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Experimental investigation of Forced convective heat transfer coefficient from W shaped ribbed surface

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Abstract

The development of thermal systems has stimulated in methods to improve heat transfer. Tubes with artificial roughness obtained by providing dimples on the tube surface are competitive in comparison to performance and cost of other enhanced techniques currently employed in turbulent flow. In our experimentation forced convection heat transfer characteristics from dimpled tube has been investigated. The effect of variation in dimple diameter and dimple arrangement (inline and staggered) has been investigated for Reynolds No range 12000 to 26000 dimpled tube. Additionally the effect of variation in dimple tube and diameter on pressure drop across test section has also been investigated. This experiment was carried out to observe if the use of dimples on tube could enhance heat transfer characteristics without severe penalties associated with pressure drops for turbulent flow. The results show that heat transfer enhancement under forced convection can be achieved by using dimple tubes. The enhancement in convective heat transfer coefficient is observed as 18% and in Nusselt number as 27 % as compared with plain tube for same Reynolds number.

Keywords:*Dimple tube, Heat transfer enhancement, Forced convection, Surface Geometry, Thermal performance factor.*

1. Introduction

For well over century, it important to improving methods of heat transfer enhancement and it hasgained greater significance inall type areas like microelectronic cooling, central processing units, macro and micro scale heat exchangers, gas turbine internal airfoil cooling, fuel elements of nuclear power plants, and bio medical devices etc. (Han et al, 1984).In case of the electronics industry, due to the demand for smaller and more powerful products, power densities of electronic components have increased. The maximum temperature of the component is one of the main factors that control the reliability of electronic products. Thermal management has always been one of the main issues in the electronics industry, and its importance will grow in coming decades. The use of heat sinks is the most common application for thermal management in electronic packaging. Heat sink performance can evaluated by factors: material, surface area, flatness of contact surfaces, configuration. Aluminum is the most common material because of its high conductivity (205W/mK), low cost, low weight, and easiness with respect to manufacturability (Diego et al, 1992) (Ashwini et al, 2016). Copper is also use for heat sinks because of high conductivity (400W/mK), but its disadvantages is high weight (Carl-olof et al, 1997). To combine the advantages of aluminum and copper, heat sinks can be made of aluminum and copper bonded together. To improve performance, heat sinks should designed to have a large surface area since heat transfer takes place at the surface. In addition, flatness of the contact surface is very important because a nominally flat contact area reduces the thermal interface resistance between the heat sink and heat source. Ribs are often use in order to enhance forced convective heat transfer between a wall and a Fluid. However, depending on the application the design of the ribs will be different.Ribs willused to increase the heat transfer rate from surface to the surrounding fluid when 'h' value is generally smaller on the surface. Familiar examples are the ribs around the blades of gas turbine. The use of rib, in addition to enhancing heat transfer coefficient considerably, results in higher frictional penalty. In this work, it has proposed to investigate experimentally andnumerically the forced convective heart transfer coefficient from W shaped ribbed surface.The ribbed arrangement can used for augmentation of heat transfer in vertical fins. Each arrangement has higher value of Nusselt number for higher height. This is due to increased heat transfer area.

Rib Geometrical Features Rib heat transfer performance is significantly dependent on geometrical features and flow conditions. Effects on the flow are characterize by the flow Reynolds number and the rib geometry including rib height (e), rib spacing (p), rib angle-of attack and rib shape. Based on these, the rib geometrical features are commonly introduced as non-dimensional parameters such as rib pitch-to-rib height ratio (p/e) and the rib height-to-channel hydraulic diameter ratio (e/Dh). The aspect ratio AR of the channel, defined as the ratio between the width (W) and the channel height (H), is another important non-dimensional parameter. In general, ribs used in experimental study have a square cross section, with atypical relative rib height (e) of 5-10% of the channel hydraulic diameter (Dh) and p/e ratio varying from 7 to 15 (Ayushman et al, 2014).

1.2. Gap Analysis

Most Research in Heat exchanger hasdone with plane, rectangular, parallel rectangular, discrete rectangular, triangular, c shaped, v shaped etc. geometry, there have many heat losses or large amount of heat is useless. Using another developed geometry, we can increasing the heat transfer rate of system.Hence, it is a challenging task for development of improved and increasing heat transfer rate of system using another shape of rib with existing space and to improve the effectiveness.

