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# Heat Transfer Enhancement of Shell and Tube Heat Exchanger Using Twisted Tapes

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**Abstract: The objective of this paper is to investigate the heat transfer rate of a shell & tube heat exchanger with the use of twisted tapes in the tubes of the heat exchanger. The use of the twisted tape causes the swirl flow behavior that enhances the heat transfer coefficient considerably. The investigation is made in a circular tube with twisted-tape inserts using KERN method. The fluid flow and thermal fields are simulated computationally in an effort to characterize their structure. Apart from this, issues like long term performance & detailed economic analysis of heat exchanger is studied to achieve high heat transfer rate in an existing or new heat exchanger while taking care of the increased pumping power. It was found that the heat transfer coefficient and the pressure drop in the tubes with the longitudinal twisted tape inserts were 7–16% and 100–170% greater than those of plain tubes without inserts. When the longitudinal strip inserts with holes were used, the heat transfer coefficient and the pressure drop were 13–28% and 140–220%, respectively, higher than those of plain tubes. The heat transfer coefficient and the pressure drop of the tubes with twisted-tape inserts were 13–61% and 150–370%, respectively, higher than those of plain tubes. Furthermore, it was found that the reduction ratio in the heat transfer area of the tube of approximately 18–28% may be obtained if the twisted-tape tube inserts are used.**

**Keywords: Twisted tapes, Kern Method, Reduction ratio, Shell and Tube Heat exchanger**

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## 1. Introduction

Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, while designing a heat exchanger using any of these techniques, analysis of heat transfer rate & pressure drop has to be done. Nowadays, twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries, due to their effectiveness, low cost and easy setting up. Insertion of a twisted tape in a heat exchanger tube is classified as passive enhancing technique. In general, twisted tape introduces swirl into the bulk flow which consequently disrupts a thermal boundary layer on the tube surface. Mechanisms of heat transfer enhancement by twisted tape inserts can be concluded as follows (1) the decrease of hydraulic diameter which leads to the increase in flow velocity due to portioning of the tube (2) the increase of flow path length due to helical configuration of the twisted tape (3) the increase of shear stress at wall tube and improvement of fluid mixing by secondary or swirl flow and (4) the fin contribution if the tape insert is in good thermal contact with the wall of the tube. Variants of twisted tapes have been evaluated as described below. [1-2] studied the flow friction and heat transfer characteristics of turbulent flow in a circular tube equipped with tube fitted with V/square-cut twisted tape.[3] performed the experimental and numerical investigation on the thermal performance of the tube equipped with *TT* and three modified twisted tapes (perforated, notched, and jagged twisted tapes). [4][5] investigated the effect of CCC/serrated twisted tape on thermal performance factor in a round tube. Most of the modified twisted tapes mentioned above, [6] offered higher heat transfer rates than the typical ones. For better understanding on the influences of a twisted tape on heat transfer result, the flow structure characteristics in a circular tubes were experimentally studied using shell and tube heat exchanger with 18 number of tubes, in the present work. Experiments were performed using twisted tape tube inserts with twist ratio ($y/W=5$), to generate swirl intensities.

## 2. Twisted-Tape

It is well known that energy transport is considerably improved if the flow is stirred and mixed well [7&8]. This has been the underlying principle in the development of enhancement techniques that generate swirl flows. Among the techniques that promote secondary flows, twisted-tape inserts are perhaps the most convenient and effective [9].They are relatively easy to fabricate and fit in the tubes of shell-and-tube heat exchangers. The geometrical features of a twisted tape, as depicted in Fig.1 are described by its 180º twist pitch $H$, the thickness $\delta$, and the width $w$. In most usage, where snug-to-tight-fitting tapes are used, $w \cong d$ , and the severity of the tape twist is characterized by the dimensionless ratio $y = (H /$

