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Heat Transfer Enhancement with Centrally Hollow Twisted Tapes in a Tubular Heat Exchanger

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Abstract—*Twisted tape is widely used techniques in tubular heat exchanger for heat transfer enhancement. In this study, a new tube insert is made, named centrally hallow twisted tape and its effect on the heat transfer enhancement of a tube under laminar flow condition is experimentally studied. Experimentation is carried out at constant wall heat flux and thermally developing region with variations of Reynolds number from 600- 1600 with step size 200. In experimentation mainly two parameters varied 1) centrally hollow width 2) Boundary clearance between twisted tape and wall. As centrally hallow width increase heat transfer enhancement increase and maximum enhancement when hollow of 8 mm. Also enhancement decreased as clearance increase. The optimum overall heat transfer enhancement of the tape increase by 21.4% compared to conventional twisted tape. The results shows that the centrally hallow twisted tape is a very good high performance tube inserts also increase in friction factor is less compared to rise in heat transfer.*

1. INTRODUCTION

Tubular heat exchangers used in various fields such as refrigeration, air-conditioning, chemical engineering, metallurgy, electric power and widely used in these fields. High rate of heat transfer performance is very crucial for the use of heat exchangers in these fields because it is relates to the energy saving benefits. Therefore it is necessary to improve the performance of the heat exchangers by heat transfer enhancement techniques. Increase the heat transfer in the tube side is the main way to enhance the performance of heat exchangers.

There are three techniques to improve heat transfer rate, namely 1) Passive technique 2) Active technique and 3) Compound technique. Among the three techniques passive technique mostly used because that does not need external energy source.

Twisted tapes, as one of the passive technique, have been extensively studied due to their advantages of good performance, easy to manufacture, easily installed or replaced for cleaning purposes. Lots of efforts have been made to increase convective heat transfer in tubes with the twisted tape inserts, to achieve a good heat transfer performance as well as a low friction factor. In all kind of twisted tape the disturbance of boundary layers is not weakened too much. Centrally hallow twisted tape have four strips so it increase the disturbance of boundary layer.

2. NOMENCLATURE

C hollow width of the cross hollow twisted tape, mm

S clearance of the twisted tape, mm

cp specific heat at constant pressure of water, J/kg K

Re Reynolds number

Nu Nusselt number

f friction factor

u flow velocity, m/s

h heat transfer coefficient, W/m^2 K

p pressure of water, Pa

T temperature of water, K

PEC comprehensive heat transfer performance

coefficient

Nu Nusselt number of a plain tube

f friction factor of a plain tube

μ Viscosity of water at bulk temperature

μ_s Viscosity of water at wall surface temperature

CX Twisted tape of X hallow width X varies from

0,2,4,6,8 and 10 mm.

3. LITERATURE REVIEW

Pengxiao Li [1] studied a new tube insert, named centrally hollow twisted tape, is developed and its effect on the heat transfer enhancement performance of a tube under laminar flow conditions is numerically studied. Compared with the conventional twisted tape, the overall heat transfer performance of the new type of tape increases by 28.3%.The results show that under laminar flow conditions, the cross hollow twisted tape is a very good high-performance tube inserts.

Jian guo. [2] Carried a comparative study between center cleared twisted tape and the short-width twisted tape was performed numerically in laminar tubular flows. The computation results demonstrated that the flow resistance can be reduced by both methods; however, the thermal behaviors are different from each other. The thermal performance factor of the tube with center-cleared twisted tape can be increased by 7-20% as compared with the tube with conventional twisted tape.

Eiamsa-ard et al., [3] studied the effect of the clearance between the tube wall and twisted on the heat transfer. The results showed that when clearance are 0.0, 0.1, 0.2, and 0.3 the heat transfer rate increased by 73.6%, 46.6%, 17.5% and 20.1% respectively. It concludes that the clearance reduces resistance, but it will also reduce the heat transfer rate.

Y. Raja Sekhar [4] Experiment was conducted in a pipe under laminar flow using water and nanofluids. The increase in heat transfer rate in plain tube with use of nanofluids is greater by 8-12% compared to the flow of water in a plain tube. The nanofluid of 0.5% particle concentration is having highest friction factor compared to water. Twisted tapes and nanofluids in the pipe flows is advantageous since it is visible from the results that the energy gained with heat exchange is more than the energy spent on pumping power.

