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Performance Assessment of Heat Exchanger Tubes to Improve the Heat Transfer Rate in Turbulant Flows by Using Different Types of Twisted Tapes Inserts in Tubes

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Abstract- The article presents an investigation of the effect of different twisted tapes like alternate clock wise, counter clock wise(c-cc twisted tape),and serrated-edge insert on heat transfer and pressure loss behaviors in a constant heat-fluxed tube. In the experiments, this twisted tape was inserted into the entire test tube with a constant twist ratio in order to generate a continuous swirling water flow. Two geometry parameters of the serrated twisted tape (STT) to be considered in the present work are the serration width ratio and the serration depth ratio and in case of c-cc twisted tapes included three twist ratio y/w=30,4.0,and5.0 as well as each with three twist angles, $\theta=30^0, 60^0$ and 90^0. The measurements have been conducted for the water flow rate based on Reynolds numbers in the turbulent regime from 4000 to 20,000.The experimental results of the STT inserted tube are compared with those of the plain tube. The results show that the heat transfer rate in terms of Nusselt number, Nu increases with the rise in the depth ratio but decreases with raising the width ratio. The heat transfer rate is up to 72.2% and 27% relative to the plain tube. The thermal performance factor of the STT tube under constant pumping power is evaluated and found to be above unity indicating that using the STT tube is advantageous over the (twisted tube) TT tube or the plain tube. In case of c-cc twisted tape experiments have been performed over a Reynolds number range under uniform heat flux condition, using water as working fluid. In addition, correlation of the Nusselt number and friction factor for using the both twisted tapes are also determined.

Keywords: clock wise, counter clock wise and serrated twisted tapes, heat transfer enhancement, twist ratio, twist angle.

1. INTRODUCTION

Twisted tapes have been used extensively as a swirl generator to enhance convection heat transfer rate in finding the way to reduce the weight, size and cost of heat exchanger systems in several industrial applications such as chemical engineering process, heat recovery process, air conditioning and refrigeration systems, chemical reactors, power plant, and nuclear reactor, etc. Tubes with twisted tape insert are also an important group of the continuous swirling flow device that generates twin swirling flow motion over the whole tube length of flow at constant heat transfer coefficient (h) and friction factor (f). There are many devices used for producing swirl flow in the tube such as helical vanes, helical grooved tube, helical screw-tape, axial-radial guide vanes and snail entry while the twisted tape is one of the most popular group because of low cost, low maintenance, low pressure loss and ease of construction. All of swirling flow devices have been used to generate the tangential velocity, thin the boundary layer. Insertion of twisted-tapes in tubes is one such augmentation technique. Fig.1 shows the layout of a full-length twisted-tape insert inside a circular tube. they can be easily employed to improve the thermal performance of the existing systems. Twisted-tapes reduce the dominant thermal resistance of the viscous stream and reduce the required heat transfer surface area. However, the thermal improvements are accompanied by increased pressure drop. Date and Singham [1], Date [2], and Hong and Bergles [3] investigated heat transfer enhancement in laminar, viscous liquid flows in tubes with uniform heat flux (UHF). Ray and Date predicted the heat transfer in a square sectioned duct fitted with twisted tape in both laminar and turbulent flows. They found that the plain tube fitted with serrated twisted tape provides heat transfer higher than the plain tube without tape inserts One way for enhancing heat transfer in a tube is by using a twisted tape having serrate edges in order to increase mixing or turbulence intensity and breaking down the boundary layer apart from using continuous swirling flow in the tube. The aim of the present work is to investigate the heat transfer rate (Nu) and friction factor (f) characteristics of continuous swirl flow through a round tube fitted with serrated twisted tape (STT) using the water as the test fluid. Aoyama et al. [33,34] studied the laminar heat transfer in a horizontal taining a twisted-tapes wirler. In the present study, the alternate clockwise and counter clockwise twisted tape inserts with novel design are therefore presented and proposed for heat transfer enhancement. This modified twisted tape is designed to offer periodic change of swirl direction along the test tube, which is expected to provide better mixing than the typical one. The experiments are conducted to examine the Nusselt number and flow friction characteristics in a circular tube under uniform heat flux condition. In the test, influences of (1) typical twisted tapes (single twisting direction), (2) twisted-tapes with C–CC arrangement at various twist ratios (y/w = 3.0, 4.0 and 5.0), and (3) twist angle (h = 30o, 60o and 90o), on heat transfer rate (Nu), friction factor (f) and heat transfer enhancement index (ₒ) characteristics in a heat exchanger are studied experimentally in the Reynolds number range of 4000-20,000.The geometrical details of all twisted tapes used in the present work are depicted in Fig3..