*d)*.The helical twisting nature of the tape, besides providing the fluid a longer flow path or a greater residence time, imposes a helical force on the bulk flow that promotes the generation of secondary circulation. The consequent well-mixed helical swirl flow significantly enhances the convective heat transfer. In most cases, depending on how tightly the tape fits at the tube wall and what material it is made of, there may be some tape-fin effects as well[10]. The enhanced heat transfer due to twisted-tape inserts, is also accompanied by an increase in pressure drop and suitable trade-offs must be considered by designers to optimize their thermal-hydraulic performance ratio $y = (H / d)$. The helical twisting nature of the tape, besides providing the fluid a longer flow path or a greater residence time, imposes a helical force on the bulk flow that promotes the generation of secondary circulation[11] [12] and [13]. Theconsequent well-mixed helical swirl flow significantly enhances the convective heat transfer[14 ]&[15]. In most cases, depending on how tightly the tape fits at the tube wall and what material it is made of [16], there may be some tape-fin effects as well. The enhanced heat transfer due to twisted-tape inserts, is also accompanied by an increase in pressure drop and suitable trade-offs must be considered by designers to optimize their thermal-hydraulic performance.

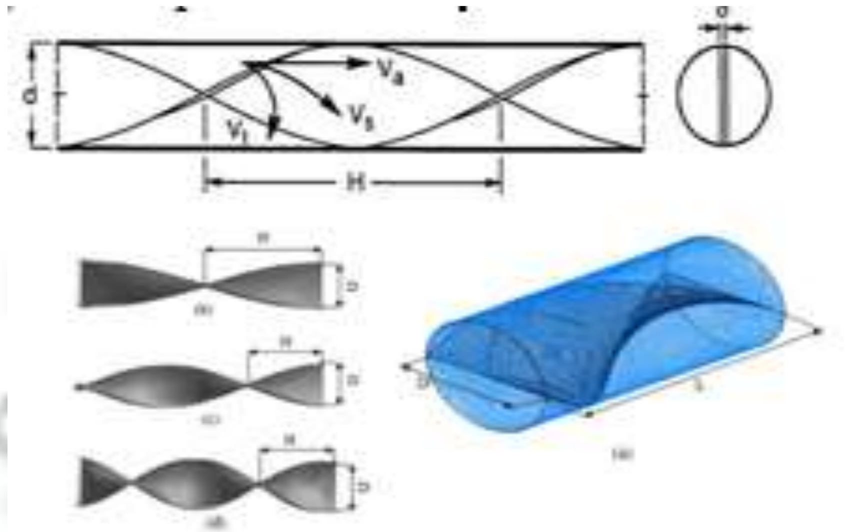


**Fig 1: Structure of the Twisted Tape**

## 2. FABRICATION OF TWISTED TAPES

The stainless steel strip of length 125cm, width 16mm and thickness 1.80mm were taken. Holes were drilled at both ends of every tape so that the two ends could be fixed to the metallic clamps. Desired twist was obtained using a Lathe machine. One end was kept fixed on the tool post of the lathe while the other end was given a slow rotatory motion by rotating the chuck side. During the whole operation the tape was kept under tension by applying mild pressure on the tool post side to avoid its distortion.fig(2)

