International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-7, Issue-6, March 2019

Analysis of Heat Energy Transfer and Friction Characteristics for Turbulent Flow in a Copper Tube with Various Inserts.

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Abstract*: *The core aim of presented work is to determine the heat energy transfer and pressure loss in copper tube with various inserts fitted in counter-swirl and co-swirl directionality. The experimented information have been picked for single (ST), twin co-swirl (COS) and twin counter-swirl (CTS) twisted tapes (TT) with twist ratio (TR) 3.5, 4.5 and 5.5 and the Reynolds number (Re) is maintained between 5000 to 15000. The significant growth in heat transfer has been recorded with TT inserts with TR 3.5, the synchronous growth in friction with reference to the plain empty tube. The ultimate rise in the heat energy transfer and frictional losses are achieved to be 2.02 and 4.09 times of the plain empty tube. The highest gained in thermo-hydraulic performance factor has been recorded 1.27 for CTS inserts with TR 3.5. Gain in heat energy transfer is very significant rather than rise in friction factor in terms of overall enhancement in thermal performance of the system.

IndexTerms*: *Heat transfer, Reynolds number, Friction factor, twisted tape, swirl flow.

I. INTRODUCTION

Geometrically profiled tapes have been utilized widely though a swirl generator. It increases the heat energy transfer rate in open passages and economizes the size, weight and cost of the heat exchanging devices in many operations like as thermal engineering processes, heat recovery processes chemical and nuclear reactors and most of the power plants. Twisted tapes inserted circular tubes are also a vital category of the consistent turbulence flow devices which produce twin turbulence flow momentum across a full test tube with stable heat energy transfer rate and frictional losses. Heat energy transfer growth methodologies are classified into two approaches: the Active approach, which demands an outside power, the passive approach, it doesn't demand any outside power. The thermal resistance among the fluid is largely responsible in thermal performance of the heat exchanger. So many methods have been used so far, the circular copper tube with TT inserts is the most efficient method. The TT inserted copper pipe produce turbulence flow and enhance the swirling flow intensity which is significant effective reasons for heat energy transfer rate and avoidable pressure drop. The accurate design modification of the twisted tape is very difficult work and it is a major principle for heat transfer growth at an avoidable frictional losses. So many studies on the circular copper tube by using twisted tapes with various geometrical configurations for heat transfer growth have been performed. P. Promvonge and S. Eiamsa-ard [1] conducted the study on which they have used both the simultaneously twisted tapes and conical rings as swirl generator tabulators to evaluate the heat energy transfer, frictional losses and efficiency in a copper pipe. It has been investigated as if the tube inserted the twisted tape and conical rings gives the higher heat transfer rate 367% and thermal enhancement efficiency was 1.96 times at twist ratio 3.75 as versus with the empty pipe. The Reynolds number range in between 6000 to 21000. The composite of twisted tapes and conical rings gave much better the heat transfer coefficient as compare to simply conical rings. Smith Eiamsa-ard and Pongjet Promvonge [2] performed investigation on the influence of the helical screw-tapes in inserted double pipe heat exchanger on the heat energy transfer rate and friction factor. The helical screw-tapes consist of stainless steel and having geometrical configuration of width 17 mm and pipe wall clearance was 4mm. The Reynolds number range was kept in between 2000 to 12000. Investigation indicated in which loose-fit helical screw without having core rod generate significant heat energy transfer rate results. Pethkool et al. [3] performed experiment in which the helically corrugated tube has been used to rise the heat energy transfer rate in the heat exchanging devices. The consequences in that experiment on the heat energy transfer rate, frictional losses and thermal performance characteristics in helically corrugated tube have been investigated. The Reynolds number range was used in between 5500 to 60000. The helically corrugated tube augmented the heat energy transfer rate and thermo-hydraulic index in the range 123 % to 232 % and 2.3 when compared with the plain empty circular copper pipe. The solid and perforated conical ring inserted circular tube has been used to determine the heat energy transfer rate and frictional flow characteristics with the turbulent flow by Kongkaitpaiboon et al. [4]. The Reynolds number was in the range of 4000 to 20000. The investigation indicates that with diminishing the pitch ratio and perforation the enhancement shown in heat transfer rate. Guo et al. [5] have been reported that the circular tube inserted with centered cleared twisted tapes with short width used in laminar flow to examine the heat transfer rate and friction factor.

