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HEAT TRANSFER ENHANCEMENT IN A CIRCULAR TUBE FOR TURBULENT FLOW OF WATER USING PERFORATED RECTANGULAR STRIPE INSERT

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Abstract-*An Experimental study was conducted to evaluate the enhancement of heat transfer for turbulent flow through a tube using water as the working fluid with perforated rectangular stripe inserts. In this experiment, there are 2 insert having perforation diameter of 8 mm and 10 mm are used with corresponding porosities of 2.94% & 4.59 % respectively. The aluminum inserts were 800 mm in length, 32 mm width, 2 mm thickness and the spacing between two adjacent holes are 50 mm for two inserts. The test section consisted of a circular copper tube of 26.6 mm inner diameter, 900 mm length with five K-type thermocouples. Bulk temperature and pressure drops were measured. Heat transfer coefficient, friction factor and Nusselt number were calculated to analysis heat transfer enhancement of circular tube fitted with/without inserts in turbulent regimes (4000<Re<13000). Heat transfer rate for inserts of perforation dia of 8mm &10 mm was increased by 2.2, 3.4 and Nusselt number was risen by 1.7, 2.12 times respectively compared to smooth tube.*

Keywords: Perforated Rectangular Stripe Insert; Heat Transfer Rate; Friction Factor; Pressure Drop; Heat Transfer Enhancement

1. INTRODUCTION

Heat transfer augmentation technique is improving continuously. The study to increase heat transfer has been started at the beginning of twentieth century. Many investigations are already successfully completed and being used in many sectors. According to the modern studies, it is observed that the performance dealt with perforated rectangular stripe inserts ‘is the most economical heat transfer enhancement tool. It is important to verify the implementation of heat exchanger tool to know the tube side as well as shell side heat transfer. Heat exchanger is the tool which provides heat transfer between two or more fluids and develops the high performance thermal system. It improves the heat exchanger effectiveness for internal and external flows. Naturally, the mixing of the fluids are increased by increasing flow vorticity, unsteadiness, turbulence or by limiting the growth of fluid boundary layers close to the heat transfer surfaces.

Heat transfer augmentation techniques are widely used in areas specified as temperature effort transform, air conditioning and preservation systems and chemical reactors. Basically the experiments are studied, using different shapes of inserts, different types of materials, in varieties experimental works for dissimilar environments. Due to rapid growth of industrialization the research on this topic has been enlarged significantly. Nowadays it is one of the most important topics to enhance heat transfer with minimizing the material cost. Many researches have been carried out to increase convective heat transfer for various flow conditions, reducing friction factor and use of power.

Bergles et *al.* [1] declared the obtainable literature on convection temperature soul. According to the literature, the augmentation techniques were classified into two categories (Passive and active).Passive augmentation techniques, which required no external power, and active techniques, which do required external power. The fourteen techniques were grouped in terms of their application to the various modes of heat transfer. Mass transfer was included for completeness. The nonviolent methods were supported on the identical principle. Use of this technique causes the whirl in the volume of the fluids and disturbs the literal line layer so as to growth strong articulator mass devices were generally victimized as supine alter transpose enhancement techniques:

- Inserts
- Extended aboveground
- Shallow modifications
- Use of additives

Perforated rectangular stripe inserts provides an additional disturbance to the fluid in the section of the tube wall and vorticity behind the cuts and thus leads to a higher energy soul improvement in comparison with smooth tube. Salam et *al.* [2] made an investigation to enhance tube side heat transfer with rectangular shaped twisted tape insert. It was observed that, the Reynolds numbers were varied from10000 to 19000 ranges with heat flux variation rangingfrom14 to 22 kW/$m^2$for smooth tube and 23 to 40 kW/m^2 for tube with insert. Nusselt numbers for smooth tube were compared with Gnielinski correlation and errors were found from -6% to -25% ranges with R.M.S. value of 20%.Nusselt numbers in tube with rectangular-cut twisted tape insert were enhanced by 2.3 to 2.9 times with the increase of friction factors by 1.4 to 1.8 times compared to the smooth tube. Heat transfer enhancement efficiencies were found in the range of 1.9 to 2.3 and increased with the increase of Reynolds number. Mesh or spiral brush inserts were used by Megerlin et *al.* [3] to enhance heat transfer in short channels subjected to high heat flux. For turbulent flows the heat transfer coefficient can be developed as much as 8.5 times that in a smooth tube, but pressure drop was very high. Sarada et *al.* [4] made an investigation with varying width twisted tape inserts ranging from 10 mm to 26 mm. The Reynolds number varied from 6000 to 13500. It was found that the increment of heat transfer with twisted tape inserts as compared to plain tube varied from 36~48% for width 26 mm and 33~39% for width 22 mm inserts. A new idea was postulated by Hsieh and Huang [5] to foretell heat transfer and pressure drop of laminar flow in horizontal tubes with/without longitudinal inserts. They said that enhancement of heat transfer as compared to a conventional bare tube at the same Reynolds number to be a factor of 16 at $Re \leq 4000$, while a friction factor rise of 4.5.Friction and heat transfer characteristics of turbulent air flowing through tubes with twisted strip swirl promoters were studied experimentally and analytically by Thorsen and Landis [6]. Data were obtained for pitch-to-diameter ratios as low as 3.15 and for Reynolds numbers up to 100,000. Both heating and cooling tests were run for tube wall to fluid bulk temperature ratios from 0.6 to 1.9 to assess compressibility and buoyancy effects. Eiamsa-ardet*al.*[7] conducted an experimental study for a round tube with short-length twisted tape insert on the mean Nusselt numbers, friction factor and enhancement efficiency characteristics under uniform wall heat flux boundary conditions. For swirling flow, the short-length tape was established for generating a strong swirl flow at the tube entry when the full-length twisted tape was inserted into the tube at a single twist ratio of y/w=4.0. The enhancement efficiency with the short-length insert was found to be lower than that with the full-length insert. Eiamsa-ardet*al.*[8] were continued the investigations and used DI-coil in common with the insert at lower Reynolds number and found the highest thermal performance factor of around 1.25. Again, Eiamsa-ardet*al.*[9] made an experiment using single twisted tapes and full-length dual twisted tapes with three different twist ratios (y/w=3.0, 4.0 and 5.0) and also regularly-spaced dual twisted tapes with three different space ratios (s/D=0.75, 1.5 and 2.25). The result observed that the heat transfer of the tube with dual twisted tapes was higher than that of the plain tube with/without single twisted tape insert. Altaie et *al.* [10] studied with ribs assembly of 5x5 mm cross section and fitted in the tube and separated by 8cm pitch. Results of temperature and velocity distribution along the tube center line for the case of tube with internal ribs were compared with that of plain tube, those results showed that the use of internal ribs enhance the heat transfer rate and found to possess the highest performance factors for turbulent flow. Heat transfer performance for turbulent flow in a circular tube with a porous/perforated twisted tape insert was experimentally investigated by Wazed et *al.* [11]. In the analysis a wide range of Reynolds numbers (1.3 x 10^4 to 5.2 x 10^4) were observed. The heat transfer coefficient was enhanced (up to 5.5 times) in the cost of increasing pumping power (1.8 times) in turbulent flow through a tube with the inserts. The heat transfer effectiveness in a tube with a perforated twisted tape insert was found to increase up to 4.0 times compared with the value for the plain tube. An investigational research of heat transfer performance of porous twisted tape insert in a circular tube was carried out by Ahamed et *al.* [12]. In arrange of Reynolds number 1.3 x 10^4 to 5.2 x $10^4$the results found for tube with porous twisted tape insert, the average heat transfer coefficient was 2.60 times higher, the heat flux was 1.55 times higher, the friction factor was 2.25 times higher and the pumping power was 2.0 times higher than plain tube values.

