Heat transfer enhancement by using twisted tape insert

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Abstract - *Tubular heat exchanger is a device that enables exchange of heat between two fluids which are at different temperatures and separated by a solid wall occurs in many engineering applications. The one way to enhance the performance of Tubular heat exchanger is to improve tube side heat transfer rate. Twisted tape insert is one of the passive heat transfer enhancement techniques, which are extensively used in various heat transfer applications such as, air conditioning and refrigeration systems, heat recovery processes, food and dairy processes, chemical process plants. A small scale experimental setup was done to enhance the heat transfer rate of tubular heat exchanger. The heat enhancement of Heat Exchanger is done using twisted tape inserts with various twist ratios (TR=3.78, 3.89, 4.22). The effects of two dimensionless parameters namely Nusselt number & Friction factor on the effectiveness of Tubular Heat Exchanger are studied. The turbulent flow was created by inserting the twisted tape inserts into the test pipe creating high rate of turbulence in pipe, which results in increasing heat transfer enhancement and pressure drop. The twisted tape twisting. The length and width of insert was 1000 mm and 45 mm respectively. The outside diameter & inside diameter of test pipe is 50 mm & 48 mm respectively. The length of test section is 1000 mm. The Reynolds number is varied from 5000 to 25000. The results of varying twisted tape inserts with different twisted ratio have been compared with the values for the smooth tube. It showed that the highest heat transfer rate was achieved for the twisted tape with twist ratio 3.78.*

***Key Words*: Heat Exchanger, Twisted tape Inserts, Twisted tape inserts with different twisted ratio, Pressure Drop, Reynolds number, Nusselt number.**

1. INTRODUCTION

Heat exchanger is a device facilitating heat transfer between two or more fluids. It is extensively used in several industries, such as thermal power plants, chemical processing plants, air conditioning equipment's generally are operated in turbulent/swirl flow conditions where their performance in terms of energy transfer rate is high, compared with laminar flow by virtue of the high degree of turbulence/swirl flow. Also in turbulent flow, a high intensity of turbulence will enhance the rapid mixing of fluid properties, and the mixing can help to increase the effective area of heat transfer, leading to higher heat transfer rates. Heat exchanger have been classified in many different ways. The design of heat exchanger is complicated, requiring a consideration of different modes of heat exchanger, pressure drop, sizing, long term performance estimation as well as economic aspect. Tubular heat exchanger are generally built of circular tubes, although elliptical, rectangular or round/flat twisted tubes have also been used in some applications. There is considerable flexibility in design because the core geometry can varied easily by changing the tube diameter, length and arrangement. Tubular exchangers can be designed for high pressures relative to environment and high-pressure difference between the fluids. Tubular exchangers are used primarily for liquid to liquid and liquid to phase change (considering or evaporating) heat transfer applications. The tubular exchangers may be classified as shell and tube, double pipe, and spiral tube exchangers. There are all prime surface exchangers except for exchangers having fins outside/inside tubes. In many engineering applications the high performance thermal systems are needed and thus, various methods to improve heat transfer in the system are need and thus, various methods to improve heat transfer in the system have been developed extensively. The conventional heat exchangers can be generally improved by means of various augmentation techniques with emphasis on several types of surface enhancements. Enhanced surface can create one or more combinations of the following condition that are favourable for the increase in heat transfer rate with an undesirable increase in friction:

a. Interruption of boundary layer development and rising turbulence intensity.
b. Increase in heat transfer area.
c. Generating of swirling and/or secondary flows.

Heat transfer augmentation techniques are generally classified into three categories namely: active techniques, passive techniques and compound techniques. Passive heat transfer techniques do not require any direct input of external power. Hence many researchers preferred passive heat transfer enhancement techniques for their simplicity and applicability for many applications. In the present work the experimental investigation of the augmentation of turbulent flow heat transfer in a horizontal tube is done by means of twisted tape with air as the working fluid.

Twisted tape inserts

Twisted tape inserts cause the flow to spiral along the tube length. The tape inserts generally do not have good thermal contact with the tube wall, so the tape does not act as a fin.

