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REVIEW OF HEAT TRANSFER AUGMENTATION BY USING TWISTED TAPE INSERT IN LAMINAR REGION

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Abstract: *Heat transfer augmentation techniques are used to increase rate of heat transfer without affecting much on overall performance of system. This report presents the result obtained from experimental investigation of heat transfer and friction factor characteristics in horizontal tube by means of twisted tape inserts of various twist ratios with water and as working fluid. The experiments are conducted in Raynolds number range 1100 to 2500 with twisted tape inserts of different twist ratio(y=H/D) in the range 6.12 to 8.34. The inner tube is made of copper with inner and outer diameter 19.5 mm and 24.5 mm respectively. Twisted tape is made up of stainless steel of 1 mm thickness and 1900 mm length. Hot and cold fluid flow though tube and shell side respectively as working fluid. The results obtained from twisted tape are compared with plain tube results. The experimental data analysis revels that, when we use twisted tape inserts, shows great promise for enhancing heat transfer rate and heat transfer rate is maximum for lower twist ratio(y). The result showed that for twisted tape insert with twist ratio y = 6.12 shows increase in Nusselt number values by 38%,and friction factor by 98.48% as compared to plain tube value with water as working fluid. From performance ratio we can say that twisted tape performs effectively at low Reynolds number range. Finally new generalized correlations function for predicting heat transfer and friction factor for laminar flow of water are proposed with tape inserts*

Keywords: *Heat transfer augmentation, friction factor, twisted tape inserts, twist ratio.*

I. INTRODUCTION

In Industrial Applications, Heat transfer fluid such as water, mineral oil and Ethylene Glycol play an important role. The heat transfer Augmentation with flow of water in circular pipe has been observed; the use of twisted tape inserts for further enhancement is the aim of this study. Shaha and Dutta [1] reported experimental data on twisted tape generated laminar swirl flow friction factor and Nussult number for a large Prandle number (205<Pr< 518) and observed that on the basis of constant pumping power short length twisted tape is good choice because in this case swirl generated by the twisted tape decays slowly down streams which increases the heat transfer coefficient with minimum pressure drop as compared to full length twisted tape. Fig.1 shows the different types of twisted taps. Manglik and Bergles [2] considered twisted tape with twist ratio (3, 4.5 and 6.0) using water (3.5<Pr<6.5) and proposed correlation for Nussult number and friction factor and reported physical description and enhancement mechanism. Loknath [3] reported experimental data on water (240<Re<2300, 2.6<Pr<5.6) of laminar flow through horizontal tube under uniform heat flux condition and fitted with half-length twisted tape. He found that on the basis of unit pumping power and unit pressure drop half-length twisted tape is more efficient than full length tape. Shaha and Chakraborty [4] found that laminar flow of water (145<Re<1480, 4.5<Pr<5.5, tape ratio 1.92<y<5.0) and pressure drop characteristics in a circular tube fitted with regularly spaced, there is drastic reduction in pressure drop corresponding reduction in heat transfer. Thus it appears that on basis of constant pumping power a large number of turn may yield improved thermo hydraulic