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Experimental Study of Heat Transfer Augmentation in Concentric Tube Heat Exchanger with Different Twist Ratio of Perforated Twisted Tape Inserts

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Abstract— *In this study an experimental investigation has been carried out for heat transfer and pressure drop characteristics in a concentric double tube heat exchanger using perforated twisted (PT) tape inserts in inner tube of various twist ratio. The experiment was perform with perforated tape of two different twist ratio (p/w= 3, 4) and fixed axial pitch ratio (s_x/w=0.625) and constant hole diameter ratio (d/w=0.208). The experiments were performed in counter flow manner of the fluid cold water flow in inner tube and hot water flow in annulus part. In this experiment Reynolds number varies from 1900 to 5200. For comparison experiments were also performed with typically twisted (TT) tape and plane tube. The experimental result shows that heat transfer rate and friction factor of plane tube and with TT tape insert. The result shows that nusselt number increases with decrease in twist ratio (p/w). PT inserts with p/w=3 and 4, provides nusselt number up to 26% and 14% higher than plane tube respectively, 10% and 8% higher than typically twisted tape respectively. In inner tube an average friction factor generated by PT tape with twist ratio d/w=3 and 4 is found up to 207% and 87% more than plane tube respectively, 46% and 38% more than TT tape respectively. The empirical correlation of nusselt number and friction factor are also developed by experimental results.*

Keywords*— Perforated twisted tape, pitch, twist ratio, space ratio, free space introduction.*

I. INTRODUCTION

It has been commonly known that the performance of heat exchangers, for single-phase flow can be improved by many augmentation techniques in general, heat transfer enhancement technique can be divided into two groups, namely active and passive techniques. The active technique requires extra external power source. The other is passive technique, which requires no direct employment of the external power. Heat transfer enhancement technology has been developed and widely applied to heat exchanger applications; for example, refrigeration, automotive, chemical process industry and so on. Among various techniques, insertion of twisted tapes is one of the most promising techniques, which has been widely adopted for heat transfer augmentation. Tube with twisted tape insert is frequently used in heat exchanger systems because of it low cost, less maintenance and compact. But the increase in friction factor is seemed to be the punishment of this technique. Optimization of the twisted tape design is therefore a challenging assignment to meet the requirement of satisfactory heat transfer enhancement with the acceptable friction increase. S. S. Giri, Dr. V. M. Kriplani [1] have been done their effort to increase the heat transfer characteristic using inserts in the tube. Panida Seemawute, Smith Eiamsa-Ard [2] have been worked on visualization of flow and heat transfer in tube with twisted tape consisting of alternate axis. S. K. Saha, A. Dutta, S. K. Dhal [3] have been given their effort to study on heat transfer characteristics and friction factor of laminar swirl flow through a circular tube fitted with regularly spaced twisted-tape elements. Some modified twisted tapes were designed to minimize pressure loss [3–8]. But all modified twisted tapes mentioned above generated lower pressure drop than TT tape inserts, they give significantly lower heat transfer rate, so overall heat transfer performance is decreases. It happens because of lower swirl intensity due to modified twisted tape. Ferroni et al. [9] reported the experimental data for investigated physically separated, multiple, short length twisted tapes. It was observed that pressure drops at least 50% lower than that of full length twisted tape. Smith et al. [10, 11] done experiment on helical screw tape with and without core-rod inserts and with alternate clockwise and counter-clockwise arrangement. The heat transfer rate gained by using the tape without core -rod is better than that by one with core-rod.

In this my experiment, I have made modification on PT tape. Holes are made in the middle of the twisted tape due to this more turbulence is generated in the tube. Therefore, in the present study, the effects of PT tape inserts on heat transfer performance with corresponding increase in friction factor through a concentric double pipe heat exchanger with different twist ratio of PT tape are experimentally investigated. The empirical correlations are developed for predicting the heat transfer, friction.

