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

ICMERE2019-PI-187

AUGMENTATION OF HEAT TRANSFER USING COILED PERFORATED TWISTED TAPE INSERT

Zahid Parvez[1,*], M.M.K.Bhuiya[2], Bodius Salam[3]

Department of Mechanical Engineering, Chittagong University of Engineering &Technology (CUET), Chattogram 4349, Bangladesh
zahidparvez1996@gmail.com[1,*], mkamalcuet@gmail.com[2], bsalam@cuet.ac.bd[3]

Abstract- *An experimental investigation was carried out to evaluate the heat transfer (Nusselt number), friction factor (f) and thermal enhancement efficiency (η) in a circular tube with three porosities (Rp=1.7%, Rp=4.1%, Rp=5.6%) using coiled perforated twisted tape insert. The experiment was performed in a turbulent flow region with Reynolds number ranging from 2774 to 6530 using water as the working fluid. The Nusselt number (Nu) and friction factor (f) increased from 73-154 and 48-148%, respectively, higher than the smooth tube. Moreover the thermal enhancement efficiency (η) was increased from 1.12-1.5, 1.29-1.84, 1.24-1.7, respectively, for Rp=1.7, Rp=4.1 and Rp=5.6% at a constant pumping power in comparison to the plain tube..*

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

1. INTRODUCTION

Heat transfer enhancement means maximizing the utility and 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 avoid the formation of hot spots which may effect 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.

Tube inserts are used for heat transfer improvement and fouling mitigation in different| industrial fields like petroleum refineries and chemical plants for several years. There are many kinds of inserts employed in the heat exchanger tubes such as helical/twisted tapes, ribs/fins/baffles, louvered strip insert twisted tape, swirl flow devices insert, wire coil insert, winglet type vortex generators, conical ring insert and brush and pin elements inserts. Combination of varied inserts and tube with artificial roughness provided promising results. In the case of using numerous propeller varieties, heat transfer improvement was dependent on a higher number of blades and blade angle and lower pitch ratio. There are three types of heat transfer augmentation techniques. Active, passive and compound. Choi and Eastmen suggested that the heat transfer effectively increase with the use of various types of solid particles (size <100 nm), metallic (e.g. - cu, Ag, Al) and various types of solid particles in conventional fluid what was named later as Nano fluid [1].Bunya et al.[2] carried out an investigation that thermal performance factor, Nusselt number with perforated twisted tap insert for different pore dia. In the experiment Reynolds number ranged from 7200-4980 using only air as working fluid. It was found in that investigation that Nusselt number, thermal performance factor, friction factor was 110-340%, 28%-59% and 110-360 higher. Himal et al.[3] investigated Reynolds number ranging b from 9317-18193 , Nusselt number 26.96-50.85 and found that heat flux increased by 1.54-1.83 times and performance found in the range of 1.78-2.26 after addition of insert. Wang and Sunden found relations for ethylene glycol and polybutene (Re no.10000-70000).It was found that twisted tape insert was more effective for low Prandlt number and wire coil effective for high Prandlt number fluids.[4] Ahamed et al.[5] did an analysis of heat transfer enhancement for perforated twisted tap insert. Reynolds number ranged from 1.3 x 10^4 to 5.2 x 10^4 .It was found that heat transfer coefficient 2.6 times greater and heat flux was found to be 1.5 times greater than smooth circular tube. Amjad et al. [6] carried out an experiment on convective heat transfer study on ZnO based nanofluid.The experiment was conducted by the preparation of zinc oxide Nano fluids by adding zinc oxide particles on base fluid (water) for different concentrations (0.1, 0.3, 0.3 and 0.4%).The temperature of the fluid was kept constant (80^0 C).The experiment concluded that enhancement of heat transfer was up to 46-7-% for the volumetric concentration of 0.2% and with the increase of concentration heat transfer reduced. Saha et al. [7] 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. Razzak et. al. [8] used U-cut twisted tape insert into the tube for turbulent flow. They found Reynolds number by using this insert was 10153< Re <19217. For smooth tube without insert heat flux range was between 18.33 to 28 kW/m^2 and on the other hand using this insert it was 32.07 to 47.27 kW/m^2. Nusselt number was increased by 2.76 to 3.24 times and friction factor was increased by 1.6 times than the plain tube without insert. Promvonge et al.[9] found the convective heat transfer with conical rings inserts in a circular tube. For diameter ratio d/D = 0.7 – 0.5, average heat transfer rate were 197- 333%, 138 – 234% and 91 – 175% more for using diverging rings, converging-diverging rings and converging rings than the plain tube. In this experiment, the range of Reynolds number was 6000-26000.Salam et.al. [10] carried an investigation in a circular tube for turbulent flow using rectangular cut twisted tap insert. The Reynold number ranged from 10000-19000.The investigation found using such insert gave Nusselt number increased up to 2.3-2.9 times.

