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EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER ENHANCEMENT OF WATER USING TWISTED TAPES WITH RECTANGULAR CUTS

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Abstract*- Heat transfer enhancement technology provides many advantages in heat exchanger applications. It becomes even more significant in the retrofit design of shell-and-tube heat exchangers, where additional heat transfer area is often required. Tube inserts are frequently used in such applications. The study of improved heat transfer performance is referred to as heat transfer augmentation, enhancement, preliminary design of enhance heat exchangers. The heat transfer characteristics and the pressure drop in the horizontal pipe with twisted tape insert are investigated where result was observed for different number of rectangular slots in the same strip. The inner and outer diameters of the inner tube are 0.0266 m and 0.03 m respectively. The twisted tapes with rectangular cuts are made from the stainless steel strip with thickness of 3 mm and the length of 1035 mm. The test runs are done at the water mass flow rates ranging between 0.164 and 0.284 kg/s, respectively compared with those without twisted tape . It is observed that heat transfer coefficient was increased with insert than without insert where range of Re is between 9997~19085. A comparison was developed with different heat transfer parameters on convective heat transfer coefficient (h), heat transfer rate(q), Nusselt number(Nu) based on three stages of using plain tube (with insert, primary insert, secondary insert) experimentally.*

Keywords: Twisted tape, Rectangular slot, Tube insert, Reynold number, Heat transfer coefficient.

1. INTRODUCTION

The heat transfer duty or thermal performance of heat exchangers can be improved by heat transfer enhancement techniques. Twisted tape insert has been used as one of the passive heat transfer enhancement techniques and are the most widely used tubes in several heat transfer applications. Twisted tape insert can create one or more combinations of the following conditions that are favorable for increasing the heat transfer coefficient with a consequent increase in the friction factor:

1) Interruption of the development of the boundary layer and increase in the degree of turbulence.
2) Effective heat transfer area increase, and
3) Generation of rotating and/or secondary flows.

Single phase heat transfer may be increased by artificially roughened surfaces and other augmentation techniques such as vortex generators and modifications to the duct cross section and surface. These augmentation techniques belong to the so called passive techniques to increase the heat transfer coefficient in the tube side. Recently, attention has been paid to heat transfer enhancement by means of swirl strips, twisted tapes and meshes in heat exchanger tubes. These tube inserts are believed to enhance convective heat transfer by creating one or more following combinations:

1) Continuously interrupting the development of boundary layer of the fluid flow and increasing the degree of flow turbulence
2) Continuously increasing the effective heat transfer area
3) Continuously generating secondary flow

There were several studies on enhancement method using various inserts. Among the many techniques investigated for augmentation of heat transfer rates inside circular tubes, a wide range of inserts have been utilized, particularly when turbulent flow is considered; the inserts studied included tapered spiral inserts, rings, discs, streamlined shapes, mesh inserts and spiral brush inserts. Mesh or spiral brush inserts were used by Shou-Shing et al. [1] to enhance turbulent heat transfer in short channels subjected to high heat flux. Enhancement of up to 8.5 times in turbulent heat transfer coefficient was obtained.

