Experimental and Numerical Analysis of Heat Transfer Augmentation Through a Pipe using Twisted Tapes

Mr. Yogesh B. Rakate
M.E. Thermal Student
Department of Mechanical Engineering
Sardar Patel College of Engineering, Andheri (West), Mumbai.

Mr. Kunal Bhavsar
Workshop Superintendent
Department of Mechanical Engineering
Sardar Patel College of Engineering, Andheri (West), Mumbai.

Dr. S.S. Umale
Associate Professor
Department of Mechanical Engineering
Sardar Patel College of Engineering, Andheri (West), Mumbai.

Abstract

The performance of heat exchangers, for single-phase flows in particular, can be improved by many active and passive augmentation techniques. One such passive augmentation technique used for analysis this paper is vortex generation with the help of twisted tapes. An experimental analysis is carried out on a plain tube and tube with twisted tape under different mass flow rates and heat flux. A tube of 48mm diameter and 400mm length was taken for the experiment and a twisted tape of twist ratio y_w=9.09 and thickness 2mm with 400mm length was inserted in the tube. Air supplied through the tube was heated up by the band heater. Temperatures of the air at different sections were recorded with the help of thermocouples. These experimental results are then compared with the numerical model for validation. A parametric study is carried out of different twist ratios of twisted tapes on temperature distribution of air at different section of the tube along its length. Three different twist ratios were considered 9.09, 6.05 and 3.64. Among these it was found that the twisted tapes with 3.64 gave an improved heat transfer as compared to other two twist ratios as well as the plain tube.

Keywords: Augmentation, Vortex Generators, Twisted Tapes, Twist Ratio, CFD

I. INTRODUCTION

The performance of heat exchangers, for single-phase flows in particular, can be improved by many active and passive augmentation techniques. The augmentation techniques used to increase the heat transfer coefficients are classified either active or passive. Typical examples of passive augmentation are surface roughness, displaced promoters, and vortex generators. Surface roughness-introduced through knurling or threading or formed by repeated ribs promotes augmentation through the disturbance of the laminar sub-layer that is close to the surface. These methods are used to improve heat-transfer coefficients inside tubes or outside tubes or rods. Displaced promoters include inserts that alter flow mechanics near the surface by disturbing the core flow. Examples are baffles and mixing elements. Vortex flow can be created through coiled wires, stationary propellers, or twisted tapes.

Active augmentation, which has also been studied extensively, requires the addition of external power to bring about the desired flow modification. Examples include heat-transfer surface vibration, fluid vibration, and electrostatic field introduction of the several methods discussed above.

The most popular and successful technique has been augmentation through surface roughness. This is mainly because of its effectiveness in enhancing the heat transfer and its simplicity in application.

This research paper used augmentation technique of heat transfer through the pipe, which uses reduced width twisted tapes of different twist ratios. In most engineering applications, a geometry enhancement results in both an area increase and a change in the heat transfer coefficient. An important consequence of surface enhancement is the increase in the fluid pressure drop.

There have been many literature surveys and reviews on augmentation of convective heat transfer. Some have been general reviews while others have had more restricted coverage. These surveys generally have addressed the technical aspects of enhanced heat transfer of enhanced tube, that the variation in heat transfer coefficient and friction factor or pressure drop relative to that of unenhanced tube or smooth tubes operating at the same fluid conditions. In present study the heat transfer characteristics and pressure drop characteristics on reduced width and baffled reduced width of different twist ratios over plain tube are considered. Twisted tapes a type of passive heat transfer augmentation techniques have shown significantly good results in past studies.

The twisted tapes act as disturbance to the fluid flow and also creates swirl motion of fluid which increases turbulence and hence boundary layer thickness gets reduced which will result to increase convective heat transfer by reducing convective resistance. So by using twisted tapes heat transfer coefficient can be enhanced in turn augmentation in heat transfer can be achieved. In contrast, it is inevitable to also account for the pressure drop occurring due to twisted tapes.