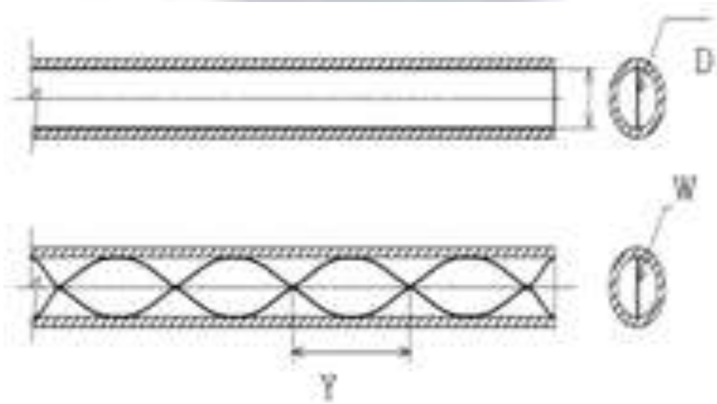


**FIG 2: PLAIN PLATE CONVERTED TO TWISTED TAPE**

## 3. EXPERIMENTAL SETUP OF SHELL AND TUBE HEAT EXCHANGER

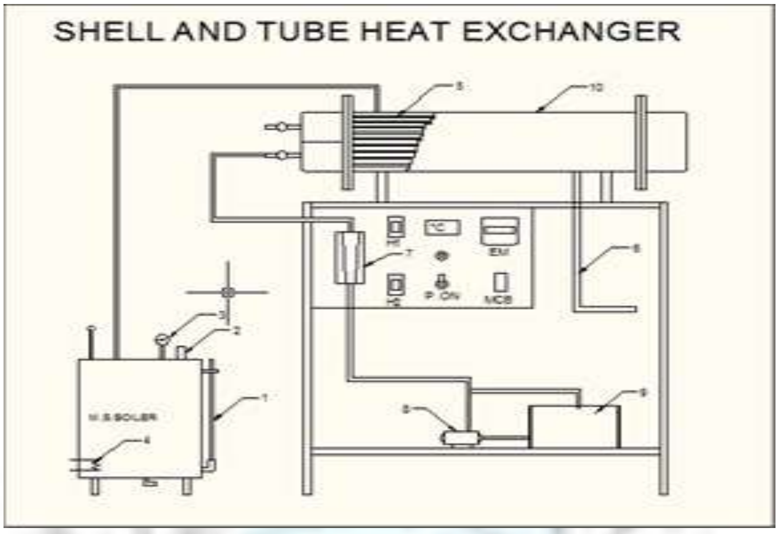


**Fig 3: Schematic Diagram of Shel and Tube Heat exchanger**

**Table No. 1: Description of components of shell & tube Heat exchanger**

| NO | DESCRIPTION |
|---|---|
| 1 | WATER LEVEL INDICATOR |
| 2 | PRESSURE RELIEF VALVE |
| 3 | PRESSURE GAUGE |
| 4 | HEATER |
| 5 | TUBE |
| 6 | WATER OUTLET |
| 7 | ROTAMETER |
| 8 | PUMP |
| 9 | WATER TANK |
| 10 | SHELL |

### 3.1 COMPONENTS OF SHELL & TUBE HEAT EXCHANGER

The principal components of an STHE are:

**Shell**: Shell diameter should be selected in such a way to give a close fit of the tube bundle. In this setup the shell diameter is usually taken as 0.2m and is made of Stainless steel.

**Tubes** : Tube OD of ¾ and 1“““ are very common to design a compact heat exchanger. With increase in number of tubes, the heat transfer coefficient is increased. Stainless steel is commonly used tube materials.

**Tube pitch**: Tube pitch is the shortest centre to centre distance between the adjacent tubes. The tubes is generally triangular patterns (pitch).

**Tube passes**: The number of passes is chosen to get the required tube side fluid velocity to obtain greater heat transfer co-efficient and in this setup 2 passes is chosen.

**Baffles:** Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. In this experiment four baffles are used.

**Rotameter**: In this setup two rotameter are used. One is for measuring mass flow rate on shell side and another for tube side. The readings will appear in digital form.

**Pumps**: Two pumps are used of half HP pump.

**Heater**: heater is provided on one side of tank, to heat water. The hot water is supplied to shell or tube depending upon requirement.

## 4. NOMENCLATURE

$A_s$: Area of the shell side cross flow section ($m^2$).

$A_t$: Area of the tube side cross flow section ($m^2$).

$P_t$ : Tube pitch (m).

$D_o$: Tube outside diameter (m).

$D_i$: Tube inside diameter (m).

$D_s$: Shell inside diameter (m).

$L_b$: Baffle spacing (m)

$L_s$: Length of shell (m).

$L_t$: Length of tube (m).

$t_b$: Tube thickness (m).

$G_s$: Shell side mass velocity (kg/ $m^2$-s).

$G_t$: Tube side mass velocity (kg/ $m^2$-s).

$U_s$: Shell side linear velocity (m/s).

$U_t$: Tube side linear velocity (m/s).

$m_s$: Mass flow rate of the fluid on shell side (kg/s).