In CUET, some students worked on the enhancement techniques. Seema Dey (2007) [2] studied the experimental set up used for determining tube side heat transfer coefficient using a straight tape. She used Reynolds number, Re = 4102.52 ~ 21906.80. She found heat transfer rate, Q = 2506.20~7612.58 watt (for plain tube) and heat transfer rate, Q = 2819.48 ~ 8458.43 watt (for plain tube with insert). She also found the convection heat transfer coefficient, h = 1587.30 ~ 4826.21W/m^2.°C (for plain tube) and h = 1868.74 ~ 5559.542 W/m^2.°C (for plain tube with insert), Nusselt number Nu = 68.09 ~ 207.04 (for plain tube) and Nu = 80.17 ~ 238.5 (for plain tube with insert). Nasrin Akhter (2008) [3] studied the experimental investigation of tube side heat transfer enhancement using triangular strip inserts and used Re = 4463.91 ~ 11159.77 and Q = 676.59 ~ 4268.76 watt (plain tube without insert) and Q = 1015.011 ~ 2114.61 (with insert). She also found h = 326.63 ~728.61 $W/m^2.°C$ (without insert) and h = 477.38 ~ 1093.34 $W/m^2.°C$ (with insert) and Nu = 14.01 ~ 31.25 (without insert), Nu = 20.48 ~ 46.91 (with insert). Shair Razin (2009) [4] studied the experimental investigation of tube side heat transfer enhancement using cross strip. He used Re = 1131.36 ~ 3643.63 and Q = 1.9 ~ 11.59 watt (plain tube without insert) and Q = 3.79 ~ 24.41watt (with insert). He also found h = 5 ~13.52 $W/m^2.°C$ (without insert) and h = 12.2 ~ 48.64 $W/m^2.°C$ (with insert) and Nu = 4.74 ~ 12.76 (without insert), Nu = 11.52 ~ 45.5 (with insert). Gazi Fahim Afzal (2009) [5] studied the experimental investigation of tube side heat transfer enhancement using porous cross strip. He used Re = 1131.36 ~ 3643.63 and Q = 1.9 ~ 11.59 watt (plain tube without insert) and Q = 2.96 ~ 24.405 watt (with insert). He also found h = 5 ~ 13.52 $W/m^2.°C$ (without insert) and h = 8.2 ~ 39.34 $W/m^2.°C$ (with insert) and Nu = 4.74 ~ 12.76 (without insert), Nu = 7.78 ~ 36.75 (with insert). Md. Nazmul Hossain (2010) [6] studied the experimental investigation of tube side heat transfer enhancement using segmented cross strip. He used Re = 1445.07 ~ 5677.84 and Q = 4.72 ~ 12.38 watt (plain tube without insert) and Q = 7.34 ~ 20.46 watt (with insert). He also found h = 3.25 ~11.27 $W/m^2.°C$ (without insert) and h = 6.15 ~ 26.31 $W/m^2.°C$ (with insert) and Nu = 3 ~ 10.44 (without insert), Nu = 5.68 ~ 24.37 (with insert). So objective of our total experiment can be described as below.

The experiment focuses on reviewing conventional heat transfer enhancement techniques inside the tube by using twisted tape with cuts insert. The main objectives of present work are given below:

1) Modification of the experimental set up used for determining the tube side heat transfer co-efficient.
2) To find the tube side heat transfer co-efficient and friction factor.
3) To find the percentage of increase of heat transfer enhancement using twisted tape with cuts inserts and compared it to the tube.
4) To find the pressure drop in tube side with twisted tape with cuts inserts.

2. METHODOLOGY

To enhance heat transfer rate twisted tape with cuts insert was used. Convection is the transfer of potential energy, for example heat, by means currents within a fluid. When a portion of a fluid is less dense, it rises due to gravity. This experimental investigation was carried out for measuring tube side heat transfer coefficient of water using twisted tape with cuts insert.

1) A 939.8 mm 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.
2) A constant heat flux condition was maintained by wrapping Nicrome wire around the test section and fiber glass insulation over the wire. This was used to heat the test section.
3) Outer surface temperature of the tube was measured at five points of the test section maintaining equal distance from one point to another point by K-type thermocouples.
4) Two thermometers were used at the inlet and outlet section of the tube for measuring the bulk temperatures. At the outlet section the thermometer was placed in a mixing box to get the average outlet temperature.
5) Pressure drop was measured at two points of the test section by using manometer.
6) Open loop system of water supply was used.
7) The rate of flow was measured with the help of Rotameter in the travelling path of inlet water.
8) Two types of temperature were measured during the experiment. One regarding tube outer surface temperature and another one was water inlet-outlet temperature.
9) Data was taken for only plain copper tube without insert and with inserts.

The local convective heat flux of a fluid heat passing over a surface is expressed as

$$q=h\,(T_w-T_b) \qquad (1)$$

Where:

q= Heat transfer rate (W/m^2)

h= Convective heat transfer coefficient ($W/m^2\,°c$)

T_s= surface/wall temperature (K)

T_b=Bulk temperature (K)

This expression is known as Newton's law of cooling, and the proportionality constant h (W/m^2 K) is termed as convective heat transfer coefficient. Experiment is described below with all necessary equipments.