S.Eiamsa-ard et al. [1] did a case study on thermal performance assessment of a heat exchanger tube equipped with full length and regularly-spaced twisted tapes as swirl generators. From their experimental results they concluded that at similar conditions, full length twisted tapes gave higher heat transfer rate, friction factor and thermal performance factor than regularly spaced ones. The augmented heat transfer, friction factor and thermal performance factor decreased with increasing space ratio.

S.Eiamsa-ard, K. Nanan et al.[2] investigated heat transfer enhancement by perforated helical twisted-tapes. The heat transfer enhancement by P-HTTs with different perforation diameter ratios (d/w = 0.2, 0.4 and 0.6) and perforation pitch ratios (s/w = 1.0, 1.5 and 2.0) were compared to that by non-perforated helical twisted tape, referred as a typical helical twisted tape (HTT) and they concluded that the use of P-HTTs leads to the reduction of heat transfer and friction loss as compared to those of HTT due to a diminishing fluid flow blockage and turbulence intensity. For the range examined, the maximum thermal performance factor of 1.28 is obtained by using the P-HTT with the smallest perforation diameter (d/w = 0.2) and the largest perforation pitch (s/w = 2.0) at the lowest Reynolds number of 6000.

Pongjet Promvonge et al [3] studied experimentally heat transfer augmentation in a helical ribbed tube with double twisted tape inserts. The work was conducted in the turbulent flow regime, Reynold's number ranging from 6000 to 60000, using water as the working fluid. Based on his work he concluded that for the inserted ribbed tube, the Nu tends to increase with the rise in Reynold's number while the friction factor and TEF were decreasing with the increasing Reynold's number. The co-swirl tube yields higher Nu and f than the ribbed tube at higher twist ratio.

Fabio Toshio Kanizawa [4] did evaluation of the heat transfer enhancement and pressure drop penalty during flow boiling inside tubes containing twisted tape insert. They presented experimental data for pressure drop and heat transfer coefficient for two-phase flows in tubes containing twisted-tape inserts. The experiments were performed for R134a as working fluid. In general, it was concluded that the use of reduced twist-ratios values provide higher overall heat transfer enhancement factors for intermediary vapor quality.

In the present work the fluid and thermal behavior of the fluid inside the tube with and without twisted tapes is analyzed experimentally under different mass flow rates and different heat fluxes. The experimental results are validated numerically. A parametric study of different twist ratios was carried out numerically.

II. EXPERIMENTAL SETUP

Fig. 1: Experimental setup

The experimental set-up as shown in Fig. 1 consists of different components which are listed below.

1) Blower.
2) Calming section.
3) Rotameter.
4) Heating element & insulation.
5) Test section.
6) Thermocouples.
7) Control panel.

The blower was used to supply a high-pressure air to the calming section. The calming section was of 1.5 meter long tube & was used to minimize pulsating flow occurred due to the non - uniform supply of air by the blower. The other end of the calming section was connected to the rotameter to measure the mass flow rate. A glass tube type purge rotameter manufactured by Fitzer

India was used to measure the volume flow rate of the air. The range of the product is from 1 lpm to 300 lpm. The flow rate was recorded in lpm and then it was converted to the kg/s unit and mass flow rate was obtained. The band heater was used for heating the test section. This band heater was wrapped over the test section to get uniform heat flux. The band heater has a length 400mm, inner diameter 48 mm and heat capacity of 500 W. The heater was wounded by asbestos rope and cotton cloth as insulation to reduce heat loss to atmosphere. There are two test sections: one is plain tube test section in which there is no twisted tape is inserted in the tube. The other one is test section having twisted tape of twist ratio 9.09 inserted in the tube as shown in Fig. 2. The twisted tape was made up of mild steel.

Fig. 2: Twisted tape

Six calibrated thermocouples made of chromel-alumel (K-type) material were used. One end of each thermocouple was inserted in the grooves made on the test section and other end was connected to control panel. These thermocouples were inserted at 6 intervals of 80mm from section inlet, including the inlet and outlet of tube section, to measure the temperatures of air at different sections. Control panel was used for controlling power rating of heater & measuring different temperatures. For the same power input the mass flow rate was varied in 4 steps and the readings were recorded. And then the power input was varied in five steps. In this way for one power rating we got 4 readings & for 5-power rating we got 20 steady state readings for one test section.