$m_t$: Mass flow rate of the fluid on tube side (kg/s).

$\rho_s$: Shell side fluid density ($kg/m^3$).

$\rho_t$: Tube side fluid density ($kg/m^3$).

$D_e$: Shell side equivalent diameter (m)

$R_{es}$: Shell side Reynolds number.

$R_{et}$ : Tube side Reynolds number.

$P_{rs}$ : Shell side Prandtl number.

$P_{rt}$: Tube side Prandtl number

$\mu_s$: Shell side fluid Viscosity (N-s/ $m^2$).

$\mu_t$ : Tube side fluid viscosity (N-s/ $m^2$).

$\mu_w$: Viscosity a wall temperature (N-s/ $m^2$).

$C_{ps}$: Shell side fluid heat capacity (kJ/kg'K).

$C_{pt}$ : Tube side fluid heat capacity (kJ/kg'K).

$K_s$ : Shell side fluid thermal conductivity (kJ/s-m'K).

$K_t$ : Tube side fluid thermal conductivity (kJ/s-m'K).

$h_s$: Shell side heat transfer coefficient (W/ $m^2$'K).

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$h_i$: Tube side heat transfer coefficient (W/ $m^2$'K).

$N_b$: Number of baffles.

$N_t$ : Number of tubes.

f : Friction factor.

$\Delta P_s$: Shell side pressure drop (Pa).

$\Delta P_t$ : Tube side pressure drop (Pa).

$n_p$ : Number of tube passes.

## 5. SUBSCRIPTS:

**s:** **shell side**

**t:** **tube side**

**i:** **inlet**

**o:** **outlet**

**b:** **baffles**

**p:** **passes**

**Table No. 2: Heat Exchanger data at the shell side**

| Sl. No | Quantity | Symbol | Value |
|---|---|---|---|
| 1 | Shell side fluid | | Water |
| 2 | Shell side Mass flow rate(kg/sec) | Mt | 0.060 |
| 3 | Shell ID(m) | Ds | 0.2 |
| 4 | Shell length(m) | Ls | 0.800 |
| 5 | Tube pitch(m) | Pt | 0.03 |
| 6 | No. of passes | n | 1 |
| 7 | Baffle spacing(m) | Lb | 0.2 |
| 8 | MeanBulk Temperature($^o$C) | $\Delta$T | |
| 9 | No. of baffles | N | 4 |

**Table: 3 Heat Exchanger data at the tube side**

| Sl. No | Quantity | Symbol | Value |
|---|---|---|---|
| 1 | Tube side fluid | | Water or nana fluid |
| 2 | Tube side Mass flow rate (Kg/sec) | Mt | 0.060 |
| 3 | Tube OD (m) | Do | 0.019 |
| 4 | Tube ID(m) | Di | 0.016 |
| 5 | Tube thickness(m) | Tp | 0.0162 |
| 6 | Number of Tubes | N | 18 |
| 7 | Tube length(m) | Lt | 0.825 |

**Table.No. 4 Fluid Properties of water**

| Sl. no | Property | Unit | Cold water shell side | Hot water tube side |
|---|---|---|---|---|
| 1 | Specific Heat (Cp) | KJ/kg. K | 4.187 | 4.187 |
| 2 | Thermal conductivity (k) | W/m. K | 0.00098 | 0.00098 |
| 3 | Density (ϱ) | kg/m. s | 1000 | 1000 |
| 4 | Viscosity (Ω) | $kg/m^3$ | 0.00088 | 0.00086 |

## 6. CALCULATIONS PROCEDURE

The procedure for calculating the shell-side heat-transfer coefficient and pressure drop for a single shell pass exchanger is given below The main steps of design following the Kern method are summarized as follows:

