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Heat Transfer Augmentation by Forced Convection from Various Ribbed Surfaces

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Abstract-Heat transfer Enhancement techniques are used in heat exchanger systems in order to enhance heat transfer & improve thermal performance. One of the ways to enhance heat transfer rate is to increase the effective surface area & residence time of the heat transfer fluid. The thermal characteristics of turbulent flows over ribbed surfaces are of great importance for engineering applications due to the heat transfer enhancement. In experimental study to avoid high pressure drop and pumping power for the fluid, low velocity flow is often applied. Ribs can be used to induce turbulence and thus enhance the heat transfer. The velocity and temperature measurements carried out in a wind tunnel were recorded by a constant- temperature hot wire anemometer and a copper-constant thermocouple, respectively. The ribbed wall destabilized the flow. The separations and reattachments over the ribbed wall increase fluid mixing, create flow unsteadiness, interrupt the development of the thermal boundary layer and enhance the heat transfer. The flow rates have been varied between the Reynolds numbers 500 and 10.000, covering the range from laminar to low turbulent flow.

The results show that Ribbed Wall Effectively Enhances the Heat Transfer performance.

Keywords: *heat transfer enhancement, ribbed surfaces, forced convection etc.*

1. INTRODUCTION

Enhancement of forced convection is important in several engineering applications. Surface modifications like rib-roughening are commonly used in applications such as compact heat exchangers and internal cooling of gas turbine blades and vanes. This paper gives a brief summary of convective heat transfer and fluid flow in some ribbed ducts. Details of the flow pattern and the influence of rib configuration and arrangement on the heat transfer are presented. Experimental and numerical investigations of the forced convection heat transfer in flat channels with rectangular cross section are presented in this report. The heat transfer is enhanced by rib-roughened surfaces applied to the wider walls of the duct. The flow rates have been varied between the Reynolds numbers 500 and 10.000, covering the range from laminar to low turbulent flow.

The efficiency of compact heat exchangers can be improved for example by means of boundary layer modification and active surface enlargement ribs are often used in design of heat exchanger ducts in order to enhance the heat transfer rate and thus to improve the overall process efficiency. Historically ribs have been introduced in the cooling passages of gas turbine blades because of the extremely high thermal loads and reduced dimensions. It has been found that the main thermal resistance to the convective heat transfer is due to the presence of a viscous sub-layer on the heat-transferring surfaces.

The presence of ribs makes the viscous sub-layer break down by virtue of flow separation and reattachment, which reduces the thermal resistance and considerably enhances the heat transfer. However, the use of ribs gives rise to higher friction and hence higher pumping power. Thus, many experimental studies have been carried out to determine the rib configuration and arrangement that produce optimum effects. Attempts have been made to overcome the adverse effect by changing the geometry of the rib cross section.

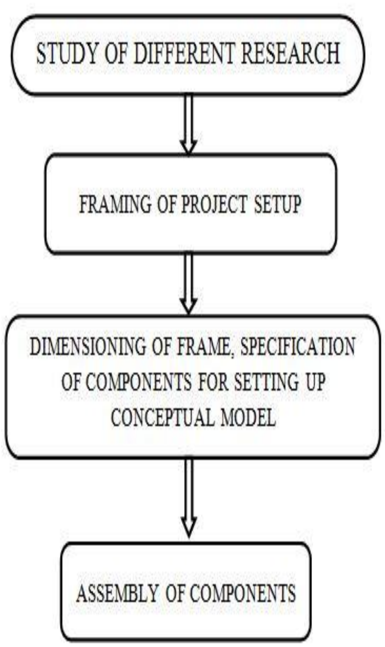
In addition to varying the rib cross section profile, another way to avoid hot spots is to replace the solid-type ribs by perforated ribs. Because part of the air flow passes through the perforated ribs and directly impinges on their circulating region behind the rib, the hot spots may not arise. Heat transfer enhancement by means of various techniques is an important task for research, which is also paid tribute to by the huge and growing number of publications on this subject, especially in recent times.