Laminar Flow: the flow of a fluid when each particle of the fluid follows a smooth path, paths which never interfere with one another. One result of laminar flow is that the velocity of the fluid is constant at any point in the fluid.

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Turbulent Flow: irregular flow that is characterized by tiny whirlpool regions. The velocity of this fluid is definitely not constant at every point.

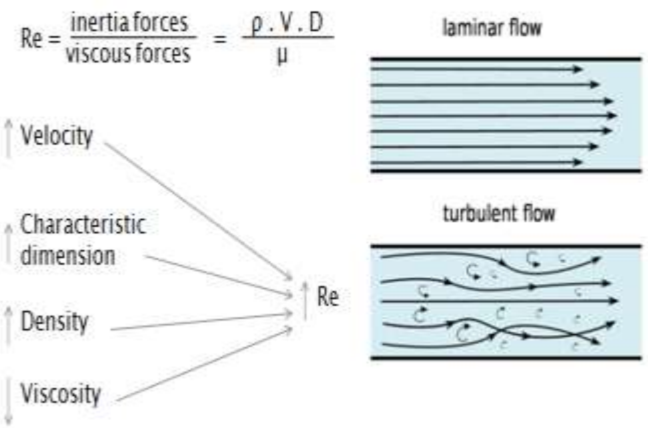

Fig. 1. Laminar and turbulent flow.

II. Experimental Setup and Procedure

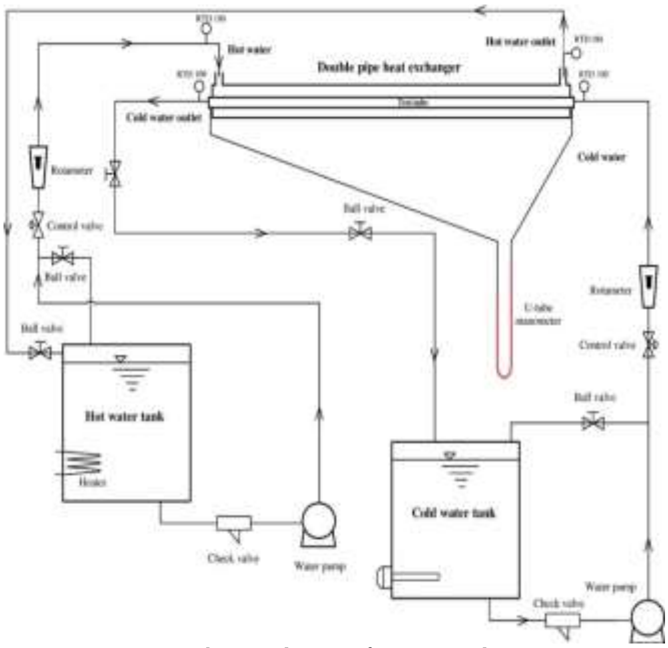

Fig. 2. Schematic diagram of experimental setup.

A schematic diagram of the experimental setup is shown in Fig. 1. This schematic diagram consists of a test section, hot water loop, cold water loop and data measurement system. The test section is the horizontal double pipes heat exchanger with twisted tape insert. The test section designed such that inserts can be changed easily. In addition to the loop component, a full set of instruments for measuring and control of temperature and flow rate of all fluids is installed at all important points in the circuit. The test section made from the straight cupper pipe consists of an outer pipe and inner pipe. The dimensions of the inner and outer pipes of the heat exchanger are: di = 28 mm, do = 32 mm, Di =42 mm, and Lo = 1600 mm. Cold water was passed through the inner pipe, while hot water was flowing through the annulus.

