

Experimental Investigations in Circular Tube to Enhance Turbulent Heat Transfer Using Various Types of Twisted Tape Inserts

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Abstract

This work shows the results obtained from experimental investigations of the augmentation of turbulent flow heat transfer in a horizontal tube by means of twisted tape inserts. Six types of twisted types used with total length of 1200mm and diameter of 50mm are considered for experimentation as follows: normal twisted tape regularly spaced twisted tape, triangular-cut twisted tape, rectangular-cut twisted tape, semicircular-cut twisted tape, and drilled twisted tape. The range of Reynolds number extends from 4500 to 23500. Correlations for Nusselt number, friction factor, and enhancement efficiency are developed for each type of twisted tape inserts from the obtained results. It is observed that the enhancement of heat transfer increases as the type of twisted tape changes from one to six, respectively.

دراسة عملية لخصائص انتقال الحرارة والكفاءة لجريان الهواء المضطرب خلال انبوب دائري مجهز بأنواع مختلفة من الأشرطة الملتوية

الخلاصة

يبين العمل الحالي النتائج التي تم الحصول عليها من الدراسة العملية لتحسين انتقال الحرارة لجريان مضطرب بأنبوب أفقي بواسطة حشر شريط ملتو. ستة أنواع من الأشرطة الملتوية استخدمت للتجريب بطول كلي مقداره 1200 ملم وبقطر 50 ملم كما يلي : شريط ملتو اعتيادي , أشرطة ملتوية تفصلها مسافة منتظمة , شريط ملتو ذو قطع مثلث , شريط ملتو ذو قطع مستطيل , شريط ملتو ذو قطع نصف دائري , وشريط ملتو مثقب. يمتد رقم رينولدز من 4500 إلى 23500 أستنبطت علاقات تجريبية من النتائج الحاصلة لرقم نسلت , عامل الاحتكاك , وكفاءة التحسين لكل نوع من أنواع حشر الشريط الملتوي. لوحظ ان كفاءة انتقال الحرارة تزداد كلما تغير نوع الشريط الملتوي من الأول إلى السادس. على التوالي.

Introduction

Heat exchangers have several industrial and engineering applications. The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate and pressure drop estimations apart from issues such as long-term performance and the economic aspect of the equipment. The major challenge in designing heat exchangers is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of heat exchangers in specific applications, such as space application, through an augmentation of heat transfer. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in marine applications and in chemical industries. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity (gases and oil) and desalination plants, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow (breaking the viscous and thermal boundary layers), but in the process pumping power may increase significantly and ultimately the pumping cost becomes high. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years, such as twisted tape inserts, coil wire inserts, brush inserts, mesh inserts, strip inserts, etc. Twisted tape inserts inside circular tubes provide a means of increasing the surface heat transfer coefficient within the tubes of

tubular heat exchangers. The tape consists of a long metal strip which has been twisted

about its longitudinal axis as shown in **Fig.(1)**, the width of the tape being equal to the internal diameter of the tube.

Many authors studied the heat transfer enhancement process inside tube fitted with twisted tapes under different shapes, passages, working fluids, and type flow. **Date,1974** showed theoretically that the using of augmented turbulent viscosities in a tube containing a twisted –tape make the Nusselt number predictions more realistic. **Hong and Bergles, 1976** used water and ethylene glycol as a working fluid flow inside metal tube with twisted tape and showed that the friction factor is affected by tape twist only at high Reynolds numbers in accordance with analytical predictions. **Saha et al, 1989** proved experimentally that regularly spaced twisted-tape elements perform significantly better than full-length twisted tapes at the high Reynolds number, high twists, and small spacing on the basis of both constant pumping power and constant heat duty. **Date et al, 1990** extracted relationships for relevant parameter from previous numerical prediction of laminar flow in a tube containing a full-length twisted tape and regularly twisted-tape elements to yield a correlation for friction factor that reflects the influences of secondary flows and wall shear. **Hill et al, 1996** used two types of short twisted tapes. One was of the conventional form and one had fish bails at it trailing edge for annular air –water flow in a tube. A significant better performance was obtained using tape with fishtails. **Sivashanmugam and Sundaram, 1999** showed experimentally that the lower value of twist ratio gives a maximum gain in energy transfer rate inside a double pipe heat exchanger that decreases with the Reynolds number and becomes constant for Reynolds number greater than 3000. **Kumar and Prasad, 2000** improved the performance of solar water heater using

