ISSN 2395-1621

Heat Transfer and Pressure Drop Characteristics in Laminar and Turbulent Flow in a Circular Duct Fitted with Peripherally Perforated Twisted Tapes

#1 Manoj Hajare, #2 N.C.Ghuge, #3 D.D.Palande

1 manoj.hajare@gmail.com

2 nilghuge@gmail.com

3 palande1@rediffmail.com

#123 Department of Mechanical Engineering, Matoshree College of Engineeing
Nashik, Maharashtra, India

#1 ME Students, #23 Associate Professor

ABSTRACT

To improve the heat transfer in heat exchangers, active and passive techniques are used. Insertion of geometrically modified twisted tapes is one of the popular techniques. Several modifications have been proposed, such as, surface modifications, cuts – Rectangular, V Cuts, bends, pins and perforations. The current work is concentrated on the enhancement of heat transfer by using peripherally perforated twisted tapes. The perforations are of different diameter and the pitch is also varied and the results compared with the plain twisted tape having no inserts. Tapes having three twist ratios are used in the experimentation. The motivation for selection of peripheral perforations is creation of higher turbulence near the tube wall.

The perforation of three different diameters, viz. 3, 6 and 9 mm are made on different tapes and also the pitch selected is twice, thrice and four times the diameter of the perforations. The results from the different twisted tapes are compared with plain twisted tapes having no perforations. The enhancement in heat transfer and increase in the friction factor are studied at different Reynolds numbers.

Keywords— heat transfer enhancement, inserts, perforated twisted tape, Nusselt number

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. Introduction

Heat exchangers are the devices used for transferring heat between two fluids or between a fluid and a surface . Engineers constantly strive to improve the heat transfer by such devices. One of the widely adopted solution is to make use of one of the heat augmentation techniques, either active or passive. Insertion of a twisted tape is one of the effective ways of improving the heat transfer in heat exchangers. The turbulence created by the twisted tapes is the major contributor to the enhancement of the heat transfer. However, using twisted tape increases both desirable heat transfer rate and undesirable friction loss and pumping power (pressure drop). It has been found that, he relationship between heat transfer enhancement and pressure drop is inverse.

To increase the heat transfer coefficient and simultaneously reduce or keep pressure drop at the same level, twisted tapes are generally modified geometrically, however, correct design modification to a twisted tape is a challenging task. The objective is to achieve desired heat transfer enhancement at a reasonable friction loss.

Several modifications have been proposed, such as, surface modifications, cuts – Rectangular, V Cuts, bends, pins and perforations. The current work is concentrated on the enhancement of heat transfer by using peripherally perforated twisted tapes. The motivation for selection of peripheral perforations is creation of higher turbulence near the tube wall.

II. MODIFICATIONS TO TWISTED TAPE

A variety of modifications are studied for the twisted tapes. They are described below.

V-cut twisted tape insert

V-Cuts are introduced in the PTT on both top and bottom alternately in the peripheral region with different dimensions of depth and width to improve the fluid mixing near the walls of the test section.[13]

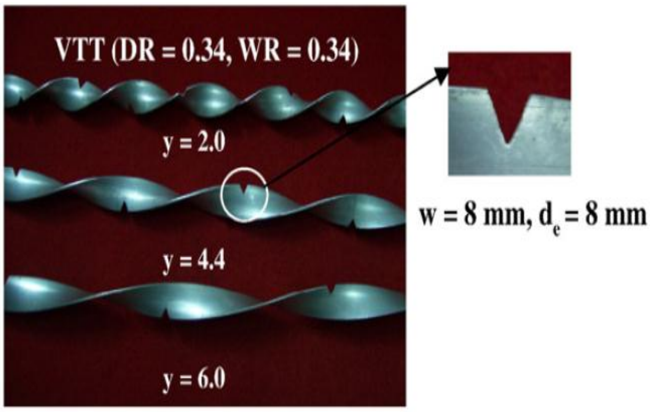


Fig. 2. V-cut twisted tape geometry

ii. Peripherally cut twisted tape insert

The peripherally cut tape comprises the small gaps in the peripheral region of the tape. This style of tape is believed to offer similar mechanism found for the promising twisted tapes.[17]