performance compared with single turn on twisted tape. Royds [5] reported that tube inserted with twisted tape performs better than plain tube and twisted tape with tight twist ratio provides better heat transfer at a cost of increase in pressure drop for low Prandle number fluid. This is due to the small thickness of thermal boundary layer for low Pradle number fluid and tighter twist ratio disturb entire thermal boundary layer thereby increasing heat transfer with increase in pressure drop. Date [6] reported that friction and Nu for water flow in tube containing twisted tape deviate 30 percent than experiment with plain tube. Klaczak [7] found usefulness of short length twisted tape with water (1300<Re <8000) than full length twisted tape. Al-fahed et al. [8] found that there is an optimum tape width depending upon twist ratio and Re for best thermodynamic characteristics for full length tape with water. Manglik and Bergles [9] developed correlation for both lamina and turbulent flow (3.5<Pr<6.5) with tape but shows that correlation for laminar turbulent transition need to be developed with water. For more details readers can referee Waghole et al. [10]. Several investigations have been carried out to study the effect of turbulators (turbulent promoters)with different geometries on thermal behaviors in the heat exchanger, for example twisted-tapes [11,12], wirecoils [13,14], dimpled or grooved tubes [15,16], winglet/fins [17,18], and combined turbulators. However, twisted tapes as one of passive turbulators have been applied extensively to enhance convection heat transfer in heat exchanger systems due to the need for finding the way to reduce the size and cost of those systems. For decades, the heat transfer enhancement by twisted-tape insert has been widely investigated both experimentally and numerically. Krishna et al. [19] experimentally investigated the heat transfer characteristics in a circular tube fitted with straight full twist insert with different spacer distances. Influence of the tube equipped with the short-length twisted tape on Nu, f and thermal performance characteristics for several tape-length ratioswas examined by Eiamsa-ard et al. [20]. The effect of twisted tape consisting wire-nails and plain twisted tapes with three different twist ratios fitted in a heat exchanger pipe using water as the test fluid on thermal characteristics was studied experimentally by Murugesan et al. [21]. Liao and Xin [22] reported the heat transfer behaviors in a tube with three-dimensional internal extended surfaces and twisted-tape inserts with various working fluids. Chiu and Jang [23] presented the experimental and numerical analyses on thermal–hydraulic characteristics of air flow inside a circular tube with 5 different tube inserts; longitudinal strip inserts both with/without holes and twisted-tape inserts with three different twist angles for inlet velocity ranging from 3 to 18 m·s−1. Eiamsa-ard and Promvonge [24] conducted an experimental study on turbulent flow and heat transfer characteristics in a tube equipped with two types of twisted tapes: (1) typical twisted tapes and (2) alternate clockwise and counterclockwise twisted-tapes. Nine different clockwise and counterclockwise twisted-tapes were tested in that work and included the tapes with three twist-ratios and three twist-angles. The experiments were performed for Reynolds number of 3000 to 27000 using water as working fluid. The twin and triple twisted tapes used to generate twin and triple swirl flows in a circular tube were reported by Chang et al. [25].

