Journal of Engineering and Sustainable Development
www.jeasd.org
Vol. 22, No.03, May 2018
ISSN 2520-0917

EXPERIMENTAL INVESTIGATION OF ENHANCEMENT HEAT TRANSFER OF INSERT TWISTED TAPE OF CIRCLAR CUT WITH WIRE COIL IN THE DOUBLE PIPE HEAT EXCHANGER

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Abstract: The combined effect of wire coil with twist tape inserted in a circular tube using hot air as the test fluid on heat transfer rate and pressure drop were investigated experimentally. The twisted tape used in this work is made of an aluminum sheet with dimensions (1250 mm length, 18 mm wide, 1 mm thick, twist ratio y =8 and y=5.8). The wire coil was made of copper with diameter (d=3mm), the wire coil with two coil pitch ratio (CR=p/d=10 and CR= p/d=5). Reynolds number used in experiments ranged between (9648 to 18144) and the inlet temperatures for hot and cold fluid are 75^0C and 30^0C respectively. The experimental results showed that combined wire coil with twisted tape gives 1.268 enhancement efficiency higher than those with each device alone and plain tube, also give better performance as compared to the twisted tape and wire coil alone.

Keywords: *Heat Transfer, Twisted Tape, wire coil, Heat Exchanger, Enhancement*.

بحث عملي لتحسين انتقال الحرارة بأضافة شريط ملتوي بقطع دائري مع واير داخل مبادل حراري مزدوج الأنبوب

الخلاصة:تم أجراء بحث عملي لدراسة تأثيراتحاد شريط ملتوي مثقب معسلك لولبي ادخلت في الأنبوب الداخلي للمبادل الحراري على خصائص الجريان (أنتقال الحرارة وهبوط الضغط). الشريط الملتوي مصنوع من معدن الالمنيوم (الطول 1250ملم، العرض 18ملم، السمك 1 ملم، نسبة الألتواء y=8 و y=5.8) اما wire coil مصنوع من معدن النحاس قطره 3 ملم وكانت نسبة الخطوة فيه الى القطر من CR =10 الىCR=5. عدد رينولدز المستخدم في التجارب تراوح مابين (9648-18144) ودرجة حرارة دخول المائع الحار والبارد هي75^0C و30^0C على التوالي.في التجربة كان الهواء الحار يمر داخل الانبوب الداخلي بينما الماء البارد يمر حول الانبوب. النتائج العملية بينت 1.268كفاءة التحسين في اتحاد الشريط الملتوي مع سلك لولبي اكبر من الشريط الملتوي لوحده واكبر من سلك لولبي لوحده وايضا افضل اداء كمقارنة منهما.

1. Introduction

The enhancement system of heat transfer is great significance in improving the performance of these applications. So to implement this goal, many techniques such as (twisted tape, coils, louvers, rings, etc…) can be inserted in heat exchangers to augmentations heat transfer convection by increasing turbulent intensity [2].The earliest works on augmentation, Eiamsa-ard, Promvonge [3], investigated experimentally the convective heat transfer and friction factor characteristics in citcular tube with V-nozzle inserts at a uniform heat flux.Three pitch ratios (PR) of V-nozzle were considered in this study (PR==2.0, 4.0, and 7.0).The results showed that V-nozzle have a significant

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effect on the enhancement of heat transfer rate at about 27% over plain tube. It is found that the smaller pitch ratio (PR=2.0) gives a maximum enhancement about 1.19 due to reverse/ re- circulation flow. Eiamsa-ard, Promvonge [4] studied the effect of helical tapes inserted in a tube on the enhancement of heat transfer with Reynolds number range between (2300-8800). Different parameters were considered such as helical tape with or without acentered-rod. The results show that thehelical tape with rod gives highest enhancement about 10 % more than without rod. Also the result show that the highest Nusselt number is about 50% with using helical tape insert at S=5.0 for Re < 4000. [5] studied experimentally the heat transfer characteristicsby using conical-ring turbulators and a twisted-tape inserted in a circular tube. The different parameter such as Reynolds number range from 6000 to 26000 and twisted-tape with ratios (y=3.75 and y=7.5) were considered in this study. The resultsrevealedthe value of the Nusselt number for the conical-ring and twisted tape was 4 to 8% times more than the values with the conical-ring a lone. The enhancement efficiency is about 1.96 in the tube with the conical-ring and the twisted tape of y=3.75 for Reynolds number over 16000. Murugesan, Mayilsamy, Suresh [6] studied experimentally the heat transfer characteristics by using twisted tape with trapezoidal-cut inserted in circular tube with Reynolds number range between 2000-120000. The results show that the heat transfer coefficient and fiction factor was increased for tape with trapezoidal-cut. Yadav [7] studied experimentally the heat transfer and fiction factor characteristics by using half-length twisted tape inserted in a U-bend double pipe. The results show increasing in heat transfer coifficent about 40% for twisted tap due to swirl or vortex motion.