1.3. Proposed Work

Proposed work concentrates on developing the ribbed plates with different shapes as shown in below fig. to study "Natural convection heat transfer from staggered horizontal rectangular fins". Experimental system is to be developed to achieve the above stated objective, which includes mainly at examining the heat transfer enhancement from horizontal rectangular ribbed plates under forced convection. To evaluate the convection heat transfer rate various forms of patterns of ribs is to be generated on flat plate as shown in Fig No. 5.The experiment is to be conducted to investigate the effect of ribbed surface on the pressure loss and heat transfer characteristics, where ribs are located on the flat plate. An aluminum plate of rectangular cross section with various ribs on surface is fitted in a long rectangular duct. The other end of the duct is to be connected to the delivery side of the blower and the air flows past the ribbed plate surface perpendicular to its axis. Bottom end of the plate project outside the duct & is heated by a heater. Temperatures at different points along the length of the ribbed plate are to be measured by thermocouples connected along the length of the plate. The air flow rate is to be measured by orifice meter fitted on the delivery side of blower.

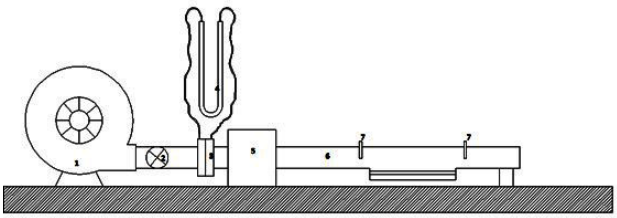
2. Project Overview

The enhancement of heat transfer is an important part the subject of thermal engineering. The heat transfer from surfaces may in general enhanced by increasing the heat transfer coefficient between a surface and its surroundings, by increasing the heat transfer area of the surface. Therefore, ribs must be designed to achieve maximum heat removal with minimum material expenditure, taken into account, and with the ease of manufacturing the fin shape. A large number of studies have been conducted on optimizing rib shapes. Other studies have introduced shape modifications by cutting some materials from plate itself to make cavities, holes, slot, grooves or the channels through the plate body to increase heat transfer areas and or the heat transfer coefficient. One popular heat transfer augmentation technique involves the use of rough or interrupted surfaces of different configurations. The concept of heat transfer through ribs on surface is one method of improving the heat transfer characteristic in the force convection. This will be give an objectives

1. To investigate and evaluate different geometries and experimental analysis on flat plate changing the geometries of ribs.
2. To find the effect of W shape ribbed roughened rectangular plate on forced convection heat transfer coefficient compared with the continuous rectangular flat plate for same heat input.
3. To find the effect of W shape ribbed roughened rectangular plate on forced Nusselt number compared with the continuous rectangular flat plate for same heat input.
4. To find the Effect of different W shape ribbed Geometries on heat transfer coefficient.

3. Experimental Setup

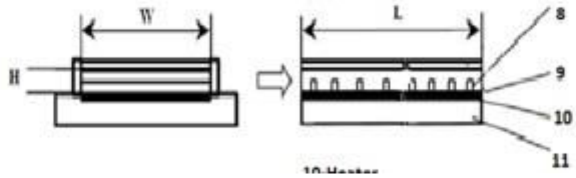
Fig. shows the schematic diagram of the experimental system. The system is composed of number of parts: Blower, Orifice meter with U-tube manometer, a hard plywood Planium box, a connecting G. I. Pipes, A brass valve to regulate the airflow, an acrylic sheet box that contains assembly of ribbed plate with, a plate heater, which heats the plate, and an Asbestos plate, which is insulator. In addition, devices for measurement and control of parameters. Six channel temperature indicators with PT-100 sensors are used to measure temperature of air at different locations. Experimentationis conducted to investigate the effect of ribs on the heated plate in the forced convection heat transfer from heated plate.



1.Blower 2.Flow Control valve
3.Orifice meter 4.U- tube manometer
5.Planiuum Box 6.Rectangular duct of acrylic sheet
7.RTD for I/L and O/L temperature measurement

Fig.2 Schematic diagram of the experimental apparatus.