II. EXPERIMENTAL ANALYSIS

2.1 Experimental Setup

Actual image of experimental setup is shown below.

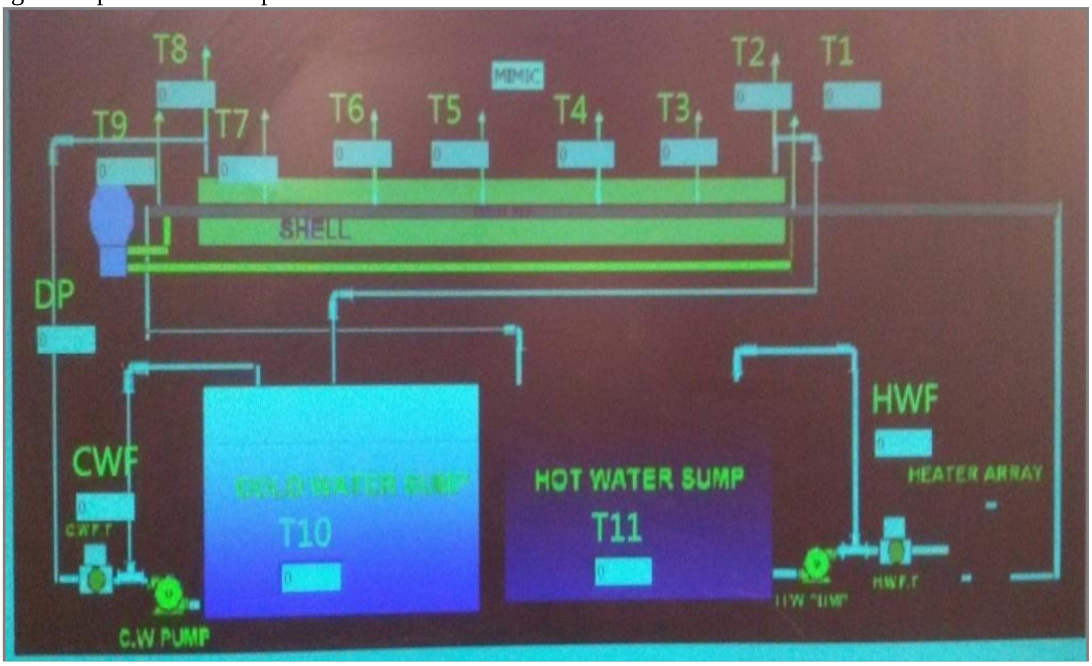

Figure 2.1: schematic diagram of experimental setup

2.2 Experimental Approach

The experimental set up consist of the testing section, heat transfer fluid tank, pump, heater, temperature control system, data acquisition systems, valves, pipes etc. The Heat transfer fluid (water) is pumped through the flow meter and heaters in series enter in heat exchanger tube and continued to be heated to the required experimental temperature. The water is heated by six electrical heaters in series. The heat flux on testing section can be changed to the required value by changing the number of electrical heater in working. Figure 2.1 shows schematic diagram of experimental set up. The analysis of Nusselt number versus Reynolds number and other parameter for experimental data is carried out. As per experimental data a generalized correlation function for laminar flow heat transfer and friction factor is investigated. The experimental procedure is as follows: At first the fluid pump is switched on and fluid is allowed to flow for few minutes. Then the electrical heaters are switched on. The number of electric heaters in working is adjusted as per requirement. The flow rate of fluid through the shell is set to desired value and kept constant with the help of flow control valve and flow transmitters. Flow transmitter, pressure transmitters and temperature transmitters are connected to data acquisition system. First the variations in wall temperature at all location are observed until constant value is attained at different locations. Then the outlet bulk temperature of fluid is monitored. The steady state condition is attained when outlet fluid temperature did not fluctuate over some duration of time. At the steady state condition thermocouple readings are monitored with help of data acquisition system. The pressure difference between two ends of test section is recorded automatically. The fluid flow rate is changed with the help of flow control valve after each experimental run, hence changed the Reynolds number. Number of electrical heater in working are kept constant so that uniform temperature can be obtained. Different data are taken in similar way in each experimental run at steady state condition.

III. RESULTS & DISCUSSION

3.1 Validation of Experimental Setup

First of all the result obtained from experiments on heat transfer and friction factor characteristics in plain tube are validated in terms of Nusselt number and friction factor with water as working fluid. Figure 3.1 shows graph of friction factor versus Reynolds number for plain tube. Nusselt number and friction factor obtained from present plain tube experiment are compared with those from proposed correlations of Dittus and Bolter for the Nusselt Number and proposed correlation by Fanning for friction factor. The data obtain from the experiments for plain tube is reasonable agreement with literatures available for laminar flow heat transfer. This result revealed the accuracy of experimental setup and measurement technique.

