Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2019
(ICMERE2019) 11 – 13 December, 2019, Chittagong, Bangladesh

ICMERE2019-PI-223

EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER ENHANCEMENT WITH PERFORATED TRIANGULAR SHAPE TWISTED TAPE INSERT

Deepto Roy[1], Zahid Parvez[2], Muhammad Mostafa Kamal Bhuiya[3], Bodius Salam[4] and Md.Maruf Billah[5]

Department of Mechanical Engineering, Chittagong University of Engineering &Technology (CUET), Chattogram 4349, Bangladesh
deeptohr04@gmail.com*, zahidparvez1996@gmail.com*, mkamalcuet@gmail.com*, bsalam@cuet.ac.bd, maruf@cuet.ac.bd

Abstract*- The present work deals with an experimental investigation to evaluate the heat transfer (Nusselt number) and friction factor (f) in a circular tube with equilateral triangular perforated twisted tape. The equilateral triangular perforated area of 7, 11, 15 mm^2 were applied in this study. The experiment was performed in a turbulent flow region with Reynolds number ranging from 2774-6530 using water as the working fluid. The twist ratio of 3.2 was considered to conduct the experiment. The Nusselt number (Nu) and friction factor (f) increased from 67 -137% and 51-128% in comparison to the smooth tube values. The maximum heat transfer and friction factor were observed at a perforated area of 7mm^2. Moreover, heat transfer and friction factor correlations were developed to predict the heat transfer and friction factor.*

Keywords: Triangular perforated twisted tape insert, Heat transfer rate, Friction factor, Nusselt Number.

1. INTRODUCTION

Heat transfer enhancement is the process of increasing the effectiveness of heat exchangers. Enhancing heat transfer is very essential in industries that are equipped with electronic and mechanical machines and devices because heat must be removed as early as possible to reduce the loss of heat and to avoid the formation of hot spots which may affect and lead to permanent damage of the machines. The goal of enhancement of heat transfer rate is to achieve high heat transfer rate using minimum pumping power, minimize cost of energy and material along with reducing the size and shape of the heat exchangers. To boost and enhance thermal efficiency various heat transfer enhancement techniques are widely used from the last 20th century. Today use of different types of inserts and are widely used which is basically a passive technique. Among various inserts twisted tap insert with the combination of triangular perforation can be a promising technology. It may be used in various section of machineries in industrial or research purposes. The research is done without the considerations of friction losses and viscous effect. The insert enhances heat transfer for the swirl generator which cause the breakdown of the boundary layer thickness due to continuous geometric changes in surfaces which lead to greater convective heat transfer. Use of triangular shape perforation in twisted tap is basically a passive technique. Eiamsa-ard [1] reports on heat transfer enhancement and friction factor characteristics in the tubes inserted with rectangular-winged twisted tapes(TT-RWs). The wing-depth ratio (d/W) was varied from 0.1 to 0.3 while the tape twist ratio was kept constant at y/W = 4.0. According to the results, the TT-RW with d/W = 0.3 yields the highest Nusselt number which is around 100% higher than that of the plain tube. Saha et al. [2] experimentally investigated the effect of regularly spaced twisted tape in heat transfer and pressure drop characteristics in a circular tube. They found that the Reynolds number, Prandtl number, twist ratio, space ratio, tape-width, rod-diameter and phase angle lead the heat transfer characteristics. They concluded that poor heat transfer from tape width reduction and there is no effect of higher than zero phase angle; rather it creates manufacturing complexity. Nakhchi and fahan [3] suggested that the heat transfer coefficient increased up to 23.20% with increasing the nanoparticle volume fraction from 0% to 1.5% where Cu-water used as nanofluid with cross cut twisted tape with alternate axis. Here Reynolds number is in the range of 5000 to 15000.Somravysin and Eiamsa-ard [4],Suggested that heat transfer rates increased with decreasing twist ratio in the enhancement test of dual twisted tape. .Nu numbers are 107%, 97.7%,77.4% for the twist ratio 2,3,4 respectively. Thermal performance was increased to 1.16, 1.26, 1.19 respectively with the corresponding twist ratio 2.Singh and Maithani [5] showed that heat transfer coefficient increased 4.1% with square wings in multiple square perforated twisted tapes. Here the Reynolds number is varied from 5000 to 27000.This study also showed that an increase of about 6.96 and 8.34 times in the Nu_{rs} and f_{rs} respectively.

