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Experimentation and Performance Evaluation of Heat Exchanger Using Z-Ribs

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ABSTRACT

Various techniques are used in regard to heat exchangers design to improve their performance. One of the way to achieve this is to use active & passive techniques which will enhance the heat transfer rates. Active techniques include use of external aid to alter the fluid orientation, use of pumps, vibrators etc. Passive techniques include the rough surfaces, dimples on surfaces, coils, twisted tapes inserted in tube of heat exchangers. In this work passive technique of enhancement is used. The Z-shaped ribs with different angles (30°,45°,60°) fitted to rectangular duct. Percentage increment in Nusselt number observed with one perforated baffle(six hole) and one solid baffle is about 12.45 % & that with one solid and two perforated baffle (six hole) is about 28%. Percentage increment in overall heat transfer coefficient was observed up to 12.45% with one perforated baffle(six hole) and one solid baffle while that observed with one solid and two perforated baffle (six hole) is about 28 %.

***Keywords*— Heat Exchangers, Passive Technique, Inserts, Baffles, Enhancement**

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I. INTRODUCTION

The operation of many engineering systems results in generation of heat. This unwanted by product cause serious overheating problems and sometime lead to failure of system. The heat generated within the system must be dissipated to its surrounding in order to maintain the system at its recommended working temperature and functioning effectively and reliably. This is especially important in cooling of gas turbine blades, process industries, cooling of evaporators, thermal power plants, air conditioning equipment radiators of space vehicle and automobiles and modern electronic equipments. In order to overcome this problem, thermal system with effective emitters as ribs , fins etc. are desirable.

The need to increase the thermal performance of the systems, thereby affecting energy, material and cost savings have led to development and use of many techniques termed as “Heat transfer Augmentation”. This techniques also termed as “Heat transfer Enhancement” or “Intensification”. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger.

Like jet impingement, baffles, and other heat transfer enhancement techniques, insertion of ribs in heat transfer devices is popular to promote better mixing of the coolant and increase cooling performance. Applications of the Z-shaped ribs may be in gas turbine blade coolant path, air-cooled solar collectors, heat exchangers, and power plants. The ribs are usually attached to the heated surface to augment heat transfer by providing additional area for heat transfer and better mixing. Heat transfer augmentation techniques refer to different methods used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques broadly divided in two groups viz. passive, and active. Active techniques involves some external power input for the enhancement of heat transfer, some examples of active techniques include induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc .and Passive techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices, for example, use of inserts, use of rough surfaces etc.

In this work passive technique of enhancement is used. The Z-shaped ribs with different angles (30°, 45°, 60°) fitted to rectangular duct.

Monsak Pimsarn, et al. [1] investigated the heat transfer characteristics and associated friction head loss in rectangular channel with Z-shaped ribs. These ribs were set on the rectangular duct at 30º, 45 º,60 ºof flat rib was set at 90 º relative to air flow directions. Soo Whan Ahn,et al. [2] Investigated the heat transfer and friction factor characteristics in rectangular duct with one side roughen by five different shapes. In this they examined the effect of rib shape geometries as well as Reynolds number on heat transfer .They used five different shape of ribs e.g. square, triangular, circular, semicircular and arc these ribs were sequentially installed on bottom wall of duct. Rajendra karwa, et al. [3] Carried out the experiment to measure heat transfer rate and friction factor in rectangular section duct with fully perforated baffles and half perforated baffles fixed to one of broader wall. Prashant Datta, et al.[4] investigated the local heat transfer characteristics and the associated frictional head loss in a rectangular channel with inclined solid and perforated baffles. The main objective of the study was to augment both local and global heat transfer behaviour of a gaseous fluid (air) by placement of two inclined baffles. Kang-Hoon Ko, et al. [5] carried out experiment to measure module average heat transfer coefficients in uniformly heated rectangular channel with wall mounted porous baffles. Baffles were mounted alternatively on top and bottom of the walls. Paisarn Naphon [6] have investigated the heat transfer characteristics and pressure drop in the channel with V corrugated upper and lower plates under constant heat flux. He has carried out the analysis on channel with two opposite corrugated plate on which all configuration peaks lie in staggered arrangement. Teerapat chompookham et al. [7] have done experimental investigations to study the effect of combined wedge ribs and winglet type vortex generators (WVGs) on heat transfer and friction loss behaviour for turbulent air flow through a constant heat flux channel. To create reverse flow in channel , two types of wedge (right-triangle) ribs were introduced . Mohammad Mashud ,et al. [8] research, a solid cylindrical fin and two other cylindrical fin with circular grooves and thread on their outside surface are investigated experimentally. The heat input to fin varied such that the base temperature is maintained constant under steady state. Smith Eiamsa-ard, et al. [9] investigated the effect of helical tapes in tube over the heat transfer. They inserted a helical tape in tube with view to generating swirl that helps to increase the heat transfer rate of tube. The flow rate of tube is considered in Reynold number between 2300-8000. Smith Eiamsa-ard , Sarawut Rattanawong , et al.[10] Investigated heat transfer ,friction loss and enhancement efficiency behaviour in heat exchanger tube with propeller type swirl generator at several pitch ratio.