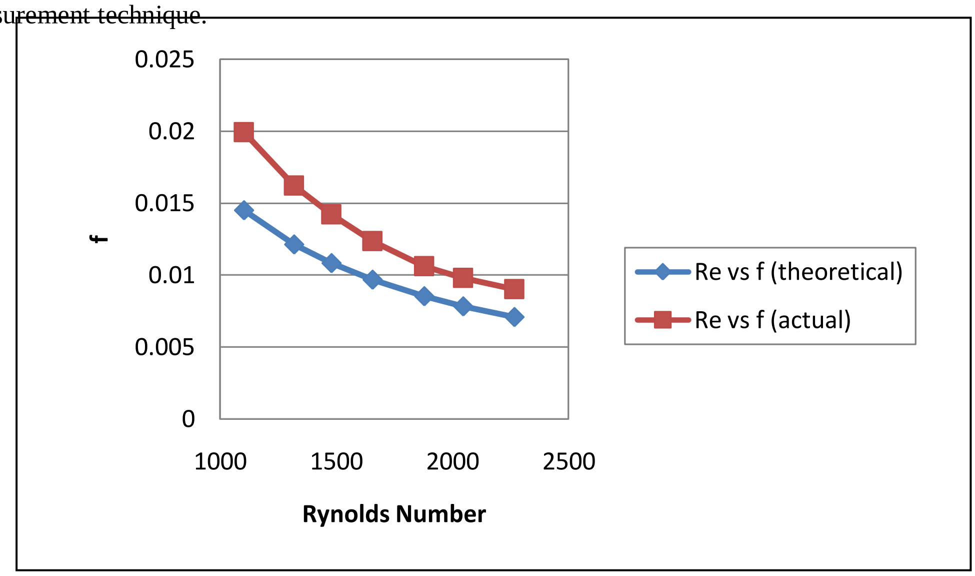

Figure 3.1: Experimental and theoretical friction factor for plain tube

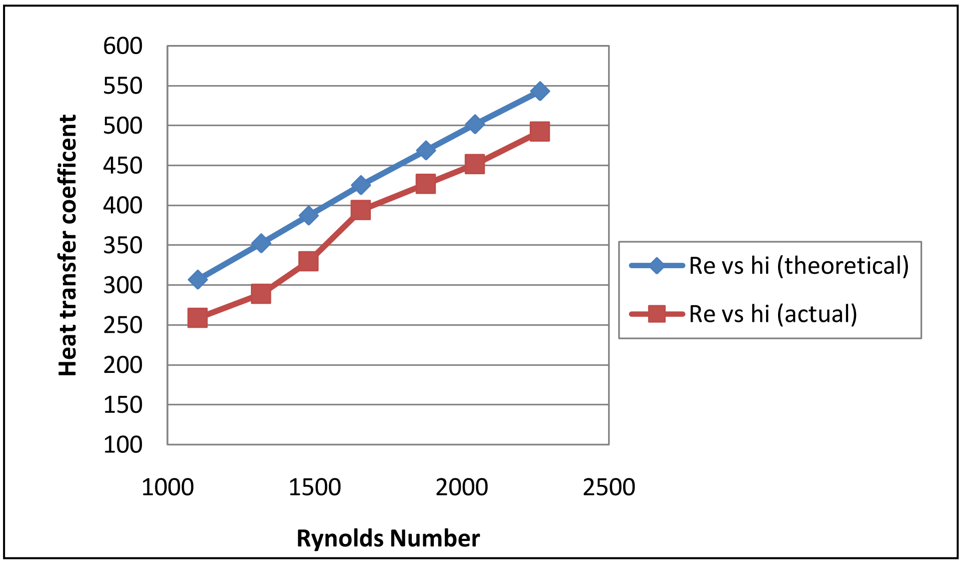

Figure 3.2: Experimental and theoretical Nusselt number for plain tube

3.2 Friction Factor for Augmented Tube

Figure 3.3 shows that variation of friction factor vs. Reynolds Number for tube fitted with twisted tape inserts of various twist ratio(y = 6.12, 7.23, 8.34). The friction factor for tube with twisted tape higher than for plain tube and decreases with increase in Reynolds number for given twist ratio. From figure 3.3 it could be clear that the friction factor is in similar trend for both plain tube and tube with twisted tape insert. The friction factor for tube with twisted tape is higher than plain tube because of large contact surface area and pressure generation due to reducesed flow area. Friction factor is maximum for twisted tape insert with twist ratio 6.12 and minimum for twist ratio 8.34. Friction factor increases with decrease in twist ratio because intensity of swirl generation increases.

