# Numerical and Theoretical Analysis on Heat Transfer and Flow Characteristics of Helical, Conical, and Inclined Rectangular Coiled Tube in-Tube Heat Exchanger using Nanofluids

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**Abstract –***Recent developments are carried out in the design of heat exchangers to achieve the demand of industries which has led to the evolution of helical coiled heat exchangers for their numerous advantages over a straight tube. In this present study, the CFD analysis is done on various geometrical types of helical, conical, and inclined rectangular coiled tube in- tube heat exchangers using water and three nanofluids such as $Al_2O_3$/water, $TiO_2$/water, and MWCNT/water by changing the volume concentrations of nanoparticles percentages in water as 0.2%, 0.4%, and 0.6%. The entire analysis was done in ANSYS Fluent R19.0 in the selected range of Dean number from 1300 to 1700. The results are validated with the theoretical approach by evaluating the flow characteristics of heat exchangers such as heat transfer coefficient, Nusselt number, pressure drop, and friction factor. The MWCNT/water nanofluids in conical coiled tube in-tube heat exchangers, shows better results in overall work. Both theoretical and CFD results are having a good agreement for the inner tube of a coiled tube in tube heat exchangers.*

***Key Words: CFD, Theoretical, Nanofluids Volume Concentrations, Flow Characteristics, Dean number, Helical, conical, and inclined rectangular coiled tube in- tube heat exchangers.***

## 1. INTRODUCTION

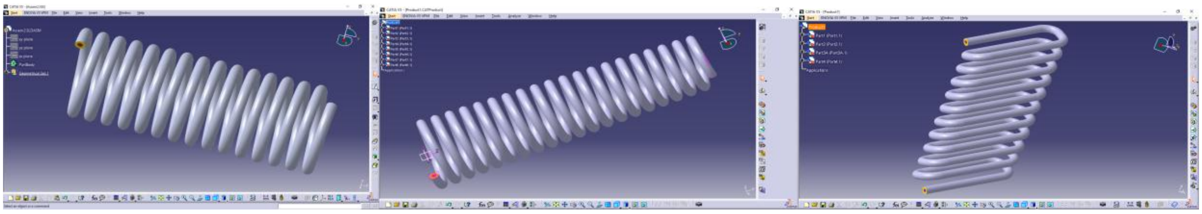
The design of helical exchangers is considered very important for enhancement of the heat transfer process to acquire the cooling demand in the present industries. However, there is vast research done on curved tubes and helically coiled tubes, because those designs are having a good turbulence due to the presence of good secondary flow which occurs due to centrifugal force which will enhance the flow characteristics of heat exchangers. However, the helical tubes are compact and help in the endurance of large heat removal from thermal systems when compared to straight tubes. Ganesh Kumar et al.[1] work on double pipe heat exchanger by improving the nusselt number. They studied the heat transfer and pressure drop characteristics of activated carbon(AC)- solar glycol (SG) with nanofluid of 0.2%,0.4%, and 0.6% volume concentrations, and their work showed that AC nanomaterials in SG enhance the heat transfer and pressure drop. Wae I.A.Aly [2] worked on coiled tube in tube heat exchanger with $Al_2O_3$/water nanofluids of volume concentrations of nanoparticles of 0.5%,1.0%, and 2.0% with different coil diameters. He studied that increasing coil diameter and nanoparticle concentrations will increase the heat transfer coefficient. Y.M.Ferng et al. [3] worked on the effect of changing dean number and pitch size on helically coil tube heat exchangers. They concluded that changing dean number and pitch size are very effective in heat transfer.A.Moktari Andekani, et al.[4] had improve the heat transfer rate in helically coil tubes using Ag-water nanofluids by experimentally and concluded that helically tubes had gives better results than straight tubes under turbulent flow. Vijaya Kumar Reddy K et al.[5] had done a added semicircular plates in annulus region of helically coiled tube in tube heat exchangers. They also studied that with increasing outer flow rate with respect to inner flow rate will causes reduction in LMTD. P.C.Mukesh Kumar et.al [6] worked on helically coiled tube in tube heat exchanger experimentally and numerically. they concluded that increasing of volume concentrations of nanoparticles in water will enhance the heat flow characterstics of nanoparticles of heat exchangers.[7]Gabrieta Humanic [7] studied that increasing of dispersed partricles in water as increases the convective heat transfer coefficients. His results shows 2% CuO, will give 14% of heat transfer for inner and outer by 19% than pure water in double tube helical heat exchangers. B.C.Pak et al.[8] had studied hydrodynamically dispersed particles of $Al_2O$ and $TiO_2$ with fluids. They studied that dispersed particle of fluid at 3% was 12% lower than that of pure water by using empirical relation of nusselt number. Yimin Xuan et al.[9] had found concepts for heat transfer correlations for nanofluids, by considering that nanofluids is a mixture of fluid with solid particles. Yang et al.[10] worked on characterstics of convective heat transfer of nanofluids in a helically coiled tube heat exchanger of the working fluid and revealed the nanofluids are superior heat transfer fluids. From the above all, it is concluded that they all investigated the flow characteristics on helically with changing in coil diameters, pitch size and flow patterns. So, in my study I mainly focuses on the different designs of helically coiled tube in tube heat exchangers and to determine which design is best for better heat transfer and flow characteristics of using different nanofluids.