Liao et al. [5] experimentally studied the heat transfer and friction factor characteristics in tubes with 3D internal extended surfaces and twisted tape inserts. The results show that this method was of particular advantages to enhance the convective heat transfer for laminar tube side flow of highly viscous flow.

Eiamsa-ard and promvonge [6] developed a twisted tape with serrated edge. Results shows that this type of inserts were about 1.04 -1.27 and 1.02-1.12 times those in the tube with smooth twisted tape inserts.

Rahimia et al. [7] experimentally studied heat transfer and friction factor characteristics of the tube fitted with perforated, notched and jagged inserts was better than the conventional twisted tape in the thermal performance factor.

4. EXPERIMENTAL SETUP AND PROCEDURE

The Schematic diagram of the proposed experimental setup is shown in Fig. The experimental setup consists of a 1 m long copper tube, a cooler, a storage tank, and a variable displacement pump with a by-pass valve arrangement. The test section of the tube is wrapped with nichrome wire heater to give a constant heat flux input to the test section.

Fig. 1: Photographic Image of Experimental Setup

The outer surface of the test section is well insulated to minimize heat loss to the surrounding. Seven thermocouples are provided, in which two are used to record the inlet, outlet temperatures of the working fluids and the remaining thermocouples are brazed on the outer periphery of the test section of the tube, to measure the average surface temperature of the tube. Pressure drop across the test section is measured by providing pressure transducers. Flow meter is incorporated in order to measure flow rate of working fluid. The aspect ratio of the test section is sufficiently large for the flow to be hydro-dynamically developed.

The working fluid under investigation is forced through the test section with pump connected to the sufficient capacity of storage tank. The fluid is heated by receiving heat from the test section and is allowed to cool by passing it through a cooler. By recirculation, the cooler in the flow loop helps in achieving steady state condition faster.

4.1 Physical model of centrally hollow twisted tape

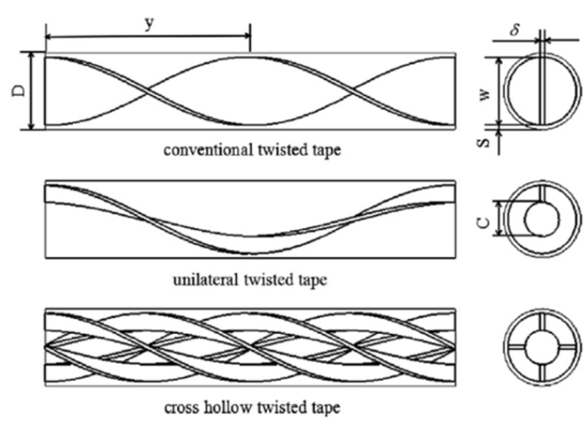

Fig. 2: Tube fitted with conventional, unilateral and centrally hallow tape.

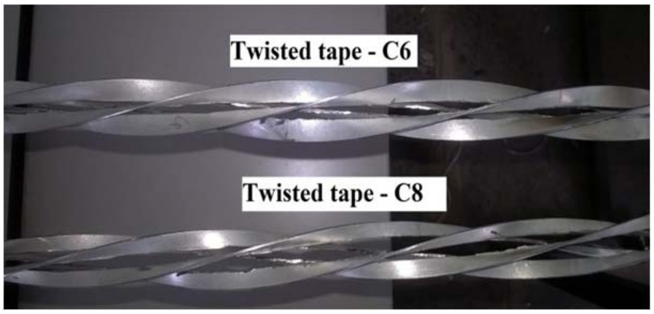

Fig. 3: Centrally hallow twisted tapes of hollow width 6 and 8 mm.

The geometry of a conventional twisted tape, unilateral twisted tape, and centrally hollow twisted tape are shown in Fig. 2. For centrally hollow twisted tape, L is equal to 180˚ twist pitch (y), while for unilateral twisted tape, L is equal to 360˚ twist pitch (2y). The variables for the centrally hollow twisted tape are the hollow width of the centrally hollow twisted tape (C), clearance (S). C is varied 0-10 mm with step size 2 mm and clearance S is varied 0-2 mm with step size 1 mm.

