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Effect of Twisted Tape Insert on Heat Transfer Enhancement in Counter Flow Co-Axial Double Pipe Heat Exchanger using CFD

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ABSTRACT

The twisted tape has great potential as a device for enhancing heat transfer. Twisted tapes hold the advantage over other techniques as they ease of installation and operation. From the previous studies, it is also found that there were rare researches on a combination of twisted tape insert and nanofluids. Therefore, the scope of the present study is concerned with the enhancement of the double pipe heat exchanger performance through twisted tape insert. To achieve these aims, a numerical model was constructed in order to investigate the effect of twisted tape on the heat transfer coefficient. This study investigates the heat transfer characteristics of Counter flow co-axial double pipe heat exchanger using Al_2O_3/water nanofluids by inserting twisted tape turbulator of pitch 25mm inside the inner tube. The Al_2O_3/water nanofluids 0.4-1.6 % particle volume concentrations were used. The simulation were conducted under the turbulent flow in the Reynold's number range of $4000 < Re < 20000$. It is found that from the computational outcomes, the heat exchanger with twisted tape insert unveiled the best Nusselt number of 487.24 at Re=20,000 at 1.6 vol. % of nanoparticle. By comparison, the Nusselt number of double pipe heat exchanger with twisted tape insert is 8.27 % higher than with wire coil insert.

KEYWORDS: *Heat Exchanger; Passive Techniques; Turbulators; Twisted Tape insert; Nano-fluid; and Computational fluid dynamics*

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I. INTRODUCTION

In different processes from industrial, commercial and domestic applications heat exchangers are applied. The heating or cooling of the fluid flow is a standard procedure. Additional uses can be heat recovery or rejection. The good performance of the heat exchanger will contribute to the efficient design and cost savings of the heat exchanger. Heat exchanger is the heat transfer device that can be defined by fluid movement mode or design methods between two or more fluids. For certain engineering applications, heat exchangers for the convective heat transfer of fluid inside the tubes are also utilized. Improving the intensity of heat transfer in all forms of technological thermal equipment is of immense importance to industry. In addition to primary energy conservation, it often contributes to size and weight reduction. In order to improve thermal performance, several techniques such as heat transfer augmentation / enhancement are used. Some of the leading techniques used in passive heat transfer methods primarily at turbulence flow is twisted tape inserts. Twisted tape is one of the most important strengthening methods used in heat exchangers for heat transfer enhancement.

Enhancement of heat transfer using various techniques has received strong attention over the years in order to reduce the size and cost of heat exchanger. Many techniques have been developed for enhancing heat transfer rate in heat exchanger as the effective ones:

1. Nanofluids
2. Inserting fluid turbulators
3. Roughening heat exchanger surfaces.

Although for better heat transfer, combination of all the three or any two techniques can be used.

1.1. Turbulators

Turbulator is an ideal device for efficient heat transfer optimization. This consists of various metal wire such as carbon steel, stainless steel, chromium-nickel alloy, copper, brass, and aluminum. The system is inserted into the tube side of industrial boiler, heat transfer shell & tube, and other forms of heat transfer devices. It is designed to maintain turbulent flow and helps improve the efficiency of heat transfer by increasing the surface area of the flow of substances.These are commonly used in manufacturing, engineering, construction, petrochemical, refining, power and gas compression applications and so on in air-cooled heat transfer and cooling towers.

There are mainly five type's turbulator:
- Spring turbulator.
- Soldered turbulator.

- Twisted turbulator.
- Hollow rod turbulator.
- Flexible turbulator.

1.2. Twisted Tape insert devices

Twisted-tape inserts are very popular among the swirl flow devices that are used to create swirl or secondary flow due to their good thermal performance in a medium such as single and two phase flow, boiling and condensation, which are proper to design and application problems.

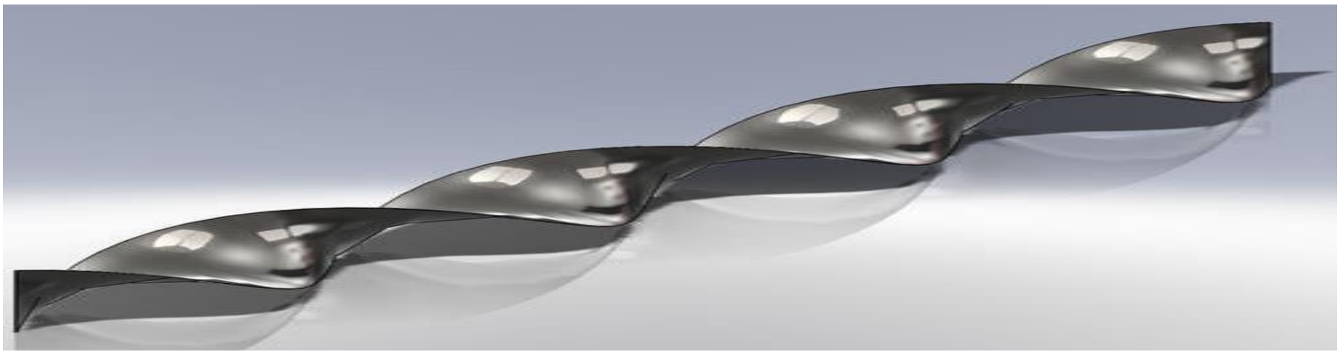

Figure 1. Typical configuration of TT.

TT inserts increase the coefficients of heat transfer with pressure drop rise. These are commonly used over decades because of the nature and application simplicity to produce the swirl flow in the fluid. The size of the new heat exchanger can be greatly reduced by using TTs for a specified heat charge in the new heat exchanger. And it offers a competitive benefit over the equipment's fixed costs. Another advantage of TTs is its fast development and implementation which is substantial compared to other generators of swirl flows.

