Journal of Chemical and Pharmaceutical Sciences ISSN: 0974-2115

INFLUENCES OF COMBINED INSERTS ON HEAT TRANSFER ENHANCEMENT IN CIRCULAR TUBE EQUIPPED WITH INSERTS

P. Prakash[1], K. Karuppasamy[2]
Department of Mechanical Engineering, Regional Centre of Anna University, Tirunelveli, Tamilnadu, India,
***Corresponding author: Email: prakash1033@gmail.com,**

ABSTRACT

Experimentation on heat transfer and friction factor characteristics of circular tube fitted with combined inserts by passing water as the working fluid under uniform wall heat flux conditions with the Reynolds number varies from 528 to 1131.The experiment investigation focus on optimum heat transfer by inserting different geometries of inserts. The different geometries of plain twisted tape and rectangular cut twisted tape are fabricated by changing the parameters of twist ratio and depth ratio with uniform wire coil pitch of 28 mm. Experimental result shows that for combination of wire coil and rectangular cut twisted tape increased the maximum Nusselt number of 207% and combination of wire coil and plain twisted tape increased the maximum Nusselt number of 196.7% compare to plain tube. Likewise heat transfer increases that the friction factor also be increased to 3.3 times for combined wire coil and rectangular cut twisted tape and 2.9 times for combined wire coil and plain twisted tape compare to plain tube. The empirical correlations developed for the tube with combined inserts of Nusselt number, friction factor in the manner of twist ratio, depth ratio from the experimental values.

KEYWORDS: Depth ratio, combined inserts, Twist ratio, Depth ratio, Enhancement efficiency.

INTRODUCTION

Nowadays demand for material and electric power is high, so desired optimization in the heat exchanger field to make the efficient compact heat exchanger. In the heat exchanger there are two techniques are currently being used one is active technique another one is passive technique. Among the above method passive technique are mostly like by researchers used in solar water heater and other convective heat transfer applications. Most researchers are concentrating in the field of designing proper geometrise of inserts for increasing the turbulence in the fluid flow phenomena. Investigated the heat transfer and friction factor characteristics in circular tube equipped with combination of spiral ribs and twisted tape with oblique teeth inserts and concluded that the combination of insert achieves better than spiral ribs alone. Investigated the Nusselt number, friction characteristics of tube with circular rings and twisted tape and concluded that the compound enhancement devices provide higher heat transfer rate than circular ring alone. Experimental investigation on Nusselt number, fiction factor, thermal enhancement efficiency characteristics of tube with perforated twisted tape insert and the test results exposed that the tube fitted with perforated twisted tape gives higher Nusselt number and friction factor. Investigated the tube side convective heat transfer, friction factor, thermal enhancement efficiency by passing water through tube with rectangular cut twisted tape insert and concluded that higher heat transfer achieved by tube with inserts than compare to plain tube. Experimental investigations on heat transfer and pressure drop in counter flow heat exchanger of tube with plain twisted tape, square cut twisted tape at three different twist ratio and the test result shows that the tube with square cut twisted tape gives higher heat transfer and friction factor than plain twisted tape.

They also investigated by inserting different geometries of inserts like v-cut, U-cut twisted tape in the same experimental setup and concluded that by inserting different geometries of inserts heat transfer and pressure drop are increased than plain twisted tape insert and the reason for this much enhancement is different cut effect. Investigated the heat transfer effect by inserting peripherally cut twisted tape in tube at different depth and width of cut using water as the working fluid under uniform wall heat flux conditions and the test results shows that the tube with peripherally cut twisted tape gives higher heat transfer than plain twisted tape, furthermore concluded that the increasing depth of cut and decreasing width of cut gives better performance. Investigated the heat transfer and pressure drop in circular tube fitted with three different pitch ratios of wire coil (p/d=1, 2, 3) separately from tube wall and they concluded that the wire coil are advantageous for all Reynolds number, reason for rising heat transfer are reverse flow are occurred by the wire coil.

