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HEAT TRANSFER ENHANCEMENT USING OVERLAPPED DUAL TWISTED TAPE INSERTS WITH NANO FLUIDS

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The thermal performance of a heat exchanger can be improved by various techniques. It is a major concern when coming to industries as the heat losses play a major role in efficiency of the overall plant. The present work is carried out to enhance the heat transfer rate of a tubular heat exchanger by incorporating overlapped dual twisted tapes (ODTT) or inserts into a tube and carrying out the experiment for different twisting ratios of ODTT's. In addition to this Al_2O_3 nano particles are used as additives to increase the value of heat transfer coefficient(h) thereby improving the Nusselt number(Nu) and overall thermal performance. The addition of ODTT's resulted in improved residence time, more contact surface area and improved fluid mixing and swirling for effective heat transfer to take place. The experiment is repeated for nanofluid concentrations of 1% and 2% and also for varying twisting ratios of Yo/Y = 1.5, 2 and 2.5. The tube with 1% nanofluid concentration and twisting ratio Yo/Y=2 yielded better results in comparison with all other combinations.

***Keywords*:** Overlapped dual twisted tapes (ODTT), Al_2O_3 nano particles, Nanofluids

1. Introduction

Heat transfer enhancement techniques plays a vital role in various engineering applications such as nuclear reactor, chemical reactor, automotive cooling systems, refrigeration etc. HTE techniques can be classified into 2 categories (i) Active method : by supplying external power source to the fluid or the equipment; (2) Passive method : by turbulence promoter (such as special surface geometries, twisted tape, propeller, tangential inlet nozzle, spiral fin etc) or fluid additives (such as nano fluid). With respect to cost, operation and installation passive method has drawn great attention.

Among all devices of passive methods, swirl flow devices produce secondary recirculation on the axial flow leading to an increase of tangential and radial turbulent fluctuations , that leads to greater mixing of fluid inside a heat exchanger tube and subsequently reduces a thickness of the boundary layer. Twisted tapes are generally equipped along the core tube to generate swirl causing the fluid transfer between core tube and near wall tube. Which initiates several mechanisms for heat transfer augmentation by improving flow velocities caused by partial blockage of the tube flow, which directs toward reducing the hydrodynamic or thermal boundary layer thickness. The geometries of twisted tapes have significant influences on fluid mixing and heat transfer rate. More pumping power is required when twisted tapes are equipped inside the tube. Therefore economic consideration has to be taken into account by using twisted tape with a proper geometry.

Since Whitham et al. [1] reported the success of using twisted tapes in improving heat transfer in heat exchanger, heat transfer enhancement using the devices have been extensively studied.

Rahimi et al. [2] numerically evaluated heat transfer enhancement by modified twisted tapes including jagged perforated and notch twisted tapes.

Sivashanmugam et al.[3,4] showed that right-left helical screw inserts exhibited a superior heat transfer enhancement to straight helical twist.

Nagarajan et al.[4,5]reported that the geometries of left-right twisted tapes played an important role in governing heat transfer , friction factor and thermal performance.

Eiamsa-ard et al.[6]investigated the effect of coupling twisted tapes on heat transfer enhancement in a heat exchanger.

Change et al.[7] examined the heat transfer and pressure drop characteristics in a tube fitted single, twin and triple twisted tapes in a heat exchanger.

As nano technology has emerged, nano fluid which is the suspension of nanometer-sized particles or nano particles such as TiO_2, Al_2O_3 and CuO are currently attractive for using in heat transfer systems as alternative medium due to their greater thermal conductivities as compared to that of base fluids. In general, nanofluid with higher particle loading gave higher heat transfer rate and friction loss. With proper particle loading, most nanofluid yielded appreciable heat transfer enhancement with insignificant friction loss. Heat transfer enhancement by using twisted tape together with nanofluid is a promising approach.

Eiamsa-ard et al.[8] reported the effect of the regularly spaced dual twisted tape inserts at three different space ratios on the pressure drop and heat transfer behaviours.

Zhang et al [9] studied the heat transfer enhancement by triple and quadruple twisted tapes with induced multi-longitudinal vortices in a tube.

2. Modelling and Analysis

Overlapped dual twisted tapes were incorporated in a 19 mm diameter pipe as shown in fig 1. The tube with ODTT is then subjected to multiple flow circulations with water as a standard heat transfer medium and then adding 1% and 2% of Al_2O_3 nano particles by volume. The design is done using NX 11.0 (Unigraphics).

