Experimental investigation on copper tube by using double passive augmentation technique used for heat exchanger performance enhancement.

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Abstract – *An experimental investigation is carried out to study of the effect of internal surface roughness of copper tube having an internal threading of Whitworth type along with the insertion of Mild steel twisted tape (Double passive Augmentation) on the heat transfer properties of Heat exchangers. Test tube of 25 mm ID, 35 mm OD and 3.4 mm pitch is experimentally tested on the smooth tube before threading after threading and threading along with insertion of twisted tape in the flow. Mica heaters are wrapped on the copper tube for giving constant heat flux and tube is then insulated by glass wool insulation for no leakage of heat to environment. Six K Type thermocouples are soldered on the test tube at 134 mm apart to measure the outer surface temperature. Water is use as the working fluid. Nusselt no. friction factor, thermal enhancement factor were tested on the tube having internal threading along with twisted tape insert and compared it with the smooth tube. From the data obtained by the graphs, we conclude that the heat transfer rate in the test tube of having internal threading along with twisted tape found highest as compared to the smooth tube and the tube having only threading has enhances the heat transfer as compare to the smooth tube because of the swirling of flow due to pitch and mixing due to insertion of twisted tape.*

Key Words: Whitworth, *Mild steel twisted tape, Double passive Augmentation, heat transfer rate, Nusselt no.*

1. INTRODUCTION

Heat exchangers are extensively used in a variety of manufacturing processes for heating and cooling applications. . The heat exchangers have an important role in the energy storage and recovery. The heat transfer phenomenon is depends on the various parameters like surface roughness, obstacles to flow, fluid vibration, geometrical conditions of the tube in heat exchangers. This is the techniques comes under the passive augmentation technics. There are two types of augmentation techniques. Active technique includes

Surface vibrations, Fluid vibration, electrostatic fields. These techniques are complex which require external power input to cause modification in flow and increases heat transfer rate. In Passive techniques, by simply changing the surface geometry of the surface which causes the swirling flow which increases the heat transfer rate.

2. LITERATURE REVIEW

Various researchers have carried out the work on the passive augmentation techniques to shows that how the effects of surface geometry and the insertion of twisted tape enhances the heat transfer properties as follows.

Kalmegh [1] paper of this researcher shows that by simply changing the internal surface geometry of the flow channel enhances the heat transfer rate. Pravin. [2] In 2016 by simply inserting V Shape turbulator thermal characteristics enhances applicable to heat exchanger in his work. Wang [3] studied forced convective heat transfer in three-dimensional porous pin fin channels. The effects of pin fin form are also remarkable. With the same physical parameters, the overall heat transfer efficiencies in the long elliptic porous pin fin channels are the highest while they are the lowest in the short elliptic porous pin fin channels. Paisarn Naphon [4] studied the enhancement in the heat transfer rate by inserting the coiled wire at varying Reynolds number concluded in his work. Eiamsa [5] in his work shows that the heat transfer rate obtained by using the tape without core rod is found to be better than that by one with core-rod around 25-60% while the friction is around 50% lower. Thianponga [6] experimentally investigated the effect of perforated twisted-tapes with parallel wings on heat transfer enhancement in a heat exchanger tube. The result showed that as compared to plain twisted tube, PTT increases heat transfer rate up to 208%. Fan et al. [7] numerically and computationally studied the heat transfer and flow characteristics in a circular tube fitted with louvered strip inserts. It was observed that the Nusselt number is augmented by around 4 times that of the smooth tube. Hence it confirms that the louvered strip has a good effect of heat transfer enhancement. Promvonge et al. [8] experimentally investigated the heat transfer augmentation in a helical-ribbed tube with double twisted tape inserts. It was found that the compound enhancement devices of helical-ribbed tube and the twin twisted tapes show a considerable improvement of heat transfer rate and thermal performance relative to the smooth tube and the helical-ribbed tube acting alone. Mohammed et al. [9] numerically and computationally studied the heat transfer enhancement of Nano fluids in a double pipe heat exchanger with louvered strip insert. The result obtained by [7] was same that is the Nusselt number is augmented by around 4 times for the louvered strip insert than that of the smooth tube. Bhuiya et al. [10] experimentally investigated the thermal characteristics in a heat exchanger tube fitted with triple twisted tape inserts. It was found that the Nusselt number was obtained 1.73 to 3.85 times higher than those of the plain tube values for the tube with triple twisted tape inserts. The friction factor for the tube with triple twisted tape inserts was achieved 1.91 to 4.2 times higher than those of the plain tube values at the comparable Reynolds number. Khan et al. [11] conducted experiment on turbulent flow characteristics obtained in forced convection heat transfer with asymmetric heating has been carried in developed region of square duct. The duct is made of heat resisting materials, whose bottom surfaces for all the ducts are made up of 12mm thick aluminium sheets. The bottom surface of the rough duct is the rib- rough wall having roughened with triangular, trapezoidal, and saw tooth (forwards and backward ribs). The experiments have been conducted for different Reynolds number varies from 50000 to 560000 It is found in the result that Nusselt number increases by 25.75percent varies in saw tooth backward, 27.43 per cent in saw tooth forward, 26.71 per cent in triangular 24.43percent in trapezoidal ribbed wall over non ribbed wall with an increase of Reynolds number up to 12 per cent. Esmaeilzadeh et al. [12] experimental studied on heat transfer and friction factor characteristics of g-Al2O3/water through circular tube with twisted tape inserts with different thicknesses. It was observed that the highest enhancement is achieved at maximum thickness and volume concentration. Nano fluids have better heat transfer performance when utilized with thicker twisted tapes. More the thickness of twisted tape is more the increase of friction factor is. Ultimately, the convective heat transfer enhancement outweighs the effect of friction factor increase, leading enhanced thermal performance. Pramanik et al. [13] studied heat transfer and the pressure drop characteristics of laminar flow of viscous oil through rectangular and square ducts with internal transverse rib tabulators on two opposite surfaces of the ducts and fitted with twisted tapes under constant heat flux conditions. The combined use of full-length twisted tape and transverse ribs enhance the thermo hydraulic performance of the square and rectangular ducts compared to the use of only twisted tape or only transverse ribs for laminar flow. However the performance evaluation shows that the short-length twisted tape in square and rectangular ducts with rib turbulators, through which laminar flow occurs under constant wall heat flux boundary condition performs worse than the full length twisted tape.

