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Research Article

Performance evaluation of heat transfer and friction factor characteristics in a tube using square notched twisted tape inserts

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Abstract

The present work represents numerical analysis of square notched twisted tape insert in a tube by varying pitch with air as a working fluid. The results for simple twisted tape insert, square notched with single and double slot twisted tape insert at different twist ratio (4, 5, and 6) determined. Reynolds number varied from 35000-45000.Both pressure drop, heat transfer coefficient, Nusselt number are calculated and compared with plane tube. It is found that heat transfer enhancement of square notched twisted tape single slot and double slot is about and 32.31%, 39.2% as compared with plane tube.

Keywords: *Heat transfer enhancement, Air, square notched twisted tape with single and double slot, CFD simulation.*

Nomenclature

A	Area of heat transfer, $[\pi d_o L]$(m²)
Di	Inside tube diameter, (m)
Do	outside tube diameter, (m)
De	Depth of square cut, (mm)
W	Width of square cut, (mm)
Y	Twist ratio (Y/W)
L	Length, (mm)
W	Width of insert, (mm)
δ	Thickness of insert, (mm)
$\dot{m}$	Mass flow rate of air, (kg/sec)
μ	dynamic viscosity of Air, (kg/s)
K	Thermal conductivity of air, (W/mk)
K_w	Thermal conductivity of copper pipe,((W/mk)
h_s	heat transfer coefficient of smooth pipe, ,(W/mk)
h_e	heat transfer coefficient of the pipe using twisted tape insert,(W/mk)
Q	Rate of heat transfer, (W)
Q	Heat flux, (W/m²)
Re	Reynolds number
C_p	Specific heat of fluid, (KJ/kg*K)
ΔP	Pressure drop, (KPa)
ΔT	Temperature difference between inlet and outlet
T_{wi}	average inner surface temperature, (K)
T_{wo}	average is outer surface temperature, (K)
$T_{wo,i}$	local outer surface temperature,(K)
T_b	bulk temperature, (K)
h	Heat transfer coefficient, W/m²K
Nu	Nusselt number
f	Friction factor
ρ	density of air (kg/m³)
U	Velocity (m/s)

Subscripts

i	Inlet
o	Outlet
b	bulk

1. Introduction

Heat transfer enhancement techniques are widely used in areas like heat recovery process, air conditioning, refrigeration systems (Satyajit *et al* 20150, chemical reactors, process industries, heating, cooling in evaporators, thermal power plants, radiators for space vehicles, automobiles (Gawandare *et al* 2014).There are three main types of heat transfer enhancement techniques. They are as follows:

(a) Passive technique

The technique does not need any external power input is known as Passive technique.

These techniques generally use surface to the flow channel by incorporating inserts. They provide higher heat transfer coefficient by disturbing the flow behavior expect for extended surfaces. Heat transfer enhancement by this technique can be achieved by using treated surface, rough surface, extended surface, swirl flow devices.

(b) Active technique

The technique need any external power input is known as active technique.
Examples: mechanical aids, surface vibration, and electrostatic fields (Kanojiya *et al*, 2014).

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(c) Compound technique

The combination of passive and active technique may be employed simultaneously to enhance heat transfer of any device, which is greater than that of produce by any of that technique separately, then that technique is known as compound technique.

The performance evaluation of heat transfer and friction factor in a tube with different twisted tape inserts are analysed by using computational fluid dynamics (CFD), (Eisma *et al* 2014). The correlations for Nusselt number, heat transfer coefficient, friction factor were proposed.

In the present work presents the computational fluid dynamics (CFD) simulation i.e. flow analysis determination of heat transfer coefficient, Nusselt number, friction factor, performance evaluation criteria in a tube with square notched twisted tape with single slot, double slot for twist ratio 4,5,6, Reynolds number between 35,000 and 45,000. Then this result obtained for tube fitted with square notched twisted tape with single slot, double slot, twisted tape, plane tube compared with experimental results and literature.

2. Literature survey details

(Satyajit *et al* 2015) investigated the characteristics of heat transfer and pressure drop at a place of horizontal and double pipe with square jagged twisted tape inserts with working fluid is as water. As a result of insertion of square jagged twisted tape in concentric double tube heat exchanger gives better effectiveness on a flow friction characteristics and heat transfer rate those are experimentally investigated and shows that combination of twisted tape inserts with square jagged performs significantly better than individual enhancement technique.