## 2. METHODOLOGY

For conducting CFD analysis on the helical, conical, and inclined rectangular coiled tube in tube heat exchanger, the models are designed in CATIA V5 version package. The dimensional parameters considered for the above coiled tube in- tube heat exchangers are mentioned below:

| **Dimensional Parameter** | **Dimensional value** |
|---|---|
| inner dia. of inner coil ($d_{ii}$) | 5.35mm |
| Outer dia. of inner coil ($d_{io}$) | 6.35mm |
| Internal dia. of outer coil ($d_{oi}$) | 12mm |
| External dia. of outer coil ($d_{oo}$) | 12.7mm |
| Coil pitch (P) | 20mm |
| No. of turns (n) | 1.15 ( helically)<br>2.20 (conically)<br>3.11 (inclined rect.) |
| Height of tube(h) | 1. 312.7mm (helically)<br>2. 400mm (conically)<br>3. 264.69mm (inclined rect.) |
| Material | Copper |
| Thermal conductivity(K) | 401 w/mk |
| Density ($\rho$) | 8960kg/m$^3$ |

**Table -1: Dimensional parameters and material properties of tube in tube heat exchanger**



(a) (b) (c)

**Figure -1:** CATIA models of (a) helical,(b) conical and (c) inclined rectangular coiled tube in-tube heat exchangers

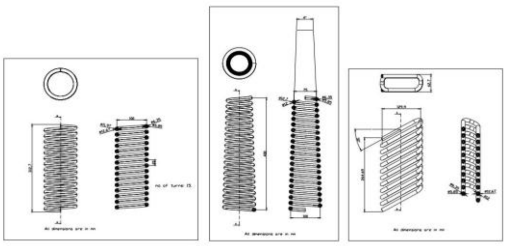
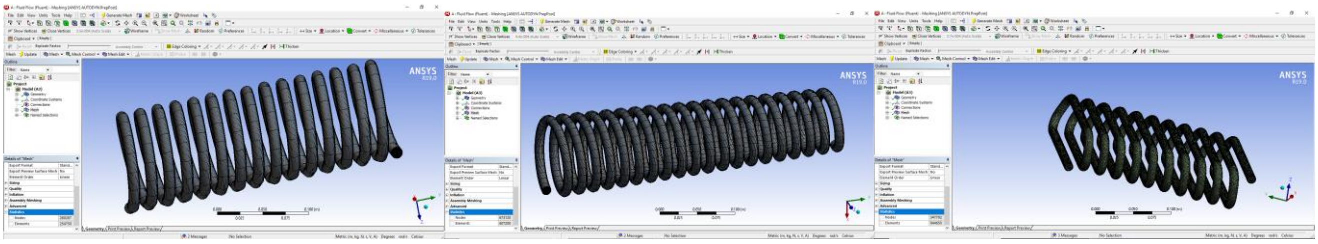


**Figure -2:** Dimensional representation of helical, conical, and inclined rectangular coiled tube in-tube heat exchanger

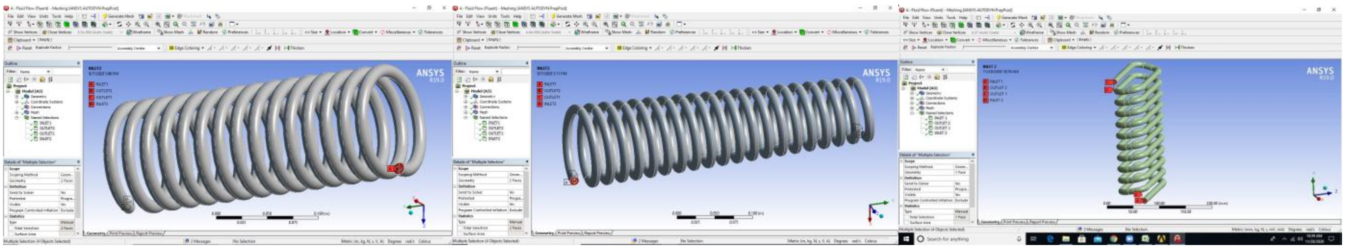
### A. NUMERICAL ANALYSIS

The designed models are solved by meshing through the overall length of tube in tube heat exchangers using ANSYS R19.0. The meshing is done by collaboration of cells for tetrahedral and quadrilateral expressions at boundary conditions.



(a) (b) (c)

**Figure -3:** Meshing formation of (a) helical,(b) conical, and (c) inclined rectangular coiled tube in-tube heat exchanger



(a) (b ) (c)

**Figure -4:** Boundary conditions of (a)helical, (b) conical and (c)inclined rectangular coiled tube in-tube heat exchanger

**Details of meshing**

| Domain | Nodes | Elements |
|---|---|---|
| Inner fluid | 53463 | 44750 |
| Outer fluid | 84336 | 75000 |
| Inner pipe | 21084 | 15000 |
| Outer pipe | 21084 | 15000 |
| Total | 179967 | 149750 |

**Table -2: Meshing details for helical coiled tube in- tube heat exchanger**

| Domain | Nodes | Elements |
|---|---|---|
| Inner fluid | 62504 | 51600 |
| Outer fluid | 201936 | 180000 |
| Inner pipe | 50484 | 36000 |
| Outer pipe | 50484 | 36000 |
| Total | 179967 | 149750 |

**Table -3: Meshing details for conical coiled tube in- tube heat exchanger**

| Domain | Nodes | Elements |
|---|---|---|
| Inner fluid | 91025 | 205925 |
| Outer fluid | 279739 | 63875 |
| Inner pipe | 72840 | 50020 |
| Outer pipe | 72480 | 50020 |
| Total | 516444 | 369840 |

**Table -4: Meshing details for inclined rectangular coiled tube in- tube heat exchanger**

| **Constraints** | **standards** |
|---|---|
| 1.inner tube | $Al_2O_3$/water, $TiO_2$/water and MWCNT/water nanofluids |
| 2.outer tube | water |

| | |
|---|---|
| 3.Dean number | 1300 to 1700 |
| 4.velocity | For inner (calculated by respective dean number)<br>For outer (1.2m/s²) |
| 5.initial temperature of inner tube | 305K |
| 6.initial temperature of outer tube | 338K |

**Table -5: Testing conditions**

Calculation of thermophysical properties of nanofluids is done using empirical relations as given by :

Thermal conductivity

$$k_{nf} = \mathrm{k_{bf}} \frac{(\mathrm{knp} + 2\mathrm{kbf} - 2\emptyset(\mathrm{kbf} - \mathrm{knp}))}{(\mathrm{knp} + 2\mathrm{kbf} + \emptyset(\mathrm{kbf} - \mathrm{knp}))}$$

Specific heat capacity

$$\mathrm{Cp_{nf}} = (1 - \emptyset)\mathrm{cp_{bf}} + \emptyset \mathrm{cnp}$$

Density

$$\rho_{\mathrm{nf}} = (1 - \emptyset)\rho \mathrm{w} + \emptyset \rho_{\mathrm{np}}$$

