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*Research Article*

# Numerical and Experimental Study of Heat Transfer Characteristics with Centrally Cleared Two Twisted Tapes

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### Abstract

*One of the key ways to enhance the heat transfer is use of twisted tape inserts. But along with the heat transfer it also increases pressure drop which results in increase in pumping power.So optimized tape design is required to achieve optimum cost. To get improved heat transfer coefficient with reasonable pressure drop two twisted tapes with center clearance is proposed. Effect of addition of two twisted tapes inside a tube at constant heat flux condition is reported in this paper. Results obtained for single twisted tape insert and two twisted tape inserts are compared analytically as well as numerically. Air is used as a test fluid. Study is carried out in turbulent region. Results are compared at Reynolds's number 45,000 for no twisted tape, one twisted tape & two tapes. Results for two twisted tapes with twist ratios 3, 4, 5 are compared at Reynolds's number 45,000. Heat transfer coefficient is improved as compared to plain tube& single tape by 2.2% to 10.1%.Optimum results are obtained at twist ratio 5.*

**Keywords:** *Centrally Cleared Twisted Tape, Heat transfer coefficient, Twist Ratio.*

### Nomenclature

$D_i$ Inner Diameter of pipe (mm)
$D_0$ Outer Diameter of pipe (mm)
l Total Length of pipe (mm)
L Effective Length of pipe (mm)
$L_p$ Pressure tapping length of pipe (mm)
Q Heat flux (W)
$\rho$ Density of Air (kg/m$^3$)
$C_p$ Specific heat of Air (kJ/kg°C)
V Velocity of Air (m/s)
Nu Theoretical Nusselt number
y Twist Ratio (mm)
w Width of insert (mm)
p Pitch of insert (mm)
k Thermal Conductivity of air (W/m°C)
A Effective Area of pipe (m$^2$)
Ai Flow Area (m$^2$)
h Heat transfer coefficient(W/m$^2$°C)
Re Reynolds's number
$T_s$ Surface Temperature (°C)
$T_m$ Mean Temperature (°C)
$Nu^{act}$ Nusselt number actual
$f^{act}$ Friction factor actual
$f^t$ Friction factor theoretical
m Mass flow rate of air (kg/s)

### 1. Introduction

Shell and tube exchangers are widely used in petrochemical industries, refineries, power plants, chemical industries & fertilizers. Performance of heat exchanger is measured in terms of heat transfer coefficient & pressure drop. High heat transfer coefficient is always desirable as it reduces surface area of heat exchanger. Less surface area leads to less manufacturing cost which ultimately results in less plant cost.

To achieve high heat transfer coefficient different heat transfer enhancement techniques are invented by different researchers.They are mainly classified as Active technique & Passive technique. In both the techniques turbulence in fluid is increased by some mean. Passive method includes different geometries like fins, tube inserts, various baffle geometries; treated surfaces, extended surfaces, vortex generator devices to create turbulence.

Twisted tape inserts are used to improve tube side heat transfer coefficient. It is very effective method of heat transfer enhancement. Different twist ratios & widths are used to improve heat transfer. Twisted insert generates swirl flow inside the tube. It increases the velocity of fluid & film boiling near the tube wall can be avoided. Wide research is carried out to improve performance of twisted tape. Performance of twisted tape with geometries like rectangular notched twisted tape (Bodiussalam *et al*, 2013),varying width twisted tape(S. Naga Sarada,2010), peripherally cut twisted tape,(Smith Eiamsa-ard et. al,2011) is studied. After addition of two and three twisted inserts flow resistance value increases by 9.4 to 14.4 times for two

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inserts& 13 to 21 times for three inserts (J.D. Zhu *et al*, 2015). It was observed that Nusselt number values for two & three tapes are almost close. But pressure drop for three tapes are high as compared to two tapes.P. (Eiamsa-ard *et al*, 2014) proposed performance of regularly spaced twisted tape. In perforated twisted tape with parallel wings perforation turns the fluid flow at center axial rather than turbulent(C. Thianpong *et al*, 2012). Less pressure drop was observed.(ShyyWoei Chang, 2007) proposed broken twisted tape. Above all types of inserts produce swirl flow inside the tube geometry. Turbulence increases the velocity as well as pressure drop. Pumping power of heat exchanger is directly proportional to pressure drop of twisted insert. As pressure drop increases pumping power also increases which leads to high operational cost. Optimum solution has to be determined to keep the exchanger cost optimum.

