

## Experimental Analysis of Heat Transfer Enhancement In Rectangular Channel Fitted With V-Shaped Ribs

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**Abstract:-** Experimental investigations have been carried out to study the effects of the V-Shaped ribs of different angle (45° and 30°) on the performance rectangular duct. Heat transfer coefficient and friction factor are analyzed with using mentioned passive heat transfer enhancement methods. This paper presents the experimental analysis of heat transfer enhancement in rectangular channel with v-shaped ribs and its effect on the heat transfer rate. Experimental study shows that the heat transfer rate increases with the v-shaped rib of 45° and 60° with the rate of 1.65 and 2.14 respectively. Also the rate of heat transfer rate further increases when we used broken v-shaped ribs 45° and 60° by 2.55 and 2.76

**Keywords: -** heat transfer enhancement, v-shaped ribs, rectangular channel

### 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 it's recommended working temperature and functioning effectively and reliably. This 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.

### II. LITERATURE REVIEW

Dong Hyun Lee a, Dong-Ho Rhee b, Kyung Min Kim a, Hyung Hee Cho a, Hee Koo Moon [12], "Performed Detailed measurement of heat/mass transfer with continuous and multiple V-shaped ribs in rectangular channel." They Investigated Effects of aspect ratio on heat/mass transfer were investigated in rectangular channels with two different V-shaped rib configurations, which are continuous V-shaped rib configuration with a 60 attack angle, and multiple (staggered) V-shaped rib configuration with a 45 attack angle. They concluded Effects of aspect ratio on heat/mass transfer were investigated in rectangular channels with two different V-shaped rib configurations, which are continuous V-shaped rib configuration with a 60o attack angle, and multiple (staggered) V-shaped rib configuration with a 45o attack angle. The square ribs were attached on the test section in a parallel manner. A naphthalene sublimation method was used to measure the local heat/mass transfer coefficients. For the continuous V-shaped rib configuration, two pairs of counter-rotating vortices were generated in the channel, and high transfer region was formed at the center of the ribbed walls. However, for the multiple V-shaped rib configuration with 45o attack angle, asymmetric secondary flow patterns were generated

due to its geometric features, resulting in uniform heat/mass transfer distributions. The effect of channel aspect ratio was more significant for the continuous 60° V-shaped rib than for the multiple 45° V-shaped rib configuration.

A fluid flow channel is easily found in various energy conversion systems. Enhancing convective heat transfer in a channel can improve the durability of hot components of gas turbine engine, the effectiveness of heat exchanger and the efficiency of solar air heater, etc. Heat transfer can be improved by installing various turbulators such as ribs, dimples and baffles. Introducing ribs to a coolant channel is one of the most typical methods to enhance heat transfer between solid surfaces and fluid flow. The rib turbulators augment heat transfer in the internal cooling passages because they cause flow separation and reattachment, which result in breakage of the laminar sublayer. In addition, when the angled ribs are installed in a channel, the heat transfer is enhanced with generated secondary flow structures. Karwa et al. reported that 10-40% augmented thermal efficiency was obtained by installing ribs on the absorber plates of solar air heaters.

In the last few decades, many studies have been performed to find optimal conditions of various rib design parameters include rib height, angle of attack, rib-to-rib pitch and rib arrangement. Mittal et al. compared the efficiency of various roughness elements and concluded that inclined ribs including V-shaped ribs possessed better efficiency in the higher range of Reynolds number (more than 12,000). In recent years, the V-shaped rib configurations have been widely investigated. Choi et al. measured the detailed heat/mass transfer distribution in a square channel with V- and L-shaped continuous/discrete ribs. The results showed that continuous L-shaped ribs had higher heat transfer rate than the other ribs. However, discrete L-shaped ribs showed better thermal performances due to the low friction loss. Lau et al. investigated the average and local heat transfer characteristics in a square channel with V-shaped rib arrangements. They reported that 60° and 45° V-shaped ribs enhanced heat transfer on both ribbed and smooth walls, but caused higher pressure drop than angled full ribs.