The presence of the ribs significantly changes the thermal characteristics of the flows due to the velocity field varies. The ribbed wall destabilized the flow. The separations and reattachments over the ribbed wall increase fluid mixing, create flow unsteadiness, interrupt the development of the thermal boundary layer and enhance the heat transfer. In order to understand the heat transfer evolution of this complex flows, experiments should be carried out in turbulent flows.

II. METHODOLOGY

1. During experimentation pressured difference across the orifice meter, temperature of the heated surface and temperatures of air at inlet and outlet of the test section and Pressure drop across the test section are measured. The mass flow rate of air is determined from the pressure drop across the orifice meter, the useful heat gain of the air is calculated, and the Nusselt number and Reynolds number are calculated. The friction factor was determined from measured vales of pressure drop across the test section.
2. Using the data obtained from experiments, the heat transfer, friction factor and the thermal performance characteristics of fluid for rectangular ribs with different arrangement are calculated. These calculated data is analyzed to find out increased heat transfer from different arrangements of rectangular ribs.

3. Our methodology for this mega project is shown in following flow chart :



III. BASIC TERMS FOR HEAT TRANSFERANDFLUID FLOW

- ***Convection :***

The process of heat transfer between a solid surface and fluid in the motion is called convection.

- ***Natural Convection :***

In case the fluid moves due to density difference caused by heat transfer between solid surface and fluid it is said to be by natural convection.

- ***Forced convection :***

If the fluid motion is imparted by external means like pump, fan, blower, compressor, etc. the convection is called forced convection.

- ***Laminar Flow:***

It is defined as that type of flow in which fluid particles move along well defined paths and stream line and all the streamlines are straight and parallel. Thus the particles move in laminas or layers gliding smoothly over the adjacent layer. This type of flow is called streamline flow or viscous flow.

Shear stress in a laminar flow depends almost only on viscosity - μ - and is independent of density - ρ.

- ***Turbulent Flow:***

It is defined as that type of flow in which the fluid particles move in a zig-zag way. Due to the movement of particles in zig-zag way, eddies formation takes place which is responsible for high energy loss.

Shear stress in a turbulent flow is a function of density - ρ.

- ***Transitional flow:***

Transitional flow is a mixture of laminar and turbulent flow, with turbulence in the center of the pipe, and laminar flow near the edges. Each of these flows behave in different manners in terms of their frictional energy loss while flowing and have different equations that predict their behavior.

Turbulent or laminar flow is determined by the dimensionless Reynolds Number.

- ***Reynolds Number***

The Reynolds number is important in analyzing any type of flow when there is substantial velocity gradient (i.e. shear.) It indicates the relative significance of the viscous effect compared to the inertia effect. The Reynolds number is proportional to inertial force divided by viscous force.

$$\textbf{Reynolds number} = \frac{VD}{\nu}$$

The flow is

Laminar when Re < 2000

Transient when 2000 < Re < 4000

Turbulent when 4000 < Re

- *Nusselt Number (Nu) :*

It is defined as the ratio of convection heat flux to conduction heat flux in the fluid boundary la

yer.

Nu = Rate of heat transfer by convection / Rate of heat transfer by conduction.

$$\textbf{Nu} = \frac{hL}{k}.$$

The value of Nu as unity indicates that there is no convection; the heat transfer is by pure conduction.

IV. CLASSIFICATION OF AUGMENTATION TECHNIQUES:

Generally, heat transfer augmentation techniques are classified in three broad categories:

(a) Active method,
(b) Passive method,
(c) Compound method.

The active and passive methods are described with examples in the following subsections.

Active method

This method involves some external power in put fourteen henchmen of heat transfer and has not shown much potential lowing to complexity in design. Furthermore, external power is not easy to provide in several applications. Some examples of active methods are induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc.