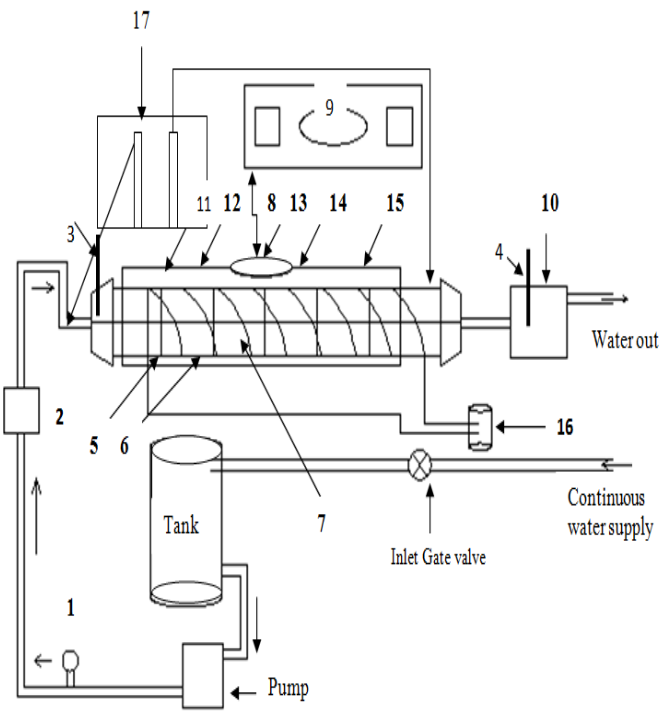

Fig 2.1: Experimental Setup

1. Gate valve
2. Rotameter
3. Inlet thermometer
4. Outlet thermometer
5. Insulation
6. Test section (copper tube)
7. Nichrome-wire coil
8. AC source
9. Thermo-electric monitor
10. Mixing box
11. Thermocouple 1
12. Thermocouple 2
13. Thermocouple 3
14. Thermocouple 4
15. Thermocouple 5
16. Voltage regulator
17. Manometer

Fig.2.2: twisted tape with rectangular cuts

Fig 2.3: Twisted tape strip with 9 rectangular cuts **(Insert 1)**

Fig 2.4: Twisted tape strip with 18 rectangular cuts (**insert 2**)

Fig 2.5: Test Section

3. DATA COLLECTION AND ANALYSIS

Calculation of convection heat transfer coefficient for turbulent flow is very complicated because the related formulae are empirical and have error in the range of ±10% to ±25%.

3.1 Data Collection Method

1. Water was made to circulate throughout the system by a pump and different flow rate were maintained by regulating rotameter.
2. Then constant voltage was supplied to the heater by a voltage regulator and current was also supplied to the heater by a voltage regulator and current was also supplied to the thermocouple monitor.
3. When the temperature in the inlet and outlet thermometer and thermocouple monitor become steady reading was taken for a given flow rate. Again increasing flow rate, in the same procedure next reading was taken.
4. The flow rate was taken from 165ml per sec and increased by 30ml per sec up to 315 ml per sec for plain copper tube without insert and up to 315 ml per sec for plain tube with stainless steel twisted tape with cuts insert.
5. In first step, data were taken for only plain copper tube without insert and then insert of stainless steel was inserted in the copper tube and data was taken following the same procedure.

3.2 Data Collection

Parameter	Value
Tube inside diameter	26.6 mm = 0.0266 m
Tube outside diameter	30 mm = 0.03 m
Tube thickness	3.4 mm = 0.0034m
Tube test length	0.90 m
Thermal conductivity of copper	379 W/m°C
Viscosity of water	0.00087 Kg/m.sec (at 28°C)
Density of water, ρ	1000 kg/m^3
Thermal conductivity of water, k	0.62 W/m°C
Specific heat of water (at 28 °C), C_p	4177 J/kg°C
Outside surface area	0.0718 m^2
Inside surface area	0.0702 m^2
Insert length	1035mm
Depth of cuts	8mm
Width of cuts	13mm
Thickness	3mm
Number of cuts primary **(insert 1)**	9
Number of cuts secondary **(insert 2)**	18
Distance between middle of the cuts **(insert 1)**	90mm
Distance between middle of the cuts **(insert 2)**	45mm

3.3 Necessary Equation For Calculaton Process

Parameter	**Formula**
Ouside surface area	πdL

Inner surface area	$\pi d_i L$
Heat transfer rate, Q	$mc_p(T_o-T_i)$
Cross sectional area, A_x	$\pi d_i^2/4$
Velocity, V	m/A_x, where m is the flow rate
Reynolds Number, Re	$\rho V d_i/\mu$
Nusselt number, Nu	hd_i/k
Prandtl number, Pr	$\mu C_p/k$, μ and k at bulk temperature
Convective heat transfer coefficient	$Q/\{A_s(T_{inner\ surface}-T_{bulk})\}$
Gnielinski equation, Nu_D	$\frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7(f/8)^{1/2}(Pr^{2/3}-1)}$; where f= $(0.790\ln R_e-1.64)^{-2}$
The experimental friction co-efficient f_{ex}	$\frac{2\Delta P d_i}{\rho L {u_m}^2}$; Where $u_m=\frac{\dot{Q}}{\frac{\pi}{4}{d_i}^2}$
The rate of heat transfer through the wall by conduction is, Q	$2\pi LK\,(T_{outside\ surface}-T_{inner\ surface})/\ln(r_o/r_i)$
Bulk temperature, T_b	$(T_i+T_o)/2$
Outer surface temp	(Thermocouple1+------+ Thermocouple 5)/5
Inner surface temp	Outer surface temp. – Wall temp difference
% of error	$\{(Nu_{exp}-Nu_{th})/Nu_{exp}\}\ 100$
Heat flux	$q = Q/As$; Where, $A_s = \pi d_i L$
Pressure difference, Δp	$\Delta h\rho g$