Revised Manuscript Received on 30 March 2019.
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The thermal performance factor with centered cleared twisted tapes as comparison to normal twisted tape can be increase up to 7 to 20% by this technique. S. Eiamsa-ard et al. [6] conducted the investigation in that they used the straight and oblique delta winglet TT with different types of TR and wing cut ratios with the Reynolds number range of 3000 to 27000. The experimental analysis has been shown in which the Nusselt number and thermo-hydraulic performance index enhancement on use of oblique delta winglet TT with minimum TR. K. Wongcharee and S. Eiamsa-ard [7] conducted the experiment in which they used alternative-axis and wings twisted tapes like as triangular, rectangular and trapezoidal wings in copper test tube to study the growth of heat energy transfer rate and friction. The best result found in case of alternative axis and trapezoidal wings twisted tapes with maximum enhancement in heat transfer, thermo-hydraulic performance and frictional losses of 2.84, 1.42 and 8.02 as versus with the smooth tube. S. Eiamsa-ard and P. Promvonge [8] used the alternative clockwise and counter-clockwise TT inserts which having various TR and twist angles in circular tubes with the Reynolds number range 3000 to 27000. The investigation indicates the circular tube increase the heat energy transfer rate, frictional flow characteristics and thermo-hydraulic index with using counter clockwise TT as compared with simple TT inserts. S. Eiamsa-ard et al. [9] mentioned in study the effect of counter/co-swirl flow in circular tube by using twin TT with various TR on the heat energy transfer rate and frictional behavior. The Reynolds number range was used 3700 to 21000. The study indicates the counter swirl flow was significantly effective than the co-swirl flow, it enhance the heat energy transfer coefficient and thermal performance index. Chinaruk Thianpong et al. [10] determined the comparative study of dimpled tube and twisted tapes together with various dimpled pitch ratio and twist ratios with the Re range in between 12000 to 44000. The study detected the growth in heat energy transfer coefficient and thermo hydraulic performance index by using diminish twist ratios and pitch ratios. But with utilizing together the dimpled tube and TT the friction factor is undesirably increasing which was not significant for the experiment. S. Eiamsa-ard et al. [11] performed the experiment to determine the enhancement in heat energy transfer coefficient and flow friction characteristics in copper test tube which is having regularly spaced steel TT inserts. In which experiment they used different TR and space ratios with wide variety of the Reynolds number. The significant growth in Nusselt number and frictional characteristics observed due to swirling flow momentum generated by the secondary flow at TR 6 and free space ratio 3 as compared with plain smooth tube. S. Eiamsa-ard et al. [12] studied the significant influence of uniform/non uniform TT inserts with rotated axis length in copper test tube for the variety of 5000 to 21500 Reynolds number. It investigated that after a critical examine the experimental data the non uniform rotated axis length with diminished twist ratio can generate the significant heat transfer and flow characteristics. K. Nanan et al. [13] investigated that the circular tube using helical twisted tapes insert with wide range of the Reynolds number 6000 to 20000. The whole analysis was performed by taking various helical pitch ratios and twist ratios. After a critical analysis of experimental data the results cleared out the thermal performance enhancement of 1.28 times as versus with the smooth tube. The results analysis cleared that the perforation of TT not gave the significant heat energy transfer rate and frictional characteristics with comparison to the without perforated TT. K. Wongcharee and S. Eiamsa-ard [14] conducted the experiment for the laminar flow (Re=830 to 1990) with utilizing the clockwise and counter clockwise TT inserts in circular tubes. The analysis of experimental data cleared that the counter clockwise twisted tapes with minimum twist ratio gave better heat transfer growth. S. Eiamsa-ard et al. [15] conducted an investigation that those implemented short length twisted tapes in circular tubes with a vast variety of Re in between 4000 to 20000. The investigation of data gave the thermal enhancement of the test tube using short length TT inserts was not so significant as compared to the full length TT inserts. S. Eiamsa-ard et al. [16] conducted the examination in that they used serrated TT insert in copper tube to observe the thermo hydraulic characteristics. They used vast variety of Re in between 4000 to 20000. The complete analysis in experiment indicated that the significant growth in heat transfer 72.2 % compared to the plain circular smooth tube. P.S. Kathait and A.K. Patil [17] performed the experimental investigation in the heat exchanger on the increment of heat energy transfer coefficient and friction characteristics with using the discrete corrugated rib roughness in tube. The critical observation of the experimental data indicated that corrugated round tube with 5 number of space carried 2.73 and 2.78 growth the heat energy transfer rate and friction factor characteristics. C. Vashisth et al. [18] conducted the experiment in which they used a twisted tapes inserts of versatile geometries and twist ratios (2.5, 3 and 3.5) in a copper tube of heat exchanging devices. The Re range in between 4000 to 14000. The strong investigation of data indicated that heat transfer growth and thermo-hydraulic performance 2.42 and 6.96 times as compared to the plain smooth while using the four set of counter twisted tape. The review of literature survey indicates that the wide range of circular tube configurations, materials and inserts have been studied to examine the growth of heat energy transfer rate and frictional characteristics. This is found by the previous studies which the friction factor continuously enhances with the growth of heat transfer rate by use of various inserts in plain circular tube. It is not an ordinary task to select an appropriate configuration of insert in the direction where friction propagated and the Nusselt number is boosted. This has been indicated by the several previous studies in which the application of more inserts in option to alone insert resulted in superior heat transfer increments. To fulfill the demands futuristic investigation of multiple inserts in copper test tube of heat transferring devices, the current examination has been selected to explore the heat energy transfer rate and friction flow behavior alternatives within copper test tubes with twisted tapes insert. The study information acquired for single, twin counter swirl and twin co-swirl TT inserts with TR 3.5, 4.5 and 5.5 while the Reynolds number in between 5000 to 15000.