Viscosity

$$\mu nf = (1 + 2.5\emptyset)\mu bf$$

**Properties of nanofluids**

| **Nanofluids** | **Concentrations(%)** | Density(kg/m³) | Specific heat capacity(j/kg k) | Thermal conductivity(w/mk) | Viscocity(kg/ms) |
|---|---|---|---|---|---|
| **$Al_2O_3$/water nanofluids** | 0.2 | 1537.8 | 3525.6 | 1.71 | 0.0012 |
| | 0.4 | 2078.2 | 2856.2 | 2.87 | 0.0016 |
| | 0.6 | 2018.8 | 2202.8 | 3.11 | 0.002 |
| **$Tio_2$/water nanofluids** | 0.2 | 1577.6 | 3491.6 | 1.19 | 0.0012 |
| | 0.4 | 2518.2 | 2796.2 | 1.49 | 0.0016 |
| | 0.6 | 2738.8 | 2100.8 | 2.34 | 0.002 |
| **MWCNT/water nanofluids** | 0.2 | 1217.6 | 3561.23 | 1.062 | 0.0012 |
| | 0.4 | 1438.2 | 2935.66 | 1.80 | 0.0016 |
| | 0.6 | 1658.8 | 2310 | 3.24 | 0.002 |

**Table -8: Properties of nanofluids**

**The water properties are**

| description | velocity | density | Specific heat capacity | Thermal conductivity |
|---|---|---|---|---|
| values | 0.001003 | 998.2 | 4182 | 0.6 |

**Table -9: Properties of water**

**B. GOVERNING EQUATIONS**

The empirical equations used to evaluate the flow characteristics and heat transfer in this work under K-€ model at walls and boundaries.

Continuity equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho U1}{\partial x1}+\frac{\partial \rho U2}{\partial x2}+\frac{\partial \rho U}{\partial x}=0$$

Momentum equation

$$\rho\left(u\frac{\partial U}{\partial x}+v\frac{\partial V}{\partial x}\right)=-\rho g-\frac{\partial \rho}{\partial x}+\mu\frac{\partial^2 y}{\partial x^2}$$

Energy equation

$$\rho Cp\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k\frac{\partial^2 T}{\partial y^2}$$

Turbulent kinetic energy

$$\frac{\partial}{\partial x2}(\rho k u2)=\frac{\partial}{\partial x2}\left\{\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x2}\right\}+\mu_t\left(\frac{\partial u_1}{dx_2}+\frac{\partial u_2}{\partial x_1}\right)-\rho\epsilon$$

$$u_t=\rho C_\mu\frac{k^2}{\epsilon}$$

**C. ASSUMPTIONS**

- The thickness of the outer wall is neglected.
- Turbulent flow is considered.
- Considered counter flow heat exchanger
- Steady-state heat conditions are taken
- Natural convection and radiation were neglected
- Incompressible fluid.

**D. VALIDATION**

The validation of this work is done by comparing the CFD and ideal theoretical calculations by taking the empirical relations are:

## Theoretical calculations

1. The inner nusselt number is given by

$$Nu_i=0.023Re^{0.88}Pr^{0.33}$$

2.The inner heat transfer coefficient is calculated by $Nu_i=\frac{h_i d}{k}$

Hence, $h_i=\frac{Nu*k}{d_i}$

3.The friction factor is calculated for smooth pipe under turbulent flows are calculated by

$$f=\frac{0.316}{Re^{0.25}}$$

4.The pressure drop is evaluated by

$$\Delta P=\frac{fl\rho v^2}{2d_i}$$

**NUMERICAL CALCULATIONS**

The nusselt number and friction factor is calculated by CFD results of heat transfer coefficients and pressure drop .

$$Nu_i = \frac{h_i d}{k}$$

$$f = \frac{2d\Delta p}{l\rho v^2}$$

## 3. RESULTS AND DISCUSSIONS

### 3.1. Temperature and pressure distribution

The below figure 4 represents the points of static pressure and static temperature of three models at 0.2% MWCNT/water nanofluids in which minimum temperature and pressure are marked as blue and maximum temperature and pressure is marked as red at inner coil temperature is 305 K and outer coil temperature is 338 K.

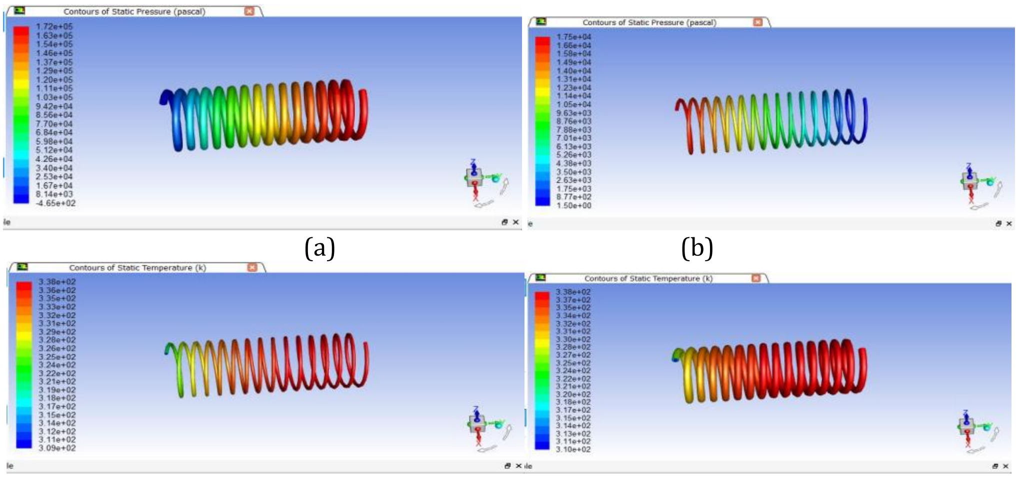



**Figure -5:** (a),(b) are static pressure and static temperature contours, and (c),(d) are static pressure and static temperature contours of helical coiled tube in-tube heat exchangers