4. RESULT AND DISCUSSION

4.1 For plain tube:

i. Reynolds number, Re = 9966.58 ~ 17236.49
ii. Heat transfer rate, q= 14702.93~19047.07 W/m^2
iii. Convective heat transfer coefficient, h= 1172.49 ~1984.07 W/m^2 °c
iv. Nusselt number, Nu= 50.30~85.12
v. Friction factor, f = 0.061~ 0.036

4.2 For plain tube with primary insert:

i. Reynolds number, Re= 9997.33671~ 19085.82463
ii. Heat transfer rate, q= 19243.88~20993.32 W/m^2
iii. Convective heat transfer coefficient,
iv. h= 2885.67~3492.26 W/m^2 °c
v. Nusselt number, Nu= 123.80~140.9533
vi. Friction factor, f = 0.089458~0.044181

4.3 For plain tube with secondary insert:

i. Reynolds number, Re= 9997.33671~ 19085.82463
ii. Heat transfer rate, q= 21076.63~ 22742.77 W/m^2
iii. Convective heat transfer coefficient, h= 3117.369 ~ 4328.658 W/m^2 °c
iv. Nusselt number, Nu= 133.7452 ~ 185.7134
v. Experimental friction factor, f = 0.143132 ~ 0.056454

5. DISCUSSION ON RESULT

It has been found from the result that, in case of plain tube heat transfer rate is increasing with the increase of flow rate because more water is passing through the tube and 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 twisted tape with cuts was inserted in the copper tube, heat transfer rate was increased compared to plain tube without insert. When the number of cuts was increased then the heat transfer rate, heat flux also increased. 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. For being twisted tape with cuts the rate of flow increases as the existence of another secondary flow through the hole. But pressure drop was increased gradually with the increase of flow rate than the plain tube.