(Gawandare *et al* 2014) Reynolds number varied from 5000 to 16000. Increase in Nusselt number in plain twisted tape inserts with the twist ratio of 5.2 was found to be 44 % and similarly for twist ratio 4.2, 3.2 it was found to be 82% and 154% respectively. The friction factor was increased for twist ratios 5.2 in square jagged twisted tape was found to be 12%, 27% and 51% respectively. Researcher also concluded that the heat transfer increased up to 154% for 51%increase in friction factor, for less pumping power heat transfer rate can increase 9.

(Krishna *et al* 2015) determined of friction factor and heat transfer coefficient for various twisted tape inserts with varying twists and CuO Nano fluid. The results of varying twists in square jagged tape with different pitches and CuO Nano fluid have been compared with the values for the smooth tube. The 3mm thick with 4.2 twist copper insert and Nano fluid shows increase in Nusselt number values by 81% however there is increase in friction factor by only 21.5% as compared to the smooth tube values.

(Shashank *et al*, 2013) Cu insert has a higher heat transfer enhancement of 1.58 times as compared to plane tube. Aluminum and stainless steel insert has heat transfer enhancement of 1.41 and 1.31as compared to plane tube respectively. The friction factor was found to be increasing with decreasing coil wire pitch. It was higher for aluminum insert of 5 mm pitch than stainless steel and copper coil wire insert of 10 and 15 mm pitch respectively. The above finding indicates that copper can be used as coil wire insert material for higher heat transfer enhancement than aluminum and stainless steel.

(Naga *et al* 2013) Experimental investigated using five kinds (900, 600FW, 600 BW, 300 FW, and 300 BW) of louvered square leaf inserts were carried out to estimate the enhancement of heat transfer rate for air in the presence of insert. Nusselt number and pressure drop increased, overall enhancement ratio is calculated to determine the optimum geometry of tube insert.

(Murugesan *et al* 2011) Experimental investigated of heat transfer and friction in a tube fitted with plain twisted tape (PPT) and U – cut twisted tapes with twist ratios 2,4.4,6. Geometries of twisted tape with twist ratios width (W) and depth (de) is 8and 8mm.

(Amol *et al* 2014) Under turbulent condition, the increase in heat transfer rate is more than that under laminar flow condition. In this paper this literature is used for comparison with different pitch like 100,120,160 and twist ratio 4.insertion of such geometry may lead to enhance the fiction factor and pressure drop which increases the heat transfer characteristics.

(Eisma *et al* 2014) The Navier-stokes equation with energy equation was solved using the k-ε result show that turbulence model. The experimental result show that heat transfer and friction factor increased with decreasing twist ratio.

From above literature review, it is observed that the heat transfer and friction factor characteristics using various twisted tape inserts experimentally investigated. The notched twisted tape with air is used as working fluid is not reported yet. Creation of notched at different location may enhance the heat transfer rate by reduction in pressure drop. To study this possibility square notched twisted tape with single and double slot at different twist ratio, and Reynolds Number are analysed. The geometry with best possible results is finalized for further experimental analysis.

Methodology

Table 1. Details of Test Matrix

Inserts	Fixed parameter	Variable parameter
Plane tape	Length of test section	Tape pitch (y) (100,125,150)
Aluminum twisted tape	Inner and outer diameter of tube	Twist ratio (y/w) (4,5,6)
Aluminum square notched twisted tape	Width	Reynolds number (35000-45000)
Aluminum square notched twisted tape with single slot	Twisted tape thickness (δ)	
Aluminum square notched twisted tape with double slot		

3. Fluid flow plot analysis

The result of heat transfer enhancement in term of Nusselt number, with the use of square notched twisted tape, square notched twisted tape with single slot, square notched twisted tape with double slot in comparison with Plain tube and twisted tape insert. For computational fluid dynamics (CFD) simulation i.e. flow analysis constant flux condition is used (1044.32 W/m^2) and wall thickness is 1.5mm. Tube outside (do) and inside diameter (di): 38.1 and 35.1mm. The heater input (Q) is 125 W.