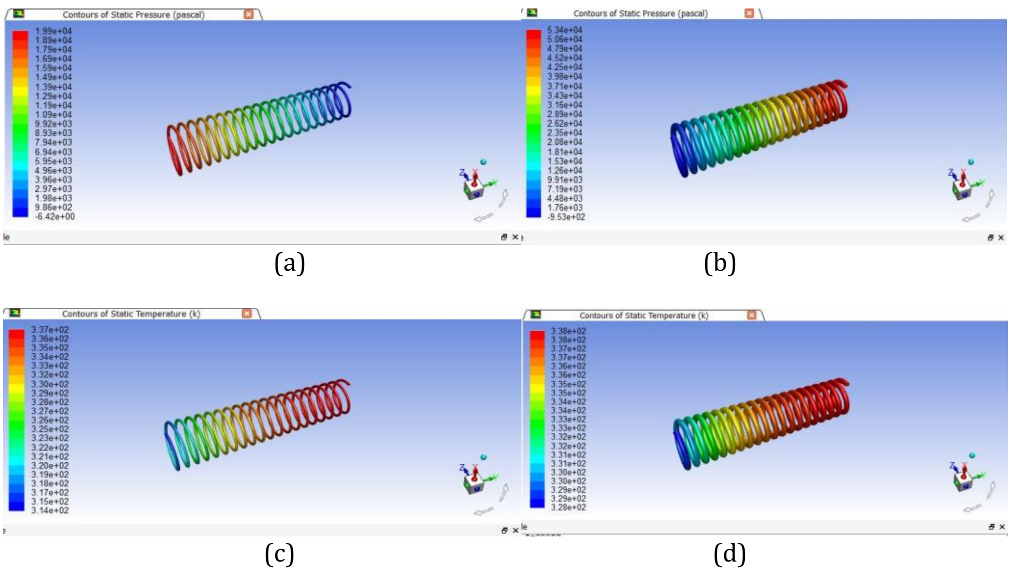
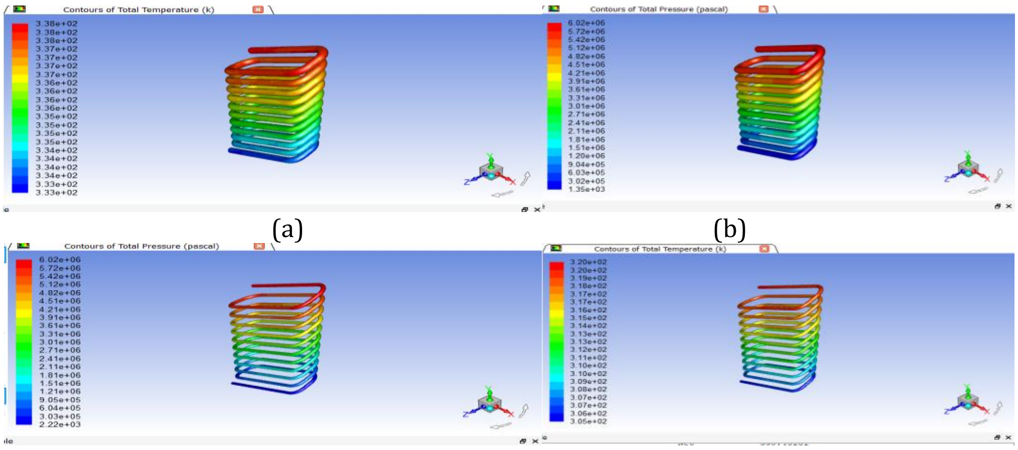



**Figure -6:** (a),(b) are static pressure and static temperature contours, and (c),(d) are static pressure and static temperature contours of conical coiled tube in-tube heat exchangers




(a) (b)

(b) (d)

**Figure -6:** (a),(b) are static pressure and static temperature contours, and (c),(d) are static pressure and static temperature contours of inclined rectangular coiled tube in-tube heat exchangers

### 3.2. Effect of helically coiled design in heat and flow characteristics

#### 3.2.1. Heat transfer coefficient

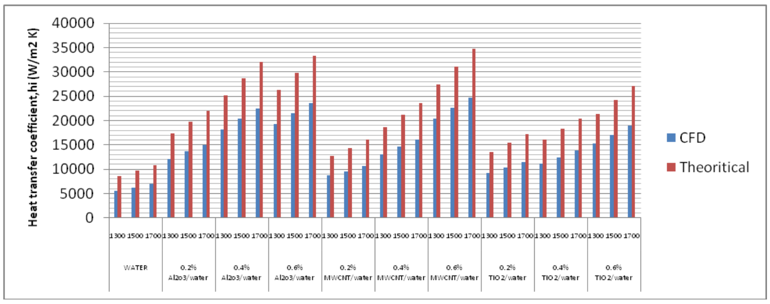



**Figure -5:** heat transfer coefficient of helically coiled tube in tube heat exchanger

From fig.5, it represents the various volume concentrations of nanoparticles in working fluid as water in percentages of 0.2%, 0.4% and 0.6% of $Al_2O_3$/water, $TiO_2$/water and MWCNT/water nanofluids. Both theoretical and CFD results are taken. it is seen that the heat transfer coefficient in theoretically and CFD is increases with increase in the volume fractions of nanofluids with lower to hiher dean numbers, because increasing in dean number results in increasing in velocity which results in intensification of secondary flow formation leading to low residence timing for dispersion of nanoparticles in base fluids. Due to higher thermal conductivity, it is found that the low heat transfer coefficient in water and $TiO_2$/water nanofluids with error of 40% between the theoretical and CFD results. The high heat transfer coefficient is found in $Al_2O_3$/water nanofluids with error between the theoretical and CFD results is 38%.

#### 3.2.2. Nusselt number

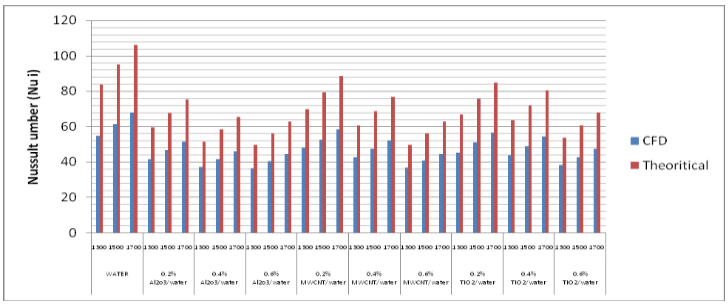



**Figure -6:** Nusselt number of helically coiled tube in tube heat exchanger

From fig.6, it is seen that nusselt number in voulme concentrations of $Al_2O_3$/water, MWCNT/water and $TiO_2$/water increases with increase in dean number both in theoritically and CFD results. The low nusselt number is found in 0.6% of $Al_2O_3$/water nanofluids with error between the theretically and CFD results is 35%. The high nusselt number is seen in water fluids in dean number of 1300,1500 and 1700 due to incraese in the brownian movement of nanoparticles dispersed in base fluid.