Perforated rectangular stripe insert is very economic and also reduce the pressure drop as well as uses of material. The experiment focuses on convection heat transfer enhancement inside the tube by using Perforated Rectangular Stripe inserts. The main aim of the current research was to find the heat flux and pressure drop using Perforated rectangular stripe insert of different porosities to choose the best one. Another important finding was to determine the efficiency of two different inserts and choose the best among them comparing with smooth tube. Heat exchanger is the apparatus providing heat transfer between two or more fluids, and they can be classified according to the mood of flow of fluid or their methods. The experiment focuses on reviewing conventional heat transfer enhancement techniques inside the tube by using perforated rectangular stripe insert. The main objectives of present work was to find the tube side heat transfer co-efficient and friction factor. Another important finding was to determine the relation between Reynolds number & Nusselt number. To determine the pressure drop in tube side with Perforated Rectangular strip insert. To find the efficiency of two different inserts and choose the best among them. There were some limitations according to the study. The heater could not wrap properly, therefore equal distance was not found in every curl. The bulk temperatures were measured by average of input and output temperatures.

2. METHODOLOGY

To enhance heat transfer rate rectangular perforated strip insert was used. Convection is the transfer of potential energy, for example heat, by means currents within a fluid. When a portion of a fluid is less dense, it rises due to gravity. This experimental investigation was carried out for measuring tube side heat transfer coefficient of water using perforated rectangular stripe insert. Here in this project perforated rectangular stripe inserts of 800mm length, 32mm width, 2 mm thickness was used, which was made of aluminum strips. A 939.8 mm long copper tube of 26.6 mm internal diameter and 30 mm outer diameter, of which length of 900 mm was used as the test section. A constant heat flux condition was maintained by wrapping Nicrome wire around the test section and fiber glass insulation over the wire. This was used to heat the test section. Outer surface temperature of the tube was measured at five points of the test section maintaining equal distance from one point to another point by K-type thermocouples. Two thermometers were used at the inlet and outlet section of the tube for measuring the bulk temperatures. At the outlet section the thermometer was placed in a mixing box to get the average outlet temperature. Pressure drop was measured at two points of the test section by using manometer. Open loop system of water supply was used. The rate of flow was measured with the help of Rotameter in the travelling path of inlet water. Two types of temperature were measured during the experiment. One regarding tube outer surface temperature and another one was water inlet-outlet temperature. Data was taken for only plain copper tube without insert and with inserts.

The local convective heat flux of a fluid heat passing over a surface is expressed as,
q=h (Tw-Tb) (1)
Where:
q= Heat transfer rate (W/m2)
h= Convective heat transfer coefficient (W/m2 K)
Tw= surface/wall temperature (K)
Tb=Bulk temperature (K)
This expression is known as Newton's law of cooling, and the proportionality constant h (W/m2 K) is termed as convective heat transfer coefficient. Experiment is described below with all necessary equipment.

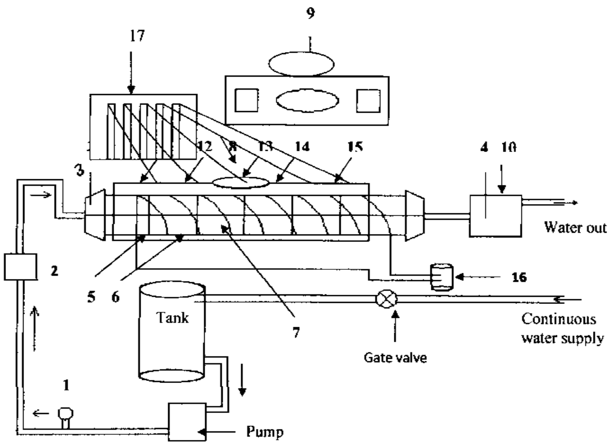

Fig. 1: Schematic diagram of experimental set-up.