2. DATA REDUCTION EQUATIONS

The experimental data were used to find out the Nusselt number, friction factor and thermal performance 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)

Porosity $Rp = \frac{n * \frac{\pi di^2}{4}}{L * Wd}$ (12)

3. EXPERIMENTAL SETUP

The coiled perforated twisted tap insert is a combination of a twisted tap insert and a coil. The whole insert was 850 mm in length, width 13 mm, thickness 1.5mm and twist ratio 3.11.The perforated diameters were 3 mm, 4.5 mm and 5.5 mm.

Fig. 1: Perforated Twisted Tap Insert

Fig. 2 : Coil Insert

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

The geometric test section consist of a smooth copper tube wired with nicrome 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 stainless steel for different perforations Rp=1.7%,4.1% and 5.6 %.The nicrome wire was spirally wounded obver the smooth

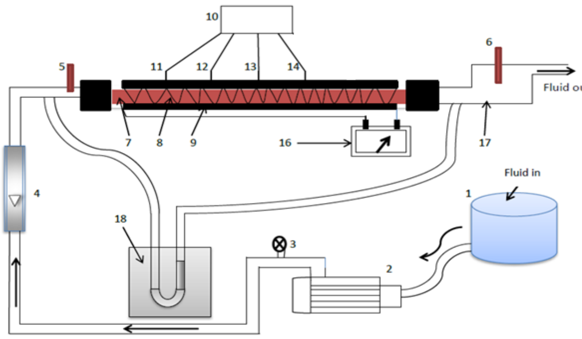


Fig. 4: Schematic diagram of the experimental apparatus

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. 1. Shows the perforated twisted tape and fig. 2. Represents the coiled which was coiled over it. And fig. 3. Demonstrates the final coiled perforated twisted tape insert. Fig. 4 shows the full experimental facility.

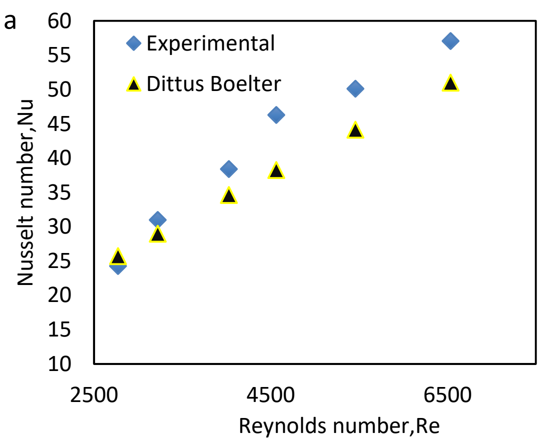
1. Tank
2. Pump
3. Gate Valve
4. Rotameter
5. Inlet thermometer
6.Outlet thermometer
7. Test section
8. Nichrome wire
9. Insulator
10. Temperature reading device
11-14. Thermocouples (4)
16. Voltage regulator
17. Mixing chamber
18. U-tube manometer

