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Analysis of Heat Transfer Augmentation in Tube Using Triangular Wavy Tape Inserts

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ABSTRACT—Researchers have done several researches on heat transfer enhancement in tube by inserting various tapes in past few years. There is need to increase the thermal performance of heat exchangers, thereby reducing size of heat exchanger and saving of material, effecting energy & cost led to development & use of heat transfer augmentation techniques. This research has been worked out to study the effect of triangular wavy tape insets with various designs on heat transfer rate, pressure drop, friction factor. The experiment was conducted for the Reynolds number in the range of 3260-14930 using triangular wavy tape inserts of dimensions 900mm of length, 24mm width and 2mm thickness. The pitch of triangular wavy tape insert is 88mm. The Nusselt number obtained from experiment is in the range of 13-79. Friction factor was found out and it lie in the range of 0.18-2.03. The experimental results indicate that the tube with the various inserts provides considerable improvement of the heat transfer rate over the plain tube.

Key words: Heat exchanger, Heat transfer augmentation, Heat transfer augmentation techniques, Triangular wavy tape insets, Reynolds number, Nusselt number, Friction factor

1. INTRODUCTION

Heat transfer occurs due to temperature difference between the two systems. In daily life, there are lots of engineering systems in which heat transfer plays very important role. Heat exchangers, boilers, condensers, radiators, heaters, furnaces, refrigerators, solar collectors etc. are the equipments of engineering systems in which heat transfer occurs. [1]

In past few years various researchers research on heat transfer augmentation. Heat transfer augmentation techniques are used to improve performance of heat exchangers. Improving the performance of heat exchangers led to saving of energy. Therefore total energy required to the system decreases. So, heat exchanger becomes compact and material required for heat exchangers is low. Energy efficient heat exchanger gives high performance. The techniques used to improve performance of heat exchangers are called as heat transfer augmentation or heat transfer enhancement techniques. Various researchers used different techniques like passive, active etc. In this paper triangular wavy tape inserts are used to enhance the heat transfer.

Suvanjan Bhattacharyya, Subhankar Saha, *et al.* [2] are used integral transverse rib with centre cleared twisted tape. Different Centre clearances are used in this experiment and results shows that friction factor and Nusselt number decreases with increase in the value of centre clearance. M.M.K. Bhuiya, M.S.U. Chowdhury, M. Saha, *et al.* [3] worked on heat transfer enhancement by using perforated twisted tape inserts in turbulent flow. Results show that friction factor for tape inserts is more than plain tube. S. Eiamsa-ard, Wongcharee, P. Eiamsa-ard Thianpong [4] used delta-winglet twisted tape inserts in tube for heat transfer enhancement. Sumana Biswas, Shuvra Saha, *et al.* [5] researched using rectangular-cut twisted tape insert for enhancement of heat transfer. From results it is observed that heat fluxes are increased and it is more than plain tube. Sujoy Kumar Saha, Suvanjan Bhattacharyya *et al.* [6] worked on thermo-hydraulics of laminar flow of viscous oil through a circular tube having integral axial rib roughness and fitted with centre-cleared twisted-tape. K. Wongcharee, S. Eiamsa-ard [7] worked on friction and heat transfer characteristics of laminar swirl flow. Alternate clockwise and anticlockwise twisted-tapes in round tubes are used for experiment. Nusselt number obtained by using this twisted tape is higher as compared with simple twisted tape. A. G. Matani, Swapnil A. Dahake [8] has done experimental investigation on study of heat transfer enhancement in a tube using counter/co-swirl generation. In this experimental study, twisted tape and double twisted tape used for counter/co-swirl generation and wire coil with twisted tapes used for co-swirl generation. Twisted tapes with wire coil perform better than individual. S. Eiamsa-ard, P. Nivesrangsan, *et. al.*[9] studied on effect of combined non-uniform wire coil and twisted tape inserts on thermal performance characteristics. Various parameters like friction factor, heat transfer are investigated to show improvement by using tapes inserts for Reynolds number range of 4600-20,000 having air as fluid. Khwanchit Wongcharee, Smith Eiamsa-ard [10]Heat transfer enhancement by using CuO/water nanofluid in corrugated tube equipped with twisted tape is presented. There are three different concentrations are made with three different twist ratio of twisted tape. The experiment was conducted for Reynolds number ranging from 6200 to 24000. P. Bharadwaj, A.D. Khondge, A.W. Date [11]experimented on spirally grooved tube with twisted tape insert and presents Heat transfer and pressure drop characteristics for Reynolds number range of 500-12000. Si-hong Song, Qiang Liao, Wei-dong Shen [12] Laminar heat transfer and friction characteristics of microencapsulated phase change material slurry in a circular tube with twisted tape inserts. Reynolds number is ranging from 200 to 2200. The Nusselt number was found in the range of 5-90. Friction factor was found in the range of 0.02-0.45.