twisted tape inserts with various values of twist to tube diameter ratio and mass flow rates to increase by (18-70%) as compared to plane collectors. **Eiamsa-ard et al, 2006** used the cold and hot water as working fluids in a double pipe heat exchanger fitted with regularly spaced twisted tape elements. Results show that the increase in the free space ratio would improve both the heat transfer coefficient and friction factor. **Eiamsa et al, 2007** revealed that the lowest value of regularly spacing twisted tape gives the heat transfer lower than full length twisted tape around (5-15 %) while it can be decreased the pressure drop around 90%. **Sivashanmugam and Nagarjan, 2007** proved that the heat transfer coefficient enhancement through a circular tube fitted with right and left helical screw inserts is higher than that for straight helical twist inserts of equal and unequal length for a given twist ratio. **Chang et al, 2007** used serrated twisted tape with different twist ratios to enhance the heat transfer inside tube by (1.25-1.67) times the heat transfer level in the tube fitted with smooth twisted tape. **Akhavan et al, 2008** submitted an empirical equation for the heat transfer coefficients during condensation of (R-134A) vapor inside horizontal tube for two cases: a plain tube and tubes with different twisted tape inserts. **Promvong 2008** indicated that the presence of wire coils together with twisted tapes inside circular tube leads to a double increase in heat transfer over the use of wire coil twisted tape alone especially at smaller twist and coil pitch ratio under the same conditions. **Thianpong et al, 2009** revealed that both heat transfer coefficient and friction factor in the dimpled tube fitted with the twisted tape, are higher than those in the dimple tube acting alone and plain tube and increases as the pitch ratio and twist ratio decrease. **Jaisankar et al, 2009** found that the minimum twist ratio gives higher percentage of enhancement performance of twisted tape solar water heater collector compared to the plain one. **Rahimi et al,**

2009 proved experimentally and theoretically that the Nusselt number and performance of the jagged insert are higher than other modified twisted tape inserts by increasing of (31% and 22%), respectively. **Murugesan et al, 2009** observed a significant increase in heat transfer coefficient and friction factor inside tube fitted with full length trapezoidal cut twisted tape. **Sharma et al, 2009** showed considerable enhancement of convective heat transfer with Al_2O_3 nano fluids compared to flow with water in a circular tube fitted with twisted tape inserts. **Seemawute and Eiamsa-ard, 2010** showed that the heat transfer rates in the tube fitted with the peripherally –cut twisted tape with alternate axis, normal peripherally-cut twisted tape, and typical tape are respectively enhanced up to (184%, 120% and 57%) of heat in the plain tube where the testing fluid is the water. **Syam sunder and Sharma, 2010** observed that the heat transfer coefficient of Al_2O_3 nano fluid is (33.5 %) times higher compared to flow of water in a tube equipped with twisted tape inserts with twist ratio of five.

All the researchers in the above literature studied the heat transfer enhancement in a tube fitted with one alone of the following twisted tapes: normal twisted tape, regularly space twisted tape fish tails twisted tape and triangular-cut twisted tape.

The present work offers new types of modified twisted tape shapes as follows: rectangular-cut twisted tape, semicircular-cut twisted tape and drilled twisted tape.

The present study of six types of twisted tape inserts had two primary goals:

- (1) Obtain turbulent flow data under carefully controlled conditions and from these data develop the first experimentally base correlation for predicting the associated heat transfer coefficients.
- (2) Compare the heat transfer performance of tubes having six types of tape generated

swirl flow with each other and with the performance of empty tube (plain tube) under similar heating conditions.

Experimental apparatus

The apparatus consists of a blower unit fitted with a tube in horizontal orientation. Nichel-chrome bend heater encloses the tube test section to a length 1200mm. Seventeen thermocouples are embedded on the walls of the aluminum tube and two thermocouples are placed in the air stream, one at the entrance and the other at the exit of the test section to measure the temperature of flowing air as shown in **Fig.(2)**. The heating tube is connected at entrance with another tube by Teflon ring to reduce the thermal losses. The calming tube contains an orifice plate (British standard unit) and a manometer to measure the flow of air through the tube which is controlled by using control valve. The pressure difference is measured by pressure transducer through the two taps placed at inlet and outlet of test section. The inside radius of the heating tube is (50mm) with (2.5mm) as thickness. A heat generation element is wound around this test tube so that the required heat input is given. Heat input can be varied by changing the voltage and current of heater using transformer. **Fig.(3)** shows clearly by sketching and dimensions six types of twisted tape inserted inside test section tube used in the present study as follows: normal twisted tape, regularly spaced twisted tape, triangular-cut twisted tape, rectangular-cut twisted tape, semicircular-cut twisted tape, and drilled twisted tape. All these twisted tapes are made up of aluminum strips of thickness 2 mm and width (50 mm). The twist ratio (TR) is defined by ratio between one length of twist (or) pitch length (s) to inner diameter of tube (d). Triangular, rectangular, and semicircular-cut taken alternately on both top and bottom of the tape to improve the fluid mixing near the wall of test section. The fluid properties were calculated as the average between the

inlet and outlet bulk temperature. Experiment was carried out at constant heat flux conditions with and without the insert.

Heat Transfer Calculations

The average heat flux from the tube wall to the fluid is defined interms of surface area.

$$Q=hA(T_s-T_b)+ \epsilon A(T_w^4 - T_b^4) \dots(1)$$

where

$$Q=m_a C_p(T_{out}-T_{in}) \dots(2)$$

hence

$$h=[m_a C_p(T_{out}-T_{in})- \epsilon A(T_w^4 - T_b^4)]/ A(T_s-T_b) \dots(3)$$

$$T_b=(T_i+T_{out})/2 \dots (4)$$

where

T_w : average tube wall temperature

It took approximately 2-3 hours to obtain a steady state for each run.

Heat transfer coefficient h is calculated using Eq.(1)

$$Nu=hd/K \dots (5)$$

The friction factor f is calculated from the following equation:

$$f = \frac{\Delta p}{\left[\frac{4L}{d} \right] \left[\frac{\rho u^2}{2} \right]} \dots (6)$$

The local values for Nu and Re were calculated on the basis of air properties corresponding to bulk fluid temperature. Experimental data obtained for Nusselt number in fully developed axial flow is compared with the correlations from literature.