1. Gate valve
2. Rotameter
3. Inlet thermometer
4. Outlet thermometer
5. Insulation
6. Test section (copper tube)
7. Nichrome-wire coil
8. Thermo-electric monitor
9. Voltage Regulator
10. Mixing Box
11. Thermocouple 1
12. Thermocouple 2
13. Thermocouple 3
14. Thermocouple 4
15. Thermocouple 5
16. Manometer

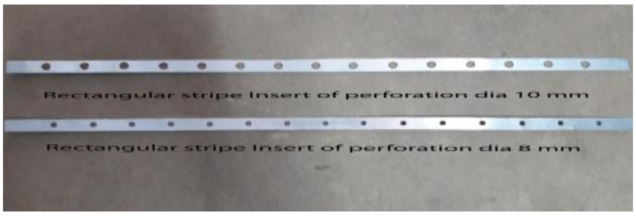

Fig. 2: Perforated rectangular stripe insert


Fig. 3: Experimental setup

3. MATHEMATICAL FORMULATIONS

Heat transfer performance of insert in water at circular tube was calculated by using the following equations.
Outer surface area was calculated from,

$$\boldsymbol{Ao = \pi doL} \qquad \textbf{(1)}$$

Where, do is outer surface diameter.
Inner surface area,

$$\boldsymbol{As = \pi diL} \qquad \textbf{(2)}$$

Where, di is inner surface diameter.
The experimental friction co-efficient,

$$\boldsymbol{f = \frac{2\Delta Pdi}{\rho LUm}} \qquad \textbf{(3)}$$

Where, mean velocity, $\boldsymbol{um = \frac{Q}{\pi di2/4}}$ **(4)**

Pressure difference,

$$\boldsymbol{\Delta p = \Delta h \times \rho \times g \times 13.6} \qquad \textbf{(5)}$$

Added heat, $\boldsymbol{Q = mcp(To - Ti)}$ **(6)**

Velocity, $\boldsymbol{V = m/Ax}$ **(7)**

Where, m is flow rate and
Cross sectional area, $\boldsymbol{Ax = \frac{\pi}{4} di2/4}$ **(8)**

Reynolds Number, $\boldsymbol{Re = \frac{\rho Vdi}{\mu}}$ **(9)**

Nusselt number, $\boldsymbol{Nuexp = \frac{hdi}{K}}$ **(10)**

Dittus Boelter equation, $\boldsymbol{Nud = 0.023Re^{\frac{4}{5}}Pr^{n}}$ **(11)**

Where n is 0.4 for heating and 0.3 for cooling.
Prandtl number, $\boldsymbol{= \frac{\mu Cp}{K}}$ **(12)**

Convective heat transfer coefficient,

$$h = \frac{Q}{A(Tinner\ surface - Tbulk)} \quad (13)$$

And heat flux, $q = \frac{Q}{As}$ (14)

Gnielinski Equation,

$$Nud = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{8}\right)^{\frac{1}{2}}\left(Pr^{\frac{2}{3}}-1\right)} \quad (15)$$

Theoretical friction factor,

$$ft = (0.79lnRe - 1.64)^{-2} \quad (16)$$

Bulk temperature, $Tbulk = \frac{Ti+To}{2}$ (17)

% of error = $\frac{Nuexp-Nuth}{Nuth} \times 100$ (18)

Efficiency, ŋ $= \frac{Nuexp-Nuth}{Nuexp} \times 100$ (19)

4. EXPERIMENTAL RESULTS

Table 1: Different paraments from experiment.

Parameters	symbol	value
For plain tube:		
Reynolds No	*Re*	4004.60~12252.87
Heat Transfer Rate	Q	313.275 ~ 902.232
Convection Heat Transfer Coefficient	*h*	283.42 ~832.88
Nusselt Number	Nu	10.82 ~35.74
Friction factor	f	0.27 ~0.075
Efficiency	ŋ	17.2 %~29.80%
For Plain Tube with Rectangular Strip Insert of Perforation Dia 8 mm		
Reynolds No	Re	4004.60~12252.87
Heat Transfer Rate	Q	563.90 ~ 1804.464
Convection Heat Transfer Coefficient	*h*	455.66 ~ 1608.52
Nusselt Number	Nu	19.10 ~68.90
Friction factor	f	0.4750 ~0.0866
Efficiency	ŋ	21.5 %~49.82%
For Plain Tube with Rectangular Strip Insert of Perforation Dia 10 mm		
Reynolds No	Re	4004.60~12252.87
Heat Transfer Rate	Q	845.84 ~ 2506.20
Convection Heat Transfer Coefficient	*h*	573.04~ 1839.44
Nusselt Number	*Nu*	24.03 ~78.90
friction factor	f	0.530 ~0.09285
efficiency	ŋ	33.56%~60.34%

