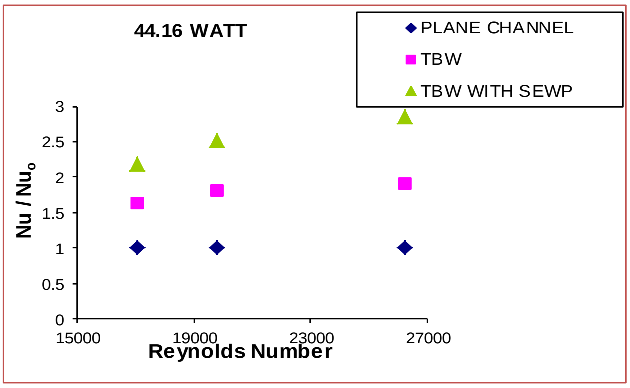

Figure 3.3 (c)

3.4 Pressure drop

Figure 3.4 shows the variation of pressure drop with Reynolds number for plane plate, TBW and TBW SEWP. Due to the presence of trpezoidal bottom wall and SEWP causes the hindrance to the flow of fluid and hence, the pressure drop is four times more than as compared to plane channel. It is also observed that the pressure drop continues to increase with Reynolds number. Fig 3.4 also shows maximum increase in pressure drop with TBWSEWP as compared to other cases.

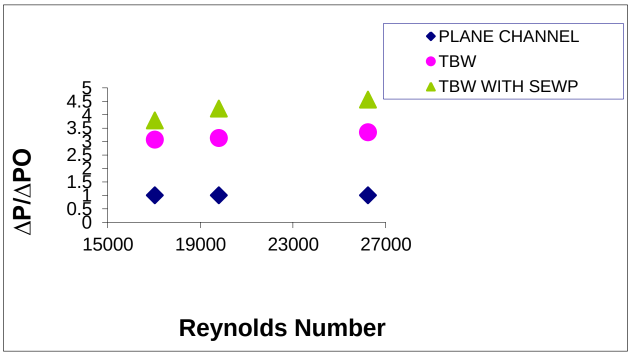

Figure 3.4 Pressure drop Vs Reynolds number along the test section

3.5 Equations

The components of experimental apparatus and instruments were fixed and tested as shown above in pictures. The velocity of the air was controlled through regulator at a desired value.The heat flux was controlled by the use of variac. The heater power was fixed at certain value until the surface temperature attained a steady state, then the value of heat transfer coefficient was calculated by using Newton's Law of cooling i.e.

Q_{conv} = h x A x(T_s-T_b) =VI (wattage given to heater) (1)

Where, T_s= Average of surface temperature

T_b=bulk Temperature $(T_{o,a} + T_{i,a})/2$ (2)
h= convective heat transfer coefficient

Nusselt number

$$\textbf{Nu} = hD_h/ k \quad (3)$$

Where, D_h is the hydraulic diameter of channel
k=conductivity of air at bulk temperature

Reynolds number

$$\textbf{Re} = UD_h/ v \quad (4)$$

Where, U is the mean velocity of air in the channel.
v is the kinematic viscosity of air at bulk temperature.

4. Result and Discussion

Heat exchanger devices are exposed to very high temperature when they are in running condition during its operation. With high temperature significant thermal stresses are developed and cause warpage because of the different coefficient of thermal expansion of the thermal devices. This experimental setup is an innovative way to enhance the heat transfer in heat the exchanger devices. Therefore, traprzoidal bottom wall with SEWP is the suitable method for augmentation in heat transfer and thermal performance of the heat exchangers. This can reduce the thermal stresses and the size of the heat exchanger devices for the same heat transfer rate. On the basis of the results obtained the following conclusions are made:

Due to the presence of waviness in trapezoidal bottom wall significantly enhances the heat transfer from the channel. Nusselt number enhanced by 40-55% at 10.88 Watt, 30-50% at 25 Watt, 30-45% at 44.16 Watt, and 25-35 % at 68.8 watt in the Reynolds number range of present study.