Passive method

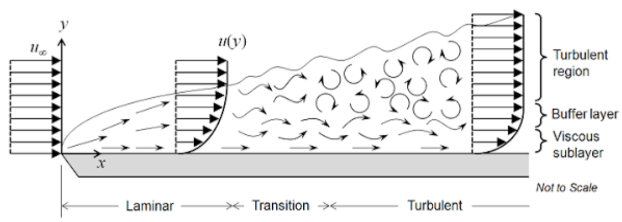
This method does not need any external power input and the additional power needed to enhance the heat transfer is taken from the available power in the system, which ultimately leads to a fluid pressure drop. The heat exchanger industry has been striving for improved thermal contact (enhanced heat transfer coefficient) and reduced pumping power in order to improve the thermo hydraulic efficiency of heat exchangers. A good heat exchanger design should have an efficient thermodynamic performance, i.e. minimum generation of entropy or minimum destruction of available work (energy) in a system in co-operating a heat exchanger.

Compound method

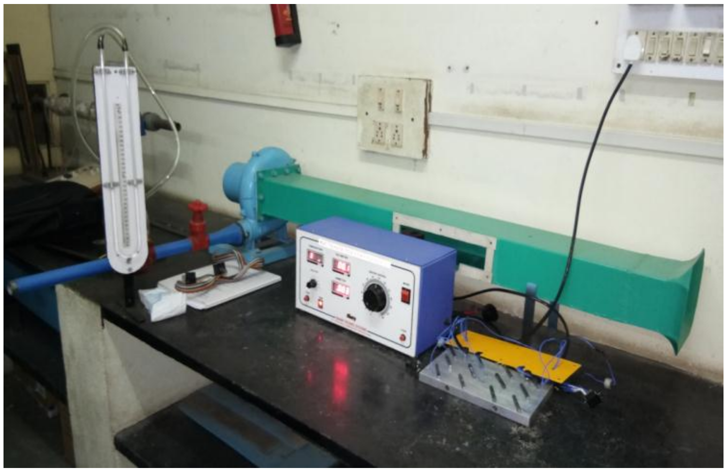
A compound method is a hybrid method in which both active and passive methods are used in combination. The compound method involves complex design and hence has limited applications

V. DIFFERENCE IN BOUNDARY LAYER CONDITION FOR 'FLAT PLATE AND RIBBED PLATE'.

The fluid flow for the flat plate is as shown in figure where at the front part of the plate, there is laminar flow up-to some distance. Then transition flow starts at the situation the Reynolds number increases to 2000 to 4000. At the last part of the plate there is a turbulent flow where the Reynolds number is greater than 4000.



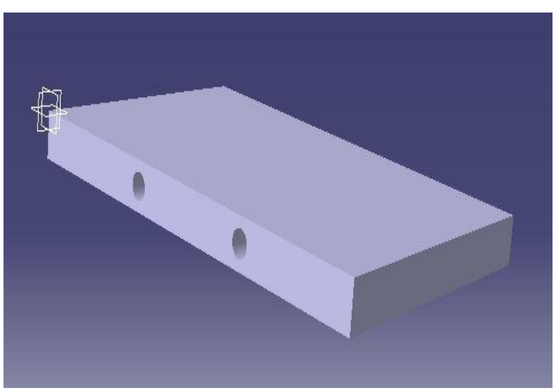
EXPERIMENTAL SET-UP

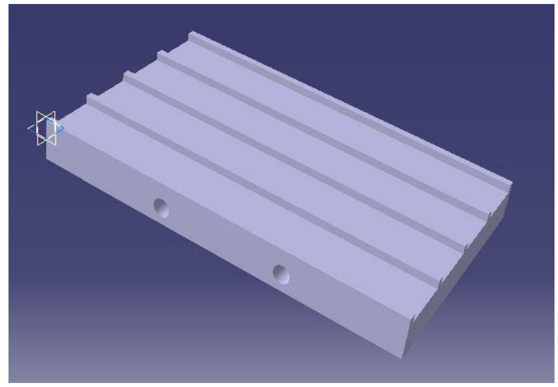


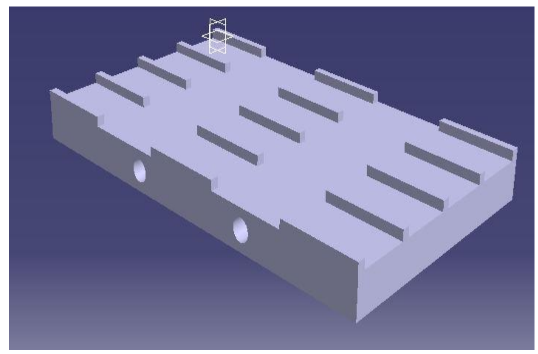
Experimental set-up for investigation of forced convection heat transfer in a square duct provided with ribs is as shown.