Results and Discussion

Validation of the Experimental Setup

The experimental setup was validated by carrying out heat transfer measurements in the circular plain tube and comparing the present Nusselt number data with those predicted by the correlation given by **Promvonge [12]** as shown in **Fig.(4)**. The present experimental data was within $\pm 2\%$ of that predicted by the correlation [12]. The empirical turbulent forced convection correlations for average Nusselt number and friction factor for plain tube have been deduced in the present work as follows:

$$Nu = 0.532 Re^{0.012} Pi^{0.3} \dots(7)$$

$$f = 18.67 \text{ Re}^{-0.687} \quad \dots(8)$$

Tube Wall Temperature Variation

Fig.(5) shows the temperature distribution along the axial distance of plain tube and tube fitted with various types of twisted tape. As can be seen from this figure that the temperature varies linearly with axial distance and it decreases respectively as the type of twisted tape changes from 1 to type 6 and the values of temperature are higher in the plain tube than that in the tube fitted with twisted tape inserts. The wall temperature at an axial station is essentially used to evaluate axially local Nusselt number and finally obtain average Nusselt number.

Average Nusselt number

The experimental turbulent swirl flow heat transfer results are presented in Fig.(6) which shows the variation of average Nusselt number versus Reynolds number for plain tube and tube fitted with several types of twisted tape as follows :(1) full length twisted tape, (2) regularly-spaced twisted tape, (3) triangular-cut twisted tape, (4) rectangular-cut twisted tape, (5) half-circular-cut twisted tape, and (6) drilled twisted tape. It was be shown that the heat transfer process in the tube improves as the type of twisted tape changes from one to six, respectively. In general, the heat transfer coefficient in the tube fitted with twisted tape inserts is better than that in the plain tube, and the Nusselt number increases with increasing Reynolds number. From the experimental results, it is clear that the twisted tape inserts caused swirl flow and pressure gradient in the radial direction. The boundary layer along the tube wall would be thinner with the increase of radial swirl and pressure resulting in more heat flow through the fluid. Moreover, swirl caused the flow to be turbulent, which led to even better convection heat transfer which increases as the type of twisted tape changes from (one) to (six), respectively. Let us discuss the present behavior step by step according to the following remarks:

- (1) Throughout the experimental results, it is obvious that the regular spaced twisted tape gave the higher values of heat transfer rate than the full length twisted tape. This was due to the more violently swirl with the regular space resulted from high values of Reynolds number (Re varies from 4500 to 23500). This fact is in contrast with work results of Eiamsa-ard et al [9] in which the Reynolds number ranged from 2300 to 7500.
- (2) The heat transfer process in the tube fitted with drilled twisted tape is better than those in other types of twisted tape because of larger total area of drills relative to total area of twisted tape causes strong spiral flow along the tube length and disturb the entire flow field.
- (3) The increasing of cutting area in the twisted tape leads to increasing of heat transfer process. So, the Nusselt number values increase respectively for twisted tape with triangular, rectangular, and semicircular (i.e., as z increases).

The heat transfer data for tube fitted with several types of twisted tapes are correlated as average Nusselt number as follows:

(type1)

$$\text{Nu} = 2.181 \text{ Re}^{0.211} \text{ Pr}^{0.3} \quad \dots(9)$$

(type 2)

$$\text{Nu} = 2.431 \text{ Re}^{0.421} \text{ Pr}^{0.3} \text{ X}^{-0.165} \quad \dots(10)$$

(types 3,4 and 5)

$$\text{Nu} = 2.531 \text{ Re}^{0.543} \text{ Pr}^{0.3} \text{ Z}^{-0.133} \quad \dots(11)$$

(type 6)

$$\text{Nu} = 3.981 \text{ Re}^{0.685} \text{ Pr}^{0.3} \text{ Z}^{-0.121} \quad \dots(12)$$

Friction Factor Results

The variation of friction factor decreases with increasing of Reynolds number as shown in Fig.(7). The behavior of friction factor is in reverse with the behavior of heat transfer process. In other words, the values of friction factor in plain tube are much lower than that in tube fitted with twisted tape inserts in which the friction factor increases as the type of twisted tape

changes from (one) to (six), respectively, because of higher tangential contact between secondary flow and the wall surface of the tube. The correlations of friction factor are deduced as follows:

(Type 1)
 $f = 19.56 \text{ Re}^{-0.632} \dots(13)$

(Type 2)
 $f = 20.34 \text{ Re}^{-0.593} X^{-0.101} \dots(14)$

(Types 3, 4 and 5)
 $f = 21.89 \text{ Re}^{-0.582} Z^{-0.099} \dots(15)$

(Type 6)
 $f = 24.56 \text{ Re}^{-0.543} Z^{-0.012} \dots(16)$

Performance Evaluation Analysis

The quality of enhancement concept is derived from the performance ratio. The performance ratio is defined as the ratio of Nusselt number to friction ratio at the same pressure drop which is derived from Dittus-Boelter equation and Blasius equation of turbulent flow [21] as follows:

$$\zeta = \frac{Nu}{\left(\frac{f}{f_p}\right)^{1/3} Nu_p} \dots(17)$$

The enhancement efficiency are plotted against Reynolds number as shown in Fig.(8) and derived in the following forms:

(Type 1)
 $\zeta = 10.542 \text{ Re}^{-0.987} \dots (18)$

(Type 2)
 $\zeta = 11.64 \text{ Re}^{-0.100} X^{-0.0125} \dots (19)$

(Types 3, 4 and 5)
 $\zeta = 13.243 \text{ Re}^{-0.122} Z^{-0.0132} \dots(20)$

(Type 6)
 $\zeta = 14.213 \text{ Re}^{-0.142} Z^{-0.0221} \dots(21)$

Conclusions

1. Experimental data compared with fundamental equation. Error within ±6% and ±7% for Nusselt number and friction factor, respectively.
2. The temperature varies linearly along the longitudinal axis of horizontal tube for turbulent forced convection with Reynolds number ranges from 4500 to 23500.
3. The heat transfer process in the double pipe heat exchanger enhances by using

twisted tape inserts. The type of twisted tape indicates the increasing amount of enhancement efficiency.

4. The performance of heat exchanger increases respectively with the use of full length twisted tape, regular space twisted tape, triangular-cut twisted tape, rectangular-cut twisted tape, half-circular-cut twisted tape, and drilled twisted tape.

5. The performance ratio decreases as Reynolds number increases, but stays more than one, so enhancement is competent in the point of energy savings.

6. The pressure drop data indicate that the friction factor depends primarily on Reynolds number. Swirl flow increases the friction somewhat at higher Reynolds number.

7. Predictive correlations for Nusselt number, friction factor, and enhancement efficiency have been developed.

Nomenclature

- A: surface area of tub,(0.188m²).
- A_c: total area of triangular, rectangular, or semicircular –cut shape of twisted tape (0.0035, 0.007, 0.0054 m²) respectively .
- A_d: total area of drills in the twisted tape,(0.0078m²).
- A_t: total area of twisted tape,(0.067 m²).
- d: inner diameter of tube, m.
- C_p: specific heat , J/kg.k.
- L: length of tube, m.
- f: friction factor
- Δp: pressure drop, N/m².
- Pr: Prandtl number (μ C_p/k).
- Nu: Nusselt number (h d/k).
- Re: Reynolds number (u d ρ/μ)
- Q : heat gained by air ,watt.
- u: velocity of air , m/s.
- m_a: mass flow rate of air, Kg/sec.
- x: regularly spaced between twisted tape, m.
- n: twisted length ,m.
- X: twisted ratio.
- Z : area ratio.
- T : air temperature, °C

Subscripts:

- in: inlet - out: outlet - b:bulk - w:wall surface - p:plain tube

Greek symbols:

ϵ : emissivity of copper - σ : Stefan-boltzmanns constant= $5.67 \times 10^{-8} \text{W/m}^2 \text{K}^{-4}$
 ζ : performance efficiency
 ρ : density of air Kg/sec - μ : viscosity of air N.s/m^2 - k : thermal conductivity of air W/m.K

References

- [1] **Date, A. W.** , " Prediction of fully developed flow in a tube containing a twisted-tape", *Int. J. Heat Mass Transfer*, Vol. 17, **1974**, pp. 845-859.
- [2] **Hong, S.W. and Bergles, A.E.**, " Augmentation of laminar flow heat transfer in tubes by means of twisted tape inserts", *ASME J. Heat Transfer*, **May 1976**, pp. 251-256.
- [3] **Saha, S. K., Gaitonde, U. N., Date, A. W.**, " Heat transfer and pressure drop characteristics of laminar flow in a circular tube fitted with regularly spaced twisted-tape elements", *Experimental Thermal and Fluid Science*, Vol. 2, Issue 3, **July 1989**, pp. 310-322.
- [4] **Date, A. W. ,and Gaitonde,** " Development of correlations for predicting characteristics of laminar flow in a tube fitted with regularly twisted-tape elements", *Experimental Thermal and Fluid Science*, Vol. 3, Issue 4, **July 1990**, Pages 373-382.
- [5] **Sivashanmugam, P. , and Sundaram, S.** , " Improvement in Performance of Heat Exchanger Fitted with Twisted Tape", *J. Energy Engineering*, Vol. 125, Issue 1, **April 1999**, pp. 35-41.
- [6] **Kumar, A., and Prasad, B. N.** , " Investigation of twisted tape inserted solar water heaters-heat transfer, friction factor and thermal performance results", *Renewable Energy*, Vol. 19, Issue 3, **March 2000**, pp. 379-398.
- [7] **Eiamsa-ard, S., Thianpong, C., and Promvonge, P.** , " Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements", *International Communications in Heat and Mass Transfer*, Vol. 33, Issue 10, **December 2006**, pp. 1225-1233.
- [8] **Chang, S. W., Jan, Y. J., and Liou, J. S.**, "Turbulent heat transfer and pressure drop in tube fitted with serrated twisted tape", *International Journal of Thermal Sciences* , Vol. 46, Issue 5, **May 2007**, pp. 506-518.
- [9] **Eiamsa-ard, S., Thianpong, C., and Promvonge, P.**, "Experimental investigations of heat transfer and pressure drop characteristics of flow through circular tube fitted with regularly-spaced twisted tape", *International Communications in Heat and Mass Transfer*, **July 2007**.pp. 534-540.
- [10] **Sivashanmugam, P. and Nagarajan, P.K.** , "Studies on heat transfer and friction factor characteristics of laminar flow through a circular tube fitted with right and left helical screw-tape inserts", *Experimental Thermal and Fluid Science*, Vol. 32, Issue 1, **October 2007**, Pages 192-197
- [11] **Akhavan-Behabadi, M.N., Kumar, R., and Rajabi-najar, A.** , "Augmentation of heat transfer by twisted tape inserts during condensation of R-134a inside a horizontal tube", *J. Heat Mass Transfer*, Vol. 44, **2008**, pp 651-657.
- [12] **Promvonge, P.** , "Thermal augmentation in circular tube with twisted tape and wire coil turbulators", *Energy Conversion and Management*, Vol. 40, Issue 11, **November 2008**, pp. 2949-2955.
- [13] **Rahimi, M., Shabanian, S.R., and Alsairafi, A.A.** , "Experimental and CFD studies on heat transfer and friction factor characteristics of a tube equipped with modified twisted tape inserts", *Chemical Engineering and Processing: Process Intensification*, Vol. 48, Issue 3, **March 2009**, pp. 762-770.
- [14] **Sharma, K.V., Syam Sundar, L., Sarma, P.K.** , "Estimation of heat transfer coefficient and friction factor in the transition flow with low volume concentration of Al_2O_3 nanofluid flowing in a circular tube and with twisted tape insert", *International Communications in Heat and*

