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Experimental Study of Heat Transfer Enhancement by Turbulence Generator in Side Pipe

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Abstract. The enhancement of heat transfer exchangers is an important matter of concern for achieving more efficient thermal energy conversion systems. The use of modified twisted tape (TT) inserts as a passive heat transfer augmentation technique is an efficient way of improving heat transfer. Twisted tape insert is one of the passive heat transfer enhancement techniques that are widely used in various applications for heat transfer, such as air conditioning and cooling systems, heat recovery systems, Processes, procedures for food and milk, plants for chemical processes. To increase the heat transfer rate of the tubular heat exchanger, in this study a small-scale experimental setup was performed. The heat improvement of heat exchanger is done using twisted tape inserts with twist ratio (y=5.5). The effects of two dimensional parameters namely Nusselt number & friction factor on tubular heat exchanger effectiveness are studied. The turbulent flow was generated by the insertion into the test pipe of the twisted tape inserts, producing a high turbulence rate in the pipe, resulting in an increase in turbulence. And hence enhancement of heat transfer and drop in pressure. The length and width of insert was 1000 mm and 21.5 mm respectively. The diameter of the test pipe outside & inside is 23 mm and 22 mm respectively. The length of test section is 2000 mm. The study is carried out for the Reynold number regime (500-6500). The results show that The maximum enhancement for Nu number at Re 500 was 32% that of the plain tube.

Keywords: Thermal Performance Coefficient, Turbulent Flow, Heat Transfer Enhancement, Nusselt Number, Friction Factor.

1. INTRODUCTION

The techniques used to increase heat transfer refer to techniques that enhance the thermo-hydraulic performance of the heat exchanger. Those methods can usually be classified into three classes, they are:

- Passive techniques: For surface or geometrical modifications of the flow channel, these types of methods are often used. These modifications are represented by adding additional devices or by inserting specific forms. Passive techniques show more advantages than the active technique, because the passive technique requires no external power or direct input.

- Active techniques: These techniques are more complicated from the point of view of use and design, as the system needs some external power input to induce the desired flow change and increase the heat transfer rate.
- Compound techniques: The compound technique is the technique that uses more than one of the techniques presented together to improve the performance of HT in heat exchangers and the thermo-hydraulic efficiency.

Heat exchanger is an apparatus that facilitates heat transfer between two or more fluids. In several industries, it is widely used, such as thermal power plants, chemical processing plants, air conditioning equipment. Operated under swirl flow conditions where their energy transfer rate performance is high compared to laminar flow due to the high swirl flow rate. A high turbulence intensity will also improve the rapid mixing of fluid properties in turbulent flow, and mixing can help increase the effective efficiency of fluid properties. Heat transfer area which results in higher heat transfer rates. In past year researchers have carried out many studies to investigate the flow mechanism and pipe flow heat transfer phenomena integrated with both conventional and modified twisted tapes.

Hasanpour et al. [1] performance intensification and pressure drop examined experimentally and analytically through a wavy pipe heat exchanger with the conventional and three twist ratios of modified (U-cut, perforated and V-cut) twisted tapes in turbulent mode (Reynold number, 5000 to 15000). The results showed maximum heat transfer performance for modified twisted tapes based on V-cut while the minimum pressure dropped attributed to the modified perforated type insert twisted tape. Additionally, maximum performance factor for V-cut inserts at the lowest twist ratio, 1.50 was recorded.

Jedsadaratanachai, W. and A. Boonloi [2] conducted a numerical study on the influence of a twisted ratio on HT and flow thermal performance within a single twisted tape circle, resulting in HT in a tube with TT being more effective than that without TT and Re number decreasing with an increase in twist ratio. Nakhchi and Esfahani [3] inspected thermal-hydraulic behavior of the heat exchanger of a circular tube fitted with single-cut rectangular and twisted double-cut tape inserts in the regime of turbulent flow. The geometries of cuts are rectangular with different cut ratios $0.25<b/w<0.75$, they revealed twisted band yield greater turbulence than single-cut band, and the Nusselt number increased by a maximum of 33.26 percent changes in the cut ratio were reported from 0.25 to 0.75.