The empty tube experimental data are similarly taken to check the difference of effects with various types of inserts in copper tube. The heat energy transfer rate and frictional losses of copper tube with TT inserts are shown with the Nusselt number and friction factor graphs as feature of TR (y) and Re. The growth carried out by the application of various inserts in copper tube are indicated across the volatility of Nusselt number and friction factor growth ratios for the full range of Re appreciated over such analysis. To verify the pattern of heat energy transfer rate and fluid motion within a copper test tube having various inserts. The fluid motion pattern is deliberated with the support of computational momentum plots.

II. EXPERIMENTAL OBSERVATION

To investigate the heat energy transfer rate and frictional behavior of copper test tube inserted with various categories inserts, the experiential methodology is accepted in this research article. The experimental details in terms of wall surface temperature of tube, the fluid's enter and exit temperature, flow rate and pressure drop with in the copper test tube are acquired under diverse current constrains and dimensions of the experiment.

A. Experimental Apparatus

The investigations are performed with utilizing an experimental apparatus whose schematic drawing is presented in the figure 1. The experimental facility made up of copper circular tube with an inner diameter (D) of 25 mm, length (L) of 1200 mm and thickness (δt) of 1.5 mm. The full length of apparatus tube is inserted by various categories of TT like a ST, COS and CTS order. The water is the working fluid in this complete analysis, which is consistently fall from the stable head water reservoir at 3 m elevation from the ground. As per demand of the experimental analysis the glove valve controls the working fluid water flow rate. To evaluate the discharge of the flow of water the rotameter is placed just after the glove valve which can evaluate up to 3000 LPH. To avoid the undesirable entrance effect of the flow of the test tube portion the calming section provided, which is made up of copper tube with a length of 2000 mm. To diminish the vibration effects and flow fluctuations the rubber bellows were used. The one part of heating test tube is fixed with the mixing portion while the heated water is authorized to arrive blended perfectly by three baffles, which is placed inside the tube at 130 mm apart in mixing section. Other portion of the copper tube enclosed with calming section, after the calming section and mixing portion, the thermocouples are employed to evaluate the temperature of working fluid water. The tube is uniformly rolled by Nichrome wire with ceramic beads coated element throughout the total outer surface to allow the uniform heat flux boundary conditions. To alter the tube wall heat flux by accommodates the potential difference (2-220 V) and current (9-15 A) the Variac transformer is used which is connected to the terminals of the heating element. The glass wool insulating foam is used as insulation over the entire test tube to diminish the heat losses from the surroundings. The PT-100 type thermocouple is utilized in the test facility to evaluate the surface temperature of the tube. The set of 10 PT-100 type thermocouples are utilized along local test tube wall for 10 different locations to tracking the temperature of surface of tube and two dipped thermocouples are used at inlet and outlet of apparatus tube to calculate the temperature of water. The PT-100 type 16 station temperature indicator is also utilized to measure the temperature from the willing station. To evaluate the pressure difference at a desired flow rate is used the micro manometer in the experimental set up.

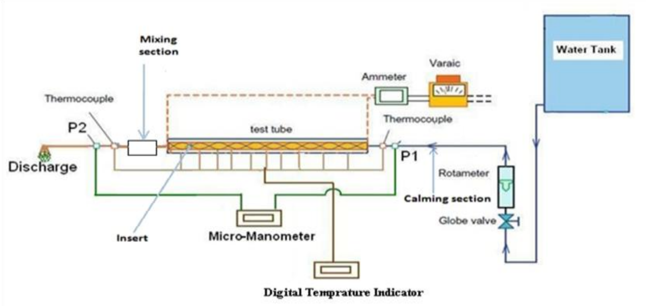


Figure 1. Schematic diagram of experimental apparatus

B. Experimental Procedure

The water is circulated at a willing flow rate from the stable head reservoir, during the analysis inserts is inserted separately in the test tube. The Variac transformer set the heat flux of heater is tolerated to attain the steady state throughout every variable of the Re. After adjusting the discharge and heat flux, the copper test tube wall surface temperatures, water inlet and outlet temperatures are seen. In starting the readings of surface temperature and water temperature are unsteady and come near to the higher values with time. After 25 minutes it has been experienced where the operating system is attained to in stable condition, which indicate the temperature at all the stations becomes freestanding with time. Quickly after attaining the stable conditions, the surface temperature among ten stations and inlet and outlet water temperature are evaluated. Through the support of a micro-manometer the difference of pressure of copper test tube is determined. The experimental information for heat energy transfer rate and frictional behavior throughout the total variety of experiment to be collected and repeated the whole methodology of experiment by changing the value of Re in terms of flow rate. The various arrangements of TT inserts are examined with changing the range and working conditions in the reviewed variety by accompanying the foresaid procedure.