### 6.1 Calculation of shell side heat transfer Coefficient:

**STEP 1**: Calculating the area of cross flow As, or hypothetical row of tubes at the shell Equator, given by

$$A_s = \{(P_t - D_o)*D_s*L_{b\}} / P_t$$

**STEP 2**: Calculate shell side mass velocity $G_s$ and linear velocity $U_s$.

$$G_s = m_s / A_s$$

**STEP 3**: Calculate the shell side equivalent diameter $D_e$ For triangular pitch:

$$D_e = [4*\{(P_t^2*\sqrt{3})/4\} - \{(\pi * D_o^2)/8\}] / [(\pi * D_o)/2]$$

**STEP 4**: Calculate shell side Reynolds number $R_{es}$.

$$R_{es} = (G_s * D_e) / \mu_s$$

**STEP 5**: Calculate shell side Prandtl number $P_{rs}$.

$$P_{rs} = (C_{ps}*\mu_s) / K_s$$

**STEP 6**: Calculate the shell side heat transfer coefficient $h_s$

$$h_s = 0.36*(K_s / D_e)* \quad (R_e \text{^} 0.55)*(P_r \text{^} 0.33)*\{(\mu_s / \mu_w)\text{^} 0.14\}$$

**Note: The value of $(\mu_s / \mu_w)$ ^0.14 = 1, for water.**

### 6.2 Calculation of shell side pressure drop.

**STEP 7**: Calculate the number of baffles on shell side $N_b$.

$$N_b = \{L_s / (L_b + t_b)\} - 1$$

**STEP 8**: Calculate the friction factor f.

$$f = \exp \{0.576 - (0.19*\mathrm{Ln}\, R_{es})\}$$

**STEP 9**: Calculate the shell side pressure drop $\Delta P_s$.

$$\Delta P_s = [4* f* G_s^2 * D_s*(N_b+1)] / [2* \rho *$$

$$D_e*\times\{(\mu_s / \mu_w)\text{^}0.14\}]$$

### 6.3 Calculation of tube side heat transfer coefficient.

**STEP 1**: Calculate the tube side cross flow section area $A_t$.

$$A_t = \{(\pi * D_i^2) / 4\}*(N_t / 2)$$

**STEP 2**: Calculate the tube side mass velocity $G_t$ and linear velocity $U_t$.

$$G_t = m_t / A_t$$

**STEP 3**: Calculate the tube side Reynolds number $R_{et}$.

$$R_{et} = (G_t * D_i) / \mu_t$$

**STEP 4**: Calculate the tube side Prandtl number $P_{rt}$.

$$P_{rt} = (C_{pt} * \mu_t) / K_t$$

**STEP 5**: Calculate the friction factor f.

$$f = \{(1.58 * Ln\ R_{et}) - 3.28\} \wedge (-2)$$

**STEP 6**: Calculate the tube side Nusselt number $N_{ut}$.

$$N_{ut} = \{(f/2)*(Ret - 1000)* P_{rt}\} / \{1 + (12.7*\sqrt{(f/2)}*(P_{rt} \wedge (2/3)) - 1)\}$$

**STEP 7**: Calculate the tube side heat transfer coefficient $h_i$.

$$h_i = (N_{ut} * K_t) / D_i$$

### 6.4 Calculation of tube side pressure drop

**STEP 8**: Calculate the pressure drop on the tube side $\Delta P_t$.

$$\Delta P_t = [\{(4* f* L_t* n_p) / D_i\} + (4* \quad n_p)]*[(\rho t*U_t^2) / 2]$$

### 6.5 Calculation of shell side heat transfer Coefficient with the data at Table: 2 & 4

$A_s = \{(P_t - D_o)*D*L_b\} / P_t$

$= \{(0.03-0.01924)*0.2*.2\}/(0.03)$

$= 0.01435\ m^2$

$G_s = ms / A_s$

$= 0.0267/0.01435$

$= 1.38\ Kg/m^2\ sec$

$D_e = [4*\{(P_t^2*\sqrt{3})/4\} - \{(\pi* D_o^2)/8\}] / [(\pi* D_o)/2]$

$=[4\{(0.03^2*\sqrt{3}/4\}\{(\pi*0.01924^2)/8\}]/[(\pi*0.0924)/2]$

$= 0.03236$

$R_{es} = (G_s * D_e) / \mu_s$

$= (1.86/0.0325)/0.00088$

$= 50.946$

$P_{rs} = (C_{ps}*\mu_s) / K_s$

$= (4.187*0.00088)/0.00098$

$= 3.76$

$h_s = 0.36*(K_s/D_e)* (R_e\wedge 0.55)*(P_r\wedge 0.33)*\{(\mu_s/ \mu_w)\wedge 0.14\}$

