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EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER & FRICTION FACTOR CHARACTERISTICS USING U-CUT TWISTED TAPE INSERT

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Abstract ***–*** *Experimental investigation of heat transfer and friction factor characteristics of circular tube fitted with U-cut twisted tape was studied. A 914 mm long copper tube of 26.6 mm inside diameter and 30 mm outside diameter was used. The test section consisting of a circular tube made of copper having 26.6 mm inside diameter, 30 mm outside diameter and 900 mm in effective length. A stainless steel U-cut twisted tape insert of 5.5 twist ratio was inserted into the plain tube. A uniform heat flux condition was maintained by wrapping Nichrome wire around the test section and fiber glass over the wire. Outer surface temperatures of the tube were measured at 5 different points of the test section by K-type thermocouples. Two thermometers were used for measuring the bulk temperatures. At the outlet section the thermometer was placed in a mixing box. The Reynolds numbers were varied in the range 10153-19217 with heat flux variation 18 to 27kW/m^2 for plain tube, and 32 to 47kW/m^2 for tube with insert. Nusselt numbers obtained from plain tube were compared with Dittus and Boelter correlation. At comparable Reynolds number, Nusselt number in tube with U-cut twisted tape insert was enhanced by 2.76 to 3.24 times with compared to plain tube.*

Keywords***:*** Heat transfer enhancement, U-cut twisted tape insert, Tube side heat transfer, Friction factor.

1. INTRODUCTION

Heat transfer augmentation techniques are widely used in areas such as heat recovery process, air conditioning and refrigeration systems, and chemical reactors. The techniques of heat transfer enhancement to accommodate high heat flux i.e., to reduce size and cost of heat exchangers have received serious attention passed years. U-cut twisted tape insert provides an additional disturbance to the fluid in the vicinity of the tube wall and vortices behind the cuts and thus leads to a higher heat transfer enhancement in comparison with plain tube and plain twisted tape.
The heat transfer and friction factor characteristics in a circular tube fitted with different tube inserts were experimentally investigated and correlations for Nusselt number and friction factor were proposed [1-5]. The heat transfer and friction factor characteristics were experimentally compared between plain twisted tape with broken and serrated twisted tape inserts [6]. More information about heat transfer by means of twisted tapes fitted in a circular tube can be viewed in other reports [7]. Ahamed studied the heat transfer in turbulent flow through tube with perforated twisted-tape inserts [8]. Sarada *et al.* experimentally investigated the augmentation of turbulent flow heat transfer in a horizontal tube by means of mesh inserts with air as the working fluid [9]. Yadav investigated the effect of half-length twisted-tape turbulators on heat transfer and pressure drop characteristics inside a double pipe u-bend heat exchanger [10].

The present work reports the experimental work on heat transfer rate and friction factor characteristics in a circular tube fitted with U-cut twisted tape insert in the region of turbulent flow. Data are compared with plain tube heat transfer values and the ranges of heat transfer enhancements are reported.

2. EXPERIMENTAL SET UP

The schematic diagram of the experimental set up is shown in Fig. 1. A long copper tube of 26.6 mm internal diameter and 30 mm outer diameter, of which length of 900 mm was used as the test section. A stainless steel U-cut twisted tape insert of 5.3 twist ratio was inserted into the plain tube. U-cut twisted tape insert shown in Figs. 2(a) and 2(b). The nichrome resistance wire was spirally wound uniformly on the outer surface of the test section to supply the heating power. Mica sheet was used between the tube and heating wire for electrical insulation. The heating wire was covered with mica sheet and fiber glass. Power was supplied to heater from an ac source of 220 volt. Five K-type thermocouples were placed on five equally spaced points in the test section to measure the outer surface temperatures of the tube. Two thermometers were placed at the inlet and outlet of the tube to measure the inlet and outlet water temperatures respectively.