1) The Nusselt number increases with the increase in Reynolds number and the air outlet temperature decreases with Reynolds number in spite of increase in heat transfer.
2) The average plate temperature with TBWSEWP is low as compare to plane channel.
3) By introducing a SEWP over the trapezoidal bottom wall further enhances the heat transfer. The Nusselt number enhanced by 60-75% at 10.88 Watt, 55-70% at 25 Watt, 45-55% at 44.16 Watt, and 30-50% at 68.8 Watt in the Reynolds number range of present study. In this way channel with TBW using SEWP has found better heat transfer characteristics.
4) The enhancement of heat transfer achieved by using a SEWP over channel with TBW is associated with an increase in pressure loss and also pressure drop increases with increase in Reynolds number.

Nomenclature

Re	Reynolds number
A	Area of plate, m^2
D_h	Hydraulic Diameter of duct, m
Q	Heat transfer, W
V	Voltage supplied to heater, volts
I	Current, amp
Nu	Nusselt number
h	Heat transfer coefficient ,W/m^2k
Ts	Average surface temperature of plate, °c
T_b	Bulk temperature of air, °c
U	Mean air velocity, m/s
k	conductivity of air , W/mK

References

Tatsuo Nishimura, Yoshiji Ohori and Yuji Kawamura((1983), Flow characteristics in a channel with symmetric wavy wall for steady flow. Journal of Chemical Engineering

E. M. Sparrow and J. W. Comb (1983), Affect of inter-wall spacing and fluid flow inlet conditions on corrugated wall heat exchanger. International Journal in Heat and Mass Transfer 26 (1983) 993-1005

Tatsuo Nishimura, Yoshiji Ohori and Yuji Kawamura and Yoshihiko Kajimoto (1985),Mass transfer characteristics in channel with symmetric wavy wall for steady flow. Deptt of Chemical Engg,

T. Brunner, W. Brenig (1988), Coupled channel calculations for the rotational excitation of molecules at corrugated surfaces. Surface Science 201 (1988) 321–334.

B. Sunden, S. Trollheden (1989), Periodic laminar flow and heat transfer in a corrugated two-dimensional channel. International Communications in Heat and Mass Transfer 16 (1989) 215–225.

G. Wang and S.P. Vanka (1998), Convective heat transfers in periodic wavy passages. International Journal of Heat Mass Transfer vol. 17 (1995) 219-3230.

K.M. Stone and S.P. Vanka (1998), Numerical Study of Developing Flow and Heat Transfer in Wavy Passages. Air Conditioning and Refrigeration Center University of Illinois Urbana IL 61801, 217.

A. Hamza, H. Ali, Y. Hanaoka (2002), Experimental study on laminar flow forced-convection in a channel with upper V-corrugated plate heated by radiation. International Journal of Heat and Mass Transfer 45 (2002) 2107–2117.

H.M.S. Bahaidarah and N.K. Anand (2005), Numerical Study of Heat and Momentum Transfer in Channels with Wavy Walls, Numerical Heat Transfer, Part A 47 (2005) 417-439

Paisarn Naphon (2007), laminar convective heat transfer and pressure drop in the corrugated channels, International Communications in Heat and Mass Transfer.

Paisarn Naphon and Kirati Kornkumjayrit (2008), Numerical Analysis On The Fluid Flow And Heat Transfer In The Channel With V-Shaped Wavy Lower Plate, International Communications in Heat and Mass Transfer 35, 839-843.

H.M.S. Bahaidarah (2009), a Two-Dimensional Study Developing Fluid Flow and Heat Transfer Characteristics in Sharp Edge Wavy Channels with Horizontal Pitch. Emirates Journal for Engineering Branch, 14 (1), 53-63.

Paisarn Naphon (2009), effect of wavy geometry configurations on the temperature and flow distributions. International Communications in Heat and Mass Transfer 36, 942-946.