II. EXPERIMENTATION & METHODOLOGY

Fig.1shows the schematic diagram of the experimental setup from front and top view .The ribs with different angle and same thickness is as shown in fig 3.2 The rectangular channel is used for this investigation and made up of EN8 material. The plexi glass is used in front of duct over 650mm 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 (Dh =0.225m) A suction mode fan is used to draw the air from entrance to exit section. The flow developed through a 200mm long unheated entrance before entering the heated test section and also 200mm 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 640mm long and 450mm 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 top surface and other side are unheated as well as insulated. Commercial fiber glass insulation(2mm) is used on external surface to prevent the heat leakage due to convection and radiation. For wall temperature measurement, four thermocouple are used at different place of heating surface.

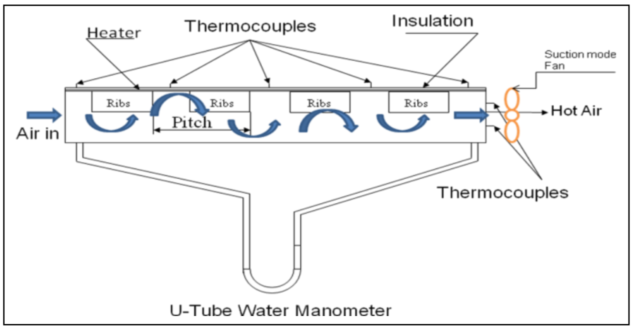

Fig..1 Front view of experimental set up

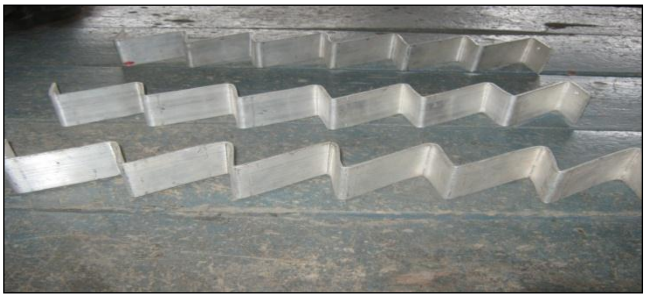

Fig.2. 60° Z-Shaped Ribs

Moreover, one thermocouple is placed inlet and three thermocouples are placed at outlet to measure the inlet and outlet bulk temperatures, respectively. Manometer is used to measure the pressure drop within the duct.

In present study, both flat solid and Z-shaped ribs of different of different angle of same thickness and height (t=3mm, h=50mm) are used. The systematic view of ribs used in this investigation is given in fig 2. Four ribs are used in this experiment of same angle at a time e.g. four Z-ribs of an angle 30°, 45°, 60° and four flat ribs. These ribs are attached in test section by providing screwing arrangement in front and back portion of the duct. These ribs are in contact with the heated top surface. Five test sections are prepared for experimentation purpose. The test section in experimental procedure validated by running through the rectangular duct without using any ribs. In second phase the experimentation is carried out by using flat rib inside the duct. In third, fourth and fifth phase flat ribs are replaced by Z-shaped ribs made up of different angles (30°, 45°, 60°) and compared their performance with each other.