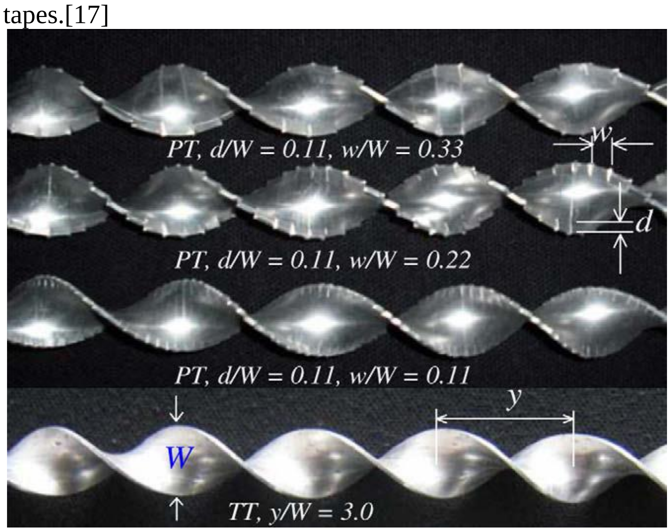


Fig.3. Geometries of peripherally-cut twisted tapes (PTs) and typical twisted tape

iii. Delta-winglet twisted tape

Tape is twisted to produce a typical twisted tape. A tape is subsequently modified to obtain the DWT by cutting at the edge of the tape with oblique shape and straight shape to produce an oblique delta-winglet twisted tape (O-DWT) and a straight delta- winglet twisted tape (S-DWT), respectively. Then the outer part of the cut is arranged to 90o (degree) relatively to the inner part, forming delta-winglet shape[10]

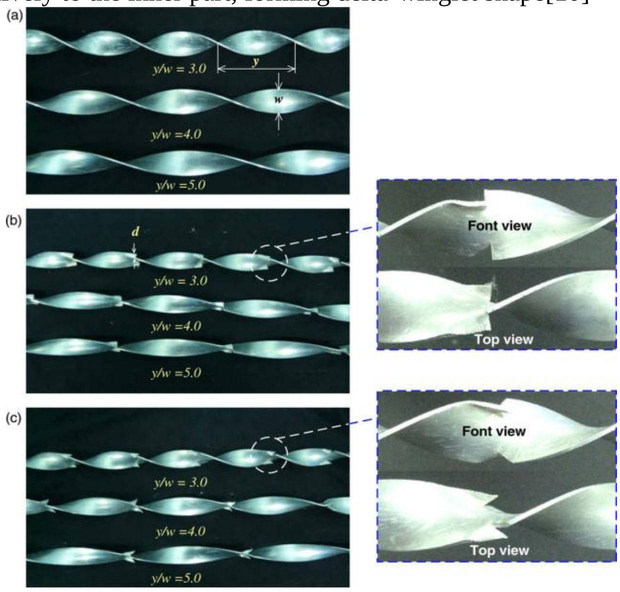


Fig.4. Twisted tape vortex generator: (a) typical twisted tape (TT), (b) straight delta-winglet twisted tapes (S-DWT) and (c) oblique delta-winglet twisted tapes (O-DWT

iv. Rectangular cut twisted tape

The twisted tape is cut in the top region of few mm depth and width rectangular cut to allow the flow from the both sides of the tape to mix at the cut regions. Figure 4 shows the twisted tape.[7]

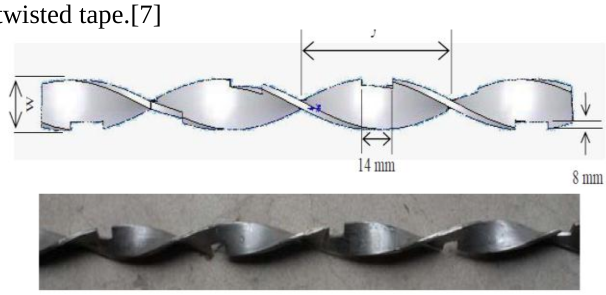


Fig.5. Rectangular cut twisted tape

III.LITERATURE REVIEW

Inserts, as a heat transfer enhancement device has been under intense research. However the significant work on modified twisted tape inserts is reviewed here.