$=0.35*(0.000616/0.0325)*(68.69^{0.55}) *(5.96^{0.33})*1$

$= 0.140\ W/m^{2o}K$

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### 6.6 Calculation of shell side pressure drop with the data at Table: 2 & 4

$N_b = \{L_s / (L_b + t_b)\} – 1$

$= \{0.800/(0.2+0.00162)\}-1$

$Nb+1= 3.96$

$f = \exp \{0.576 – (0.19*Ln\ R_{es})\}$

$= \exp \{0.567-0(0.19*Ln*68.69)\}$

$= 0.842$

$\Delta P_s = [f* G_s^2* D_s*( N_b+1)] / [2* \rho_s* D_e*\{(\mu_s / \mu_w)^\wedge 0.14\}]$

$= [0.796*(1.86^2)*0.2*3.96] / [2*1000*0.0325*1]$

$= 0.01963$ Pa

### 6.7 Calculation of tube side heat transfer coefficient with the data at Table:3 & 4

$A_t = \{(\pi* D_i^2) / 4\}*(N_t / 2)$

$= \{(\pi*0.016^2)/4\}*(18/2)$

$= 0.00180\ m^2$

$G_t = m_t / A_t$

$= 0.0221/0.00180$

$= 8.44$ Kg/m sec

$U_t = G_t / \rho_t$

$= 12.27/1000$

$= 0.008444$ m/sec

$R_{es} = (G_t* D_i) / \mu_t$

$= (12.27*0.016)/0.00086$

$=155.53$

$P_{rt} = (C_{pt}*\mu_t) / K_t$

$= (4.187*0.00088)/0.00098$

$= 3.674$

$f = \{(1.58*Ln\ R_{et}) – 3.28\} ^\wedge (-2)$

$= \{(1.58*Ln\ 223.090-3.28\}^\wedge(-2)$

$= 0.04538$

$N_{ut} = \{(f /2)*(Ret -1000)* P_{rt}\}/\{1+ (12.7*\sqrt{} (f /2)*(P_{rt} ^\wedge (2/3))-1)\}$

$=\{(0.0360/2)*(223.091000)*5.98]/\{1+(12.7*\sqrt{(0.0360/2)}*(5.98^{2/3}- 1)\}$

$=-24.26$

$h_i = (N_{ut} * K_t) / D_i$

$= (-17.066*0.000616)/0.016$

$= -1.334\ W/m^{2\ 0}K$

### 6.8 Calculation of tube side pressure drop with the data at Table:3 & 4

$\Delta P_t = [\{(4* f* L_t* n_p) / D_i\} + (4* n_p)]*[(\rho t*U_t^2) / 2]$

$=[\{(4*0.036*0.825*2)/0.016\}+(4*2)]*[(10\quad 0\quad 0*0.0122^2)/2]$

$= 0.951$ Pa.

**Table No: 5 Procedure followed for the set of readings recorde for the shell & tube heat exchanger for various mass flow rate. Flow rates on shell side & tube side**

| Sl. No | Mass flow rate | | $U_c$ | Temperature $^oC$ | | | |
|---|---|---|---|---|---|---|---|
| | Shell side | Tube side | | T1 ($T_{ho}$) | T2 ($T_{hi}$) | T3 ($T_{co}$) | T4 ($T_{ci}$) |
| 1 | 25.7 | 19.1 | 0.12 | 40.3 | 43.8 | 30.5 | 29.4 |
| 2 | 30.1 | 24.9 | 0.14 | 40 | 44.4 | 30.6 | 29.5 |
| 3 | 35.4 | 29.7 | 0.16 | 40.1 | 45.3 | 30.7 | 29.6 |
| 4 | 39.7 | 34.7 | 0.18 | 41.9 | 46.1 | 30.7 | 29.9 |
| 5 | 45.3 | 39.6 | 0.21 | 42.5 | 46.4 | 30.8 | 30 |