Thianpong et al. [6] experimentally investigated the effects of perforated twisted tape with parallel wings in heat transfer and pressure drop characteristics in a heat exchanger. This type of insert involves: the perforation in the center of the insert, reduce the pressure drop and wings produce extra turbulence near the tube walls. By this experiment they revealed that the maximum thermal performance factor 1.32 was increased compared to plain tubes and typical tapes. Fuskele and Sarviya [7] suggested that heat transfer rate was increased 1.23–1.38 times for continuous cut edge twisted tape insert in circular tube as the term of water . It also increased to 1.32–1.57 times in the case of CuO - water nanofluid. Nusselt number was increased up to 1.93–3.17 times than that of plain tube with the using of nanofluid. Salam et al. [8] carried out the experiment to measure tube side heat transfer coefficient, friction factor and heat transfer enhancement efficiency of water using rectangular cut twisted tape in the edge. They varied Reynolds number in the range 10000-19000 and heat flux varied in the range14-22 kW/m^2 without insert; 23 to 40 kW/m^2 with insert. From the study, they presented that the Nusselt number increased by 2.3 to 2.9 times and friction factor increased by 1.4 to 1.8 times over the smooth tube. They also stated that the heat transfer performance enhanced with the increase of Reynolds number. Eiamsa-ard and Kiatkittipong [9] suggested that multiple twisted tape insert had an higher impact on heat transfer coefficient than the single tube. The thermal performance factors of the tubes with quadruple, triple and dual twisted tapes varied between 1.13-1.45, 1.06-1.27, and 0.95-1.1. They also showed that thermal performance factors of the nanofluid with TiO_2 concentration of 0.07%, 0.14% and 0.21% by volume were respectively 5.8-9.8%, 4.1-7.4% and 3.1- 5.5% higher than that of the base fluid.

The main objective of the study is to evaluate the enhancement in heat transfer (Nu), to determine the fluid friction characteristics.

2. DATA REDUCTION EQUATIONS

The experimental data were used to find out the Nusselt number, friction factor at different Reynolds number in turbulent flow region for both the cases with and without using perforated twisted tape insert.

Cross sectional area, $A_x = \frac{\pi di^2}{4}$ (1)

Heat transfer rate by the heater to water was calculated by measuring heat added to the water.

Heat added to water was calculated by, $Q = mC_p (T_o - T_i)$ (2)

Bulk temperature, $T_b = \frac{To+Ti}{2}$ (3)

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

$T_{wi} = T_{wo} - Q \frac{ln(\frac{d_o}{d_i})}{2\pi kCu\, L}$ (4)

Convective heat transfer coefficient, $h = \frac{Q}{A_s(T_{wi} - T_b)}$ (5)

Reynolds Number, $Re = \frac{\rho\, Um\, di}{\mu}$ (6)

Prandtl number, $Pr = \frac{\mu Cp}{k}$ (7)

Experimental Nusselt Number, $Nu_{exp} = \frac{hdi}{k}$ (8)

Theoretical Nusselt Number, $Nu_{th} = 0.023Red^{0.8} Pr^{0.4}$ (By Dittus and Boelter) (9)

Theoretical Friction Factor, $f_{th} = (0.79lnRe-1.64)^{-2}$ (10)

Experimental friction factor, $f_{exp} = \frac{\Delta P}{(\frac{L}{di})(\frac{\rho U_m^2}{2})}$ (11)

3. EXPERIMENTAL SETUP

The experiment is related to single twisted tape with triangular perforation in the surface of twisted tape. The length of the twisted tapes is 850 mm, width is 20 mm and thickness are 1.5 mm. The perforation in the insert is equilateral triangular which has different length. There are three different triangles with the length of perforation 7mm, 11 mm, and 15mm respectively in three different inserts. Twist ratio is 3.2 and it is same in all three different inserts.