### 3.2.3. Pressure drop analysis

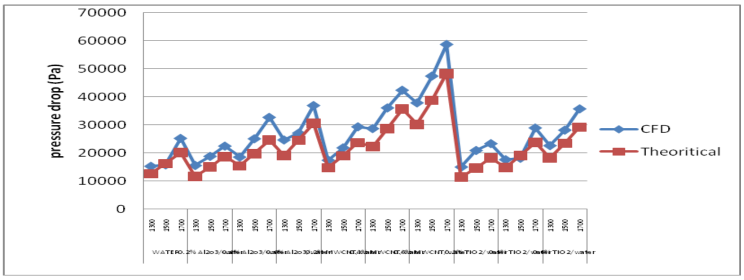



**Figure -7:** heat transfer coefficient of helically coiled tube in tube heat exchanger

For both theoretically and CFD results, there is increase in pressure of nanofluids with increase in volume concentrations of nanofluids. The low pressure drop found in volume concentrations of water fluids with error of 13.6% between theretically and CFD results . The high pressure drop is seen in 0.6% MWCNT/water fluids with 16.7% between theoritically and CFD results.

### 3.2.4. Friction factor

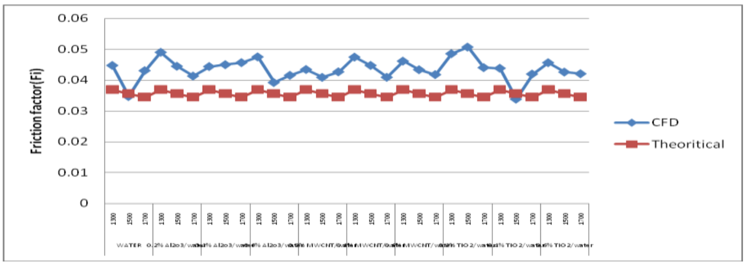



**Figure -7:** Friction factor of helically coiled tube in tube heat exchanger

From fig.7, it is seen that low friction value is found in both 0.2% $Al_2O_3$/ water and 0.4% of $TiO_2$/water nanofluids at their respective dean numbers with error of 37.5% between theretically and CFD results. The high friction factor is seen at 0.2% of $TiO_2$/water nanofluids at respective dean numbers of 1300, 1500, and 1700 with 34% of error between theoretically and CFD results.

### 3.3. Effect of conically coiled design in heat and flow characteristics

### 3.3.1. Heat transfer coefficient

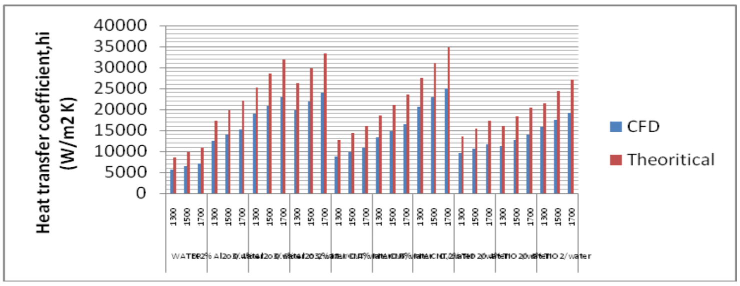



**Figure -8:** heat transfer coefficient of conically coiled tube in tube heat exchanger

from fig.8, it is seen that low heat transfer coefficient is found in water with their respective dean numbers with 32% error between the theoretical and CFD results. The high heat transfer coefficent is found in 0.6% MWCNT/water nanofluids with 34.7% error between theoretical and CFD results.

### 3.3.2. Nusselt number

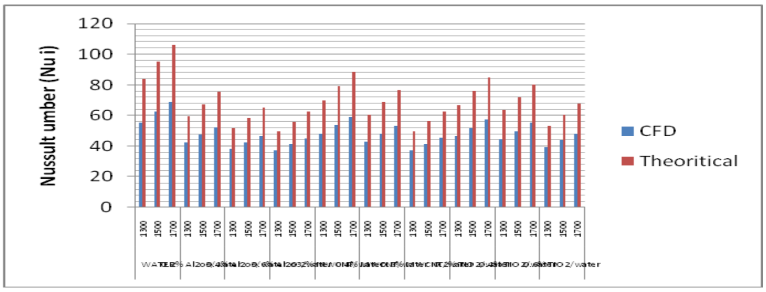



**Figure -9:** Nusselt number of conically coiled tube in tube heat exchanger

From fig.9, it is seen that lowest nusselt number is found in 0.6% of $Al_2O_3$/water nanofluids and 0.6% of MWCNT/water nanofluids . The highest nusselt number is seen in water fluids at their respective dean numbers of 1300, 1500, and 1700.

### 3.3.3. Pressure drop analysis

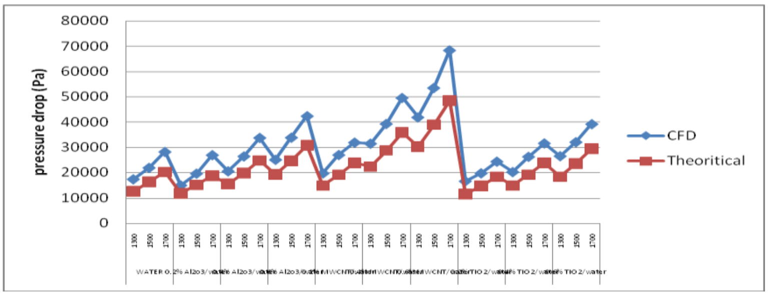



**Figure -10:** Pressure drop of conically coiled tube in tube heat exchanger

From fig.10, low pressure drop is seen in 0.2% of $TiO_2$/water nanofluids with error of 31.2% between the theoretical and CFD results. The high pressure drop is visible in 0.6% MWCNT/water nanofluids with 26% error between the theoretical and CFD results.

