Experimental Validation of Heat Transfer Enhancement in plate Heat Exchanger with Non Conventional Shapes of Rib

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Abstract-- **An experimental investigation is carried for heat transfer enhancement with the help of three shapes of rib for heat exchanger application. The aim of project is to examine the combined effect of rib–groove arrangement on force convection heat transfer in a rectangular duct. The experiment is performed on three different types of rib-groove arrangement: boot shape rib with triangular groove, rectangular rib with triangular groove, triangular rib with triangular groove. Experimental investigation is done for measuring heat transfer co-efficient, friction factor for rib groove arrangement of air for turbulent flow in a rectangular duct. Experimental setup consist of Blower, flow control valve to maintain measured quantity of flow, Orifice meter is used for flow measurement, Pressure drop is measure along test section and orifice meter with 2 U-tube manometer. A uniform heat flux condition is created by plate type nicrome wire heater of 800 W is used in the test section & asbestos insulation of 3mm thickness over the plate type heater. Outer surface temperature of tube is measured at 6 different points of test section by K-type thermocouple. The Reynolds number is varied in the range of 8000 to 18000 with constant heat flux. Nusselt number obtained from smooth is compared with Dittus- Boelter correlation. Friction factor is compared with Blasius Co-relation. Experimental setup is validated with the help of Dittus-Boelter equation and Blasius co-relation. At comparable, Reynolds number, Nusselt number in rectangular duct with boot shape rib insert is enhanced by 1.85 to 1.92**

times the smooth duct, whereas less friction factor is obtained for triangular shape rib.

***(Keywords*: rib shape, groove, heat transfer enhancement, friction factor, Nusselt number, Reynolds number)**

I. INTRODUCTION

The heat transfer from surface may in general be enhanced by increasing the heat transfer coefficient between a surface and its surrounding or by increasing heat transfer area of the surface or by both. Ribs used in cooling channel and heat exchanger channel are most commonly used passive heat transfer techniques. So that the work related to fluid flow and heat transfer in ribbed channel is go so far. This heat transfer augmentation technique are applied to many industrial application such as shell and tube type heat exchanger , electronic cooling devices, thermal regenerators, and internal cooling system of gas turbine. Each rib on downstream separates the flow, recirculate, and impinges on channel wall and these are the main reason for heat transfer enhancement in such channel. The use of rib in heat exchanger not only increase the heat transfer rate but also substantial the pressure loss. The rib arrangement and geometry resulting in different heat transfer distribution by altering the flow field. Therefore by making the modification in rib geometry we can increase the heat transfer rate but at the same time we need to consider the pressure drop also because it increases significantly. To get high heat transfer rate and pressure

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drop under limit many different shapes of rib are analyzed in the past and recent year which are as follows: Mi-Ae Moon, Mean-Jung Park [1] were analyzed the heat transfer and friction loss performance of rib roughened rectangular duct with variety of cross section using three dimentional –reynold-average-navier-stroke equation They reported that new boot- shaped rib design showed the best heat transfer performance than the square rib with average friction loss performance. Monsak Pimsarn, Pongjet Promvonge [2] were performed experiment on z shaped rib in which z shaped rib set on the rectangular duct at 30º, 45º,and 60º relative to the air flow direction. R. Tauscher, F. Mayinger [3] deals with the experimental and numerical investigation of the forced Convection heat transfer in flat channel with rectangular cross section. Uses Reynolds number ranges from 500- 10000. They studied the various configurations such as rib- shape, size, spacing, angle of attack, arrangement, duct width and height. They judged the mean heat transfer and heat transfer performance by measuring mean fluid temperature at entrance and exit of test section. They reported that most effective rib- pitch to height ratio of P/e= 10 and application of groove in spacing of ribs shows the better performance. Smith Eiamsa- ard, Pongjet Promvonge [4] were performed experiment to examine the combined effect of rib groove tabulators on the turbulent forced convection heat transfer in rectangular duct. Result showed that rectangular rib with triangular groove arrangement provide maximum heat transfer rate and friction factor than other. While triangular rib with triangular groove gives higher thermal enhancement index for all pitch ratios. The rib groove tabulators at PR= 6.6 provide higher heat transfer up to 80%. Thermal enhancement index is higher with use of tabulator at lower Reynold number. Ponjet Promvonge, Chinaruk Thianpong [5] were studied the forced convection heat transfer and friction loss behaviors for air flow constant heat flux channel with different shaped ribs They reported that in line rib arrangement provide higher heat transfer rate and friction factor than staggered one. C. Thianpong, T. Chompookham, S. Skullong, P. Promvonge [6] were studied the heat transfer rate and friction factor behavior of different height of triangular ribsThey reported that i) uniform rib height shows better performance ii) heat transfer enhancement is higher at ratio e/H= 0.26 iii) Nusselt number is constant with rise of Reynolds number. K. H. Dhanwade, H. S Dhanwade [7] were performed experiment to study the heat transfer enhancement with circular perforation equipped on horizontal flat surface in horizontal rectangular duct. Experiment performed with clearance ratio (C/H)= 0.45, inter fin spacing ratio(S/ H)= 0.22, duct width= 150mm, H= 100mm. They reported that heat transfer rate increases with perforated fin that with solid fins. It also reduces the fin weight so low weight saves the material of fin and also decreases the expenditure on fin material