5. DISCUSSION

It has been found from the result that, in case of plain tube heat transfer rate is increasing with the increase of flow rate because more water is passing through the tube taking more heat gradually. Pressure drop also increased with the increase of flow rate in the plain tube. On the other hand it has been also found that when perforated rectangular stripe insert was inserted in the copper tube, heat transfer rate was increased compared to plain tube without insert. Heat transfer rate was increased because water was flowing through the tube there developed two components of flow, axial component of flow and radial component of flow which were responsible for breaking down of water film, so the flowing water was taking more heat from the plain tube without insert. But pressure drop was increased gradually with the increase of flow rate than the plain tube. So, it is found that, where disturbance in water flow is greater, breaking down of water film, heat carrying capacity, pressure drop is also more. So, comparing the two rectangular stripe inserts of perforation dia 8mm & 10 mm respectively, the rectangular stripe insert of 10 mm is better than rectangular stripe insert of perforation dia 8 mm.

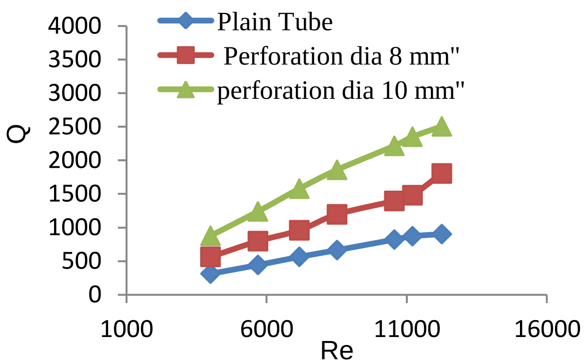

Fig. 4: Variation of convective heat transfer rate with Reynolds Number

From Fig 4, the heat transfer rate with rectangular strip insert of perforation dia 10 mm is higher than the rectangular stripe insert of perforation dia of 8mm and all the inserts is higher than without insert. Because when insert is used the heat transfer rate is increased and more disturbance in flow causes more heat transfer.

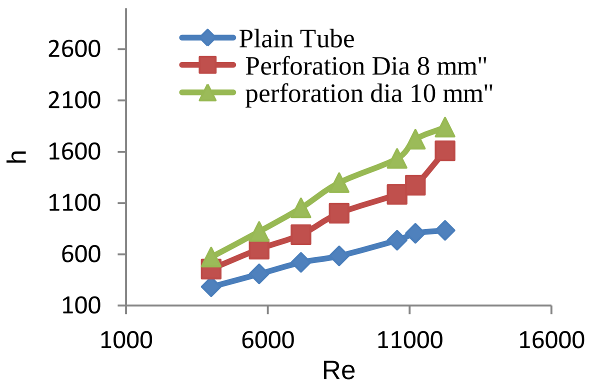

Fig. 5: Variation of convective heat transfer coefficient with Reynolds Number .

It is found in Fig. 5 that for the increasing of same Reynolds no. increasing heat transfer coefficient both with two rectangular strip insert of perforation dia 8 mm and 10mm respectively and without insert.

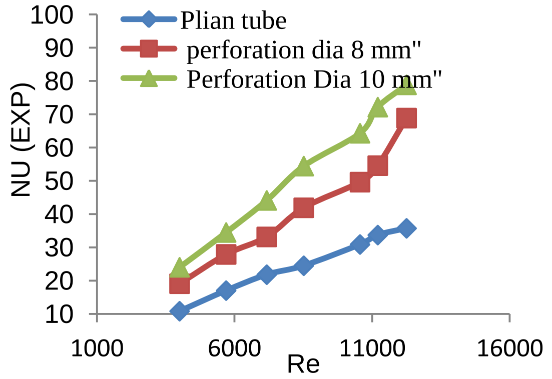

Fig. 6: Variation of Nusselt number with Reynolds number

Fig 6 shows that with the increase Reynolds no. Nusselt number increases in both cases: rectangular strip with insert of perforation dia 8mm, 10mm respectively and without insert. The Nusselt number with Rectangular Strip insert of perforationdia10mm is higher than the rectangular strip insert of perforation dia 8mm and all the inserts is higher than without insert. Because convective heat transfer coefficient is increased for using insert.