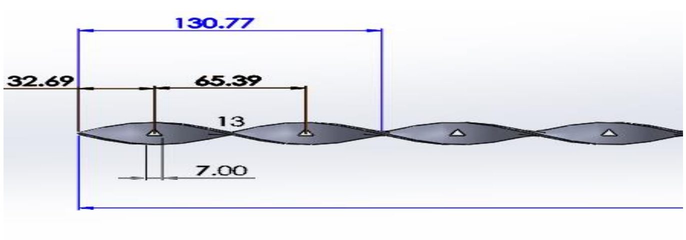
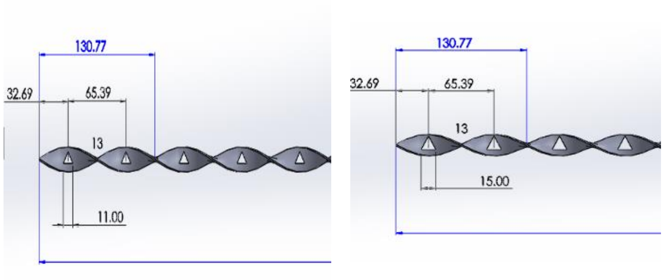


Fig. 1: Twisted Tape with 7mm triangular perforation



(a) (b)

Fig. 2 : Twisted Tape with (a) 11 mm and (b) 15 mm triangular perforation

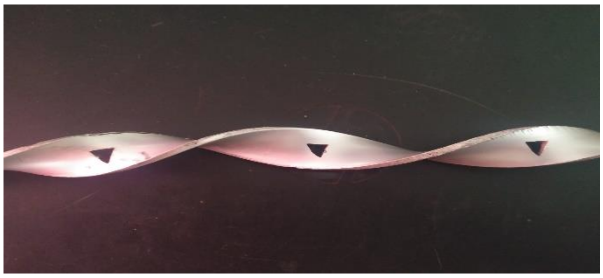


Fig. 3: Photographic view of triangular perforated twisted tape insert

The geometric test section consists of a smooth copper tube wired with nichrome wire to heat it. It was 26.6 mm inner diameter and 30 mm of outer diameter and 900 mm in length. The insert was made of aluminum for different perforations 7mm, 11mm and 15mm triangular shape. The nichrome wire was spirally wounded over the smooth tube and a voltage regulator was attached to it for heating the smooth tube. The inlet and outlet temperature of the fluid were measured by two thermometers. Four K type thermometers were caused to measure the surface temperature. The pressure drop was measured by a U tube manometer. Fig. 4 shows the full experimental facility.

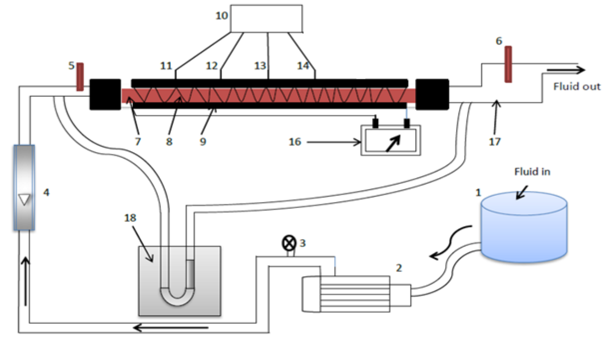


Fig. 4: Schematic diagram of the experimental apparatus

1. Tank
2. Pump
3. Gate Valve
4. Rotameter
5. Inlet thermometer
6. Outlet thermometer
7. Test section
8. Nichrome wire
9. Insulator
10. Temperature reading device
11-14. Thermocouples (4)
16. Voltage regulator
17. Mixing chamber
18. U-tube manometer

4. RESULTS AND DISCUSSION

The study investigated the heat transfer, friction factor using triangular perforated twisted tap insert for different perforation. The results have been found from the charts, tables and calculations and have been discussed graphically.