P. Murugesan et.al[13]. conducted experiments to determine heat transfer and friction factor for different twist ratios (y=2.0, 4.4 and 6.0) and three different combinations of depth and width ratios (DR=0.34 and WR=0.43, DR=0.34 and WR=0.34,DR=0.43 and WR=0.34). The results showed that the mean Nusselt number and the mean friction factor in the tube with V-cut twisted tape (VTT) increase with decreasing twist ratios (y), width ratios (WR) and increasing depth ratios (DR). Experimental investigations of heat transfer, friction factor and thermal performance factor characteristics of circular tube fitted with plain twisted tape and V-cut twisted tape for twist ratios 2.0, 4.4 and 6.0 were presented. The V-cut tapes with different depth and width ratios were tested.

The V-cut twisted tape offered a higher heat transfer rate, friction factor and also thermal performance factor compared to the plain twisted tape. In addition, the influence of the depth ratio was more dominant than that of the width ratio for all the Reynolds number.

The thermal performance factors for all the cases are more than one indicating that the effect of heat transfer enhancement due to the enhancing tool is more dominant than the effect of the rising friction factor and vice versa.

The empirical correlations for the Nusselt number, friction factor and the thermal performance factor for PTT and VTT were developed and fitted with the experimental data.

Smith Eiamsa-ard et.al[17] investigated Effects of peripherally-cut twisted tape insert on heat transfer, friction loss and thermal performance factor characteristics in a round tube under uniform heat flux. They tested Nine different peripherally-cut twisted tapes with constant twist ratio (y/W = 3.0) and different three tape depth ratios (DR = d/W = 0.11, 0.22 and 0.33), each with three different tape width ratios (WR = w/W = 0.11, 0.22 and 0.33). Water was used as the working fluid and Re range of 1000 to 20,000 was selected.

The experimental results revealed that both heat transfer rate and friction factor in the tube equipped with the peripherally-cut twisted tapes were significantly higher than those in the

tube fitted with the typical twisted tape and plain tube, especially in the laminar flow regime. The higher turbulence intensity of fluid in the vicinity of the tube wall generated by the peripherally-cut twisted tape compared to that induced by the typical twisted tape was referred as the main reason for achieved results. The obtained results also demonstrated that as the depth ratio increased and width ratio decreased, the heat transfer enhancement increased. They concluded, the peripherally-cut twisted tape enhanced heat transfer rates in term of Nusselt numbers up to 2.6 times (turbulent regime) and 12.8 times (laminar regime) of that in the plain tube.

S. Eiamsa-ard et.al.[10]investigated Heat transfer, flow friction and thermal performance factor characteristics in a tube fitted with delta winglet twisted tape, using water as working fluid. The experiments were conducted using the tapes with three twist ratios (y/w = 3, 4 and 5) and three depth of wing cut ratios (DR = d/w = 0.11, 0.21 and 0.32) over a Reynolds number range of 3000–27,000 in a uniform wall heat flux tube.