The heat is generated within the plate with plate type heating element located below heating plate. An arrangement is made to measure and vary the heat



8 Rib 9 Aluminium Plate
10 Heater 11 Thermal Insulation

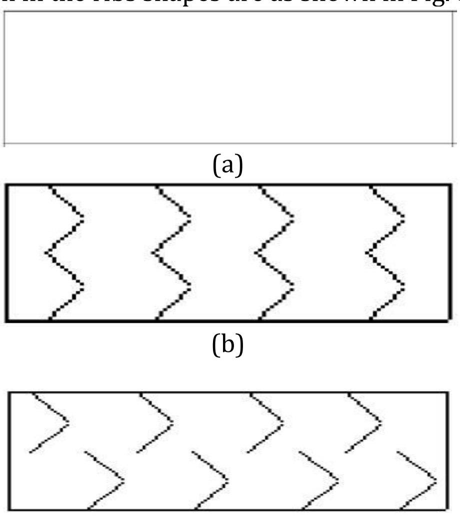
Fig.3 Schematic diagram of Plate assembly

Input with the help of transformer, and additional measuring instruments like voltmeter and ammeter.

The surface temperatures is measured with the help of RTD's (PT-100 sensors) mounted at different locations of plates. Ten RTD's are to be fixed on the plate (5 on test sides) in order to measure the base temperature and one RTD is to be used to measure air temperature. Each RTD (PT-100 sensor) is to be fixed to the surface of the test plate at equal space locations along the plate length. The apparatus will be allowed to run until the steady state for particular heat input. The recording of temperature will begin after steady state has been reached. Same procedure is repeated for different heat input and readings will be noted at steady state. Heat input to heater is varied from 20W to 100 W in the step of 20W.

Test Plates (Plates with different ribs on surface)

This experimentation work concentrates on developing three sets of different ribbedPlates of size (28cm x 10 cm x 1 cm) with variation in the width of ribs from 8 to 12 mm with rib height 2 mm to investigate the Enhancement in Forced convection heat transfer from W shape ribbed surface. Thermal performance of the proposed ribbed plates is compared with the plain vertical heated plate. Aluminium or Copper can be selected for Experimentation due to easy availability. The plain plate and proposed ribbed plates with variation in the ribs shapes are as shown in Fig. 5.



(a) (b) **(c)**

Fig. 5 (a) Rectangular plane plate (b) Rectangular plate with parallel W shaped rib with 90^0 (c) Rectangular plate with Discrete W shaped rib with 90^0

Experimental procedure

We are Make all electrical connections i.e. main supply to Dimmerstat from Dimmerstat to voltmeter and ammeter after this supply is connected to the plate type heater. For blower and digital temperature indicator also required electrical connections. After connection all start blower adjust mass flow rate as 5×10^{-3} kg/s and adjust the wattage given to heater as 20 W and for same wattage adjust the mass flow rate as 6×10^{-3}, 7×10^{-3}, and 8×10^{-3} and for constant wattage of 20W and forDifferent mass flow rate reading taken corresponding temperature readings until steady state is reached with respect to time.Next step is to take reading the properties of air at bulk mean temperature properties include density, specific heat, Dynamic viscosity etc. After then we have to calculate Reynolds number, Prandtl's number from available data has calculated, then find out the convective heat transfer coefficient and this experimental convective heat transfer coefficient is compared with Theoretical convective heat transfer coefficient.

4. Result Analysis

Testing of setup includes the experimentation to investigate the effect of ribs on the heated plate in the forced convection heat transfer from heated plate. The heat isgenerated within the plate with plate type heating element located below heating plate. An arrangement is made to measure and vary the heat input with the help of transformer, and additional measuring instruments like voltmeter and ammeter. A provision is made to measure the mass flow rate of flowing air with orifice meter and U tube manometer. The surface temperatures is measured with the help of RTD's (PT-100 sensors) mounted at different locations of plates. Six RTD's are to be fixed on the plate (4 on test sides) in order to measure the base temperature and one RTD is to be usedto measure air temperature. Each RTD (PT-100 sensor) is to be fixed to the surface of the test plate at equal space locations along the plate length.