4.1. Heat transfer characteristics

Fig. 5.1 shows the relationship between Reynolds number and Nusselt number of triangular perforated twisted tape insert. It has been shown that Nusselt number gradually increased with the increase of Reynolds number for all other cases. With the increase of Reynolds number, the flow rate increased with led to the intensity of turbulence increased that finally resulted with the increase of convective heat transfer. Nusselt number for triangular perforated twisted tap insert was much higher than the plain tube. The reason behind it can be explained that coiled porous twisted tape insert created good mixed of fluid or swirl effect. The effectiveness of heat transfer enhancement by triangular perforated twisted tap insert was found by comparing the ratio Nu_p/Nu_s which is shown in Fig. 5.2. This was found from the investigation that the ratio was always higher than one. The result showed that the ratio for various perforation of insert decreased with the increase of Reynolds number. This showed that role of using inserts in more turbulent flow was much more dominant at low Reynolds number in comparison to higher Reynolds number. According to the experiment result, Nusselt number with inserts for different perforation were 67% -137% higher than those with the values of plain tube.

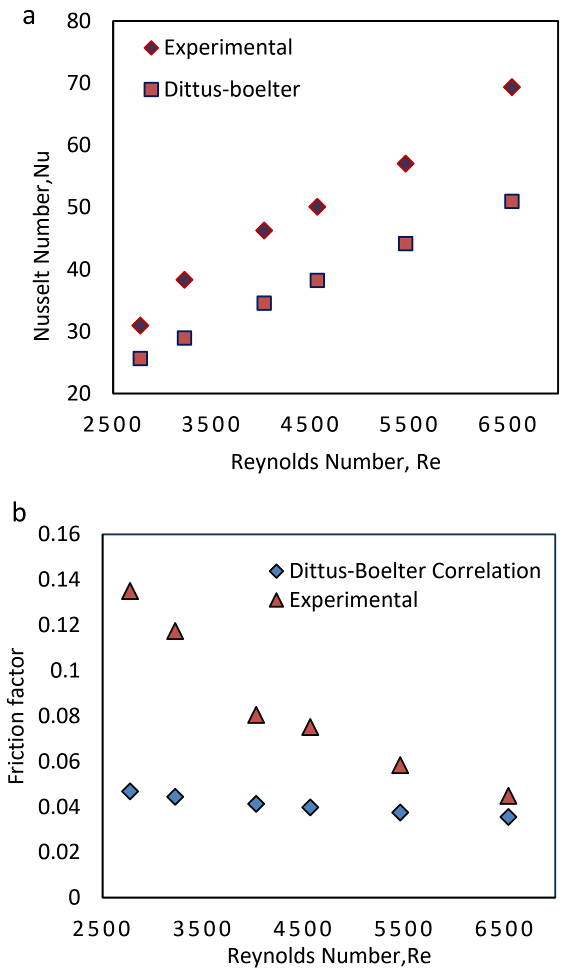
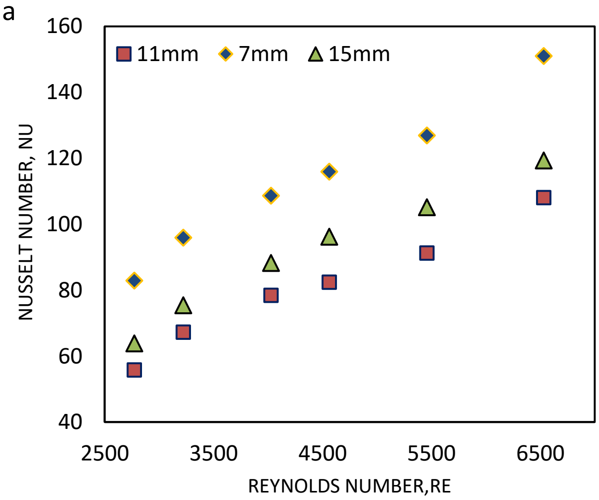


Fig 5.1: Verification of the plain tube: (a) Nusselt number and (b) friction factor.