Han et al. studied the V- and L-shaped ribs with a different angle of attack and compared the results with simple angled rib cases of parallel/cross arrangements. The research demonstrated that the 60° ribs had higher heat transfer coefficients with higher friction loss than the 45° ribs for both the V-shaped and angled rib cases. Taslim et al. performed experiments with 13 different rib configurations, including V- and L-shaped ribs, and reported that V- and L-shaped ribs showed highest heat transfer rate.

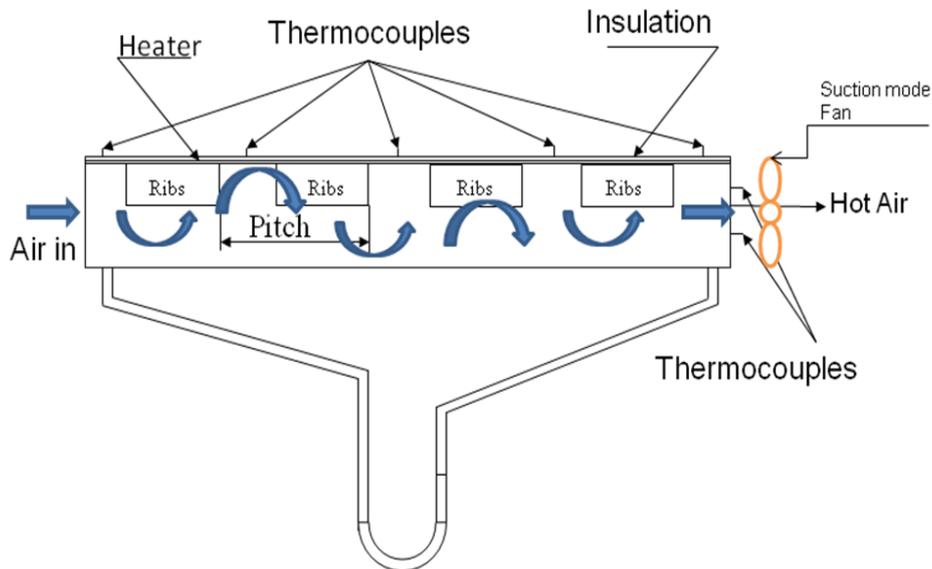
Monsak Pimsarn, et al. [1] investigated the heat transfer characteristics and associated friction head loss in rectangular channel with Z-shaped ribs. These ribs were set on the rectangular duct at 30°, 45°, 60° of flat rib was set at 90° relative to air flow directions. These ribs were fitted in Z-shape (Z-rib) aligned in series on whole surface of upper plate. The constant heat flux is provided to top surface only. The comparison among the result of Z-ribs with 30°, 45°, 60° and flat rib with same rib height, pitch ratio and smooth channel is done. The thermal enhancement factors of all Z-ribs are higher than flat rib. The 45° Z-rib provide highest increase in heat transfer rate and best thermal performance.

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. To understand the characteristics of heat transfer enhancement the friction factor is also measured. The square rib has highest value of friction factor, while triangular type rib has a substantially higher heat transfer performance than any other one.

### III. EXPERIMENTAL SET-UP

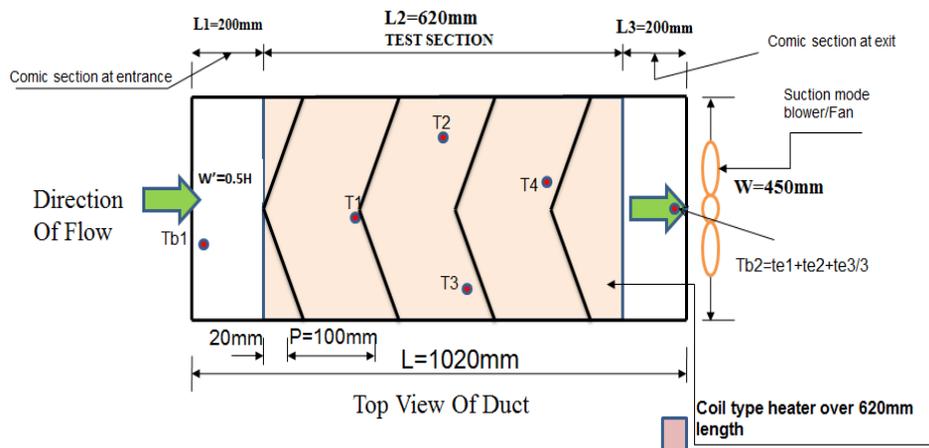
Fig.1 shows the schematic diagram of experimental setup from front and top view. The ribs with different angle and same thickness is as shown in fig 3.2. The rectangular channel is used for this investigation and made up of Aluminium material. The Sheet metal is used in front of duct over 650mm length 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 ( $D_h = 0.225m$ ). 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.



