Heat Transfer Enhancement in a Tube Fitted with Rotary Twisted Tape Inserts

Mr. Shyam S. Darewar[1], Dr. Vinayak M. Kale[2]
[1]*Department of Mechanical Engineering, Pune University, Modern College of Engineering, Pune.*
[2]*Department of Mechanical Engineering, Pune University, Indira College of Engineering and Management, Pune.*

Abstract- **This paper represents experimental investigation of heat transfer enhancement by using rotary twisted tape inserts. An Aluminium twisted tape of three different twist ratios (y= 3.0, 4.0 and 5.0) was used for the experimentation. The effect of fixed and rotary twisted tapes on heat transfer enhancements and Pressure drop was studied. The experiment was performed by using copper pipe of 800mm length having 35mm inside diameter and thickness of 1.5mm. Nichrome wire was wound over a copper pipe to maintain uniform heat flux condition. Outer surface temperatures of the tube were measured at 6 different points of the test section by J-type thermocouples and two thermocouples were inserted inside the pipe at two ends two measure inlet and outlet temperature of the air. The Reynolds number was varied from 35,000 to 45,000. The experimental result shows that for the rotary twisted tape inserts at higher RPM, heat transfer rate increases as compared to fixed twisted tapes. The higher Nusselt number obtained in this experimentation is 2.025times the smooth pipe without inserts.**

Index Terms- **Heat transfer enhancement, Rotary twisted tape inserts Nusselt number, pressure drop, heat transfer enhancement efficiency, swirl flow.**

I. INTRODUCTION

Turbulence or swirl flow has wide interest in the industrial application from the past decades because of its promising characteristics. Few of the industrial application of the swirl flow are, vortex tubes, cyclone separators, agricultural Spraying machines, gasoline engines, diesel engines, gas turbines, furnaces, vortex dust collectors, heat exchangers and many other practical heating devices. Devices using Swirl flow are designed to impart a rotational motion about an axis parallel to the flow direction to the bulk flow.

Twisted tape inserts are one of the swirl generator belongs to the above category used for the heat transfer enhancement in the heat exchanger. To improve the performance of heat exchanging devices, to reduce material cost and surface area and decreasing the difference for heat transfer thereby for reducing external irreversibility, Among different passive means to increase heat transfer coefficient, twisted tape inserts are promising. The twisted tape develops the swirl flow inside the pipe which ensures greater mixing of the flow. The swirl flow continuously changes the boundary layer thickness and form new boundary layer after breaking one, this improves the thermal contact of the fluid with tube thereby increasing heat transfer rate. The twisted tape has continuous change in its geometry due to the twists which result in high turbulence inside the pipe which increases heat transfer coefficient significantly. This is a passive technique of creating a swirl flow inside a pipe to improve heat transfer rate as it does not requires any external power source. The twisted tapes can be inserted easily inside the pipe of heat exchanger. But due to the high intensity of the turbulence pressure drop is also increases which result in higher pumping power requirement. So it is necessary to find the optimum trade off between the heat transfer rate and pressure drop.

Many researchers have studied the effect of different geometries of twisted tape on heat transfer enhancement and the associated pressure drop.

Marner and Bergles were the first investigators to recognize the importance of uniform wall temperature (UWT) boundary condition to a major group of heat exchanger used in chemical industry. They studied UWT heating and cooling of ethylene glycol (Pr = 24-85, Re =3803470) using single twisted tape insert of y=5.4 in a tube and internally finned tubes, and observed that both heat transfer and friction factor increased substantially beyond particular Reynolds number, at which secondary swirl flow and turbulence were induced in the flowing fluid.[1]

Manglik and Bergles correlated heat transfer and pressure drop for twisted tape inserts for uniform wall temperature conditions using water and ethylene glycol as working fluid, for laminar flow condition and explained physical description of enhancement mechanism. Depending upon the flow rate and tape geometry, the enhancement in heat transfer is due to the tube partitioning and flow blockage, the large flow path and secondary fluid circulation. They proposed laminar flow correlations for the friction factor and Nusselt number, including the swirl parameter, which defines the interaction between viscous, convective inertia and centrifugal forces.