Mass Transfer, Vol. 36, Issue 5, **May 2009**, pp. 503-507.

[15] Thianpong, C., Eiamsa, P., Wongcharee, K., and Eiamsa-ard, S., "Compound heat transfer enhancement of a dimpled tube with a twisted tape swirl generator", International Communications in Heat and Mass Transfer, Vol. 36, Issue 7, **August 2009**, pp. 698-704.

[16] Murugesan, P. , Mayilsamy, K. , Suresh, S. , and Srinivasan, P.S.S. , "Heat transfer and Pressure drop characteristics of turbulent flow in a tube fitted with trapezoidal-cut twisted tape insert", International Journal of Academic Research, Vol. 1, No. 1, **September 2009**, pp. 123-128.

[17] Jaisankar, S., Radhakrishnan, T.K. , and Sheeba, K.N. , "Experimental studies on heat transfer and friction factor characteristics of forced circulation solar water heater system fitted with helical twisted tapes", J. Solar Energy, Vol. 83, Issue 11, **November 2009**, pp. 1943-1952.

[18] Syam Sundar , L., and Sharma, K.V. , " Turbulent heat transfer and friction factor of Al_2O_3 nanofluid in circular tube with twisted tape inserts", Int. J. Heat and Mass Transfer, Vol. 53, Issue 7-8, **March 2010**, pp. 1409-1416.

[19] Seemawute, P, and Eiamsa-ard, S. , "Thermohydraulics of turbulent flow through a round tube by a peripherally-cut twisted tape with an alternate axis", International Communications in Heat and Mass Transfer, Vol. 37, In **uly 2010**, pp. 652-659.

[20] Hills, J.H., Azzopardi, B.J., and Barhcy, A.S., " Spatial unsteadiness-away towards intensive gas-liquid reactors", Trans. I. Chem. E., Vol. 74, **1996**, pp. 567-574.

[21] Hasim, F., Yoshida, M., and Miiyashita, H., " heat transfer enhancement by a combination of a helically ribbed tube with twisted tape inserts, Journal of Chemical Engineering of Japan 36, **2003**, pp. 1116-1122.