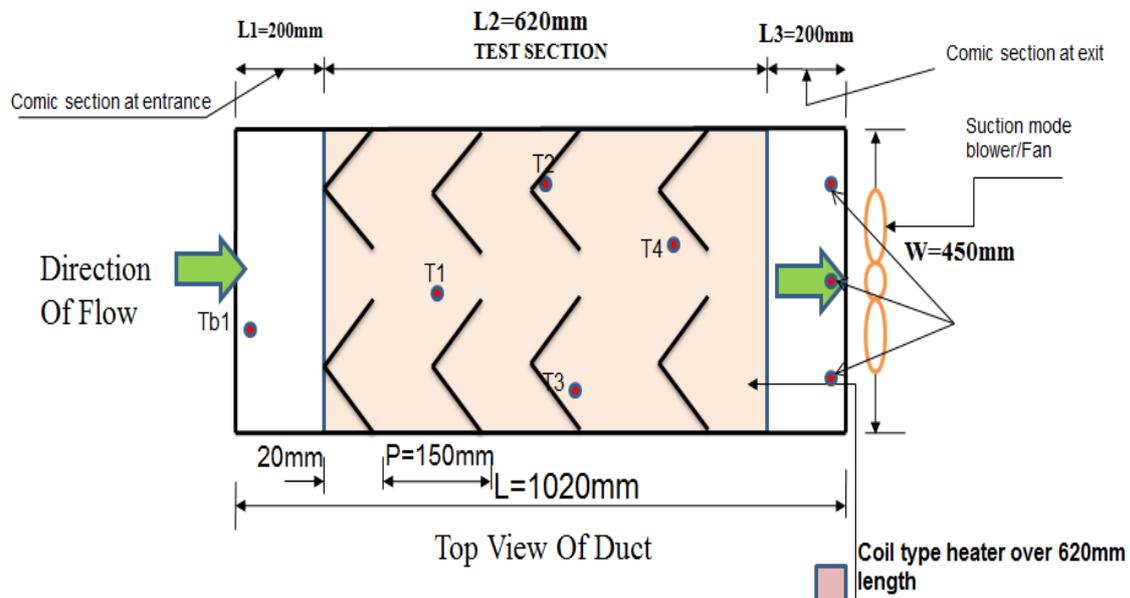
U-Tube Water Manometer

Commercial fiber glass insulation 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. Moreover, one thermocouple is placed inlet and three 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.



- Where, W -Width of Duct (3H) =450mm    W'- Width Of Rib=0.5H=75mm    ● Thermocouples  
 L - Length Of Duct =1020mm    P - Pitch of rib =H=150mm  
 H - Height of duct =150mm    α- Angle of Z-rib  
 t-Thickness of rib =3mm    h=height of rib 50mm  
 Tb<sub>1</sub> & Tb<sub>2</sub> = Thermocouples for measuring inlet & exit temp of bulk air  
 T<sub>1</sub>,T<sub>2</sub>,T<sub>3</sub>,T<sub>4</sub> -Thermocouples measuring top surface temp. of wall

