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(Research article)

Experimental Set-up for Heat Transfer Analysis in a Channel having Trapezoidal Bottom Wall with a Sharp Edged Wavy Plate

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Abstract

Heat transfer enhancement using a sharp edged wavy plate in a channel having trapezoidal bottom wall is experimentally taken for heat transfer analysis. Air is taken as working fluid. The sharp edged wavy plate is placed in the centre of the channel. By inserting a sharp edged wavy plate and making the channel bottom wall trapezoidal the flow is disrupted and secondary flow is created, which leads to destabilization of boundary layer and hence increase in heat transfer as compared to plane channel. This paper suggests a way to augment the heat transfer in heat exchanger devices using sharp edged wavy plate and trapezoidal bottom wall of the channel.

Keywords: *Heat transfer, Forced convection, trapezoidal wavy plate, Channel flow*

1. Introduction

Heat transfer augmentation is the process of improving the thermal performance of heat transfer devices. In general, designing of heat exchangers there is a need to increase energy saving and decrease cost. Enhancement of heat transfer has developed over the years and is the main focus in the heat exchanger industry. Enhanced surface yield higher heat transfer coefficient when compared to plane surfaces. A surface can be enhanced in two ways; either by active enhancement which requires deployment of external power which is operationally costly and involves high capital cost thus are commercially unviable. While passive enhancement involves adding extended surface (e.g. fins), or employing interrupted surface (e.g. corrugations). Using corrugated plates is a suitable method to increase the thermal performance and higher compactness. They are applied as turbulence promoters to augment heat transfer, which causes induced breaking and destabilize the fluid flowing, so the wavy surfaces are a suitable for improving the thermal performance of heat transfer devices.Compact heat exchanger can be classified in two ways, plate types or primary surface heat exchanger. The hydraulic diameters for most heat exchangers are very small and often in the range of 1 mm to 10 mm. The advantages of compact heat exchangers over the traditional shell and tube heat exchanger are high thermo-hydraulic performance, small size and compact volume. These advantages make compact heat exchangers very attractive for industrial applications. Compact heat exchangers are extensively used in power, process, automotive and aerospace industries. Special channel shapes, such as wavy channel under investigation, provides mixing due to secondary flows formation, separation or disruption. In such channels waviness causes the flow directions to change periodically. These wavy channel surfaces are attractive for their simplicity of manufacturer, potential for enhanced thermal performance and easy to usage in both plate and tube type exchangers. The boundary layer separates and reattaches periodically around the trough regions to permute enhanced heat transfer, but with increased pressure drop penalty.

Wavy channels are easy to fabricate and can provide significant heat transfer enhancement. Therefore, wavy passages have been considered in studies as a means to enhance heat/mass transfer in compact exchange devices.

Fig. 1 Wavy plate having horizontal pitches on sharp edges (Trapezoidal wavy bottom plate)