II. EXPERIMENTAL SET-UP

Fig.1. shows the schematic diagram of the experimental setup from front view. The rectangular channel is used for this investigation and made up of SR sheet material. The plexi glass is used in front of duct over 300mm length in middle portion. All the geometrical dimensions are in term of channel height while the heat transfer coefficient are presented in term of channel hydraulic diameter (D_h = 0.044m). A blower is used to draw the air from entrance to exit section. Orifice meter is used to measure the mass flow rate. The flow developed through a 150 mm long unheated entrance before entering the heated test section and also 100 mm long unheated area is used after the heated test section this portion is provided in order to get the stream line flow before and after test section this portion is called as comic section. The heated test section is 300 mm long and 150 mm width. The uniform heat flux plate type heater is fabricated from nicrome wire. This heater is connected in series with dimmerstat in order to supply the same amount of heat to heater. The heater is provided on bottom surface

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and other side is unheated as well as insulated. Commercial glass wool insulation is used on external surface to prevent the heat leakage due to convection and radiation. For wall temperature measurement, four thermocouples are used at different place of heating surface. Moreover, one thermocouple is placed inlet and one thermocouple is placed at outlet to measure the inlet and outlet bulk temperatures, respectively. Manometer is used to measure the pressure drop within the duct.

Fig.1. Schematic view of experimental set-up

In experiment, boot shaped rib with groove, triangular shaped rib with groove and rectangular shaped with groove are used. Four test sections are prepared for experimentation purpose. One test section in experimental procedure is validated by running through the rectangular duct without using any ribs. In second phase the experimentation is carried out by using triangular shaped rib with groove inside the duct. In third, boot shaped rib with groove. In fourth phase, rectangular shaped rib with groove compared their performance with each other.

Three rib groove arrangements are as follows:-

1) Boot shaped rib with triangular groove

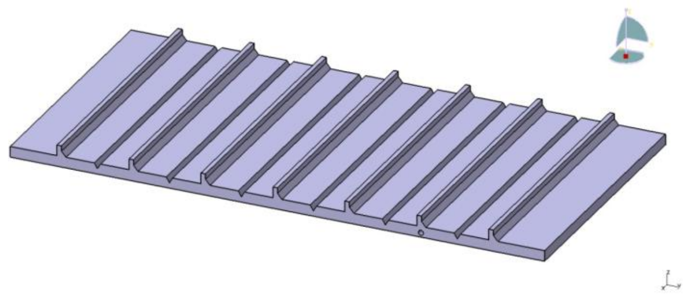

Fig.2 Boot shaped rib with triangular groove

2) Rectangular shaped rib with triangular groove

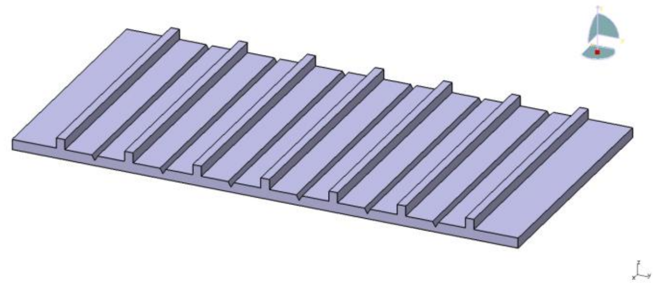

Fig.3. Rectangular shape rib with triangular groove

3) Triangular shaped rib triangular groove

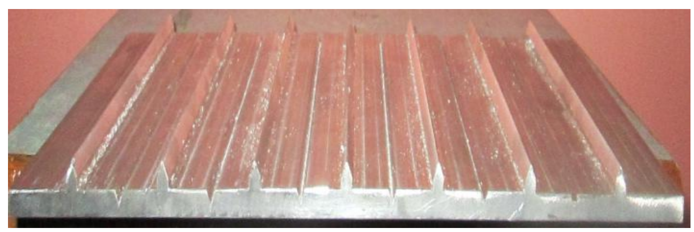

Fig.4. Schematic view of Triangular shape rib with triangular groove

III. DATA REDUCTION

In the experiment surface temperature (T_w), temperature at inlet (T_{b1}), outlet temperature (T_{b2}), pressure drop (Δp) and mass flow rate (m) were collected and calculated under the steady state condition. The parameter of data reduction are, the Nusselt number (Nu), the friction factor (f) and the reynold number (Re).