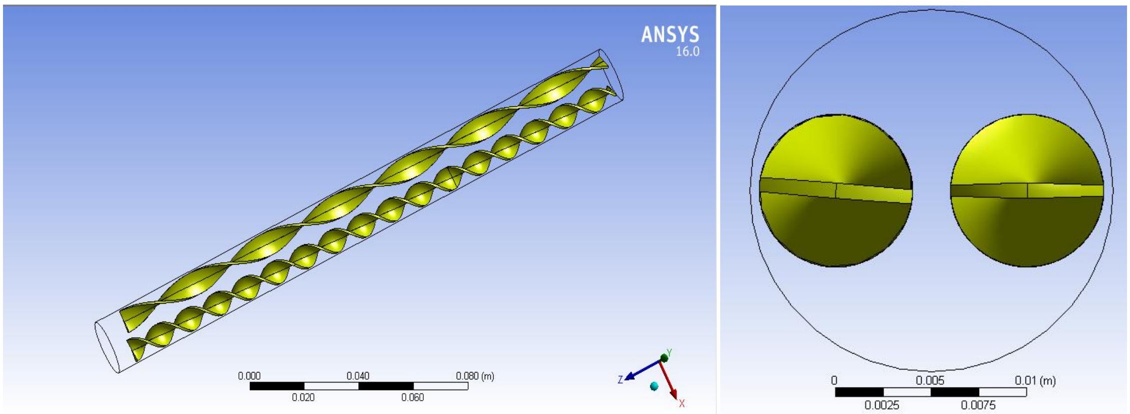


Fig 1: Tube with Overlapped Dual Twisted Tapes (ODTT)

The geometry or tube with ODTT is imported and meshed using CFX pre-processor. The mesh domain with type of elements used is shown in Fig 2. Other mesh preferences are mentioned below.

Physics Preference	- CFD
Solver Preference	- CFX
No. of Nodes	- 16415
No. of Elements	- 80033
Mesh type	- Tetra Mesh
Growth rate	- 1.2

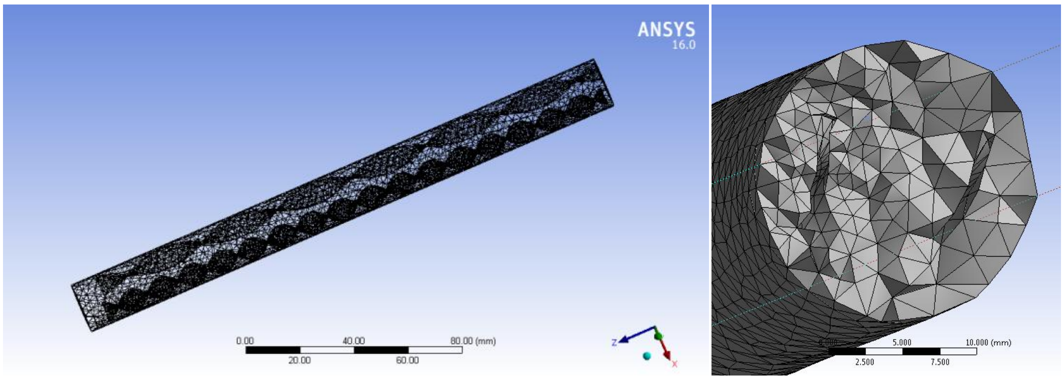


Fig 2: Meshed Domain and cut section showing tetra elements

The domain is then setup with boundary conditions in CFX solver. Some of the assumptions while assigning boundary conditions include smooth and no slip wall along with negligible back pressure. The inlet velocity is considered as 0.15m/s and domain settings are taken as mentioned.

Fluid Definition	- Material Library (Al_2O_3)
Morphology	- Continuous Fluid
Buoyancy Model	- Non Buoyant
Domain Motion	- Stationary
Reference Pressure	- 1.0000e+00 [atm]
Heat Transfer Model	- Total Energy
Turbulence Model	- k epsilon
Turbulent Wall Function	- Scalable

3. Methodology

The experiment is carried out for different Yo/Y twisting ratios of ODTT's.