The continuous twisted tape insert shown in Figure 2.7(a) has been investigated for turbulent flow. The insert consists of a thin twisted strip that is slid into the tube. To allow easy insertion of the tape, there is usually a small clearance between the tape width and the tube inside diameter. This clearance results in poor thermal contact between the tape and the tube wall, so the heat transfer from the tape may be quite small. The blockage caused by the finite tape thickness increases the average velocity. Heat transfer enhancement may occur for three reasons:

a. The tape reduces the hydraulic diameter, which causes an increased heat transfer coefficient, even for zero tape twist.
b. The twist of the tape causes a tangential velocity component. Hence, the speed of the flow is increased, particularly near the wall. The heat transfer enhancement is a result of the increased shear stress at the wall and mixing by secondary flow.
c. Heat is transferred from the tape, if good thermal contact with the wall exists. However, little heat transfer is expected from a loosely fitting tape.

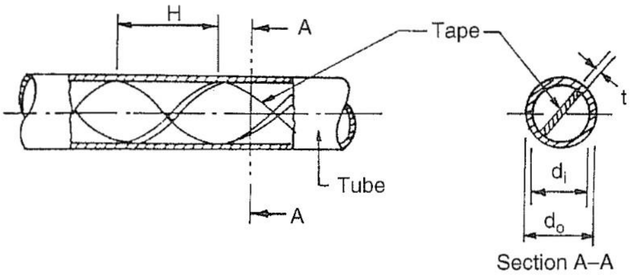

Fig. 1 Twisted Tape insert

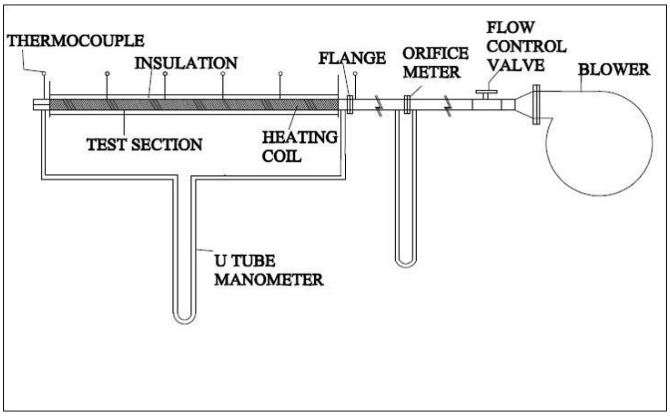

Fig.2 The schematic diagram of experimentation

Fig. 3 Actual photograph of experimentation

2. EXPERIMENTAL WORK

2.1 Experimental Setup

The experimental set up and the various measuring devices are shown in Fig.2 & Fig.3. The apparatus consist of a blower unit fitted with the test pipe. The test section is surrounded by nichrome heater. Four thermocouples are embedded on test section and two thermocouples are placed in the air stream at the entrance and exit of test section to measure air temperatures. Test pipe is connected to the delivery side of the blower along with the orifice to measure flow of air through the pipe. Input to the heater is given through power unit and is measured by meters. It is also noted that only a part of the total heat supplied is utilized in heating the air. A temperature indicator is provided to measure the temperature in the pipe wall in the test section. Air flow is measured with the help of an orifice meter and the water manometer fitted on the board. The valve at the outlet of pipe is used to vary the flow rate of air. At inlet of test section a tapping with valve is provided to measure pressure drop. The outer surface of the test section was well insulated to minimize heat loss to surrounding.

2.2 Procedure

First of all blower was started then flow control valve was operated to get required deflection on manometer which was connected to orifice meter to get desired value of Reynolds number. Then constant heat was supplied to the test section by giving current supply to the heating coil wound around the test section. The electrical output power controlled by adjusting the dimmer stat. The readings of the thermocouples were observed every 5 minutes until the steady state condition was achieved. After achieving the steady state inlet temperature, outlet temperature and surface temperature were recorded. The experiment was performed for different Reynolds number (5000-25000). Initially the experiment was carried out for plain tube. Then the experiment was carried out for different twisted tape of twist ratio 3.78, 3.89, 4.22 insert alternately for the same flow conditions. The width of twisted tapes used are 45 mm. Each insert was taken and inserted into test section axially through one end. It is taken care that the strip doesn't scratch the inner side of test section and get deformed. The fluid properties were calculated as the average between the inlet and outlet bulk temperature.