The objective of this work is to study the effect of combined wire coil with twisted tape and each device alone on enhancement heat transfer.

2. Experiments Apparatus

The experimental rig is presented schematically in figure.1&figure.2; the type of heat exchanger used in this investigation is double-tube heat exchanger. The inner tube was made of copper with dimensions (L=1250 mm length, Di=24 mm inner diameter and t= 1.5 mm thick), the outer tube was made of iron with dimensions (75 mm inner diameter and 3.5 mm thick) as shown in figure (3). The outer surface of heat exchanger was covered by a rubber (25 mm thick) to minimize heat loss and insulate it from surroundings. Air was heated by an electrical heater and supplied through inner tube by a centrifugal fan (270W) then outlet through open loop. Air flow was adjusted by control ball valve to give the flow rates. Water supplied from chilled water tank through outer tube by using centrifugal pumpwith electrical motor having (220V), (0.5 hp), (50 Hz), the flow of water was adjusted by using control valve and measured using flow meter (blue-white F 400) having flow ranges of 0-20 lpm with ±0.1 lpm accuracy. To measure pressure drop at the inlet and outlet of the heat exchanger, water U-tube manometer was used for this purpose. Twisted tape inserted in inner tube was made of an aluminum sheetwith dimensions (1 mm thickness, 18 mm wide, and 1250mm tape length) was fixed from two side. The twist ratio(y) is defined by ratio between twist pitch (H=144mm and H=104mm) to tape width (w=18mm) and (twists ratio y =8 and y=5.8), the holes of 8 mm diameter were made in twisted tape as shown in figure (4-a) and figure (4-b). The wire coil used was made of copper with coil pitches (p=30mm and p=15mm), and two coil pitch ratio. This ratio is define as the ratio of the coil pitch length to the wire diameter (CR=p/d=10 and CR=p/d=5) as shown in figure (4-c) and figure (4-d). The inner coil diameter is 18 mm and the wire diameter is 3 mm then from two side equal 6 mm became 24 mm is the same inner tube diameter. The details of wire coil and twisted tapes inserted in the tube are demonstrated in figure (4-e) and figure (4-f).Four thermocouples type Kwith an accuracy of ± 0.1 K are inserted at the inlet and outlet of inner tube and annulus. These thermocouples were used to sense temperatures of air and water at the inlet and the outlet of inner and outer tubes. A digital thermometer (type TM-903A) was used to read these temperatures.