5. DATA ANALYSIS

Experimentation is conducted under constant heat flux boundary condition, temperature of pipe surface at different locations, Voltage and current supplied to the heater and pressure drop is recorded. The Reynolds number (Re), Nusselt number (Nu), Fanning friction coefficient (f), and PEC are defined as follows:

$$Re = \frac{\rho u D}{\mu} \quad (1)$$

$$Nu = \frac{hD}{\lambda} \quad (2)$$

$$f = \frac{\Delta p}{\left(\frac{1}{2}\rho u^2\right)(L/D)} \quad (3)$$

$$PEC = \frac{Nu/Nu_0}{(f/f_0)^{1/3}} \quad (4)$$

The heat transfer coefficient is estimated with Newton's law of cooling.

Energy balance equations

$Q = VI$ (5) $Q = \dot{m}\, c_p\, \Delta T$ (6)

$h = Q/(A_s\, \Delta T)$ (7)

Similarly, the pressure drop across the test section was measured by pressure transducer as shown in the experimental setup.

6. VALIDATION OF EXPERIMENTAL SETUP

To validate the experimental setup, measurements were first evaluated for Nusselt number and friction factor by conducting experiments in a plain tube with water at different Reynolds number. The experimental Nusselt number data is compared with Nusselt number from Sider Tate correlations.

$Nu=1.86*[Re^{1/3}]*[Pr^{1/3}]*[(D/L)^{1/3}*[(\mu_b/\mu_w)^{0.14}]$

The variations of average Nusselt number with different Reynolds number is shown in Fig. The variation of friction factor for water in a plain tube with increasing Reynolds number is shown in Fig. 4.

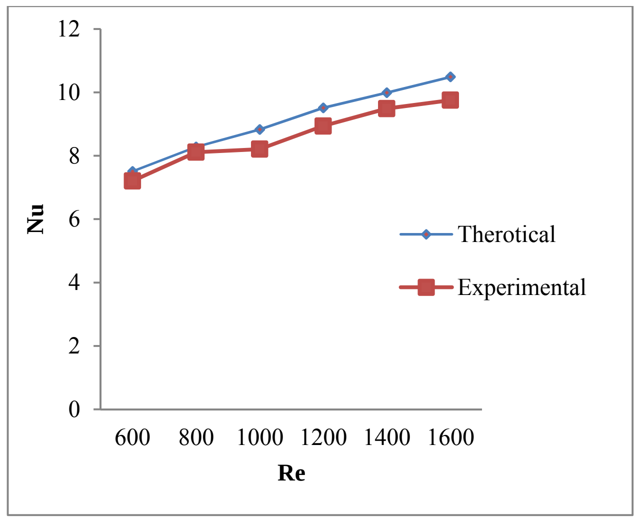

Fig. 4: Comparison of the experimental results and theoretical data of Nusselt number

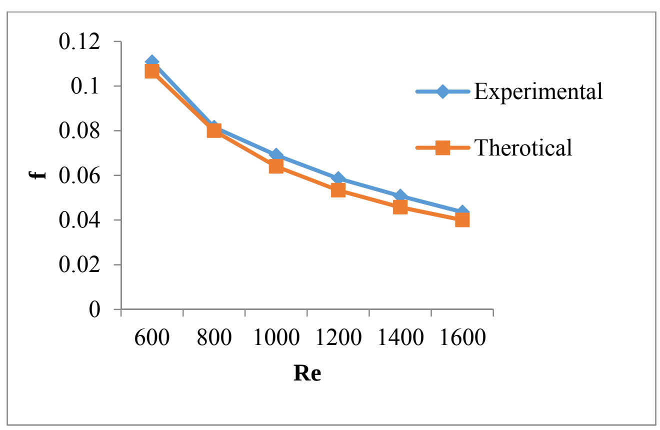

Fig. 5: Comparison of the experimental results and theoretical data of friction factor

It is found that 7.6 % deviation of Nusselt number with respect to theoretical Nusselt number and deviation of friction factor is approximately zero. The deviation of present experimental values compared to theoretical data of literature is found to be less than 10% hence validating the experimental setup.