Solution of this problem wasproposed by (S.NagaSarada, 2010) by use ofvarying width of twisted tape. It was used to check the pressure drop change with respect to change in width of twisted tape.For rectangular notched tapeNusselt's number is enhanced 2.3 to 2.9 times. Friction factor is improved by 1.4 to 1.8 times of smooth tube (Bodiussalam *et al*, 2013). Centrally hollow twisted tape gives improved flow pattern near wall but due to central clearance less pressure drop is observed. But these tapes are difficult to manufacture (Pengxiao Li, 2015).

Recent research is done for heat transfer coefficient improvement along with the pressure drop reduction. Various baffle geometries are proposed but they are difficult to manufacture. So pipe containing two twisted tape with central clearance is proposed. Due to two tapes flow pattern near tube wall improves but due to central clearance pressure drop remains reasonable.

Numerical simulation is done on Ansys to observe the flow patterns & for checking the performance of new tape geometry.

*2.1 Test Setup geometry*

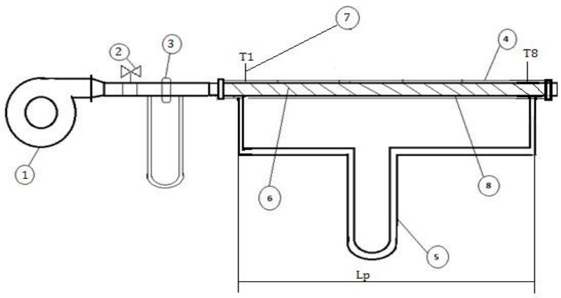


**Fig.1** Experimental Set-up diagram

1- Air Blower
2- Ball type flow control valve
3- Orifice Meter
4- Insulating Material
5- Manometer
6- Heating Element
7- Thermocouple

Test Set-up consists of Standard 1 1/2" Copper pipe having outer diameter $D_0$= 38.1 mm. Thickness of test pipe is 1.5 mm. Inner tube diameter ($D_i$) is 35.1 mm. Tube length of test pipe is 1000 mm. Effective length (L) is considered as 800 mm.

It is assumed that test pipe is at constant heat flux condition. Heat flux provided is 125 W. Heat flux is provided by 30 gauge Nichrome wire whose resistivity is 0.15 ohm/cm. Nichrome wire is wound around the test pipe throughout the length. Air is used as a test fluid. Air blower having capacity 450 W (Volumetric capacity = 1.6 $m^3$/sec) is used to supply air.Reynolds's number range chosen for experimentation is 45,000.Pressure reading length ($L_p$) is 860 mm.Eight number of thermocouples are used to measure the temperature. Out of eight two are inserted inside the test pipe to measure the inlettemperature ($T_1$) & outlet temperature ($T_8$). Remaining six are mounted on surface of test pipe ($T_2$ to $T_7$)to measure the surface temperature. J type thermocouple is used for temperature measurement. First thermocouple is mounted at 100 mm from start of test pipe. Eighth thermocouple is mounted at 900 mm. Remaining thermocouples are mounted at 114 mm distance apart from each other.

To avoid heat loss test pipe is insulated using Asbestos material. Simple arrangement of thermocouples is shown below.

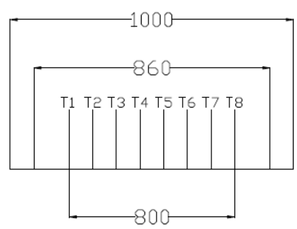


**Fig.2**General Arrangement of Thermocouples

*2.2 Actual Test Section*

Two numbers of twisted inserts are made of Aluminium having 1000 mm length. Width of insert is 14 mm for all twist ratios. Twist Ratios selected are 3, 4 & 5. Thickness of insert is 2 mm. Twisted insert material is Aluminum. Central clearance between the two tapes is maintained as 4 mm. Clearance between the test pipe & insert is maintained as 1.5 mm.Twisted tape parameters at different twist ratios are given below.