4. RESULTS AND DISCUSSION

The study investigated the heat transfer, friction factor and thermal enhancement efficiency using coiled perforated twisted tap insert for different porosities. 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 coiled 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 coiled perforated twisted tap insert was much higher than the plain tube. The reason behind it can be explained that coiled perforated twisted tape insert created good mixed of fluid or swirl effect. From the experiment it was found that Nusselt number got changed with the change of perforation of the coiled perforated twisted tap insert. Over the range investigated the coiled perforated twisted tap insert for perforation Rp=4.1% gave the highest Nusselt number than Rp=1.7% or Rp=5.6% perforation. The effectiveness of heat transfer enhancement by coiled perforated twisted tap insert was found by comparing the ratio Nu_p/Nu_s which is shown in Fig. 5.2.The was found from the investigation that the ration was always higher than one. The result showed that the ratio (η) 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 porosities were 74%-154% higher than those with the values of plain tube.



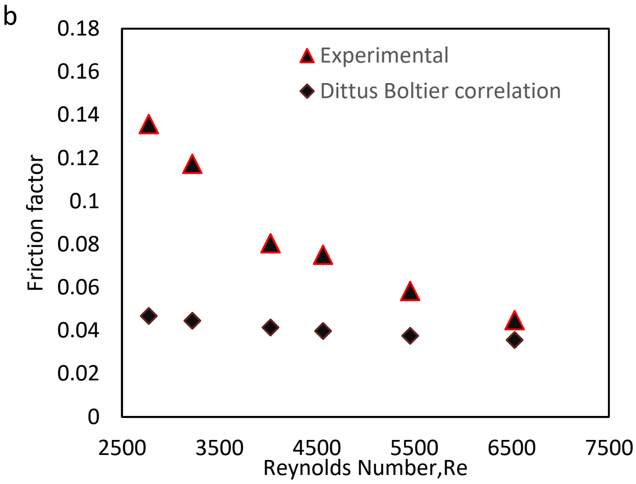


Fig 5.1: Verification of the plain tube: (a) Nusselt number and (b) friction factor.