Following table shows that results obtained by various researchers

Table 1.1: Results given by various researchers

Sr. no	Research scholar	Tape Used	Reynolds No.	Results	
				Friction Factor	Nu No.
1	Suvanjan Bhattacharyya, Subhankar Saha	Centre Cleared Twisted Tape	10-1000	0.017-1.2	3-15
2	M.M.K. Bhuiya, M.S.U. Chowdhury, M. Saha	Perforated Twisted Tape	7200-49800	0.017-0.15	20-100
3	S. Eiamsa-ard, Wongcharee, P. Eiamsa-ard Thianpong	Delta-Winglet Twisted Tape	3000-27000	0.05-0.25	20-200
4	Bodius Salam, Sumana Biswas, Shuvra Saha	Rectangular-Cut Twisted Tape	10000-19000	0.06-0.12	100-310
5	K. Wongcharee, S. Eiamsa-ard	Alternate Clockwise and Counter Clockwise Twisted-Tapes	830-1990	0.2-0.6	10-55
6	A.G. Matani, Swapnil A. Dahake	Twisted tapes with wire coil	5000-18000	0.15-0.55	45-117
7	P. Bharadwaj, A.D. Khondge, A.W. Date	Spirally grooved tube with twisted tape	500-12000	0.04-0.7	20-130
8	Si-hong Song, Qiang Liao, Wei-dong Shen	Twisted tape	200-2200	0.02-0.45	5-90

1.1 HEAT TRANSFER AUGMENTATION TECHNIQUES

Heat transfer augmentation techniques are divided into three types as

A. Passive Techniques:
B. Active Techniques:
C. Compound Techniques:

A) Passive Techniques:

Heat transfer augmentation achieved by using inserts or introducing additional devices. External power input is not required in passive techniques. There are various passive techniques as given below:

(a) Treated Surfaces: Treated surfaces are used in condensing and boiling and this technique includes application of coating.

(b) Extended Surfaces: fins are the example of extended surfaces and fins are used in heat exchanger to enhance heat transfer.

(c) Displaced Enhancement Devices: these devices are used in forced convection. Various inserts are inserted to displace fluid from core to surface side.

(d) Swirl Flow Devices: rotating type of flow generated by using these devices. Inlet Vortex Generators, Twisted Tape Inserts are the different types of swirl flow devices.

B) Active Techniques:

For heat transfer enhancement, there is external power input is required. This technique is more difficult to design and there are very less applications. Mechanical Aids, Injection, Surface Vibration and Electrostatic Fields are different examples of active techniques.

C) Compound Techniques:

Combination of active techniques and passive techniques is called as compound techniques. Its purpose is to improve thermo hydraulic performance of a heat exchanger.

2. EXPERIMENTAL SETUP

Experimental setup consists of blower unit, orifice meter, ball valve, u tube manometers and test section. Air flows through test section by using blower unit. The ball valve is used to change the flow rate of air through the test section.