3. EXPERIMENTATION

3.1 Experimental set up description

An experimental setup consist of the 800 mm copper tube of ID 25mm, OD 35 mm and having 3.4 mm pitch of Whitworth threads are made. Constant heat flux is provided by the Dimmerstat and Mica heaters are wrapped for giving the heating. Six K type thermocouples are soldered to the test tube at 134 mm apart for measuring the surface temperature and two additional thermocouples are placed to inlet & outlet for measuring the inlet & outlet temperatures of the flow. After making all connection of thermocouples, tube is insulated by the Glass wool insulation and finally covered by the PVC pipe. Tap water is used as working fluid. For measuring the pressure drop, U tube manometer is used. Similar procedure was repeated for three cases viz. Smooth tube, the test tube with threading and threading along with the insertion of Mild steel twisted tape of length 410 mm and having width 18 mm of thickness 2 mm.

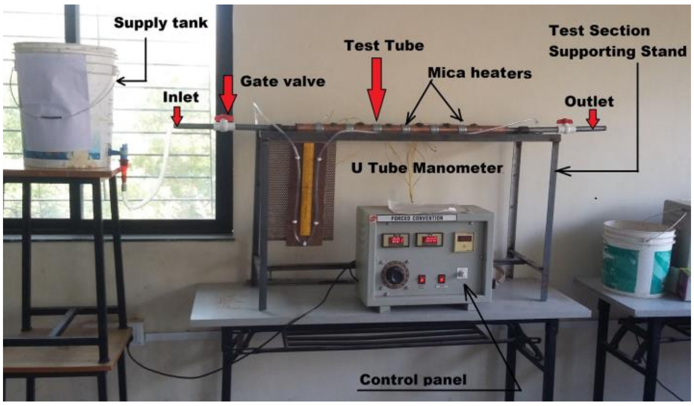

Fig. 1. Photograph of Experimental Setup.

Fig. 2 Photograph of Mild steel twisted tape.

3.2 Experimental procedure

Inlet section of set up is connected to the gate valve of water tank which takes water and pumped through test section. The flow rate of water is controlled by gate valve and was measured manually using stop watch and measuring jar. The flow rate varied using gate valve for different values of Reynolds number and kept constant during experimentation. After switching on the heater power the sufficient time was given to attain the steady state condition. In each run data were taken for water flow rate, water inlet, water outlet and tube outer surface temperature and pressure drop readings.

- Open the supply valve and adjust the flow by means of gate valve and to some desired difference in the manometer level.
- Start the heating of test section with the help of Dimmerstat and adjust desired heat input with the help of voltmeter and ammeter.

