Experimental Investigation of Forced Convection Heat Transfer from Vertical Grooved Plates

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Abstract: Increasing the heat transfer rate has become prime task in electronic industry because of miniaturization of equipments. Recently many investigators carried out numbers of experiments for achieving maximum heat transfer rate, the present investigation mainly focus on increasing the thermal dissipation from the surface by providing grooves over the surface of aluminum plates with various ranges of length to width ratio and length to depth ratio. The experiment was carried out for varying Reynolds number and varying the amount of heat flux given to the plate. It has been observed that variation in L/D ratio and flow rate affects the heat transfer rate and friction factor.

Keywords: Nano fluids; Heat flux; Groove flat plate, air, Reynolds number, heat transfer coefficient.

1. Introduction

Plates have received considerable attention because of the fact that they have been used widely in industrial applications. They have found extensive use in heat exchangers. When improvement in the process of heating or cooling is required, then better design of plate compactness and spatial geometry is very essential. The use of heat transfer enhancement has become widespread during the last 50 years. The goal of heat transfer enhancement is to reduce the size and cost of heat exchanger equipment, or increase the heat duty for a give size heat exchanger. This goal can be achieve in two ways: active and passive enhancement. Of the two, active enhancement is less common because it requires addition of external power to cause a desired flow modification. On the other hand, passive enhancement consists of alteration to the heat transfer surface or incorporation of a device whose presence results in a flow field modification. One of the popular enhancements is the introduction of grooves on the surface of the heat exchanger. The apparent advantages of grooved plates are that they increase the heat transfer rate by providing additional surface area.

Inspite of the above facts, only a very few studies have been reported in the literature on the flat plate with grooves. Ashish Dixita & Anil Kumar Patila [1] carried out an experimental study on different types of grooves which were made on the extended surfaces. They found that the heat transfer was more for fins having inclined grooves. Chang, S. W., Su, L. M., Yang, T. L., and Chiou, S. F [2] made an experimental study on fin channels having 90° staggered ribs and developed correlation to study the influence of Reynolds number and L/B on heat transfer, also suggested the optimum length to gap ratio that results in increased heat flux. The increment in heat transfer was up to 140–200 % using 90° staggered ribs. Kadir Bilen, Murat Cetin, Hasan Gul, Tuba Balta [3] conducted an experiment on tubes having grooves of different geometry. The ratio L/D was fixed in their study. They mainly developed a correlation for heat transfer and friction factor. The results of their study revealed that heat transfer enhancement does occur for tubes having grooves as compared with tubes without grooves. Faheem Akthar, Abdul Razak R Kaladgi and
Mohammed Samee A Dafedar [4] conducted an experimental investigation of the natural convection heat transfer over circular dimpled surfaces. The arrangement was inline. The various heat transfer parameters considered were Nusselt number, heat transfer coefficient and heat transfer rate. They concluded that heat transfer enhancement occurs for the dimpled surfaces as compared to flat plates. In another study, Amjad Khan, Mohammed Zakir Bellary, Mohammad Ziaullah, Abdul Razak Kaladgi [5] carried out an experimental study on plates having dimples of circular shapes. The analysis was carried out for different arrangements like centrally increasing the diameter of dimples in the direction of flow; centrally decreasing the diameter of dimples in the direction of flow etc. They concluded that heat transfer enhancement does occur for plates having dimples but at the cost of pressure drop. N. K. Ghaddar, K. Z. Korczak, B. B. Mikic, A.Y. Patera [6], numerically studied the heat transfer characteristics in the channels having grooves on one plate. They solved the Navier-stokes and energy equations numerically and showed complex flow patterns of flow recirculation flow separation etc. Tang xinyi and zhu dongsheng [7] conducted experimental and computational study (using software) on rectangular channels having ribs and grooves. They used the SST turbulence model to solve the equations and carry out the simulations. They found that the Nu ratio and Cf were more for the channels having ribs and grooves as compared to the channels having only ribs. Apurba Layek, J. S. Saini, S. C. Solanki [8], carried an experiment to study the effect of heat transfer on a duct having ribs and grooves on one surface. They observed an increment in the Nusselt number by about 3.24 times as compared to smooth surface. Ali Najah Al-Shamani, K. Sopian, H. A. Mohammed, Sohif Mat, Mohd Hafidz Ruslan, Azher M. Abed [9] computationally studied heat transfer characteristics of a channel having ribs and grooves on one wall. They used the STD K-epsilon turbulence model to solve the governing equations. They carried the investigation on various ribs and groove combination. They also used different nano fluids with different concentrations. They found that trapezoidal rib groove of good height gives the maximum heat transfer rate. Smith Eiam-saard and Pongjet Promvonge [10] conducted an experiment to study heat transfer characteristics in a duct using 3 types of groove and rib combination. They found an increment in the heat transfer as compared to smooth duct.