1.3. Nanofluids

The single phase heat transfer fluids such as water, engine oil, ethylene glycol, propylene glycol and transformer oil are mainly used in process industries, chemical and thermal power plants. The heat transfer performance of single phase heat transfer fluids, in general, is very poor due to the low values of their thermal conductivity. The heat transfer intensification is very important to achieve significant energy and cost savings. Therefore, one possible route is increase the thermal conductivity of the working fluids. As it is well-known, solid materials possess higher thermal conductivity when compared to single phase fluids. The addition of solid particles to the single phase fluids technique observed enhanced thermal conductivity values. However, the simple dispersion of solid particles in single phase fluids leads to their sedimentation and consequent clogging of the flow passages; moreover, the particles cause erosion on the flow passage walls, while increasing the pressure drop across the installations.

Later on, dispersed micrometer size solid particles in single phase fluids and observed thermal conductivity enhancement, but also faced particle sedimentation in the base fluid, which reduces the enhancement in thermal conductivity. In 1995, Choi prepared nanofluids (fluids containing nanometer size solid particles) and observed marked enhancement of thermal conductivity. The dispersion of nanometer size particles in single phase fluids presents higher specific surface area than conventional colloidal suspensions and is more stable than conventional slurries

Nanofluids are a novel class of heat transfer suspensions of metallic or nonmetallic nanopowder with a size of less than 100 nm in base fluids and they can increase heat transfer potential of the base fluids in various applications. In the last decade, nanofluids have become an intensive research topic because of their improved thermal properties and possible heat transfer applications.

II. LITERATURE REVIEW

A considerable amount of experimental as well as analytical and computational research has been carried out on the enhancement of heat transfer. In this chapter, a brief survey of the relevant literature is presented to indicate the extent of work already reported in open literature pertaining to the enhancement of heat transfer by various turbulators in the heat exchanger.

Naphon et al. (2006) experimentally studied the heat transfer and pressure drop characteristics in horizontal double pipes with helical ribs. Their results showed that the helical ribs have a significant effect on the heat transfer and pressure drop augmentations. The pressure drop across the tube with helical rib is produced by: drag forces exerted on the flow field by the helical rib, flow blockage due to area reduction, turbulence augmentation and rotational flow produced by the helical rib.

Salimpour (2008) performed an experimental investigation in order to study the heat transfer characteristics of temperature dependent-property engine-oil inside shell and coiled tube heat exchangers. They found that the coil-side heat transfer coefficients of the coiled tubes with larger pitches are less than those of the ones with smaller pitches; and the effect of pitch on Nusselt number is more discernible in high temperatures.

Promvonge (2009) studied the effects of wires with square cross section forming a coil used as a turbulator on the heat transfer and turbulent flow friction characteristics in a uniform heat flux. Their experimental results revealed that the use of coiled square wire turbulators leads to a considerable increase in heat transfer and friction loss over those of a smooth wall tube.

Eiamsa-ard et al. (2012) studied the heat transfer enhancement attributed to helically twisted tapes (HTTs). They observed that heat transfer rate and friction factor increase as the tape twist ratio and helical pitch ratio decrease.

Mohammadi and Sabzpooshani (2013) studied single pass solar air heater with fins and baffles attached over the absorber plate. They showed that attaching fins and baffles leads to noticeable increase in the outlet air temperature, useful energy gain and efficiency in comparison with the simple air heater. With increasing the mass flow rate, the rate of enhancement of outlet temperature reduces sharply.

Heat transfer in counter flow heat exchangers with helical turbulators studied by **Zaman khan (2014),** His results demonstrated that the model could be used as a useful tool for optimization of heat exchanger performance in the presence of a turbulator. Comparisons with experimental data showed reasonably agreement with large eddy simulation results.

Akpinar (2015) studied the effects of mounting helical (spring shaped) wires on heat transfer, friction factor and dimensionless exergy loss in a double pipe heat exchanger. He observed that heat transfer rates increased with decreasing pitch and with increasing helical number of the helical wires used in the experiments. The heat transfer rates in this heat exchanger increased up to 2.64 times with the help of the helical wires.

Gunes et al. (2016) investigated the heat transfer and pressure drop in a coiled wire inserted tube in turbulent flow regime. Their experimental results revealed that the best operating regime of all coiled wire inserts is detected at low Reynolds number, leading to more compact heat exchanger.

The heat transfer enhancement by using coiled wire inserts during forced convection condensation of R-22 inside a horizontal tube was experimentally investigated by **Agrawal et al. (2017).** They found that the use of helically coiled wires were found to increase the condensing heat transfer coefficients by as much as 100% above the plain tube values on a nominal area basis.

Kongkaitpaiboon et al. (2017) used perforated conical ring (PCR) as turbulator devices for enhancing the heat transfer rate in a heat exchanger system. They found that the heat transfer rate and friction factor of PCRs increase with decreasing pitch ratio (PR) and decreasing number of perforated hole (N). However, the thermal performance factor increases with increasing number of perforated whole and decreasing pitch ratio.

Durmus et al. (2018) used snail entrance in order to increase heat transfer in concentric double pipe heat exchangers. They concluded that the swirl flow effect of the snail caused some increase in pressure drop while this effect was unimportant compared with the improvement in heat transfer capacity.

The influences of circular-ring turbulators (CRT) and twisted tape (TT) swirl generators on the heat transfer enhancement, pressure drop and thermal performance factor characteristics in a round tube were reported by **Eiamsa-ard et al. (2018)** .They found that the increases of mean Nusselt number, friction factor and thermal performance, in the tube equipped with combined devices, respectively, are 25.8%, 82.8% and 6.3% over those in the tube with the CRT alone.