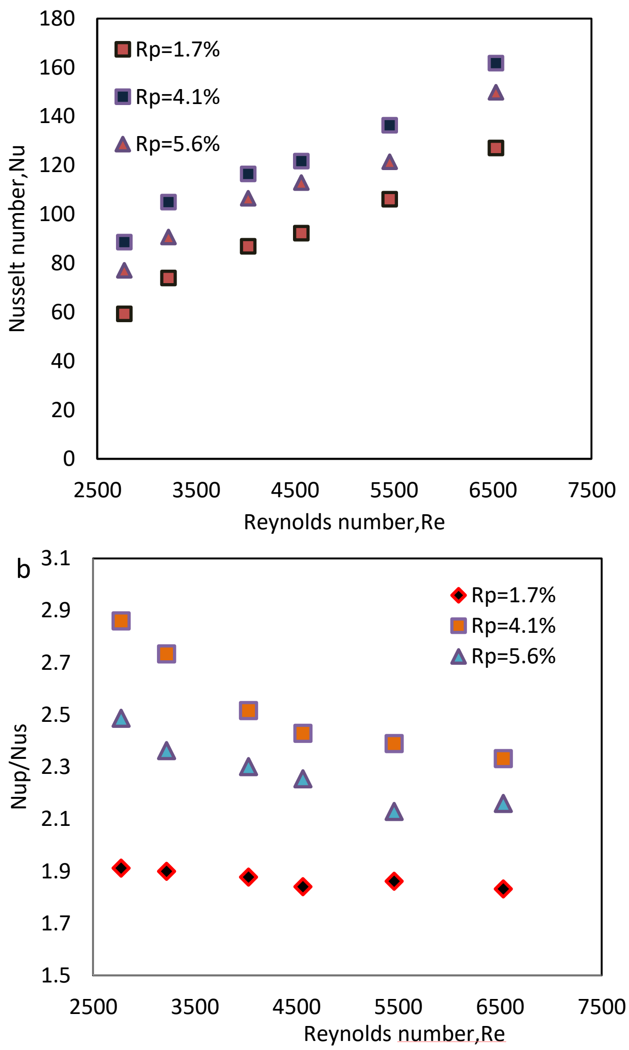


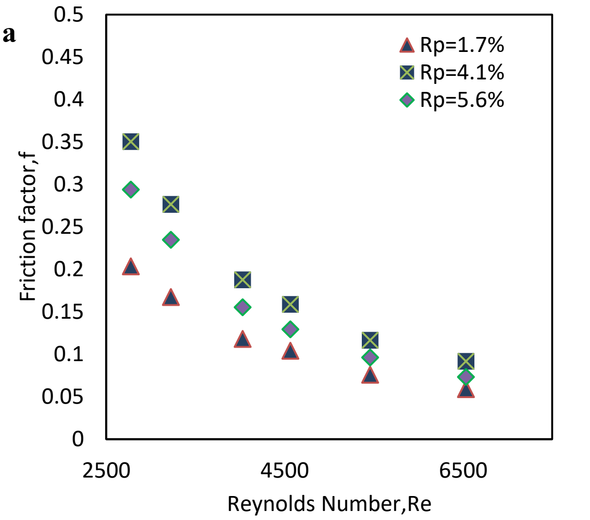
Fig. 5.2: (a) Relationship between Nusselt number and Reynolds number (b) effectiveness

4.2. Fluid flow characteristics

The effect of friction on coiled perforated twisted tap insert has been described in fig. 5.3.It shows the relationship between friction factor and Reynolds number for different porosities (Rp) with and without insert. The friction factor usually decrease 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 Rp=4.1 %.This mean that for the perforation Rp=4.1% it caused rapid turbulence and extreme swirl effect.

a



b

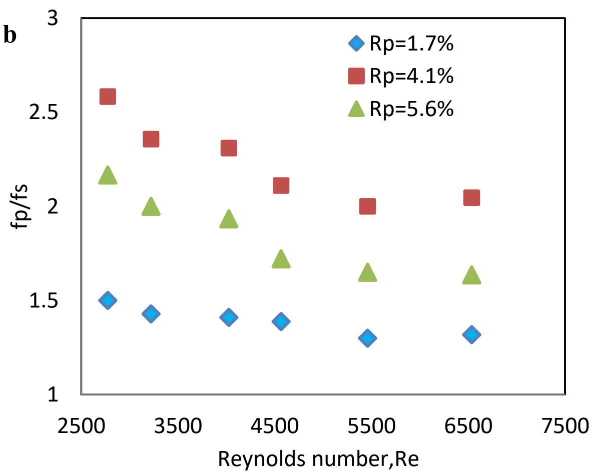


Fig. 5.3: Relationship between friction factor and Reynolds number

Fig. 5.3 showed that the variation of friction factor ratio (f_p /fs) with Reynolds number for different porosities. It was found from the investigation that the friction factor for coiled perforated twisted tape insert was 48%-143% higher than the plain tube.

4.3. Thermal enhancement efficiency evaluation

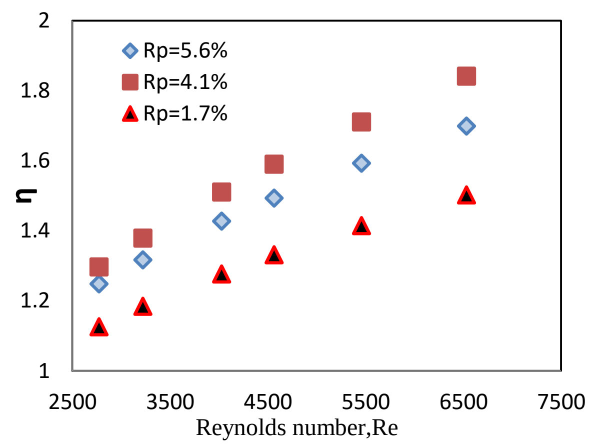


Fig. 5.4: Heat transfer enhancement efficiency

From Fig. 5.4 it was found that thermal enhancement efficiency increase with the increase of Reynols number. Coiled perforated twisted tap insert gave the best efficiency for Rp=4.1%.