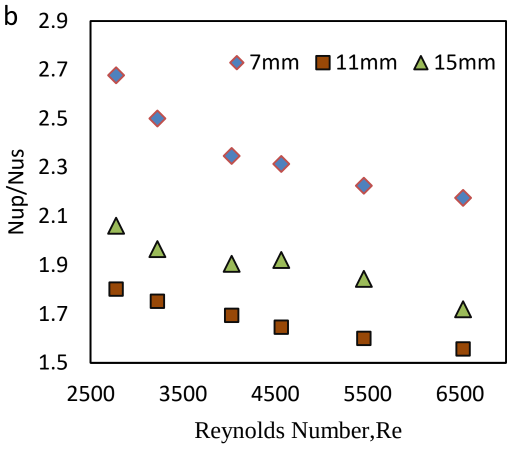
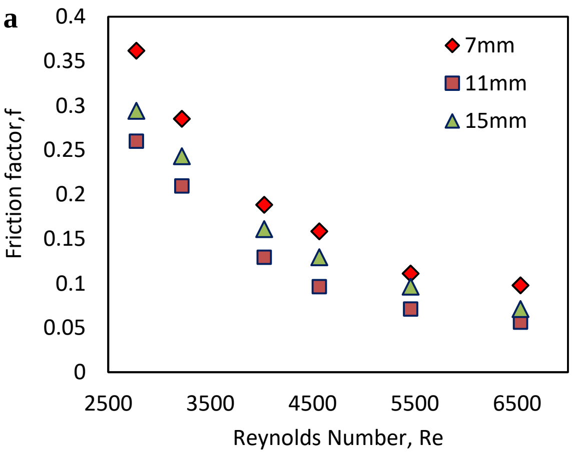


Fig. 5.2: (a) Relationship between Nusselt number and Reynolds number (b) effectiveness

4.2. Fluid flow characteristics

The effect of friction on triangular perforated twisted tap insert has been described in Fig. 5.3. It shows the relationship between friction factor and Reynolds number for different perforation with and without insert. The friction factor usually decreases with the increase of Reynolds number. Reason behind this can be explained with the increase of Reynolds number larger contact area with long flow path increased. Besides for lower Reynolds number huge amount of air can mix and pass with water creating very high friction. The experiment carried that friction factor changes with the change of perforation and the maximum amount of friction factor was found for 7mm equilateral triangular perforation. This mean that for the perforation it caused rapid turbulence and extreme swirl effect. It was found from the investigation that the friction factor for triangular perforated twisted tape insert was 51%-128% higher than the plain tube.



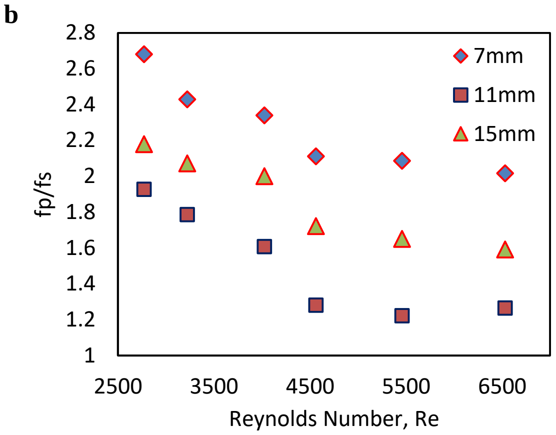


Fig. 5.3: Relationship between friction factor and Reynolds number

5. CONCLUSION

An experimental study was carried out to find out the frictional effect and heat transfer characteristics for different triangular area perforation (7 mm, 11mm, and 15mm) of triangular perforated twisted tape insert. From the experiment it was proved that triangular perforated twisted tape insert was found to be a very efficient insert. Based on the calculations and investigational result, notable findings are summarized below:

- ✓ Triangular perforated twisted tape insert offered a good heat transfer rate. Nusselt number increased 67% -137% in comparison to the smooth tube. Three different perforations were used. For 7mm, 11mm, 15mm Nusselt number was found 83.26-151.07, 55.87-108.10and 63.90-119.32 respectively.
- ✓ Friction factor also increased with the increase of Reynolds number. Friction factor for 7mm, 11mm, and 15mm perforation was 0.09-0.36, 0.05-0.26 and 0.07-0.29 respectively. Further calculations show that friction factor increased 51%-128% in comparison to the friction factor of plain tube.

6. ACKOWLEDGEMENT

The authors would like to gratefully acknowledge the Chittagong University of Engineering & Technology (CUET) for their support of this research.