Akansu (2018), studied heat transfers and pressure drops for porous-ring turbulators in a circular pipe. He found that the recirculation regions are larger at higher blockage ratio. Blockage ratio and Nusselt number increments were not proportional.

Akyürek et al. (2018), experimentally investigated the effects of Al2O3/Water nanofluids at various concentrations in a concentric tube heat exchanger having a turbulator inside the inner tube. Comparisons were done with and without nanofluid in the system as well as with and without turbulators in the system. Results were drawn and a number of heat transfer parameters were calculated on the basis of observed results. Various heat characteristics such as change in Nusselt number and viscosity with respect to Reynolds number, behavior of nanofluid at various volume concentrations, changes in heat transfer coefficient, effect of the difference of pitch of turbulators on the heat transfer of nanofluid etc. were studied. They concluded that there exists a relationship between the varying pitches and the turbulence in the flow caused i.e. when the pitch is less there is more turbulence and vice versa.

In this present study the objective is to evaluate the following aspects using ANSYS 17.0 simulation. The main objectives of the dissertation are as follows:

- To study heat transfer characteristics of the double pipe heat exchanger with and without twisted tape insert.
- To develop model of double pipe heat exchanger with twisted tape insert.
- Validation will be carried on CFD model with comparison of previous model.
- Compare the heat transfer rate, Nusselt number and overall heat transfer coefficient with respect to without insert.

III. CALCULATION INVOLVED

The data reduction of the measured results is summarized in the following procedures:

The Reynolds number is given by,

$$Re = \frac{\rho V D}{\mu}$$

The mass flow rate is calculate on the basis of below formula,

$$\dot{m} = \rho A V$$

Where, ρ is the density of fluid, A is the cross sectional area of the pipe and V is the velocity of fluid.

Therefore, for fluid flows in a concentric tube heat exchanger, the heat transfer rate of the hot fluid in the inner tube can be expressed as:

$$q_h = \dot{m}_h c_{ph}(T_{hi} - T_{ho})$$

Where $\dot{m}_h$ is the mass flow rate of hot fluid, c_{ph} is the specific heat of hot fluid, T_{hi} and T_{ho} are the inlet and outlet temperatures of hot fluid, respectively.

While, the heat transfer rate of the cold fluid in the outer tube can be expressed as:

$$q_c = \dot{m}_c c_{pc}(T_{co} - T_{ci})$$

Average heat transfer rate is given by:

$$Q_{avg} = \frac{q_h + q_c}{2} = UA\theta_m$$

Where, $\theta_m = \frac{\theta_1 - \theta_2}{2}$

θ_m is the logarithmic mean temperature difference.

U is the overall heat transfer coefficient.

Calculation of Nusselt Number,

$$Nu = \frac{\frac{f}{2}(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{2}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}$$

Where, $f = [1.58\, ln(Re) - 3.82]^{-2}$

$$Pr = \frac{\mu c_p}{K}$$

$f \rightarrow friction\ factor$
$Nu \rightarrow\ Nusselt\ number$
$Pr \rightarrow Prandtl\ number$

IV. Geometry Setup and Modelling

In this study, a solid model of a double pipe heat exchanger is built on the basis of a heat exchanger used for the experimental research conducted by **Akyürek et.al. (2018).** The physical model consists of a Counter flow co-axial double pipe heat exchanger. The inner pipe through which nanofluid flows was made from Aluminium. The inner diameter of the Aluminium tube is 12 mm and wall thickness is 2 mm and an outer tube of having 33 mm internal diameter is made of polyethylene. The total length of the test section is 1300 mm. Here in this work we have performed the numerical analysis of double pipe heat exchanger having twisted tape turbulator inside the inner tube. Here in this work, twisted tape turbulator which have 25 mm pitch and the length of 1300 mm was introduced inside the inner tube in the double pipe heat exchanger in order to investigate the effect on heat transfer characteristics.

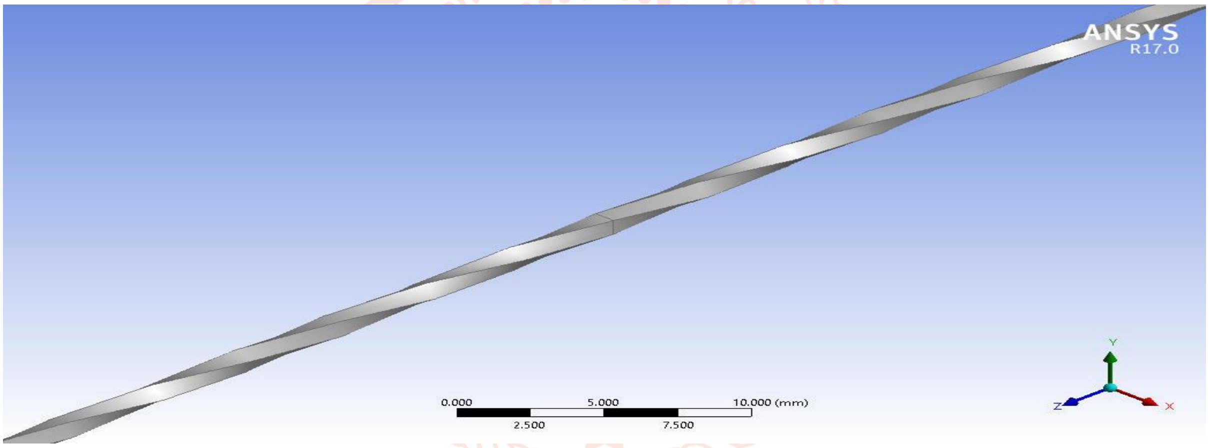

Figure 2. Geometry of twisted tape insert.