Jafar, K.S. and B. Sivaraman [4] studied the experimental work on the thermal performance of parabolic solar collectors includes a water heater system filled with nail twisted tape absorber. They observed that compared to plain twisted tape, Nu number improved with nail twisted tape and maximum collector performance efficiency was with a lower twist ratio. Saysroy and Eiamsa-ard [5] studied numerical analysis of the thermal and fluid behaviors of the tubes with multichannel twisted tapes has been investigated under constant wall temperature condition. The multi-channel twisted tapes were arranged periodically in the tubes. Twist ratio of tape was varied from 2.0 to 4.0 and channel number of tape number of channel was varied from 2 to 8 . The study was carried out in both laminar and turbulent flow regions ($800 \leq Re \leq 2000$ and $5000 \leq Re \leq 15{,}000$) using water as the working fluid. Their findings indicated the number of Nusselt increase in flow with higher channel number and lower twist ratio for low to high numbers of Reynolds.

Al-Amin et al.[6] this research uses a rotating TT insert to analyze the effect on the heat transfer coefficient, heat transfer rate and heat enhancement efficiency. The findings suggest that at a higher flow rate and RPM, this amount of Nusselt should have increased. Tamna et al. [7] studied experimental work on heat transfer enhancement in a round tube by insertion of double twisted tapes in common with 30° V-shaped ribs has been conducted. Air as the test fluid flowed through the test tube having a constant wall heat-flux with Reynolds number (Re) from 5300 to 24,000. The combined vortex generators called V-ribbed twisted tape were obtained by incorporating V-shaped ribs into the edges of double cut-twisted tapes having a similar twist ratio of 4 . Results revealed Important improvement in thermal and Nusselt performance of Tubular heat exchangers compared to TT with No Ripple, Where the maximum thermal enhancement factor is about 1.4 for the V-ribbed twisted tape but is around 1.09 for the twisted tape with no rib. Dhumal et al. [8] focused primarily on the TT inserts with different twisting ratios and pitches and their influence on the Re number 7500-13000.

Results showed that increasing the twisting ratio led to a reduction in the number of Nu and the pressure drop. Based on the above literature review, different experimental and numerical methods were investigated to improve the quality of the heat transfer technique by means of a pipe fitted with several types of inserts. Current research to perform experimental work using circular pipe with twisted tape (TT) insert to examine the improvement of heat transfer in a circular pipe flow.

2. EXPERIMENTAL WORK

2.1 Experimental Setup

The water pump unit was firstly adapted with the test pipe and then connected at supply side including an orifice provided for measuring the water flow inside the pipe. A suitable heater was mounted around the test section of the pipe. Six thermocouples were used to measure the temperature of the water along the pipe’s testing section. Four of them were inserted inside the pipe test section and the rest were mounted within the water stream at the entry and exit points. The heater was connected to a power supply unit to provide the required heating energy of flux. The clamp meter was used to measure the provided voltage and current. It is important to mention that not all the generated heat has been used to heat the water, but some amount of it. The pipe wall temperature within the test section was measured using a temperature indicator. The test section outer surface was completely insulated in order to ensure minimum value of the heat loss out to the surrounding. There is two gages pressure at outlet and the inlet of test section for measuring the drop in the pressure as shown in the figures 1,2.

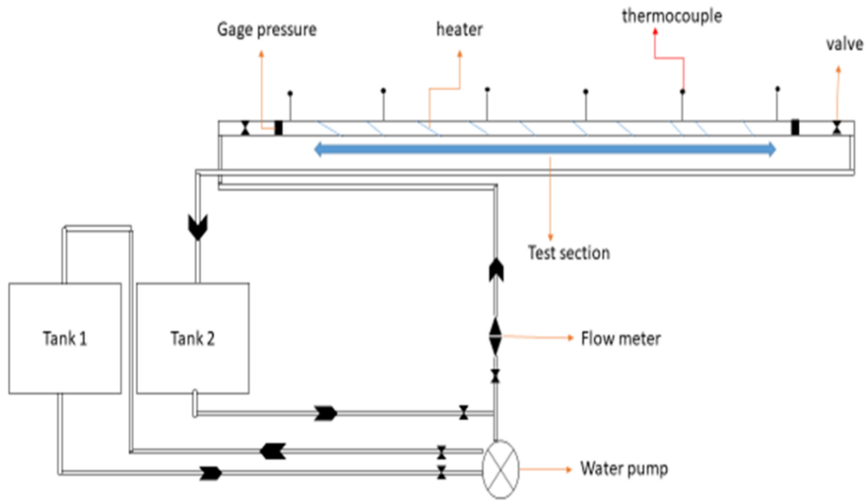

Figure 1. The Schematic Diagram of the Experiment.