In this experimental effort, it is intended to search for the changes in the convection heat transfer coefficients of the inner pipe side in turbulent flow producing by PT tape. For this purpose, the PT tape insert was installed on the inner pipe side of the concentric double pipe heat exchanger as a swirl generator. For comparison, in this study also tested inner pipe without insert (plain tube) and with TT tape insert. The inlet and outlet temperatures of the hot water and cold water measures with the help of K-type thermocouples. The temperatures were read by using a multi-channel digital thermometer. Pressure loss of the inner pipe side was determined by using U-tube manometer that was filled with water. The inlet temperature at the hot water side was kept constant at 56℃ and cold water side was ambient temperature at 29℃. The hot water constantly flowed at 0.142 kg/s whereas the hot water flow rate was adjusted

Fig. 3. Photographic view of experimental setup.

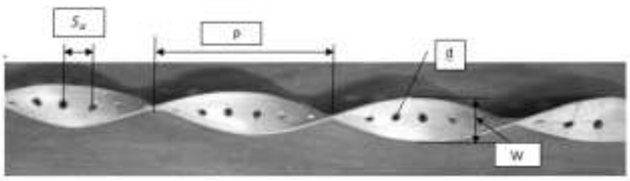

Fig. 4. Perforated twisted tape.

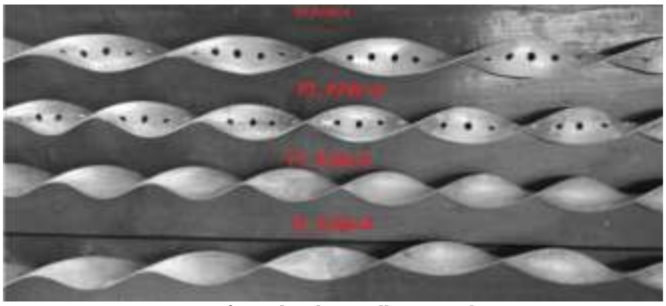

Fig. 5. Perforated and typically Twisted tapes.

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Twisted tape insert was made from aluminum strip with a thickness of 1 mm, a width of 24 mm and the length of 1600 mm. Twisted tape insert was fabricated by twisting a straight strip, about its longitudinal axis of different pitch length of y = 76 and 96 mm and tape-twist ratio of 3 and 4. So PT tape insert have two different twist ratio. PT tape inserts were the modified from the TT tape by drilling the small holes with hole diameters of 5 mm along the tape longitudinal axis with fixed axial pitch lengths of Sx = 15 mm and constant values of perforation hole diameter ratio 0.208.

Rotameter- Two rotameters are used for measuring discharge of water, one for hot water and one for cold water.

Thermocouples- Four thermocouples are used for measuring inlet and outlet temperature of water.

Water pump- Two water pumps are used one for hot water and one for cold water.

Manometer- Manometer is use for measuring the pressure difference between inlet and outlet of cold fluid in terms of water head.

Test section- Concentric tube part is called test section, where cold water flow in inner tube and hot water flow in annulus. Twisted tape is inserted in inner tube.

Electric heater- Electric heater used for making hot water, which is supply in test section.

Control panel- Control panel is use where all readings are shown, pumps and electric heaters are control.

Working fluid- Working fluid water is used in both section.

III. Data Reduction

The experimental data taken at steady state condition were used to calculate the Nusselt number, friction factor at different Reynolds number in turbulent flow region in the inner pipe side for the cases plain tube, with using TT tape insert and PT tape inserts.

Mass flow rate is calculated by

$\dot{m}$=ρ*Q, where Q is discharge which can be obtained by rotameter

Velocity of water

$V=\frac{\dot{m}}{\rho a_1}$

Heat supplied by hot water is calculated by

$Q_h=\dot{m}c_p(T_{hi}-T_{ho})$

Heat gained by cold water is calculated by

$Q_c=\dot{m}c_p(T_{co}-T_{ci})$

Now average heat transfer

$Q_{avg}=\frac{Q_h+Q_c}{2}$

$Q_{avg}=U_iA_i\theta_{LMTD}$

Nusselt number can be calculated by

$Nu=\frac{\bar{h}_x * L_c}{K}$

$L_c=\frac{4A_{cs}}{p}$,

$A_{cs}=\frac{\pi d_i^2}{4}$ - (w*t),

$p=\pi * d_1$+2*(t+w)