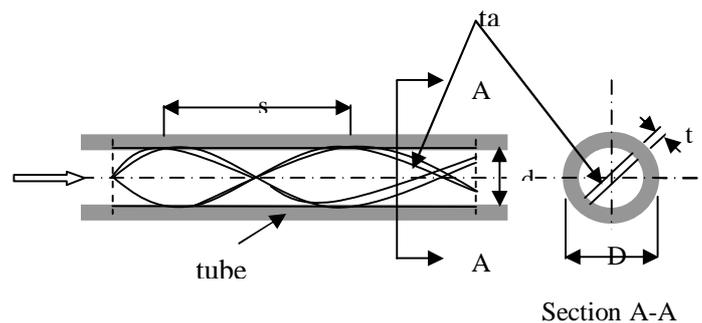
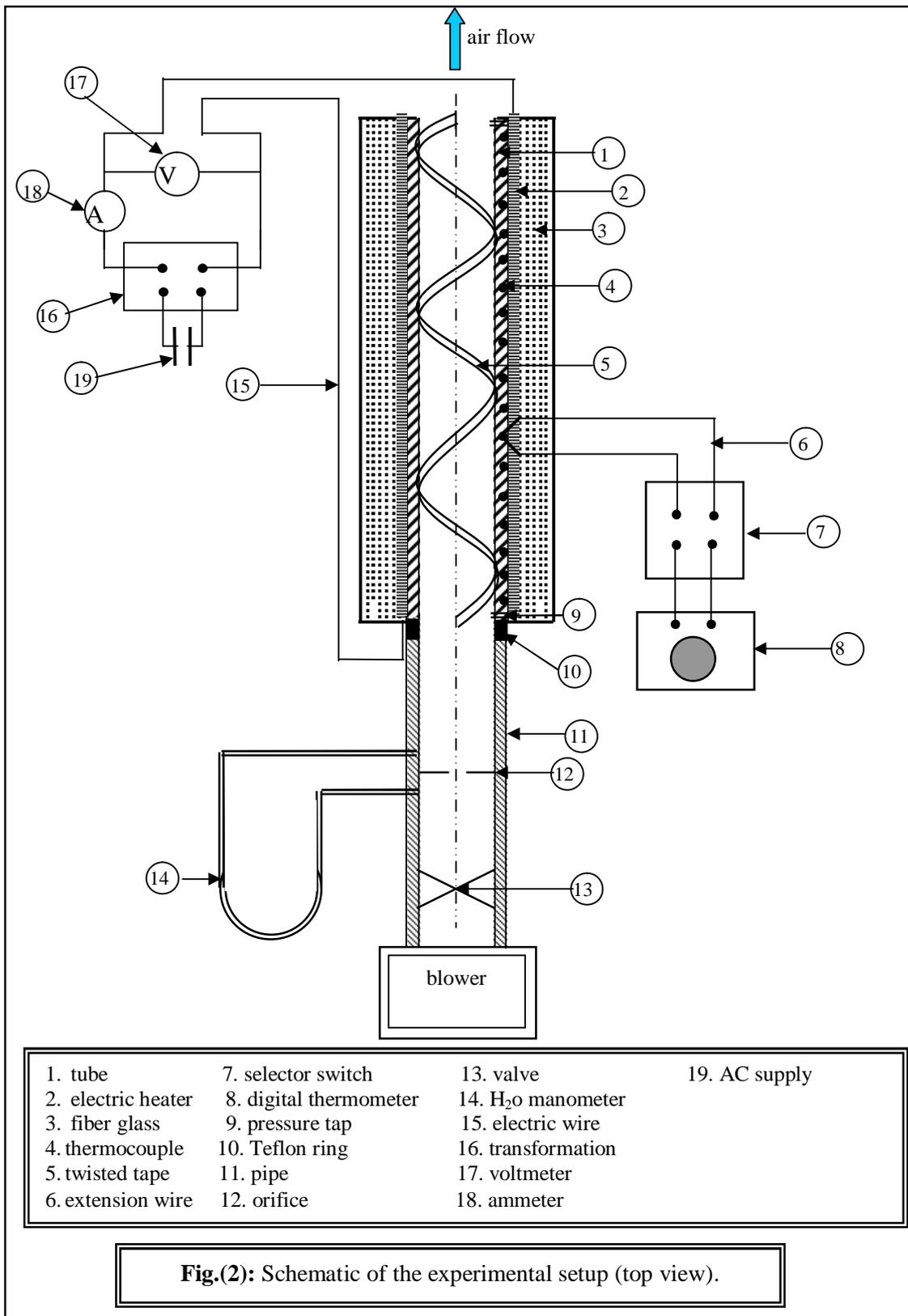


Figure (1): Circular tube fitted with twisted tape.