Shivkumar and Raja Rao studied compound laminar flow heat transfer augmentation laminar flow heat transfer to power law fluid in spirally corrugated tubes with twisted tape inserts. But they did not observe any better results compared to the case twisted tape insert in the plain circular

Watcharin Noothong, Smith Eiamsa-ard and Pongjet Promvonge investigated the influence of twisted-tape inserts on enhancement heat transfer efficiency, Nusselt number and flow friction behaviours in a double pipe heat exchanger is studied. In the experimental condition, a twisted-tape was inserted into the inner tube at twist ratios: y = P/D = 5.0 and 7.0, respectively. All of the experiments were carried out at the same inlet condition with the Reynolds number of the inner tube, Re = 2000 to 12000. He found that In the case of the twisted tape inserts, the means Nusselt numbers (of the inner tube or hot air) increased about 188% for y = 5.0 and 159% for y = 7.0, when compared with the plain tube. It was shown that the smaller of the twist ratio, the higher in mean Nusselt number. [1]

Anil Singh Yadav studied Influences of the half length twisted tape insertion on heat transfer and pressure drop characteristics in U-bend double pipe heat exchanger. The experimental results revealed that the increase in heat transfer rate of the twisted-tape inserts is found to be strongly influenced by tape-induced swirl or vortex motion. The heat transfer coefficient is found to increase by 40% with half-length twisted tape inserts when compared with plain heat exchanger. It was found that on the basis of equal mass flow rate, the heat transfer performance of half-length twisted tape is better than plain heat exchanger, and on the basis of unit pressure drop the heat transfer performance of smooth tube is better than half-length twisted tape. It is also observed that the thermal performance of Plain heat exchanger is better than half length twisted tape by 1.3-1.5 times. [2]

P. Eiamsa-ard, N. Piriyarungroj, C. Thianpong, S. Eiamsa-ard studied Effects of the regularly-spaced twisted tape (RS-TT) on the heat transfer, friction factor and thermal performance factor behaviours in a heat exchanger are reported along with those of a full length twisted tape. The full length (or typical) twisted tapes with two different twist ratios (y=P/W=6.0 and 8.0), and the regularly-spaced twisted tape (RS-TT) with two different twist ratios (y=6.0 and 8.0) and three free space ratios (s=S/P=1.0, 2.0, and 3.0) were employed for comparative study. The experimental results show that heat transfer rate and friction increased with decreasing twist ratio and space ratio. At similar conditions, full length twisted tapes (s =0) offered higher heat transfer rate, friction factor and thermal performance factor than RS-TT ones (s=1.0, 2.0 and 3.0) as they induced more consistent swirling flows and thus turbulence. This reveals that it is possible to gain promising trade off between enhanced heat transfer and increased friction by selecting the twisted tape with proper geometries. [3]

Gaurav Johar et al. Modified twisted tape inserts as Passive Heat transfer augmentation device. Effect of Reduced width twisted tape (RWTT), Baffled Reduced width twisted tape (BRWTT1) & Baffled Reduced width twisted tape with holes (BRWTT2) on heat transfer and friction factor for heating of water for Reynolds number range 2500-30000, was studied experimentally in a double pipe heat exchanger. Three tapes of different twist ratio (y=3.69, y=4.39, y=5.25) for RWTT, BRWTT1 & BRWTT2 were used. Based on constant flow rate, the heat transfer coefficient were found to be 1.18-3.66, 2.61-7.07 & 3.58-8.08 times the smooth tube values for RWTT, BRWTT1 & BRWTT2 respectively. The friction factor values were found to be 3.23-5.96, 7.79-11.23 & 8.86-14.4times the smooth tube values for RWTT, BRWTT1 BRWTT2 respectively. Based on constant pumping power the heat transfer coefficient values were found to be 0.881.62, 1.59-3.70 & 2.12-4.49 times the smooth tube values for RWTT, BRWTT1 & BRWTT2 respectively. Based on Increase in Heat transfer coefficient, Performance evaluation criteria R1 & R3, it was concluded that Baffled Reduce width twisted tape & Baffled Reduced width twisted tape with holes performs much better than Reduced width twisted tapes(RWTT) of the same twist ratio. [1]

