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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 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.

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

I. INTRODUCTION

Heat is the form of energy that can be transferred from one system to another as a result of temperature difference. Heat transfer is commonly encountered in engineering systems and other aspects of life. The engineering heat transfer applications include equipments such as heat exchangers, boilers, condensers, radiators, heaters, furnaces, refrigerators, solar collectors etc.[1]

Heat exchangers are mostly used devices in many areas of the industries. Hence the using of high performance heat exchangers is very important for improving heat transfer rate, minimizing the size of heat transfer system and saving the material of heat exchanger. Energy efficient heat exchanger gives high performance. In last few years significant efforts have been made to develop the heat transfer enhancement techniques in order to improve the overall performance of the heat exchangers. Nowadays energy prices are increasing and the interests in these techniques is closely tied to it and, with the present increase in energy cost, so expectation is that the heat transfer enhancement field will go through a new phase. Although there is need to develop novel technologies, experimental work on the past work done by researchers. Hence, there have been continuous efforts to improve the efficiency of heat exchangers by various methods.

Suvanjan Bhattacharyya, Subhankar Saha, et al. [2] presented heat transfer enhancement in a circular tube Laminar flow having integral transverse rib roughness. It fitted with centre-cleared twisted-tape. Centre clearance c=0, 0.2, 0.4, 0.6. The friction factor and Nusselt number decreases with increase in the value of centre clearance initially however, but after c=0.4, no appreciable changes occur in the friction factor and Nusselt number. Experimental results shows that the combination of tapes with rib perform better than individual. M.M.K. Bhuiya, M.S.U. Chowdhury, M. Saha, et al. [3] proposed heat transfer and friction factor characteristics through a tube fitted with perforated twisted tape inserts in turbulent flow. From experiment, it has been found that the heat transfer enhancement occur by using perforated twisted tape inserts with corresponding increase in friction factor in comparison to that of the plain tube. S. Eiamsa-ard, Wongcharee, P. Eiamsa-ard Thianpong [4] experimented on heat transfer enhancement in a tube using delta-winglet twisted tape inserts. mean Nusselt number and mean friction factor in the tube using this tape increase with decreasing twisted ratio and increasing depth of wing cut ratio. Sumana Biswas, Shuvra Saha, et al. [5] researched on enhancement of heat transfer using rectangular-cut twisted tape insert. By using this tape heat fluxes increased and it is more than those for smooth tube. Heat transfer enhancement takes place because of higher values of heat transfer coefficient, although temperature difference between wall and bulk fluid significantly decreased for the tube with insert. 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. The tapes used for experiment are alternate clockwise and counter-clockwise twisted-tapes in round tubes. Nusselt number obtained by using alternate clockwise and counter clockwise twisted tape is significantly 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 Influence of combined non-uniform wire coil and twisted tape inserts on thermal performance characteristics. In this paper, heat transfer, friction factor and thermal performance behaviours in a tube equipped with the combined devices between the twisted tape (TT) and constant/periodically varying wire coil pitch ratio are experimentally investigated. The experiments were conducted in a turbulent flow regime with Reynolds numbers ranging from 4600 to 20,000 using air as the test fluid. Khwanchit Wongcharee, Smith Eiamsa-ard [10] Heat transfer enhancement by using CuO/water nanofluid in corrugated tube equipped with twisted tape is presented. The investigated ranges are made on three different CuO concentrations: 0.3, 0.5 and 0.7% by volume, at three different twist ratios of twisted tape:

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y/w=2.7, 3.6 and 5.3 for two different arrangements of twisted direction of twisted tape relative to spiral direction of corrugated tube: parallel and counter arrangements, and within the Reynolds number from 6200 to 24000. P. Bharadwaj, A.D. Khondge, A.W. Date [11] presents Heat transfer and pressure drop in a spirally grooved tube with twisted tape insert. In this paper, experimentally determined pressure drop and heat transfer characteristics of flow of water in a 75-start spirally grooved tube with twisted tape insert are presented. They worked within the Reynolds number range of 500-12000, with the twist ratio of 3.4, 7.95, and 10.15. They got Nusselt number in the range of 20-130 and friction factor in the range of 0.04-0.7. 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. The performance ratio increases with decreasing the twist ratio only in a definite Re range, and the Re range decreases with decreasing twist ratio. Re number was found in the range of 200-2200. 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

II.HEAT TRANSFER AUGMENTATION TECHNIQUES

Heat transfer augmentation techniques are divided into three types as

A. Passive Techniques:

B. Active Techniques:

C. Compound Techniques:

In Passive techniques, there is not required any external power but active techniques require external power.