2.3 Data Reduction

In the present work the air used as the test fluid is flowed through a uniform heat-flux and insulated tube. At steady state heat taken by the air is assumed to be equal to the convection heat transfer from the test section to air which is expressed as:-

$$Q_{convection} = Q_{air} \quad (1)$$

In which

$$Q_{air} = \dot{m} * c_p * (T_o - T_i) \quad (2)$$

$$Q_{convection} = h * A * (T_s - T_b) \quad (3)$$

Where

$$T_s = \frac{T_2+T_3+T_4+T_5}{4} \quad (4)$$

$$T_b = \frac{T_1+T_6}{2} \quad (5)$$

The average heat transfer coefficient, h is estimated as follows:

$$h = \dot{m} * c_p * (T_o - T_i) / A * (T_s - T_b) \quad (6)$$

Where

$$\dot{m} = Q \times \rho_{air} \quad (7)$$

$$Q = \frac{c_d \times A_p \times A_o}{\sqrt{A_p^2 - A_o^2}} \times \sqrt{(2gh_w)} \quad (8)$$

The Nusselt Number, Nu is estimated as follows:

$$Nu_{th} = 0.023 \times Re^{0.8} \times Pr^{0.4} \quad (9)$$

$$Nu = hd/k \quad (10)$$

The Reynolds number is given by

$$Re = \frac{\rho v d}{\mu} \quad (11)$$

The Friction factor, f is estimated as follows:

$$f_{th} = 0.448 \times Re^{-0.275} \quad (12)$$

$$f = \frac{\Delta p}{(\frac{L}{D})(\frac{\rho v^2}{2})} \quad (13)$$

Where

$$\Delta P = \rho \times g \times h_w \quad (14)$$

Calculation table for Plain tube:-

Table 1 Calculation table for Plain tube

Re	T_s	T_b	V_{air} (m/s)	m_{air} (kg/s)	Nu	f
25000	52	36	7.97	0.0187	62.28	0.0238
23000	55.75	36.5	7.34	0.0172	59.53	0.0281
21000	58.75	37	6.7	0.0157	57.72	0.0330
19000	58.5	37	6.06	0.0142	52.83	0.0337
17000	62.25	37.5	5.42	0.0127	47.91	0.0411
15000	66	38	4.78	0.0112	42.70	0.0439
13000	69.25	38.5	4.15	0.0097	37.91	0.0514
11000	71.25	39	3.51	0.0082	33.99	0.0614
9000	73.5	39.5	2.87	0.0067	29.01	0.0917
7000	74.75	40	2.23	0.0052	24.09	0.1516
5000	77	40.5	1.59	0.0037	17.74	0.1723

Calculation table for Twisted tape inserted inside Plain tube:-

Table 1 for twisted ratio, y = 3.78

Re	T_s	T_b	V_{air} (m/s)	m_{air} (kg/s)	Nu	f
25000	45.25	32.5	7.97	0.018	94.93	0.1063
23000	47.25	32	7.33	0.017	87.62	0.1256
21000	48.25	33	6.69	0.015	80.00	0.1318
19000	49.5	34	6.06	0.014	71.21	0.138
17000	49.75	33.5	5.42	0.012	70.91	0.1436
15000	51	34	4.78	0.011	68.35	0.1476
13000	51.25	33.5	4.14	0.009	49.64	0.1474
11000	52.75	34	3.50	0.008	45.44	0.1372
9000	54	34.5	2.87	0.007	40.22	0.2050
7000	55.75	35	2.23	0.005	32.66	0.3389
5000	57.25	34.5	1.59	0.004	19.15	0.3321