### 3.3.4. Friction factor

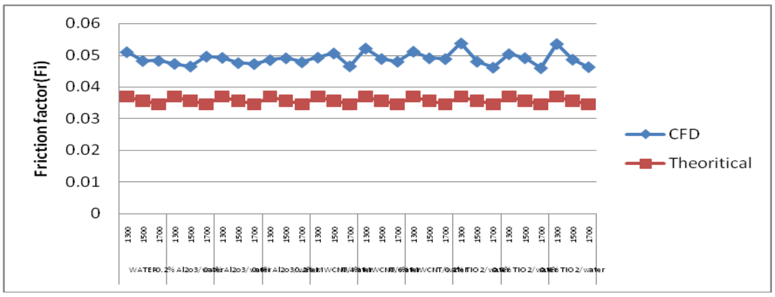



**Figure -11:** Friction factor of conically coiled tube in tube heat exchanger

The above fig.11, represents the low friction value at both 0.2% MWCNT/water with error of 30.6% and at 0.2%, 0.4% of $TiO_2$/water nanofluids with error of 31% between the theoretical and CFD results. This is due to that the models are predicting the bending losses during analysis due to which, increasing in the friction factor so enormously in case of CFD results.

### 3.4. Effect of helically coiled design in heat and flow characteristics

#### 3.4.1. Heat transfer coefficient

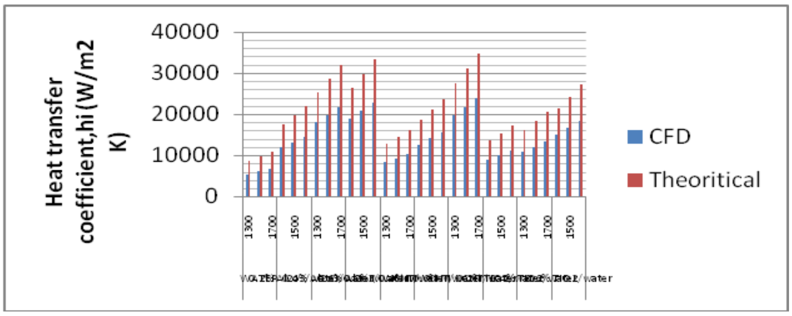



**Figure -12:** heat transfer coefficient of inclined rectangular coiled tube in tube heat exchanger

Fig.12, shows that the low heat transfer coefficient is seen in water at dean numbers of 1300, 1500, and 1700. It is also seen that, the high heat transfer coefficient is at 0.6% of MWCNT/water nanofluids with error of 36.15% between the theoretical and CFD results.

#### 3.4.2. Nusselt number

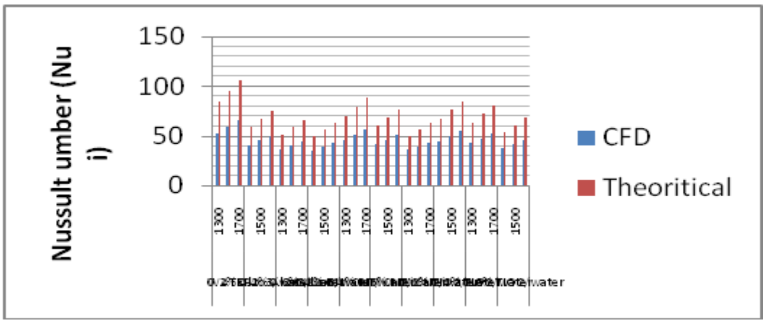



**Figure -12:** Nusselt number of inclined rectangular coiled tube in tube heat exchanger

It is seen that, the nusselt number increases with increase of volume concentrations and with dean numbers. From fig.12, the low nusselt number is visible in 0.6% MWCNT /water and 0.6% of $Al_2O_3$ /water nanofluids with error of 30% and 28% respectiovely. The high nusselt number is seen at water fluids with 38% error between the theoretical and CFD results.

#### 3.4.3. Pressure drop

The fig.13, shows that the low pressure drop is visble in water fluids and high pressure drop is shown at 0.6% MWCNT/water nanofluids at 1300,1500, and 1700 dean number with error of 20% between the theoretical and CFD results.

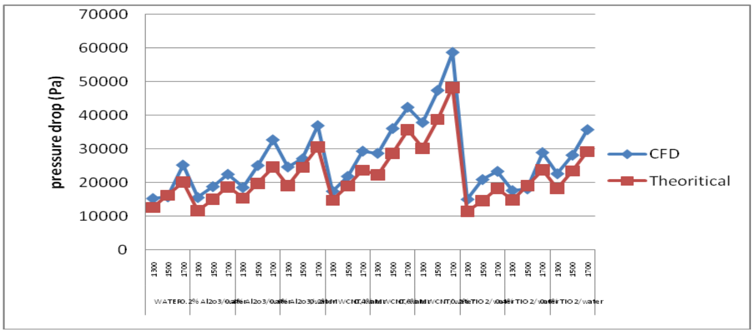



**Figure -13:** Pressure drop of inclined rectangular coiled tube in tube heat exchanger

### 3.4.4. Friction factor

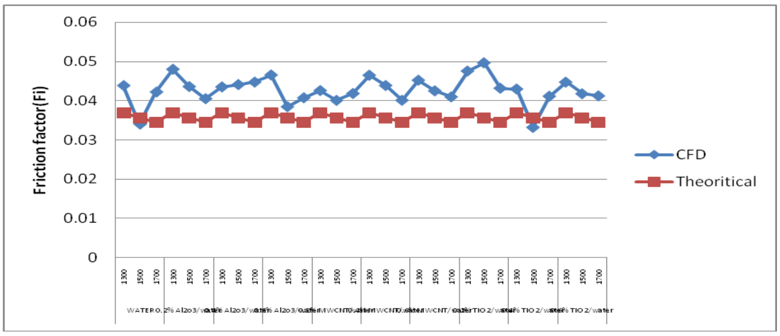



**Figure -14:** Friction factor of inclined rectangular coiled tube in tube heat exchanger

From fig.14, the low friction factor value is shown at 0.4% of $TiO_2$/water nanofluids and high friction factor value is seen at 0.2% $TiO_2$/water with respective dean numbers with error of 10% and 35% respectively.