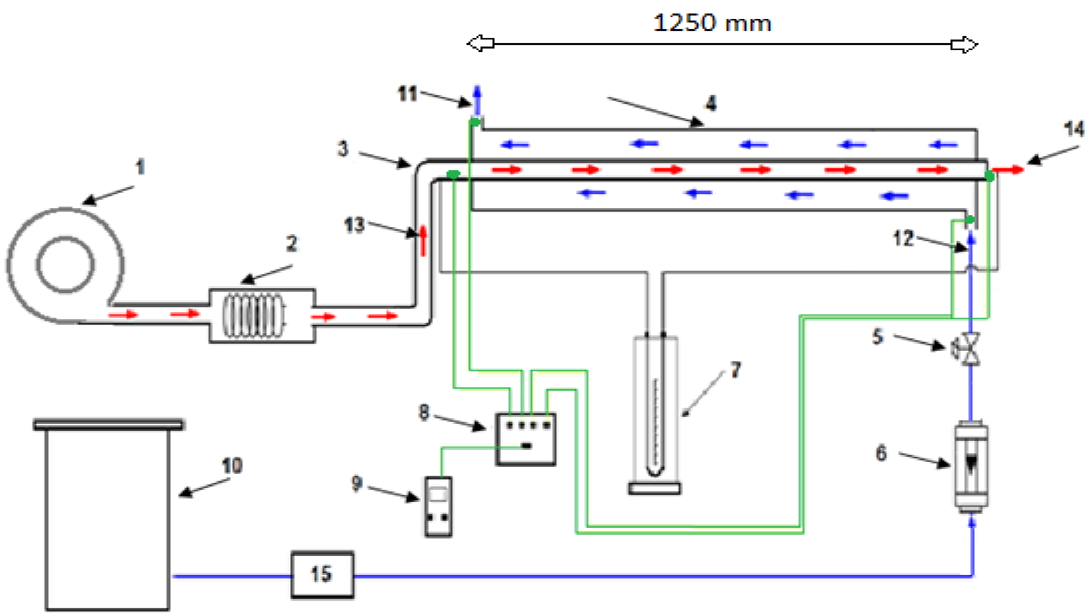

Figure 1. Schematic diagram of experimental apparatus

1.Centrifugal Fan 2.Electrical Heater 3.Inner Tube 4.Outer Tube 5.Control Valve 6. Flow meter 7. U-Tube Manometer 8.Selector switch 9. Digital Thermometer 10.Water Tank 11.Water out 12.Water in 13.Air in let 14.Air out let 15.pump

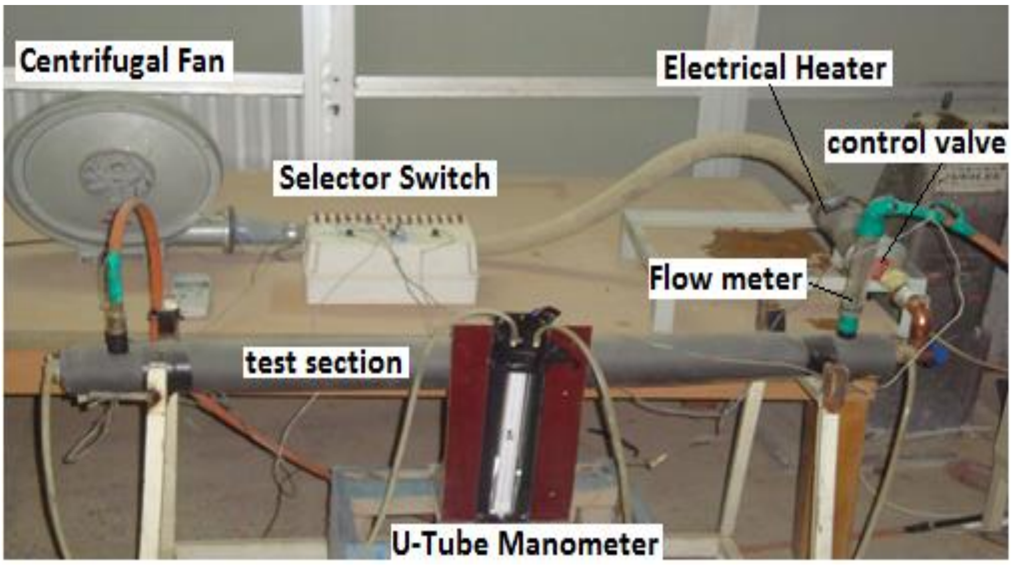

Figure 2. Experimental rig

 https://doi.org/10.31272/jeasd.2018.3.3

Figure 3.Inner & Outer Tubes

Twisted tape characteristics
Thickness, (Z=1mm)
Tape width, (w=18mm)
Twist pitch, (H=144mm and 104mm)
Twist ratio, (y= H/w) (y=8 and 5.8)

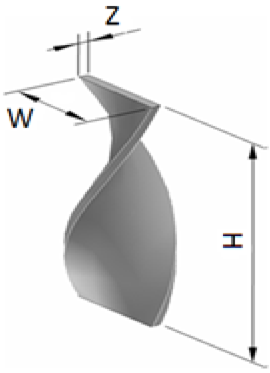

Figure 4-a. Geometrical characteristics of twisted tape

Figure 4-b. twisted tape with hole cut at different twist ratios (y=8 and y=5.8)