III. Experimental results

Fig. 3 shows comparison of air temperatures at different section of tube with and without twisted tapes with twist ratio y_w=9.09 and Heat flux 432.37 W/m^2 with varying mass flow rate. Fig. 3 concludes that there is very little increase in air temperature near the inlet in case of tube consisting twisted tape, but the air temperature increases as it reaches the exit of the tube gaining the heat supplied from the tube wall. The increase in air temperature of twisted tape as compared to plain tube is small because the twist ratio is large i.e. less number of turns, resulting in lesser heat transfer co-efficient. To analyze the effect of different twist ratio on thermal behavior, numerical method was used which both cost and time is saving.

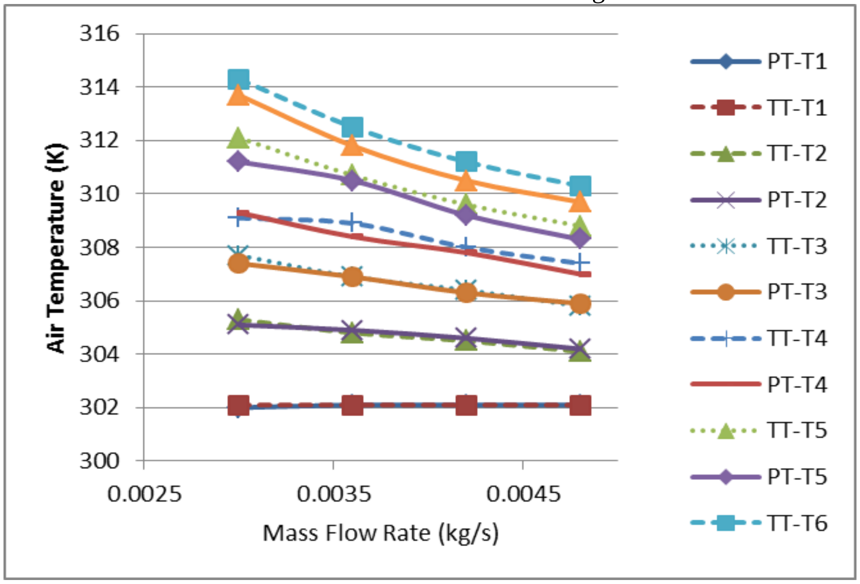
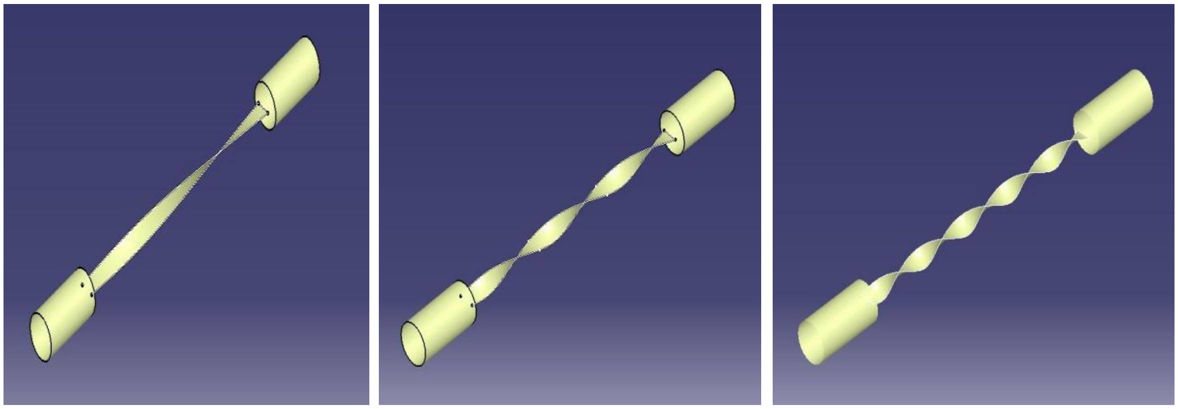