III.CONSTRUCTIONAL FEATURES

The material selected for the duct is EN8 having composition carbon(C) 0.40%, silicon (Si) 0.25%, manganese (Mn) 0.80%, sulphur (S) 0.015%,and phosphorous (P) 0.015%. as it easily available in plate form. EN8 is an unalloyed medium carbon steel with good tensile strength. Tensile properties can vary but are usually between 500-800 N/mm2. The flat and Z-shaped ribs are placed on a horizontal channel. As the main objective of the project is to compare the performance of of Z-shaped ribs with no ribs and to check the heat transfer performance of Z-shaped ribs with different angle (30° ,45° ,60°)

The experimental setup consists of following components

- Fan: - Fan is used to produce airflow. Fan produce air flows with high volume and low pressure. The fan used in project is having specifications as speed- 3000rpm, size – 4 inch
- Control Valve: - Control valve is the fan regulator placed in the flow path of air and is given the knob having graduations in degrees .By varying the regulator we increase the mass flow rate of bulk air and take various readings.
- Thermocouples: - Thermocouples are used to sense the temperature. Thermocouples are widely used type of temperature sensor and can also be used as a means to convert thermal potential difference into electric potential difference. There are variety of thermocouples available, depending upon the applications the particular thermocouple is selected. In our project we are using eight copper-constantan thermocouples having range of –160 to 400 ^{0}C.
- Duct with solid and Z-shaped Ribs: - One set of flat rib and other three sets of Z-shaped ribs with different (30° ,45° ,60°) angle.
- Heater: - Plate type heater is used. The length of heater is 620mm and width 450 mm. The heater is used in this project to heat the top surface of the duct.

IV.DATA REDUCTION

Mean bulk temperature, $T_{mean} = T_{b2} + T_{b1} /2$

Hydraulic Diameter, D = 4A/P

where,

D - Hydraulic diameter in m

A - Area of channel m^2

P - Perimeter of channel m

Mass flow rate, m = ρAV

heat transfer coefficient (h)

$Q = m*Cp*(T_{b2} - T_{b1}) = h*A*(Tw - (T_{b1}+T_{b2})/2)$

where,

Q- heat transfer rate from heater

h-heat transfer coefficient W/m^{2}k

As-Heat transfer area m^2

T_{b2}-bulk temperature at exit ^{0}C

T_{b1}-bulk temperature at inlet ^{0}C

T_w-avg. heater surface temp. = $(T_1+T_2+T_3+T_4)/4$

Reynolds's Number, Re = (ρ*D*v) /μ

Nusselt Number, Nu = h*D*/k

Pressure drop (ΔP) = ρ*g*h

Friction factor, f =ΔP*2* D / L_t * ρ*v^2

The local heat transfer coefficient, h_x, can be calculated as:

$$q_{conv} = h_x(T_{p,x} - T_{b,x})$$

Where t_{px} is the local temperature of the upper surface of the heater plate, while t_{bx} is the bulk fluid temperature at 5 .The bulk fluid temperature can be found from the following relation:

$$q_{conv}\,x = \dot{m}C_{pf}(T_{b,x} - T_{b,x=0})$$

Where ṁ is the fluid mass flow rate per unit width.

The local Nusselt number can be found as:

$$Nu_x = {h_x D}/{K_f}$$

Where, D is the hydraulic diameter and K_f is the thermal conductivity of the fluid.

The average Nusselt number is given by:

$$f = \frac{1}{L}\int_0^L Nu_x dx$$

Where, L is the length of the test section.

The friction factor is calculated over the test section length as:

$$f = 2D\Delta p/Lpu^2$$

Where Δp is the pressure drop over the test section, while u is the average inlet velocity. The thermal enhancement factor is the ratio of the heat transfer coefficient of a roughed surface to that of a smooth surface at equal pumping power and can be expressed as:

$$TEF = \left(\frac{Nu}{Nu_s}\right)(f_s/f)^{1/3}$$

Where, Nu_s and f_s are the Nusselt number and friction factor of a smooth channel.

The Nu_s for a smooth channel can be expressed by the Dittus-Boelter correlation for heating as :

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

Also, the friction factor of a smooth channel can be expressed by the Blasius correlation

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

V.RESULT & DISCUSSION

The experimentation was carried out with the rectangular channel without and with using Passive heat transfer enhancement methods. Overall heat transfer coefficient and friction factors are calculated for all cases. Parameters were plotted for Reynolds no. and mass flow rate. Following graphs are plotted to compare the performance of different ribs used in rectangular channel. From fig.3, it is observed that the heat transfer coefficient increases with increase in Reynolds no. As Reynolds no. increases, the air flow will cause more turbulence so due to which the heat transfer rate will increase. From fig. 3 it is observed that the rectangular duct without using any ribs gives the less heat transfer coefficient with the use of Z-shaped ribs create more turbulence in duct which increases the heat transfer coefficient. 60° Z-shaped ribs gives maximum value of heat transfer coefficient as compared to 30°, 45°and flat rib.