Specification of inserts

Working fluid: Air
Material: Aluminium
Width of twisted tape (W): 25mm
Pitch (Y): 100,125and150mm
Twist ratio (Y/W): 4, 5, and 6.
Length of insert (L): 1000mm
Thickness of insert (δ): 1.2mm

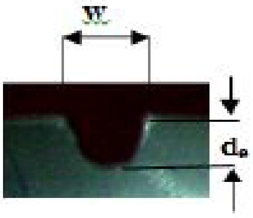

Fig.1. Geometry of square notched twisted tape slot

w= 8mm
de = 8mm

fig1. Shows the geometry of square notch twisted tape slot. The dimensions are shown in above.

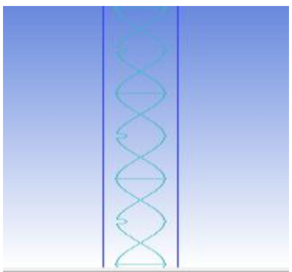

Fig.2. Geometry of square notched single slot twisted tape

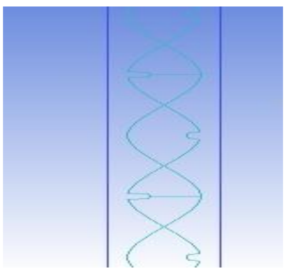

Fig.3. Geometry of square notched double slot twisted tape

For single and double square notch the dimensions are, w= 8mm and de = 8m

Heat transfer coefficient in case of double square notch twisted tape is higher than square notch single slot twisted tape for all pitch ratios with reduction in pressure drop because of development of secondary flow. Therefore double square notch geometry is considered for further study.

Fluid flow plots

In fig.4 a) shows fluid flow plots of pressure drop of plane tube. At the inlet pressure drop is more and at the outlet pressure drop is less. The pressure drop is 160 KPa.

Fig.4 b) shows velocity plot. At the inlet flowing the velocity more and outlet it is reduces.