Figure 2. Photograph of the Experimental Device.

1. **Variable Voltage**
2. **Flowmeter**
3. **Water Pump**
4. **Heater,**
5. **Thermocouple**
6. **Tank 1**
7. **Tank 2**
8. **Gauge Pressure**

2.2 Procedure

After the water pump started, the valve for controlling the flow operated to find the required indicator on flow meter, that directly connected to inlet gage pressure and pipe heat exchanger to get the desired Re. Next, a constant value of the heat flux was applied to the test section by controlling the current that supplied to the electrical heating coil. This coil is wounded all over the test section. The electrical power can be controlled by regulating the variable voltage. The thermocouples readings were tracked every 5 min. until we obtain the steady state condition. Once we get this state, the surface, outlet, and inlet temperatures are recorded. The experiment was done out at several values of the Re (500-6500). The experiment was initially performed for tube of the plain geometry. Then it performed for twist tape when TT= 5.5 added alternately for the same flow conditions. The insert was taken in and axially inserted by one end into the test section. The twisted tape was carefully inserted inside the test section to ensure no distortion or scratching occur.

Twisted tape inserts, A twisted tape is a twisted metal strip formed by a suitable technique to obtain the necessary shape and dimensions inserted along the fluid flow to improve the heat transfer (HT). With lower frictional factor it can increase the HT rates. The use of this strip inside the tubes provides a simple passive technique for enhancing convection HT by inducing swirls within the heavy fluid flow, which in turn causes disturbance in the boundary layer on the inner surface of the tube due to rapid variations in the surface geometry. The twist of the tape causes a tangential velocity component. Hence, the speed of the flow is increased, particularly near the wall. The improvement in heat transfer is a result of increased shear stress on the wall and secondary flow mixing. Figure 3 explain the parameters of twisted tape insert.

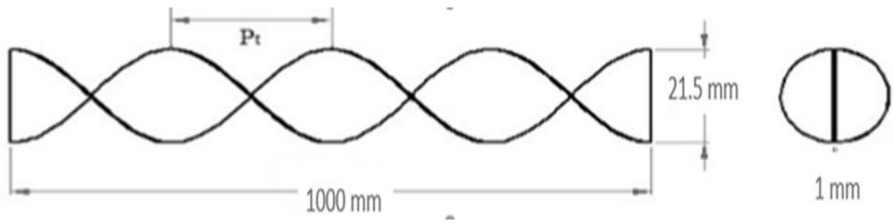

Figure 3. Twisted Tape Insert

2.2 Calculation Methodology

In the present work the water used as the working fluid is flowed through a tube with uniform heat-flux and isolated tube. The heat transferred to the water at a steady state is assumed to be equal to the transfer of convection heat from the test section to the water at a steady state that is to be expressed as:[9]

$$q_{Convection} = q_{water} \quad (1)$$

$$h_{exp} A \Delta T = m^{\cdot} cp_w \Delta T$$

$$h_{exp} \mathrm{A}(T_S - T_b) = m^{\cdot} cp_w (T_o - T_i)$$

$$h_{exp} = \frac{m^{\cdot} cp_w (T_o - T_i)}{A(T_S - T_b)} \quad (2)$$

Where:

T_s is average surface temperature

$$T_S = \frac{T_2 + T_3 + T_4 + T_5}{4} \quad (3)$$

And T_b is the average bulk temperature

$$T_b = \frac{T_1 + T_6}{2} \quad (4)$$

$$Nu_{exp} = \frac{h_{exp}\ D}{K_w} \quad (5)$$

-Experimental friction factor:

$$f_{exp} = \frac{2\ \Delta P\ D}{\rho L\ V^2} \quad (6)$$

Where f_{exp} is the experimental friction factor, (Δp) is the pressure drop, (D) is the inner diameter of pipe,(ρ) is the density of water, (L) the length of pipe, (V) the velocity of water

-Thermal performance factor was calculated from:

$$\eta = \frac{\frac{\mathrm{Nu}}{\mathrm{Nup}}}{(\frac{\mathrm{f}}{\mathrm{fp}})^{\frac{1}{3}}} \quad (7)$$

Where Nu is the Nusslet number for twisted tape and Nup is the Nusslet number for plain pipe.
f is the friction factor for twisted tape and fp is the friction factor for plain pipe.