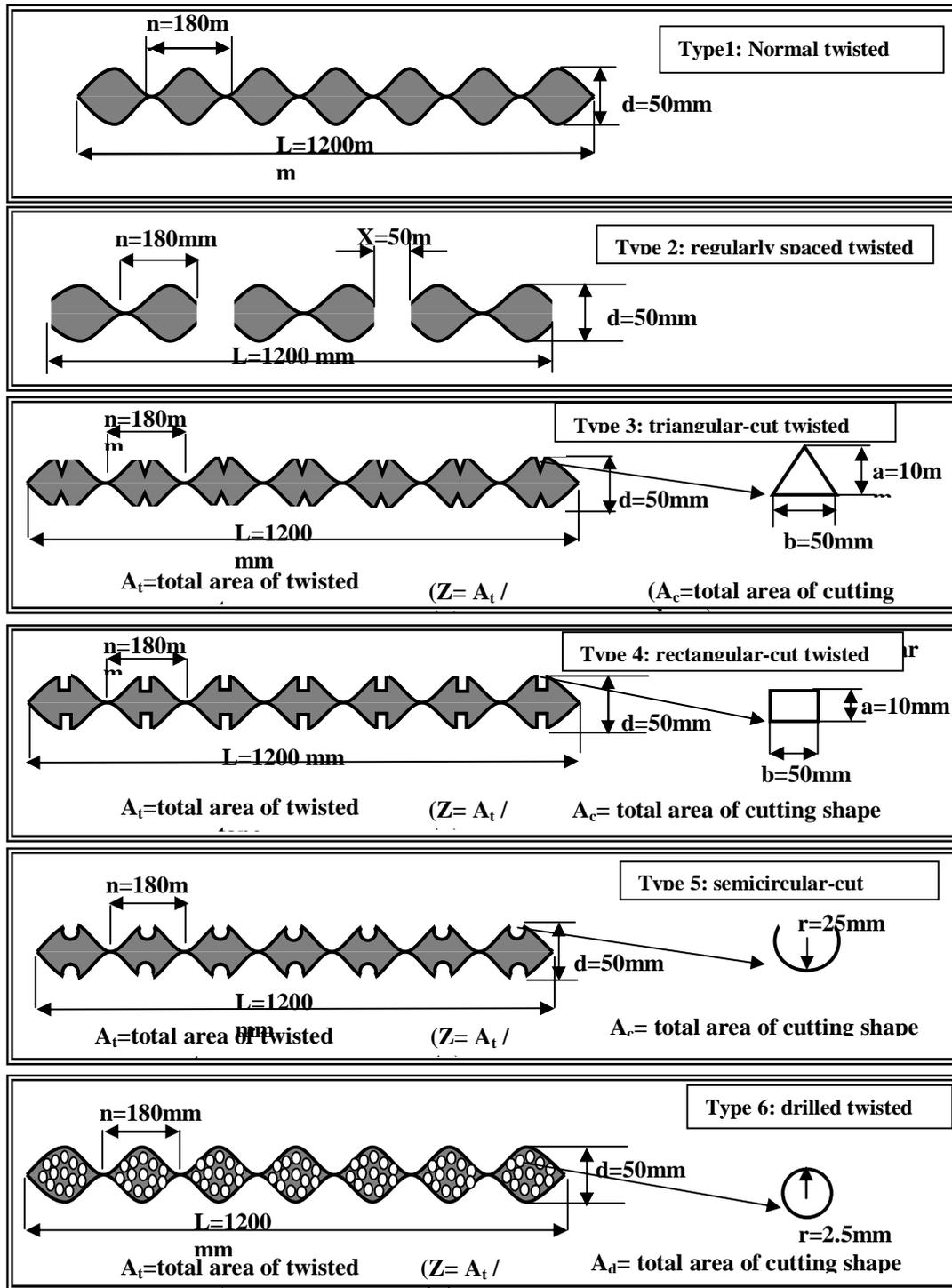
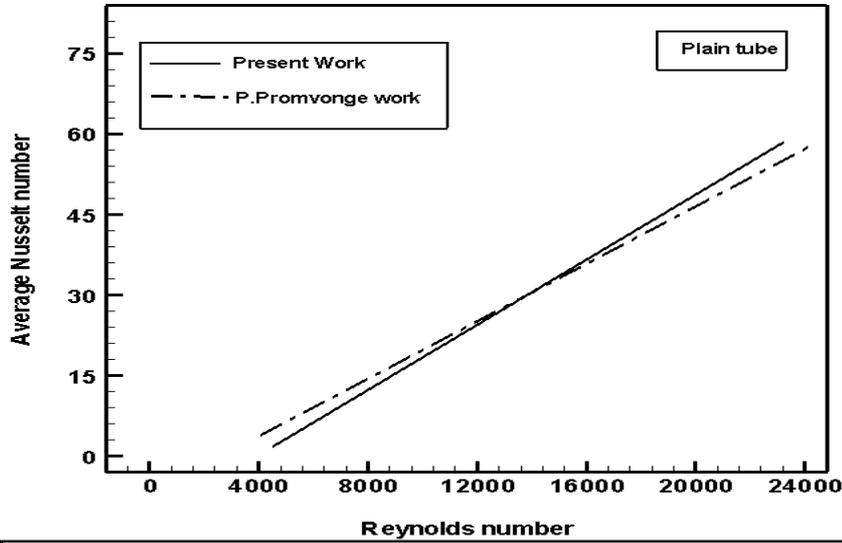


Figure (3): Types of twisted tape used in the present



Figure(4): Data verification of Nusselt number for plain tube.

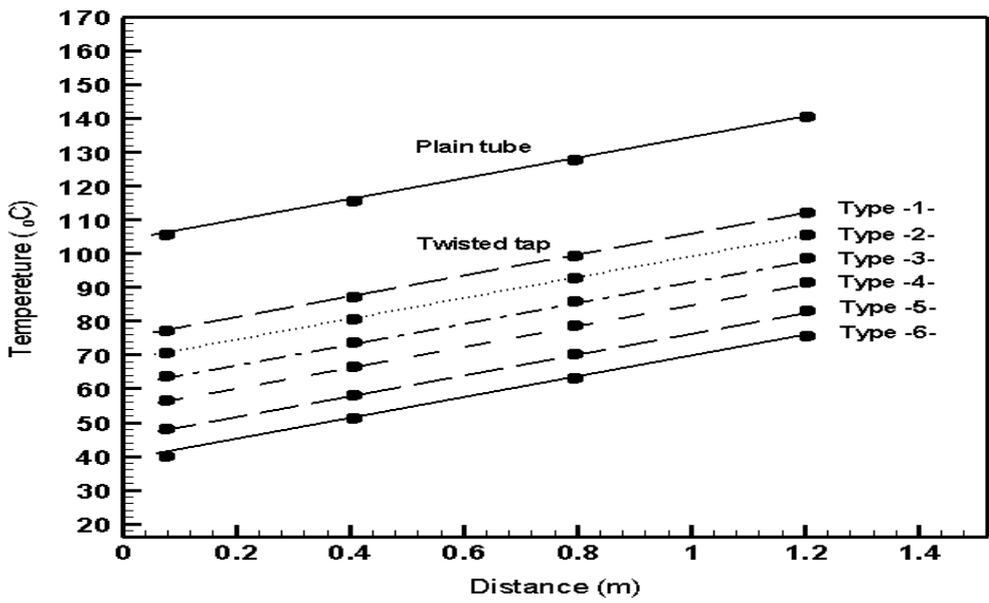


Figure (5): Temperature distribution along the axial distance of tube.