Investigated the enhancement efficiency in solar flat plate water heater by inserting the wire coil in the flow passage and concluded that the inserts are perform better at lower mass flow rate than higher mass flow rate. Investigated the heat transfer and friction factor of tube with twisted tape inserts placed separately from tube wall and found that decreasing clearance ratio and twist ratio gives better performance by using air as the working fluid under turbulent flow conditions. Studied review on wire coil inserts under uniform wall heat flux conditions and concluded that the wire coil gives higher friction factor depends on shape and pitch of wire coil in turbulent flow than laminar flow and performance efficiency is better when considering pressure drop also be a matter. Investigated in circular tube by inserting full length helical screw tape inserts at different twist ratio, increasing and decreasing order of twist ratio. Finally found that the heat transfer coefficient for all the cases almost same. Heat

Journal of Chemical and Pharmaceutical Sciences ISSN: 0974-2115

transfer and friction factor characteristics in square duct with turbulent flow under uniform heat flux conditions by inserting tandem and full length wire coil and found that full length wire coil perform better for heat transfer and tandem wire coil for reduced friction factor than full length coil, reason for enhancement was the turbulence intensity for lower space ratio were greater. Found that using wire coil increased the Nusselt number and fanning friction factor of 4.5 and 3.5 times than plain tube.

Counter vortices inside the tube are developed by inserting vortex rings and Nusselt number increased because of increasing blockage ratio and reducing pitch ratio. Investigated by inserting three different material of twisted tape and found that aluminium tapes gives better performance for heat transfer than stainless steel and insulated tapes. Better performance achieved by wire coil for turbulent flow and twisted tape for laminar flow. By using nanofluid heat transfer rate increases in addition to this further the heat transfer rate increases by using different geometries of inserts. The following terms are used in our experiments, twist ratio can be defined as the ratio between length of one twist to width of the twisted tape, depth ratio can be defined as the ratio between depth of cut to width of twisted tape, width ratio can be defined as the ratio between width of cut to width of the twisted tape, pitch ratio can be distinct as the ratio between pitch length of wire coil to inner diameter of test section.

Main aim of the project is investigation of heat transfer and friction factor of tube with combined wire coil and rectangular cut twisted tape at two different twist ratio, depth ratio and constant pitch ratio of wire coil and compare the result with the combined wire coil and plain twisted tape.

EXPERIMENTAL SETUP AND PROCEDURE

For the heat transfer studies following parameter are used as shown in below figure 1. It consist of centrifugal pump, rota meter, calming section, test section, u-tube manometer, riser section, cooling unit and fluid colleting tank are explained below as calming section are used to avoid entrance effect made of stainless steel of 14 mm inner diameter, 16 mm outer diameter, 1000 mm length and the test section of straight tube made of copper material of 14 mm inner diameter, 16 mm outer diameter and 1000 mm length. Riser sections are connected at the right end of test section and the calming section connected at the left side of test section which are connected by means of flange. Cooling unit used of down flow type with external cooling fan, colleting tank of plastic container of 7 litre capacity. To provide uniform heat flux electrical conducting nichrome wire of producing power of 300 watts are wound over the copper tube and the terminals of the nichrome wire are attached to an auto transformer by adjusting this the supply voltage are varied. Totally 8 calibrated temperature sensors of RTD PT 100 type are used out of which 6 thermocouples are located on the wall placed at a distance of 100 mm, 200 mm, 400 mm, 600 mm, 800 mm, 900 mm from inlet of test section used to measure wall temperature and two thermocouple are inserted in fluid to measure inlet and outlet fluid temperature.

To reduce outside heat losses over the electrical winding the mica sheet are tightly wounded around the heating wire. The rota meter are used to measure the amount of fluid flow to the test section are in the ranges of 0 to 2.0 litre per minute, by-pass valve are used to control the fluid flow to the test section. U tube manometers are used to measure the pressure drop occurring in the test section, which are immersed in fluid before and after the test section. Turbulators used in this experiment are shown in figure 2, wire coil are made of copper material of 12 mm outer diameter,1 mm thickness of wire, 28 mm uniform pitches, 1000 mm length and the twisted tape are made of copper material 9mm width, 1000 mm length and the twist length of 90 mm, 110 mm and the rectangular cut twisted tape made of copper material, 9 mm width,1000 mm length, twist length 90 mm, 110 mm and rectangular cut of 10 mm width, depth of 3 mm, 5 mm in the twist alternatively bottom and above are shown in figure 2. Wire coil are fabricated by winding of copper wire of thickness of 1 mm around the circular rod of 10 mm outer diameter based on suitable dimensions and twisted tape are fabricated by twisting a uniform straight strip of 1mm thickness based on suitable twist length.