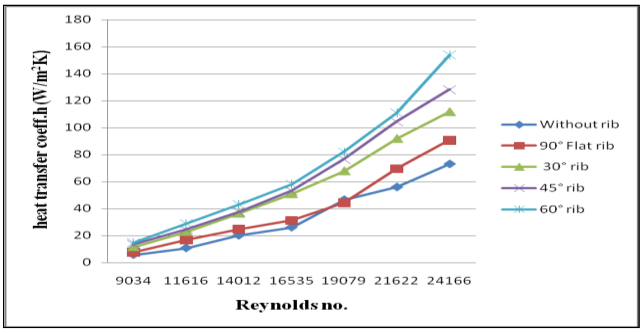

Fig.3 Heat transfer coefficient Vs Reynolds Number

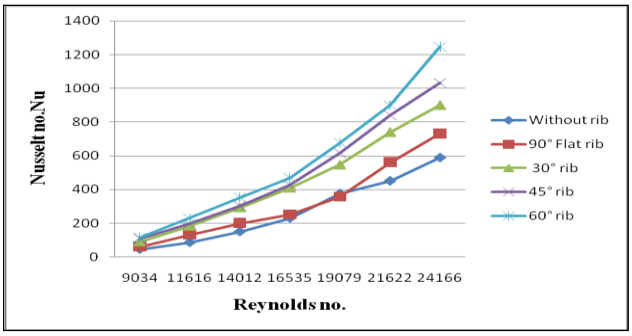

Fig.4 Nusselt Number V/s Reynolds Number

From the Fig.4, it is observed that there is increase in Nusselt number as increase in Reynolds number .As Reynolds number increases the air flow will cause more turbulence due to which heat transfer rate will increase in heat transfer coefficient (h) and $Nu=hD_h/k$ i.e increase in heat transfer coefficient increases the Nusselt number. From fig 4, it is observed that maximum Nusselt number is obtained for 60° Z-shaped ribs as compared to 45°, 30° and flat ribs and least Nusselt number is obtained for duct without rib.

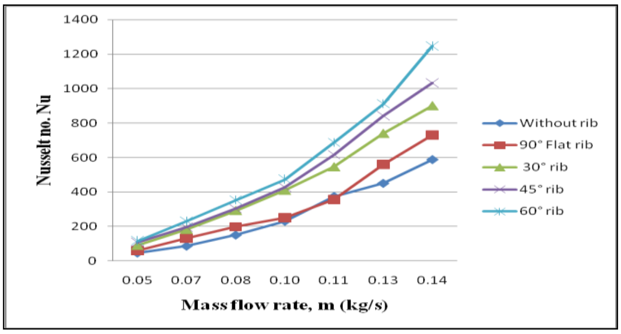

Fig.5 Nusselt Number Vs Mass flow rate

From the fig.5, it is observed that as the mass flow rate increases the Nusselt number increase. There is increase in Nu number with Z-shaped ribs as compared to when there is no ribs. This is because in the presence of Z-shaped ribs in rectangular channel the turbulence created by air is more which enhance the heat transfer rate. Also if we compared Z-shaped ribs of different angle the Nusselt number is more in case 60° Z-shaped ribs for same mass flow rate.

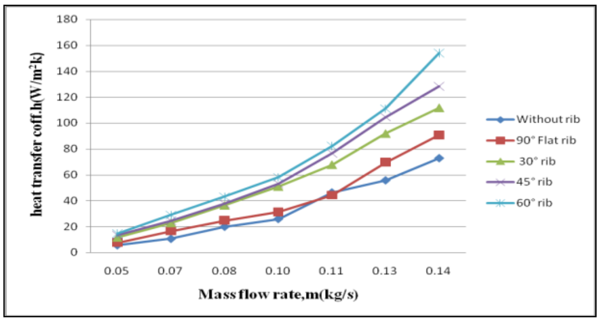

Fig.6 Heat transfer coefficient Vs Mass flow rate

From the fig.6, it is observed that the heat transfer coefficient increases with increase in mass flow rate. As mass flow rate increases, the air flow will cause more turbulence so definitely the heat transfer rate will increase. From the fig. 6 it is observed that the rectangular channel without any ribs gives least heat transfer coefficient. Use Z-shaped ribs increase the heat transfer coefficient. 60° Z-shaped ribs gives maximum value of Nusselt number as compared with other ribs.