**Table No: 6 Calculation for each mass flow rate on shell side & tube side**

| | Shell side | | | | Tube side | | | |
|---|---|---|---|---|---|---|---|---|
| Sl. No | $R_{es}$ | $P_{rs}$ | $h_o$ | $dP_s$ | $R_{et}$ | $P_{rt}$ | $H_i$ | $dP_t$ |
| 1 | 50.9 | 3.7 | 0.14 | 0.02 | 157.1 | 3.6 | 1.3 | 0.94 |
| 2 | 64.0 | 3.7 | 0.16 | 0.03 | 198.4 | 3.6 | 1.1 | 1.36 |
| 3 | 73.8 | 3.7 | 0.17 | 0.08 | 253.2 | 3.6 | 0.9 | 2.02 |
| 4 | 89.0 | 3.7 | 0.19 | 0.05 | 319.3 | 3.6 | 0.8 | 2.96 |
| 5 | 102.4 | 3.7 | 0.21 | 0.06 | 388.0 | 3.6 | 0.6 | 4.13 |

## 7. RESULTS & GRAPHS

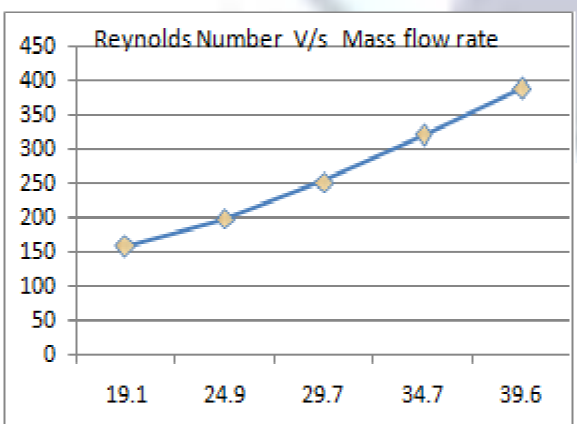


Fig-4: Tube side analysis using Twisted Tapes for Reynolds Number V/s Mass flow rate

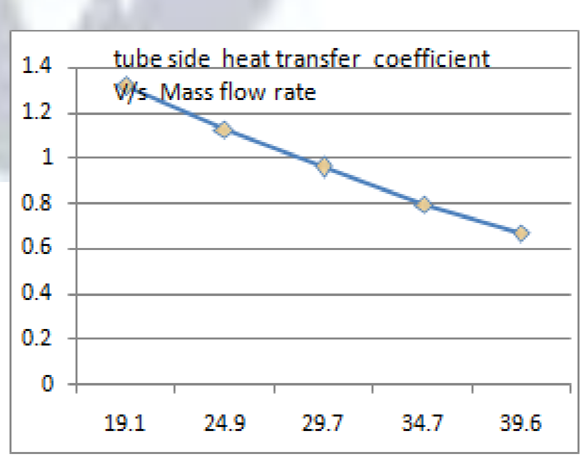


Fig-5: Tube side analysis using Twisted Tapes for Heat transfer Co-efficient V/s Mass flow rate

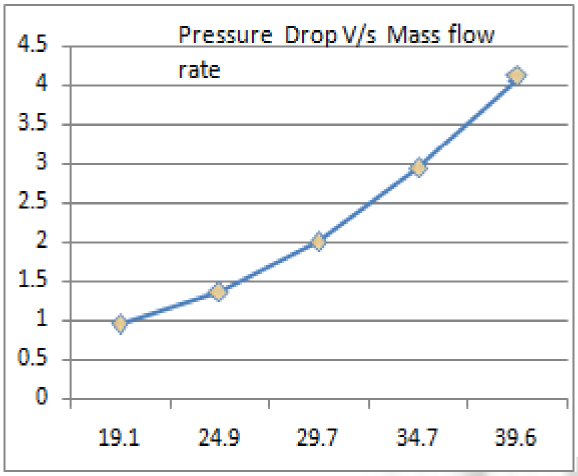


Fig-6: Tube side analysis using Twisted Tapes for Pressure Drop V/s Mass flow rate