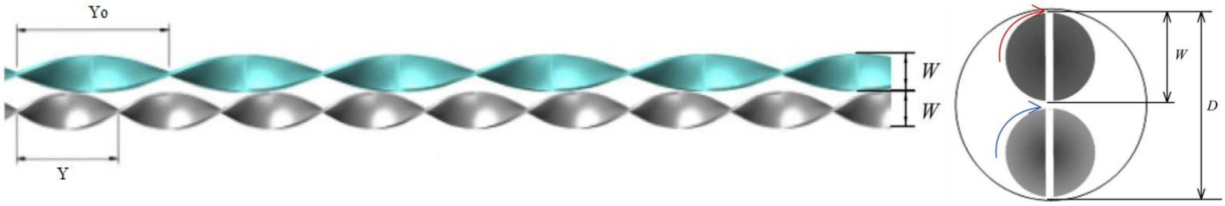


Fig 3: Overlapped dual twisted tapes (ODTT's) and its nomenclature

The ODTT twisting ratios (Yo/Y) considered are 1.5, 2.0 and 2.5 based on literature studies.

The details of the inputs and experimental conditions are mentioned below.

Inner diameter of the tube (D)	- 19 mm
Length of the tube (L)	- 1000 mm
Wall Condition	- Constant heat flux
Temperature at inlet (T_i)	- 26^0C
Base fluid	- Water
Reynolds no.	- 5400 - 15200
Nano particles	- Al_2O_3
Concentration of nano particles	- 1% and 2% by Volume
Density of nano particles	- 1007.4 Kg/m^3
Specific heat of nano particles	- 4154.7 J/KgK

The equations used to carryout theoretical calculations are discussed here.

Density of nanofluid	$\rho_{nf} = (1-\varphi)\rho_w + \varphi\rho_{np}$
Specific heat of nanofluid	$Cp_{nf} = \frac{\varphi\rho_{np}Cp_{np} + (1-\varphi)\rho_w Cp_w}{\rho_{nf}}$
Heat transfer rate of working nanofluid	$Q_f = mc_p(T_o - T_i)$
Average heat transfer coefficient	$h = mc_p(T_o - T_i)/A(T_w - T_b)$
Nusselt number	$Nu = hD/k$
Reynolds number	$Re = \rho UD/\mu$

where

φ	- Concentration of nanofluid
Cp_{np}	- Specific heat of nano particles
ρ_{np}	- Density of nano particles
ρ_w	- Density of water
A	- Inlet cross section area
k	- Thermal conductivity of nano fluid

m - Mass of nanofluid
C_p - Specific heat of nanofluid
T_o,T_i,T_w,T_b - Temperatures at outlet, inlet, wall and average fluid bulk temperature respectively.

4. Results and Discussions

The experiment is carried out using water and then adding 1% and 2% of nano particles to fluid by volume. Again the experiment is repeated for different Yo/Y twisting ratios of ODTT's incorporated in the tube. The results so obtained for different twisting ratios with different fluid concentrations are tabulated in tables 1, 2 and 3.

Table 1: Variation of h, Nu and Pd for Yo/Y=1.5

Yo/Y =1.5 (Water)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1440.5	42.56531882	34.1
8175	1678.36	49.59384137	47.79
9554	1924.74	56.87412131	64.03
10935	2183.92	64.5326283	82.54
12316	2489.04	73.54861586	103.19
14620	3014.78	89.0837014	143.51
16002	3336.54	98.59138414	170.98

Yo/Y =1.5 (1% Nano Fluid)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1901.1	54.64583964	32.84
8175	2297.9	66.0515885	46.54
9554	2733.48	78.57204236	62.74
10935	3179.19	91.38367625	81.43
12316	3631.2	104.3763994	102.63
14620	4391.9	126.2422088	143.48
16002	4851	139.4387292	171.26

Yo/Y =1.5 (2% Nano Fluid)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1951.06	54.51491176	33.69
8175	2359.04	65.91435294	47.48
9554	2806.15	78.40713235	64.37
10935	3263.7	91.19161765	83.54
12316	3727.7	104.1563235	105.29
14620	4508.59	125.9753088	147.22
16002	4979.82	139.1420294	175.7

Table 2: Variation of h, Nu and Pd for Yo/Y=2

Yo/Y =2 (Water)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1379.7	40.76874028	27.62
8175	1679.25	49.62013997	38.86
9554	1996.12	58.98332815	52.08
10935	2319.87	68.54981337	67.27
12316	2647.85	78.24129082	84.5
14620	3197.3	94.47698289	117.65
16002	3526.94	104.2175117	140.22