**Table 1** Experimental procedure parameters

| S. No | Twist Ratio (y) = $\frac{p}{w}$ | Width (w) Mm | Pitch (p) Mm |
|---|---|---|---|
| 1 | 3 | 14 | 42 |
| 2 | 4 | 14 | 56 |
| 3 | 5 | 14 | 70 |

To compare the results between single & two twisted tapes pitch ratio 4 is selected. Thickness of twisted insert i.e. 2 mm, clearance between test pipe & insert i.e. 1.5 mm is kept constant. Width of tape is 32 mm & pitch is 128 mm. Twisted tape arrangement is shown below.

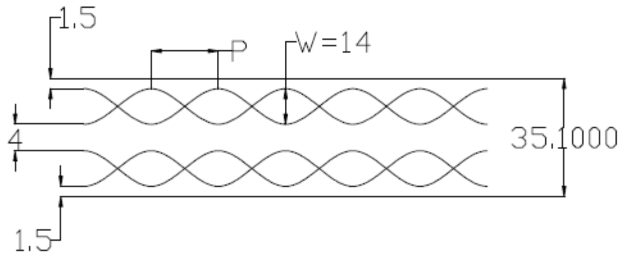


**Fig.3** Twisted tape arrangement for two tapes

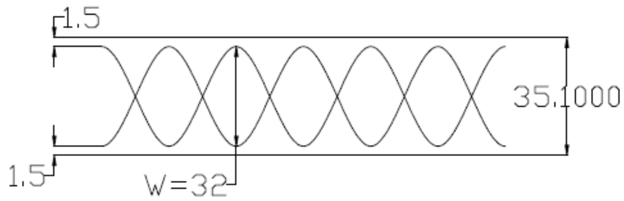


**Fig.4** Twisted tape arrangement for one tape

*2.3 Mathematical Correlations*

Heat transfer coefficient & Pressure drop values are compared for single & two twisted tapes. To calculate heat transfer coefficient, temperatures measured by thermocouples are used. Surface temperature &mean temperature is calculated based on thermocouple temperatures. Velocity is calculated based on Reynolds's number.

$$Re = \frac{\rho V Di}{\mu} \quad (1)$$

$$Pr = \frac{\mu C_p}{k} \quad (2)$$

$$Q = m \times C_p \times (T_8 - T_1) \quad (3)$$

$$Q = h \times A \times (T_s - T_m) \quad (4)$$

Where,

$$A = \pi \times D_i \times L \quad (5)$$

$$T_s = \sum_{i=2}^{i=7} T_i \;\; A = \pi \times D_i \times L \quad (6)$$

$$T_m = (T_1 + T_8)/2 \quad (7)$$

Theoretical Nusselt number is calculated from Gnielinski correlation.

$$Nu^{th} = \frac{(f^{act}/8) \times (Re - 1000) \times Pr}{1 + 12.7 \times (f^{act}/8)^{\frac{1}{2}} \times (Pr^{\frac{2}{3}} - 1)} \quad (8)$$

Where, f can be calculated using Petukhov, 1970,

$$f = (0.79 \ln Re - 1.64)^{-2} \quad (9)$$

By equating equation (3) & (4) we will get h value.

Nu actual will be based on this h value.

$$Nu^{act} = \frac{hD_i}{k} \quad (10)$$

Friction factor actual is calculated using following correlation.[1]

$$f^{act} = \frac{\Delta p}{(\frac{L_p}{D_i}) \times (\frac{\rho V^2}{2})} \quad (11)$$

Where, ΔP is pressure drop between pressure tapping.

Mass flow rate is calculated using,

$$m = \rho \times Ai \times V \quad (12)$$

Where, $Ai = \frac{\pi}{4} D_i^2$ (13)

*2.4 Results & Discussion*

Nusselt number, friction factor calculated using mathematical correlation & from numerical analysis are compared. Air is considered at 30°C.Air properties used for calculation at 30°C.
Air Properties used for calculation are as follows:
ρ = 1.166kg/m^3
μ = 1.375*10^-5kg/mS
k = 0.0264W/m°C
Cp = 1.005*10^3KJ/kgK

Values calculated at Reynolds's number 45,000 are as follows:

Mass flow rate (m) = $1.7*10^{-2}$ kg/s
Flow Area ($A_i$) = 0.088216m2
Velocity (V) = 15.11m/s
Prandtl Number = 0.52

For plain tube nusselt number & friction factor are calculated using correlation (8) & (9)
TheoreticalNusselt number =79.99
Friction Factor = 0.02147

2.4.1 Results for pressure drop

Pressure plot for plain tub, two twisted tapes with 4 twist ratio & 2 tapes with 5 twist ratio are shown below.