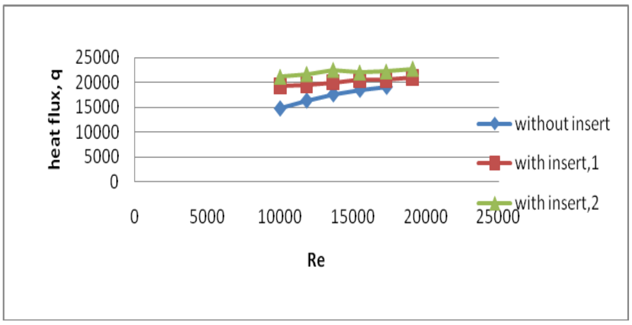

Fig.5.1 Comparison with q with Re

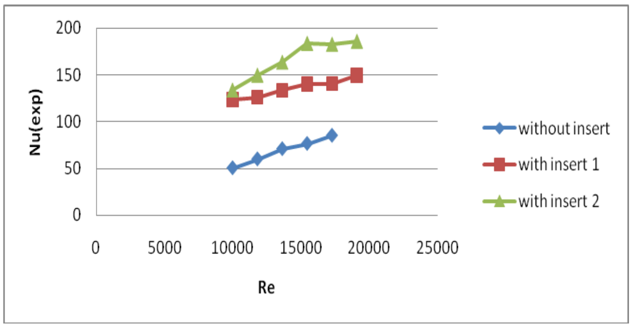

Fig.5.2 Comparison with Nu with Re

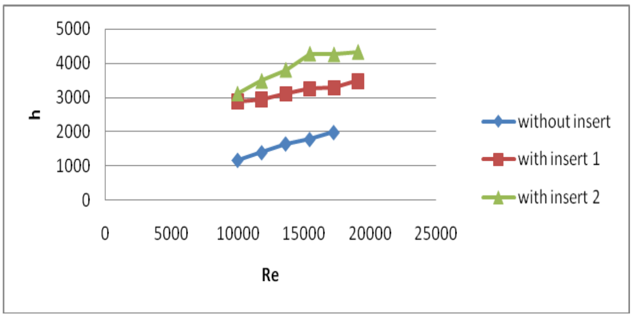

Fig.5.3 Comparison with h with Re

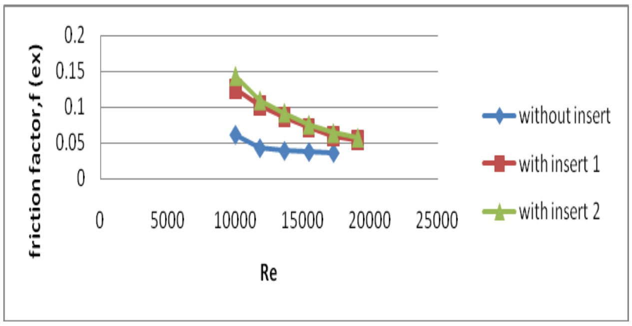

Fig.5.4: Comparison with f with Re

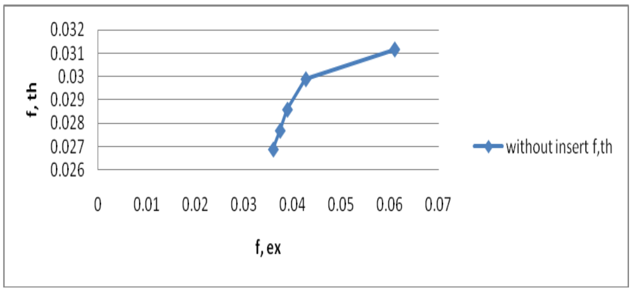

Fig.5.5: Comparison between f_{th} and f_{exp} **(without insert)**

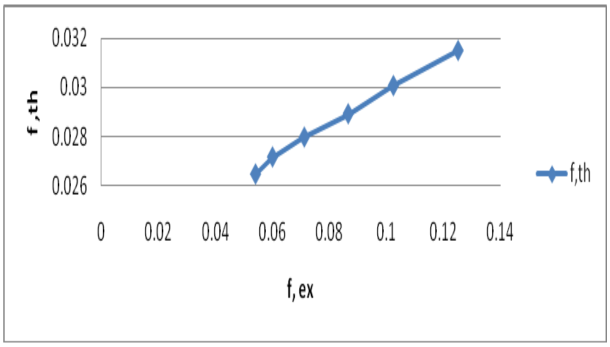

Fig.5.6: Comparison between f_{th} and f_{exp} **(with insert 1)**

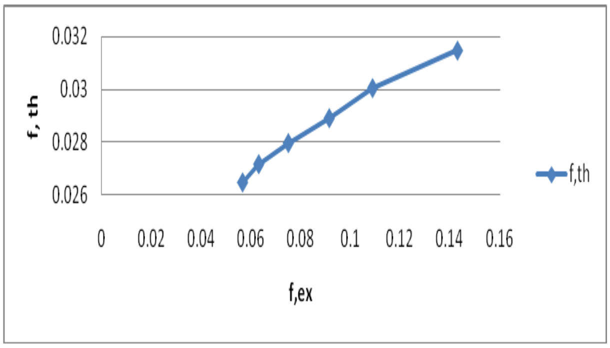

Fig.5.7: Comparison between f_{th} and f_{exp} **(with insert 2)**

6. CONCLUSION

The measurement of tube side heat transfer coefficient is an important part of heat transfer related subjects. Some of the more successful enhancement techniques currently used for heat transfer augmentation have been reviewed here. The application of single phase enhancement techniques is evaluated for tube side. Several active techniques have been identified as possibilities for tube enhancement. These techniques do require external power. But there is a power cost that needs to be considered. There are also passive techniques have been identified as possibilities for tube enhancement. Insertion of twisted tape with cuts in a tube provides a simple passive technique for enhancing the convective heat transfer by introducing swirl into the bulk flow. Experimental investigation of enhancement efficiency, heat transfer and friction factor characteristics of circular tube fitted with twisted tape with cuts strip inserts were be studied. It may be guess that the swirl flows were help in 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 twisted tape with cuts strip has made the simultaneous effects on Re, Nu and h.

7. REFERENCES

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8. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(K)
P	Pressure	(Pa)
d_i	Inner surface diameter	(m)
T_i	Inlet temperature of the water	(K)
T_o	outlet temperature of the water	(K)
A_x	Cross sectional area	(m^2)
h	Convective heat transfer coefficient	$(W/m^2\ ^oc)$
q	Heat transfer rate	W/m^2
Δp	Pressure difference	
$\bar{Q}$	flow rate of water	(m^3/s)
f	Friction factor	