For plain pipe theoretical Nu express as:

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$$Nu = 0.023 \times Re^{0.8} \times Pr^{1/3} \quad (8)$$

And theoretical friction factor expresses as:

$$f = 0.046 \times Re^{-0.2} \quad (9)$$

2.4 Validation Test

The number of Nusselt determined from experimental data are compared with the values obtained for the Nusselt number from the correlations of Dittus-Boelter as show in figure 4.[9]

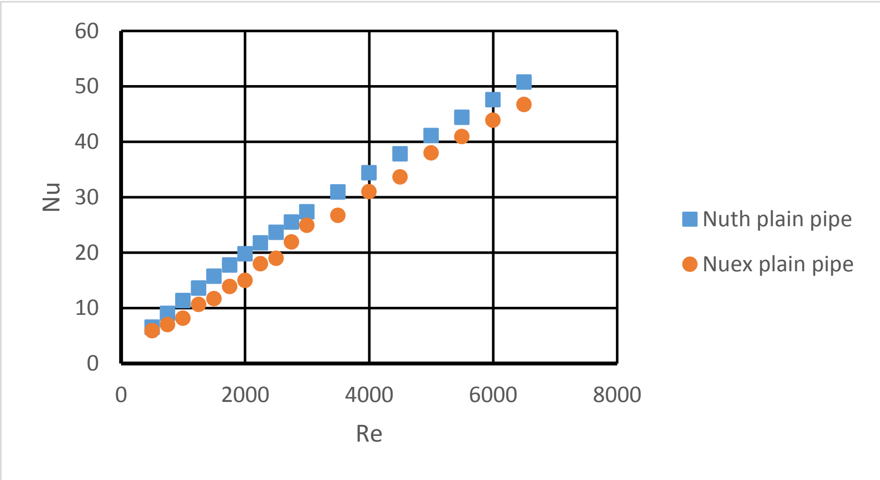

Figure 4. Comparison of Nusselt Number with Reynolds Number.

3. RESULTS AND DISCUSSION

3.1. Results

In the present work experimental research on laminar and turbulent flow heat transfer enhancement for water inside the horizontal tube in the presence of twisted tape insert with twisted ratio are done. Tables 1,2 represent the results of the experimental work.

Table 1. Experimental Result for Plain Tube

Re	V(m/s)	$m°$(kg/s)	Ts	Tb	Nupp	fpp
500	0.023	0.0088	97.6	36	5.89	0.01052
750	0.034	0.013	97.3	35	6.989	0.01017
1000	0.046	0.0175	96.86	32	8.159	0.00964
1250	0.057	0.0218	96.37	29	10.65	0.009381
1500	0.068	0.026	96.198	28	11.66	0.009212
1750	0.08	0.03	95.1	27	13.85	0.009042
2000	0.091	0.034	93.8	25.5	14.99	0.008511
2250	0.102	0.039	90.762	24	17.986	0.008333
2500	0.1143	0.043	90.54	22.7	18.9492	0.0082054
2750	0.125	0.047	83.681	21.3	21.937	0.007741
3000	0.137	0.0521	80.34	21.1	24.9165	0.007551
3500	0.16	0.06	83.8	20.5	26.7284	0.0072285
4000	0.1829	0.069	81.93	20.1	30.994	0.007004
4500	0.205	0.0781	82.75	19.8	33.6289	0.0066486
5000	0.228	0.0869	80.98	19.5	37.9976	0.00648659
5500	0.2629	0.0955	81.5	19.3	40.9356	0.0060276
6000	0.274	0.1043	82.33	19.2	43.8632	0.005375
6500	0.282	0.1077	78.6	19	46.739	0.005197

Table 2. Experimental Result for Twisted Ratio (y = 5.5)