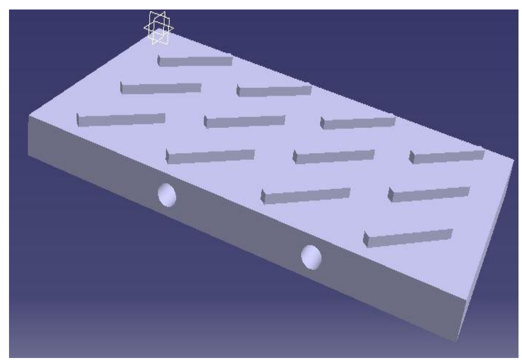
In this set-up, two opposite walls of square duct will be provided with the different configurations of ribs. The square duct is surrounded by band heater. Eight thermocouples are embedded on the test section and two thermocouples are placed in the air stream at the entrance and exit of the test section to measure air inlet and outlet temperature. The temperatures can be read directly from the temperature indicator by using selector switch. Air flow is controlled by a flow control valve and is measured with the help of orifice meter and manometer. Heat input can be set with the help of variac provided on control panel and same can be read out digitally with the help of voltmeter and ammeter.

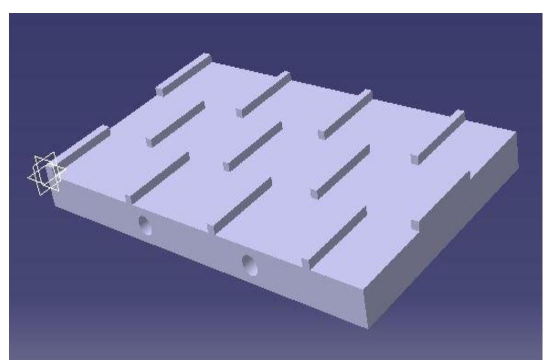
CATIA MODEL OF RIBBED SURFACE



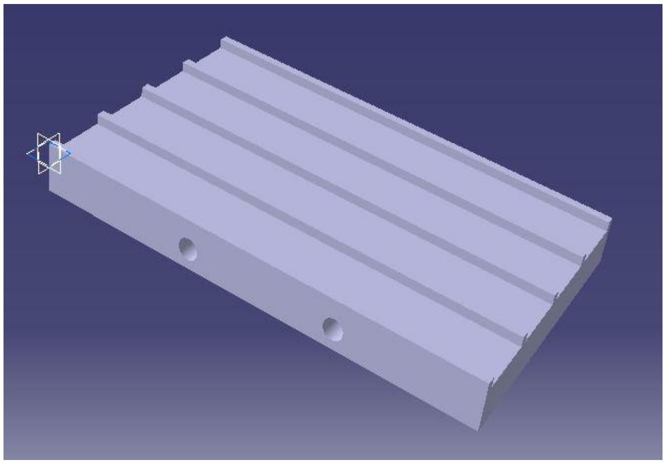








A. PARALLEL RIB PLATE



Observations:

- Ambient Temperature (T_A): **28 ^{0}C**
- Manometer Reading (ΔP): **100mmWc**
- Heater Input (q): Voltage *Current= 77 * 0.65

 = **50.05 W**

Reading:

T1	T2	T3	T4	T5	T7	T8
59.7	63.9	63.2	62.0	64.5	41	41

- Average Temperature (T) : **62.66 ^{0}C**
- Air Temperature (T∞) : **41 ^{0}C**
- **Heat Transfer By Convection:**

q= h*A*(T-T∞)

50.05 = h * 0.0375 * 21.66

h = **<u>61.62</u>W/m²K**

- **Head in manometer:**

$$H = \Delta P * \frac{\rho_W}{\rho_A}$$

$$= 0.1 * \frac{1000}{1.128}$$

= <u>88.65</u> m.