Yo/Y =2 (1% Nano Fluid)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1991.37	57.24059002	26.73
8175	2444.48	70.26493192	37.99
9554	2901.8	83.41028744	51.28
10935	3359.45	96.56512859	66.6
12316	3815.32	109.6688048	83.93
14620	4569.11	131.3359909	117.21
16002	5017.17	144.215174	139.76

Yo/Y =2 (2% Nano Fluid)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	2044.3	57.12014706	27.42
8175	2509.42	70.11614706	38.98
9554	2978.9	83.23397059	52.61
10935	3448.54	96.35626471	68.33
12316	3916.41	109.4291029	86.11
14620	4689.99	131.0438382	120.26
16002	5149.81	143.89175	143.38

Table 3: Variation of h, Nu and Pd for Yo/Y=2.5

Yo/Y =2.5 (Water)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1099.07	32.47640747	26.38
8175	1295.82	38.29017107	35.89
9554	1497.69	44.25522551	50.11
10935	1704.29	50.36004666	64.25
12316	1914.8	56.58040435	82.57
14620	2272.68	67.15539658	114.58
16002	2490.28	73.58525661	137.58

Yo/Y =2.5 (1% Nano Fluid)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1482.14	42.60311649	25.48
8175	1772.04	50.93609682	36.87
9554	2068.85	59.46770045	49.58
10935	2370.12	68.12750378	64.68
12316	2673.57	76.84996974	81.25
14620	3178.84	91.37361573	115.24
16002	3479.3	100.0101362	138.58

Yo/Y =2.5 (2% Nano Fluid)			
Reynolds number	Htc	Nusselt Number	Pressure drop
6798	1521.17	42.50327941	25.58
8175	1818.78	50.81885294	36.58
9554	2123.47	59.33225	50.28
10935	2432.72	67.97305882	66.54
12316	2744.17	76.67533824	84.54
14620	3262.28	91.15194118	118.58
16002	3570.97	99.77710294	142.2

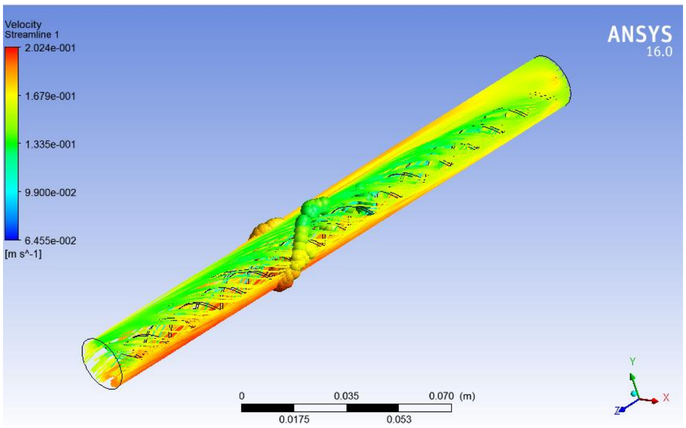
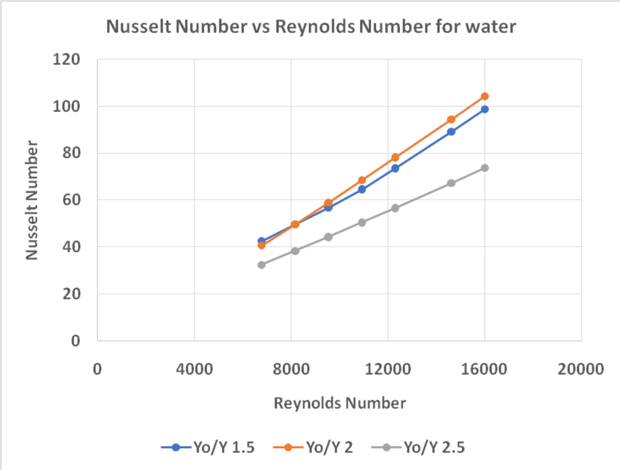
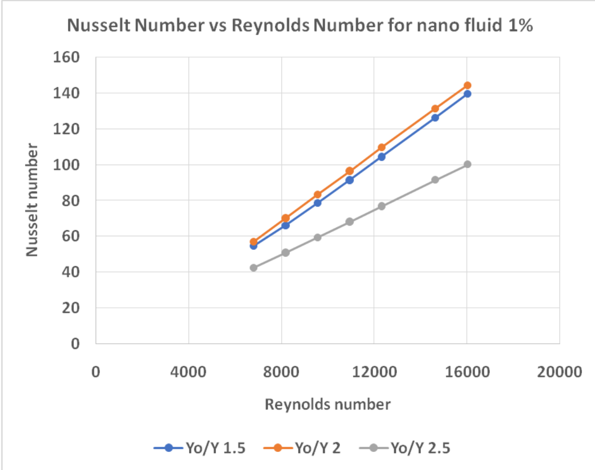