Friction factor f is calculated by

$f=\frac{\Delta P}{\left(\frac{L_c}{d_1}\right)*\left(\frac{\rho V^2}{2}\right)}$

Now theoretical Nusselt number is obtained by

$Nu=.023*R_e^{.8} * P_r^{.3}$, where

$R_e=\frac{\rho V d_1}{\mu}$ and

$P_r=\frac{\mu c_p}{K}$

Where all the properties are calculated at bulk mean temperature (T_m)

$T_m=\left(\frac{T_i+T_o}{2}\right)$,

$\Delta P=\rho g h$

IV. Uncertainty in Measurements

Uncertainty is determined by an analyzing the measured data. The uncertainty in the measurement of the pressure drop, flow rate in the tube, friction factor and Reynolds number are calculated from kline and McClintock equation. The uncertainties of flow rate, pressure and temperature measurement are estimated to ±2.5%, ± 2% and ± 0.5% respectively. The maximum uncertainty in the Reynolds number, friction factor and Nusselt number are found as ± 4.8%, ± 6.5% and ± 8.4%.

V. Results and Disscussion

Variation of Friction Factor with Reynolds Number

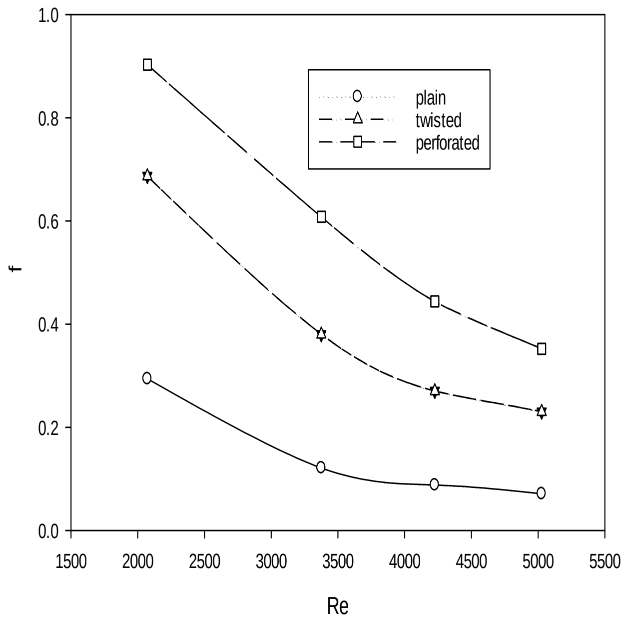

Fig. 6. Variation of friction factor for twist ratio 3.

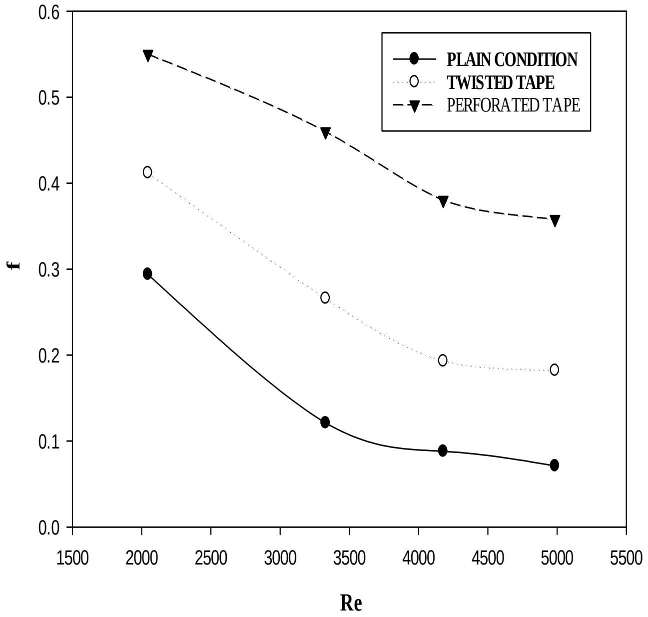

Fig. 7. Variation of friction factor for twist ratio 4.