Fig. 3: Air temperatures at different section of plain tube (PT) and with twisted tapes (TT) with varying mass flow rates (yw=9.09 and Heat flux 432.37 W/m2)

IV. NUMERICAL METHOD

A. Physical Modeling:

A 3 dimensional physical model of the twisted tape is created on CATIA V5 software. This model as shown in Fig. 4 (a) is prepared with reference to the actual physical model used in experimental investigation. The length of the twisted tape is 400mm and pitch i.e. distance between two successive twists is taken as 200mm which makes the twisted tape of twist ratio of 9.09. The thickness is 2mm and the width of twisted tape is 22mm. This twisted tape is inserted in a tube with 48mm diameter and 100 mm extra length is provided at both the ends. The extra length is provided to obtain a well-developed flow in the test section. Also a geometry resembling plain tube test section is created which is not inserted with any twisted tape. Dimensions of both the geometries for the tube are same. Two more physical models were created with the same dimensions for the tube but with different twist ratios for twisted tapes, one with a twist ratio of 6.05 and other one with a twist ratio of 3.64 which are shown in Fig. 4(b) and 4(c) respectively. Fig. 5 shows the different part name of the model. Apart from these parts there will be twisted tape wall which will be there inside the tube section.



(a) (b) (c)

Fig. 4: (a) yw= 9.09, 4(b) yw= 6.05, 4(c) yw= 3.64

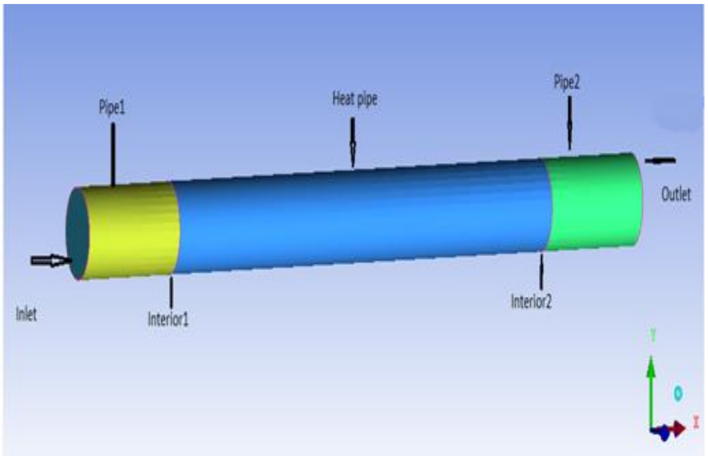
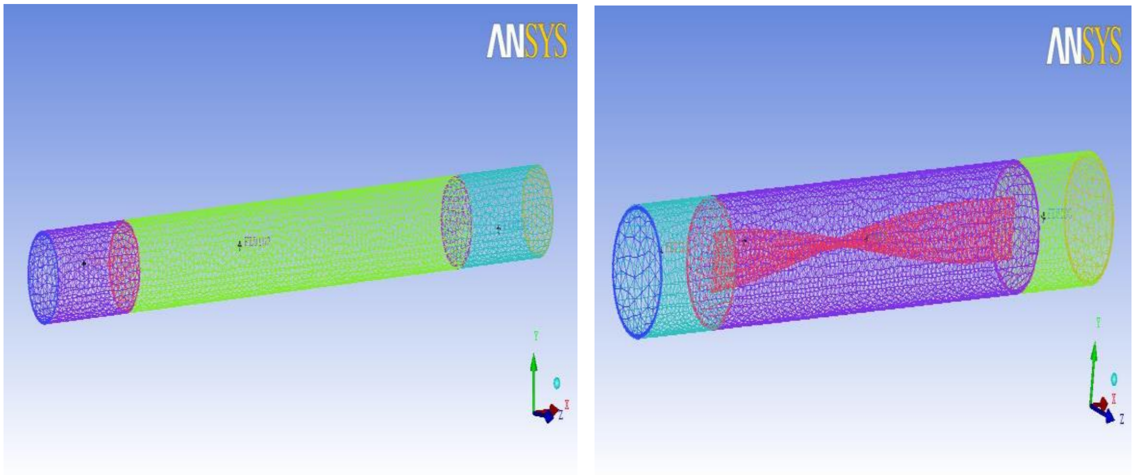