Bodius Salam, Sumana Biswas, Shuvra Saha, Muhammad Mostafa K Bhuiya did the experimental investigation for measuring tube-side heat transfer coefficient, friction factor, heat transfer enhancement efficiency of water for turbulent flow in a circular tube fitted with rectangular-cut twisted tape insert. A copper tube of 26.6 mm internal diameter and 30 mm outer diameter and 900 mm test length was used. A stainless steel rectangular-cut twisted tape insert of 5.25 twist ratio was inserted into the smooth tube. The rectangular cut had 8 mm depth and 14 mm width. A uniform heat flux condition was created by wrapping nichrome wire around the test section and fiber glass over the wire. At comparable Reynolds number, Nusselt numbers in tube with rectangular-cut twisted tape insert were enhanced by 2.3 to 2.9 times at the cost of increase of friction factors by 1.4 to 1.8 times compared to that of smooth tube. Heat transfer enhancement efficiencies were found to be in the range of 1.9 to 2.3 and increased with the increase of Reynolds number. [4]

P. Murugesan, K. Mayilsamy, S. Suresh performed Experimental investigation of heat transfer and friction factor characteristics of circular tube fitted with plain twisted tapes (PTT) and U–cut twisted tapes (UTT) with twist ratios y = 2.0, 4.4 and 6.0. The Nusselt number and friction factor values for the tube with UTT are noticeably higher than that of plain tube and also tube equipped with PTT. Over the range of Reynolds number considered average thermal enhancement factors in the tube equipped with PTT are found 1.15, 1.06, and 1.02 and tube equipped with UTT are 1.22, 1.10 and 1.06 respectively for twist ratios y =2.0, 4.4 and 6.0. The thermal enhancement factors for all the cases are more than unity indicates that the effect of heat transfer enhancement due to the enhancing tool is more dominant than the effect of rising friction factor and vice versa. [5]

M.M.K. Bhuiya, M.S.U. Chowdhury, M. Shahabuddin, M.Saha, L.A.Memon investigate, the influences of triple twisted tapes on heat transfer rate, friction factor and thermal enhancement efficiency The investigations were conducted using the mild steel triple twisted tapes with four different twist ratios (y = 1.92, 2.88, 4.81 and 6.79) for Reynolds number ranging from 7200 to 50,200 under uniform heat flux condition. The results indicated that the presence of triple twisted tapes led to a higher increase in the heat transfer rate over the plain tube. The Nusselt number and friction factor of using the triple twisted tape inserts were found to be increased up to 3.85 and 4.2 times when compared with the plain tube, respectively. The heat transfer performance was evaluated based on the constant blower power and the performance was achieved to be 1.44 by the use of triple twisted tape inserts. [6]

K. Nanan, C. Thianpong, P. Promvonge, S. Eiamsa-ard has investigate the influence of perforated helical twisted-tapes (P-HTTs) on the heat transfer, friction loss and thermal performance characteristics under a uniform heat flux condition. The P-HTTs were obtained by perforating typical helical twisted-tapes (HTTs) with a prospect to reduce the friction loss of fluid flow. The experiments were conducted using P-HTTs' three different diameter ratios (d/w) of 0.2, 0.4 and 0.6, and three different perforation pitch ratios (s/w) of 1, 1.5 and 2. The helical pitch ratio and twist ratio were fixed at P/D = 2 and y/w =3.Tests were performed for Reynolds number between 6000 and 20,000. The experimental results reveal that the use of P-HTTs leads to the reduction of friction loss as compare to that of HTT. Heat transfer, friction loss and thermal performance factor increase as d/w decreases and s/w increases. For the present range, the maximum thermal performance factor of 1.28 is obtained by using the P-HTT with d/w = 0.2 and s/w = 2.0 at the Reynolds number of 6000. [7]