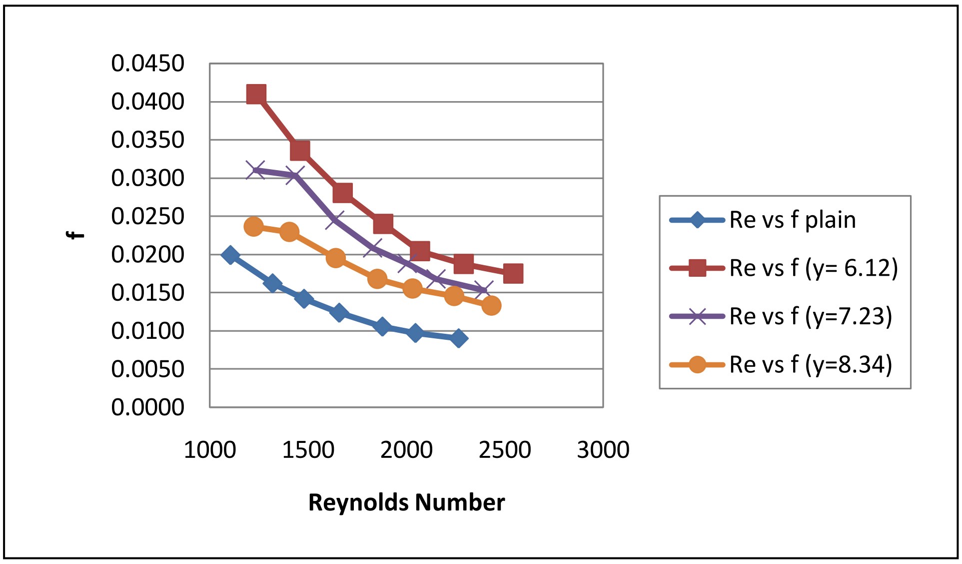

Figure 3.3: Friction factor versus Reynolds number for augmented tube

3.3 Nusselt Number for Augmented Tube

Figure 3.4 shows variation of Nusselt number with Reynolds number for plain tube and tube fitted with twisted tape insert of various twist ratio (y=6.12, 7.23, 8.34).

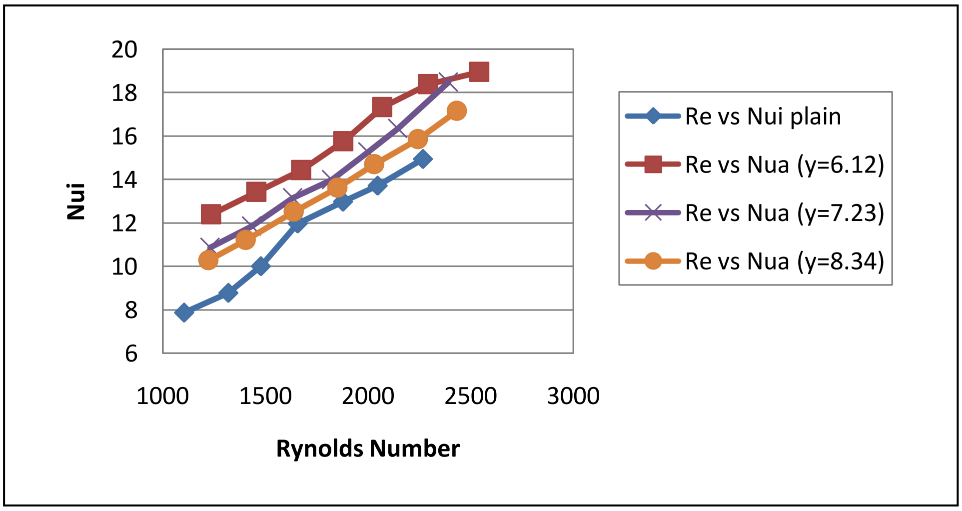

Figure 3.4: Nusselt number versus Reynolds number for augmented tube

From figure 3.4 it is clear that Nusselt number for tube with twisted tape insert is higher than Nusselt number for plain tube for given Reynolds number due to swirl flow generated by tape insert. As twist ratio decreases, a higher degree of swirl is generated which increases turbulence and hence the Nusselt number increases as twist ratio decreases. From figure it is clear that, much higher improvement in Nusselt number is observed for twisted tape with twist ratio 6.12 because it increases secondary flow generation which disturbs the entire thermal boundary layer.