5. CONCLUSION

An experimental study was carried out to find out the heat transfer characteristics and frictional effect for different porosities (Rp =1.7, 4.1 and 5.6%) of coiled perforated twisted tape insert. The heat transfer rate increased for coiled perforated twisted tape insert with corresponding increase in friction factor. From the experiment it was proved that coiled perforated twisted tape insert was found to be a very efficient insert. Based on the calculations and investigational result, notable findings are summarized below:

Coiled perforated twisted tape insert offered a good heat transfer rate. Nusselt number increased 74%-154% in comparison to the smooth tube. Three different porosities were used. For Rp=1.7%, 4.1%, 5.6% Nusselt number was found 59.26-127.17, 88.63-168.8 and 77.06-150 respectively.

Friction factor also increased with the increase of Reynolds number. Friction factor for Rp =1.7%, 4.1%, 5.6% was 0.06-0.33, 0.09-0.35 and 0.07-0.29 respectively. Further calculations show that friction factor increased 48%-143% in comparison to the friction factor of plain tube.

Thermal enhancement efficiency also increased with the increase of Reynolds number. For Rp=1.7%, 4.1%, 5.6% thermal enhancement efficiency was 1.12-1.5, 1.29-1.84 and 1.24-1.7 times respectively than the plain tube at constant blower power.

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] S.U.S.Choi, and J.A. Eastman, Enhancing Thermal Conductivity of Fluids with Nanoparticles, Energy Technology Division and Material Science

Division, Argonne National Laboratory, Argonne, Illinois, Oct. 1995.
[2] M.M.K. Bhuiya, M.S.U. Chowdhury, M. Saha, M.T. Islam- "Heat transfer and friction factor characteristics in turbulent flow through a tube fitted with perforated twisted tape inserts', International Communications in Heat and Mass Transfer
[3] Himal Barman, Sazal Kumar Bala, Sumana Biswas, Biplob Barman, Shailen Saha, Shailen Saha, Jamal Uddin Ahamed, "AUGMENTATION OF HEAT TRANSFER USING COILED PERFORATED TWISTED TAPE INSERT", International Conference on Mechanical Engineering and Renewable Energy 2015 (ICMERE2015) 26 – 29 November, 2015, Chittagong, Bangladesh
[4] L. Wang, and B. Sunden, "Performance comparison of Heat and Mass Transfer, vol. 29, no. 1, pp. 45-56, 2002.
[5] J.U.Ahamed, M.M.K.Bhuiya, R.Saidur, and H.H.Masjuki, M. A. R. Sarkar, A. S. M. Sayem, and M. Islam, "Forced convection heat transfer performance of perforated twisted tape insert", Engineering e-Transaction, vol. 5, no. 2, pp. 67-79, 2010. S. Al-Fahed, and W. Chakr.
[6] Aditya Suresh Naik, Pavan Kumar N, Akshay Kumar G, Musturu Devaraja, "Investigation of Heat Transfer Enhancement in a Pipe using Zinc Oxide/Water Nanofluid and Twisted Tape Insert, IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 5 Issue 4, April 2015
[7] S. K. Saha, A. Dutta, S. K. Dhal, "Friction and heat transfer characteristics of laminar swirl flow through a circular tube fitted with regularly spaced twisted-tape elements", International Journal of Heat and Mass Transfer.44(2),4222-4223,2001
[8] M. A. Razzaq, M. A. M. Hossain, and J. U. Ahamed, "Enhancement of heat transfer of water for turbulent flow through tube using U-cut twisted tape inserts," Mech. Eng. Res. J., vol. 2017, no. April, pp. 1–6, 2017.
[9] P. Promvonge, "Heat transfer behaviors in round tube with conical ring inserts," Energy Convers. Manag., vol. 49, no. 1, pp. 8–15, 2008.
[10] B.salam,S.Biswas,S,Saha,M.M.K.Bhuiya,"Heat transfer enhancement in a tube with rectangular cut twisted tape insert, ," Procedia Eng., vol. 56, pp. 96–103, 2013

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