C. Configuration of twisted tapes

During the experiment, the circular copper tube is inserted of various twist pitch and width to compile the data regarding the heat transfer and friction. The all TT operated in this presented work consist of twisting the aluminum strips. The three various geometries inserts are placed, namely (ST), (COS) and CTS inserts with TR 3.5, 4.5 and 5.5. Figure 2 reveals the configuration of various categories of inserts utilized in present experimental work. The variety of configurationally dimensions of twisted tape inserts is given below inside the table 1.

Table 1 Details of TT insert

TT	ST	COS	CTS
Tape width (w)	24 mm	12	Same as COS
Tape pitch length(l)	84, 108 and 132 mm	42, 54 and 66 mm	Same as COS
Twist ratio (y)	3.5, 4.5 and 5.5	Same as ST	Same as COS
Tape Thickness (δ)	0.8 mm	Same as ST	Same as ST
Material	Aluminum	Same as ST	Same as ST
Swirl type	Single swirl flow	Co-swirl flow	Counter-swirl flow

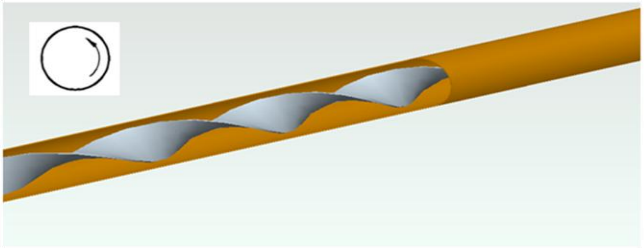


Fig. 2(a) Copper tube with ST inserts.

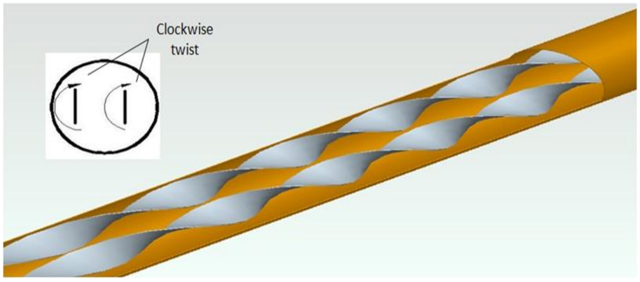
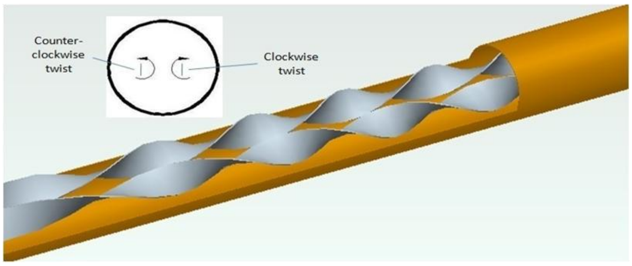


Fig. 2 (b) Copper tube with COS inserts.



D. Uncertainty in Test setup

To procure the uncertainties for evaluations the diminish data are examined. The uncertainty in the experimental data evolution is according to the theory given by Kline and Mc Clintock [19]. The higher uncertainties of non-dimensional dimensions are ± 4.26 % for the Reynolds number, ± 3.87 % for the Nusselt number (Nu) and ± 6.85 % for the friction factor. The uncertainty in the velocity of flow in test tube is ± 4.03 % and pressure has a approximating rated uncertainty of ± 5.92 %.

E. Heat energy transfer and friction factor measurements

Under uniform heat flow conditions in this experiment, working fluid water is utilized which propagate within the copper test tube. The accompanying methodology is used to change the experimental data in terms of flow rate, temperature and pressure into the major characteristics of fluid motion and heat energy transfer rate. The heat energy losses from the test section are estimated to be equal to the heat energy transfer rate at steady state which possibly stated as:

$$Q_{fluid} = Q_{convection}$$

Where the heat energy receive by the working fluid water may be expressed as,

$$Q_{fluid} = mC_p(T_{out} - T_{in})$$

The convective heat energy transferred from the surface of tube wall can be expressed as,

$$Q_{convection} = hA_s(T_s - T_b)$$

Where T_s is the average temperature of surface test tube wall and T_b is the average temperature of water at inlet and outlet of test tube.

$$A_s = \pi D L$$

Where A_s is the surface area of the test tube, D and L are the diameter and length of the copper test tube. The average heat transfer coefficient (h) of surface of the test tube is calculated by balance of the energy equations as,

$$h = \frac{mC_p(T_{out} - T_{in})}{A_s(T_s - T_b)}$$

In the experimental analysis results, the average Nusselt number is calculated as follow,

$$Nu = \frac{hD}{k}$$

Where k is the thermal conductivity of the working fluid water which evaluated from the fluid properties at the local mean bulk temperature ($T_b = (T_{out} + T_{in})/2$). The friction factor of test tube with or without inserts may be evaluated by pressure drop ΔP, across the test tube total length.

$$f = \frac{2D\Delta P}{L\rho U^2}$$

Where ρ is the density of the working fluid water at mean bulk temperature and U is the average velocity of water evaluated from flow rate of water. All the thermal physical properties of working fluid water, Nu and Re are evaluated on the basis of local mean bulk temperature. The Reynolds number evaluated as:

$$Re = \frac{UD}{\nu}$$

Where, ν is the kinematic viscosity of the working fluid water at mean bulk temperature. It is very crucial to acknowledge the current plain smooth tube data of Nusselt number and friction factor in perfectly generated motion of water with the correlations from the old investigations.