Rate of heat transfer (Q),

$$Q = m \times C_p \times (T_{b1}-T_{b2})$$

Overall Heat Transfer Coefficient (h),

$$Q = h \text{ x } A \text{ x } [T_w - (T_{b1}+T_{b2}) / 2]$$

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Hydraulic diameter, D_h = 4A/P

Nusselt number, Nu = hD_h/K

Reynolds number, (Re) = $\rho D_h v/\mu$

Friction factor is calculated by, (f)

$$f = \frac{2 \times \Delta p \times D_h}{\rho \times l \times v^2}$$

IV. RESULT AND DISCUSSION

Validation of experiment for smooth duct

In the beginning, results of the present smooth duct are validated with those obtained from the standard empirical correlation of Dittus-Boelter and that of Blasius for friction factor as given below;

Nusselt number correlation

Empirical correlation of Dittus-Boelter;

$$Nu = 0.023Re^{0.8}Pr^{0.4}$$

Empirical correlation of Blasius;

$$f = 0.316Re^{-0.25}$$

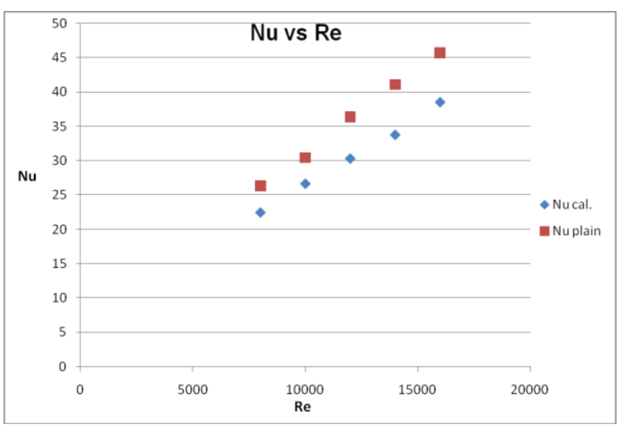

Fig.5. Verification of Nusselt number for smooth duct

The comparisons of Nusselt number and friction factor for the present smooth duct with existing correlations are shown in fig.5 & fig.6 respectively. These figures shows the validation of experiments for heat transfer in terms of Nusselt number and friction factor for the plain tube and are in good agreement with results obtained from Dittus-Boelter and Blasius correlation. It is found that Nusselt numbers in the present smooth duct agree well with those achieved from Dittus-Boelter correlation within ±7.0758 % shown in fig.5 The present friction factors are within ±9.9955% as compared to those achieved from Blasius correlation shown in fig.6

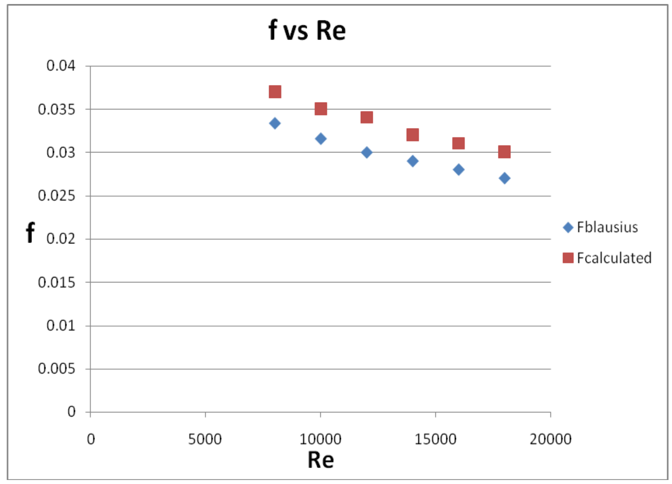

Fig.6. Verification of friction factor for smooth duct

Effect of Nusselt number with Reynolds number for smooth duct and all rib groove arrangement

Combine graph for the variation of Nusselt number with Reynolds number for smooth duct, triangular rib, rectangular rib and boot shaped rib insert is shown in fig.7.