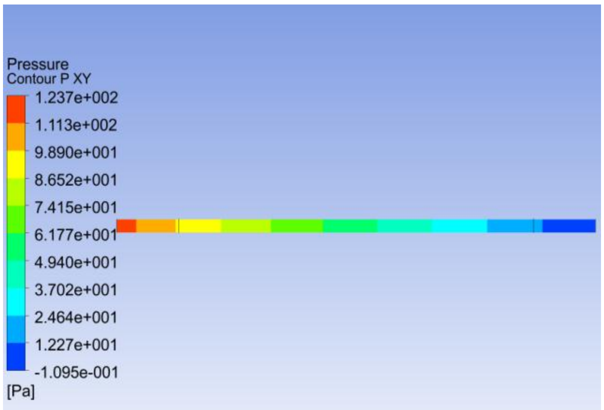


**Fig. 5** Pressure variation across the length for plain tube

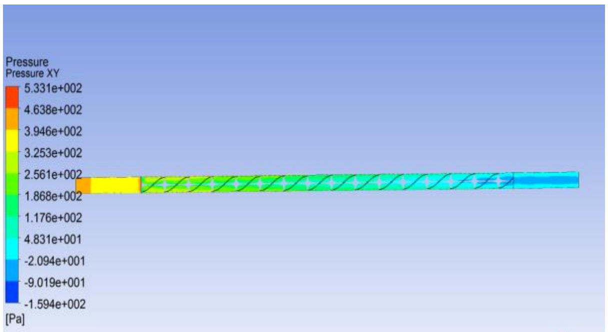


**Fig. 6** Pressure variation across the length for tube With 1 tape & twist ratio 4

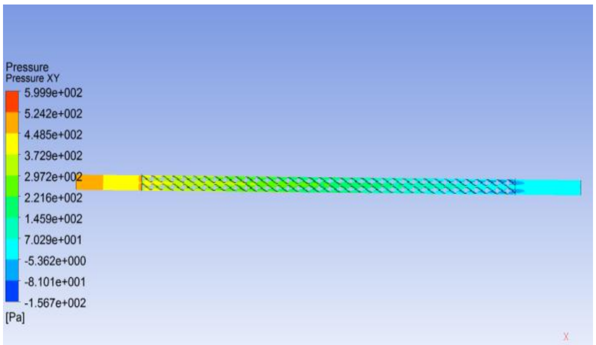


**Fig. 7** Pressure variation across the length for 2 tapes with twist ratio 4

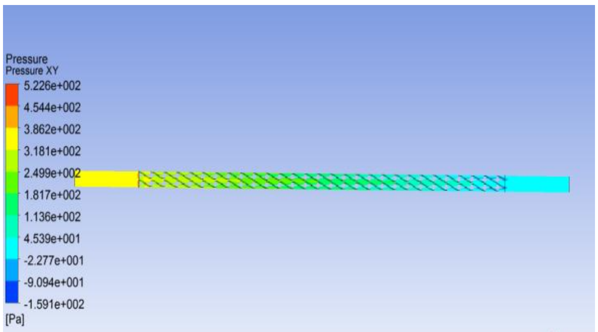


**Fig. 8** Pressure variation across the length for 2 tapes with twist ratio 5

**Table 2** Pressures observed at Pressure tapping points in tabular form

| Twisted tape Geometry | Pressure at Point P70 | Pressure at point P930 |
|---|---|---|
| Plain Tube | 91.10 | 19.86 |
| 1 Twisted tape y = 4 | 254.7 | 3.3 |
| 2 Twisted tape y = 3 | 615.13 | 63.62 |
| 2 Twisted tape y = 4 | 376.34 | 37.45 |
| 2 Twisted tape y = 5 | 311.77 | 45.41 |