Re	V(m/s)	$m°$(kg/s)	Ts	Tb	Nu y=5.5	f y=5.5
500	0.023	0.0088	54.625	33	8.72611	0.04708675
750	0.034	0.013	50.558	31	12.8311	0.035068
1000	0.046	0.0175	44.4	28	17.1595009	0.0266674
1250	0.057	0.0218	43.9	27	20.382	0.0230867
1500	0.068	0.026	42.05	25.1	23.151	0.019945
1750	0.08	0.03	41.86	24.6	25.322	0.01704
2000	0.091	0.034	41.13	24.5	27.9548	0.0160832
2250	0.102	0.039	42.46	23.4	30.735	0.0125104
2500	0.1143	0.043	42.38	22.2	31.99	0.011053
2750	0.125	0.047	41.2	22	34.8	0.010034
3000	0.137	0.0521	42.57	21.9	36.29	0.009085
3500	0.16	0.06	45.3	21.4	38.5	0.007199
4000	0.1829	0.069	42.4	20.5	45.73	0.006198
4500	0.205	0.0781	44.30	20	47.79	0.006186
5000	0.228	0.0869	44.709	19.7	51.906	0.006166
5500	0.2629	0.0955	47.38	19.4	53.062	0.006124
6000	0.274	0.1043	48.49	19	55.94	0.00609
6500	0.282	0.1077	45.45	18.9	59.88	0.00589

3.2. Discussion

Figure 5 represents an increase in the number of Nusselt with an increase in the number of Reynolds in the pipe flow with twist ratio TT (y=5,5). notable improvement is therefore observed in the rate of heat

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transfer with an increase of Re from 500 to 6500 due to the increase in swirl flow intensity and heat convection in the turbulent flow regime under consideration. This behavior can be attributed by the good turbulence developed on the side of water when the twisted ratio is 5.5. That, in turns increases the capacity of transferred heat for the water and that increases Nu.

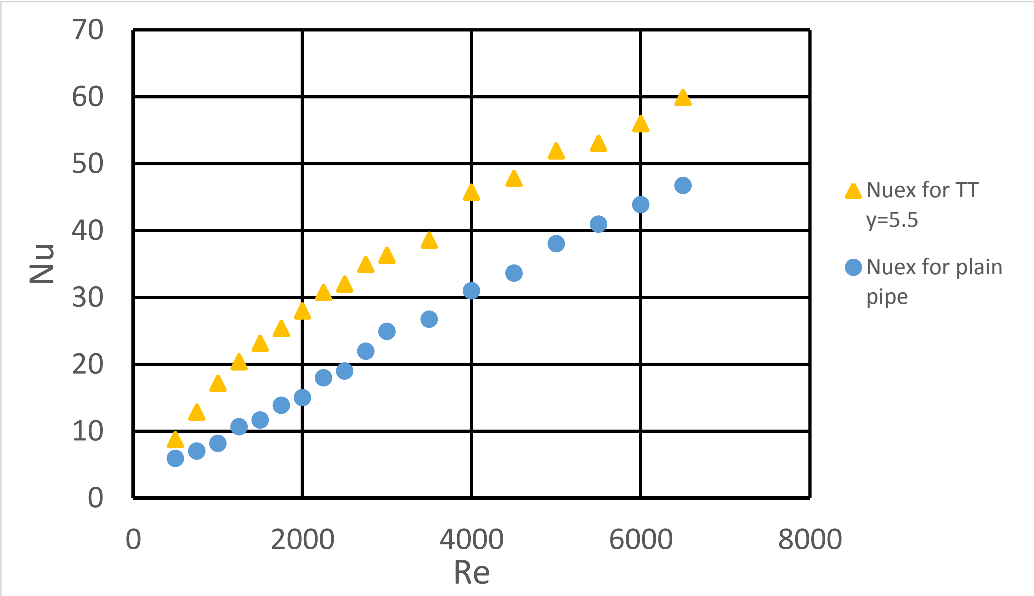

Figure 5. Experimental Nu Number with Re

Figure 6 shows the variation of friction factor with Reynolds number for insert in comparison to plain pipe. It is seen that the value of friction factor decrease in all cases with increasing number of Re number. Also observed to be highest friction factor for twisted tape of (y=5.5). This might be because of the highest intrusion caused flow of water. This is due to the resistance to the flow and turbulence caused by the higher velocity of the fluid flow. The friction factor is directly related to the pressure drop of a system therefore; high pumping power is required to run the system at a high frictional factor.