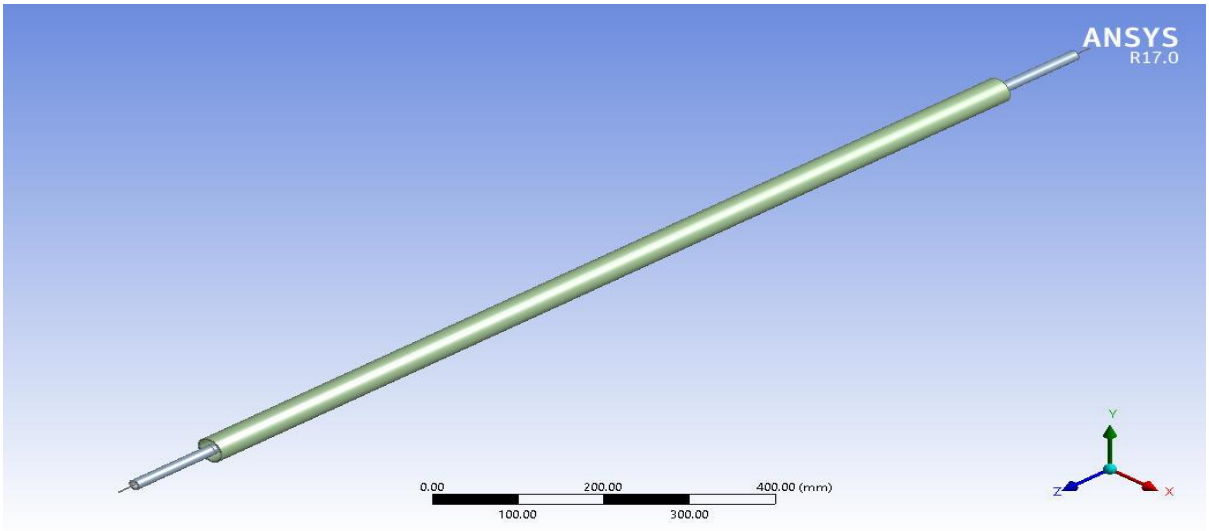

Figure 3. Geometry of double pipe heat exchanger with twisted tape turbulator.

After completing the geometry of a Counter flow co-axial double pipe heat exchanger with twisted tape turbulator the next step is meshing. The designed model of Heat Exchanger is meshed in ICEM Meshing. The meshing type have done is quardcore.

Table 1 Meshing details.

Number of nodes	1478570	Quadcore mesh
Number of elements	1348686	Quadcore mesh

The Fluent 17.0 was used to calculate computationally. In this research, a three-dimensional, steady, incompressible and turbulent model was created. In research, the approach used to differentiate the governing equations was a finite element. For this convective term, the researchers used a simpler algorithm, and for connecting calculations of the pressure and velocity the second order upwind method was implemented. A standard k-epsilon equation was used with flow and energy equations to solve turbulence. The numerical simulation was with a 3-Dimensional steady state turbulent flow system. In order to solve the problem, governing equations for the flow and conjugate transfer of heat were customized according to the conditions of the simulation setup. The governing equations for mass, momentum, energy, turbulent kinetic energy and turbulent energy dissipation are expressed as follow,

Mass:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0$$

Momentum:

$$\frac{\partial(\rho u_i u_k)}{\partial x_i} = \frac{\partial\left(\mu \frac{\partial u_k}{\partial x_i}\right)}{\partial x_i} - \frac{\partial p}{\partial x_k}$$

Energy Equation:

$$\frac{\partial(\rho u_i t)}{\partial x_i} = \frac{\partial\left(\frac{K}{C_p}\frac{\partial t}{\partial x_i}\right)}{\partial x_i}$$

Turbulent kinetic energy:

$$\frac{\partial(\rho K)}{\partial t} + \frac{\partial(\rho u_i K)}{\partial x_i} = \frac{\partial\left(\alpha_k \mu_{eff} \frac{\partial k}{\partial x_j}\right)}{\partial x_j} + G_k + \rho\varepsilon$$

Turbulent energy dissipation:

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho u_i \varepsilon)}{\partial x_i} = \frac{\partial\left(\alpha_\varepsilon \mu_{eff} \frac{\partial \varepsilon}{\partial x_j}\right)}{\partial x_j} + C_{1\varepsilon}\frac{\varepsilon}{k}G_k + C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}$$

For any kind of analysis material property are the main things which must be defined before moving further analysis .There are thousands of materials available in the ANSYS environment and if required library is not available in ANSYS directory the new material directory can be created as per requirement.

Table 2 Thermodynamic Properties of material and working fluids

Input Parameters	Symbols	Water	Al_2O_3	Aluminium	Polyethylene	Units
Thermal conductivity	K	0.598	36	202.4	0.313	W/m-K
Specific heat capacity	c_p	4182	880	871	1900	J/kg-K
Density	ρ	998	3970	2719	970	kg/m^3

Here the effective properties of the Al_2O_3/water nanofluid are defined as follows:

Pak and cho [24], **Patel** [25] and **Ebrahmnia- Bajestan** [26] suggested the below equations for determining density, thermal conductivity, specific heat and viscosity of nanofluids.

$$\rho_{nf} = \emptyset_p \rho_p + (1 - \emptyset_p)\rho_{bf}$$

$$(\rho C_p)_{nf} = (1 - \emptyset_p)(\rho C_p)_{bf} + \emptyset_p(\rho C_p)_p$$

$$K_{nf} = K_{bf}\left\{\frac{K_p + 2K_{bf} - 2\emptyset_p(K_{bf} - K_p)}{K_p + 2K_{bf} + \emptyset_p(K_{bf} - K_p)}\right\}$$

$$\mu_{nf} = \frac{\mu_{bf}}{(1 - \emptyset)^{2.5}}$$

Where,

$\emptyset_p$ = Volume concentration of nanoparticle dispersed in water.

ρ_{nf} = Density of nanofluid.