Fig 2 Top view and detail dimension of duct with Ribs (Soild) Arrangements



- |                              |                                     |
|------------------------------|-------------------------------------|
| DUCT –                       | RIBS- Aluminium- Single row/ double |
| W -Width of Duct (3H) =450mm | W'- Width Of Rib=0.5H=75mm          |
| L - Length Of Duct =1020mm   | P - Pitch of rib =H=150mm           |
| H - Height of duct =150mm    | $\alpha$ - Angle of V-rib – 45, 60  |
| Plate heater – 620 X 450 mm  | t-Thickness of rib =3mm             |
|                              | h=height of rib 50mm                |

Fig. 3 Top view and detail dimension of duct with Ribs (Broken) Arrangements

#### IV. RESULT AND DISCUSSION

The experiments were carried out on the test rig initially without using any rib and the different heat transfer characteristics were calculated and then the same is done using different angled V-Shaped ribs within duct . The experimentation is divided in following cases.

- Case I: Experimentation on Rectangular duct without using any rib.
- Case II: Experimentation on Rectangular duct with 45° V-Shaped ribs.
- Case III: Experimentation on Rectangular duct with 60° V-Shaped ribs.
- Case IV: Experimentation on Rectangular duct with 45° V-Shaped broken ribs.
- Case V: Experimentation on Rectangular duct with 30° V-Shaped broken ribs.

##### 4.1 Heat transfer coefficient Vs Reynolds Number

From the Fig. 4 a. 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 the Fig. 4a it is observed that the rectangular duct without using any ribs gives the less heat transfer coefficient with the use of V-Shaped ribs create more turbulence in duct which increases the heat transfer coefficient. 60° V-Shaped ribs gives maximum value of heat transfer coefficient as compared to 30° and 45°. Also the heat transfer coefficient further increases when two rows of broken v-shaped ribs were used.

#### Nusselt No. Vs Reynolds No.

From the Fig. 4b, 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 4b it is observed that maximum Nusselt number is obtained for  $60^\circ$  V-Shaped ribs as compared to  $45^\circ$ ,  $30^\circ$  and flat ribs and least Nusselt number is obtained for duct without rib. Also the nussult further increases when two rows of broken v-shaped ribs were used.

#### Nusselt Number Nu Vs Mass flow rate

From the fig.4c, it is observed that as the mass flow rate increases the Nusselt number increase. There is increase in Nu number with V-Shaped ribs as compared to when there is no rib. This is because in the presence of V-Shaped ribs in rectangular channel the turbulence created by air is more which enhance the heat transfer rate. Also if we compared V-Shaped ribs of different angle the Nusselt number is more in case  $60^\circ$  V-Shaped ribs for same mass flow rate. Also the nussult no. further increases when two rows of broken v-shaped ribs were used.

#### 4.4 Heat transfer coefficient Vs Mass flow rate

From the Fig. 4d, 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.4d, it is observed that the rectangular channel without any ribs gives least heat transfer coefficient. Use V-Shaped ribs increase the heat transfer coefficient.  $60^\circ$  V-Shaped ribs gives maximum value of Nusselt number as compared with other ribs. Also the heat transfer coefficient further increases when two rows of broken v-shaped ribs were used.

#### 4.5 Heat transfer enhancement factor Vs Reynolds No.

From the Fig.4e, 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.

#### 4.6 Nusselt Number ratio Vs Reynolds Number

From the Fig.4f, it is observed that as the Reynolds no. increases there is decrease in Nussult no. ratio is observed as well as there is increase in enhancement factor is observed for some Reynolds number but if we observe the nussult no. goes on decreasing with increase in Reynolds number.