4.1 Observation Tables

Reading for Plain plate for constant Heat input P=20 W

Table 1 Reading for plain Plate for P= 20 W

No.	m	T1	T2	Tb	T3	T4	T5	T6	Tav
	Kg/s	^oC	^oC	^oC	^oC	^oC	^oC	^oC	^oC
01	0.005	37.2	41.2	39.2	83.6	84.1	84.8	85.1	84.4
02	0.006	36.7	40.1	38.4	79.1	79.9	80.8	81.8	80.4
03	0.007	36.1	39.2	37.7	73.5	73.9	74.3	75.7	74.4
04	0.008	35.2	37.7	36.5	67.9	68.2	68.7	70.3	68.8

Reading for Parallel W shaped rib with 90^0Plate for constant Heat input P=20 W

Table 2 Reading for Plate Parallel W shaped rib with 90^0 Plate for P= 20 W

No.	m	T1	T2	Tb	T3	T4	T5	T6	Tav
	Kg/s	^oC	^oC	^oC	^oC	^oC	^oC	^oC	^oC
01	0.005	35.1	39	37.5	60.8	61.3	62.2	62.9	61.8
02	0.006	34.8	38.1	36.5	58.6	59.1	59.9	60.5	59.5
03.	0.007	34.1	36.9	35.5	54.7	55.2	55.9	56.3	55.5
04	0.008	33.7	36.1	34.9	51.1	51.9	52.5	52.8	52.1

Reading for Discrete W shaped rib with 90^0 Plate For constant Heat input P=20 W

Table 3 Reading for Plate Discrete W shaped rib with 90^0Plate for P= 20 W

No.	m	T1	T2	Tb	T3	T4	T5	T6	Tav
	Kg/s	^oC	^oC	^oC	^oC	^oC	^oC	^oC	^oC
01	0.005	35.8	39.7	37.7	62.6	62.9	64.5	64.6	63.7
02	0.006	35.1	38.4	36.7	59.9	60.3	60.8	61.1	60.5
03	0.007	34.9	37.8	36.4	56.3	56.7	57.7	57.9	57.2
04	0.008	33.7	36.2	34.9	52.5	52.9	54.1	54.3	53.5

Calculation

Consider Reading from Table for Sample Calculations,

Table 4 Reading for calculation

M	T1	T2	Tb	Tav
Kg/s	ºC	ºC	ºC	ºC
0.006	36.7	40.1	38.4	80.4

1. Bulk mean temperature,

$$Tb = (T1 + T2)/2 \ (1)$$

2. Average wall surface Temperature,

$$Tw = (T3 + T4 + T5 + T6)/4 \ (2)$$

3. The experimental convective Heat transfer coefficient (hexp.)

$$Q = hexp \ \times A \ \times T \ (3)$$

h= Q/ (A× T)

Where,

Q= Total heat supplied in Watt considering losses of conduction and radiation

A= Surface area of plate in m2

And$\Delta T = Tw - Tb$

$hexp = Q/(A \ \times T)$

4. Convective Heat Transfer coefficient (hplane.)

We know that correlation for Nusselt number for Ribbedsurface (Dittus-Boelter Equation)

$$Nu = 0.023 \ \times \ Re^{0.8} \ \times \ Pr^{0.4} \ (4)$$

Reynolds number is calculated as follows

$$Re = \frac{(m \times Dch)}{(Ach \times \mu)} \ (5)$$

Where, m = Mass flow rate of air in kg/s

Dch= Hydraulic mean diameter in m, Dch = (4 x Ach)/p

Ach= C/S Area of rectangular channel in m²

μ = Dynamic viscosity in Kg/ms

Prandtl's Number is calculated as,

$$Pr = \ \mu \ \times \frac{Cp}{K} \ (6)$$

Where,

μ = Dynamic viscosity in Kg/ms

Cp = Specific heat of air in J/Kg K

K = Thermal conductivity W/mK

Nusselt number is given by

$$Nu = hth \ \times \frac{Dch}{K} \ (7)$$

hplane= Nu x K/ Dch

After completing all calculations, compare hplane and hexp.

hexp. = 14.66 W/m²K

hplane = 15.46 W/m²K

4.2 Result tables

Results for Plain Plate for constant Heat input P=20 W

Table 5 Results for plain Plate for P= 20 W

No.	M	Re	hexp.	Nuexp.
1	0.005	4376.97161	13.60027	16.65033
2	0.006	5266.20981	14.63648	17.985047
3.	0.007	6143.9114	16.75019	20.582342
4.	0.008	7055.0848	19.01724	23.541782