E. Esmaeilzadeh, H. Almohammadi, A. Nokhosteen, A. Motezaker, A.N. Omrani performed experimental study to investigate heat transfer and friction factor characteristics of ϒ-Al_2O_3 /water nano fluid through circular tube with twisted tape inserts with various thicknesses at constant heat flux. In this work, ϒ-Al_2O_3/water nano fluid with two volume concentrations of 0.5% and 1% were used as the working fluid. The twist ratio of twisted tape remained constant at 3.21, while the thicknesses were changed through three values of 0.5 mm, 1 mm and 2 mm. The experiments were performed in laminar flow regime from 150 to 1600 Reynolds numbers. Results indicated that twisted tape inserts enhanced the average convective heat transfer coefficient, and also more the thickness of twisted tape is more the enhancement of convective heat transfer coefficient is. Also, the highest enhancement was achieved at maximum volume concentration. Results showed that nano fluids have better heat transfer performance when utilized with thicker twisted tapes. At the same time, the increase in twisted tape thickness leads to an increase in friction factor. In the end, the combined results of these two phenomena result in enhanced convective heat transfer coefficient and thermal performance. [8]

Veeresh Fuskele, Dr. R.M. Sarviya performs the experimentation on heat augmentation in double pipe heat exchanger using a new kind of insert called twisted wire mesh. Inserts when placed in flow of liquid, create a high degree of turbulence resulting in an increase in the heat transfer rate and pressure drop. The work includes determination of friction factor and heat transfer coefficient for twisted wire mesh having twist ratio of y=5 and y=7. The experimental result of twisted tape results were compared with the smooth pipe. For twisted wire mesh it was observed that the heat transfer coefficient varied from 2.09 to 1.69 times and the friction factor increased to 4.3 to 4.0 times the smooth pipe. [9]

From the literature review it is clear that by changing the geometry of the twisted tape different results are obtained which shows that the twisted tape inserts increases the heat transfer rate as compare to the smooth tube without inserts but at the same time pressure drop is also increases. The results also show that with decreasing twist ratio the heat transfer rate increases but with considerable pressure drop. The present experimentation was performed by using rotary twisted tape inserts. The main objective of this experimentation is to find the effect of rotary twisted tape inserts on heat transfer coefficient and pressure drop. The twisted tape of three different twist ratios (y=3.0, 4.0 and 5.0) was used for the experimentation. The Reynolds number was varied from 35000 to 45000.