The enhancement of the heat transfer in a tube fitted with delta- winglet twisted tapes which act as swirl generator and turbulator was experimentally investigated. The values of Nusselts number and friction factor in the test tube equipped with delta-winglet twisted tape were noticeably higher than those in the plain tube and also tube equipped with typical twisted tape. Nusselt number and friction factor increased with decreasing of twist ratio (y/w) and increasing depth of wing cut ratio (DR) for all Reynolds numbers. In addition, the O-DWT gave higher Nusselt number and friction factor than that of the S-DWT. The thermal performance factor in the tube with O-DWT was greater than that with S-DWT and the factor increases with decreasing Reynolds number and increasing twist ratio. Over the range considered, the performance factor in the tubes equipped with the O-DWT and S-DWT were found to be around 0.92–1.24 and 0.88–1.21, respectively. Several DWT tapes give the thermal performance factor higher than unity while the typical twisted tape provides lower unity. It is obvious that the DWT performs better heat transfer enhancement than that typical twisted tape. It indicated that the heat exchanger fitted with DWT are more compacted than one with the typical twisted tape.

Bodius Salam et.al.[7] investigated tube-side heat transfer coefficient, friction factor, heat transfer enhancement efficiency of water for turbulent flow in a circular tube fitted with rectangular-cut twisted tape inserts under uniform heat flux conditions for a Reynolds number range of 10000 to 19000.

The Nusselt number increased with the increase of Re. The experimental Nusselt number values fell within a broad range of -6% and -25% of the Gnielinski, 1976 value. The experimental Nusselt number values were enhanced by 2.3 to 2.9 times compared to Nusselt number values using plain twisted tapes. An average of 68% enhancement of heat flux was observed for tube with rectangular-cut twisted tape insert than that of smooth tube. The experimental friction factor values were found to be 39% to 80% higher than friction factor values using plain twisted tapes.

IV. EXPERIMENTAL SETUP

The test section length is selected to be 54 mm. Over the test section a plate heater will be installed which will supply heat to the test section. All readings will be taken under constant wall heat flux conditions. A variac transformer is provided to vary the input to the plate heater. The Blower capacity is selected to be 0.5 kW. A calming section is added before the test section having a length of 600 mm to ensure a fully developed flow. The test section also has a length of 600 mm. Manometers are used to measure the pressure drop across the test section. Eight thermocouples are installed evenly across the length of the test section to measure the wall temperature and two thermocouples measure inlet and exit temperature of air based on which the bulk fluid temperature of air are calculated. The properties of air are determined over the mean bulk fluid temperature. To measure the pressure drop across the test section a manometer is used. To measure the air flow rate, a venturimeter is provided at the exhaust side of the blower.

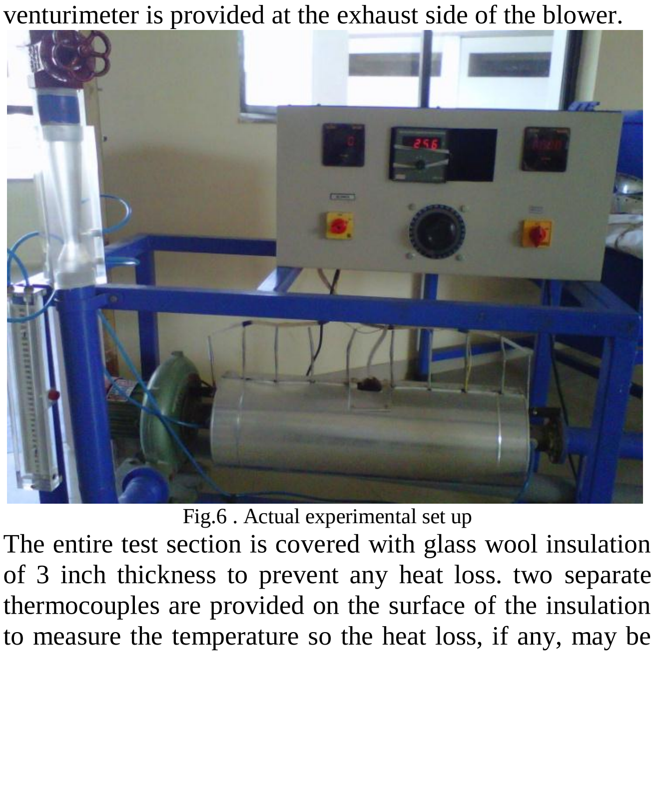
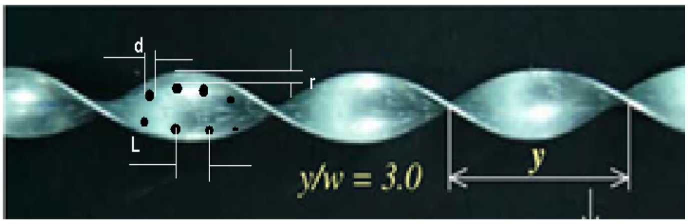