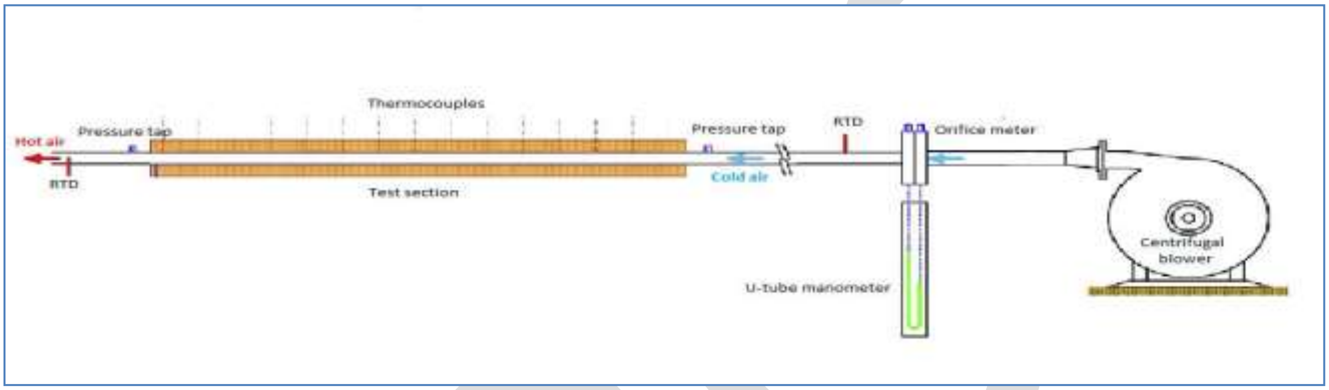

Fig. 2.1: Experimental Setup

By changing flow rate, we can vary Reynolds number of the flow. Orifice meter is used to measure flow rate of air in test section. U-tube manometer is placed for measuring the pressure drop between test section ends. Two thermocouples are fixed at inlet and outlet to measure temperatures at inlet and outlet and six thermocouples are mounted on test section to measure the temperatures on the surface of test section. There is a control panel which consists of an ammeter, voltmeter, temperature indicator, thermocouple knob and the dimmerstat. Heat input is given by the maintaining the voltage using dimmerstat.

Fig.2.2:Actual Setup

Test section: It consists of a test pipe of stainless steel. Stainless steel pipe is wounded by mica sheet to electrically insulate the test section. Nichrome wire heater of capacity 1500W is wound over the mica sheet for giving heat input. It is connected with the dimmerstat to supply current. Product of voltage and current gives the heat given to nichrome wire. Another mica sheet is wound on the nichrome wire to insulate. The glass wool is used as the thermal insulator to reduce heat loss to atmosphere. Two thermocouples are fixed at inlet and outlet to measure temperatures at inlet and outlet and six thermocouples are mounted on test section to measure the temperatures on the surface of test section.

Fig. 2.3: Steel Pipe with Thermocouples Mount over it

Tape Geometry: The mild steel tapes of width 24 mm and pitch of 88 mm used as inserts for heat tansfer enhancement. The length of tape is 900 mm. the various tape designs TWT-D1,TWT-D2 and TWT-D3 as follows,

Figure 2.4: Photograph of TWT of various designs

3. EXPERIMENTAL PROCEDURE

1 Start the blower unit to allow the air through test section
2 Adjust the ball valve to change the flow of air.
3apply the heat input to nichrome wire by using dimmerstat.
4 Note down the voltage and current from the voltmeter and ammeter.
5 Note down the temperatures from the temperature indicator at an interval of 20 minutes by varying thermocouple knob.
6 Observe the steady state readings.
7 Again adjust the ball valve to change the flow rate of air and repeat the procedure for three different manometer readings.
8Note down the difference between manometer levels to measure the pressure difference across the test section.
9 Take the readings for tube without insert and for various tapes inserts named as TWT-D1, TWT-D2and TWT-D3.

4. DATA REDUCTION

In the experiments, the heat transfer rate in the tube is taken into account under a uniform heat flux condition by using air as the working fluid.
The bulk mean temperature of the fluid in the test tube is given by

$$T_m = \frac{(To + Ti)}{2}$$

The mean surface temperature of the tube is calculated from 6 points of local wall temperatures lined between the inlet and the exit of the test tube.

$$T_S = \frac{T2+T3+T4+T5+T6+T7}{6}$$

Rate at which air is heated, is given by

$$Q_A = mC_p\,(T_o - T_i)$$

m= Mass flow rate of air,
C_p = Specific heat of air at T_b,
T_i =Temperature at inlet of the tube,
T_o =Temperature at outlet of the tube,
The convection heat transfer from the test section is given by,

$$Q_C = hA_s\,(T_s - T_b)$$

Where,
h= Convective heat transfer coefficient

A_s = inner surface area ($\pi \times D_i \times L$),
D_i= Inner diameter of the tube,
L= Length of the test section.

Here the heat carried away by air is equal to heat transfer by convection.

$$Q_A = Q_C$$

The average heat transfer coefficient (h) and the mean Nusselt number (Nu) are estimated by

$$h = \frac{mCp\,(To - Ti)}{hA(Ts - Tb)}$$

The Nusselt number is defined as

$$Nu = \frac{hD}{k}$$

K= thermal conductivity at Tm

The Reynolds number is written as

$$Re = \frac{\rho UD}{\mu}$$

The experiment pressure losses, ΔP across the test tube are arranged in non-dimensional form by using the following equation

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)(\rho \frac{U^2}{2})}$$

Where, U is mean velocity in the test tube and L is the test tube length. All of thermo-physical properties of the air are determined at the overall mean air temperature (Tm).