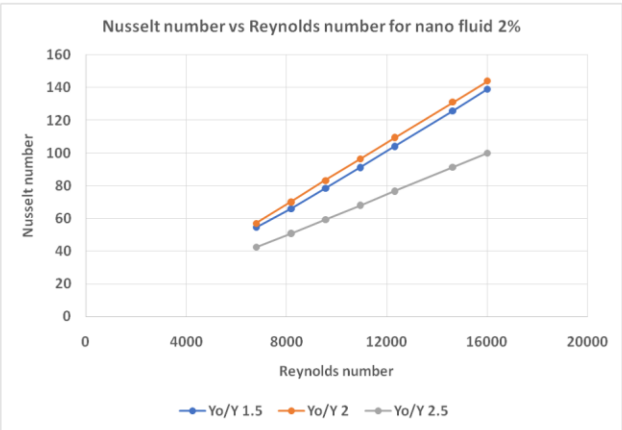
Fig 4: The velocity streamlines showing the effect of ODTT inserts in test tube

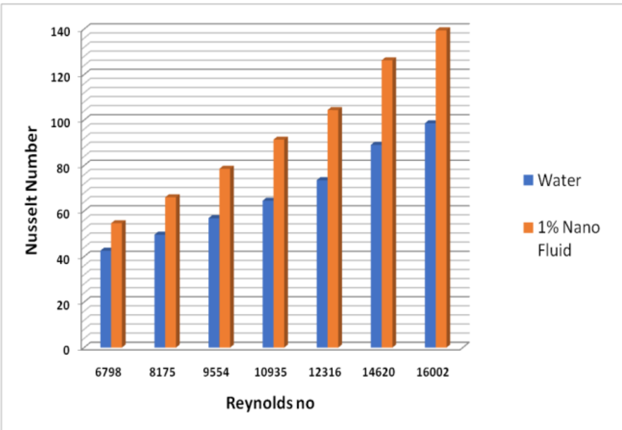
The tables 1, 2 and 3 show the variation of heat transfer coefficient (h), Nusselt number (Nu) and pressure drop (p) for varying reynolds numbers (Re) in the range of 5400 to 15,200. The corresponding results are plotted in figures 5, 6 and 7. A comparison has been made by varying twisting ratios and concentration of nanofluid which are discussed in subsequent section.





(a) Water **(b) 1% Nanofluid**





(c) 2% Nanofluid **(d) 1% Nanofluid vs water**

Fig 5: Nusselt number vs Reynolds number for varying twisting ratios(Yo/Y)

From the plots shown in fig 5, it is observed that among all the twisting ratios, Yo/Y= 2 yielded better results and further raise in twisting ratio resulted in drop of thermal performance of the tube. In addition to that, the nusselt number has shown a significant raise for increase in nanofluid concentration upto 1% thereafter which the performance declined. It is also observed that the thermal performance when tested for water exhibited better performance in the absence of nano particles at low reynolds numbers ranging in between 6000 to 8500. For all the other twisting ratios and concentrations, the nanofluid with 1% concentration and twisting ratio of Yo/Y = 2 gave best results.

5. Conclusion

The influence of multiple twisted tapes with a ODTT arrangement and Al_2O_3 nano particles in water as a working fluid on heat transfer enhancement are described in this study.

1. Nusselt number has increased significantly as a number of tapes increased.
3. The addition of Al_2O_3 nanoparticles in water resulted in improved thermal performance.
4. Over the ranges of Reynolds number 5400-15200 Nusselt number(Nu) in tubes with 1% nanofluid is higher than that of plain tube. Further increase in concentration resulted in performance decline.
5. The twisting ratio of Yo/Y=2 yielded better results in comparison with 1 and 1.5.

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