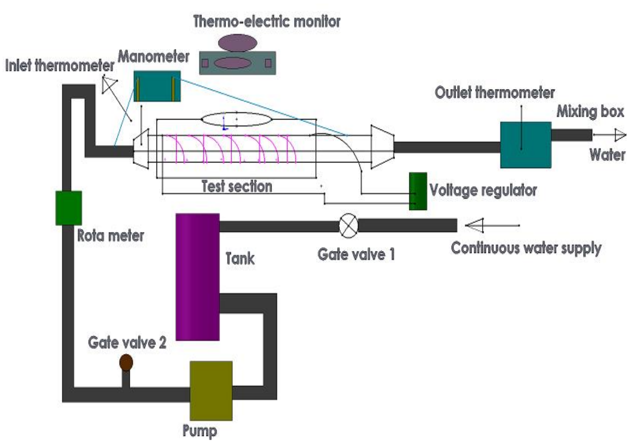

Fig. 1: Schematic diagram of experimental setup

To measure the outlet temperature, the thermometer was placed in a mixing box, which was thermally insulated to minimize the heat loss. A Rota meter of 26 L/min capacity was provided to measure the water flow rate.

Fig. 2(a): Photograph of U-cut twisted tape

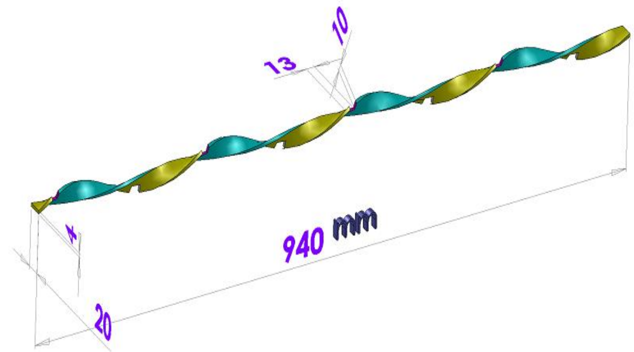

Fig. 2(b): Photograph of U-cut twisted tape

Initially, water was taken in the reservoir and pumped to the test section through the Rota meter. The flow rate of water was varied by the gate valve for different data and kept constant during the experiment. The flow rate was taken from 165 $ml/$sec increased by 30 ml/sec upto 315 ml/sec. After switching the heating power the sufficient time was given to attain the steady state condition. In each run, data were taken for a particular water flow rate, water inlet, outlet and tube outer surface temperatures.

3. DATA REDUCTION

Heat transfer supplied by the heater to water was calculated for measuring heat added to the water. Heat added to water was calculated by,

$$Q = mc_p(T_o - T_i) \quad (1)$$

Heat transfer coefficient was calculated from,

$$h = Q/\{A(T_{is} - T_{bulk})\} \quad (2)$$

And heat flux was obtained from,

$$q = \frac{Q}{A_s} \quad (3)$$

Where, $As = \pi diL$ (4)

The bulk temperature was obtained from the average of water inlet and outlet temperatures,

$$T_{bulk} = \frac{(T_i - T_o)}{2} \quad (5)$$

Tube inner surface temperature was calculated from one dimensional radial conduction equation,

$$T_{is} = T_{os} - \frac{q * \ln(^{d_o}/_{d_i})}{2\pi kL} \quad (6)$$

Tube outer surface temperature was calculated from the average of five local tube outer surface temperatures,

$$T_{os} = \frac{\text{Thermocouple } 1 + \cdots + \text{Thermocouple } 5}{5} \quad (7)$$