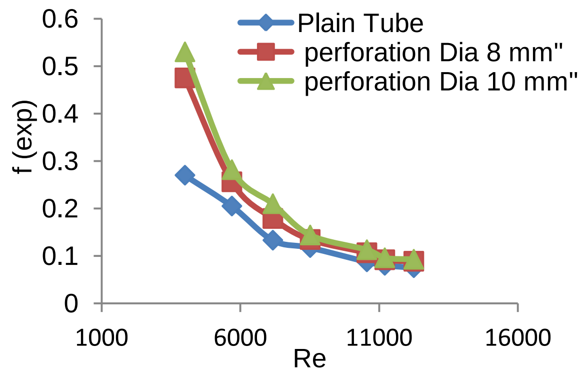

Fig. 7: Variation of Friction factor with Reynolds number

From Fig 7, the friction factor with rectangular strip insert of perforation dia 10 mm is higher than the rectangular strip insert of perforation dia 8 mm and all the inserts is higher than without insert. Because when insert is used the pressure drop is increased.

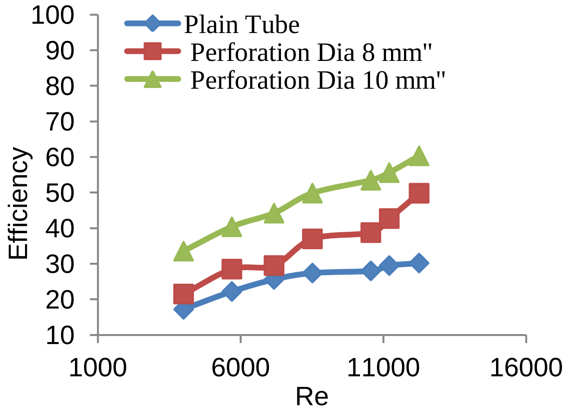

Fig. 8: Variation of Efficiency with Reynolds number

From Fig 8, the efficiency with rectangular stripe insert of perforation dia 10 mm is higher than rectangular stripe insert of perforation dia 8 mm and all the inserts are higher than without insert. Therefore, it can be said the efficiency was increased when insert is used.

6. CONCLUSION

Some of the more successful enhancement techniques currently used for heat transfer augmentation have been reviewed here. The application of single phase enhancement techniques is evaluated for tube side. Several active techniques have been identified as possibilities for tube enhancement. An experimental investigation was carried out to determine Tube side heat transfer coefficient, friction factor, for turbulent flow in a circular tube which was fitted with perforated rectangular stripe insert. Nusselt number for perforated rectangular stripe insert was increased by 1.7 to 2.12 times than that of the plain tube. Heat Transfer rate for perforated rectangular stripe insert was increased by 2.2 to 3.4 times than that of the plain tube. Friction factor was decreased with the increase of Reynolds number for both of the case. Efficiency for perforated rectangular stripe insert was increased by 1.37 to 1.90 times than that of the plain tube.

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8. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(K)
P	Pressure	(Pa)
d	Tube diameter	(m)
r	Radius	(m)
L	Tube length	(m)
A	Area	(m2)
um	Mean velocity	(m/s)
V	Velocity	(m/s)
m	Mass flow rate	(kg/s)
ρ	Density	(kg/m3)
μ	Dynamic viscosity	(kg/m-s)
Cp	Specific heat	(J/kg.K)
Q	Heat transfer rate	(W)
q	Heat flax	(W/m2)
h	Heat transfer	(W/m2.K)
kw	coefficient	(W/m.K)
Nu	Thermal	Dimensionless
ΔP	conductivity	Dimensionless
f	Nusselt number	Dimensionless
Pr	Pressure drop	Dimensionless
Re	Friction factor	Dimensionless
η	Prandtl number	Dimensionless