3.4 Performance Ratio R1 and R3 for Augmented Tube

Figure 3.5 shows plot for performance ratio R1versus Reynolds Number (based on constant flow rate) for different tapes inserts. Performance ratio R1 evaluates effectiveness of tube inserts on equal flow rate basis.

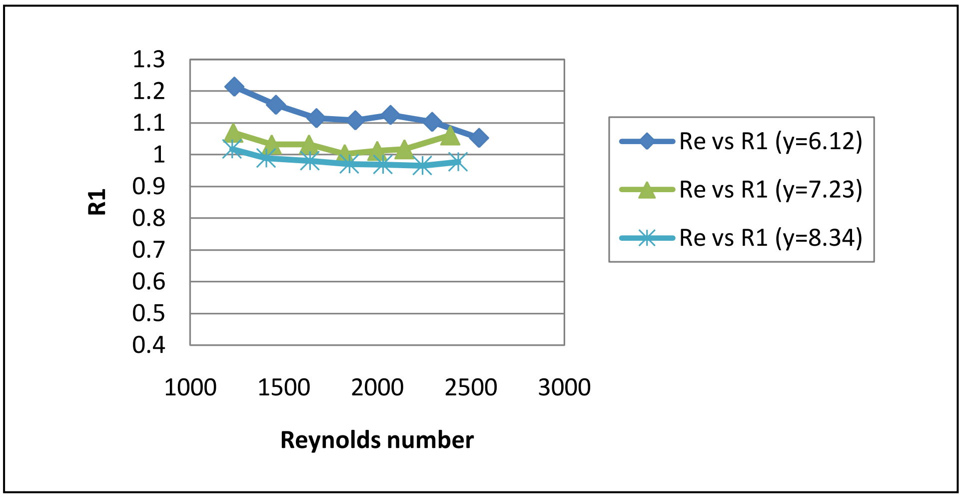

Figure 3.5: Performance ratio R1 versus Reynolds number for augmented tube

It is applicable for situation where heat transfer enhancement is more important than pressure drop. From figure 3.5 it could be seen that maximum R1 for given condition is observed for twist ratio 6.12 then deceases as twist ratio increases. Therefore on the basis of performance ratio R1 twisted tape with twist ratio 6.12 is best suitable for enhancing rate of heat transfer if increase in pressure drop is not important. Maximum value of R1 is observed for lowest Reynolds number and then decreases as Reynolds number increases. When we use twisted tape in turbulent flow to enhance secondary flow, the effect is not that high because the turbulence is already high because of high flow rate. This indicates that such tapes are much effective at lower Reynolds number. Average value of performance ratio R1 and R3 for different twist ratio are listed in table 3.1.

Table 3.1: Performance ratio R1 and R3 for augmented tube

Twist Ratio (y=H/D)	Average value of R1	Average value of R3
6.12	1.1251	0.7585
7.23	1.0324	0.7464
8.34	0.9812	0.7688