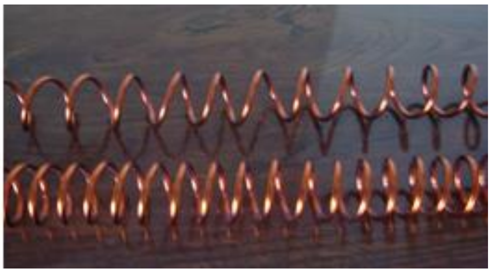

Figure 4-c. Wire coil with two pitch to diameter ratios (CR= 10 and CR= 5)

Wire coil characteristics
Coil pitch, (P=30mm and 15mm)
Wire diameter, d=3 mm
Inner coil diameter, D=18 mm
Pitch to diameter ratio (CR=P/d) (CR=10 and CR=5

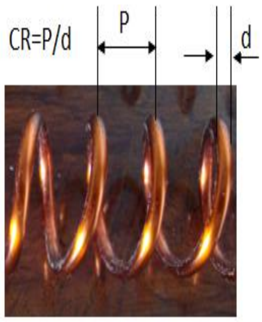

Figure 4-d. Geometrical characteristics of wire coil

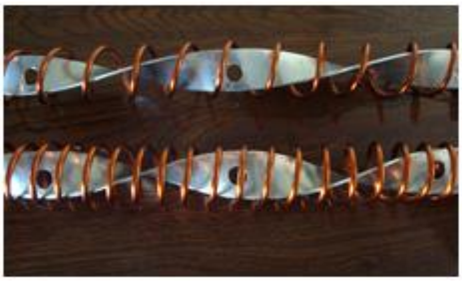

Figure 4-e. combined wire coil and twist tape

Figure 4-f. combined wire coil and twist tape inserted

2.1. Procedure

Firstly, the centrifugal fan was switched on, and then the rate of air flow was adjusted by using control valve. Then the electrical heater was switched on (the temperature of air flow was set to 75± 0.5 ^{0}Cby thermostat. The cold water was pumped from the tank (its temperature was set to 30 ± 0.5 ^{0}C through the flow meter then through the annulus. The system release about half hour to obtain steady state condition, then, temperatures at the inlet and outlet of inner and outer tubes (for air and water) are recorded. Also the pressure drop across the test tube was measured. Eight values of Re was considered from 9648 to 18144 and the experiments was repeated.

2.2. Data Reduction

Heat absorbedQ_c by the cold water can be written as follow:

$$Q_c = m_c Cp_c (T_{c,o} - T_{c,i}) \quad (1)$$

The heat supplied from the hot air,Q_h can be determined by

$$Q_h = m_h Cp_h (T_{h,i} - T_{h,o}) \quad (2)$$

The average heat transfer rate for cold and hot flow is

$$Q_{avg} = \frac{Q_c + Q_h}{2} \quad (3)$$

$$Q_{avg} = UA_i \Delta T_{LMTD} \quad (4)$$

$$\Delta T_{LMTD} = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln \frac{(T_{h,i} - T_{c,o})}{(T_{h,o} - T_{c,i})}} \quad (5)$$

The inner side heat transfer coefficient (hi) is determined by neglecting the conduction thermal resistance of tube wall through.

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} \quad (6)$$

The coefficient of heat transfer for outside tube (ho) was estimated by correlation of Dittus- Boelter [8].

$$Nu_o = \frac{h_o D_h}{k} = 0.023 Re^{0.8} Pr^{0.3} \quad (7)$$

$$D_h = D_o + D_i \quad (8)$$

where, $D_h$is Hydraulic diameter,D_o inner diameter of outer pipe,D_i outer diameter of inner pipe.

Thus, $Nu = \frac{D_i h_i}{k}$ (9)

Where k is calculated by using mean bulk fluid temperature(T_b).

$$T_b = \frac{T_i+T_o}{2} \tag{10}$$

Friction factor f can be written as:

$$f = \frac{\Delta P}{\left[\frac{4L}{d_1}\right]\left[\frac{\rho u^2}{2}\right]} \tag{11}$$

$$\Delta P \text{Deviation } \% = \frac{\Delta P_1+\Delta P_2}{\Delta P_1} \tag{12}$$

whereΔP_1 is the measured pressure drop in this work and ΔP_2 is the calculated pressure drop according to [9] .

The enhancement efficiency (η) is defined as the ratio of (Nussult number ratio with and without inserted turbulator) to the (friction factor for flow with and without turbulator [10, 11].

$$\eta = \frac{\frac{Nu_a}{Nu_p}}{\left(\frac{f_a}{f_p}\right)^{\frac{1}{3}}} \tag{13}$$

Where Nu_a,f_a,Nu_p andf_p for a tube configuration with and without a augmented respectively.