Theoretical Nusselt number was calculated from Dittus Boelter correlation,

$$Nu_{th} = 0.023\mathrm{Re}^{0.8}\mathrm{Pr}^{0.4} \quad (8)$$

Where,

$$Re = \rho V d_i/\mu \quad (9)$$

$$Pr = \mu Cp/k_f \quad (10)$$

$$Nu = h d_i/k_f \quad (11)$$

Mean water velocity was obtained from,

$$v = m/A_x \quad (12)$$

Cross sectional area,

$$A_x = \pi d_i^2/4 \quad (13)$$

Friction factor at any location,

$$f = \frac{2\Delta p d_i}{\rho v^2 L} \quad (14)$$

Where,

$$\Delta p = p_i - p_x$$

4. RESULTS AND DISCUSSIONS

It has been found from the result that, in case of plain tube heat transfer rate increased with the increase of flow rate. More water was passed through the tube taking more heat gradually. Pressure drop also increased with the increase of flow rate in the plain tube. On the other hand it has been also found that when U-cut twisted tape insert was inserted in the copper tube, heat transfer rate was increased compared to plain tube without insert. Heat transfer rate was increased because water was flowing through the tube there developed two components of flow, axial component of flow and radial component of flow which were responsible for breaking down of water film, so the flowing water was taking more heat from the previous one. But pressure drop was increased gradually with the increase of flow rate than the plain tube. Nusselt numbers for the plain tube and the tube with U-cut twisted tape insert are shown in Fig. 3. It is observed that, Nusselt numbers increased with the increase of Reynolds number and U-cut twisted tape insert gave higher values of Nusselt number than those for plain tube. For plain tube Nusselt numbers, Nu_{exp} increased from 53 to 118 with the increase of Reynolds number from 10152 to 19216 respectively. For tube with U-cut twisted tape insert for Re = 10540, Nusselt number, Nu_{exp} was found to be 147 and for Re = 19870, Nu_{exp} was increased to 382. At comparable Reynolds numbers, Nusselt numbers in tube with U-cut twisted tape insert were enhanced by 2.76 to 3.24 times compared to those of plain tube with the average enhancement of 3 times.

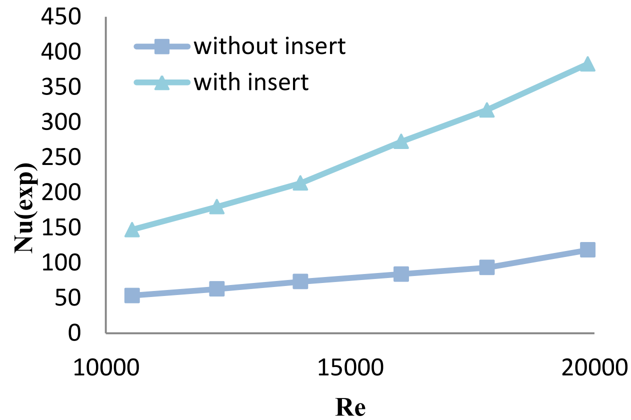

Fig. 3: The variation of Nusselt number with Reynolds number

Figure 4 shows the heat flux variation for plain tube and tube with U-cut twisted tape insert. It is seen that, heat fluxes increased with the increase of Reynolds number and twisted tape insert gave higher heat fluxes than those for plain tube. A higher value of heat transfer coefficient was responsible for this enhancement.

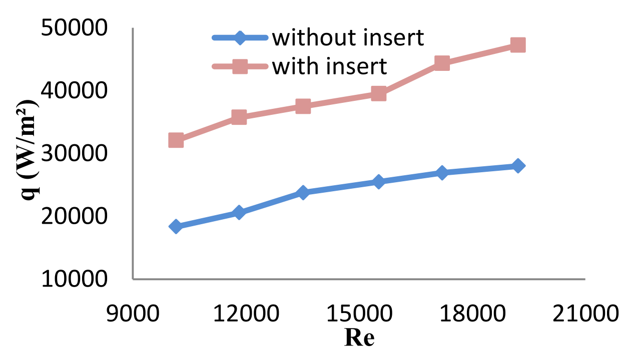

Fig. 4: The variation of heat flux with Reynolds number

Figure 5 shows the heat transfer coefficient variation for plain tube and tube with U-cut twisted tape insert. It is seen that heat transfer coefficient increased with the increase of Reynolds number and U-cut twisted tape insert gave higher heat transfer coefficient than those for plain tube. Because when insert was used heat transfer rate was increased.