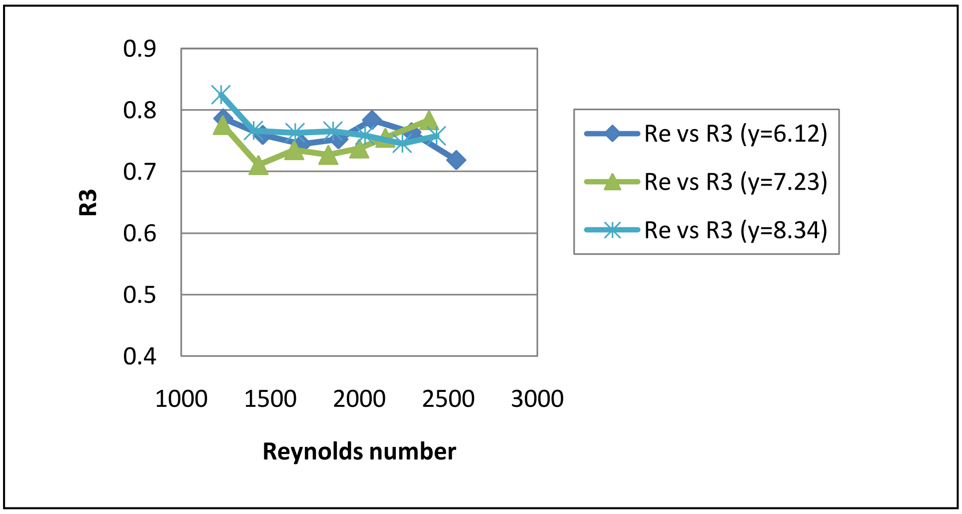

Figure 3.6: Performance ratio R3 versus Reynolds number for augmented tube

Performance ratio R3 is thermo-hydraulic assessment of tube insert. From figure 3.6 it can be observed that maximum value of R3 is observed for twist ratio 8.34, but value of R3 for twist ratio 8.34 is not much higher than twist ratio 6.12. Therefore on the basis of performance ratio R1 and R3 we can say that twisted tape with twist ratio 6.12 is found to be best.

IV. EMPIRICAL CORRELATION FOR FRICTION FACTOR AND NUSSELT NUMBER

4.1 Friction Factor Correlation

Based on experimental data, empirical correlation have been proposed for predicting friction factor and Nusselt number from value of Reynolds number for different twist ratio

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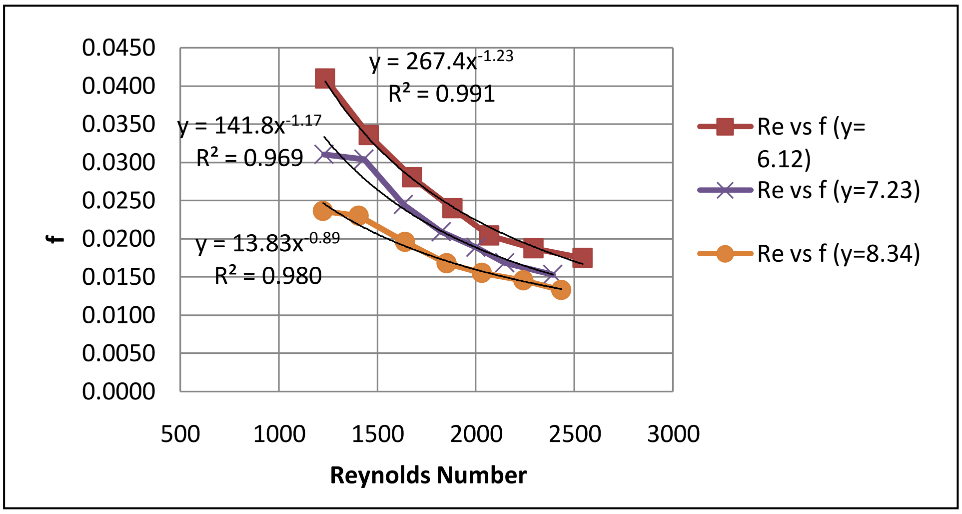

Figure 4.1: Friction Factor correlation for twisted tape inserts

Correlations for predicting friction factor have been proposed for twisted tapes inserts in table 4.1.