Fig.6 . Actual experimental set up

The entire test section is covered with glass wool insulation of 3 inch thickness to prevent any heat loss. two separate thermocouples are provided on the surface of the insulation to measure the temperature so the heat loss, if any, may be estimated.A control valve is provided on the outlet side to control the flow rate of air.

In the experiments, the plain tapes and perforated twisted tapes are inserted into the tube as shown in Fig. 5. The tube is wound by electrical plate heater to maintain the tube at the constant heat flux condition. The tube is well insulated to prevent heat loss. The insulation used is a 3 inch thick glass wool insulation. The system consists of (1) a heating tube with insulator, (2) thermocouples for measuring the fluid and the tube wall temperatures, (3) a data logger connected with a PC, (4) a variac transformer for controlling the electrical power output to the test section, (5) an amp/volt meter, (6) a centrifugal blower (7) a venturimeter for measuring the volumetric air flow rate, (8) two pressure taps for measuring the pressure drop across the test section, (9) a calm section with the length of 600 mm (or 11D) which connected to the entrance of the heating section for ensuring the fully developed flow of the entering fluid.

In the experiments, the Reynolds numbers of the air is varied in the range between 1000 and 5,000. The Prandtl number values are calculated based on the bulk flow temperature (Tb = (Ti + To)/2). The inlet temperature (Ti) will be maintained at around atmospheric conditions while outlet temperature (To) will be raised depending on the operating conditions by using the input from the variac. During the test, eight local temperatures of the tube wall will be measured using type-K thermocouples while the inlet and outlet fluid temperatures will be measured with another 2 thermocouples. The pressure drop across the test length will be measured with manometers.



Tape Thickness : 3 mm
Tape Width : 52 mm
Twist Ratio : 3

Perforation Dia. 3,5 and 7 mm
Pitch Ratio (L/d) : 2,3 and 4
Material of Inserts : Al

Recess : 5 mm

Fig.7 . Geometry of the perforated twisted tape

To ensure the steady state for each condition, the period of around 25–50 min depending on the Reynolds number and tape shape will be taken prior to the data record. The heat gained by the water in term of enthalpy change will be calculated with the help of following equation.

$$Q_w = MC_p\,(T_o\text{-}T_i) \qquad (1)$$

In the experiments, the heat equilibrium test, it is assumed that, the heat supplied by electrical heating (Q_{VI} = IV) under uniform heat flux condition (UHF) is between 3% and 5% higher than that the heat received by the air (Q_a), this is due to the heat leak from the tube wall.

$$(Q_{VI} - Qa\ )\ x\ 100\%)\ /Q_{VI} \leq 5\% \qquad (2)$$

The average value of heat absorbed by the fluid were taken for internal convective heat transfer coefficient calculation by the following equation,

$$Qc = h_A(\check{T}_s\text{-}\ T_b) \qquad (3)$$

where A is the internal surface of the tube wall (πDL) and Tb is the mean bulk flow temperature (Tb = (To + Ti)/2).

The mean inner wall surface temperature ($\check{T}_s$) of the test tube is calculated from 8 stations of surface temperatures lined between the inlet and the exit of the test tube.