ρ_{bf} = Density of base fluid.

ρ_p = Density of nanoparticle.

$(C_p)_{nf}$ = Specific heat of nanofluid.

$(C_p)_{bf}$ = Specific heat of base fluid.
$(C_p)_p$ = Specific heat of nanoparticle.
K_{nf} = Thermal conductivity of nanofluid.
K_{bf} = Thermal conductivity of base fluid.
K_p = Thermal conductivity of nanoparticle.
μ_{nf} = Dynamic viscosity of nanofluid.
μ_{bf} = Dynamic viscosity of base fluid.

Table 3 Properties of Al_2O_3-H_2O nanofluid

Concentration (% by weight)	Density (kg/m³)	Specific heat (J/kg-K)	Thermal Conductivity (W/m-K)	Dynamic viscosity (Pa-s)
0.4	1010.008	4128.0980	0.602	0.001120
0.8	1022.016	4075.4627	0.613	0.001260
1.2	1033.664	4024.0500	0.620	0.001440
1.6	1034.024	3998.7886	0.627	0.001580

Here in the analysis the boundary condition is same as considered by scholar's **Akyürek et.al. [2018]** during the experimental work. The discretized flow domain was set up with appropriate boundary conditions. The velocity flow boundary conditions were assigned to inlets whereas it was pressure outlet boundary conditions, in case of the outlets. The heat exchanger surfaces were treated as standard wall boundaries. The outer walls were provided with insulated boundary conditions whereas the inner walls were provided with coupled-thermal wall boundary conditions. The boundary conditions of heat exchanger working fluids are consolidated in Table 4.

Table 4 Details of boundary conditions

Detail	Boundary Type	Value
Outer pipe inlet-Hot water	Velocity inlet	0.0084 m/s
Inner pipe inlet -Working fluid i.e. (Water+Al_2O_3)	Velocity inlet	Velocity of Working fluid i.e. (Water+Al_2O_3) changes as the Reynolds number of changes.
Outlet	Pressure outlet	0 Pa (gauge)
Hot water inlet temperature	Temperature inlet	343 K
Working fluid(Water+Al_2O_3) inlet temperature	Temperature inlet	293 K
Inner surfaces	Standard wall	Coupled
Outer surfaces	Standard wall	Heat flux=0

V. RESULTS AND DISCUSSIONS

This segment aims to evaluate the effect of twisted tape turbulator insert in a Counter flow co-axial double pipe heat exchanger. To study the performance of a Counter flow co-axial double pipe heat exchanger with twisted tape insert subject to flow, the variations in the temperature and Heat transfer are measured.

5.1. Numerical model validation

To check that the numerical model meets specifications and fulfills its intended purpose of the double pipe heat exchanger, mathematical equations were used to calculate outlet temperature of the cold fluid, heat transfer rate and Nusselt number for the cases of concentric pipe with variable axial velocity (classic heat transfer problem).For this we considered water as a working fluid. Here cold fluid i.e. water flows as different Reynolds number inside the heat exchanger with wire coil insert. Here in this section Water as cold fluid is flowing at a Re 20,000. Whereas the hot fluid is flowing at a speed of 0.0084 m/s. the temperature contour, pressure contour and Nusselt number of heat exchanger for this Re number is shown in the below fig.

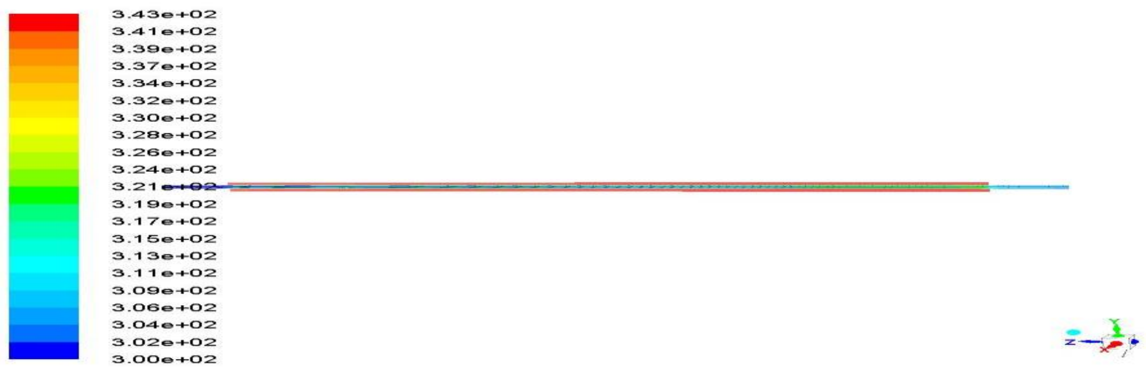

Fig 4. Shows the temperature contours of heat exchanger with wire coil (25mm pitch) insert for Re = 20,000 and Water as a working fluid.