Table 4.1: Friction factor correlation for twisted tape inserts

Twist ratio	Friction factor correlation	R^2 value	Accuracy of proposed correlation
6.12	$f_a = 267.4\ Re^{-1.23}$ (4.1)	0.991	Maximum deviation of 9.2565% from actual value
7.23	$f_a = 142\ Re^{-1.17}$ (4.2)	0.969	Maximum deviation of 10.822% from actual value
8.34	$f_a = 13.83\ Re^{-0.89}$ (4.3)	0.980	Maximum deviation of 4.522% from actual value

4.2 Nsselt Number Correlation

Nusselt number varies with Reynold number and prandtl number. The Nusselt number can beco related to Reynolds number using the following equation.

$Nu_a \ \alpha \ Re \times Pr^{0.3}$ (4.4)

$Nu_a / Pr^{0.3} \ \alpha \ Re$ (4.5)

Figure 4.2 is graphical plot of $Nu_a / Pr^{0.3}$ α Re for twisted tape inserts of different twist ratio. The fit is found to be the best possible approximation for the data

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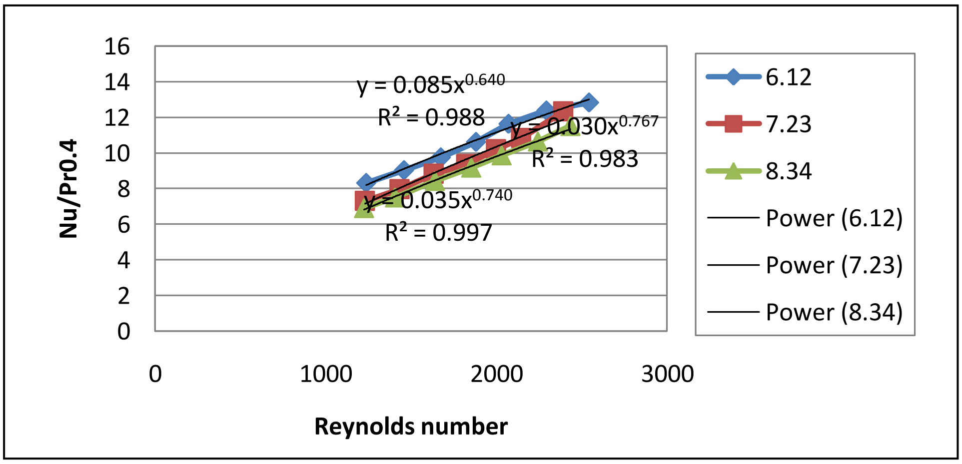

Figure 4.2: Nsselt number Correlation for twisted tape inserts

Table 4.2: Nusselt number correlation for twisted tape inserts

Twist ratio	Nusselt number correlation	R^2
6.12	$Nu=0.085\ Re^{0.640}\ Pr^{0.3}$ (4.6)	0.988
7.23	$Nu=0.030\ Re^{0.640}\ Pr^{0.3}$ (4.7)	0.983
8.34	$Nu=0.035\ Re^{0.640}\ Pr^{0.3}$ (4.8)	0.997

V. CONCLUSION

An experimental study is conducted to investigate heat transfer performance by means of twisted tape insert. The study conducted revels that use of twisted tape insert cause an increase in rate of heat transfer at cost of increase in pressure drop. From experimental result we can conclude that

1. Maximum increase in Nusselt number and friction factor for twisted tape with y=8.34 was found to be 18.76% and 36.36% respectively.
2. Maximum increase in Nusselt number and friction factor for twisted tape with y=7.23 was found to be 24.55% and 70.45% respectively.
3. Maximum increase in Nusselt number and friction factor for twisted tape with y=6.12 was found to be 37.90% and 98.48% respectively
4. From all the experimental result obtained we can conclude that enhancement in heat transfer is more with less twist ratio.
5. On the basis of performance ratio, twisted tape with y=6.12 gives best performance as compared to other twist ratio.

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