As we decreases twist ratio the friction factor is increses because more restiction is produces in flow and larger area comes in contact of water in case of lower twist ratio, So higher friction factor is obtained in twist ratio3.

Variation of Nusselt factor with Reynolds number

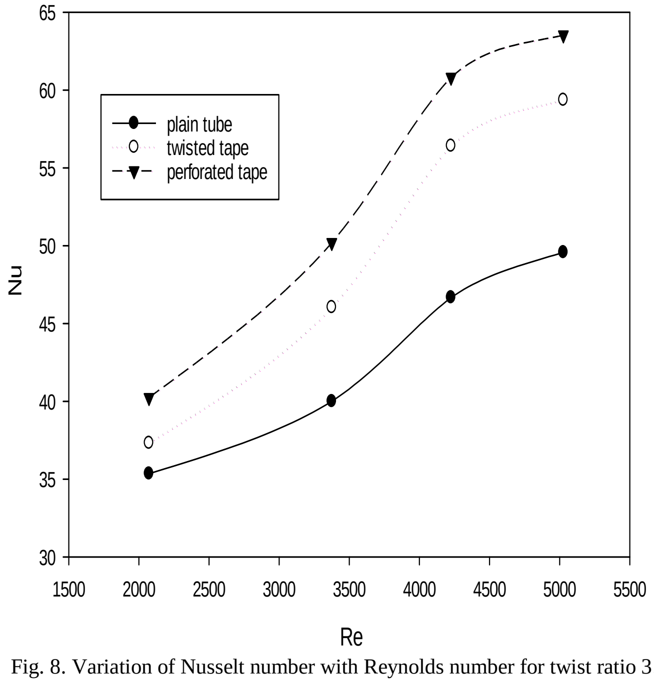

Fig. 8. Variation of Nusselt number with Reynolds number for twist ratio 3.

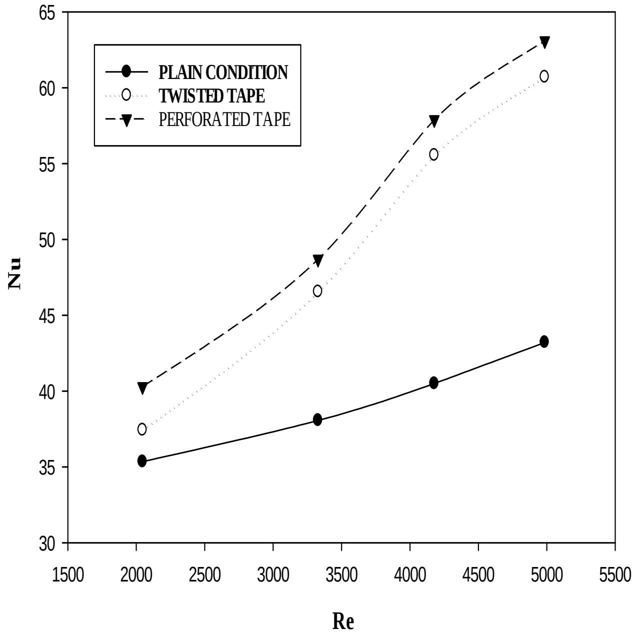

Fig. 9. Variation of Nusselt number with Reynolds number for twist ratio 4.

Variation in Nusselt number with Reynolds number in case of twist ratio 3 is higher than twist ratio 4 because more turbulence and longer path travelled by water in case of twist ratio 3. Hence heat transfer is higher in case of twist ratio 3 than twist ratio 4.