- Volume Flow Rate Of Air: **0.004 m³/sec**
- Velocity In Duct:**<u>0.333</u> m/sec**
- Significant Diameter of Duct: **0.104 m.**
- **Reynolds Number:**

$$RE = \frac{V_D * D}{\nu}$$

$$= \frac{0.333 * 0.104 * 10^6}{16.96}$$

= **2041.9**

- **Nusselt number :**

$$Nu = \frac{hL}{k}.$$

$$Nu = \frac{61.62 * 0.25}{0.0275}$$

Nu = **558.**

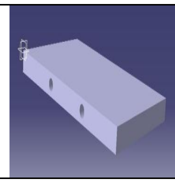
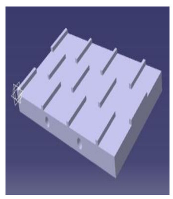
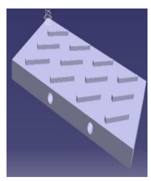
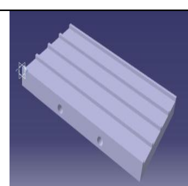
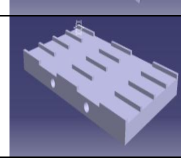
Similarly, for **75mmWc** we get convective heat transfer coefficient 'h', Reynolds number and Nusselt number are:

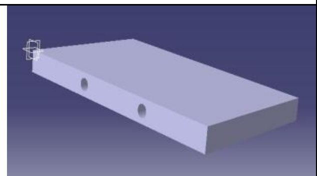
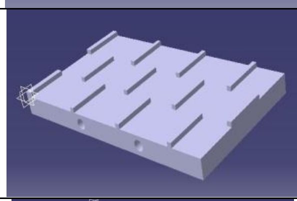
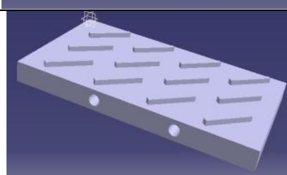
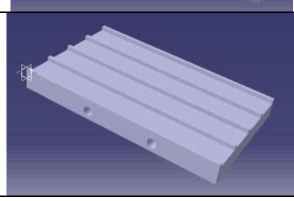
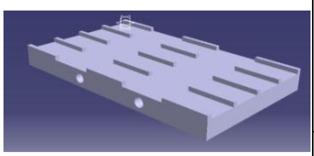
h = **<u>59.30</u> W/m²K**