7. RESULTS AND DISCUSSION

Effects of the central clearance width

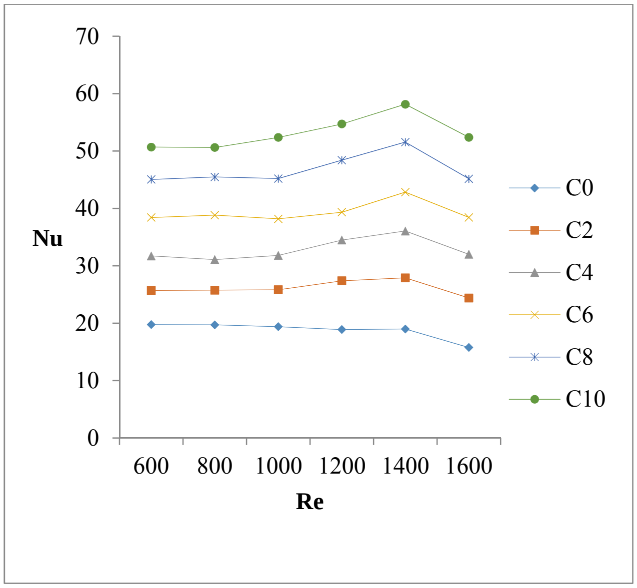

Fig. 6: Variation of Nusselt with Reynolds number.

As shown in graph the as Reynolds number increases, the Nusselt number also increases. As hallow width increase up to 8 mm Nusselt increases and further increase in hallow width drop the Nusselt number. For low Reynolds number (800-1200) Nu has little change when C increases from 0 to 6 mm. When width increases to 8 mm, Nu increases and more heat transfer coefficient. The optimum overall heat transfer enhancement of the tape increase by 21.4% compared to conventional twisted tape.

The enhancement phenomena about heat transfer of the center (1) the twisted tape generates swirls, which enhance the heat transfer. As the hollow width increases enhancement weakened. (2) The hollow part generates irregular disturbance [2]. As the hollow width increases, the irregular disturbance makes the fluid in the core region and boundary region to mix more evenly, results to an increase in the heat transfer. However, when the hollow width increases beyond a certain value, the irregular disturbance is decreased.

Fig.7 shows that when the hollow width increases, the friction factor decreases significantly. When the hollow width C is 8 mm, the f of the cross hollow twisted tape decreases by 38.5–44.8%. And the f of the cross hollow twisted tape is larger than that of the center-cleared twisted tape with the same hollow width because a larger area of the tape is in contact with the fluid. Therefore, it is necessary to make a hollow part on the twisted tape to reduce the resistance.

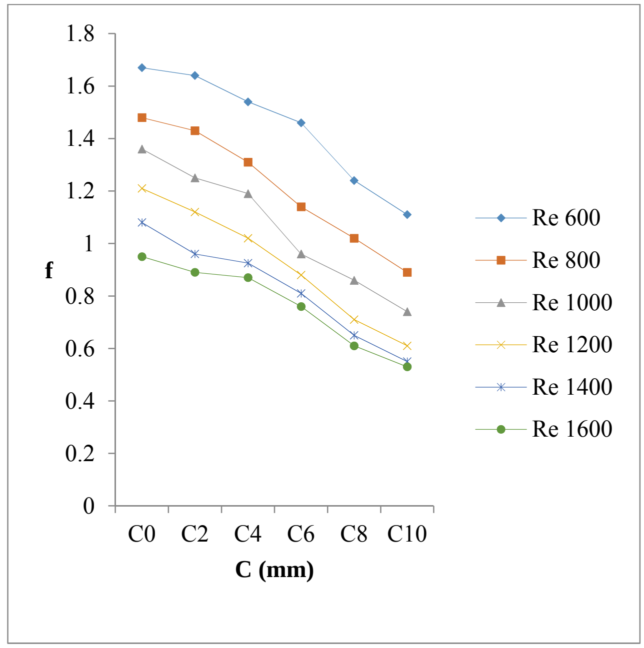

Fig. 7: Variations of friction factor with hollow width.