### 3.5. Final results

For validation, the CFD results are compare with the theoretical calculated values of helical, conical and inclined rectangular coiled tube in-tube heat exchanger with using nanofluids at 0.2%, 0.4% and 0.6% of volume concentrations of nanoparticles in water. Mostly, the MWCNT/water nanofluids in conical coiled tube in- tube heat exchanger at various considered concentrations are showing better results for heat transfer coefficient, nusslet number, pressure drop and friction factor while comparing with other heat exchangers.

### 3.5.1. heat transfer coefficient at 0.2%, 0.4% and 0.6% of MWCNT/water nanofluids

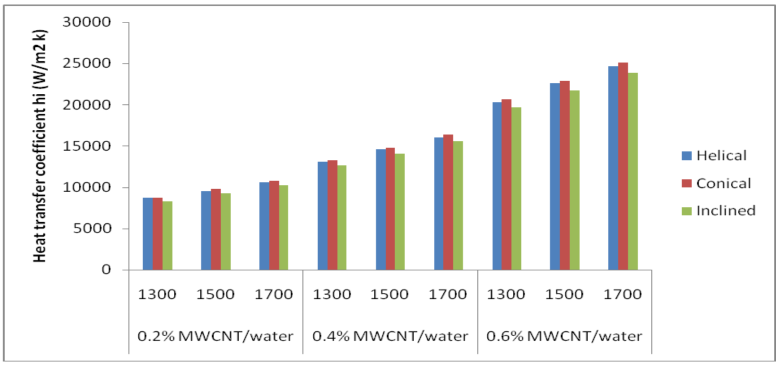



**Figure -15:** Graphs for heat transfer coefficient of MWCNT/water in various tube in-tube heat exchangers

| Tube in tube heat exchanger | 0.2% MWCNT/water | | | 0.4% MWCNT/water | | | 0.6% MWCNT/water | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dean no-1300 | Dean no-1500 | Dean no-1700 | Dean no-1300 | Dean no-1500 | Dean no-1700 | Dean no-1300 | Dean no-1500 | Dean no-1700 |
| helical | 8700.67 | 9527.85 | 10600 | 13046.9 | 14582 | 16059.13 | 20323.6 | 22581.44 | 24627.3 |
| conical | 8733.4 | 9749.2 | 10732 | 13264 | 14810 | 16383.2 | 20693 | 22837 | 25075 |
| Inclined rectangular | 8296.73 | 9261.75 | 10195.4 | 12600.8 | 14069.5 | 15564.04 | 19658.35 | 21695.15 | 23821.25 |

**Table -10: heat transfer coefficient values of MWCNT/water nanofluids in helical, conical and inclined rectangular tube in-tube heat exchanger**

from all the results, it is seen that MWCNT/water nanofluids ar 0.6% showing better results than 0.2% and 0.4% volume concentrations of nanoparticles in water.so, the best results of all 0.6% voume concentration of nanoparticles in water in helical, conical and inclined rectangular are taken in fig.15, and comparision is made on it. From fig.15 it is seen that from all respective dean numbers,conical coiled tube in-tube heat exchanger with 0.6% of MWCNT/water nanofluids showing higher heat transfer coefficient

### 3.5.2. Nusselt number at 0.2%, 0.4% and 0.6% of MWCNT/water nanofluids

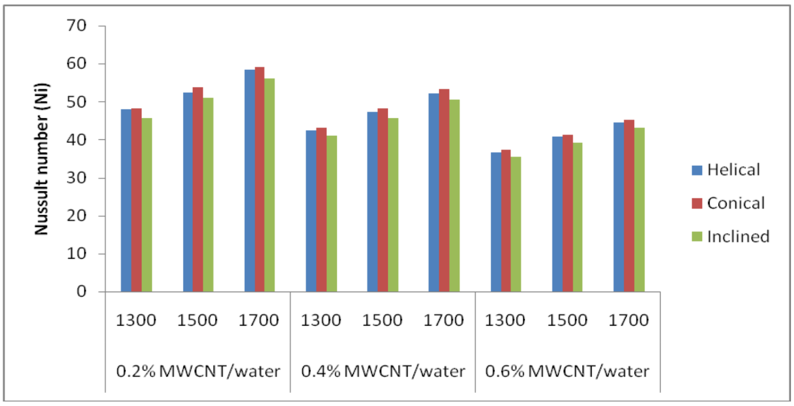



**Figure -16:** Graphs for Nusselt number of MWCNT/water nanofluids in various tube in-tube heat exchangers

| Tube in tube heat exchanger | 0.2% MWCNT/water | | | 0.4% MWCNT/water | | | 0.6% MWCNT/water | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dean no.-1300 | Dean no.-1500 | Dean no.-1700 | Dean no.-1300 | dean no.-1500 | Dean no.-1700 | Dean no.-1300 | Dean no.-1500 | Dean no.-1700 |
| helical | 47.92742 | 52.48392 | 58.38983 | 42.40243 | 47.3915 | 52.19217 | 36.69539 | 40.77204 | 44.46596 |
| conical | 48.10771 | 53.70328 | 59.11695 | 43.108 | 48.1325 | 53.2454 | 37.36236 | 41.23347 | 45.27431 |
| Inclined rectangular | 45.70233 | 51.01811 | 56.1611 | 40.9526 | 45.72588 | 50.58313 | 35.49424 | 39.1718 | 43.01059 |

**Table-12: Nusselt number values of MWCNT/water nanofluids in helical, conical and inclined rectangular tube in-tube heat exchanger**

From fig.16, while increasing the dean number with respect to volume concentrations of nanofluids, the nusselt number foe conical is shows the better results than the helical and inclined rectangular coiled tube in-tube heat exchanger.the highest nusselt number is obtained at 0.2% of MWCNT/water nanofluids in conical coiled tube in-tube heat exchanger.