- Take readings of thermocouples at an interval of 10 minutes, until steady state is reached.
- Wait for steady state and take reading of all thermocouples at steady state.
- Note down heater input.
- Above Same procedure was repeated for remaining two test tubes viz. threaded tube and threaded tube along with the Mild steel twisted tape insert into the flow channel.

4. REGRATION ANALYSIS

Regression analysis is a statistical procedure used to find relationship among a set of variables. Regression finds the line that best fits the observations. It does this by finding line that result in the lowest sum of squared errors. Since the line describes the mean of effect of in- dependent variables, by definition, the sum of actual errors will be zero. It you add up all the values predicted by the model, the sum is the same. That is, the sum of the negative errors (for points below line) will exactly offset the sum of the positive errors (for points above the line). Summing just the errors wouldn't be useful because the sum is always zero. So, instead, regression uses the sum of the squares of the errors. An ordinary Least Squares regression finds the line that result in the lowest sum of squared errors.

4.1 Introduction to least square method

A line of fit is a straight line that is the best approximation of the given set of data. It is used to study the nature of the relation between two variables. A line of best fit can be roughly determined using an eyeball method by drawing a straight line on a scatter plot so that the number of points above the line and below the line is about equally (and the line passes through as many points possible). A more accurate way of finding the line of best fit is the least square method. Use the following steps to find the equation of line of best fit for a set of ordered pairs.

Step 1: Calculate the mean of x-values and mean of y-values.
Step 2: Compute the sum of the square of the x-values.
Step 3: Compute the sum of each x-value multiplied by its corresponding y- value.
Step 4: Calculate the slope of the line using the formula

$$m = \frac{\sum XY - \frac{\sum X \sum Y}{n}}{\sum x^2 - \frac{(\sum X)^2}{n}}$$

Where, n is the total number of data points.
Step 5: Compute the y-intercept of the line by using the formula

$$b = \bar{y} - m\bar{x}$$

Where, x and y are the mean of the x-coordinate and y-coordinate of the data points respectively.
Step 6: Use the slope and the y-intercept to form the equation of the line.

Smooth tube

Table 1 Calculation table for Smooth tube

Re	Nu-exp	Re*Nu-exp	Re^2
4000	30	120 x 10^ 3	16 x 10^ 6
5000	35	175 x 10^ 3	25 x 10^ 6
6000	40	240 x 10^ 3	36 x 10^ 6
7000	45	315 x 10^ 3	49 x 10^ 6
8000	50	400 x 10^ 3	64 x 10^ 6
9000	60	540 x 10^ 3	81 x 10^ 6
∑ Re = 39 x 10^3	∑ Nu-exp = 260	∑ Re*Nu-exp = 1.79 x 10^ 6	∑ Re^2 = 271 x 10^ 6

Substituting table values and find Nu-pred = 5.71 x 10 ^ -3 Re = 6.2183

Threaded Tube

Table 2 Calculation table for Threaded tube

Re	Nu-exp	Re*Nu-exp	Re^2
4000	80	320 x 10^ 3	16 x 10^ 6
5000	95	475 x 10^ 3	25 x 10^ 6
6000	110	660 x 10^ 3	36 x 10^ 6
7000	130	910 x 10^ 3	49 x 10^ 6
8000	155	1240 x 10^ 3	64 x 10^ 6
9000	165	1485 x 10^ 3	81 x 10^ 6
∑ Re = 39 x 10^3	∑ Nu-exp = 735	∑ Re*Nu-exp = 5090 x 10^ 3	∑ Re^2 = 271 x 10^ 6

Nu-pred = 17.8571 x 10 ^ -3 Re = 6.42857

Threaded + Twisted tape

Table 2 Calculation table for Threaded tube

Re	Nu-exp	Re*Nu-exp	Re^2
4000	100	400 x 10^ 3	16 x 10^ 6
5000	115	575 x 10^ 3	25 x 10^ 6
6000	135	810 x 10^ 3	36 x 10^ 6
7000	155	1085 x 10^ 3	49 x 10^ 6
8000	180	1440 x 10^ 3	64 x 10^ 6
9000	200	1800 x 10^ 3	81 x 10^ 6
∑ Re = 39 x 10^3	∑ Nu-exp = 885	∑ Re*Nu-exp = 6110 x 10^ 3	∑ Re^2 = 271 x 10^ 6

Nu-pred = 20.42857 x 10 ^ -3 Re = 14.7142857.