2.4.2 Results for Temperature

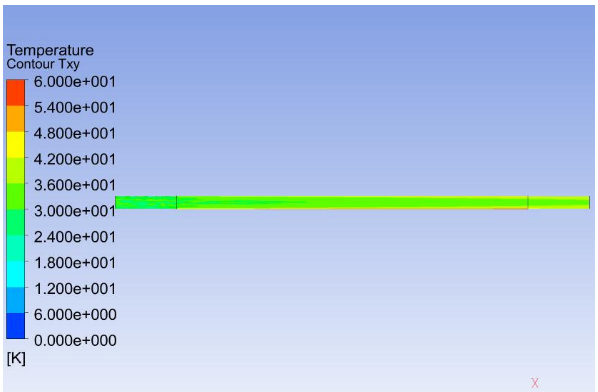


**Fig. 9** Temperature variation across the length for Plain tube

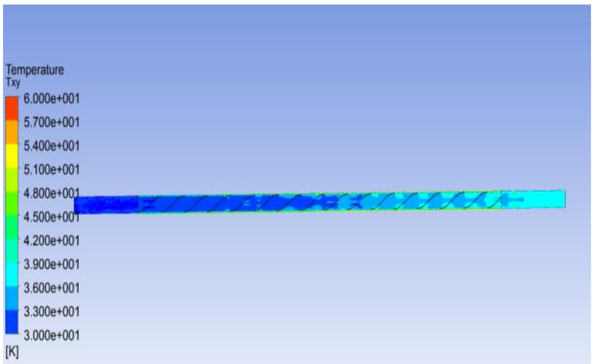


**Fig. 10** Temperature variation across the length for 1 tape with twist ratio 4

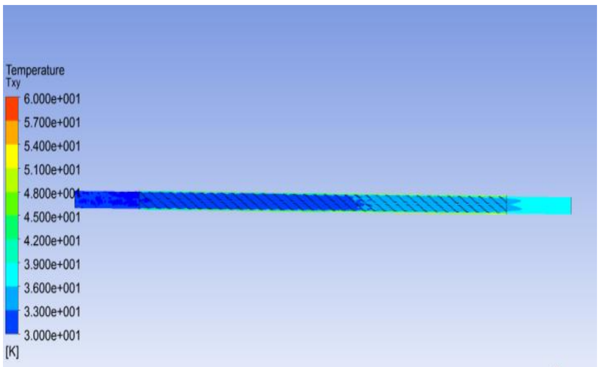


**Fig. 11** Temperature variation across the length for 2 tapes with twist ratio 4

**Table 3** Mean temperatures & Surface temperatures in tabular form

| Twisted tape Geometry | $T_s$ | $T_m$ |
|---|---|---|
| Plain Tube | 50.98 | 30.79 |
| 1 Twisted tape y = 4 | 47.55 | 33.29 |
| 2 Twisted tape y = 3 | 47.41 | 32.85 |
| 2 Twisted tape y = 4 | 47.75 | 32.59 |
| 2 Twisted tape y = 5 | 48.94 | 32.70 |

Based on the above values, actual Nusselt number, Friction factor & heat transfer coefficients are obtained.

**Table 4** Results obtained from simulation at Re= 45000

| Twisted tape Geometry | h W/m²K | $Nu^{act}$ | $f^{act}$ |
|---|---|---|---|
| Plain Tube | 15.06 | 20.09 | 0.0218 |
| 1 Twisted tape y = 4 | 61.34 | 81.55 | 0.0770 |
| 2 Twisted tape y = 3 | 68.19 | 90.66 | 0.1691 |
| 2 Twisted tape y = 4 | 63.066 | 83.84 | 0.1039 |
| 2 Twisted tape y = 5 | 62.71 | 83.37 | 0.0817 |

## Conclusions

1. Heat transfer enhancement is observed due to improved flow patterns near tube walls. Turbulence is increased due to two twisted tapes. It is observed that heat transfer coefficient for two tapesis increased by 2.18% to 10.1% as compared to single twisted tape.

2. Friction factor is increased for two twisted tapes due to more turbulence. It is observed that as pitch is increased friction factor value decreased.

3. Maximum pressure drop is observed at 3 twist ratio with two tapes. It is due to more number of twists along the length. Due to central clearance inside the tube flow pattern changes to near about axial at centre of the tube. Due to which pressure drop value remains reasonable. Pressure drop value for two tapes with twist ratio 5 and pressure drop for one tape is near about same. Difference in pressure drop value is 5%.

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