2. EXPERIMENTAL DETAILS

2.1. *C-CC Twisted Tapes*

The C-CC. twisted-tapes were made of aluminum strips with thickness of 1.0 mm (δ), width of 18 mm and length of 1000mm.while being held under tension. For typical twisted-tapes, the straight tapes were twisted with three different twist lengths in 180^0 rotation (y) in a single clockwise direction. On the other hand, the novel alternate clockwise and counter-clockwise twisted-tapes were obtained by modification of typical tape via the following steps: (1) for every two twist lengths, the tape was cut on both sides with 4 mm depth of cut, (2) both sides at the cut were twisted simultaneously to the required different angles with respect to that of the former twist length (called twist angle (θ)=30^0,60^0,90^0),which is in arrangement for producing of swirl flow in opposing direction with regard to that of the former twist length (from clockwise to counterclockwise and vice versa).The details of twisted-tapes are shown in Fig1.

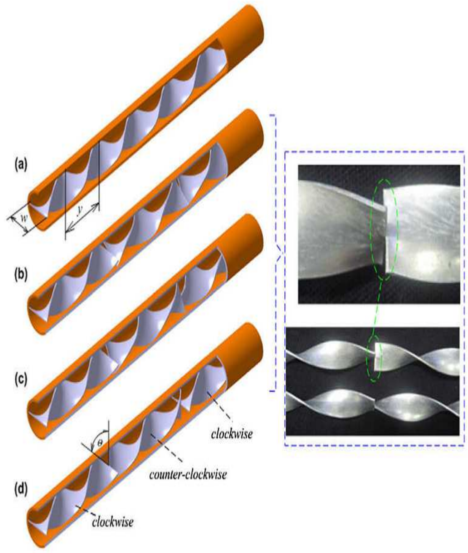
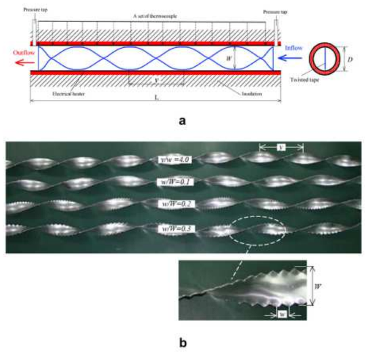


Fig1.Test tube fitted with twisted-tapes (a)The typical twisted-tapes (TT),(b) C-CC.TT. with θ=30^0,(c) C-CC.TT.with θ=60^0,(d) C-CC.TT with θ=90^0.

2.2. *Serrated Twisted Tapes*

The characteristic geometries of all tape are illustrated inFig.2.Each of the twisted tape made of aluminium was 1250 mm long, 0.8 mm thick and inserted into the test tube having a uniform heat flux condition. The test tube fitted withTT is presented in Fig3.The geometrical dimensions of the STT where y is the pitch length of 180^0 twist, d is the tape thickness, W is the tape width and D is the inner tube diameter; the severity of the twist is usually referred to as a dimensionless twist ratio, y/W. In each test run, the STT was inserted into the whole length of the test tube with a constant twist ratio, y/W=4.0. The tape edge was cut to be serrate shape (V-cut) with two geometry parameters:(1) the serration width ratio (w/ W = 0.1, 0.2 and 0.3) and (2) the serration depth ratio (d/W = 0.1, 0.2 and 0.3). The details of the test condition and twisted tape geometries are summarized in Table 1.



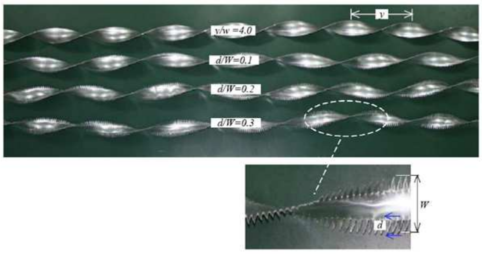


Fig2. Test tube fitted with typical twisted tape(TT) or twisted tape with serrated edge(STT):(a)TT,(b)STT at various serration width ratio w/W, and (c) STT at various serration depth ratio,d/w.

2.3 *Experimental Setup*

A schematic diagram of the apparatus with the basic components and fluid flow systems is presented in Fig3.The loop consisted of a 0.5 hp centrifugal water pump, Rota-meter for measurement of volumetric water flow rate, and the heat transfer test section.The copper test tube has an inside diameter of 19 mm, an outside diameter of 22 mm, a tube thickness (t) of 1.5 mm and a length (L) of =1000 mm. During the test, the test tube is heated by continually winding flexible electrical wires, providing a uniform heat flux boundary condition. The electrical output power is con- trolled by a variac transformer to obtain a constant heat flux along the entire length of the test section and by keeping the current less than 9 amps. The outer surface of the test tube is well insulated to minimize convective heat loss to surroundings, and necessary pre- calculation are taken to prevent leakages from the system.