In the current investigation, the Nusselt number and friction factor from the data are versus with correlations given by Dittus-Boelter and Blasius [20].

III. VALIDATION OF EXPERIMENTAL APPARATUS:

The validity of the investigated data is checked with predicting the data on heat energy transfer rate and friction factor characteristics for plain empty test tube without inserts. The Nusselt number and friction factor data toward flow across the empty test tube are matched with the data received by the Dittus-Boelter and Blasius standard correlations.

Dittus-Boelter correlation:

$$Nu=0.23Re^{0.8}Pr^{0.4}$$

The graphs presented in Figure 3 and 4 on the Nusselt number and friction factor, which obtained from the investigated data regarding to heat transfer rate and friction factor within empty test tube are matched with data received from the foresaid correlations. According to Dittus-Boelter and Blasius correlations the average absolute deviations for the empty test tube in the experimental data for Nusselt number and friction factor are detected to be 2.55% and 5.24%, appropriately.

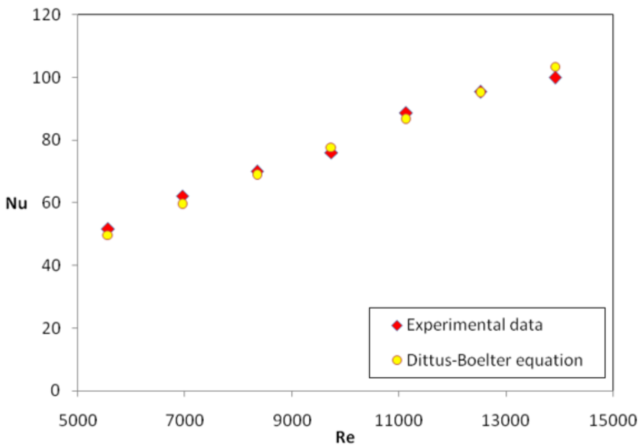


Figure 3. Validation of empty tube Nusselt number.

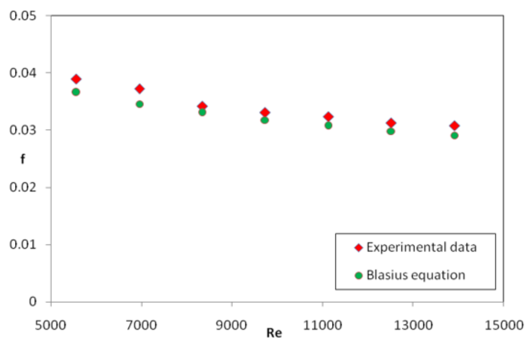


Figure 4. Validation of empty tube friction factor.

IV. EXPERIMENTAL RESULTS ANALYSIS AND DISCUSSION:

In present segment, the heat energy transfer rate, frictional behavior and also thermal hydraulic performance within copper test tube inserted with COS and CTS are shown which is obtained from the calculations of the experimental data. The experiments are conducted using single and twin TT with three various TR, y = 3.5, 4.5 and 5.5 for the wide range of Re 5000 to 15000. As cleared already, Nu and Re are evaluated with the help of diameter of copper test tube. The experimental data are investigated for the terms of Nu and friction factor (f) against Re. At same pumping power level, analyzing the thermal hydraulic performance index of heat energy transfer activators for the heat energy transfer rate growth potency is investigated.

A. Effects of the Reynolds number:

Figure 5 and 6 presented that at the TR (y) 3.5, the Nu changes with the variation in Re for the copper test tube with or without TT inserts. Which can be clearly noted that by these plots the Nu is directly proportional and f is inversely proportional to the Reynolds number, which means on increasing Re the Nu is increasing and f is decreasing. The highest value of Nu and f predicted at the CTS inserts for the entire variety of Reynolds numbers. The graphs indicate that significantly maximum values are attained by Nu and f as an investigation of the use of the TT inserts.

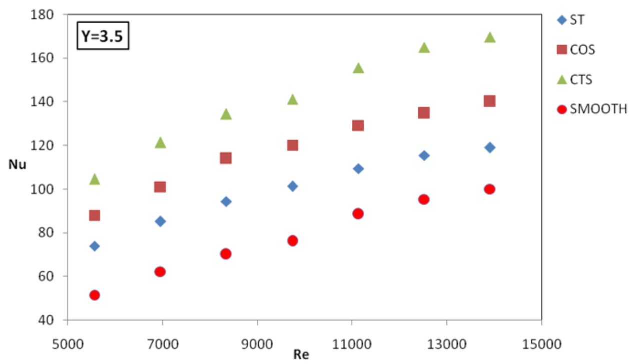


Figure 5. Plots of Nusselt number versus Reynolds number for TT inserts at TR 3.5.