3. Results and Discussion

Fig (5-a) and Fig (5-b) show comparison between the results of friction factor and Nusselt number of the present experimental work with values obtained of the plain tube from the correlation of Blasius equation andDittus-Boelter [1].The comparison show a good agreementwith maximum deviation of (1.36 %) forfriction factor and (7.9) for Nussult number and the results obtained are reliable.

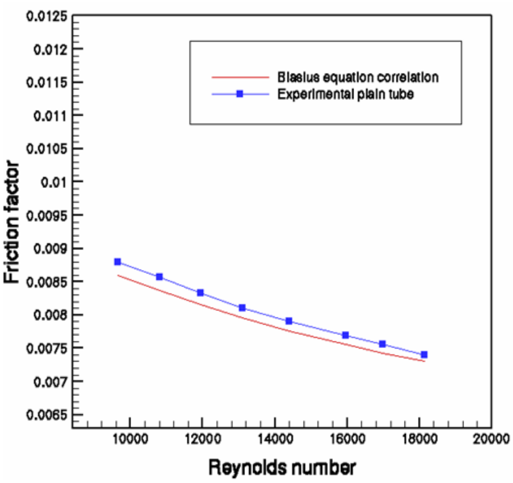

Figure 5-a.data verification of friction factor number for plain tube

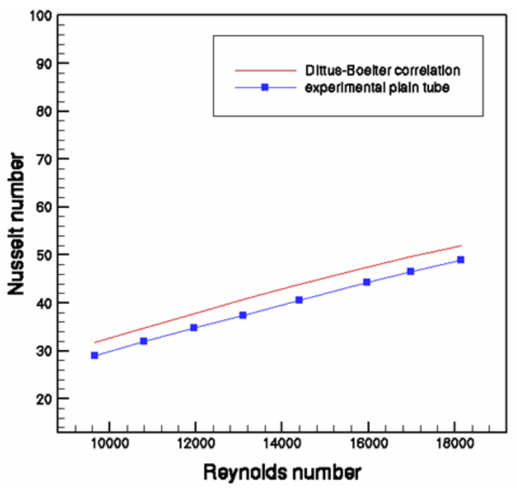

Figure 5-b. data verification of Nusselt number for plain tube

Fig (6) shows the Nusselt number versus Reynolds number for plain tube and twisted tape with circle holes cut insert with two twist ratio (y=8) and (y=5.8) as well as for wire coil insert with two pitch to diameter ratios (CR=p/d=10 and CR= p/d=5) . The Nusselt number increases with increase of Reynolds number for all cases. Also increases with reduction of the twist ratio of twisted tape because the smaller of twist ratio and circle cut improve generation of the turbulent flow and also caused swirl. The figure also report that Nusselt number for wire coil is higher than twisted tape because helical shape of wire coil generated swirl flow near the wall and lead to more turbulence. The Nusselt number for lower values of wire coil pitch to diameter ratios (CR= p/d=5), is higher than that for higher values (CR =10) because of decreasing in wire coil pitch to diameter ratios results in increase in number of turns of wire coil which results in more recirculation zones near the wall that leads to increase the Nusselt number. The Nusselt number in the case of combination of twisted tape with smaller twist ratio (y=5.8) and wire coil with lower pitch to diameter ratios (CR= p/d=5) are more than each device alone and plain tube. This enhancement is due to the strong turbulence intensity generated by the combination which leads to rapid mixing of the flow. Also the decrease in twist ratio and lower wire coil pitch to diameter ratios gives longer flowing path which leads to longer residence time of the flow and more efficient heat transfer.