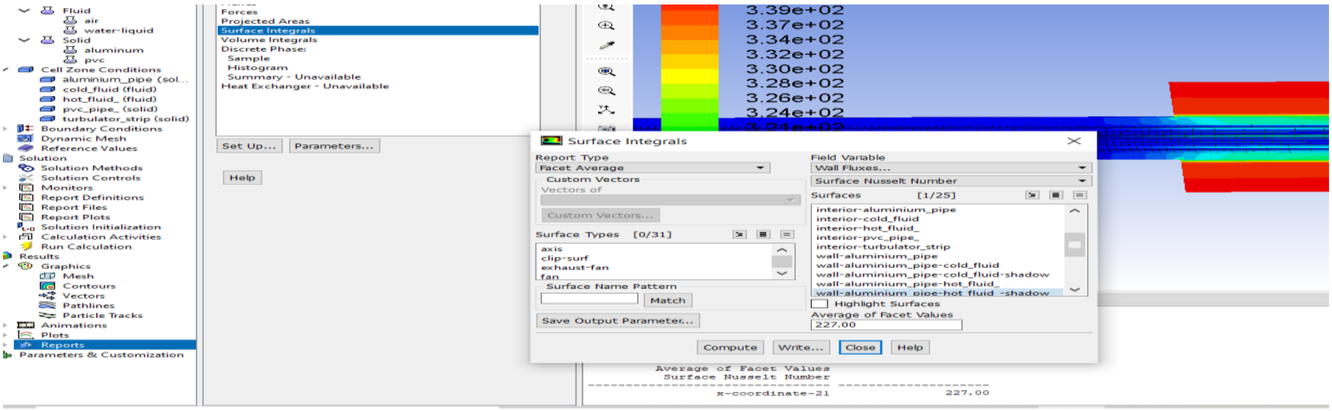

Fig 5. Shows the Nusselt number of heat exchanger with wire coil (25mm pitch) insert for Re = 20,000 and Water as a working fluid.

Likewise from the above calculation for Re = 20,000, we have calculated the value of Nusselt number (Nu) for different Reynolds numbers. The value of overall heat transfer coefficient for heat exchanger with wire coil (25mm pitch) insert at different Reynolds number is shown in the below table.

Table 5.Indicates the Nusselt number values determined from CFD models opposed to the values derived from Akyürek et.al. [2018].

S. No.	Reynolds number	Nusselt Number (Base Paper)	Nusselt Number (Present Study)
1.	4000	98	99.71
2.	8000	135	138.56
3.	12000	160	162.45
4.	16000	185	189.54
5.	20000	225	227.00

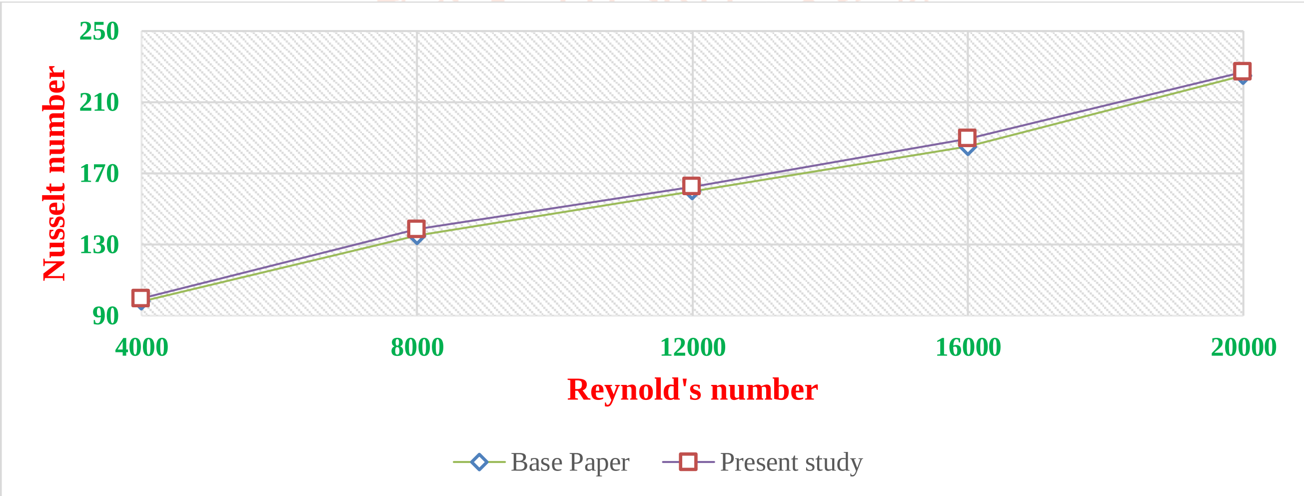

Figure 6. Nusselt number values determined from CFD models opposed to the values derived from Akyürek et.al. [2018].

5.2. Simulation results of Counter flow co-axial double pipe heat exchanger with twisted tape turbulator

In order to analyze the effect of twisted tape turbulator on heat transfer, here in this section, we have considered Water + Al_2O_3 as a working fluid. Here it considered four volume fraction of nano fluid that is 0.4%, 0.8%, 1.2% and 1.6%. The boundary conditions were same as considered during the analysis of heat exchanger having wire coil turbulator. Here in this section we are analyzing the effect of twisted tape turbulator in heat exchanger, and try to find out the effect of twisted tape turbulator in respect of Nusselt number.

Table 6. Effect of twisted tape turbulator in Nusselt number considering Water -Al_2O_3 nanofluid with different vol. % as working fluid

Reynold's number	Nusselt number			
	0.4 vol. %	0.8 vol. %	1.2 vol. %	1.6 vol. %
8000	172.02	225.77	258.38	306.02
12000	203.06	263.02	306.14	361.3
16000	227.22	309.9	357.34	422.42
20000	257.72	363.96	422.46	487.24