2.4 Test condition and Method

In the apparatus setting bellow, the inlet cold water at 27^0C from a water pump was directed through the Rota-meter and passed
to the heat transfer test section.The pressure drop of the heat transfer test tube was measured with a pressure trans-ducer. The volumetric water flow rates from the centrifugal water pump were varied by adjusting the globe valve and measured by the Rota-meter situated upstream of the test tube. The inner and outer temperatures of the water were measured at certain points with a data logger unit in conjunction with the RTD PT 100 type temperature sensors. Fifteen thermocouple were tapped on the local wall of the plain tube and the thermo-couples were placed round the plain tube to measure the cir-cumferential temperature variation, which was found to be negligible. In which Re. ranges from 4000 to 20,000 for turbulant flow regimes.

3. DATA REDUCTION

In the present work, the water is used as working fluid and flowed through a circular tube with uniform heat flux conditions. At steady state, the heat absorbed by cold water is assumed to be equal to the convective heat transfer from the test section which can be expressed as:

$Q_{water} = Q_{conv.}$, Where $Q_{water} = MC_{pw}(T_0\text{-}T_i)$,

The convective heat transfer from the test section can be written by:
$T_b = (T_0+T_i)/2$ $\check{T}_w = \Sigma\, T_w / 15$

in which T_w is the local inner wall surface temperature.

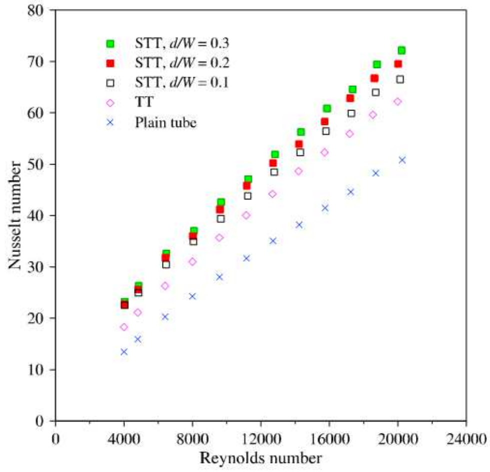
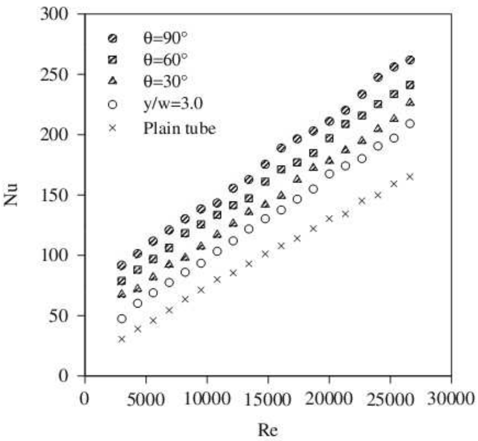


Fig 3 Reynolds Number Vs Nusselt Number

4. RESULT AND DISCUSSION

4.1. Effect of alternate clockwise and counter-clockwise twisted tape

Effect of the novel alternate C–CC twisted tapes at various twist ratios, y/ w = 3.0, 4.0 and 5.0, on the Nusselt number.For all runs, Nusselt number is consistently increased with increasing Reynolds number. This is due to the fact that the rise of Reynolds number leads to an increase in degree of turbulenc intensity



Fi4.comparisons between Re. and Nu. Number with different twist angle.

4.2.Effect of serrated twisted tapes

Effects of the STT at different serration width (w/W=1.0,2.0,and3.0) and depth ratios(d/W = 1.0,2.0 and 3.0) covering a wide variation of flow rates corresponding to the range of 4000<Re<20,000.

4.3. Thermal performance

The value of the thermal performance factor must be greater than unity .