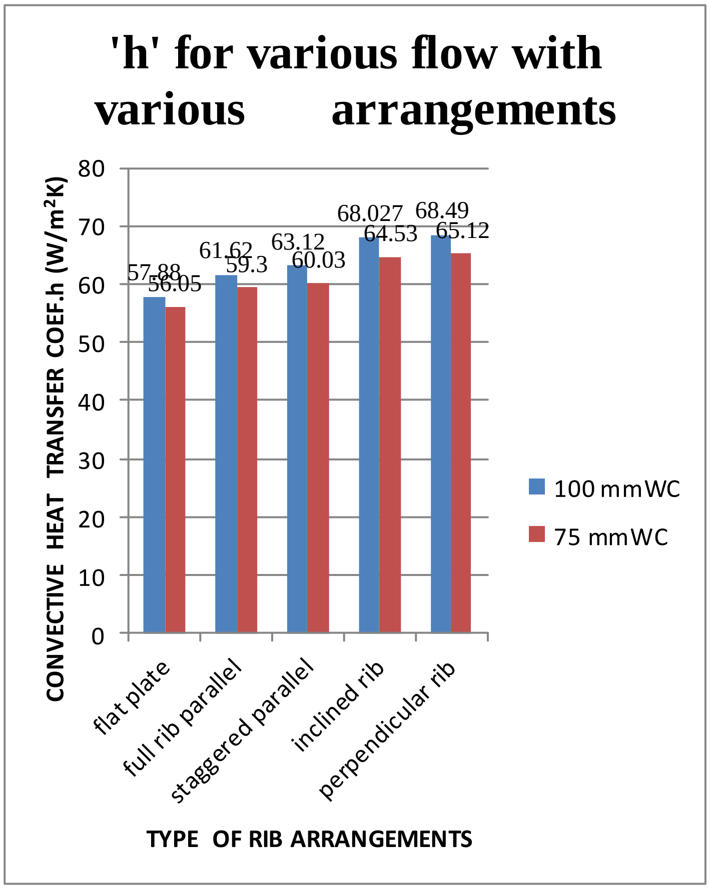
Re =**<u>1805</u>**

Nu =**<u>537</u>**

Result Table for Mild Steel Ribs.

Sr. No.	No. Of ribs	Patterns	ΔP (mmWc)	h (W/m² K)	Reynolds number	Nusselt No.
1.	0		100	57.88	2127	524
			75	56.05	1846	508
2.	12		100	68.49	2132	621
			75	65.12	1822	590
3.	12		100	68.027	2132	616
			75	64.53	1844	585
4.	25		100	61.62	2141	558
			75	59.30	1805	537
5.	15		100	63.12	2050	572
			75	60.03	1845	544

Sr. No.	No. Of ribs	Patterns	ΔP (mmWc)	h (W/m^2K)	Reynolds number	Nusselt No.
1.	0		100	57.88	2127	524
			75	56.05	1846	508
2.	12		100	75.37	2131.5	682.69
			75	71.65	1845	649
3.	12		100	74.62	2132.42	676
			75	70.28	1844.52	636.6
4.	25		100	68.53	2132	620.74
			75	65.44	1844.73	592.7
5.	15		100	70.13	2041.98	635.23
			75	66.24	1845.75	600

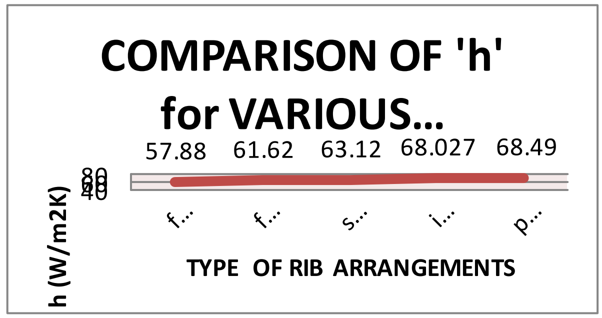


In above graph we plotted heat transfer coefficient vs types of ribs arrangement for flows of 100 mmWc and 75 mmWc. We can see the variation in 'h' as per change in flow and with respect to arrangement of ribs on the test plates.

In this chart we can see the convective heat transfer coefficient 'h' for 100 mmWc for various arrangement of ribs on test plate. The heat transfer coefficient is increasing as per the area opposes the flow of fluid. The parallel ribs are showingrelatively less heat transfer coefficient than inclined or perpendicular ribs on the plate.

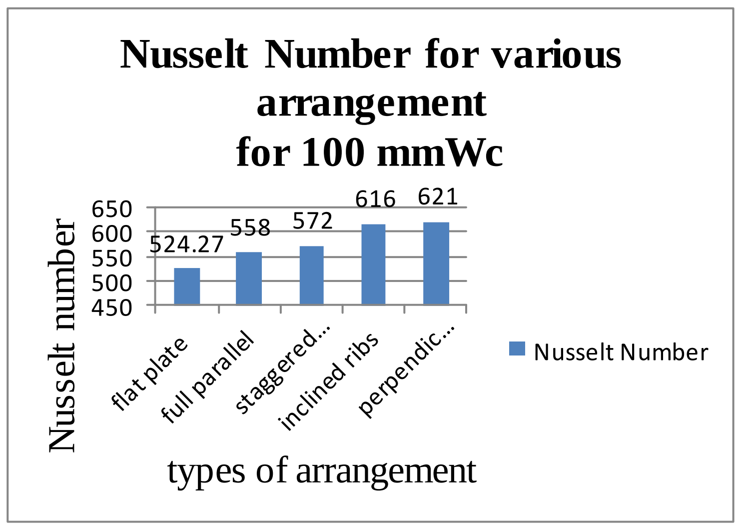
If we add more obstruction to fluid then we can get more heat transfer coefficient. This shows that we can vary 'h' by varying arrangements.