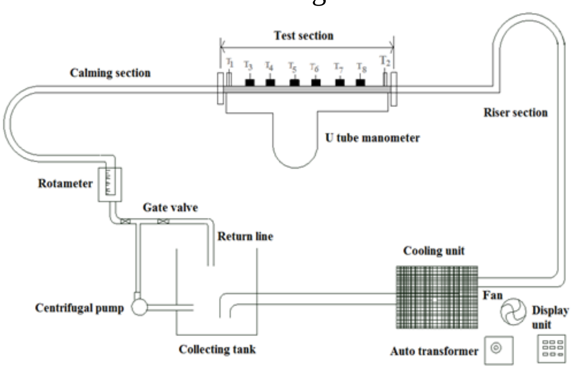

Fig. 1. Experimental setup

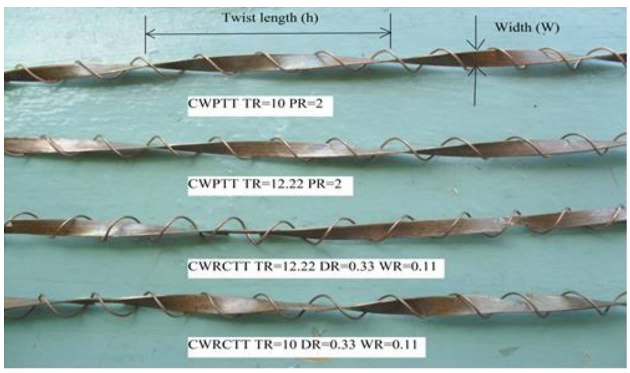

Fig. 2.Different geometries of inserts at two different twist ratio

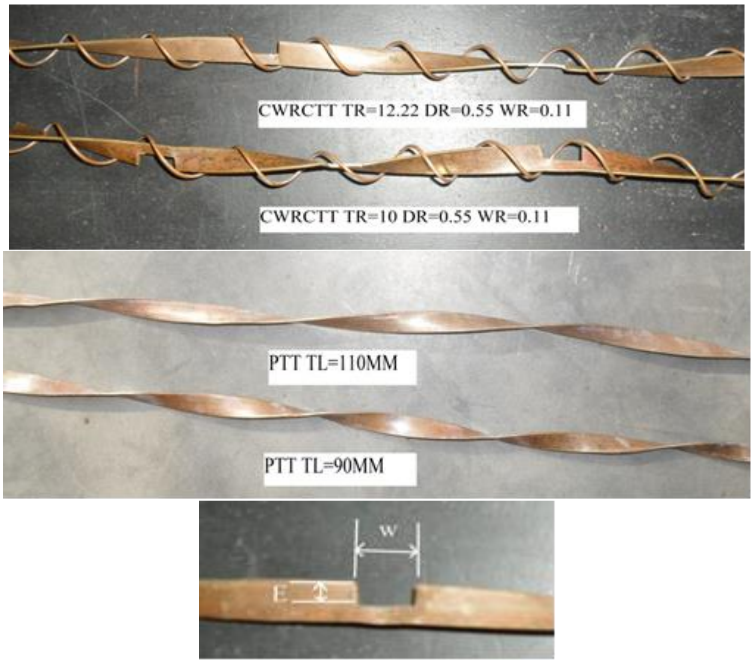

Fig. 2.Different geometries of inserts at two different twist ratio

The experimental procedure starts with fluid of deionised water of five litres are filled in the plastic container then the centrifugal pumps sucks the fluid from the container and the discharged fluid passes through calming section, test section, and cooling unit. By using gate valve desired amount of flow are varied by using rota meter. When the fluid passes through the test section, it starts to absorb the heat from the wall and the heated fluid are get cooled passing through cooling unit then the cold fluid are again circulated then the readings are noted. After completion of smooth tube reading combination of different geometries of insert are inserted in the smooth tube then the readings for different geometries of insert are noted for comparisons.