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2. Literature review

Considerable research has been carried out on the use of passive vortex generators in the heat transfer enhancement. Many researchers [1-8] have carried out experimental and numerical research in both laminar and turbulent flow with corrugated channels, array of wavy passages, sinusoidal wavy passages, V-corrugated plates etc. To make it specific only papers directly relevant to the study are described in the review. Bahaidarah and Anand [9] numerically investigated two-dimensional steady developing fluid flow and heat transfer within a periodic wavy passage and compared with the straight channel. In this work, sinusoidal and arc-shaped configurations were studied for a range of geometric parameters. The effects of varying the Reynolds number (Re), length ratio (L/a), and height ratio (H_{min}/H_{max}) on the developing velocity profiles, streamlines, isotherm, pressure drops, and Nusselt number were examined. Bahaidarah et al. [10] further studied numerically two-dimensional developing fluid flow and heat transfer through a periodic wavy channel with staggered walls and compared with non-staggered walls. The lower wall was displaced relative to the upper wall by one-fourth, one-half, and three-fourths of the total one-module length. It was found that sinusoidal channel with one-half displacement provide lower normalized pressure drop value when compared to all other channels whether staggered or non-staggered. The module average Nusselt number increased with Reynolds number. The heat transfer enhancement ratio for arc-shaped channels with three-fourth displacement was as high as 5.7%. Naphon et al. [11] numerically investigated heat transfer characteristics and pressure drop in the corrugated channel under constant heat flux. Two opposite corrugated plates with angles 20°, 40° and 60° were tested. It was found that the heat flux has 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. The average plate temperature decreases as air Reynolds number increases. By increasing wavy angle pressure drop also increased. Naphon and Kirati [12] analyzed heat transfer and flow developments in the channel having one side corrugated plate under constant heat flux conditions. The corrugated plate with the corrugated tile angle of 40° was simulated. The channel height of 7.5 mm was taken. A finite volume method with the structured uniform grid system was employed for solving the model. Breaking and destabilizing in the thermal boundary layer were promoted as fluid flowing through the corrugated surface. Therefore, the corrugated surface has significant effect on the enhancement of heat transfer. Bahaidarah et al. [13] studied numerically a two-dimensional steady developing fluid flow and heat transfer through a periodic wavy passage (sharp edge-shaped configurations), with and without horizontal pitch. In this work four different types of wavy geometry, triangular without horizontal pitch (l/L = 0) and triangular horizontal pitch (l/L = 0.1, ¼, and ½) were considered. Triangular wavy channel without horizontal pitch (l/L = 0) provided lower normalized pressure drop values when compared to triangular wavy channel with horizontal pitch and it kept increasing with (l/L). Naphon et al. [14] numerically studied heat transfer and flow distributions in the channel with various geometric configurations under constant heat flux conditions. The effects of geometry configuration of wavy plates, wavy plate arrangements, and air flow rates on the temperature and flow developments were considered in this study. It was found that the sharp edges of wavy plate had significant effect on the flow structure and heat transfer enhancement as compared to trapezoidal shaped wavy plate. Quaresma and Cotta [15] studied convective heat transfer enhancement in low Reynolds number flows and channel with wall corrugation. A hybrid numerical-analytical solution methodology for the energy equation was proposed in partial transformation mode for a transient formulation. The hybrid approach was first for the case of smooth parallel-plates channels. An illustrative sinusoidal corrugation shape was adopted and the influence of Reynolds number and corrugation geometric parameters was then discussed. The above literature survey shows that the numerous experimental and theoretical studies have been performed to enhance heat transfer in the heat exchanger devices; however there is still a room to discus.

3. Problem formulation

Literature review shows that many experimental and theoretical attempts have been made to improve the heat transfer enhancement in the heat exchangers using waviness in channel walls. No attempts so far has been made to enhance the heat transfer with the combination of trapezoidal wavy channel having sharp edged wavy plate at the height of 15mm, in a turbulent flow. In the present study attempt is made to suggest a new method for heat transfer enhancement using sharp edged wavy plate along with the channel having trapezoidal bottom wall in the heat exchangers.

4. Experimental set up

The experimental set up proposed for the study is presented in figure 2. The experimental equipment consists of a rectangular duct. It consist of four parts, first part is the inlet section. A straightener is used in the inlet section to minimize the turbulence in the air and to keep a uniform air flow before entering the test section. A port is