7. REFERENCES

[1] P. Eiamsa-Ard, C. Thianpong, and S. Eiamsa-Ard, "Influences of twisted-tape with parallel rectangular-wing on thermal performance of a heat exchanger," *Proc. 2011 Int. Conf. Util. Exhib. Power Energy Syst. Issues Prospect. Asia, ICUE 2011*, pp. 1–6, 2012.

[2] S. K. Saha and P. Langille, "Heat transfer and pressure drop characteristics of laminar flow through a circular tube with longitudinal strip inserts under uniform wall heat flux," *J. Heat Transfer*, vol. 124, no. 3, pp. 421–432, 2002.

[3] M. E. Nakhchi and J. A. Esfahani, "Performance intensification of turbulent flow through heat

exchanger tube using double V-cut twisted tape inserts," *Chem. Eng. Process. - Process Intensif.*, vol. 141, no. February, p. 107533, 2019.

[4] P. Somravysin, S. Eiamsa-ard, W. Changcharoen, V. Kongkaitpaiboon, and M. Pimsarn, "Thermal Enhancement in Tubes with Dual Twisted Tapes," *Appl. Mech. Mater.*, vol. 751, pp. 239–244, 2015.

[5] A. R. S. Suri, A. Kumar, and R. Maithani, "Experimental investigation of heat transfer and fluid flow behaviour in multiple square perforated twisted tape with square wing inserts heat exchanger tube," *Heat Mass Transf. und Stoffuebertragung*, vol. 54, no. 6, pp. 1813–1826, 2018.

[6] S. Shi, L. Gao, L. Ma, Z. Chen, and Y. Zhang, "Research on flicker measurement algorithm based on FFT," *Energy Procedia*, vol. 14, pp. 1709–1716, 2012.

[7] R. M. Sarviya and V. Fuskele, "Heat Transfer and Pressure Drop in a Circular Tube Fitted with Twisted Tape Insert Having Continuous Cut Edges," *J. Energy Storage*, vol. 19, no. May, pp. 10–14, 2018.

[8] B. Salam, S. Biswas, S. Saha, and M. M. K. Bhuiya, "Heat transfer enhancement in a tube using rectangular-cut twisted tape insert," *Procedia Eng.*, vol. 56, pp. 96–103, 2013.

[9] S. Eiamsa-ard, K. Kiatkittipong, and W. Jedsadaratanachai, "Heat transfer enhancement of TiO2/water nanofluid in a heat exchanger tube equipped with overlapped dual twisted-tapes," *Eng. Sci. Technol. an Int. J.*, vol. 18, no. 3, pp. 336–350, 2015.

8. NOMENCLATURE

Symbol	Meaning	Unit
Ao	Outer surface area of tube Inner	(m2)
As	surface area of tube Cross	(m2)
Ax	sectional area of tube	(m2)
Cp	Specific heat	(J/kg.K)
do	Tube outer diameter	(m)
di	Tube inner diameter	(m)
dc	Coil diameter	(m)
L	Tube length	(m)
t	Thickness	(m)
f	Friction factor	Dimensionless
q	Heat flux	(W/m2)
h	Heat transfer coefficient	(W/m2.K)
kw	Thermal conductivity	(W/m.K)
Q	Heat transfer rate	(W)
m	Mass flow rate	(kg/s)
Nu	Nusselt number	Dimensionless
ΔP	Pressure drop	Dimensionless
Pr	Prandtl number	Dimensionless
Re	Reynolds number	Dimensionless
To	Hot water temperature	(°C)
Ti	Cold water temperature	(°C)
T1	Temperature thermocouple 1	(°C)
T2	Temperature of thermocouple 2	(°C)
T3	Temperature of thermocouple 3	(°C)
T4	Temperature of thermocouple 4	(°C)
Tb	Bulk temperature	(°C)
Two	Outer surface temperature	(°C)
Twi	Inner surface temperature	(°C)
um	Mean velocity	(m/s)
V	Velocity	(m/s)
w	Twisted tape width	(m)
y	Twist ratio	Dimensionless
ρ	Density	(kg/m3)
μ	Dynamic viscosity	(kg/m-s)
η	Thermal enhancement factor	Dimensionless