DATA REDUCTION

The following equations are used for the experimental calculations

Heat supplied by the heater can be calculated from the below equation,

$$Q_1 = VI$$

Heat absorbed by the fluid from the wall can be calculated by the following equation,

$$Q_2 = mc_p(T_{f_2} - T_{f_1})$$

Average heat transfer can be calculated by the following equation,

$$Q_{act} = \frac{Q_1 + Q_2}{2}$$

Heat losses to outside the test section can be calculated by the following equation,

$$Q_1 = Q_t - Q_{losses}$$

Fluid side convective heat transfer can be calculated by the following manner,

$$h = \frac{Q_{act}}{A(T_w - T_b)}$$

Where, $A = \pi dl$

Wall temperature can be calculated from the below manner,

$$T_w = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6}{6}$$

Bulks mean temperature can be calculated,

$$T_b = \frac{T_{f1} + T_{f2}}{2}$$

Nusselt number can be calculated by the following equation,

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

Pressure drop in the test section can be calculated by using the values obtained from the U-tube manometer readings under uniform wall heat flux conditions, which is used for calculating experimental friction factor as follows,

$$f = \frac{\Delta P\ 2\ d}{(\rho v^2) l}$$

Non dimensional numbers used for the calculations of friction factor as follows,

$$Re = \frac{\rho v d}{\mu}$$

$$Pr = \frac{\mu c_p}{k}$$

For the same pumping power performance enhancement efficiency for experimental work are calculated by the method used for laminar flow

$$\text{Enhanced efficiency } (\eta) = \frac{Nu_{ci}/Nu_p}{(f_{ci}/f_p)^{0.1666}}$$

RESULTS AND DISCUSSION

Validation of experimental setup: Smooth tube readings are considered for comparison of Nusselt number and friction factor with the different geometries of inserts as well as validation of experimental work. Experimental validation are carried out for Nusselt number in laminar flow under uniform heat flux conditions with the shah equations as shown in figure 3.

$$Nu = 1.953(\text{Re pr d/x})^{1/2} \quad \text{for } (\text{Re Pr}\tfrac{d}{x}) \geq 33.33$$

$$Nu = 4.364 + 0.0722(\text{Re pr d/x})^{1/2} \quad \text{for } (\text{Re Pr}\tfrac{d}{x}) < 33.33$$

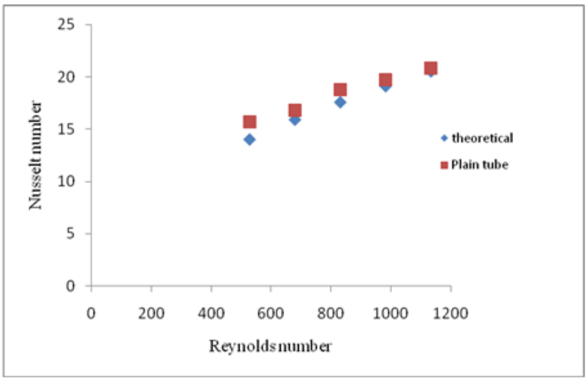

Fig. 3. Validation of plain tube Nusselt number with shah equation

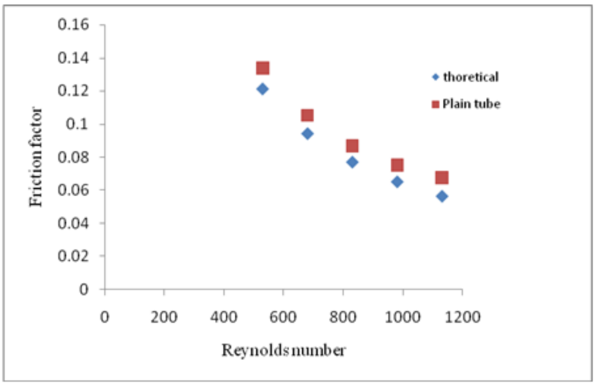

Fig. 4. Validation of plain tube friction factor with generalised friction factor equation

Figure 4 shows variation of friction factor with the Reynolds number under uniform heat flux conditions for smooth tube readings compared with the following generalised friction factor equation.

$$f = \frac{64}{Re}$$

Convective heat transfer studies: Figure 5 shows the variation of Nusselt number with Reynolds number under uniform wall heat flux conditions. Convective heat transfer was calculated based on actual heat transfer obtained from the experimentation of bulk fluid temperature and average wall temperature. Experimental values shows that the combination of wire coil and rectangular cut twisted tape gives higher Nusselt number than combination of wire coil and plain twisted tape insert and plain tube, increasing this much heat transfer is because of rectangular cut twisted tape induced effect. In addition to this small twist ratio gives higher Nusselt number than compared to larger one. In the combination of wire coil and rectangular cut twisted tape insert optimization work are carried out that is instead of going for larger twist ratio and smaller depth of rectangular cut, that the smaller twist ratio and larger depth ratio of rectangular cut gives higher convective heat transfer enhancement. By using combination of inserts increases the Nusselt number of 207% for CWRCTT of twist ratio=10, depth ratio=0.55, 201% for CWRCTT of twist ratio=10, depth ratio=0.33, 196% for CWPTT of twist ratio=10, 189% for CWRCTT of twist ratio=12.22, depth ratio=0.55, 183% for CWRCTT of twist ratio=12.22, depth ratio=0.33, 178% for CWPTT of twist ratio=12.22 than compared to plain tube. Result shows that huge rise in Nusselt number than compared to plain tube, reason for this much enhancement is may be heavier blockage of fluid as well as the shape of the insert