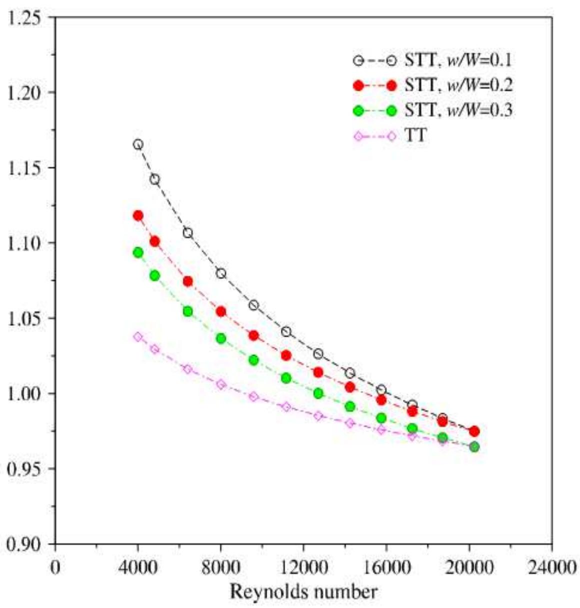
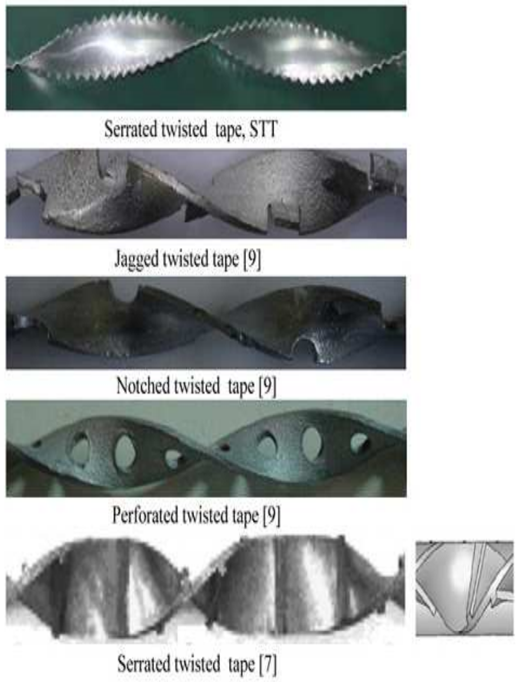
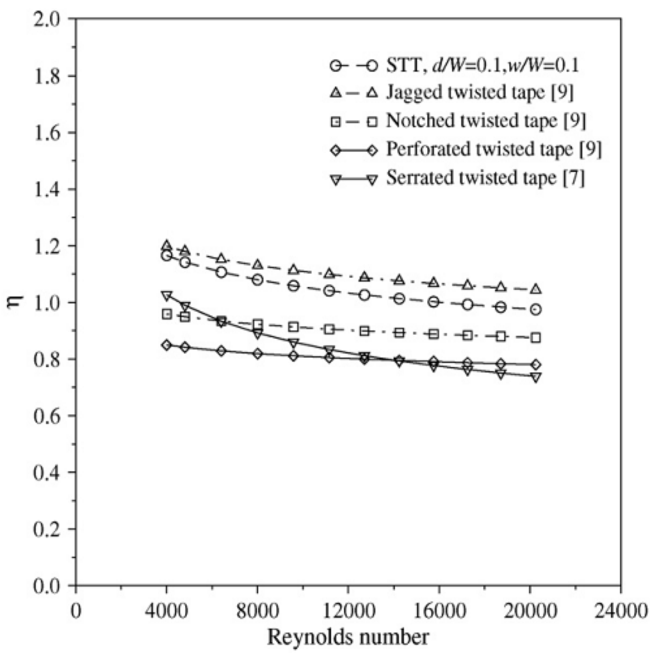


Fig5.Effect of the serration depth ratio (d/w) on thermal performance factor.

It is visible that at lower Reynolds number the increase in the thermal performance factor is comparatively
higher, but at higher Re, it is smaller.The experimental results show that the thermal performance factor vary between 0.98 and 1.17, 0.97 and 1.12, and 0.96 and 1.09 for the width ratio, w/W=1.0, 2.0 and 3.0, Respectively.The comparison of thermal performance factors in tubes equip-ped with the present STT and other tape inserts in previous work is shown in Fig8.





(Fig6.Comparison of thermal performance of the present STT with previous work)

5.CONCLUSION

In the present work, an experimental study has been conducted to investigate the heat transfer enhancement by means of twisted-tape inserts with alternate C–CC twisted and serrated twisted tapes arrangement in a circular tube under a uniform heat flux condition.From the experimental results, the conclusions can be drawn as follows:

1. In the presence of novel alternate C–CC twisted and STT tapes, the peri-odic change of swirl direction and gives to superior chaotic mixing with high turbulance flow for increasing the heat transfer rate compared with the plane tube.
2. Over the range studied, the Nusselt numbers for the tube withC–CC twisted and serrated twisted tapes. higher than those for the plane tube.
3. The heat transfer enhancement index,performance factor for STT.tends to increase with decreasing Reynolds number for all tapes inserts.

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