Table 2 for twisted ratio, y = 3.89

Re	T_s	T_b	V_{air} (m/sec)	m_{air} (kg/sec)	Nu	f
25000	48.3	32	7.97	0.0182	89.38	0.0664
23000	49.8	32	7.33	0.0167	75.28	0.0784
21000	52.8	32.5	6.69	0.0153	70.29	0.0753
19000	51.3	32.5	6.06	0.0138	68.68	0.0920
17000	53	33	5.42	0.0123	65.84	0.1149
15000	56	33	4.78	0.0109	50.52	0.1107
13000	55.8	33	4.14	0.0094	44.26	0.1473
11000	56.5	33	3.51	0.008	36.26	0.1372
9000	57.8	33	2.87	0.0065	35.21	0.2050
7000	60.8	33.5	2.23	0.0051	27.36	0.3388
5000	63.3	34	1.59	0.0036	19.86	0.3321

Table 3 for twisted ratio, y = 4.22

Re	T_s	T_b	V_{air} (m/s)	m_{air} (kg/s)	Nu	f
25000	52.3	32	7.97	0.0182	71.73	0.106
23000	53.3	32	7.34	0.0167	62.88	0.109
21000	54.5	31.5	6.70	0.0153	61.89	0.113
19000	55.3	32.5	6.06	0.0138	56.61	0.115
17000	54.8	32.5	5.42	0.0123	51.79	0.114
15000	55.3	32.5	4.78	0.0109	44.69	0.110
13000	55.3	32.5	4.15	0.0094	38.73	0.098
11000	56.8	33	3.51	0.0080	35.88	0.137
9000	57.5	33.5	2.87	0.0065	32.68	0.205
7000	58.3	33.5	2.23	0.0051	24.65	0.338
5000	59.8	34	1.59	0.0036	18.80	0.332

3. VALIDATION TEST

The Nusselt number and friction factor determined from experimental data are compared with the values obtained from the correlations of Dittus-Boelter for the Nusselt number and Blasius correlation for the friction factor. Comparison between present experimental work and standard correlations for Nusselt number and friction factor turbulent internal flow is presented in Fig.4 and Fig.5 respectively. The results of present work reasonably agree within ± 2 for Nusselt number. From Fig.5 friction factor is observed to reduce with increase in Reynolds number for plain tube.