Journal of Chemical and Pharmaceutical Sciences ISSN: 0974-2115

induce more turbulence. Wire coil and twisted tape create different angle of swirl fluid flow near the heated wall surface, which increases the mixing of water molecule inside the test section because of this energy exchange rate are increases among the water molecules. Different geometries of inserts in flow path create opportunity to meet core of the fluid on the heated surface of the wall.

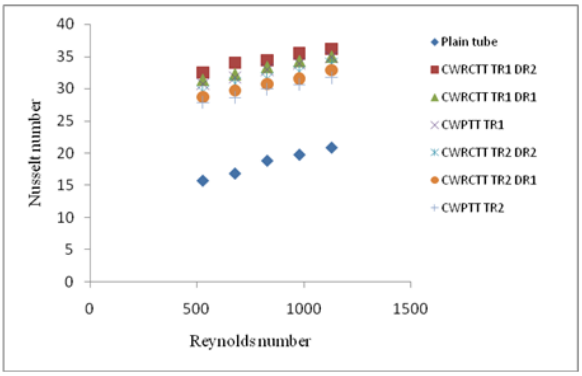

Fig. 5. Variation of Nusselt number with Reynolds number for plain tube and tube with combined inserts

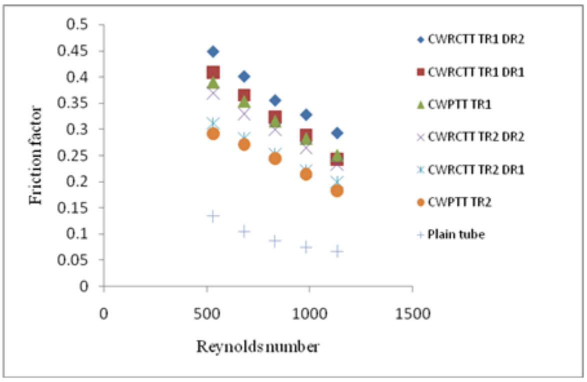

Fig. 6. Variation of friction factor with Reynolds number for plain tube and tube with combined inserts

Friction factor studies: Figure 6 shows the variation friction factor with the Reynolds number that is increasing Reynolds number friction factor are decreases. By inserting different geometries of combined inserts friction factor are increases than compared to plain tube. Increasing friction factor in the order of following manner, rectangular cut twisted tape of twist ratio 10, 12.22, depth ratio of0.55, 0.33 and combined wire coil and plain twisted tape of twist ratio 10, 12.22 and plain tube. Because of raising this much friction factor are of inserting different geometries of combined inserts, fluid flow cross sectional area are get reduced. By using combined inserts increased the friction factor of 330% for CWRCTT of twist ratio=10, depth ratio=0.55, 300% for CWRCTT of twist ratio=10, depth ratio=0.33, 292% for CWPTT of twist ratio=10, 284% for CWRCTT of twist ratio=12.22, depth ratio=0.55, 238% for CWRCTT of twist ratio=12.22, depth ratio=0.33, 218% for CWPTT of twist ratio=12.22 than compared to plain tube. Instead of going for combination of wire coil and rectangular cut twisted tape that the combination of wire coil and plain twisted tape gives lower friction factor and higher than plain tube.