Effect of twist ratio on heat transfer coefficient-

The influences of the twist ratios (P/W = 3and 4) on the heat transfer enhancement in terms of average Nusselt number in the inner pipe is displayed in Fig. It is seen that the Nusselt number rises with increasing Reynolds number for all cases. This show to the increase of turbulent intensity as the Reynolds number is increases. Which led to an amplification of convective heat transfer. The influence of using the PT tape inserts at various twist ratios on heat transfer rate is significant for all the Reynolds number. As expected from Fig. The Nusselt number obtained from the inner pipe with PT tape insert is significantly higher than those of the plain tube and the TT tape inserts. The PT tape inserts with twist ratios of 3 and 4, enhance heat transfer rate in a range of 26% and 14% above the plain tube, respectively. At the same Reynolds number, PT tape inserts consistently provide higher Nusselt numbers than TT tape insert. The better heat transfer offered by PT tape inserts caused by an extra fluid turbulence in the tube due to the presence of holes on the tapes, apart from a common swirl flow. PT tape inserts with P/W = 3 and 4, give Nusselt number up to 10% and 8% higher than TT tape insert, respectively. From the experimental results, it can be revealed that the heat transfer rate also changes with the twist ratio of the PT tape inserts.

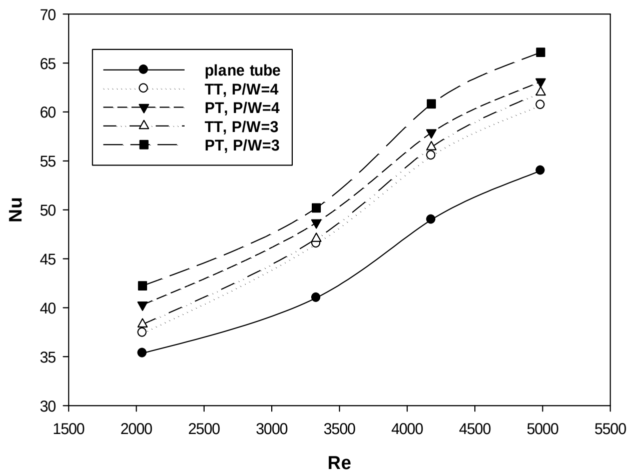

Fig. 10. Effect of twist ratio on Nusselt number.

Effect of twist ratio on friction factor-

Effect of the PT tape inserts with two twist ratios (*P*/*W* = 3 and 4) on the pressure drop in terms of friction factor in the inner pipe. The friction factor of the plain tube is also plotted for comparison. For all cases, friction factor decreases with increasing the Reynolds number. The increase in friction factor for the inner pipe with the PT tape inserts, is much higher than the plain tube. This is because of the flow blockage, larger contact surface area with longer flow path and the dissipation of dynamic pressure of the fluid due to high viscosity loss near the tube wall. Similar to the results mentioned for Nusselt number, friction factor increases with decreasing the twist ratio of the PT tape inserts. At the same Reynolds number, PT tape inserts generate higher flow frictions than TT tape insert. This is because of the extra dissipation of dynamic pressure of the fluid during act caused by the additional fluid disturbance due to the presence of holes on the tapes, resulting in an increase of interaction of the pressure force with inertial force around a velocity boundary layer. An average friction factor in the inner pipe generated by PT tape insert with twist ratios 3 and 4 is found to be around 46% and 38% higher than that induced by TT tape insert respectively.

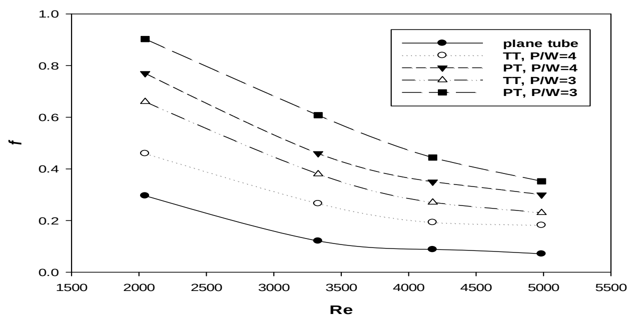

Fig. 11. Effect of twist ratio on Friction factor.