1) Passive Techniques:

These generally use surface or geometric modifications to the flow channel by introducing inserts or additional devices. Any direct input not required in passive techniques of external power. Heat transfer augmentation is achieved by following passive techniques:

(a) Treated Surfaces: this technique includes application of coating. This technique is used in condensing and boiling operation

(b) Extended Surfaces: Extended surfaces are generally in the form of fins and nowadays fins are using in heat exchangers for heat transfer enhancement.

(c) Displaced Enhancement Devices: Displaced enhancement devices are those inserts, which primarily used in confined forced convection. To increase energy transport at the heated surface by displacing the fluid from the surface of the duct with bulk fluid from the core flow, the various inserts are inserted into the flow channel

(d) Swirl Flow Devices: Swirl flow devices are used to generate rotating flow. Some of the different types are Inlet Vortex Generators, Twisted Tape Inserts. They can be used for single phase flow and two-phase flows.

(e) Coiled Tubes: Coiled tubes leads to more compact heat exchangers. Coiled tube generates secondary flows or vortices due to its curvature of coils. It promotes higher single phase heat transfer coefficients as well as improvement in most regimes of boiling.

2) Active Techniques:

Active techniques require external power to improve heat transfer rate. Design and use of these techniques are more complex and it has very limited applications. Heat Transfer Enhancement by this technique can be achieved by Mechanical Aids, Injection, Surface Vibration and Electrostatic Fields.

3) Compound Techniques:

Compound techniques are those techniques which involves simultaneous combination of above mentioned two or more techniques with purpose of improving thermo hydraulic performance of a heat exchanger.

III.EXPERIMENTAL SETUP

The heat transfer enhancement apparatus consist of a blower unit which causes the flow of air through the test section. The valve is provided to control the flow of air through the test section.

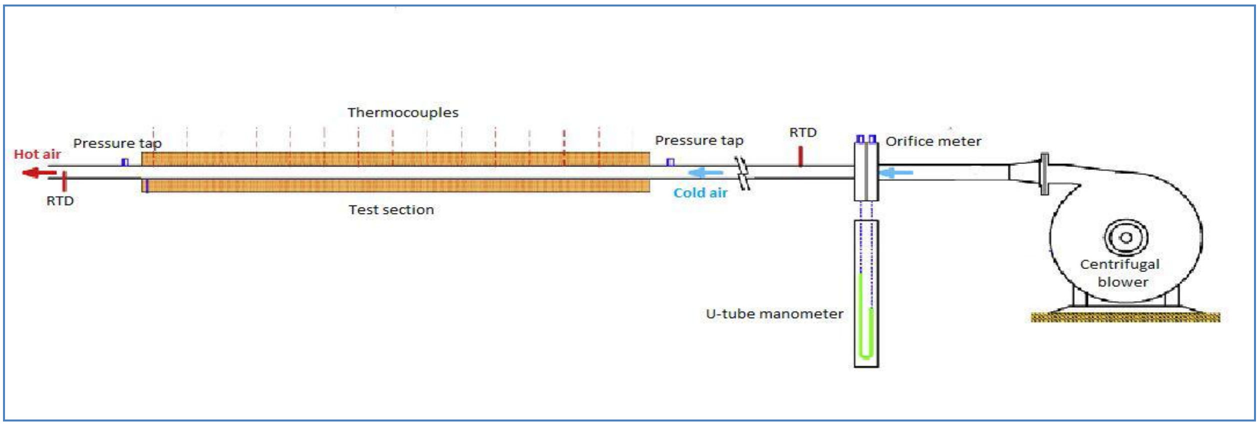

Fig. 1: Experimental Setup

This change in the flow varies the Reynolds number of the flow. The air flow is measured with the help of an orifice meter which is fitted with U- tube water manometer. Thereafter there is the test section through which heat transfer enhancement is to be calculated.

The test section pressure drop is measured with the help of another U-tube manometer. Six thermocouples are mounted on test section and two are suspended in air at inlet and exit in order to measure the measure temperatures at various points. There is a control panel which consists of an ammeter, voltmeter, temperature indicator, thermocouple knob and the dimmerstat. Heat input to the test section is controlled by the dimmerstat.