Nusselt number ratio in laminar flows: Figure 7 shows the variation of friction factor ratio with the Reynolds number of laminar flow conditions. Nusselt number ratio defined as the ratio between augmented Nusselt number and plain tube Nusselt number. From the graph it is clear that at lower Reynolds number combined inserts perform better than increasing Reynolds number. Inserting different geometries of inserts increased the Nusselt number ratio above one, which is an advantage to the experimental work. Heat transfer ratio obtained by the combined inserts in the ranges of 2.07 to 1.52

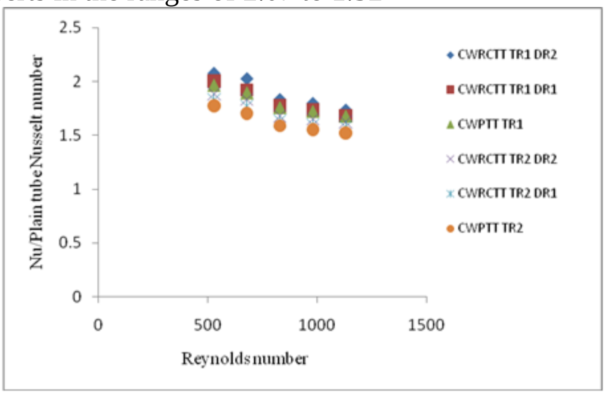

Fig. 7. Variation of Nusselt number ratio with Reynolds number for tube equipped with combined inserts

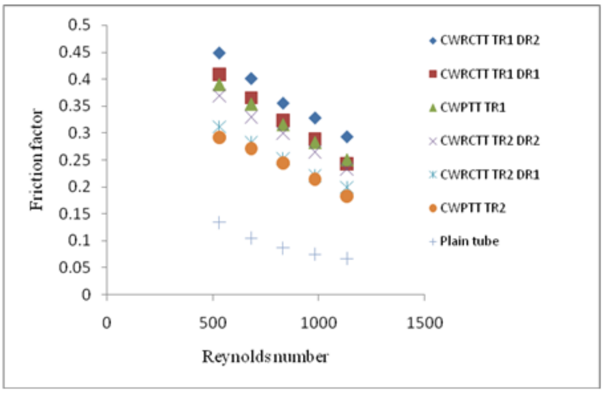

Fig. 8. Variation of friction factor ratio with Reynolds number for tube equipped with combined inserts

Friction factor ratio in laminar flows: Figure 8 shows the variation of friction factor with different Reynolds number of laminar flow conditions. By inserting different shapes of insert that the combined wire coil and rectangular cut twisted tape with increasing depth ratio and decreased twist ratio gives the increased friction factor ratio than all other inserts. Because of inserts fluid flow area are decreased as well as increases the fluid velocity as equal to that increased Reynolds number. In the experimentation obtained the friction factor ratio in the ranges of 4.35 to 2.18

Enhancement efficiency characteristics: Figure 9 shows the variation of enhanced efficiency with Reynolds number of laminar flow conditions. Because of using combinations of inserts it is necessary to evaluate the performance efficiency for justifying the inserts. From the graphs that the combined inserts gives the performance ratio greater than one. So using combined inserts of combined wire coil and rectangular cut twisted tape, combined wire coil and plain twisted tape advantageous one in the convective heat transfer field. Performance efficiency obtained in the ranges of 1.69 to 1.28, reason for increasing performance efficiency was by inserting combined inserts increases the Nusselt number than the friction factor.

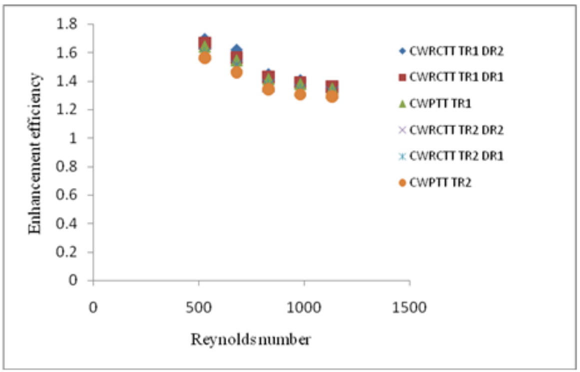

Fig. 9. Variation of enhancement efficiency with Reynolds number for tube equipped with combined inserts