5. EXPERIMENTAL CALCULATIONS

Heat added to water was calculated by,
$Q = mCp\ (Tout - Tin)$

Heat transfer coefficient was calculated from,
$h = q / (Twi - Tb)$
And heat flux was obtained from,
$q = Q / A$ where, $A = \pi\ di\ L$

The bulk temperature was obtained from the average of water inlet and outlet temperatures,
$Tb = (Tin + Tout) / 2$

Tube inner surface temperature was calculated from one dimensional radial conduction equation,
$Twi = Two - [Q \ln(do=di)/2\pi\ kwL]$

Tube outer surface temperature was calculated from the average of six local tube outer surface temperature,
$Two = [Tw_1 + Tw_{2+} Tw_{3+} Tw_{4+} Tw_{5+} Tw_6] / 6$

Experimentally Nusselt number was calculated from,
$Nu = hdi / k$

Theoretical Nusselt number was calculated from Gnielinski, 1976, correlation,
$Nu_{th} = [(f/8)(Re - 1000)Pr] / [1 + 12.7(f/8)^{0.5}(Pr^{2/3} - 1)]$

Where from Petukhov, 1970,
$F_{th} = (0.79 \ln Re - 1.64)^{-2}$

Reynolds no. is calculated by,
$R_{e} = \rho Vd/\mu$ & $Pr = \mu C_p / k$

Mean water velocity was obtained from,
$V = m / A_f$
Flow area was obtained from,
$A_f = [\pi\ di^2] / 4$

Experimentally Friction factor, f can be calculated from,
$f = \Delta P / [(L*\rho*V) / 2di]$

6. RESULT AND DISCUSSION

Fig.3 shows the variation of Nusselt number with Reynolds number in smooth tube, values obtained from theoretical correlation (Genielinski) and two different test tube having internal threading of pitch (p=3.4 mm) and Threading along with twisted tape insertion. It was observed that for all cases, Nusselt number increases with increasing Reynolds number. Also it was observed that for tube with internal threads the heat transfer rate was higher than those for smooth tube.

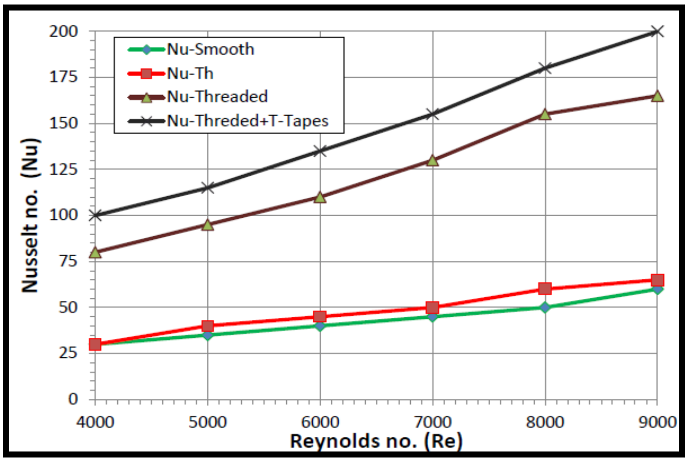

Fig. 3. Variation of Nusselt number with Reynolds number

From the graph it was cleared that the test tube having internal threads along with twisted tape insertion, the heat transfer rate is much higher than those of previous two cases. i.e. (Smooth tube and threaded tube) and values obtained from theoretical correlation (Gnielinski). This is because of, by applying the double passive heat transfer augmentation technique in last case (Threaded + T-tape) it found more scope for heat transfer as compared to previous two cases. In the second case depth provided by test tube having internal threads of pitch (p=3.4 mm) which increases the strength and turbulent intensity of water across the range of Reynolds number. In last case it is advantageous for heat transfer because of more turbulence and swirling is created due to presence of threading and twisted tape together.

Fig. 4 shows the variation of friction factor with Reynolds number for smooth tube, values obtained from theoretical correlation (Petukhov) and test tubes having internal threads. The friction factor for the test tube having internal threads is more than that of smooth tube and, maximum for threaded tube along with twisted tape inert. From the graph it was cleared that as the Reynolds number increases there is decrease in friction factor so we conclude that as velocity

