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Heat Transfer and Pressure Drop in a Circular Tube Fitted with Twisted Tape Insert Having Continuous Cut Edges

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ABSTRACT

The experimental work on heat transfer augmentation using a new kind of insert called twisted tape with continuous cut edges is carried out. The work includes the determination of friction factor and Nusselt number for new twisted tape insert having different twist ratios of 3 & 5. The experimental data obtained from plain tube and conventional twisted tape were verified with the standard correlations to ensure the validation of experimental results. The results of new twisted tape of different twist ratios have been compared with the values for the plain tube and tube with conventional twisted tape. In addition, the effects of the new twisted tape insert on the thermal performance factor are also investigated. The results obtained lead to the conclusion that higher heat transfer rates can be achieved using twisted tape inserts with continuous cut edges at the expense of a reasonable pressure drop.

1. Introduction

Cost effectiveness and ease in handling of twisted tape insert make it a popular choice among the various passive methods used for heat transfer intensification leading to reduction in cost and size of various thermo-technical equipment [1]. Use of twisted tape insert, causes the axial flow track of fluid in a tube to change to swirl flow which mixes the fluid rigorously and increases the turbulent intensity near to the tube wall surface enhancing the heat transfer [2–4]. It also increases the contact time of fluid in the tube and thus a pressure drop penalty is imposed due to increase in shear stress [5]. As per Dewan et al. [6], many researchers have reported on the use of twisted tape insert for heat transfer intensification in a circular tube. The use of modified TT in various configurations have also been reported [4]. Due to fact that the disruption of the thermal boundary layer near to the tube wall surface is directly responsible for heat transfer enhancement [4,7], twisted tape with different cut on the edges have been investigated.

Murugesan et. al [8–12]. experimentally investigated the effect on heat transfer, friction factor and thermal performance factor (TPF) of a tube equipped with square-cut, trapezoidal-cut, U-cut and wing-cut twisted tape inserts with twist ratio (y) of 2.0, 4.4, 6.0 in turbulent regimes ranging between $2000 < Re < 12{,}000$. It was reported that TPF for square-cut TT is 1.27–1.02, for trapezoidal-cut is 1.19–1.03, for U-cut is 1.22–1.06 and for wing-cut twisted tape inserts is 1.34–1.04 for the mentioned y and Re range described. Similarly, A. Hasanpour et al. [13] studied experimentally the effect of V-cut and U-cut twisted tape with width (Wr) and depth (dr)ratio varying from 0.3 to 0.6. It was reported for y 3, 5, 7 and $5000 < Re < 15{,}000$. The maximum value of Nusselt number ratio is around 1.40 for V-cut with $Wr = 0.3$ and $dr = 0.45$ and the ratio of friction factor varies from 1.05 to 2.2. It was reported that ratio of Nu number increases with the decrease in width ratio and increase in depth ratio and vica-versa in case of friction factor. Sami D. Salman et al. [1,14,15] numerically evaluated the constant heat fluxed tube with V-cut, parabolic-cut and elliptical-cut twisted tape with different twist ratio and cut depth in laminar flow conditions. Increase in Nusselt number was reported with reducing the twist ratio and cut depth. P.V. Durga Prasad et al. [16] experimentally analyzed the trapezoidal-cut twisted tape in a U-tube heat exchanger using Al_2O_3-water nanofluid in turbulent flow regimes. Nusselt number enhancement by 34.24% and friction factor increase by 1.29 times was reported.

Changzhong Man et al. [2] presented an experimental research on a new kind of twisted tape insert having cut edge with different lengths. It was revealed that Nusselt number was 1.15–1.9 times and friction factor was 1.21–5.75 times of that for the plain tube. The performance evaluation criteria (PEC) was reported to be in range of 0.82–1.06. Masoud Rahimi et al. [3] reported through CFD analysis an increase of 31% in Nusselt number and performance of a jagged twisted tape insert. Panida Seemawute et al. [4] showed experimentally the effect of peripherally-cut twisted tape insert with alternate axis in uniform heat flux circular tube under turbulent flow conditions. A maximum of 1.25 thermal performance factor was reported. Smith Eiamsa-ard et al. [5]