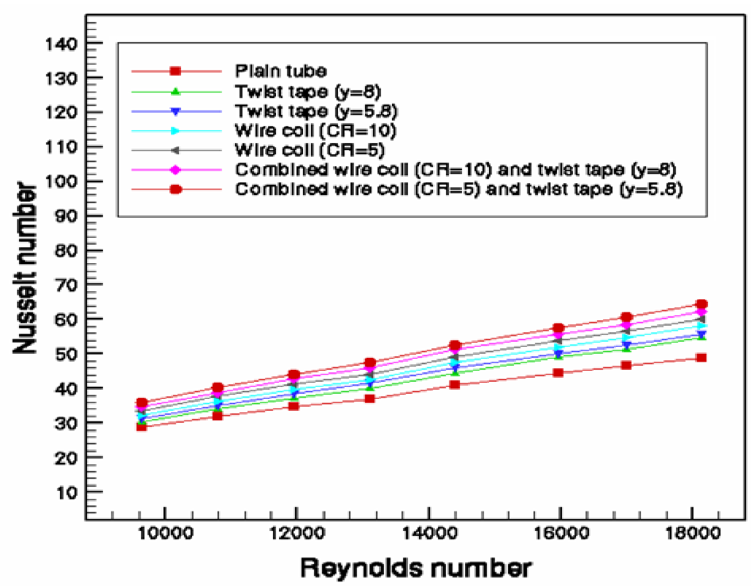

Figure 6. Variation of Nusselt number with Reynolds number

Fig (7) shows that the friction factor decreases with increase in Reynolds number for all cases. At the Reynolds number 18144 the friction facto for plain tube, (twist tape at y=8 and y=5.8), (wire oil at CR= 10 and CR=5) and (combination of y= 5.8 with CR = 5) are (0.00745, 0.00775, 0.00789, 0.00793, 0.00807, 0.00832) respectively .It is observed that friction factor with twisted tape is more than that for plain tube due to friction generated by larger contact surface areas. The friction factor also increases with decreasing twist ratio due to increase in swirl flow. The friction factor for wire coil is higher than that for the twisted tape. Lower wire coil pitch to diameter ratios (CR =5) leads to higher friction factor than higher wire coil pitch to diameter ratios (CR =10) due to increase in swirl flow and wake formation near the wall that leading to increase in drag friction. The combination of twisted tape with smaller twist ratio(y=5.8) and wire coil with lower pitch to diameter ratios (CR =5) gives significantly higher friction factor than each device alone and plain tube because of increasing in swirl flow with longer flow path caused by combination which leads to higher tangential contact between the tube wall surface and secondary flow.

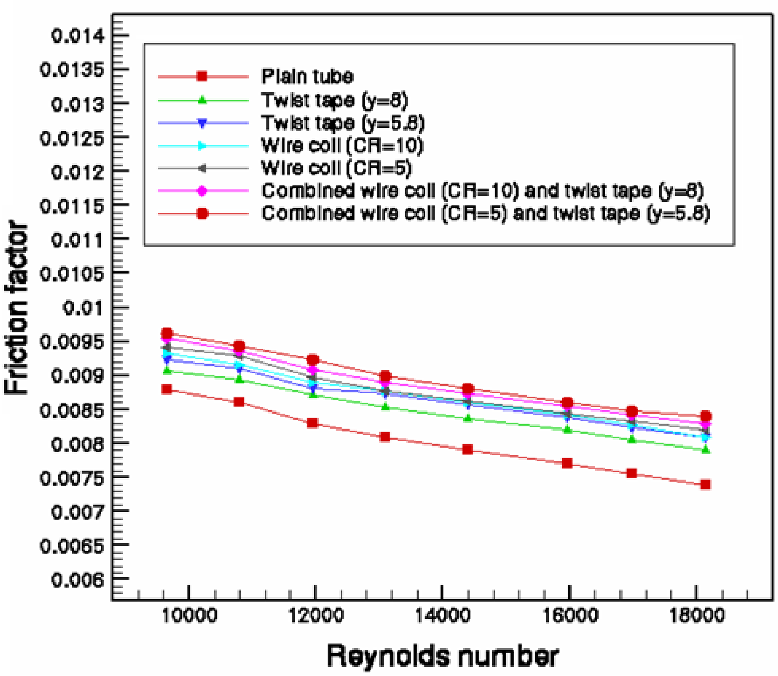

Figure 7.Variations of friction factor with Reynolds number

Figure (8) reveals the enhancement efficiency increases with increasing of Reynolds number for all cases. It is also increase by decreasing both twist ratio (y) of the twist tape and wire coil pitch to diameter ratios. The maximum value at combination of twisted tape with circular cut for smaller twist ratio (y=5.8) and wire coil with lower pitch to diameter ratios (CR= 5) is (1.268). It is observed that the insertion of the combination of twisted tape and wire coil has considerably effect on the enhancement of heat transfer.