a) Plane tube

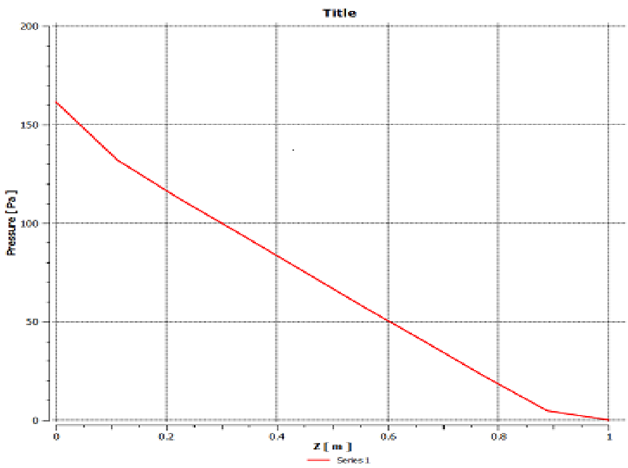

Fig.4.a) Plane tube pressure drop

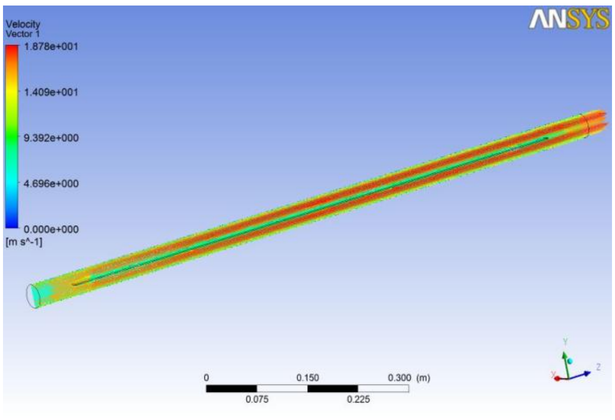

Fig. 4 b) Plane tube velocity flow

b) 100 pitch twisted tape

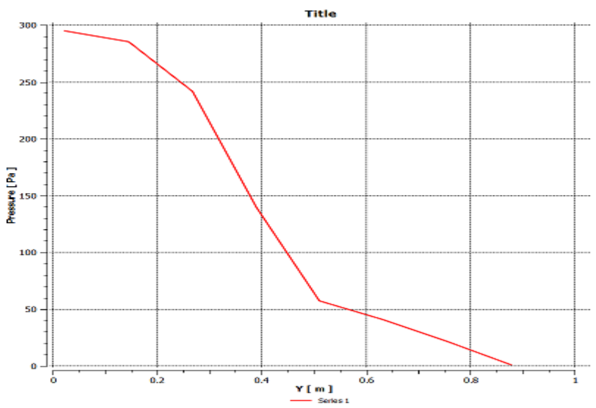

Fig.5. a) 100mm pitch square notched with twisted tape insert pressure drop

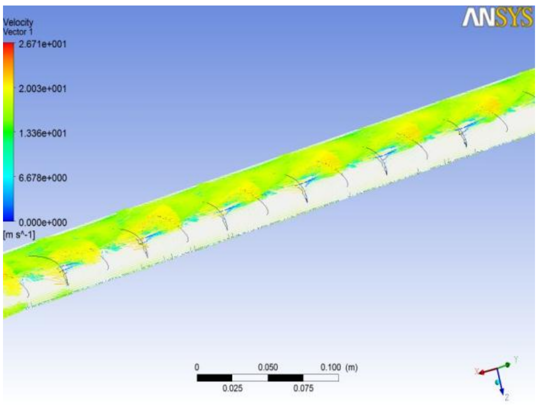

Fig.5 b) 100 pitches Square notched twisted tape velocity flow

In fig.5. a) Shows fluid flow plots of pressure drop of 100 Pitch Square notched twisted tape. At the inlet pressure drop is more and at the outlet pressure drop is less. The pressure drop is 295 KPa. Fig.5.b) shows velocity plot. At the inlet flowing the velocity more and outlet it is reduces. In fig. the velocity flow distribution is more on twisted tape. The heat transfer coefficient of square notch twisted tape is 50.12 W/m^{2}K and Nusselt number is 70.47.

i) 100mm pitch square notched with single slot twisted tape insert

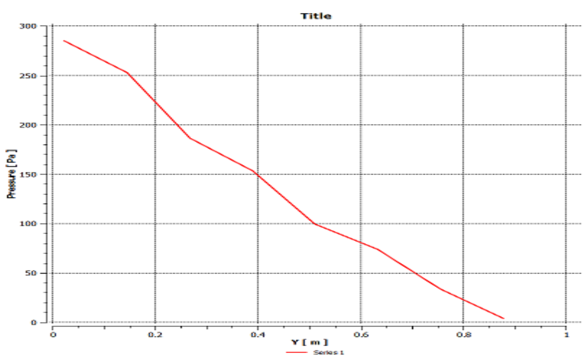

Fig.6. a) 100mm pitch square notched with single slot twisted tape insert pressure drop

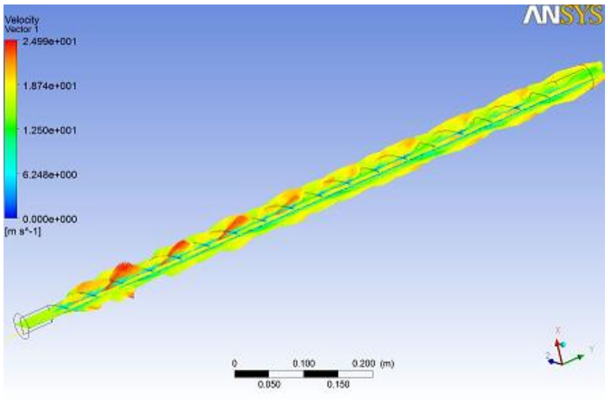

Fig. 6 b) 100mm Pitch Square notched twisted tape with single slot velocity flow

In Fig.6. a) Shows fluid flow plots of pressure drop of 100mm pitch single slot square notch twisted tape. At the inlet pressure drop is more and at the outlet pressure drop is less. The pressure drop is 270 KPa. The pressure drop is reduces as compared to 100 pitch square notch twisted tape. Fig.6.b) shows velocity plot. At the inlet flowing the velocity more and outlet it is reduces. In fig. the velocity flow distribution is more on twisted tape. The heat transfer coefficient of square notch twisted tape is 53.16 W/m^{2}K and Nusselt number is 74.23.