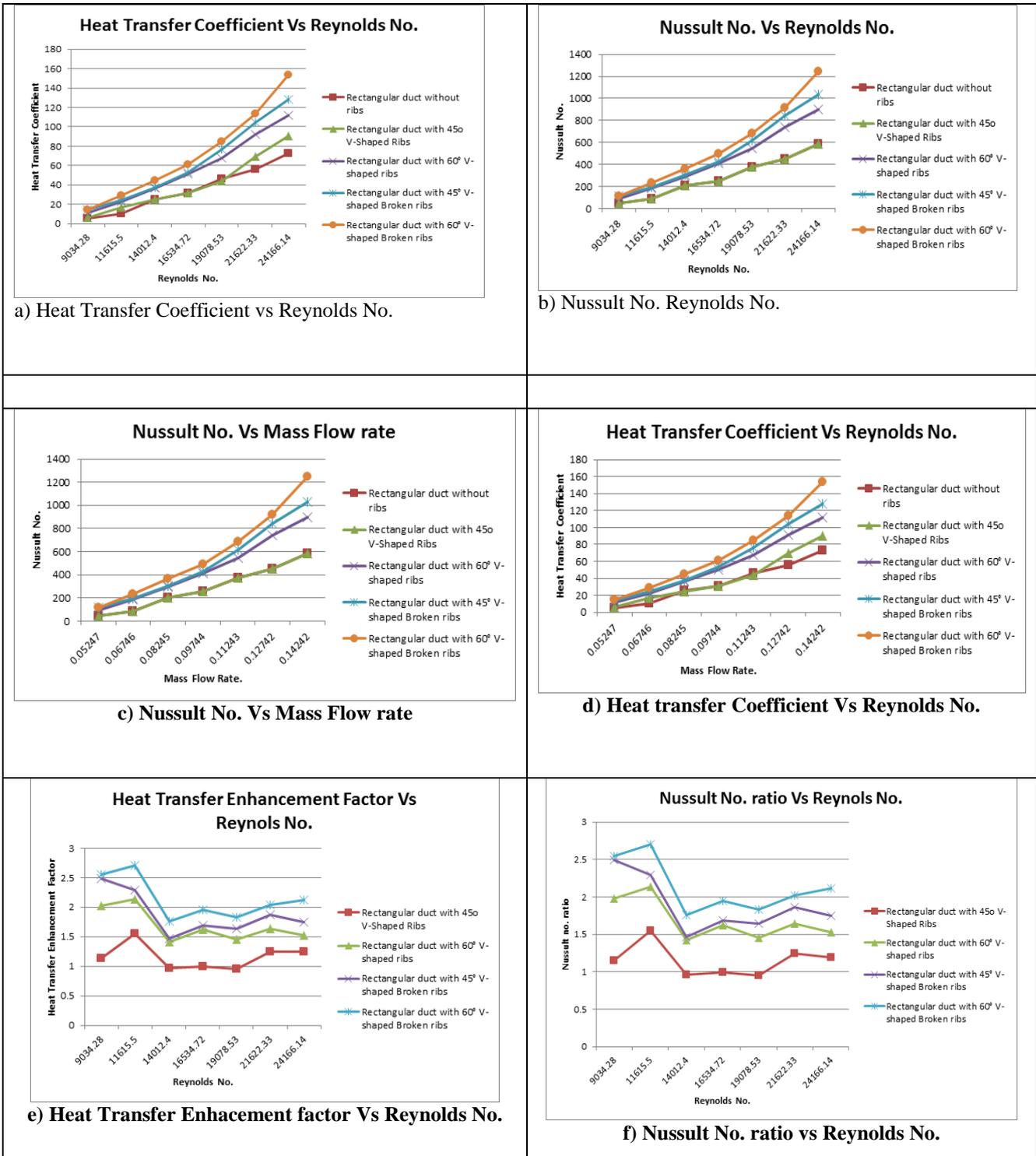


Fig. 4. Comparison of Heat transfer Characteristics

## V. CONCLUSION

The heat transfer in the rectangular duct could be promoted by using V-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 show that the heat transfer coefficient for the V-shaped ribs is more as compared to the without using any ribs in duct. The result shows that the heat transfer rate increases as the Reynolds no. increases. This increase in the heat transfer rate occurred due to the turbulence.

The V-shaped ribs with larger angle causes the maximum turbulence in the duct due to which maximum heat transfer to occur. As the angle of V-shaped ribs is reduced there is less turbulence occurs as well as the flow gets blocked in between angles.

As the angle between V-shaped ribs increases it is found that there is increase in heat transfer rate when the broken V-shaped ribs were used. So it can be concluded that increase in angle of V-shaped ribs increases the heat transfer rate.

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