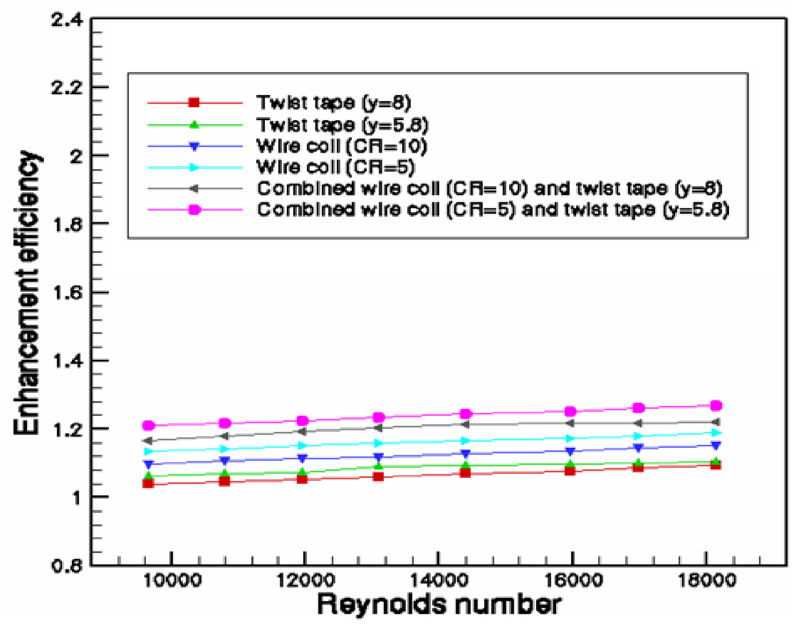

Figure 8.the variations of enhancement efficiency with Reynolds number

4. Conclusions

The experimental investigation has been performed on twisted tape with circular holes as well as wire coil each alone and combined wire coil with twist tape insert in a tube.The enhancement efficiency of (smaller twist tape y=5.8 alone), (wire coil with CR=5 alone) and (the combination of y=5.8 with CR=5) are (1.105, 1.189, 1.268) respectively..It is found that the insertion of combined wire coil with twist tape has considerable effect on the enhancement of heat transfer. In this study the combined wire coil with twist tape gives enhancement efficiency more than each device alone and plain tube also give better performance as compared to the twisted tape and wire coil alone. The enhancement efficiency, Nusselt number and fiction factor increases with reduction of the twist ratio of twist tape and lower wire coil pitch to diameter ratios. .The Nusselt numbers for tube with compound enhancement devices (wire coil and twist tape) are more than each device alone and plain tube. Also enhancement efficiency increases with increasing Reynolds number. The increases in heat transfer, friction factor, and enhancement efficiency are strongly influence by swirling motion induced by combined wire coil with twist tape.

Nomenclature

Q_h	Heat Transfer rate for hot fluid.	(W)
Q_c	Heat Transfer rate for cold fluid.	(W)
Q_{avg}	Average heat transfer	(W)
m_h	Hot air mass flow rate.	(kg/s)
m_c	Cold water mass flow rate.	(kg/s)
CP_c	Specific heat of water.	(kJ/kg K)
CP_h	Specific heat of air.	(kJ/kg K)
f	Friction factor	
L	Tube length,	(m)
K	Thermal conductivity,	(W/m K)
ΔP	Pressure Drop,	(N/m^2)
T	Temperature	(K)
Pr	Prandtl number	$Pr = \frac{\mu\, cp}{k}$
Re	Reynolds number	$Re = \frac{\rho\, v\, d}{\mu}$
u	Mean velocity in tube,	(m/s)
U	Overall heat transfer coefficient,	($W/ m^2\ K$)
h	Convective heat transfer coefficient,	($W/ m^2\ K$)
Nu	Nusselt Number	
A_o	Surface area of outer test tube,	(m^2)
A_i	Surface area of inner test tube,	(m^2)
y	twist ratio	(y= H/w)
CR	The coil pitch ratio	(CR=P/d)
p	helical pitch of wire coil,	(m)
ρ	Density,	(kg/m^3)
μ	Dynamic viscosity,	(kg/m s)
η	Enhacement efficiency	

Subscripts

hhot
ccold
ooutside, outlet
iinside, inlet
$a$augmented

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