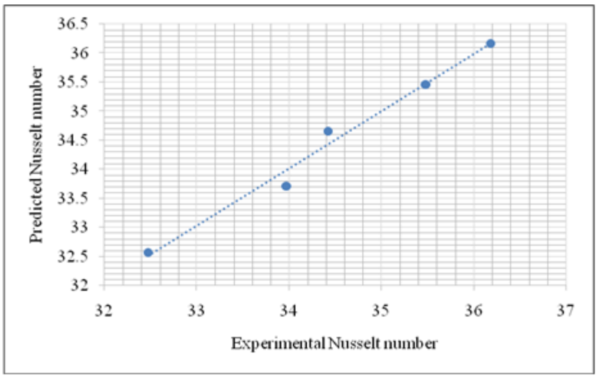

Fig. 10. Shows comparisons between experimental and predicted Nusselt number

Correlations for tube with combined inserts

From the experimental values the correlations have been correlated for Nusselt number and friction factor as follows,

$$Nu = 6.357164216\,(Re)^{0.13737637}\,(\mathrm{Pr})^{-1.53873784}\left(\frac{h}{W}\right)^{1.2748190}\left(\frac{w}{W}\right)^{-1.41110}$$

$$f = 1.387754681\,(Re)^{-0.551370807}\left(\frac{h}{W}\right)^{0.8010557424}\left(\frac{w}{W}\right)^{-0.842116048}$$

Which were formed by classical least square method and the correlations are valid only for Reynolds number in the ranges of laminar flow investigated, twist ratio 10, combined wire coil and rectangular cut twisted tape of width ratio 0.55. The comparisons between experimental Nusselt number and friction factor with the predicted Nusselt number and friction factor are shown in figure 10 and figure 11. Deviation of the experimental correlation was observed that for the Nusselt number and friction factor in the ranges of $\pm 0.8\%$ and $\pm 1\%$ respetively.

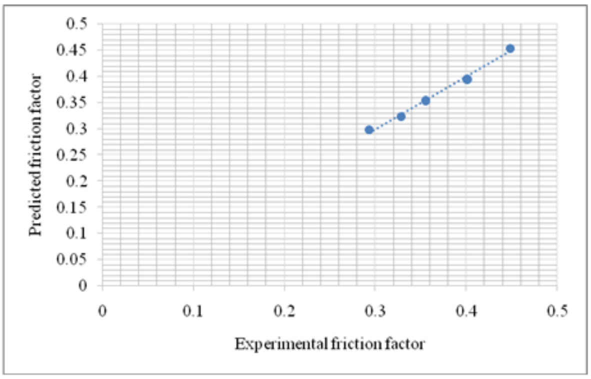

Fig.11.Shows comparisons between experimental and predicted friction factor

CONCLUSION

From the experimentation carried out in copper tube under uniform wall heat flux conditions by inserting different geometries of combined inserts and plain tube that the following are the points concluded from the laminar flow investigation. Instead of going for increasing twist ratio and Reynolds number that the decreasing twists ratio and lower Reynolds number gives higher heat transfer enhancement efficiency. Combination of wire coil and rectangular cut twisted tape gives higher heat transfer than combined wire coil and plain twisted tape. Increasing depth of rectangular cut gives higher heat transfer than smaller depth of rectangular cut. Instead of going for small twist ratio that the increasing twist ratio gives lower friction factor. Combination of combined wire coil and rectangular cut twisted tape gives higher friction factor than combined wire coil and plain twisted tape insert and plain tube. Enhanced efficiency was greater than one, so the combined inserts are advantageous one in the field of convective heat transfer. The correlations developed predict the Nusselt number and friction factor for tube with combined wire coil and rectangular cut twisted tape of width ratio 0.55, twist ratio of 10 with $\pm 1\%$.

ACKNOWLEDGEMENTS

Journal of Chemical and Pharmaceutical Sciences ISSN: 0974-2115
The authors gratefully acknowledge National Institute of Technology Trichirappalli for the support of experimental work.

REFERENCES

A. V. N. Kapatkar, B. Dr. A. S. Padalkar and C. Sanjay Kasbe, "Experimental investigaton on heat transfer enhancement in laminar flow in circular tube equipped with different inserts,"AMAE Int. J. on Manufacturing and Material Science, vol. 01, No. 01, 2011.

Alberto García, Ruth Herrero Martin, José Pérez-García, "Experimental study of heat transfer enhancement in a flat-plate solarwater collector with wire-coil inserts,"Applied Thermal Engineering, vol. 61, pp. 461-468, 2013.

Bodius Salam, Sumana Biswas, Shuvra Saha, Muhammad Mostafa K Bhuiya, "Heat transfer enhancement in a tube using rectangular-cut twisted tapeInsert,"Procedia Engineeringvol. 56, pp. 96-103, 2013.