5. RESULTS AND DISCUSSION

Heat transfer coefficient:

The experimental results of heat transfer coefficient for plain tube with various triangular wavy tape inserts as shown in below figure.

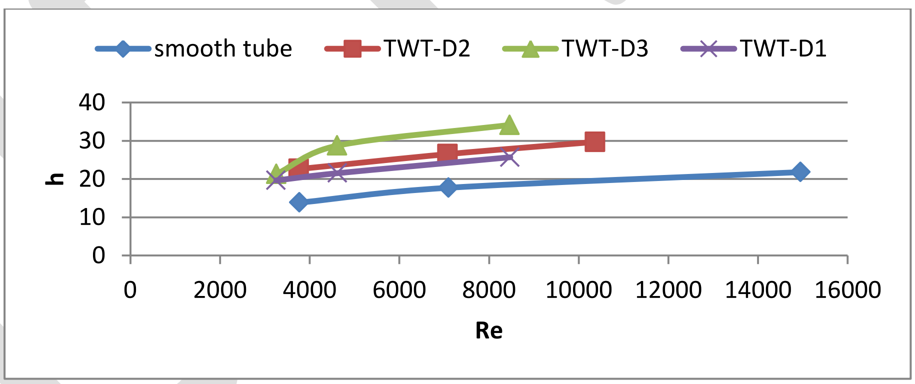

Figure 5.1: Variation of heat transfer coefficient for different inserts with Reynolds number

Figure shows that heat transfer coefficient for smooth tube is low and for triangular wavy tape of various designs is more than smooth tube. As Reynolds number increases the heat transfer coefficient also increases. This is because of better contact between heating wall and flowing fluid. Heat transfer coefficient is in the range of 13-34.

Friction factor:

Experimental results of friction factor for plain tube with triangular wavy tape with various designs as shown in below figure. Figure shows that friction factor is low for the plain tube and triangular wavy tape of various designs are more than plain tube. As Reynolds number increases friction factor decreases. Friction factor values are ranging from 0.18 to 2.0 as shown in figure.

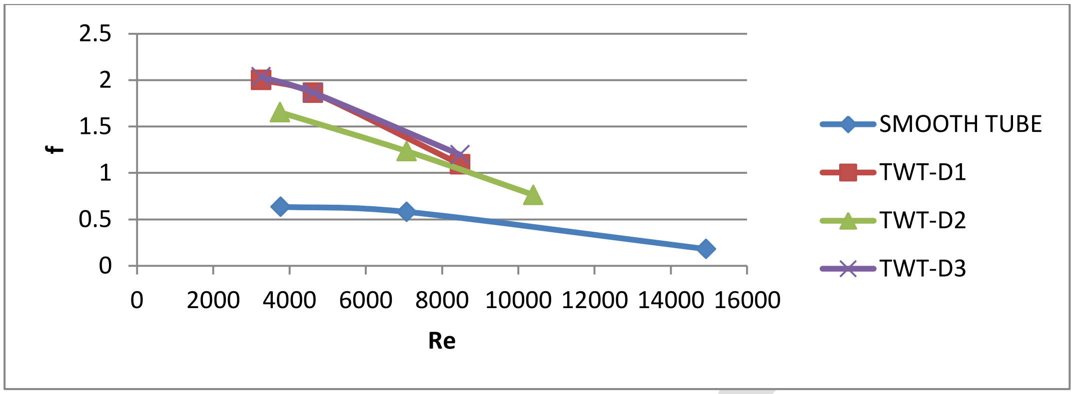

Figure 5.2: Variation of friction factor for different inserts with Reynolds number

Pressure Drop:

The experimental results of pressure drop for plain tube with various triangular wavy tape inserts as shown in below figure. Figure shows that pressure drop for smooth tube is low and for triangular wavy tape of various designs is more than smooth tube. As Reynolds number increases the pressure drop also increases. Pressure drop values are ranging from 24 to 230.