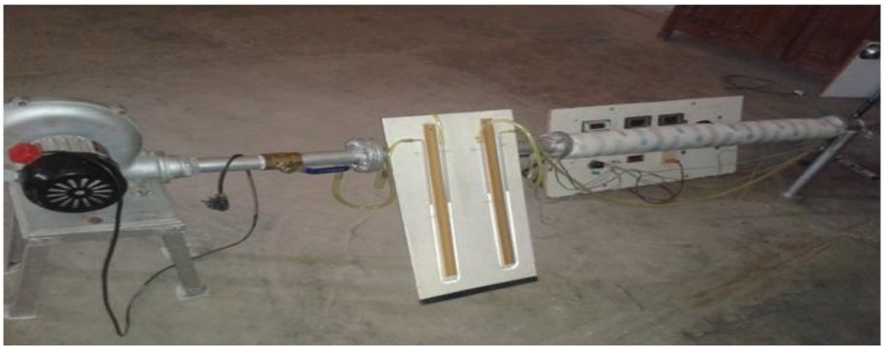

Fig.2: Actual Setup

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,

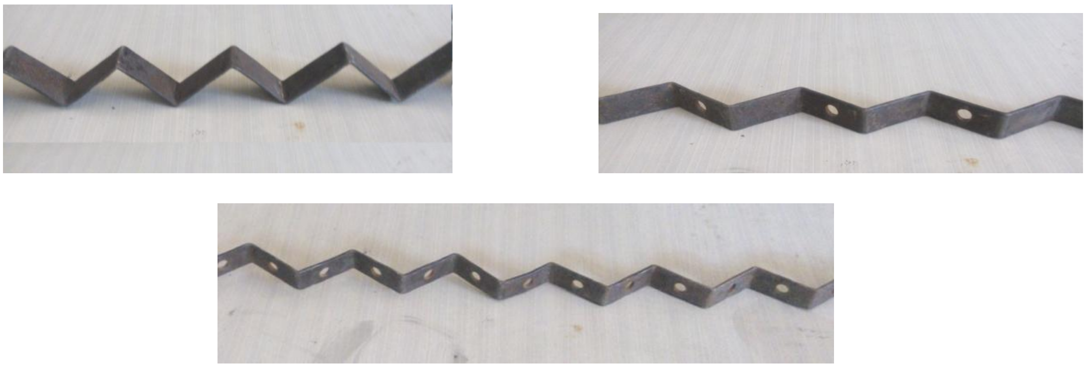

Fig 3: Photograph of TWT of various designs

IV.EXPERIMENTAL PROCEDURE

1 Start the blower and adjust the flow by means of valve to some desired difference in manometer level.

2 Start the heating of test section with the help of dimmerstat and adjust desired heat input with the help of voltmeter and ammeter.

3 Take the readings at an interval of 20 minutes, wait for steady state and take the reading of all thermocouples by varying the thermocouple knob.

4 Note down heater input current and voltage.

5 Again adjust the flow and repeat the procedure for three different manometer readings.

6 Measure the pressure difference across the test section.

7 Take the readings for tube without insert and for various tapes inserts named as TWT-D1, TWT-D2 and TWT-D3.

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V.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

$$T_m = \frac{(To \cdot}{2}$$

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.

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

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

$$h = \frac{mCp\ (To -}{hA(Ts - T}$$

The Nusselt number is defined as

Nu =

K= thermal conductivity at Tm

The Reynolds number is written as

Re =

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

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

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).

VI.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.

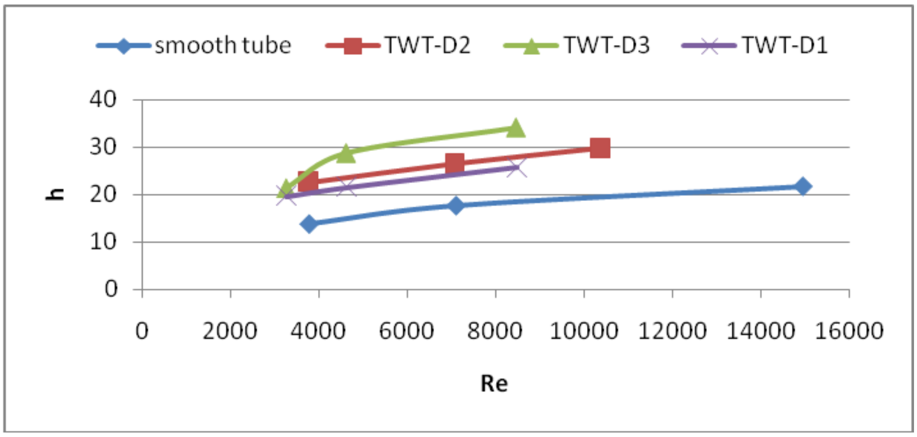

Fig 4: Variation of heat transfer coefficient for different inserts with Reynolds number

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.