Results for Parallel W shaped rib with 90⁰for constant Heat input P=20 W

Table 6 Results for Plate Parallel W shaped rib with 90⁰ for P= 20

No.	M	Re	hexp.	Nuexp.
1	0.005	4400.10571	16.3945	20.21988
2	0.006	5291.31356	17.58456	21.76825
3.	0.007	6189.5911	20.26286	25.0837
4.	0.008	7073.81838	23.625257	29.24613

Results for Discrete W shaped rib with 90⁰for constant Heat input P=20 W

Table 7 Results for Plate Discrete W shaped rib with 90⁰ for P= 20 W

No.	M	Re	hexp.	Nuexp.
1	0.005	4388.50817	18.434821	22.65238
2	0.006	5280.12685	20.08252	24.768439
3.	0.007	6173.19915	22.95489	28.416285
4.	0.008	7073.81838	25.808749	31.949121

4.3 Graphs

Graph of Nuexp.v/s Reynolds Number for All Plates for 20W

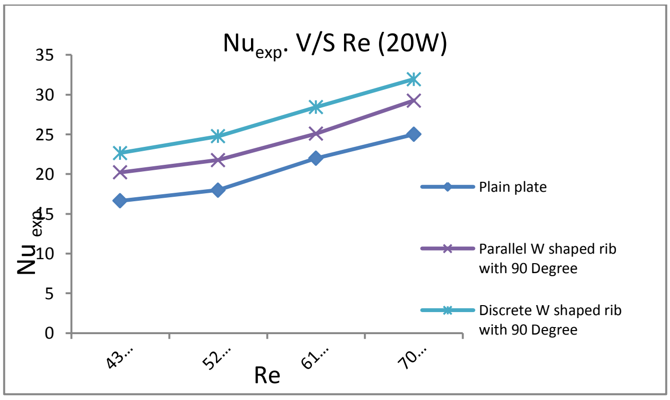


Fig. 8 Nuexp.V/S Re for all Plates for P= 20W

From graphs of NuexpV/S Re for all plates, we clearly identify that there is moreenhancement in the convective heat transfer coefficient for plate having staggered ribs withsmaller gap distance apart (20 mm) than compared with all. After that plate, havingribbedstaggered arrangement of large gap distancebetween two ribs (37mm) is second in heat transfer enhancement. In addition, after that continuous ribbed plate with larger gap distance and after this lastly continuous ribbed with small gap distance. From above graph, we conclude that maximum heat transfer enhancement takes place with staggered arrangement ribs with smaller gap distance. AsReynolds number increases, the Nusselt number also increases as shown in above graph.

Graph of hexp.V/s Reynolds Number for All Plates for 20W

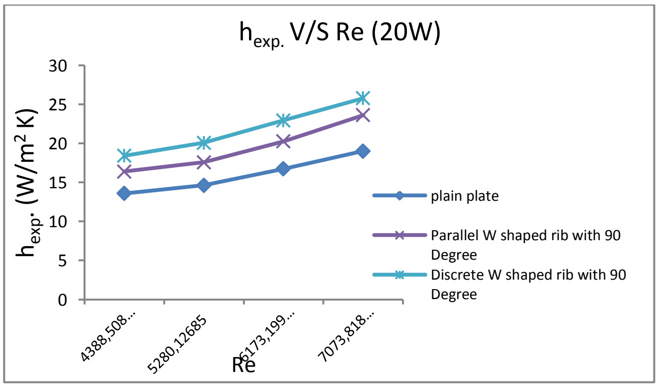


Fig. 9hexp.V/S Re for all Plates for P= 20W

From above graphs of hexp V/S Re for all plates, we clearly identify that there is moreenhancement in the convective heat transfer coefficient for plate having staggered ribs withsmaller gap distance apart (20 mm) than compared with all. After that plate, having ribbedstaggered arrangement of large gap distance between two ribs (37mm) is second in heat transferenhancement. In addition, after that continuous ribbed plate with larger gap distance and after this lastly continuous ribbed with small gap distance. From above graph, we conclude that maximum heat transfer enhancement takes place with staggered arrangement ribs with smaller gap distance. AsReynolds number increases convective heat transfer coefficient increases is clearly shown by thegraph for all readings.

Conclusions

The experimental investigation of forced convective heat transfer from ribbed surface is calculated for W shaped configurations with either parallel or discrete ribs and for single plain plate with varying heat supplied and different mass flow rates of air after completing experiment for all readings of plain plates andW shaped rib configurations theoretical and experimental convective heat transfer coefficient is calculated, we get conclusions as.