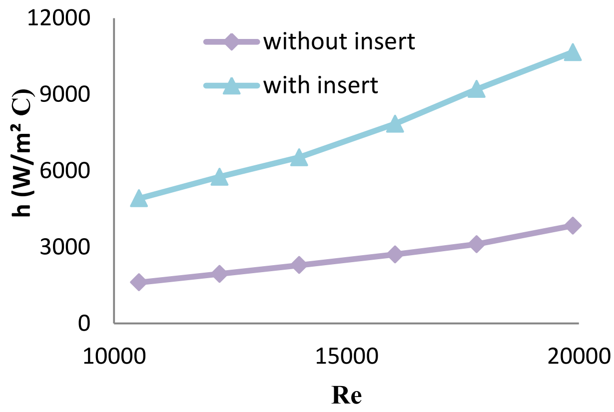

Fig.5: The variation of heat transfer coefficient with Reynolds number

Figure 6 shows the friction factor variation for plain tube and tube with U-cut twisted tape insert. From the graph it is found that for the increasing of same Reynolds no. increasing friction factor both with insert and without insert. But the increasing with insert was higher than without insert. Because when insert was used the pressure drop was increased.

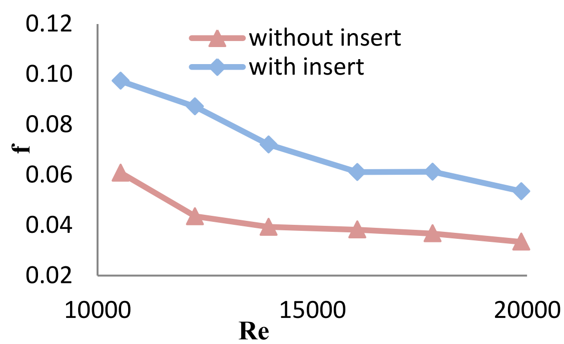

Fig. 6: The variation of friction factor with Reynolds number

5. CONCLUSIONS

An experimental investigation of heat transfer and friction factor characteristics of circular tube fitted with U-cut twisted tape insert was studied. It is found that that the swirl flows were helpful for decreasing the boundary layer thickness. This study would mainly focus on Reynolds number, Nusselt number, friction factor, and especially on heat transfer coefficient. The present experimental study of tube side heat transfer enhancement with U-cut twisted tape has made the simultaneous effects on Re, Nu and h. The results showed that

- The Nusselt number and heat flux increased with increasing Reynolds number.
- The experimental Nusselt numbers for tube with U-cut twisted tape insert were enhanced by 2.76 to 3.24 times compared to those of plain tube with average value of 3 times..
- Friction factor for plain tube without U-cut twisted tape and with U-cut twisted tape was found respectively 0.0334~0.0608 and 0.0534~0.0973.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning	Unit
A_x	Cross sectional area of heating tube	m
d	Diameter of heating tube	m
h	Convective heat transfer coefficient	$W/m\ ^o C$
L	Length of heating tube	m
M	Mass flow rate	kg/s
T_{is}	Inner surface temperature	$^o C$
T_b	Bulk temperature	$^o C$
T_{os}	Outer surface	$^o C$
T_i	temperature	$^o C$
T_o	Inlet temperature	$^o C$
ΔP	Pressure difference	N/m
p_i	Inlet pressure	N/m
p_x	Pressure at location, x	N/m
d_i	Inner diameter	m
d_o	Outer diameter	m
ρ	Fluid density	kg/m
μ	(Absolute) dynamic fluid velocity	kg/m. s
ν	Kinematic fluid velocity	m /s
k_f	Thermal conductivity of the fluid	$W/(m.^o C)$
v	Water velocity	m/s
C_p	Specific heat	$kJ/(kg\ ^o C)$
f	Friction factor	(-)
k	Thermal conductivity	$W/(m.^o C)$
Q	Heat transfer rate	W
V	Mean velocity	m/s
q	Heat flux	W/m
Pr	Prandtl number	(-)
Re	Reynolds number	(-)
Nu	Nusselt number	(-)