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Nomenclature

A	heat transfer surface area, m2
Cp	specific heat of fluid, kJ/kgK
D	inside diameter of the tube, mm
D	depth of cut, mm
F	friction factor
H	Heat transfer coefficient, W/m2K
I	current, A
K	thermal conductivity of fluid, W/mK
L	length of the test section, m
M	mass flow rate of water, kg/s
Nu	Nusselt Number
P	pressure, kPa
ΔP	pressure drop, kPa
Pr	Prandtl Number
Q	heat transfer rate, W
Re	Reynolds Number
T	thickness of the test tube, mm
ΔT	temperature difference, ºC
T	temperature, ºC
$\widetilde{T}$	average temperature, ºC
U	mean axial flow velocity, m/s
V	voltage, V
W	width of cut, mm
W	twisted tape width, mm
Y	twist pitch length, m
y/W	twist ratio

Greek Symbols

P	Fluid density, kg/m3
δ	twisted tape thickness, mm
μ	Dynamic viscosity, kg/m-sec
η	Thermal performance factor

Subscripts

B	bulk
C	convection
i	inlet
o	outlet
p	plain
s	surface
t	turbulator
w	water

Abbreviations

PT	Plain tube
TT	twisted tape
CCTT	continuous cut twisted tape
R-CCTT	continuous rectangular cut TT

also investigated the effects of peripherally-cut twisted tape insert in a round tube. Tests were performed at constant twist ratio considering three different tape depth (d/W) ratios, each with three different widths (w/W) ratios. It was revealed that with increase of tape depth ratio and decrease of tape width ratio, the Nusselt number, friction factor and thermal performance factor increases. It was found that the maximum thermal performance factor is 4.88 for laminar flow and 1.29 for turbulent flow at 0.33 depth ratio and 0.11 width ratio. Smith Eiamsa-ard et al. [7] further investigated the peripherally-cut twisted tape (PT) insert for various twist ratio keeping the depth and width constant. An enhancement of 211% and 138% in Nusselt number was obtained with the use of PT in comparison to that of plain tube and tube with twisted tape (TT). A maximum of 1.14 thermal performance factor was achieved.

S. Eiamsa-ard et al. [17] also studied the influences of straight delta-winglet (S-DWT) and oblique delta-winglet (O-DWT) twisted tape for various depth of wing cut ratios in a uniform heat wall fluxed tube over a turbulent Reynolds number range. O-DWT was found more effective than S-DWT resulting in increase in Nusselt number and friction factor with increasing depth of wing cut ratio. For the range investigated, TPF with S-DWT was 0.88–1.21 and with O-DWT it was around 0.92 – 1.24. The various cut twisted tape performed better than the conventional twisted tape due to the extra agitation produced near the tube wall.

As per the presented review, it has been proved that the heat transfer intensification by using cut twisted insert is a promising approach. In the reported work twisted tape with single cut per twist have been investigated. To extend the study of cut insert, this work introduces the use of twisted insert with continuously cut edges (CCTT) with constant depth ratio (d/W = 0.025) and width ratios (w/W = 0.05). The present work focuses on examination of the heat transfer, friction factor and the thermal performance enhancement behaviors in a constant heat fluxed circular tube having inside it a twisted tape inserts with continuous rectangular cut edges (R-CCTT) shown in Fig. 1. The heat transfer rate and friction factor were measured for different twist ratio of 3 and 5 under turbulent flow conditions ranging between $4000 < Re < 20{,}000$. The results obtained for the same are also compared with that for the conventional twisted tape and the plain tube.

2. Materials and methods

The experimental setup as shown in Fig. 2 consists of a copper tube in which water flows at room temperature (D = 20 mm, t = 1 mm and L = 1000 mm). The experimental setup has a developing section of 2.5 m, test section of 1 m and then calming section of 1 m. Asbestos rope and glass wool insulation is done on the outer of the tube for minimization of the heat loss to the surroundings. Two calibrated rotameters with flow ranges of 0–20 LPM and 0–2 LPM with ± 0.1 LPM accuracy

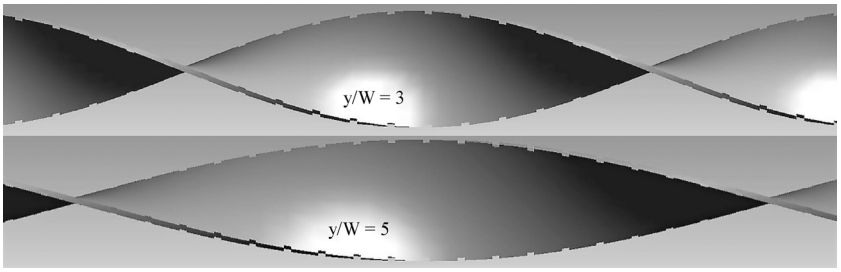

Fig. 1. Continuous rectangular cut twisted tape (R-CCTT) inserts with twist ratio 5 and 3.