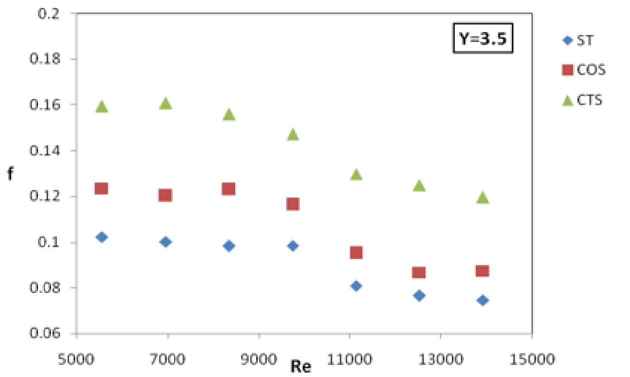


Figure 6. Plots of friction factor versus the Reynolds number for TT inserts at TR 3.5.

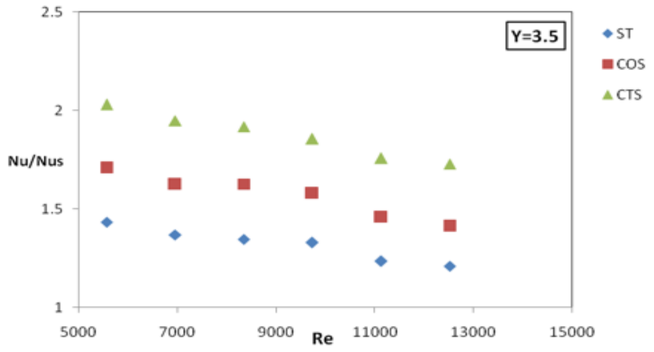


Figure 7. Plots of Nusselt number enhancement ratio versus Reynolds number for TT inserts at TR 3.5.

At the twist ratio 3.5 the maximum growth is predicted in the Nu and f enhancement ratios with the Re, which are presented in figure 7 and 8. The growths in the Nu and f enhancement ratios are shown within the manner of when the copper test tube inserted ST, COS and CTS. The Nu and f enhancement ratio variations with the Re at the TR of 5.5 and 4.5 are in keeping with flow viewed in the scenario of the TR 3.5 except the influence of the Reynolds number on these dimensionless parameters is restrict as the twist ratio enhanced.

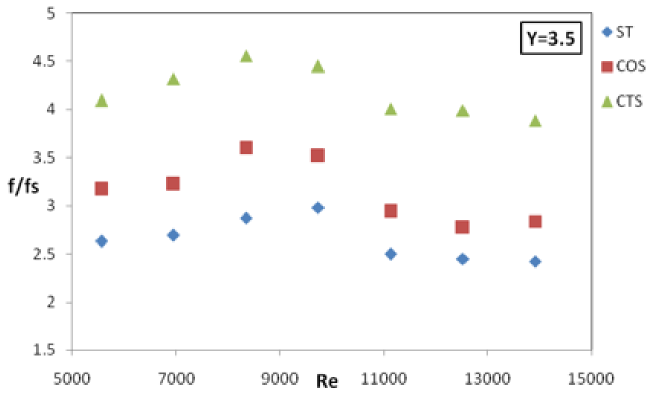


Figure 8. Plots of friction factor enhancement ratio versus Reynolds number for TT inserts at TR 3.5.

The plots of figure 9 and 10 of the Nu and f in flow to understand exactly the influence of variation in the Re on the heat energy transfer rate and frictional behavior in copper test tube with various TT inserts with various TR. As the number TT inserts increased the greater effect of Re on the Nu and f can be noted.

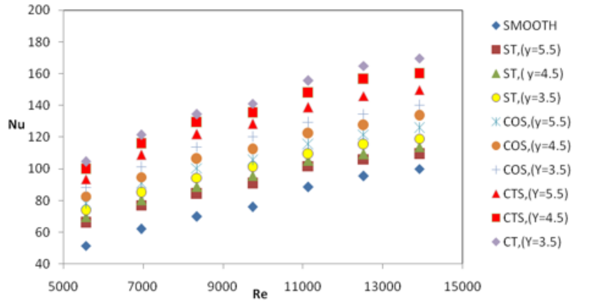


Figure 9. Plots of Nusselt number versus Reynolds number for TT inserts.

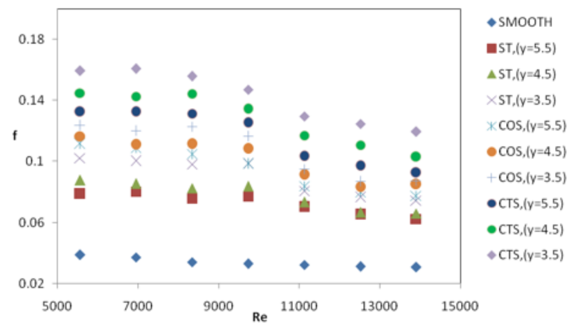


Figure 10. Plots of Friction factor versus Reynolds number for TT inserts.