The mean heat transfer coefficient will be determined using equation

$$Q_a = Q_c = MC_{pa}\ (To\text{-}Ti) = h_A(\check{T}_s\text{-}\ T_b) \qquad (4)$$

The mean convective heat transfer coefficient (h) and the mean Nusselt number (Nu) will then be estimated as follows:

$$Nu = hD/k \qquad (5)$$

In the present work, the friction factor in term of pressure drop (ΔP) across the test length (L) determined from a difference in the level of a manometer liquid (carbon tetrachloride or water) will be acquired under an isothermal flow condition and will be expressed as:

$$f = \Delta P/((L/D)(\rho U^2\,/2)) \qquad (6)$$

The thermal performance criteria (g) is defined as the ratio of the Nusselt number ratio to the friction factor ratio at the same pumping power.

$$\eta = (Nu_t/\ Nu_p)/(f_t/f_p)^{1/3} \qquad (7)$$

PARAMETERS

The tests will be conducted in a Re range of 1000 to 5000

Peripherally drilled inserts are used as the enhancement devices

All the inserts have a width of 52 mm and the drill sizes are 3,5 and 7 mm

The pitch of the drilled holes is designated by pitch ratio, expressed in terms of pitch to diameter ratio (L/d) ranging between 2,3 and 4

9 inserts will be tested and the results will be compared with the plain twisted tape insets without any perforations.

Fig.8 Peripherally perforated twisted tapes with different diameter holes and pitch

V.CONCLUSION

A Experimental investigations of heat transfer, friction factor and thermal performance factor characteristics of circular tube fitted with plain twisted tape and peripherally perforated twisted tapes with ratios of 3 and L/d of 2,3 and 4 will be carried out. The size of the perforations will be 3,5 and 7 mm. A total of 9 perforated twisted tapes will be tested and the results will be compared against the non perforated twisted tape.

In this experiment, the twist ratio is kept constant at 3, however, experiments may be conducted to find the effect of twist ratio on the pressure drop and heat transfer characteristics of twisted tapes. The experimentation is being done with air as the working fluid, similar experiments may be carried out with water and other working fluids to determine correlations for heat transfer and pressure drop.

Apart from perforated twisted tapes, several design modifications may be tested for the twisted tapes. These may be, circular cuts on the periphery of the twisted tape, attachment of pins on the surface of the twisted tapes, modifying the surface roughness of the tape by knurling, using twisted tapes which have a zigzag pattern along the length. Naturally, each of the modification will bring in enhancement in the thermal parameters but also undesired increase in the pressure drop characteristics of the tape. Although, a lot of experimentation is being done on the geometric modification of twisted tapes, the prime effort should be to find a promising area of modification where the efforts may be concentrated to find an optimum or near optimum, low cost enhancement. The end result should be commercially viable, low cost, reliable enhancement method which can be readily adopted at the design stage for new heat exchangers and also for retrofitting existing units.

ACKNOWLEDGMENT

Thanks are due to Prof.H.J.Bhangale, Head, Department of mechanical engineering, MCOER, Nashik for his valuable guidance

REFERENCES

[1] Taye Stephen Mogaji , Fabio Toshio Kanizawa , Enio Pedone Bandarra Filho , Gherhardt Ribatski, Experimental study of the effect of twisted-tape inserts on flow boiling heat transfer enhancement and pressure drop penalty, International journal of refrigeration 36(2013), 504-515

[2] Ventsislav Zimparov , Prediction of friction factors and heat transfer coefficients for turbulent flow in corrugated tubes combined with twisted tape inserts. Part 1: friction factors , International Journal of Heat and Mass Transfer 47 (2004) 589–599

[3] Ventsislav Zimparov, Prediction of friction factors and heat transfer coefficients for turbulent flow in corrugated tubes combined withtwisted tape inserts. Part 2: heat transfer coefficients, International Journal of Heat and Mass Transfer 47 (2004) 385–393