D.S. Martinez, A. Garcia, J.P. Solano, A. Viedma, "Heat transfer enhancement of laminar and transitional Newtonian and non Newtonian flows in tubes with wire coil inserts,"International Journal of Heat and Mass Transfer, vol. 76, pp. 540-548, 2014.

Halit Bas, Veysel Ozceyhan, "Heat transfer enhancement in a tube with twisted tape inserts placedseparately from the tube wall,"Experimental Thermal and Fluid Science, vol. 41, pp. 51-58, 2012.

M.Chandasekar, S.Suresh, A.Chandra Bose, "Experimental studies on heat transfer and friction factor charactaristics of Al_2O_3/water nanofluid in a circular pipe under laminar flow with wire coil inserts,"Experimental Thermal and Fluid Science, vol. 34, pp. 122-130, 2010.

M.M.K. Bhuiya, M.S.U. Chowdhury, M. Saha, M.T. Islam,"Heat transfer and friction factor characteristics in turbulent flow througha tube fitted with perforated twisted tape inserts,"International Communications in Heat and Mass Transfervol. 46, pp.49-57, 2013.

P. Murugesan, K. Mayilsamy, S. Suresh, "Heat Transfer and Friction Factor in a Tube Equipped with U-cut Twisted Tape Insert,"Jordan Journal of Mechanical and Industrial Engineering,vol. 5, pp. 559 – 565, 2011.

P. Murugesan, K. Mayilsamy, S. Suresh, P.S.S. Srinivasan, "Heat transfer and pressure drop characteristics in a circular tube fitted with andwithout V-cut twisted tape insert,"International Communications in Heat and Mass Transfervol. 38,pp. 329–334,2011

P. Murugesan, K. Mayilsamyand S. Suresh, "Turbulent Heat Transfer and Pressure Drop in Tube Fitted withSquare-cut Twisted Tape,"Chinese Journal of Chemical Engineering, vol. 18(4), pp. 609-617, 2010.

P. Sivashanmugam, S. Suresh,"Experimental studies on heat transfer and friction factorcharacteristics of laminar flow through a circular tube fittedwith helical screw-tape inserts,"Applied Thermal Engineering,vol. 26, pp. 1990-19997, 2006.

P.K.Nagarajan and P.Sivasanmugam,"Heat transfer enhancement studies in a circular tube fitted with right-left helical inserts with spacer,"World Academy of Science, Engineering and Technology, vol. 5, pp.10-22, 2011.

Pongjet Promvonge, Narin Koolnapadol, Monsak Pimsarn, Chinaruk Thianpong, "Thermal performance enhancement in a heat exchanger tube fitted with inclined vortex rings,"Applied Thermal Engineering, vol. 62, pp. 285-292, 2014.

Prabhakar Ray, Dr. Pradeep Kumar Jhinge, "A Review Paper on Heat Transfer Rate Enhancements by Wire Coil Inserts in the Tube,"International Journal of Engineering Sciences & ResearchTechnology, vol. 3(6), pp. 238-243, 2014.

Sagnik Pal, Sujoy Kumar Saha, "Laminar fluid flow and heat transfer through a circular tube having spiral ribs and twisted tapes,"Experimental Thermal and Fluid Science, vol. 60, pp. 173-181, 2015.

Sibel Gunes, Veysel Ozceyhan, Orhan Buyukalaca,"The experimental investigation of heat transfer and pressure drop in a tube with coiled wire inserts placed separately from the tube wall,"Applied Thermal Engineering, vol. 30, pp. 1719-1725, 2010.

Smith Eiamsa-ard, Panida Seemawute, Khwanchit Wongcharee,"Influences of peripherally-cut twisted tape insert on heat transfer and thermalperformance characteristics in laminar and turbulent tube flows,"Experimental Thermal and Fluid Sciencevol. 34, pp. 711-719, 2010.

Smith Eiamsa-ard, Vichan Kongkaitpaiboon and Kwanchai Nanan, "Thermohydraulics of turbulent flow through heat exchanger tubes fitted with circular-rings and twisted tapes,"Chinese Journal of Chemical Engineering, vol. 21(6), pp. 585-593, 2013.

Smith Eiasma-ard, Narin Koolnapadol, and Pongjet Promvonge, "Heat transfer behaviour in a square duct with tandem wire coil element insert,"Chinese Journal of Chemical Engineering, vol. 20(5), pp. 863-869, 2012.