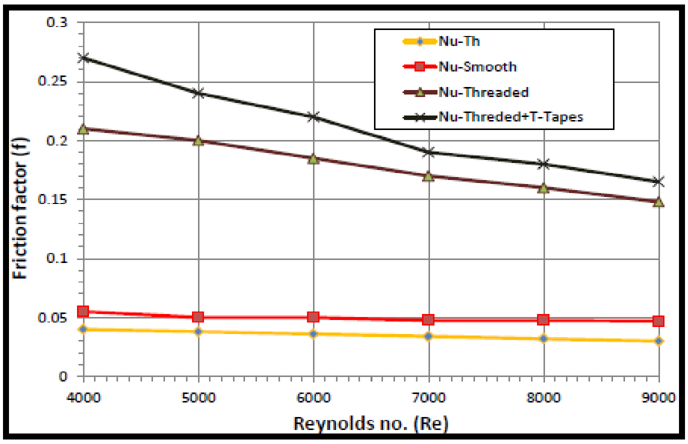

Fig. 4. Variation of Friction factor with Reynolds number

goes on increasing, friction factor is inversely proportional to the velocity. This shows that the turbulence formation advanced due to artificial turbulence exerted by internal threads and flow obstacles like twisted tapes. The friction factor of test tube having threading along with the twisted tape is highest as compared to the other two cases of smooth tube and threaded tube. This is because of, by applying the double passive heat transfer augmentation technique in last case (Threaded + T-tape) it found more scope for heat transfer as compared to previous two cases which create the distinct swirl of flow which causes the enhancement in heat transfer rate.

Fig. 5 shows the variation shows the variation of thermal enhancement factor with Reynolds number. At the same Reynolds number the thermal enhancement factor for test tube having internal threads along with the insertion (Double passive heat transfer augmentation) of twisted tape was found to be greater than those for test tube only having threading. The thermal enhancement factor for all internal threads and tapes inserts tends to decrease with increasing Reynolds number.

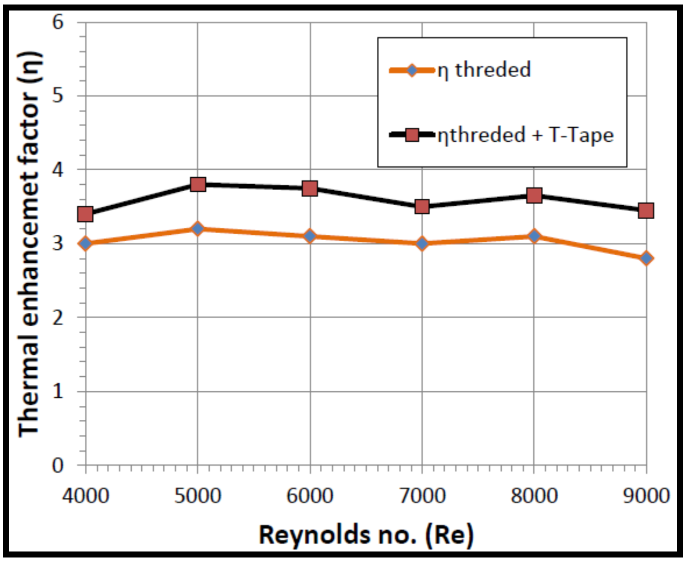

Fig. 5. Variation of Thermal enhancement factor with Reynolds number

7. CONCLUSION

An experimental investigation is carried out under this project to study of effects of surface roughness and insertion of Mild steel twisted tape (double passive augmentation) technique on the various heat transfer properties like heat transfer coefficient, thermal enhancement factor, friction factor are to be analyzed.
The following conclusions drawn after observing graphs.

1. The heat transfer increases with the test tube having internal threading along with the twisted tape insert as compared to smooth tube and the threaded tube. The result shows that heat transfer rate increases with increasing Reynolds number.
2. The heat transfer rate for the case no. 3(test tube having threading along with the twisted tape) is highest. this is only because, by applying double passive augmentation technique, depth provided in the threading and due to insertion of twisted tape, more swirl flow produces which causes more heat to transfer.
3. Friction factor increases for the test tube having internal threads along with twisted tape, compared to other two cases because more swirl flow exerted in the tube having threading along with twisted tape
4. When we compared smooth tube, internal threaded tube and internal threading along with the twisted tape insert, we can conclude that more friction losses will occurred in test tube having threading along with twisted tape , this is due to fact that in threading, obstacles are produces to flow due to double passive augmentation technique.
5. Here we can conclude that, Nusselt no. enhancement in threaded and threaded along with twisted tape is more as compared to enhancement in friction factor. i.e. Rate of increase of Nusselt no. is more than the rate of increase in friction factor. This justify that, we can use the internal threads in circular pipe
6. The performance of copper tube in heat exchanger can be improved by applying double passive augmentation technique which can improve energy efficiency of heat exchanger.

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