ii) 100 square notched twisted tape with double slot

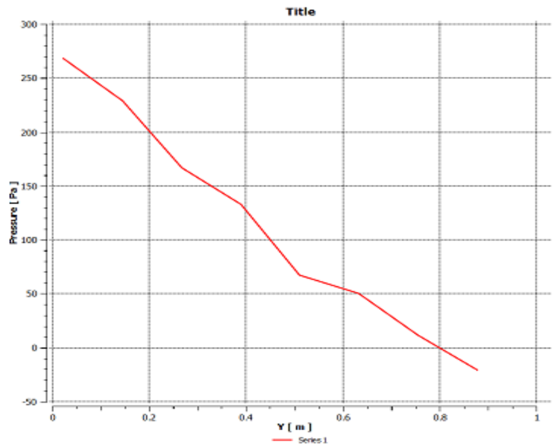

Fig.7.a) 100mm pitch square notched with double slot twisted tape insert pressure drop

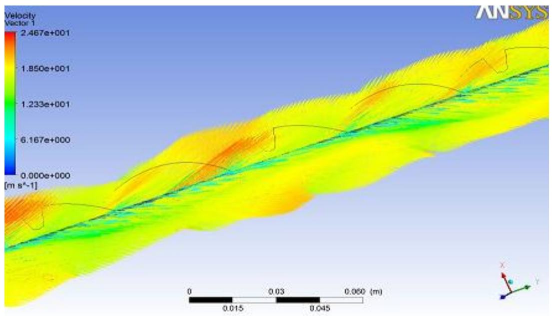

Fig.7.b) 100mm pitch square notched with double Slot twisted tape insert pressure drop

In Fig.7.a) shows fluid flow plots of pressure drop of 100mm pitch double slot square notch twisted tape. At the inlet pressure drop is more and at the outlet pressure drop is less. The pressure drop is 270 KPa. The pressure drop is reduces as compared to 100 pitch square notch twisted tape. Fig.7.b) shows velocity plot. At the inlet flowing the velocity more and outlet it is reduces. In fig. the velocity flow distribution is more on twisted tape. The heat transfer coefficient of double slot square notch twisted tape is 55.8 W/m²K and Nusselt number is 78.44.

c) 125 pitch twisted tape

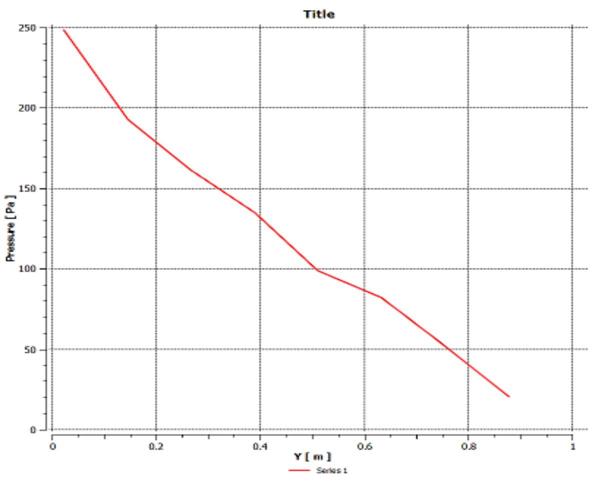

Fig.8.a) 125mm pitch square notched twisted tape insert pressure drop

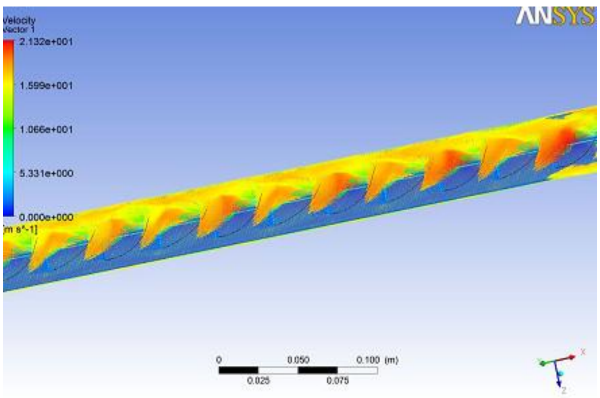

Fig.8 b) 125mm pitch square notched twisted tape inserts velocity flow

In fig.8 a) shows fluid flow plots of pressure drop of 125mm pitch square notched twisted tape. At the inlet pressure drop is more and at the outlet pressure drop is reduces. The pressure drop is 240 KPa. Fig.8 b) shows velocity plot. At the inlet flowing the velocity more and outlet it is reduces. In fig. the velocity flow distribution is more on twisted tape. The heat transfer coefficient of square notch twisted tape is 51.99 W/m²K and Nusselt number is 73.01.