Correlations for prediction of Nusselt number and friction factor-

The Nusselt number for the inner pipe fitted with PT tape inserts are correlated as a function of Reynolds number, Prandtl number and twist ratio. The friction factor is correlated as a function of Reynolds number and twist ratio. The experimental results of the Nusselt number and friction factor for the inner pipe of a concentric tube heat exchanger equipped with PT tape inserts with two different twist ratios 3 and 4 are fitted by the following empirical equations. The goodness of the fit is indicated by the value of correlation coefficient for Nusselt number 0.974 and for friction factor 0.976.

$$Nu = 0.0046 \times Re^{0.4445} \times Pr^{3.7185} \times \left(P/W\right)^{1.2594 \times 10^{-10}}$$

$$f = 2108.946 \times Re^{-1.0125} \times \left(P/W\right)^{-3.908 \times 10^{-11}}$$

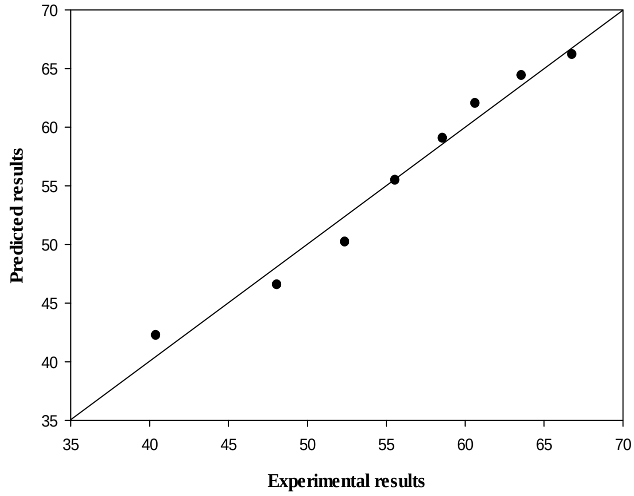

Fig. 12. Comparison between predicted and experimental Nussel number.

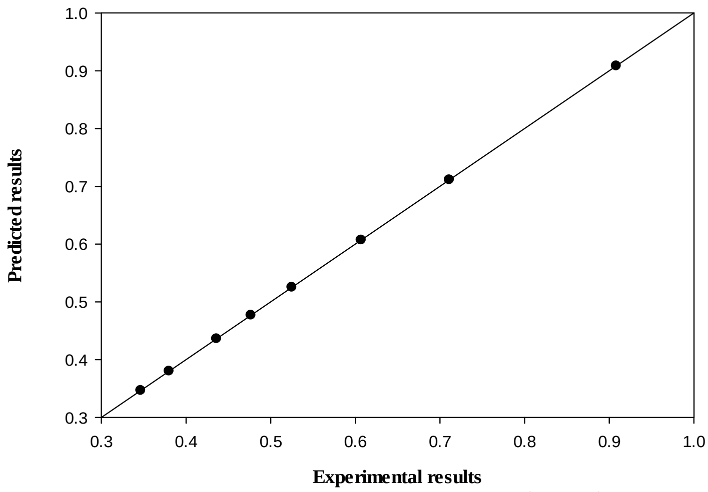

Fig. 13. Comparison between predicted and experimental friction factor.

VI. CONCLUSION

An experimental study has been done to investigate the heat transfer and friction factor characteristics in a concentric double pipe heat exchanger with different twist ratio of PT tape inserts. The experiments were performed using PT tape inserts with constant axial pitch of 0.625 and two different twist ratio of 3 and 4 for Reynolds number ranging from 1900 to 5200. The experiments using plain tube and the inner tube with TT tape insert were also conducted, for comparison. Based on the obtained results, the conclusion can be drowning as follows.

1. The PT tape inserts gives more heat transfer rate and friction factor compared to that of the plain tube and TT tape insert.
2. At the given Reynolds number, heat transfer rate and friction factor increases with decreasing twist ratio.

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