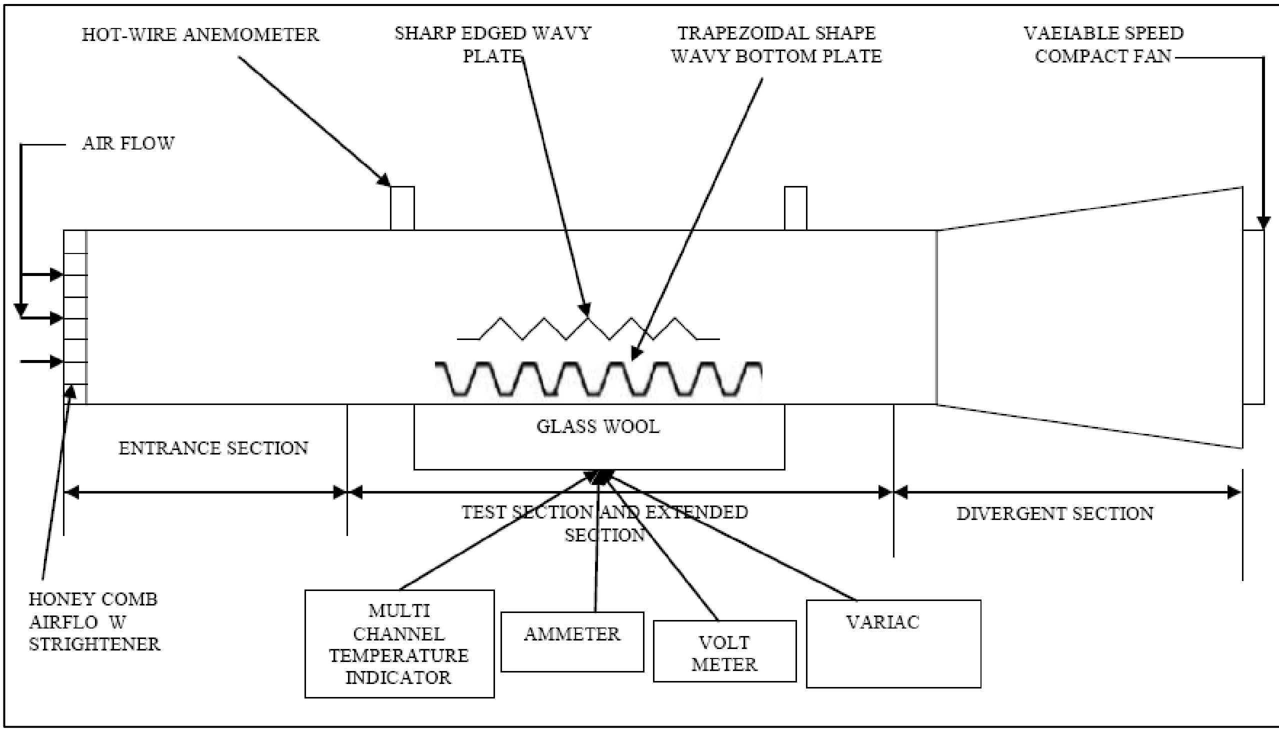

Fig.2 Schematic Diagram of Experimental Apparatus

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. The test section consists of a rectangular plate made up of aluminium, having trapezoidal cross-section. The sharp edged wavy plate is inserted in the channel. The AC power supply is the source of power for the plate type heater for heating the test section in order to maintain a uniform surface heat flux. Air as the tested fluid in both the heat transfer and pressure drop experiments, can be directed in to the system by a blower. The operating speed of the fan could be varied by using a regulator to provide the desired flow rates. The flow rate of air in the system can be measured by a hot wire anemometer. In order to measure the temperature distributions on the plate, thermocouples wires of k- type can be fitted to the plate at equal distance from the sides of the plate. A variac can be used to control the wattage of the heater and various readings are observed at different values of current and voltage.

Third part of the duct is the extended section, on the top of which the hot wire anemometer can be placed to measure the outlet velocity of the air and to measure the temperature of the outlet air. Fourth part of the test section is the divergent section. The end of the divergent section can be fitted with a blower.

5. Measuring technique

The components of experimental apparatus and instruments can be fixed and tested as shown above. The velocity of the air can be controlled through regulator at a desired value, the heat flux can be controlled and changed by the use of variac and checked by voltmeter and ammeter. The heater power can be fixed at certain value until the surface temperature attained a steady state. The heat transfer to the flowing air through the rectangular duct can be calculated by,

$$Q_{air}= Q_{conv}= maC_p\ (T_{a.o}-T_{a.i}) = VI \quad (1)$$

$$h = Q_{conv}/A\ (T_{avg} - T_b) \quad (2)$$

$$T_b= (T_{a.o}+ T_{a.i}) / 2 \quad (3)$$

$$T_{avg}= \sum T_s / 8\sum T \quad (4)$$

Where, the term A is the convective heat transfer surface area of Aluminium plate, whereas T_{avg} is the average surface temperature obtained from local surface temperatures along the axial length of plate. Then the average Nusselt number is written as:

$$Nu=hD/k \quad (5)$$

The Reynold number based on the duct hydraulic diameter D is given by:

$$Re=UD/\nu \quad (6)$$

6. Discussion and conclusion

Heat exchanger devices are needed to be very efficient during its operation. The increase in the heat transfer will reduce the size of the heat exchanger which would lead to saving cost and size of the heat exchanger for same heat transfer rate. This experimental setup is an innovative design to enhance the heat transfer in the heat exchanger devices. The use of trapezoidal bottom wall channel and the shape wavy plate causes disturbance in the flow, due to the induced breaking and destabilizing as fluid flowing through the wavy surfaces, re-circulation and swirl flows and hence the thinning of thermal boundary layer causing the increase in the heat transfer. Therefore the use of sharp edged wavy plate in a channel with trapezoidal bottom plate is a suitable method to increase the thermal performance and higher compactness of the heat exchanger.

Further the study can be carried out to find the heat transfer augmentation using the above said device and compare it with plane channel. The study can be further performed to study the modification in flow structure with the use of wavy plate by flow visualization methods. This experimental set up will be helpful to study the extra heat transfer for the same working conditions.

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