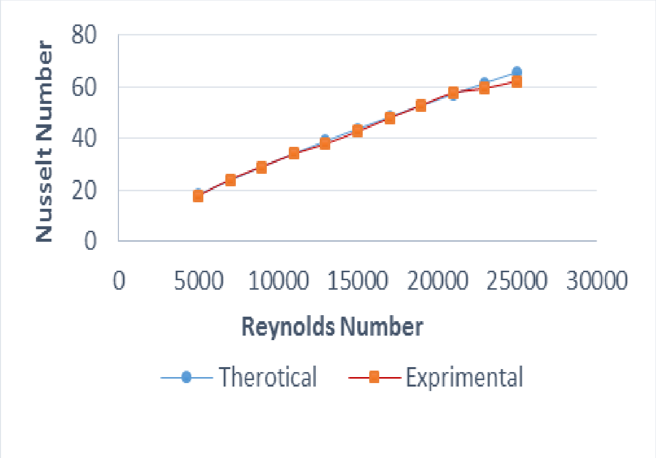

Fig.4 Comparison of Nusselt number with Reynolds Number

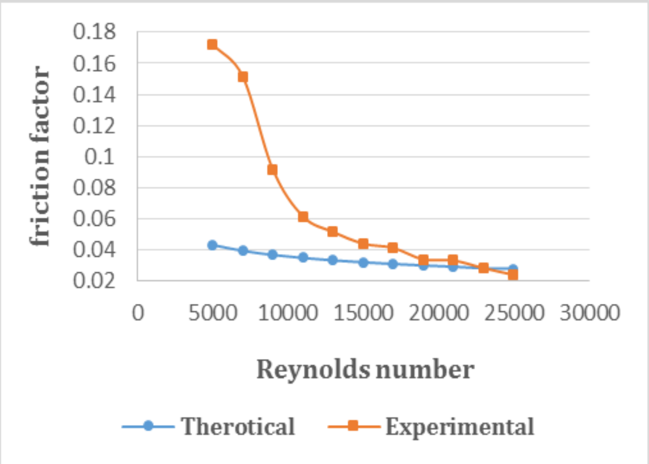

Fig.5 Variation of friction factor with Reynolds number

4. RESULT AND DISCUSSION

In the present work, experimental investigation on turbulent flow heat transfer enhancement for air inside the horizontal tube in the presence of twisted tape insert of different twisted ratio are carried out. Fig.6 shows the variation of Nusselt number with Reynolds number for all inserts in comparison to plain tube. Nusselt number increased with increase in Reynolds number. It is observed that twisted tape of twist ratio 3.78 yielded the highest value of Nusselt number .This may be due to better turbulence created on air side in the presence of twisted tape of twisted ratio 3.78, which increases the heat carrying capacity of air that led to increase of Nusselt number. Fig.7 shows the variation of friction factor with Reynolds number for all inserts in comparison to plain tube. It is seen that the value of friction factor decreases with increasing Reynolds number in all cases. Friction factor also observed to be highest for twisted tape of twist ratio 3.78 with. This may be due to highest obstruction caused to air flow.

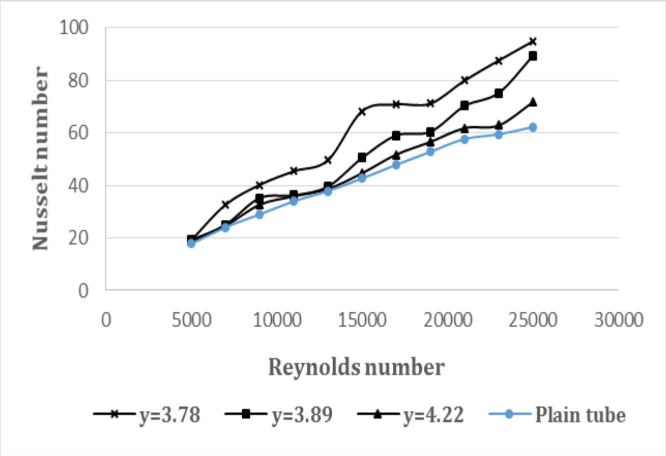

Fig.6 Comparison of Experimental Nusselt Number with Reynolds Number

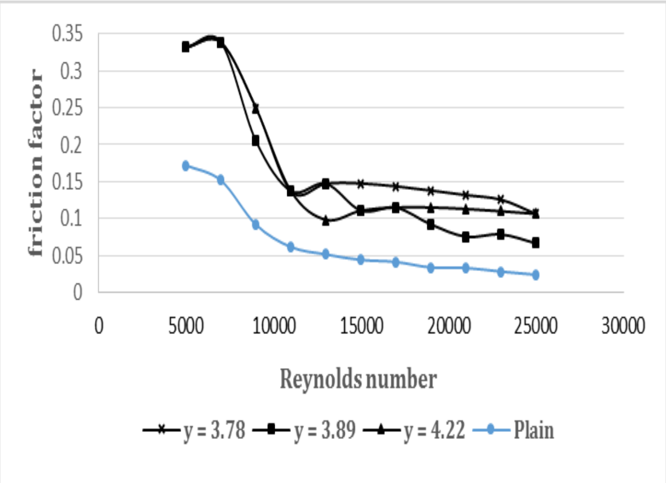

Fig.7 Comparison of Experimental Friction Factor with Reynolds Number

5. CONCLUSION

By using twisted tape inserts the highest heat transfer rate was achieved for twist ratio 3.78. In comparison with plain tube all twisted tape inserts would significantly enhance the heat transfer rate. From this experimental study the results can be concluded as follows:-

(For Reynolds number range 5000 to 25000)

1) The Nusselt number for twisted tape insert with twist ratio 3.78, 3.89 and 4.22, increased as twisted ratio decreases.

2) The Friction factor is increased as twisted ratio decreases with twist ratio 3.79, 3.88 & 4.22 respectively.

Nomenclature

f	Friction Factor
h	Heat Transfer Coefficient
Nu	Nusselt Number
Re	Reynolds Number
ΔP	Pressure drop
Q	Heat transfer rate
ρ	Density of air
T_s	Surface Temperature
T_b	Bulk Temperature
c_d	Coefficient of discharge
h_w	Head in meters of water
M	dynamic viscosity of air
K	Thermal conductivity of the air
Pr	Prandlt number
A	Surface area of tube

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