Graph No.2-Comparison of 'h' for various arrangements at 100 mmWc



Next graph shows the variation in Nusselt Number for various ribs arrangement on the test plate for the flow 100 mmWc. It shows the Nusselt Number goes on increasing with respect to the flow variation and arrangement of ribs.

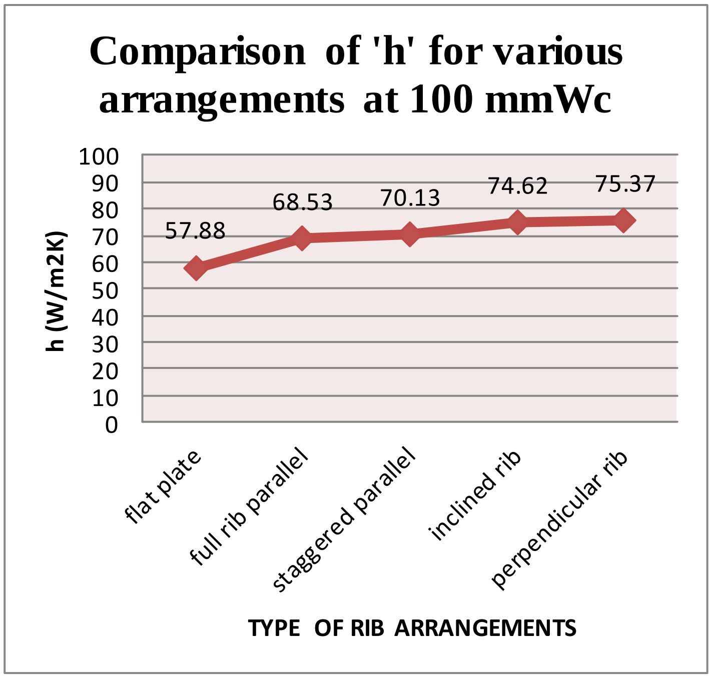
Graph No.3-Nusselt Number for various arrangementfor 100mmWc



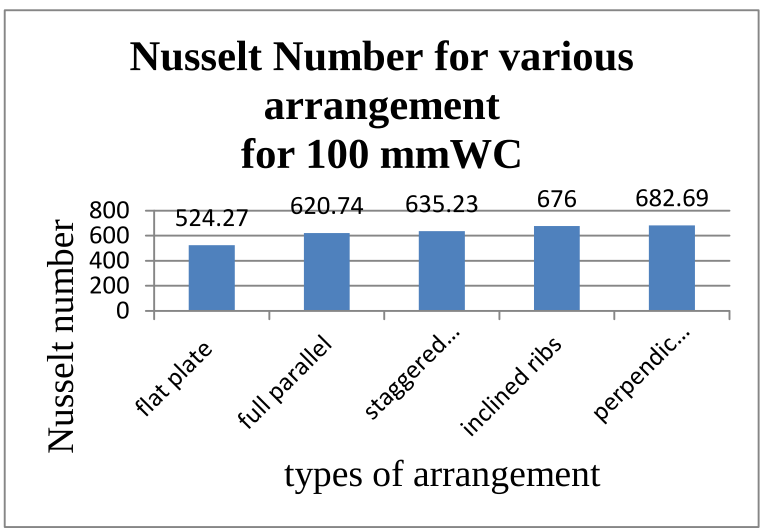
As per the graphs of 'h' and Nussult Number of Mild Steel ribs we can also plot graphs of Aluminium ribs as per the results. As like MS ribs, the Aluminium ribs also varies 'h' and Nussult number with ribs material and arrangement of ribs. Perpendicular arrangement gives maximum convective heat transfer coefficient and Nussult number. The graphs of Aluminium ribs as shown.