1. Among all different configurations of the ribbed plates the maximum convective heat transfer coefficient when compared with plain plate is for configuration with Discrete W shaped configuration.
2. The results were plotted and from graph, it shows that as Reynolds number increases with increase in mass flow rate of air for all wattage ranges the Nusselt number also increases and shows the enhancement of convective heat transfer coefficient.
3. The Discrete W shaped rib shows 27% enhancement in convective heat transfer coefficient when compared with plain plate, and 7% more than discrete V shaped rib, and 5% parallel W shaped rib.

Finally, we conclude that the Discrete W shaped rib shows the maximum enhancement in convective heat transfer rate.

References

Han, J. C. (1984) Heat Transfer and Friction in Channels with Two Opposite Rib-roughened Walls, Enhanced Internal Cooling of Turbine Blades and Vanes, ASME Journal of Heat Transfer,Vol. 106, Pp. 774-781.

Miss. Ashwini Vasant Thakare, Dr. J. A. Hole, (March 2016), Experimental Validation of Heat Transfer Enhancement in Plate Heat Exchanger with Non-Conventional Shapes of Rib, International Journal of Science, Engineering and Technology Research (Ijsetr), Volume 5, Issue 3.

Carl-olof Olsson, Bengt Sunden (4 August 1997)Experimental Study Of flow And Heat Transfer In Rib-roughened Rectangular Channels, Experimental Thermal And Fluid Science, Vol. 16, Pp. 349-365.

Pankaj N. Shrirao, Rajeshkumar U. Sambhe, Pradip R. Bodade, (Feb 2013), Convection Heat Transfer Analysis in A Circular Tube with Different Types of Internal Threads of Constant Pitch, IJEAT, Volume 2, Issue 3.

Ayushman Srivastav, Anil Kumar Patil, Gopal Nandan, (2014), Investigation of Heat Transfer and Friction in Rib Roughened Fin Under Forced Convection, International Journal of Advanced Technology & Engineering Research (IJATER) 1st International Conference On Research in Science, Engineering & Management, IOCRSEM.

Prof. Anirudh Gupta, Pramod Bhatt, (2012), an Experimental Investigation to Compare Heat Augmentation from Plane and Protruded Rectangular Fins, AIEEE, Pp.1587.

R. Tauscher, F. Mayinger, (1999), Enhancement of Heat Transfer in a Plate Heat Exchanger by Turbulence Promotor's, Journal of Heat Transfer Enhancement of Heat Exchangers, Pp. 207- 221.

Amit Garg, Sunil Dhingra, (July 2014), Numerical Simulation for Heat Transfer Enchancement in A Triangular Ribbed Channel with Winglet Vortex Generators, International Journal of Engineering Research and General Science Volume 2, Issue 4, Pp. 2091-2730.

Dr. Hole J. A., (2015), Heat Transfer Enhancement in Plate Heat Exchanger with Non-Conventional Shapes of Rib, International Engineering Research Journal (IERJ) Special Issue 2, Pp. 5397-5400.

Sujan T N, Mr. Krishnamurthy K N, Mr. Akash Deep B N, (2016), Experimental Investigation On C and V Shaped Inline and Staggered Fins Array Using Forced Convective Heat Transfer, Imperial Journal of Interdisciplinary Research (IJIR) Vol-2, Issue-9.

Navanath Ghodake, Prof. M. R. C. Rao, (2016), Forced Convection Heat Transfer Augmentation from Ribbed Surface, International Engineering Research Journal (IERJ), Pp. 134-137.

Hasibur Rahman Sardar1, Abdul Razak Kaladgi, (2015), Forced Convection Heat Transfer Analysis Through Dimpled Surfaces with Different Arrangements, American Journal of Energy Engineering, Pp. 37-45.

Faheem Akthar, Abdul Razak R Kaladgi, Mohammed Samee, (2015), Heat Transfer Augmentation Using Dimples in Forced Convection – An Experimental Approach, IJMERR, ISSN 2278-0149, Vol. 4, Pp. 01.

A. D. Yadav, V. M. Kirplani, (2015), Review Of Heat Transfer Augmentation Within A Plate Heat Exchanger By Different Shapes Of Ribs, International Journal Of Scientific Engineering And Technology, Volume 2, Issue 5, Pp. 347-350.