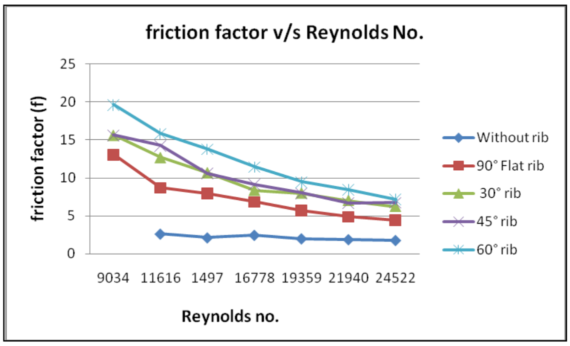

Fig.7 Friction factor Vs Reynolds Number

From the Fig.7 it is observed that as the Reynolds increases there is decrease in friction factor is observed this as the velocity goes on increasing with Reynolds number and friction factor is inversely proportional to the velocity .From fig. it is observed that least friction factor is obtained in duct without ribs and maximum friction factor is observed in 60°Z-shaped ribs.

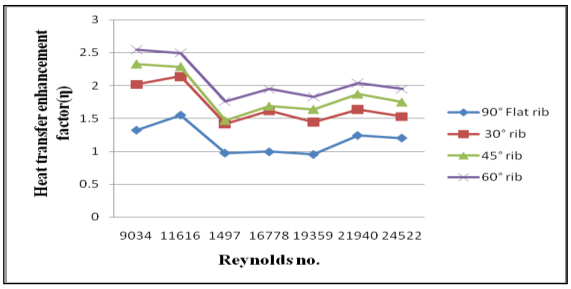

Fig.8 Variation of heat transfer enhancement factor Vs Reynolds No.

From the Fig.8 it is observed that as the Reynolds no. increases there is decrease in heat transfer enhancement factor is observed as well as there is increase in enhancement factor is observed for some Reynolds number but if we observe the overall enhancement it goes on decreasing with increase in Reynolds number.

VI. UNCERTAINTY ESTIMATION

Detailed uncertainty analysis is performed for this experimental study. The overall uncertainty of the experimentally measured variables are calculated as (Coleman and Steele, 1998)

$$U_i = \sqrt[2]{B_{i^2} + P_{i^2}}$$

where B_i is the systematic or bias error and Pi is the precision or random error of measured variable i. The variables measured in this experiment are wall temperature, pressure drop, voltage and current of the power source. In our experiment, the bias error is very small compared to the precision error. The error propagation equation developed by Kline and McClintock (1953), is used to calculate the uncertainty of Nusselt number, Reynolds number and friction factor. The maximum uncertainty in calculating the flow Reynolds number is estimated to be ±4%. Uncertainties of the measured heat flux and calculated Nusselt numbers are within ±2.5% and ±5%, respectively. On the other hand, the maximum possible error in the calculated friction factor is ±7%.

VII.CONCLUSIONS

Experimental investigations have been carried out to study the effects of the Z-shaped ribs of different angle (60°, 45°, 30°) on the performance rectangular duct. Heat transfer coefficient and friction factor are analyzed with using mentioned passive heat transfer enhancement methods. From the graph plotted above following conclusions are made.

- The heat transfer in the rectangular duct could be promoted by using Z-shaped ribs. The heat transfer rate increases in the rectangular duct with a significant rate as compared to without ribs. This increase in the heat transfer depends on the many factors but heat transfer coefficient plays important role in it. The results shows that the heat transfer coefficient for the Z-shaped ribs is more as compared to without using any ribs in duct. The result shows that the heat transfer rate is increased as the Reynolds no. increases. This increase in the heat transfer rate occurred due to the turbulence.
- The Z-shaped ribs with larger angle causes the maximum turbulence in the duct due to which maximum heat transfer to occur. As the angle of Z-shaped ribs is reduced there is less turbulence as well as the flow gets blocked in between angles.
- As the angle between Z-shaped ribs increases it is found that there is increase in heat transfer rate but increases in friction factor is observed. So it can be concluded that increase in angle of Z-shaped ribs increases the heat transfer rate but more frictional losses will occur.
- There is lot of scope for advancement in the experimentations. Following are the most prominent ways
- In this project work we have used rectangular channel with the aspect ratio of 2.3 but as per as the literature survey if we use lower aspect ratio channels give better heat transfer performance than the wide aspect ratio channel for a constant pumping power.
- Secondly we used the rectangular channel and baffle material EN8and if we use any other material having high thermal conductivity we can achieve high enhancement in heat transfer rate.

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