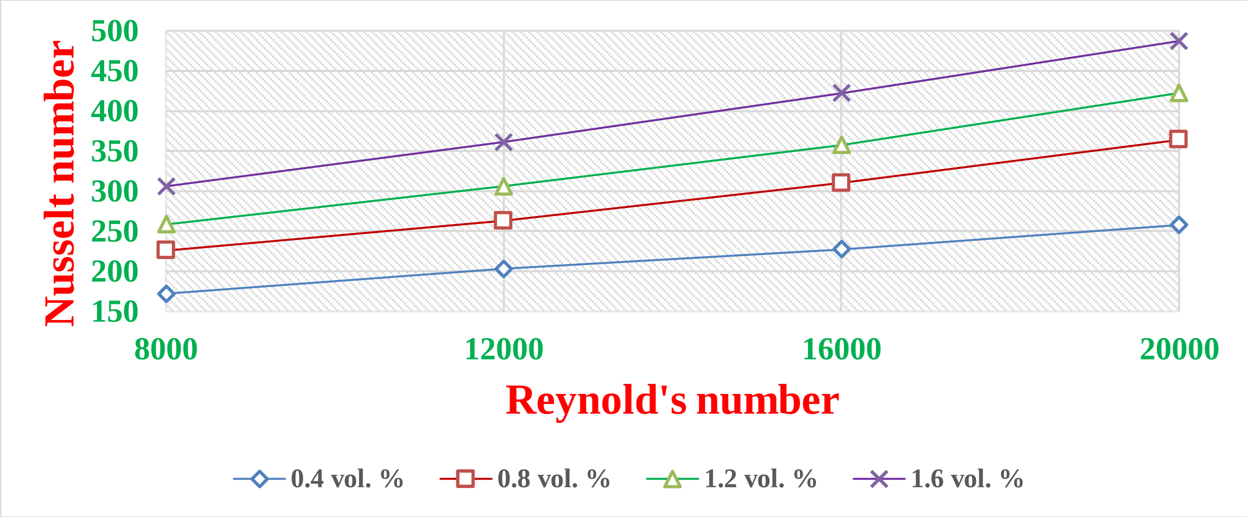

Figure 7. Effect of twisted tape turbulator in Nusselt number considering Water -Al_2O_3 nanofluid with different vol. % as working fluid.

5.3. Comparison of Present analysis with previous study

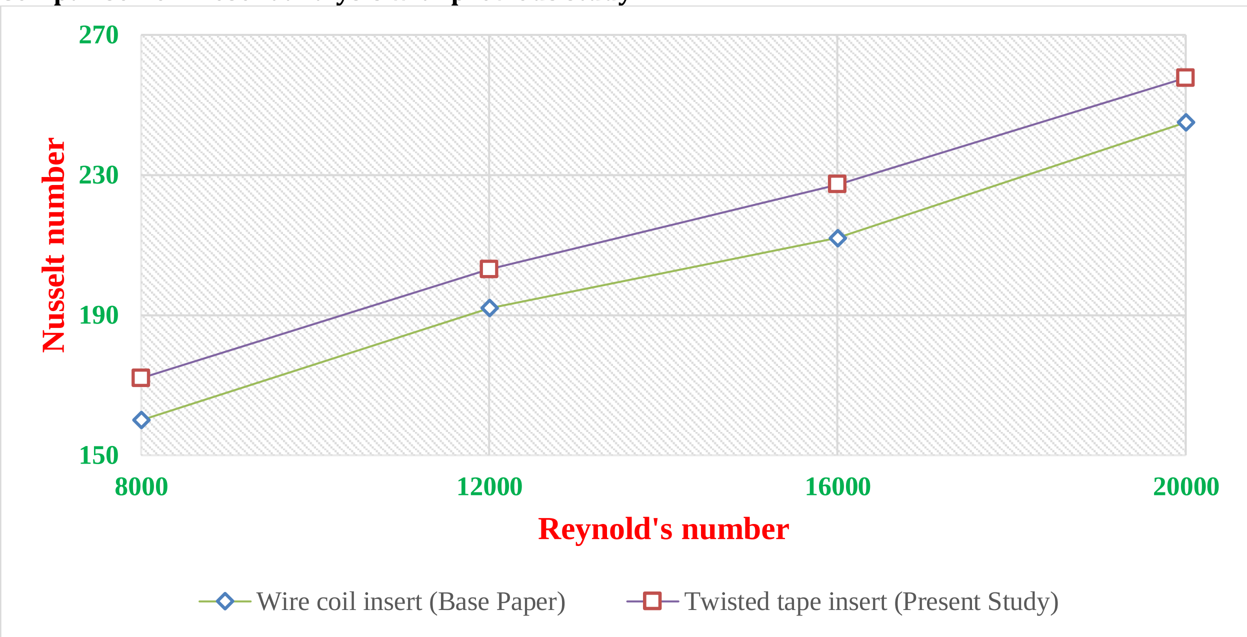

Figure 8. Nusselt number values determined from twisted tape insert models opposed to the values derived from wire coil insert (Akyürek et.al. [2018]) at 0.4 vol. %)

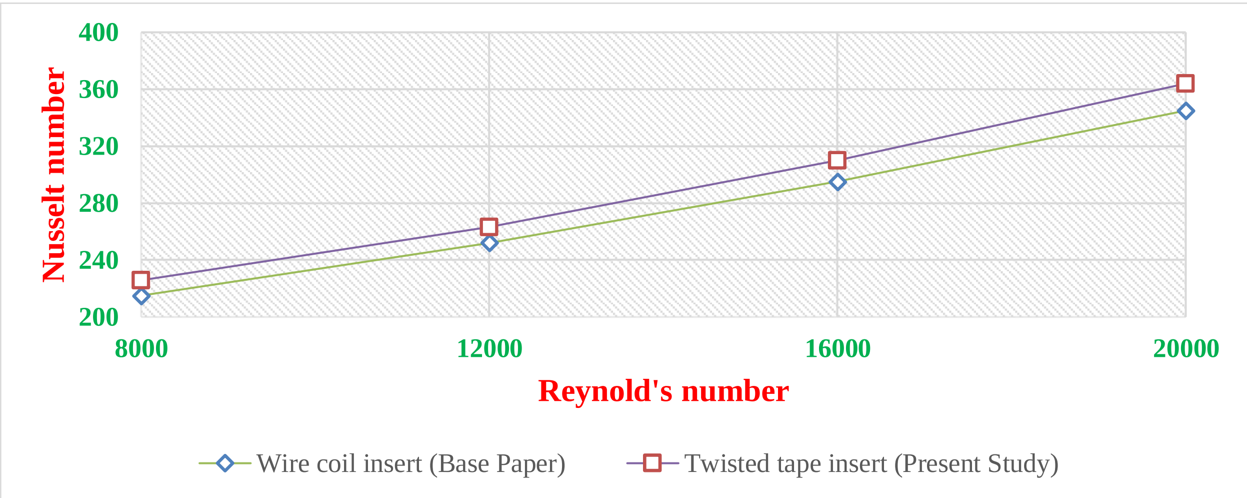

Figure 9. Nusselt number values determined from twisted tape insert models opposed to the values derived from wire coil insert (Akyürek et.al. [2018]) at 0.8 vol. %).