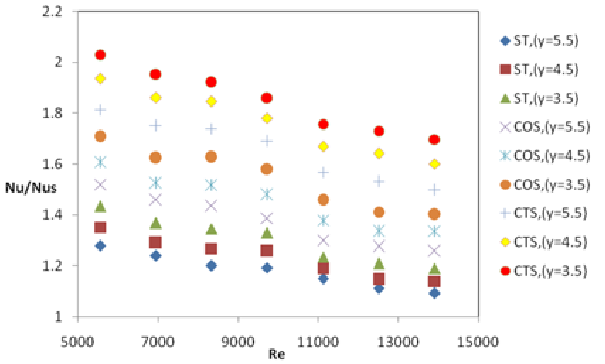


Figure 11. Plots of Nusselt number enhancement ratio versus Reynolds number for TT inserts.

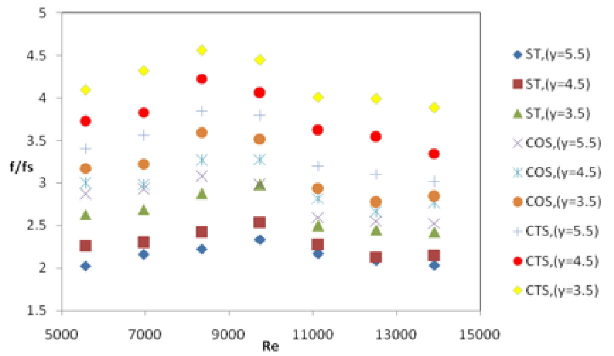


Figure 12. Plots of Friction Factor enhancement ratio versus Reynolds number for TT inserts.

Figure 11 and 12 indicates the Nu and f enhancement ratios with the variation in Re for the various TT inserted copper test tube with different TR. The Nu enhancement ratio decreases with increase in the Re in all various TT inserts that represent the range should be running for the lower value of the Re to gain significant heat energy transfer rates. The Nu enhancement ratio lie in the range of 1.19-1.43, 1.48-1.70 and 1.72-2.41 for the copper test tube utilizing the ST, COS and CTS inserts, if the TR is maintained at 3.5. The f enhancement ratios are lie in the order of 2.42-2.62, 2.83-3.17 and 3.88-4.09 for the above configurations of the inserts.

B. Influence of the twist ratio (y):

The effect of TR like 3.5, 4.5 and 5.5 on the heat energy transfer rate with in copper test tube inserted with the ST, COS and CTS is presented in figure 9. By the critical examination of investigated data, it can observed that the heat energy transfer rate growth and TR inversely proportional to each other. If the TR increases the heat energy transfer rate decreases and if the TR decreases the heat energy transfer rate increases for the working fluid water. This can be explained the actuality when the working fluid water strikes on the surface of the TT inserts tangentially and the tangential velocity portion generate a centrifugal force that recovers the boundary layer phenomenon. The zone stricken by the centrifugal force expands and appropriately boots the swirl richness of the water close to the boundary of the test tube. The huge turbulent regions have the potential to increase the heat energy diffusion amount and as a result indicate a significant gain in the Nu and f. The figure 9 to 12 plots indicate the significant performance of the CTS inserts at TR 3.5.

C. Influence of COS and CTS:

The influence of the COS (co-swirl generators) and CTS (counter–swirl generators) on the Nu and f enhancement ratio can be seen in figure 11 and 12. The investigation received for the test tube inserted with ST and the plain smooth tube is already utilized for the difference. The effect for the counter-swirl twisted tape (CTS) inserted test tube on the Nusselt number is vital throughout the Re range. In the current investigation, the methodology of the turbulence momentum in the twisted tapes ST, COS and CTS inserted test tube with working fluid water is presented. The maximum number of stream produced by the twin tapes is liable for the much better blending of the working fluid which is flow through the test tube and thus superior Nusselt number as investigation indicated in figure 9 plots. The similar swirl motion are produced in flow region due to the COS whereas the CTS arises turbulence in the just opposite direction simultaneously, thus generating significant anticlockwise-acting fluid streams, which enhance the whirl velocities of the working fluid water within the boundary of copper test tube. With the action of anticlockwise-swril motion the secondary flow generated due to which the richness of the turbulence raises which helps in the blending of the working fluid and activates the steady boundary layer inside surface wall of the copper tube. The working fluid change the flow pattern in the central core zone in the direction of surface of test tube where the peak velocity flow strikes across the test tube wall, thus obtaining significant intensity of the heat. The resistance created by the twisted tape not slightly influences the Nusselt number and pressure drop also. The rich amount of vortex flow induced with the twin counter-swirl twisted tapes (CTS) responsible for the pressure drop in the copper test tube. In case of copper test tube inserted with twin counter-swirl twisted tapes (CTS), the recirculation region in not generated due to this the extreme amount of swirl flows strikes to inside surface of the test tube. But in co-swirl twisted tapes (COS), the recirculation zone is induce in rich intensity which is responsible for the generation of thermal dead zone. The greater interface between high vortex intensities (Swirl flow) caused by the counter twisted tapes gives to better fluid mixing, which gives the significant uniform fluid temperature in copper test tubes. The flow simulations indicated in fig. 13 (a) to (c) are extremely obliging to realization of the fluid flow phenomenon and heat energy transfer in copper test tube inserted with various TT inserts brought in this investigation.