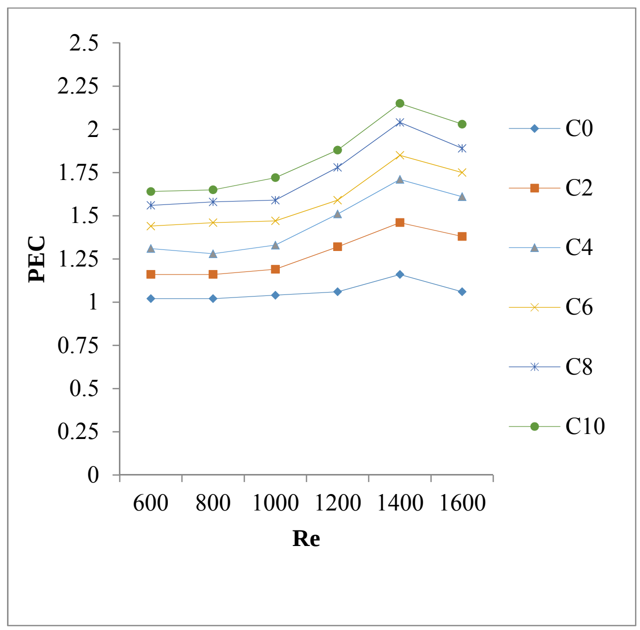

Fig. 8: Variations of PEC with hollow width

As shown in Fig. 8, the PEC of the cross hollow twisted tape has the best value when the hollow width (C) is 8 mm. The best PEC of cross hollow twisted tape is and 21.4% larger than that of cross twisted tape when Re= 1600. Under low Reynolds numbers, the resistance of the cross hollow twisted tape is very large, which leads to a worse PEC.

Effect of boundary clearance width

Boundary clearance is defined as the width between the twisted tape and tube wall. Boundary clearance is applied to 8 mm hallow width twisted tape only.

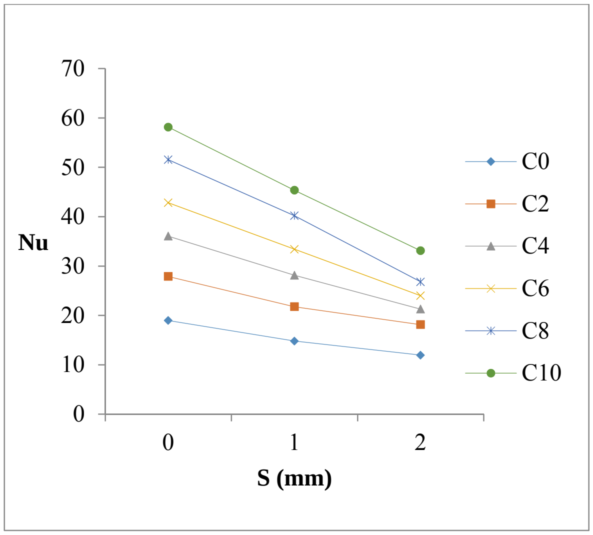

Fig. 9: Variations of Nusselt with boundary clearance

When the clearance increases, the heat transfer coefficient of the cross hollow twisted tape became weak. When the clearance decreases from 0 to 2 mm Nu decreases by 58.4 % compared to zero clearance.

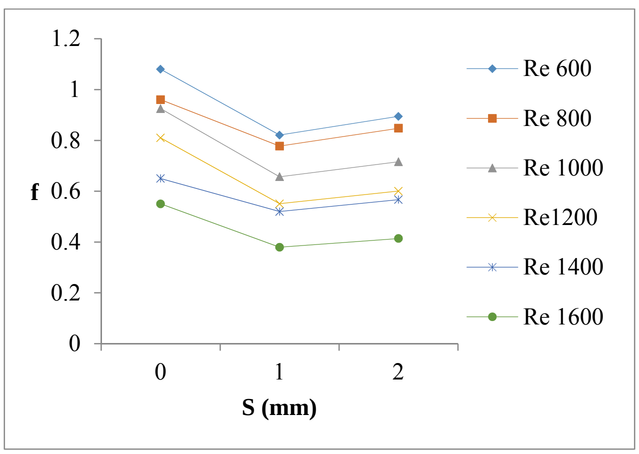

Fig. 9: Variations of friction factor with boundary clearance.

In fig.9 shows the variation of the friction factor (*f*) with the clearance (S) at different Reynolds number (Re). When the clearance continues increase up to 1 mm the swirls are located far away from the tube wall and the velocity gradient near the wall becomes smaller. Friction factor decreases firstly then again increases.

8. CONCLUSION

1. In this experimental study, first, the effect of the hollow width and clearance on the heat transfer and friction characteristics of a tube with cross hollow twisted tape inserts is analyzed.
2. The results indicate that the cross hollow twisted tape shows good overall performance. A centrally hollow tape with the hollow width of 8 mm has the best overall heat transfer performance.
3. The best overall heat transfer performance of the cross hollow twisted tape increases 1.6–21.4% compared with the conventional twisted tape.
4. The smaller the boundary clearance, the better is the heat transfer performance.
5. Centrally hollow twisted manufactured by cutting conventional twisted by using cutter and then support four unilateral tapes with ring at different locations.

9. ACKNOWLEDGMENTS

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