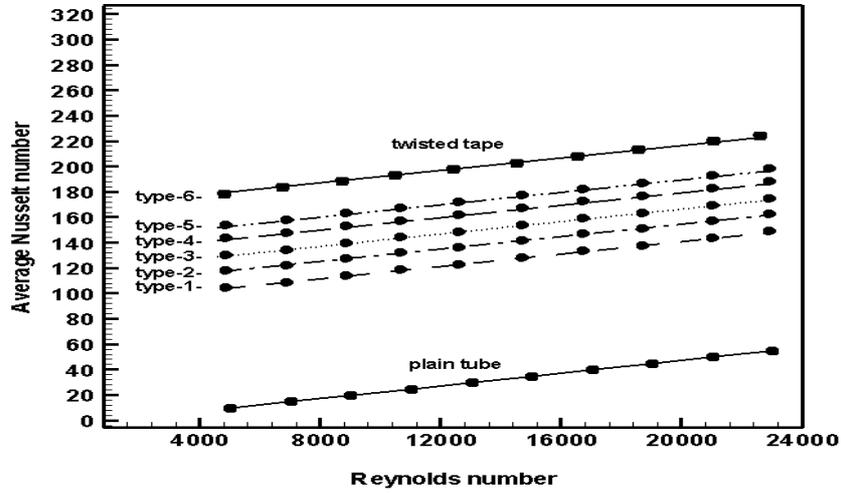


Figure (6) :Variation of average Nusselt number with Reynolds number.

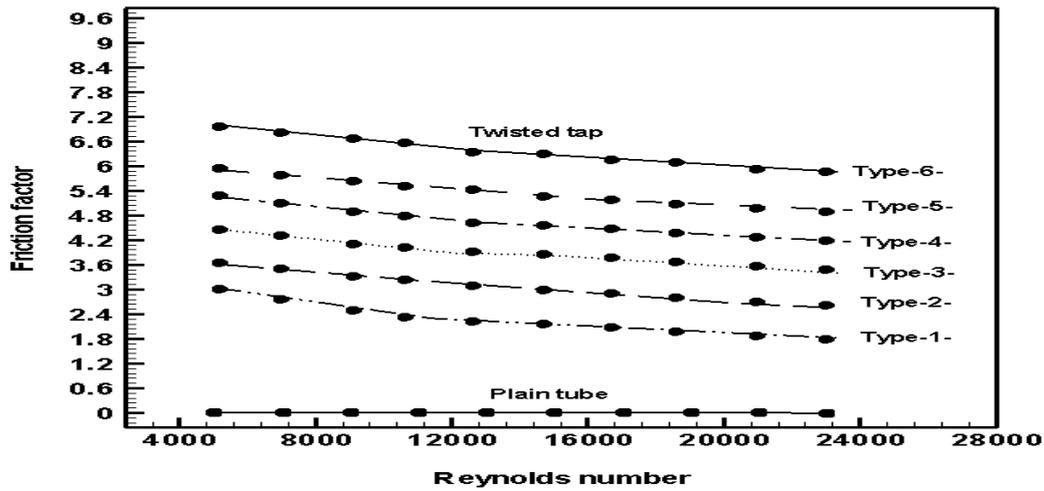


Figure (7): Friction factor versus Reynolds number for six types of twisted tape compared with plain tube.

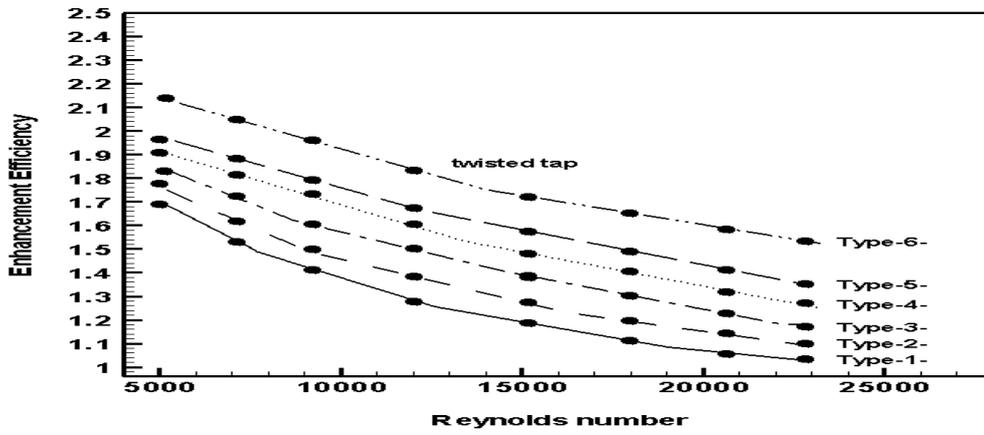


Figure (8): Enhancement efficiency versus Reynolds number for six types of twisted tape.