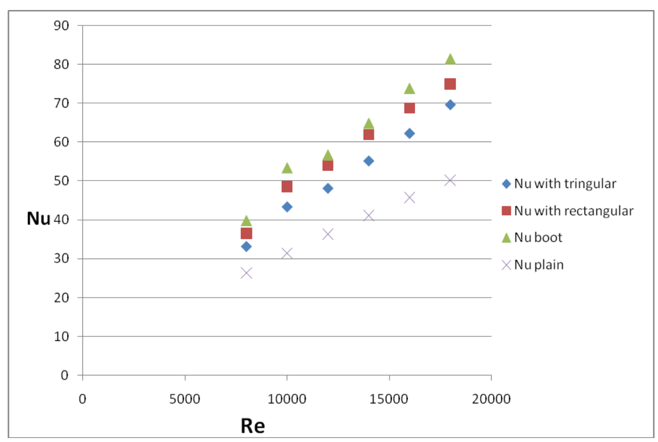

Fig.7. Variation of Nusselt number with Reynolds number for smooth duct, triangular, rectangular and boot shaped rib insert.

Nusselt number increases with the increase of Reynolds number. As heat transfer coefficient is directly proportional to Nusselt number, Nu=hD_h/K i.e increase in heat transfer

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coefficient increases the Nusselt number. From fig.7 it is observed that maximum Nusselt number is obtained for boot shape rib as compared to triangular shaped rib, rectangular shape rib and without ribs and least Nusselt number is obtained for duct without rib. In this case Nusselt no. for triangular rib insert is increased by 36% as compare to smooth duct. For boot shaped rib insert is increased by 45% and for rectangular rib insert Nusselt number is increased by 40% as compare to smooth duct.

Effect of friction factor with Reynolds number for triangular, boot shaped, smooth duct, and rectangular shaped rib

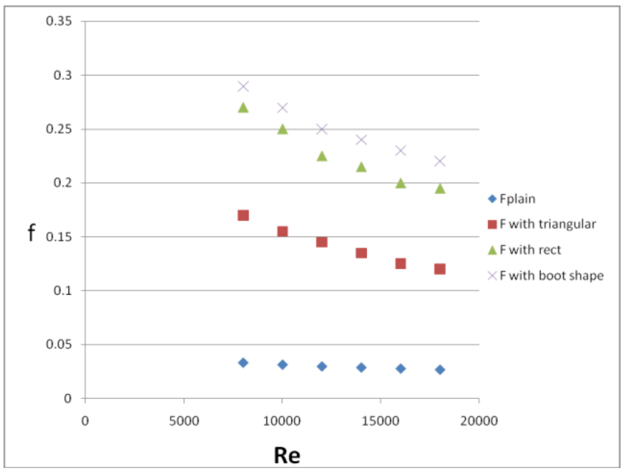

Fig.8. Variation of friction factor (f) with Reynolds number for triangular shaped, boot shaped, rectangular shaped and smooth duct

Fig.8 shows variation of friction factor with Reynolds number. From figures it can be seen that friction factor decreases with increase in Reynolds number. It is observed from figure that friction factor is lower for triangular shape rib.

V. ANALYSIS USING CFD SOFTWARE

The CAD model is prepared on the CATIA-V5R19 software of the different shapes of rib. The flow is varies and to obtain temperature counter four velocity are used that is 4.11, 4.79, 5.48 & 6.17. These velocities are gives in Y direction. Material of rib is aluminum and both flows laminar and turbulent for ribs are mentioned. So there is a facility provided in CATIA-V5R19 for that both flow can be considered at the same time and the type of flow is selected according to the flow in it automatically. And boundary conditions are also provided. So with these commands CFD analysis was done for all ribs. In CFD there are mainly two models are used:

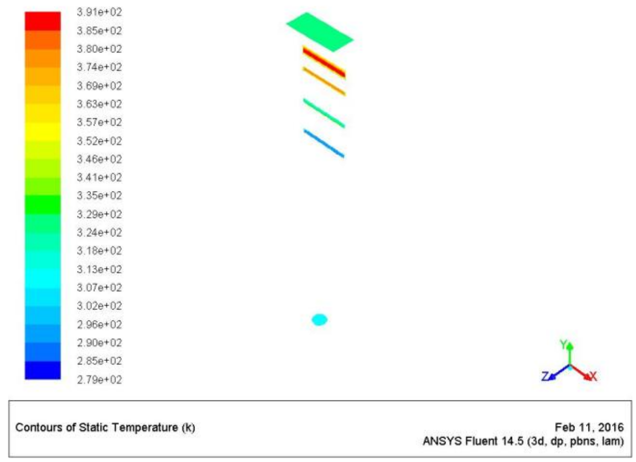

Fig.9 Temperature plot of rectangular shape rib for velocity 6.17

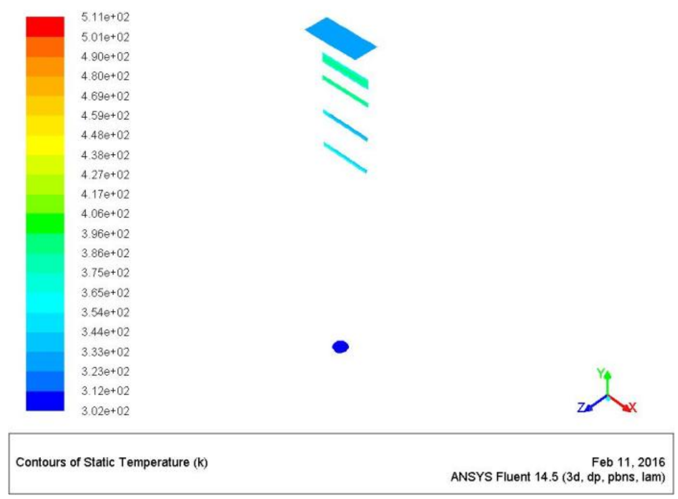

Fig.10 Temperature plot of triangular shape rib for velocity 6.17

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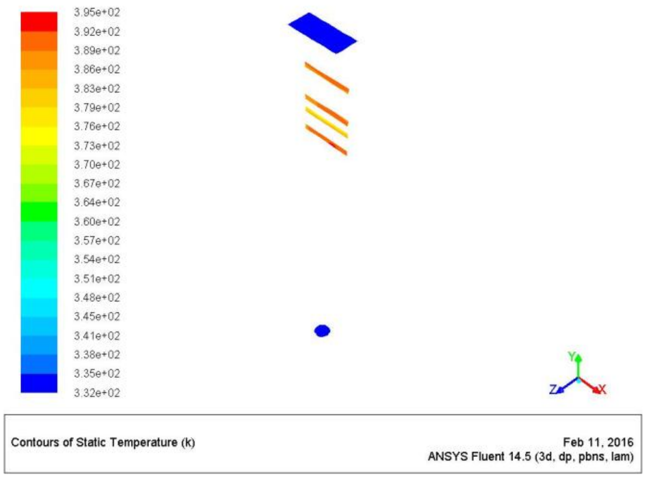

Fig.11 Temperature plot of boot shape rib for velocity 6.17

From fig.9, fig.10, fig.11 shows that surface temperature is minimum for boot shape rib hence heat transfer coefficient is higher for boot shape rib as compared to all rib groove arrangement.

Table 1. Comparison of result obtained by experiment and CFD analysis for rectangular shape rib

Rib used	**Nusselt number by CFD**	**Nusselt number by Experimental**	**Deviation in %**
Rectangular rib	79.18	75.04	5.22
Triangular rib	71.63	69.69	2.70
Boot shaped rib	84.40	81.01	4.01

The comparison between Experimental results and CFD results are shown in table 1 it is found that results are close to each other.

VI. CONCLUSION

Experimental investigations have been carried out in the rectangular duct to study the effect of various shaped ribs on heat transfer enhancement Following conclusion are made i.e. The heat transfer in rectangular duct with different -shaped ribs is found to be more as compared to without ribs. The experimental setup is validated with Dittus-Boelter and Blasius corelation. The results are in good agreement within 11% for heat transfer and within 12% for friction factor. It is concluded that boot shaped rib is having more heat transfer coefficient, which is 45% higher than that of rectangular duct without rib, working with Reynolds no in the range of 8000-18,000.

In boot shaped rib heat transfer coefficient is more because as Reynolds number increases Nusselt number also increases. Friction factor for triangular rib with triangular groove is less as compare to other rib groove arrangement. Deviation in Experimental results and CFD results is within 2 to 5%. With increase in a Reynolds number the flow is

getting more turbulent. Therefore convective heat transfer is increasing. Nusselt number is the ratio of convective heat transfer to conduction heat transfer. When we are increasing air flow velocity convective heat transfer is increasing. Therefore the increase in heat transfer occurs because more turbulence is generated within the duct by using different shaped ribs as compared to without ribs.

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