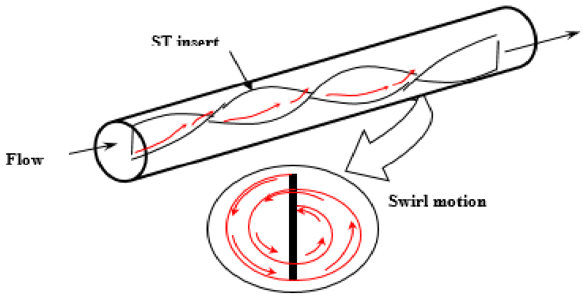


Fig. 13(a) ST insert

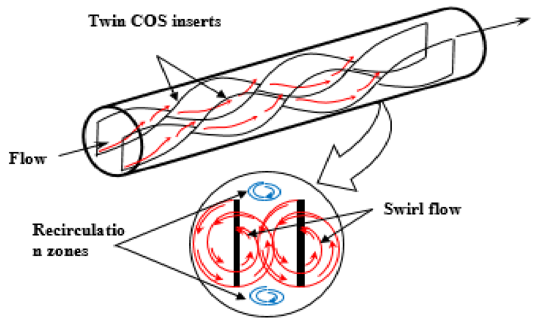


Fig. 13(b) Twin COS inserts

D. Thermal performance factor

In manner to appraise the total influence of various inserts in copper test tube, the thermal performance factor (η) is calculated with in various operations and current terms. The η stimulates the synchronous investigation of hydraulic and thermal performance whereas assigned downwards [21]:

$$\eta = \frac{Nu/Nu_s}{(f/f_s)^{\frac{1}{3}}}$$

Where Nu_s and f_s are the Nusselt number and friction factor for the plain empty copper test tube without twisted tape inserts. The thermal performance is investigated for various TT geometries to understand the effective growth within the performance. This is very clear from the already present previous study that the number of TT and their attitude have vital influence on the Nu and f boosting. The η versus Re for a copper test tube with TT plots is shown in figure 14. The performance CTS overcomes the surviving geometries regardless of the Re. The thermal performance factor has a worthless change with the Re in each situation. Which is trusted such whirl velocities enhance by CTS, which generate turbulence in the opposite direction whereas COS produce unidirectional swirl of the working fluid water in the cooper test tube. The chaotic fluid mixing enhances the turbulence richness due to the secondary flow generating by the counter-swirl flow. The maximum thermal performance factor lies within the order of 1.07 to 1.27 appropriating to CTS insert at the TR 3.5.

V. Conclusion

The presented experimental observations regarding to heat energy transfer rate and friction behavior within copper test tube with ST, COS and CTS profiles tape inserts have been provided. The fluctuations of heat energy transfer coefficient and frictional behavior have been investigated for various TT geometries with TR 3.5, 4.5 and 5.5 with changing the Re in between 5000 to 15000. The use of twin TT inserts has been recorded significant rise in heat energy transfer and frictional losses than of a single TT insert. Based on the gained results, key findings of this experimental observation can be generalized as follow:

1. For general observation, it has been observed that heat energy transfer, friction factor and thermo-hydraulic performance factor enhanced as the twist ratio (y) declines. The significant rise has been recorded in the Nusselt number, the Nusselt number increases and friction factor decreases with increase in the Reynolds number for all categories of twisted tape inserts. The Nusselt number and friction factor values have profoundly affected by the Reynolds number as the number of tapes inserts are varied.
2. The heat energy transfer rate and friction raised out maximum in case of the twin counter-swirl twisted tape inserts as compared to the twin co-swirl twisted tape inserts.
3. In all the cases as the Re increases the enhancement ratios of the Nu and f decreases. The Nu enhancement ratios come in the range of 1.19-1.43, 1.40-1.70 and 1.69-2.02 for ST, COS and CTS, appropriately at the twist ratio 3.5. The f enhancement ratios are 2.42-2.62, 2.83-3.17 and 3.88-4.09 for the above stated configurations of the inserts.

Abbreviation

δ	Thickness of the twisted tape
δt	Thickness of the test tube
ST	Single twisted tapes
COS	Co-swirl twisted tapes
CTS	Counter-swirl twisted tapes
f	Friction factor
h	Heat energy transfer coefficient, (w/m2 k)
k	Thermal conductivity of materials, (w/m k)
L	Copper tube length, (m)
y	Twist ratio
Nu	Nusselt number
Re	Reynolds number
TR	Twist ratio
η	Thermal performance factor

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