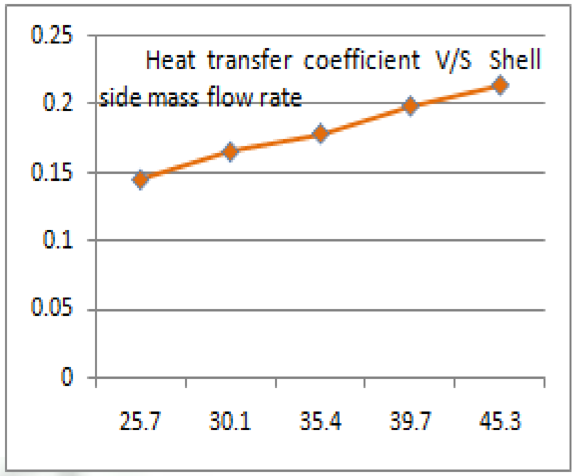


Fig-7: Shell side analysis using Twisted Tapes for Heat transfer Co- efficient V/s Mass flow rate

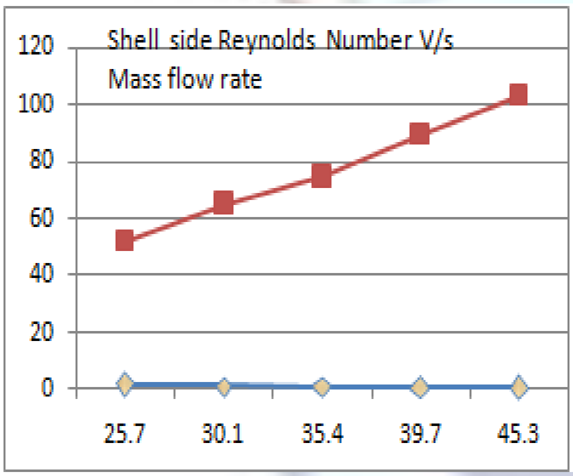


Fig-8: Shell side analysis using Twisted Tapes for Heat transfer Co- efficient V/s Mass flow rate

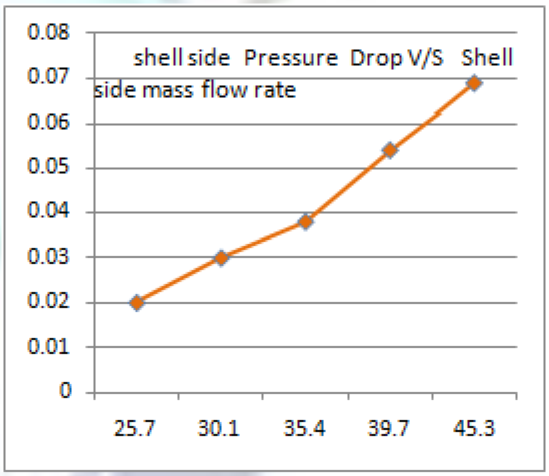


Fig-9:Shell side analysis using Twisted Tapes for Pressure Drop V/s Mass flow rate

## CONCLUSIONS

The graphs above show the Reynolds Number, pressure drop and Heat transfer coefficient on tube side & shell side respectively. The use of twisted tapes has led to the increase in heat transfer coefficient. Twisted tape introduces swirl into the bulk flow which consequently disrupts a thermal boundary layer on the tube surface. Mechanisms of heat transfer enhancement by twisted tape inserts can be concluded as follows (1) the decrease of hydraulic diameter which leads to the increase in flow velocity due to portioning of the tube (2) the increase of flow path length due to helical configuration of the twisted tape (3) the increase of shear stress at wall tube and improvement of fluid mixing by secondary or swirl flow and (4) the fin contribution if the tape insert is in good thermal contact with the wall of the tube.

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