i) 125 Square notched twisted tape with single slot

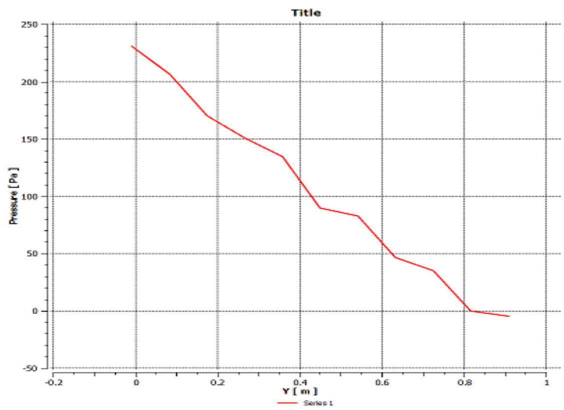

Fig.9.a) 125mm pitch square notched with single slot twisted tape insert pressure drop

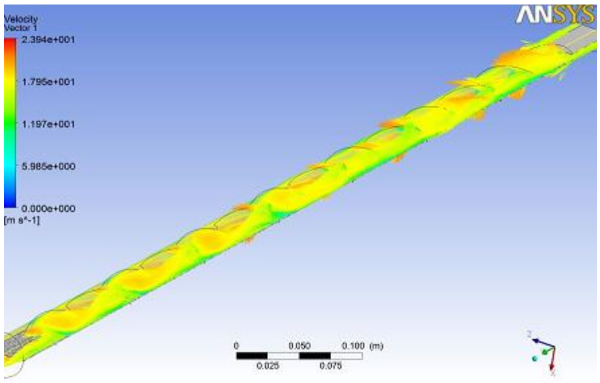

Fig.9 b) 125mm pitch square notched with single twisted tape inserts velocity flow

In fig.9. a) Shows fluid flow plots of pressure drop of 125mm single slot square notched twisted tape At the inlet pressure drop is more and at the outlet pressure drop is reduces. The pressure drop is 230 KPa. Fig.9.b) shows velocity plot. At the inlet flowing the velocity more and outlet it is reduces. In fig. the velocity flow distribution is more on twisted tape. The heat transfer coefficient of square notch twisted tape is 52.91 W/m²K and Nusselt number is 74.34.

ii) 125Square notched twisted tape with double slot

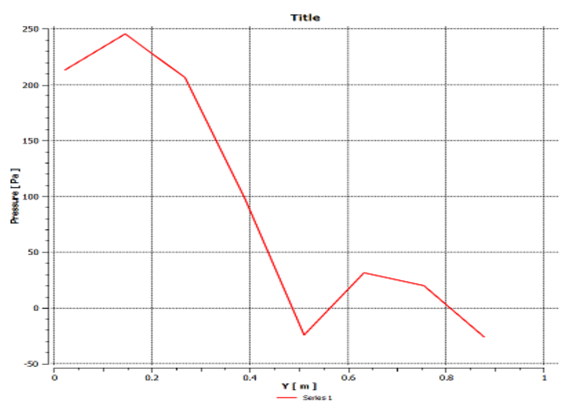

Fig.10.a) 125mm pitch square notched with double slot twisted tape insert pressure drop

From above graph it is clear that the pressure drop decreases with increasing pitch. But heat transfer coefficient increases. For double slot the heat transfer coefficient is greater compared to single slot square notch twisted tape.

Mathematical correlations for CFD simulation results

Heat transfer coefficient and pressure drop values are compared for plane tube, twisted tape, and square notched twisted tape with single and double slot. To calculated heat transfer coefficient, temperatures measured by thermocouples are used. Surface temperature and mean temperature is calculated based on thermocouples temperatures.

Velocity is calculated based on Reynolds number.