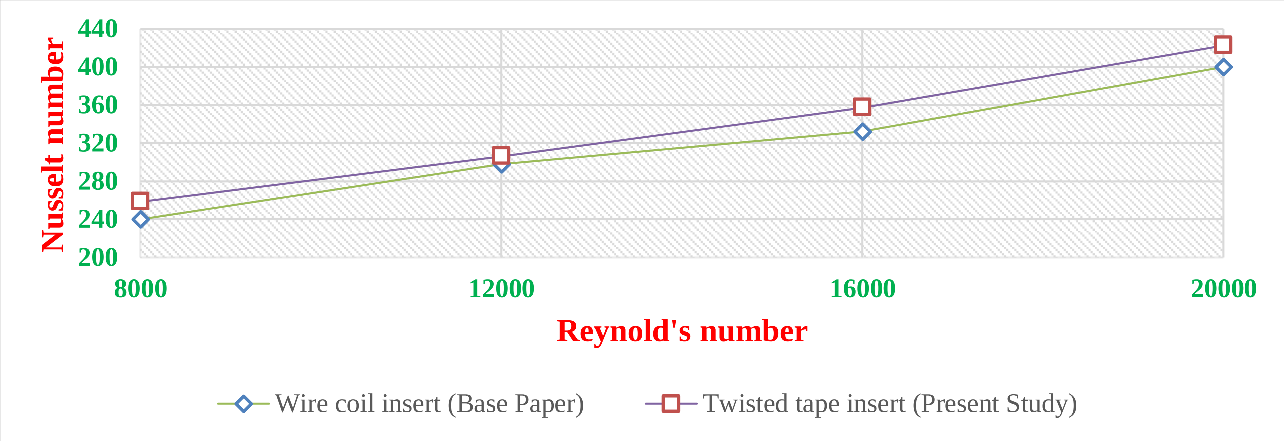

Figure 10. Nusselt number values determined from twisted tape insert models opposed to the values derived from wire coil insert (Akyürek et.al. [2018]) at 1.2 vol. %).

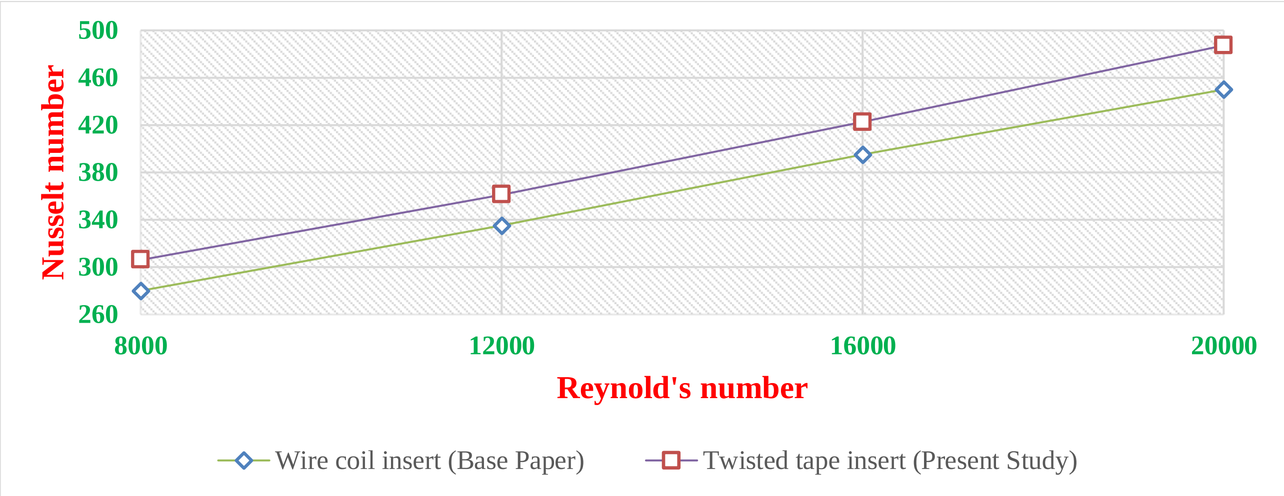

Figure 11. Nusselt number values determined from twisted tape insert models opposed to the values derived from wire coil insert (Akyürek et.al. [2018]) at 1.6 vol. %).

VI. CONCLUSIONS

In the current investigation, a numerical study was carried out to study the performance of double-tube heat exchanger. The heat exchanger performance was studied with the effect of the twisted tape insert at different Reynolds number ranges from 4000-20000 and different vol. % concentration (0.4%-1.6%). The following conclusions have been obtained.

- Normally, the presence of Al_2O_3 nanoparticles in the base fluid improves the property of convective heat transfer.
- Nusselt number seemed to increase as the turbulators placed in the heat exchanger.
- From the computational outcomes, the heat exchanger with twisted tape insert unveiled the best Nusselt number of 487.24 at Re=20,000 at 1.6 vol. % of nanoparticle.
- By comparison, the Nusselt number of double pipe heat exchanger with twisted tape insert is 8.27 % higher than with wire coil insert.

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