II. EXPERIMENTAL SET UP

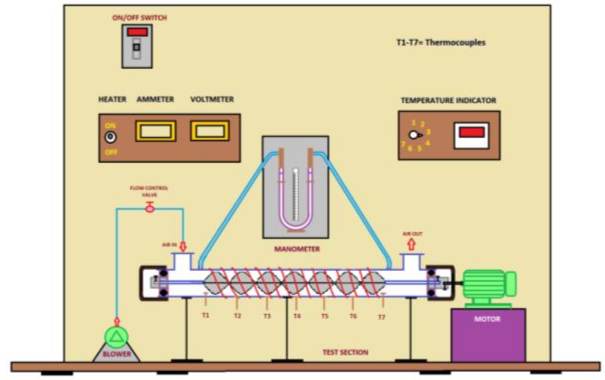


Fig 1. Experimental Set up

Fig. 1 shows schematic diagram of the experimental set up of the present experimentation. A copper pipe of inside diameter ID=35.1mm, outside diameter OD=38.1mm and length 900mm was used for the experimentation. The pipe length of 800mm was considered as test section. . Pressure tapping was provided at the distance of 860mm. A nichrome wire of gauge 30 and resistance 0.15Ω/cm was spirally wound over the test pipe. A porcelain beads were used on nichrome wire to make the test section electrically insulated. An asbestos rope was wound over nichrome wire to avoid any heat losses to the surrounding. An aluminium twisted tape of width w=20mm, thickness t=1.5mm and length 800mm was inserted inside the test pipe. The twisted tapes with three different twist ratios of (y=p/w= 3.0, 4.0 and 5.0 was used for experimentation. The twisted tapes were supported in the bearings located at the two ends. The twisted tapes were made rotated at the speed of 50RPM to 150 RPM. A blower of 450W and air capacity of 1.6m^3/sec was used for the experimentation. A ball valve was used to control the flow rate of the air according to the need of experimentation. J-type thermocouples were used for measuring the temperatures at the different point on the pipe. Six thermocouples were fixed over the surface of the pipe to measure surface temperature while two thermocouples were inserted inside the pipe to measure inlet and outlet temperature of the air. A voltmeter and ammeter were used to measure the voltage and current in the nichrome wire. A 10A dimmer stat of the range 260V was used to maintain constant heat flux condition.

Fig. 2 Twisted Tape Inserts of y=3.0, 4.0, 5.0

III. CALCULATION METHODOLOGY [10]

The heat added by the heater was calculated by the heat added to the Air. Heat added to the air is calculated by,

$$Q = \dot{m}c_p\,(T_o - T_i)$$

Where, $m^{\cdot}$ is mass flow rate of air, Cp specific heat capacity of air and ΔT is difference between inlet and outlet temperature.

Heat transfer coefficient was calculated from,

$$h = \frac{q''}{A\,(T_{wi} - T_b)}$$

Where q'' is the heat flux, T_{wi} average inner surface temperature and T_b is the bulk temperature.

Bulk temperature is given by;

$$T_b = \frac{T_i + T_o}{2}$$

Tube outer surface temperature was calculated from the average of six local tube outer surface temperatures,

$$T_{wo} = \sum_{i=1}^{n=5} \frac{T_{wo,i}}{6}$$

Where T_{wo} the average is outer surface temperature and $T_{wo,i}$ is the local outer surface temperature.

Tube inner surface temperatures were calculated from one dimensional radial conduction equation,

$$T_{wi} = T_{wo} - Q.\frac{ln\frac{d_o}{d_i}}{2\pi k_w L}$$

Where T_{wi}= outer surface temperature, T_{wo}= average outer surface temperature, Q is the heat added to Air, d_o is the outer diameter of pipe, d_i is the inner diameter of pipe, K_w is the thermal conductivity of copper pipe and L is the length of test section.

Reynolds number was calculated from;

$$Re = \frac{4m^{\cdot}}{\pi d_i \mu}$$

Where $m^{\cdot}$ the mass flow rate of Air, d_i is the inner diameter of pipe and μ is the dynamic viscosity of Air at a particular bulk temperature.

Nusselt number was calculated from,

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

Where h the heat transfer coefficient, d_i is the inner diameter of pipe, and k is the thermal conductivity of the Air at corresponding bulk temperature.

Friction Factor was given by,

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

Heat transfer enhancement efficiency was calculated from,

$$\eta = \left|\frac{h_e}{h_s}\right|$$

Where h_s is the heat transfer coefficient of smooth pipe configuration and h_e is the heat transfer coefficient of the pipe flow using rotating twisted tape insert.

Fig 3. Actual Experimental set up

IV. RESULT AND DISCUSSION

In this experimentation the twisted tape inserts were made rotated to find its effect on heat transfer rate and pressure drop characteristics. The results obtained from the experimentation with rotary twisted tape were compared with the typical fixed twisted tape inserts and the pipe without inserts.