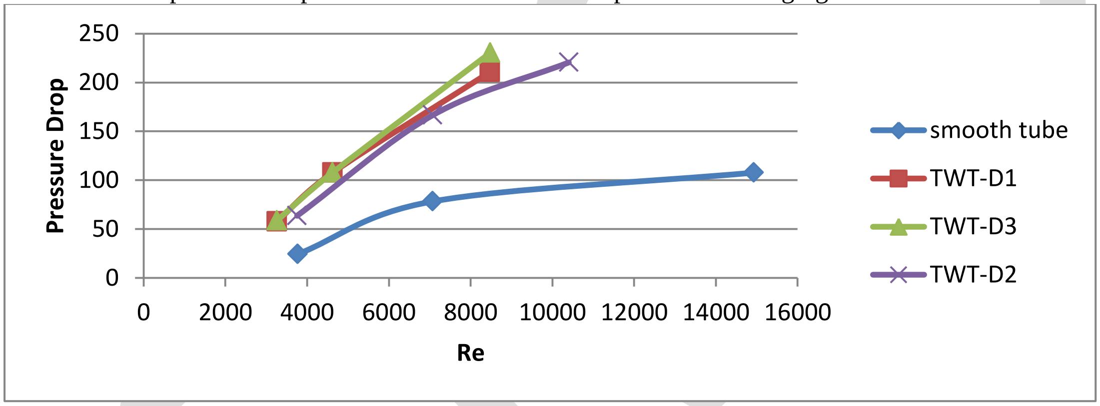

Figure 5.3: Variation of pressure drop for different inserts with Reynolds number

Nusselt number:

The experimental results of Nusselt number for plain tube with various triangular wavy tape inserts as shown in below figure. Figure shows that Nusselt number for smooth tube is low and for triangular wavy tape of various designs is more than smooth tube. As Reynolds number increases the Nusselt number also increases. Nusselt number is in the range of 19-47.

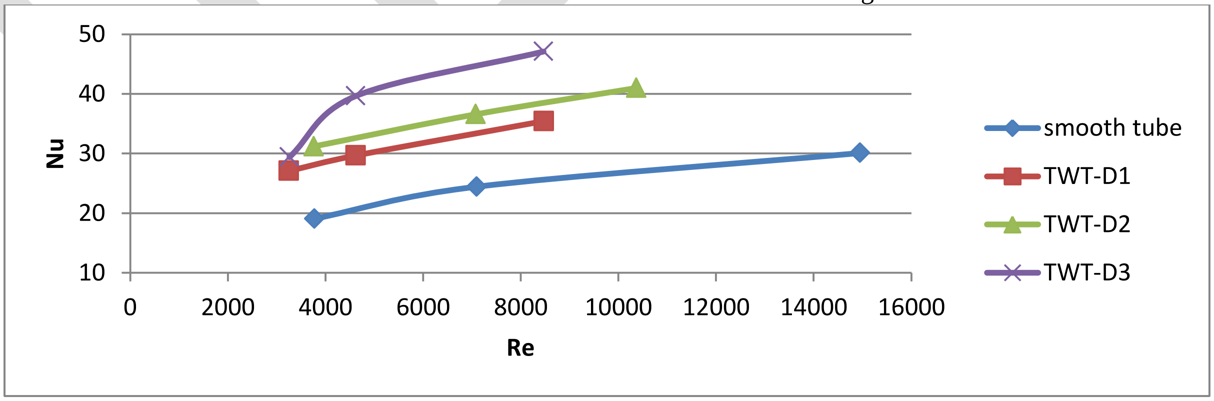

Figure 5.4: Variation of Nusselt number for different inserts with Reynolds number

CONCLUSION

Heat transfer enhancement in a tube inserted with triangular wavy tapes is studied experimentally in this present study. The work has been conducted for Reynolds number ranging in between 3260 to 14950 using air as the working fluid. The findings of the work can be drawn as follows:

1. Triangular wavy tape inserts of various designs show a considerable improvement of Nusselt number and friction factor relative to smooth tube.
2. The Nusselt number is found to increase with increase in the Reynolds number. The highest Nusselt number is found to be 47 for triangular wavy tape insert of type design 3 i.e. TWT-D3 and Reynolds number of about 8480.
3. Average convective heat transfer coefficient increases with the use of triangular wavy tape. Average convective heat transfer coefficient is found to be maximum of about 34 W/m^2K for mass flow rate of 0.00485 kg/sec. Average convective heat transfer coefficient is found to increase with increase in the mass flow rate.
4. The friction factor is found to increase with decrease in the Reynolds number and friction factor for triangular wavy tape with design 3 is found to be higher as compared to other designs and plain tube.
5. The friction factor is found to be maximum 2.0 at Reynolds number value of 3225.
6. Heat transfer for triangular wavy tape inserts is higher than plain tube.

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