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

$$P_r = \frac{\mu C_p}{K} \quad (2)$$

$$Q = hA\,(T_s - T_{mf}) \quad (3)$$

Where,

$$A = \pi D_o L \quad (4)$$

Heat transfer coefficient is calculated using following,

$$h = \frac{Q}{A\Delta T} \quad (5)$$

Nusselt number is calculated using the correlation of Dittus – Boelter equation:

$$Nu = \frac{h\,D_h}{k} \quad (6)$$

Friction factor is calculated using following,

$$f = \frac{\Delta P}{\left[\frac{L}{d_o}\right]\left[\frac{\rho U^2}{2}\right]} \quad (7)$$

Pressure drop, heat transfer coefficient and Nusselt number results by CFD flow simulation

Table 2. CFD flow simulation results

	Pressure drop(ΔP) in KPa	Temp (ΔT) in K	Heat transfer coefficient (h) in W/m²K	Nusselt number (Nu)	fiction factor (f)
Plane tube	160	30.80	33.93	47.70	0.042
100 pitch	295	20.85	50.12	70.47	0.077
100 pitch with single slot	280	19.51	53.16	74.23	0.073
100 pitch with double slot	270	18.73	55.8	78.44	0.071
125 pitch plain twisted tape	240	20.1	51.99	73.01	0.063
125 pitch with single slot	230	19.75	52.91	74.34	0.063
125 pitch Double slot	220	18.36	56.9	80.2	0.058

4. Experimental set up

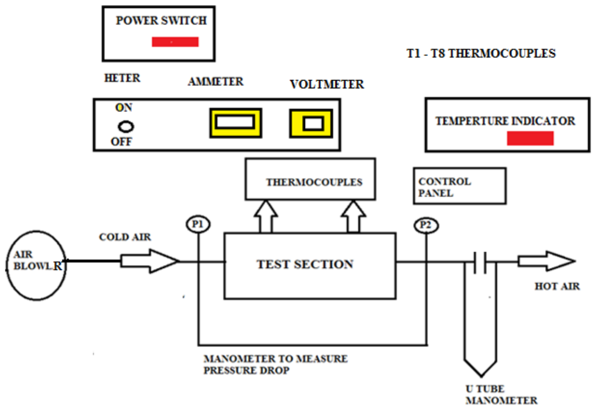

Fig.11. Block diagram of experimental set up

Fig.11 shows the block diagram of experimental set up. This experimental set up consist of air blower, control valve, cold and hot air, test section, thermocouples, control panel, U tube manometer, heater, ammeter, voltmeter. Air blower is fitted with a tube in horizontal orientation. It is connected to a smaller diameter, insulated and electrically heated copper test section of length inner diameter. Nichrome bend heater encloses the test section to cause electric heating. The control valve in the U-shaped pipe controls the airflow rate into the test section of experiment. Power input to the test tube heater is varied using a variable transformer, which is used to vary the voltage of the AC current passing through the heater and by keeping the current less than 2A. Other thermocouples are used to measure the temperatures at various points along the test section wall. The outer surface of the test section is insulated to minimize convective heat loss to the surroundings. Pressure taping is at each end of the test section connect to another U tube manometer to measure the pressure drop across the test section.

5. Sample calculation

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

$$Q = \dot{m} c_p\,\Delta T \quad (8)$$

Heat transfer coefficient was calculated from,

$$h = \frac{q}{(T_{wi} - T_b})} \quad (9)$$

Bulk temperature is given by;

$$T_b = \frac{T_i + T_o}{2} \quad (10)$$

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

$$T_{wo} = \sum_{ki=1=0}^{n=5} \frac{T_{w0,i}}{6} \quad (11)$$

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

$$T_{wi} = T_{wo} - Q \frac{\ln\frac{d_0}{d_i}}{2\pi k_{wL}} \quad (12)$$

Reynolds number was calculated from;

$$Re = \frac{4\dot{m}}{\pi d_i \mu} \quad (13)$$

Nusselt number was calculated from,

$$N_u = \frac{hd_i}{k} \quad (14)$$

Heat transfer enhancement efficiency was calculated from,

$$\eta = \frac{h_e}{h_s} \quad (15)$$

Thus, after calculating the heat transfer coefficient, friction factor and pressure drop characteristics of fluid flow and comparing it with each other we will be able to find out the best possible method of creating turbulence in a fluid flow thereby increasing heat transfer rate in the tube (AI Amin 2013) [10].

Conclusion

1) For 100 pitch (125 pitch also) double square notch twisted tape the heat transfer coefficient is higher than 100 pitch single square notch twisted tape.
2) For 100 pitch (125 pitch also) double square notch twisted tape the friction factor reduces as compared to 100 pitch single square notch twisted tape. Therefore this geometry is finalized.
3) Heat transfer coefficient enhanced about 32.31%, 39.2% using square notched twisted tape insert for 100and 125 mm pitch as compared to plane tube.
4] As Reynolds Number increases the Nusselt Number also increase.

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