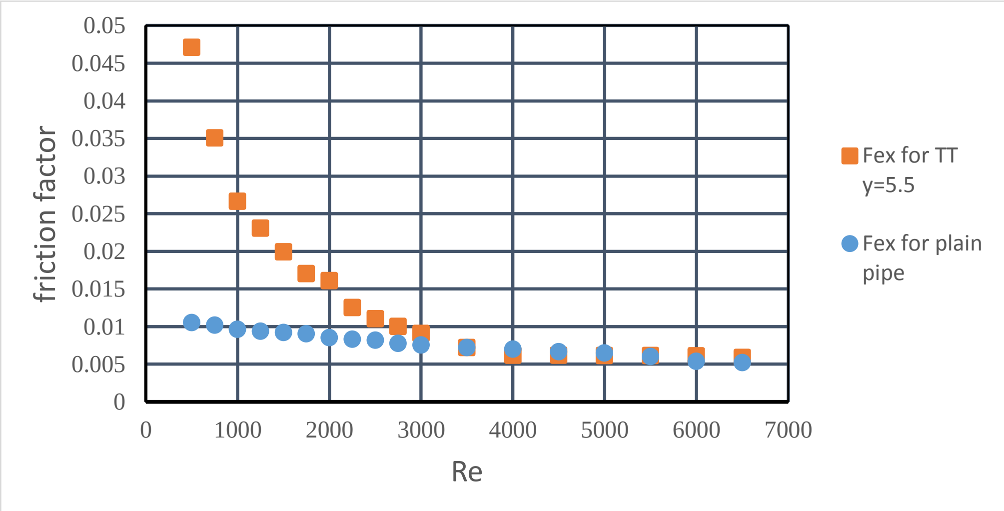

Figure 6. Experimental Frictional Factor and Re

Figure 7 shows that at lower Reynolds number **η** is higher being 1.52 maximum for Re 500 and TT with twist ratio (y=5.5). Generally, the factor of thermal performance more than unity demonstrating the domination of heat enhancement influence over the frictional increasing effect arising from the presence of tabulators and conversely is also right.

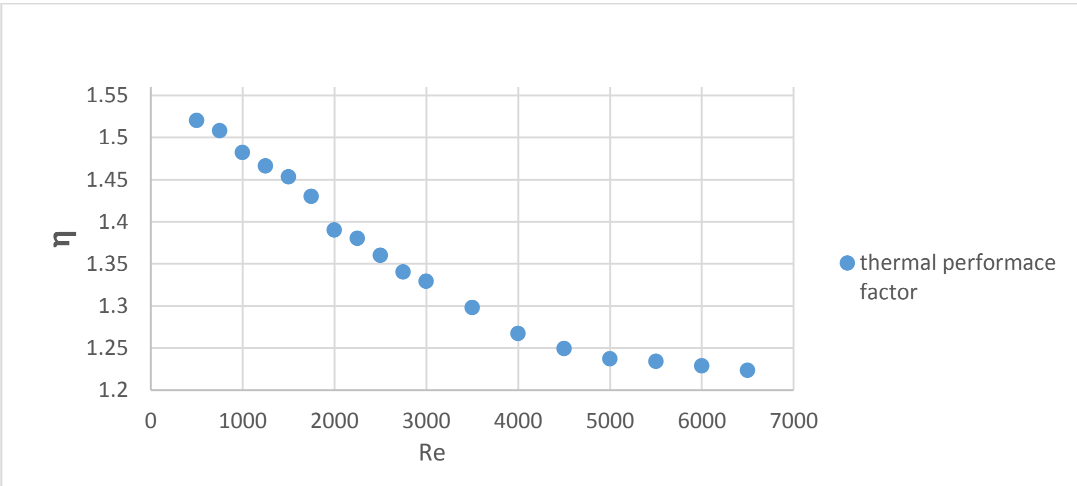

Figure 7. Thermal performance Factor and Re

4. CONCLUSIONS

The results of this experimental research can be concluded as follows:

- The heat transfer rate (Nu) increased significantly with the addition of TT of (y=5.5) against the Reynolds number. The maximum enhancement for Nu number at Re 500 was 32% that of the plain tube.

- Fluid flow characteristics for TT with (y=5.5) assessed as a friction factor, which tends to decrease with increasing Re.
- The thermal performance factor is obtained higher than unit (1.52 times from plain pipe), indicating a positive effect on energy savings in the system.

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