1. NUSSELT NUMBER (Nu)

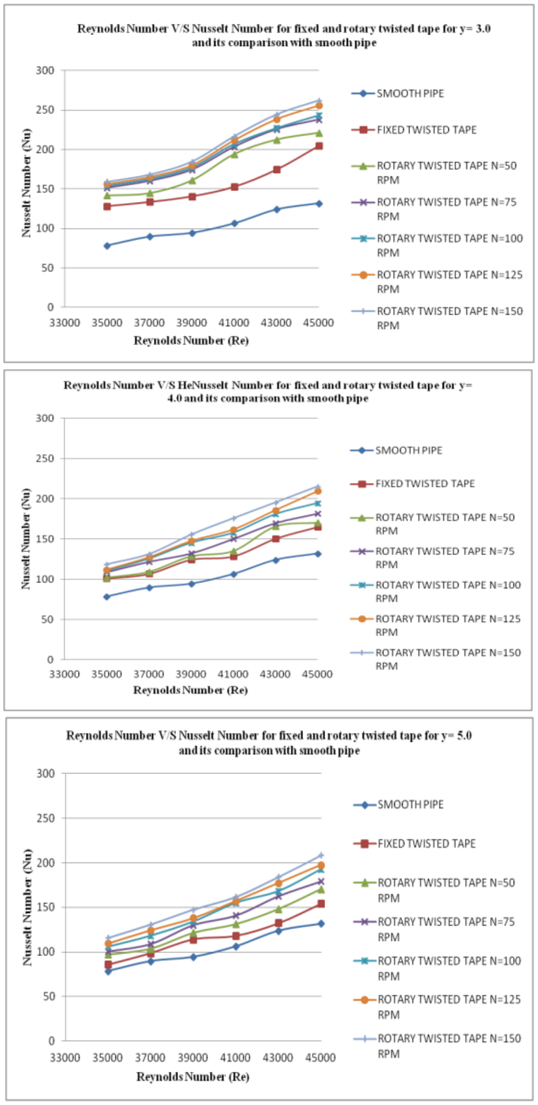
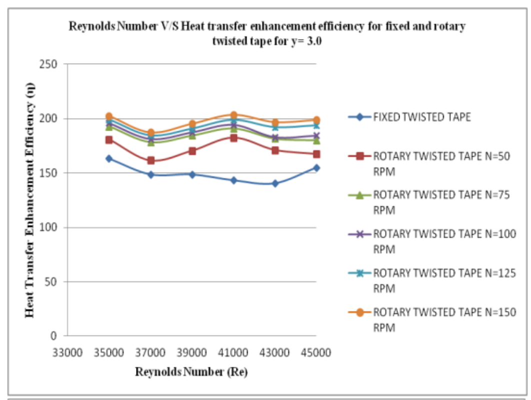


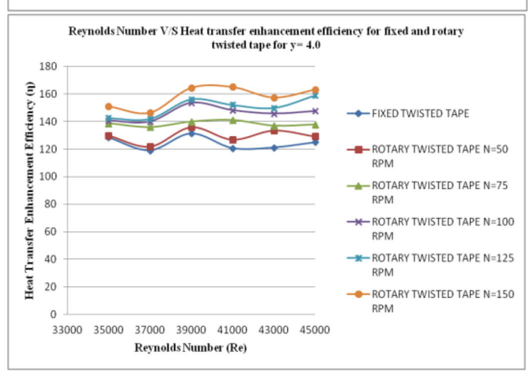
Fig 4. Reynolds Number V/S Nusselt Number for fixed and rotary twisted tape for y= 3.0, 4.0 and 5.0 and its comparison with smooth pipe

The experiment was performed by using fixed as well as rotary twisted tape inserts with varying Reynolds number. The experimental result shows that the Nusselt number for the fixed twisted tape inserts increases around 1.63 times at y=3.0, 1.28 times at y=4.0 and 1.17 times at y=5.0 compare to plain tube with increasing Reynolds number and when we compare these results with rotary twisted tape inserts, it shows that the Nusselt number of rotary twisted tape increases around 1.81 to 2.025 times at y=3.0, 1.29 to 1.63 at y=4.0 and 1.33 to 1.58 at y=5.0 with increasing RPM and Reynolds number when compared to plain tube. These values also show that with decreasing twist ratio, increasing value of Reynolds number and at higher RPM the Nusselt number was increased.