Fig. 5: Physical Model with Part Names

B. Meshing:

The meshing is done in ANSYS ICEM CFD 14.5. The volume mesh is carried out by tetrahedron and prism meshing to capture the boundary layer effect. Robust Octree method was used for meshing. Fig. 6 (a) shows the mesh for the plain tube. The maximum element size applied was 6. And the total numbers of elements created are 113104. The minimum quality of mesh was found to be 0.35, which is considered as good quality. Similarly, Fig. 6(b) shows meshing, with maximum element size 6 for twisted tape section. The total numbers of elements created were 121880 and minimum quality of mesh was 0.31.



(a) (b)

Fig. 6(a) Meshing of Plain tube, 6(b) Meshing of Twisted tape with yw= 9.09

C. Mathematical Modeling:

The physical aspect of any fluid flow is governed by following three principles:

1) Conservation of Mass
2) Conservation of Momentum
3) Conservation of Energy

These principles are represented in mathematical form as partial differentiation equations namely, continuity equation, momentum equation and energy equation.

Apart from the above equations the turbulence models are required capturing the turbulent characteristic of flow. The k-e turbulent model was taken for this case. Table 1 shows the boundary conditions used for the numerical investigation. Operating conditions were kept at Standard Temperature (300K) and Pressure (1.01325 Bar).

A 3-dimensional, steady state, pressure based solver was selected to solve the numerical model on software FLUENT. SIMPLE scheme is used for pressure velocity coupling. Properties of working fluid (air) were as follows:

$$\text{Density}=1.225\text{kg/m}^3$$

$$\text{Specific heat}=1006.43\text{J/kgK}$$

$$\text{Viscosity}=1.7894\text{e}^{-5}\text{kg/m-s}$$

Solution was initialized from inlet and calculated upto 700 iterations after which it converged.

Table – 1
Boundary Conditions

Part Name	*Boundary Type*
Inlet	*Mass flow inlet, Temperature = 302 K*
Outlet	*Pressure Outlet = 1.01325 bar*
Pipe 1	*Adiabatic Wall, No Slip*
Pipe 2	*Adiabatic Wall, No Slip*
Heat Pipe	*Wall with constant heat flux, No Slip*
Twisted tape	*Adiabatic wall, No Slip*
Interior 1	*Interior*
Interior 2	*Interior*

D. Numerical Results:

A grid independence test was carried out on numerical model in order to remove the errors associated with meshing. Fig. 7 shows the grid independence of outlet air temperature with respect to number of elements. It was found that there was hardly any change in the outlet air temperature with respect to the number of elements. Thus, a mesh with 121880 elements was selected for further analysis.

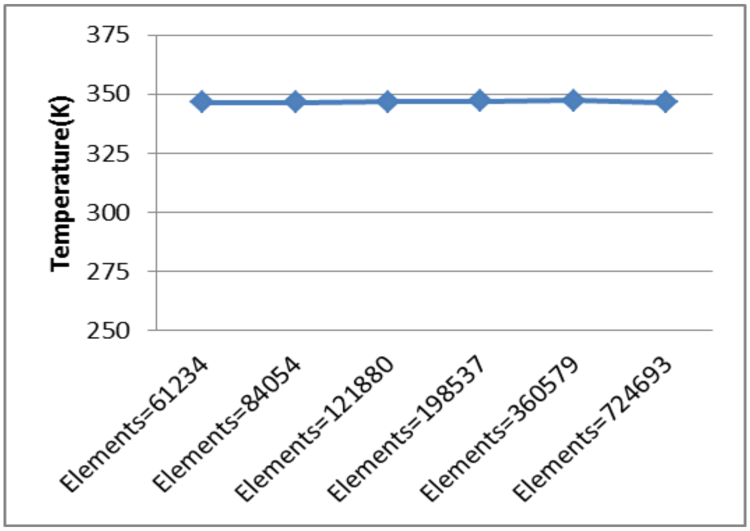


Fig. 7: Grid Independence Test

Then a numerical analysis with twisted tape of twist ratio yw = 9.09, is validated with the corresponding experimental results.