1. For Aluminium Ribs

Graph No.4-Comparison of 'h' for various arrangements at 100 mmWc



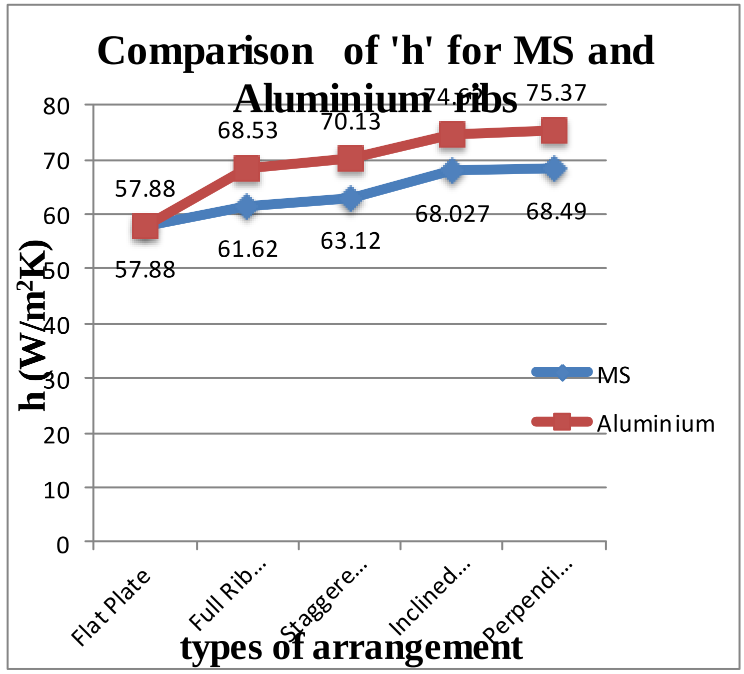
Graph No.5-Nusselt Number for various arrangementfor 100 mmWc



COMPARISON OF 'h' FOR MS AND ALUMINIUM RIBS

We have done experiments on both MS and Aluminium ribs and from that experiment's result, we get following graphs.

Graph No.6-Comparison of 'h' for MS and Aluminium ribs



We can see the value of 'h' for MS shown in blue color and for Aluminium shown in red color and this graph shows the Aluminium gives a better heat transfer rate coefficient because of their conductivity i.e. MS (50W/mK) and Aluminium (204 W/mK). So, graph shows the difference between 'h' of both with reference to 'h' of flat plate and we get and we get more 'h' for Aluminium material ribs.

APPLICATION

1. High Tension Control Panels and electronic chip
2. Heat Exchanger
3. Refrigerators
4. Engines
5. Cooling of electronic components
6. Dry type cooling towers
7. Air cooled cylinder of compressors
8. Electric motor and Transformer

9. Economizers
10. Steam power plants

- ADVANTAGES
  - By using ribs heat transfer rate can be increased without any preventive maintains.
  - It is cheapest way for increasing the heat transferring rate from the hot bodies.

- **LIMITATION**
  - We know that the length of ribs is directly proportional to heat transferring rate, but the larger length is may be cause of bending in rib.
  - Increase the weight of the engine. So overall efficiency will goes to decreasing.

CONCLUSION

An experimental study performed to understand the behavior of the heat transfer characteristics over the ribs in turbulent boundary layer under the effect of Reynolds number and Nusselt number. The findings of the results summarizing as follows:

The presence of the ribs increases the turbulent heat transfer comparing to the flat plate. The heat transfer enhancement ratios of the ribs will be bigger. The heat transfer coefficients increases with Reynolds number for all the ribs and various arrangements of ribs will more effective parameter than the Reynolds Number on the flat plate heat transfer.

Ribs applied to the heat transferring surfaces of heat exchanger ducts can induce turbulence, and will cause a transition from laminar to turbulent flow at lower Reynolds numbers compared to a smooth duct.

We can conclude by referring result table and graph that we can improve the heat transfer rate using less number of ribs by various arrangement and material.

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