2. HEAT TRANSFER ENHANCEMENT EFFICIENCY

The effect of Reynolds number and rotation of the twisted tape was studied during the experimentation and the Experimental results shows that heat transfer efficiency increases about 1.63 times at y=3.0, 1.31times at y=4.0 and 1.20 times at y=5.0 when compared to plain tube. For the rotary twisted tape inserts these values increases from 1.82 to 2.02 times at y=3.0, 1.35 to 1.65 times at y=4.0 and 1.28 to 1.58 times at y=5.0 with increasing speed from 50RPM to 150RPM and Reynolds number.





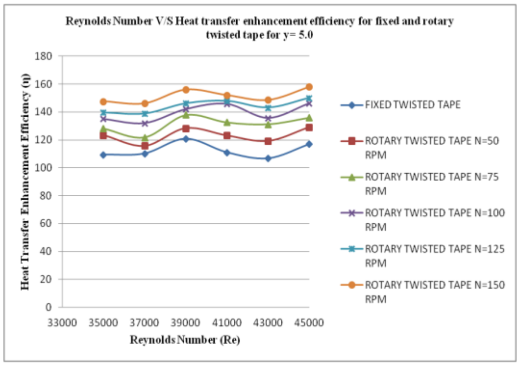


Fig 5. Reynolds Number V/S Heat transfer enhancement efficiency for fixed and rotary twisted tape for y= 3.0, 4.0 and 5.0

3. PRESSURE DROP

The insertion of twisted tape inserts increases turbulence in pipe which results in pressure drop within fluid flow. In the present experimentation the effect of rotary twisted tape on pressure drop was studied. The experimental value shows twisted tape inserts increases pressure drop respect to the plain tube. From the figure clear that pressure drop increases with the values of 4.14 times at y=3.0, 3.85 at y=4.0 and 3.42 at y=5.0 with respect to plain tube but these values does not changes significantly with the rotary twisted tape inserts at different RPM

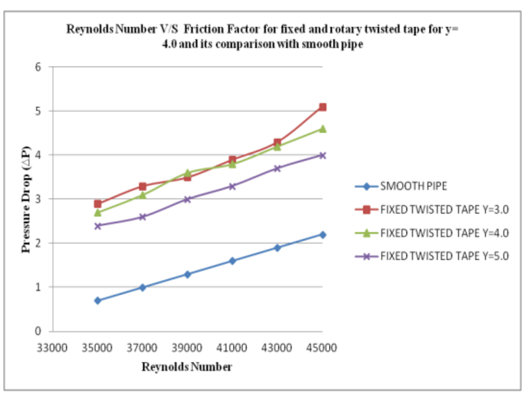


Fig 6. Reynolds Number V/S Pressure Drop for fixed twisted tape for y= 3.0, 4.0, 5.0 and its comparison with smooth pipe

V. CONCLUSION

With the results obtained from experimentation we conclude that;

- Twisted tape inserts increases the heat transfer rate within the heat exchanger by increasing turbulence in the flow.
- Turbulent flow or secondary flow increases the thermal contact by reducing boundary layer thickness.
- The turbulent flow ensures the better mixing of the fluid flow which increases heat transfer efficiency.
- The heat transfer rate increases with decreasing twist ratio but at the same time the pressure drop is also increases. At small twist ratio and higher RPM the twisted tape inserts increases the heat transfer efficiency up to 2.02 times smooth pipe without insert.
- From the results we also conclude that the rotary twisted tape inserts with higher RPM gives higher heat transfer coefficient.
- The maximum Nusselt number obtained in this experimentation was 2.025 times the smooth pipe without inserts at smaller twist ratio y=3.0 and 150RPM.
- The pressure drop within a pipe with fixed twisted tape insert increases around 4.14 times the smooth pipe without insert at smaller twist ratio y=3.0 however, these values remain constant for the rotary twisted tape from 50 to 150RPM.

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