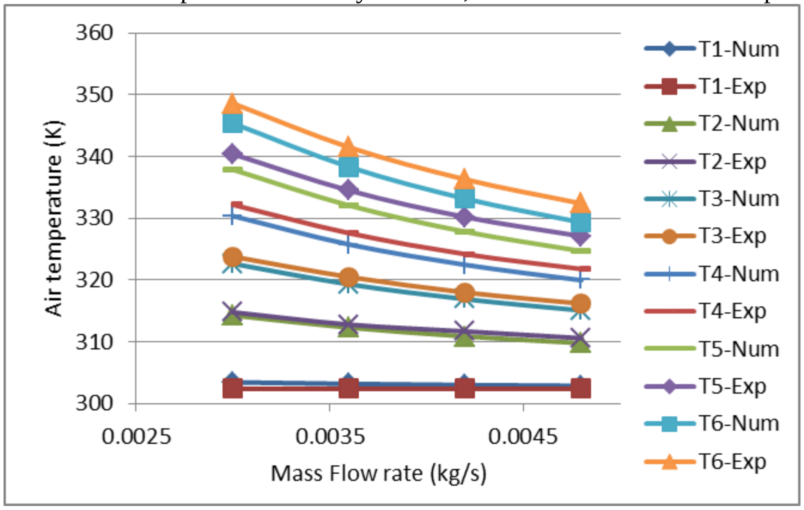


Fig. 8. Comparison of numerical and experimental results of air temperature at 6 sections along the length of the tube with varying mass flow rates

Fig. 8 shows the comparison of numerical and experimental results of air temperature at 6 sections along the length of the tube with varying mass flow rate. It shows that numerical results are in agreement of the experimental results and therefore we can proceed with the analysis of the different twist ratios with the outlet air temperature.

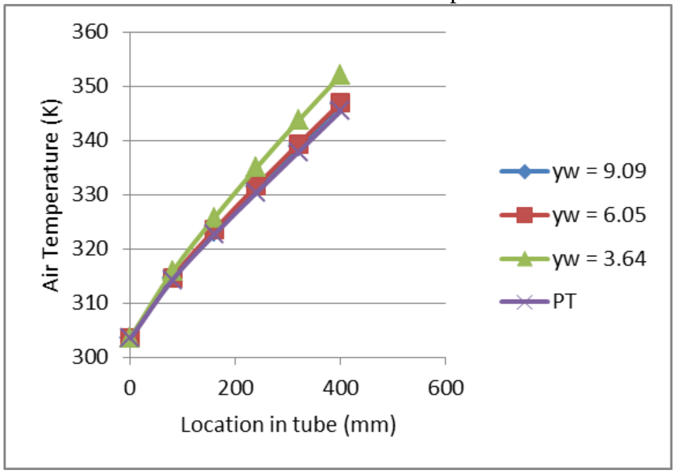


Fig. 9: Air temperature at 6 sections along the length of the tube with different twist ratios and plain tube with mass flow rate m = 0.003 kg/s and heat flux Q = 1783.86 W/m2.

Analysis of different twist ratios on air temperature distribution along the length of the tube is shown in Fig. 9. For this analysis mass flow rate was taken 0.003 kg/s and heat flux of 1783.86 W/m^2 was applied on the tube wall. Three different twist ratios y_w = 9.09, 6.05 and 3.64 were used for this analysis. Fig. 9 shows that there is very little increase in air temperature of twist ratios y_w=9.09 and 6.05 as compared to plain tube. But a change of about 7ºC was found for tube with twist tape ratio, y_w=3.64 as compared to plain tube. Hence, the twisted tape with twist ratio of y_w=3.64 is more effective than plain tube and tube with twisted tapes of twist ratios y_w=9.09 and 6.05.