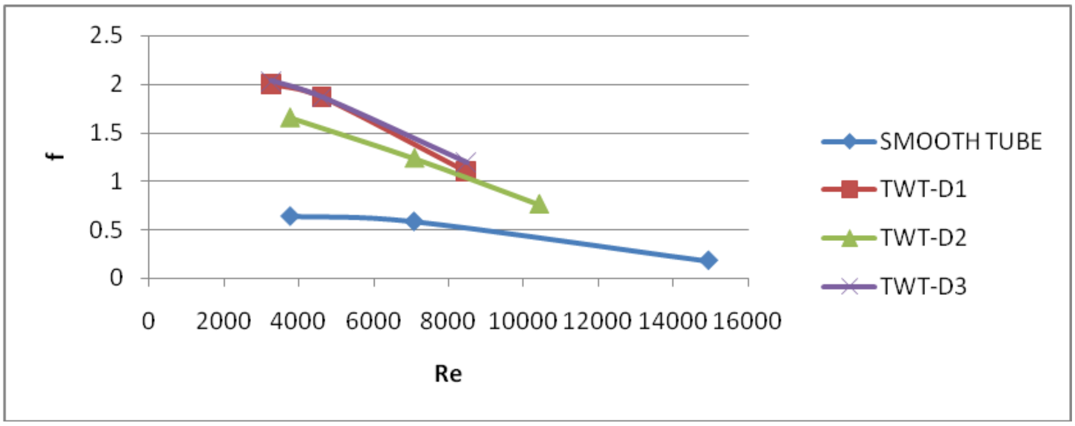

Fig 5: Variation of friction factor for different inserts with Reynolds number

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.

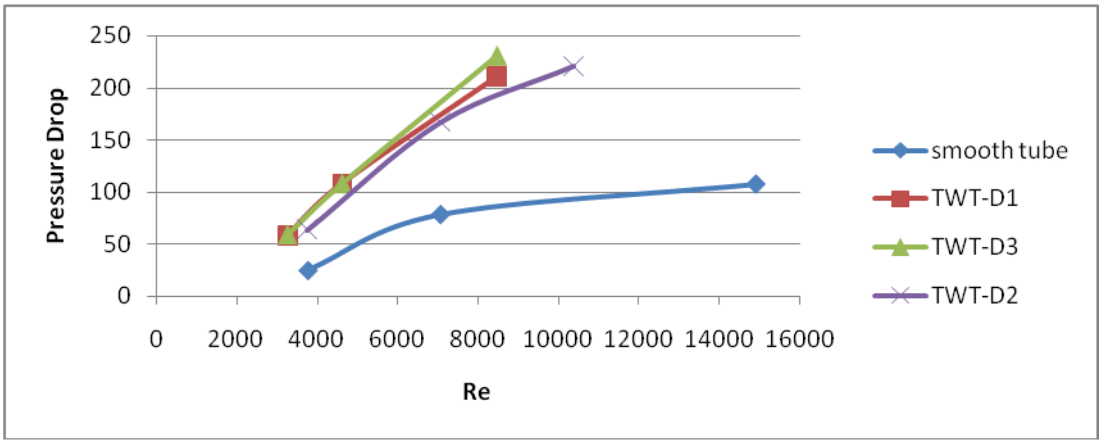

Fig 6: Variation of pressure drop for different inserts with Reynolds number

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.

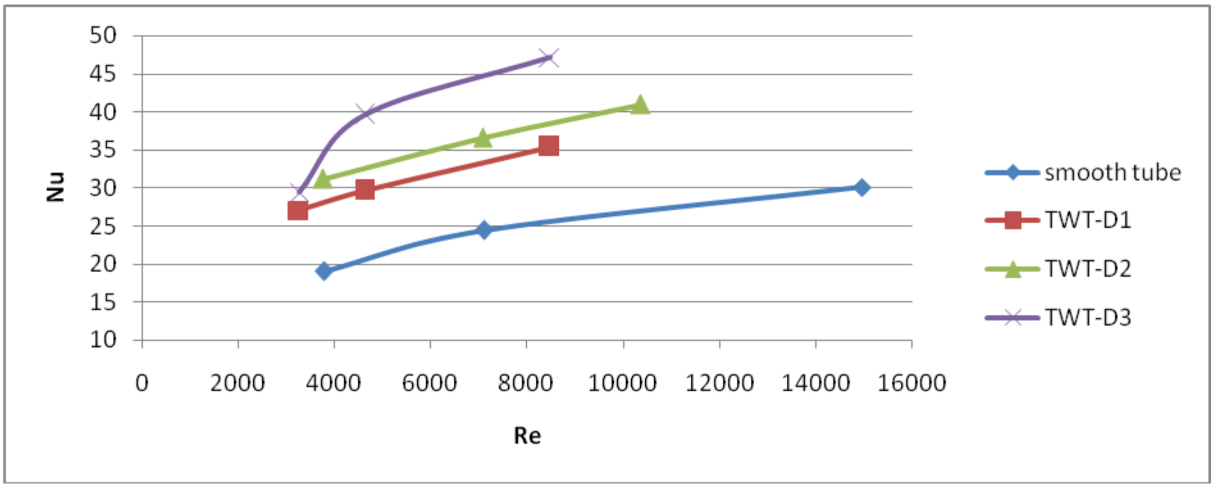

Fig 7: Variation of Nusselt number for different inserts with Reynolds number

VII.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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