2. Experimental Setup

A forced convection apparatus was adapted for this study. Figure 1 show the experimental setup used for the present study. It consists of a rectangular duct to keep the grooved plates, a blower to supply air. The air from blower passes through a flow passage consisting of pipes and finally through the rectangular duct, orifice meter was used to measure flow rate through the passage, a band heater placed inside the duct heats the air and is controlled by dimmer start. Temperature of the air at inlet and outlet were measured using thermocouples.

![Figure 1: Experimental set up](image1)
3. Results and Discussion

The aim of the experiment is to measure the temperatures along the surface of the plate for the desired constant heat flux (The heater is adjusted for the desired power input with the help of...
dimmer stat). The experiment is allowed to run till the steady conditions are reached, and the temperature reading was noted.

The parameters varied during the experimentation were:
(i) Heat Input: The experiment were carried out for different heat inputs.
(ii) Aspect ratio: The length of the groove to the width of the groove is altered during the experiment.

Figure 3: Nusselt’s number Vs of L/D ratio

Figure 3 shows the effect of length to depth ratio on Nusselt number of the plate. The results were plotted for different heat flux conditions. It was observed that Nusselt number increases as the size of groove decreases due to direct flow impingement on the downstream boundary and strengthened flow mixing by vortices at the downstream [11,12]. The formation of vortex pairs periodically shedding off from the grooves, a large up wash regions with some fluids coming out from the central regions of the grooves are the main causes of enhancement of Nusselt number & is more pronounced near the downstream rims of the dimples [13].

Figure 4 shows the variation of Nusselt number for different discharges. It can be seen that Nusselt number increases, as the value of discharge increases as expected & hence increases the heat transfer coefficient. This may be attributed to the fact that due to increased flow rates, the velocity increases and hence increases the heat transfer rate of the plate. It can also be observed that the Nusselt number is highest for L/D ratio of 12.5 and lowest for L/D ratio of 50. So length of the groove affects significantly the heat transfer rate.

Figure 4: Nusselt vs. Discharge

The Figure 5 shows the variation of heat transfer coefficient with Reynolds number for an L/D ratio of 12.5. From the figure we can say that as the Reynolds number increases, the
heat transfer coefficient increases as expected, because at high Reynolds number, turbulence mixing takes place and because of turbulence the heat transfer coefficient increases.

Fig. 5. Heat transfer coefficient vs Reynolds number

Fig. 6 shows the variation of friction factor with Reynolds number. It can be seen that as the Reynolds number increases the value of friction factor decreases as expected. This may be attributed to the fact that increases in Reynolds number increases turbulence and decreases friction in the flow.

Figure 6. Friction factor vs. Reynolds number

Figure 7. Friction factor vs. Reynolds number
Figure 7 shows variation of heat transfer rate with respect to Reynolds number. It can be seen that heat transfer rate increases as Reynolds number increases as expected. Also it can also be observed that the heat transfer rate is higher for a plate having 25 mm length groove and it decreases as groove length increases. Finally, it can be concluded that grooved plate’s helps in better enhancing the heat transfer rate compared to flat plates without grooves.

4. Conclusions

The present study deals with the heat transfer characteristics of plates with rectangular grooves placed vertically within horizontally confining walls. The steady state laminar flow forced convection heat transfer analysis of plate with rectangular groove having different length to depth ratio was undertaken. The discharge and heat flux was varied in this experiment and the following conclusions were drawn

1. Length to width ratio has major impact on heat transfer characteristics.
2. With increasing length to depth ratio of grooves the Nusselt number decreases.
3. With increase in Reynolds number, the coefficient of friction decreases but the rate in decrease is very low as Reynolds number increases.
4. The Nusselt number and heat transfer coefficient increases with increase in the flow rate.
5. Among other plates, the plate of 25mm groove length has highest heat transfer rate.

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