V. CONCLUSION

An experimental investigation was carried out for analysis of the heat transfer in the tube with and without twisted tapes under different mass flow rates. From the experimental analysis it can be concluded that the tube with twisted tape gave higher temperature as compared to plain tube due to higher heat transfer co-efficient developed by helical twisted tapes. A numerical model was developed based on the experimental model and was analyzed for different twist ratios for different mass flow rates. Numerical results were successfully validated with the experimental results. Thereafter, parametric study of different twist ratios concluded that the twisted tape with twist ratio of 3.64 gave higher heat transfer than the plain tube as well as the other two twist ratios of 9.09 and 6.05. Thus, more the twist ratio more is the heat transfer.

REFERENCES

[1] P.Eiamsa-ard, N.Piriyarungroj, C.Thianpong and S.Eiamsa-ard, "A case study on thermal performance assessment of a heat exchanger tube equipped with regularly-spaced twisted tapes as swirl generators", Case Studies in Thermal Engineering, Vol. 3, July 2014, Pg. 86-102.

[2] K. Nanan, C. Thianpong, P. Promvonge, S. Eiamsa-ard - "Investigation of heat transfer enhancement by perforated helical twisted-tapes", International Communications in Heat And Mass Transfer, Vol. 52, March 2014, Pg. 106-112.

[3] A. Hasanpour, M. Farhadi, K. Sedighi - "A review study on twisted tape inserts on turbulent flow heat exchangers: The overall enhancement ratio criteria", International Communications in Heat And Mass Transfer, Vol. 55, July 2014, Pg. 53-62.

[4] Nasiruddin, M.H. Kamran Siddiqui - "Heat transfer augmentation in a heat exchanger tube using a baffle" , International Journal of Heat and Fluid Flow, Vol. 28, Issue 2, April 2007, Pages 318–328.

[5] Pongjet Promvonge, Somsak Pethkool, Monsak Pimsarn, Chinaruk Thianpong - "Heat transfer augmentation in a helical-ribbed tube with double twisted tape inserts", International Communications in Heat and Mass Transfer, Volume 39, Issue 7,August 2012, Pages 953-959.

[6] Fabio Toshio Kanizawa, Taye Stephen Mogaji, Gherhardt Ribatski - "Evaluation of the heat transfer enhancement and pressure drop penalty during flow boiling inside tubes containing twisted tape insert" Applied Thermal Engineering, Volume 70, Issue 1, 5 September 2014, Pages 328-340.

[7] S. K. Saha and A. Dutta - "Thermohydraulic study of laminar swirl flow through a circular tube fitted with twisted tapes", J. Heat Transfer Vol. 123(3), Jan 03, 2001), 417-427.

[8] Lokanath, M. S. – "Performance evaluation of full length and half-length twisted tape inserts on laminar flow heat transfer in tubes", Proceedings of the 14th National Heat and Mass Transfer Conference and Third ISHMT-ASME Joint Heat and Mass Transfer Conference, IIT Kanpur, India, Paper No. HMT-97-031, 1997, 319-324.

[9] Smith Eiamsa-ard, Chinaruk Thianpong and Pongjet Promvonge - "Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements", Int. Communications in Heat and Mass Transfer, Volume 33, Issue 10, December 2006, Pages 1225–1233.

[10] Saha, S. K. and Chakraborty, D. "Heat transfer and pressure drop characteristics of laminar flow through a circular tube fitted with regularly spaced twisted tape elements with multiple twists", Proceedings of 14th HMTC & 3rd ISHMT-ASME HMTC, IIT Kanpur, India, pp 313-318, 1997.

[11] Sivashanmugam, P. and Suresh, S. "Experimental studies on heat transfer and friction factor characteristics of turbulent flow through a tube fitted with regularly spaced helical screw tape inserts", Applied Thermal Engineering, Volume 27, Issues 8–9, June 2007, Pages 1311–1319.