[4] Alberto Garcí a a,*, Pedro G. Vicente b, Antonio Viedma, Experimental study of heat transfer enhancementwith wire coil inserts in laminar-transition-turbulent regimes at different Prandtl numbers, International Journal of Heat and Mass Transfer 48 (2005) 4640 – 4651

[5] Alberto Garcı et.al., Enhancement of laminar and transitional flow heat transfer in tubes by means of wire coil inserts, International Journal of Heat and Mass Transfer 50 (2007) 3176 – 3189

[6] Miroslaw Zukowski, An application of infinite regular polyhedrons geometry to design heat exchangers, International Journal of Heat and Mass Transfer 51 (2008) 5851–5858

[7] Bodius Salamet.al., Heat transfer enhancement in a tube using rectangular-cut twisted tape Insert, 5th BSME International Conference on Thermal Engineering, Procedia Engineering 56 (2013) 96 – 103

[8] Z.F. Huang et.al., Enhancing heat transfer in the core flow by using porous medium insert in a tube, International Journal of Heat and Mass Transfer 53 (2010) 1164–1174

[9] Smith Eiamsa-ard , Pongjet Promvonge, Performance assessment in a heat exchanger tube with alternate clockwise and counter-clockwise twisted-tape inserts, International Journal of Heat and Mass Transfer 53 (2010) 1364–1372

[10] S. Eiamsa-ard et.al., Heat transfer enhancement in a tube using delta-winglet twisted tape inserts, Applied Thermal Engineering 30 (2010) 310–318

[11] Xiaoyu Zhang, Zhichun Liu, Wei Liu, Numerical studies on heat transfer and friction factor characteristics of a tube fitted with helical screw-tape without core-rod inserts, International Journal of Heat and Mass Transfer 60 (2013) 490–498

[12] H. Pahlavanzadeh , M.R. Jafari Nasr, S.H. Mozaffari, Experimental study of thermo-hydraulic and fouling performance of enhanced heat exchangers, International Communications in Heat and Mass Transfer 34 (2007) 907–916

[13] P. Murugesanet.al. , Heat transfer and pressure drop characteristics in a circular tube fitted with

and without V-cut twisted tape insert, International Communications in Heat and Mass Transfer 38 (2011) 329–334

[14] P. Sivashanmugam, S. Suresh, Experimental studies on heat transfer and friction factor characteristics of laminar flow through a circular tube fittedwith regularly spaced helical screw-tape inserts, Experimental Thermal and Fluid Science 31 (2007) 301 – 308

[15] Sibel Gunes, Veysel Ozceyhan, Orhan Buyukalaca, Heat transfer enhancement in a tube with equilateral triangle cross sectioned coiled wire inserts, Experimental Thermal and Fluid Science 34 (2010) 684–691

[16] Sibel Gunes et.al., The experimental investigation of heat transfer and pressure drop in a tube with coiled wire inserts placed separately from the tube wall , Applied ThermalEngineering30(2010)1719e1725

[17] Smith Eiamsa-ard et.al., Influences of peripherally-cut twisted tape insert on heat transfer and thermal performance characteristics in laminar and turbulent tube flows , Experimental Thermal and Fluid Science 34 (2010) 711–719

[18] M.A. Akhavan-Behabadi et.al., Effect of twisted tape insert on heat transfer and pressure drop in horizontal evaporators for the flow of R-134a, i n t e r n a t i o n a l j ournal of r e f r i g e r a t i on 3 2 (2 0 0 9) 9 2 2 – 9 3 0

[19] Mengyan Yang, Barry Crittenden, Fouling thresholds in bare tubes and tubes fitted with inserts, Applied Energy 89 (2012) 67–73

[20] Mariusz Markowski, Marian Trafczynski, Krzysztof Urbaniec, Identification of the influence of fouling on the heat recovery in a network of shell and tube heat exchangers, Applied Energy 102 (2013) 755–764

[21] Paisarn Naphon Single-phase heat transfer and pressure drop in the micro-fin tubes