### 3.5.3. Pressure drop at 0.2%, 0.4% and 0.6% of MWCNT/water nanofluids

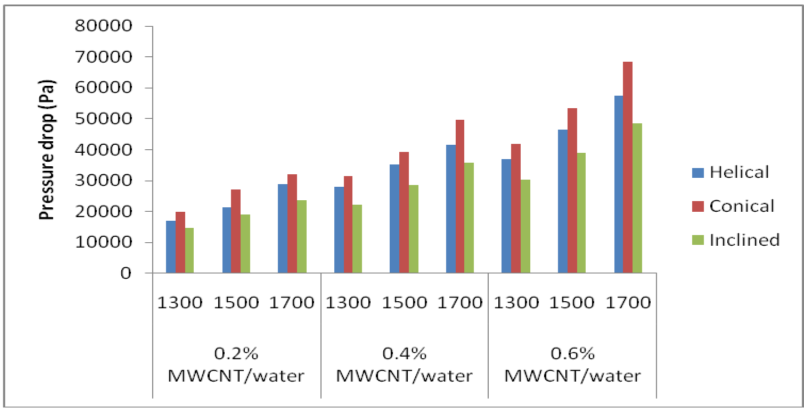



**Figure -17:** Graphs for pressure drop of MWCNT/water nanofluids in various tube in-tube heat exchangers

| Tube in tube heat exchanger | 0.2% MWCNT/water | | | 0.4% MWCNT/water | | | 0.6% MWCNT/water | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dean no.-1300 | Dean no.-1500 | Dean no.-1700 | Dean no.-1300 | Dean no.-1500 | Dean no.-1700 | Dean no.-1300 | Dean no-1500 | Dean no-1700 |
| helical | 17128.24 | 21460.04 | 28773.78 | 28152.46 | 35358.4 | 41511.82 | 37094.96 | 46414.76 | 57437.8 |
| conical | 19806 | 27068 | 31961 | 31554 | 39343 | 49616 | 41927 | 53547 | 68407 |
| Inclined rectangular | 14838.57 | 19061.23 | 23728.86 | 22333.4 | 28688.89 | 35714.1 | 30255.21 | 38865.03 | 48382.13 |

**Table-13: Pressure drop values of MWCNT/water nanofluids in helical, conical and inclined rectangular tube in-tube heat exchanger**

From fig.17, it is seen that increasing the volume concentrations of nanoparticles in nanofluids, increases the pressure drop in helical,conical and inclined rectangular coiled tube in-tube heat exchanger.the highest pressure drop is found in conical coiled tube in-tube heat exchanger at 0.6% of MWCNT/water nanofluids.

### 3.5.4. Friction factor at 0.2%, 0.4% and 0.6% of MWCNT/water nanofluids

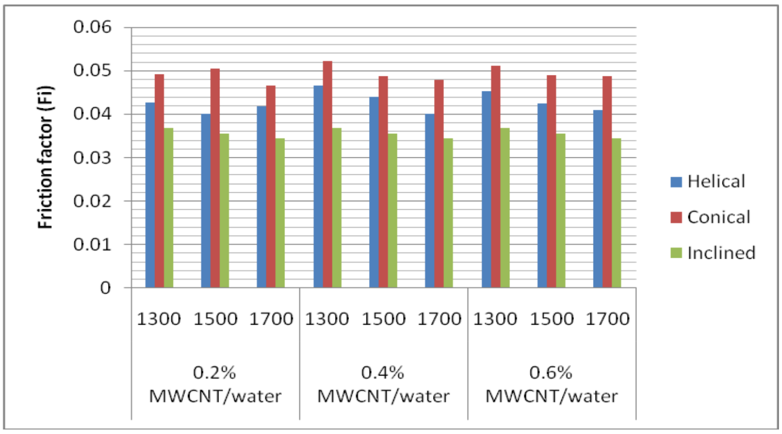



**Figure -18:** Graphs for friction factor of MWCNT/water nanofluids with various in tube in-tube heat exchangers

| Tube in tube heat exchanger | 0.2% MWCNT/water | | | 0.4% MWCNT/water | | | 0.6% MWCNT/water | | |
|---|---|---|---|---|---|---|---|---|---|
| | Dean no.1300 | Dean no-1500 | Dean no-1700 | Dean no-1300 | Dean no.-1500 | Dean no.-1700 | Dean no.-1300 | Dean no.-1500 | Dean no.-1700 |
| helical | 0.042601 | 0.04009 | 0.041849 | 0.046522 | 0.043887 | 0.040115 | 0.045249 | 0.042526 | 0.040972 |
| conical | 0.049261 | 0.050567 | 0.046485 | 0.052143 | 0.048833 | 0.047946 | 0.051143 | 0.049061 | 0.048796 |
| Inclined rectangular | 0.036906 | 0.035609 | 0.034512 | 0.036906 | 0.035609 | 0.034512 | 0.036906 | 0.035609 | 0.034512 |

**Table-14: Friction factor values of MWCNT/water nanofluids in helical, conical and inclined rectangular tube in-tube heat exchanger**

From fig.18, it is well seen that the conical tube in-tube heat exchanger is showing better friction than helical and inclined tube in-tube heat exchanger.0.4% of MWCNT/water are showing highest friction factor values. It is also seen that increasing the dean number is leads to a decrease in the friction values by 6% from 1300 to 1700 dean number.

## 4. CONCLUSIONS

Based on a through analysis of work, the following conclusion can be drawn –

- MWCNT/water nanofluids at 0.6% of volume concentrations of nanoparticles in water have shown good heat transfer coefficient, pressure drop, and friction factor value from all of the considered nanofluids on the comparison.
- When compared to water, nearly 2.5 times of the heat transfer coefficient was improved in 0.6% of MWCNT/water nanofluids in a conical coiled tube in-tube heat exchanger.
- When dean number is increasing from 1300 to 1700, slightly 20% heat transfer coefficient is increased in every geometry designs with volume concentrations of 0.2%, 0.4% and 0.6% nanoparticles.
- MWCNT/water nanofluids with 0.2% of nanaparticles concentrations shows highest nusslet number in conical coiled tube in -tube heat exchanger.
- Pressure drop of MWCNT/water nanofluids of conical tube in-tube heat exchanger has shown better results than helical and inclined rectangular tube in-tube heat exchanger with improvement of 16% and 40% respectively and 10% improvement in friction factor when compared with inclined rectangular tube in-tube heat exchanger.
- Theoretical results were done for the ideal heat exchanger. Almost all the results have a good agreement. CFD simulation software is useful to analyze this type of works to reduce the cost and provide better results.

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