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Investigation on Thermal and Flow Behaviours of MWCNT/Water Nano Fluids in a Cone Helically Coiled Heat Exchanger by Varying Pitch Sizes of the Tube Using CFD

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Abstract- **Coiled tube configurations is widely used in industries like power plants, nuclear reactors, refrigeration and air conditioning , heat recovery system, chemical processing and food industries. The coiled tube is of two types alike helical coil and spiral coiled tube. The flow pattern in helical coiled tube is complicated due to the formation of secondary flows induced by the centrifugal force. Secondary flow provides better thermal contact between the surface of the tube and fluids due to the creation of vertex and resulting the mixture of fluid which improve the temperature gradient.**

This study investigates the heat transfer and the pressure drop of cone helically coiled tube heat exchanger using (Multi wall carbon nano tube) MWCNT/water nanofluids by varying pitch size of the tubes. The MWCNT/water nanofluids 0.5% particle volume concentrations were used. The simulation were conducted under the turbulent flow in the Dean number range of 2200 < De < 4200. It is found that the maximum overall heat transfer coefficient for pitch=22 mm is 32.23% higher than the pitch=18mm in the Dean number 4200.It is found that the maximum Nusselt number for pitch=22 mm is 14.91% higher than the pitch=18mm in the Dean number 4200.From the pressure and temperature contours it was found that along the outer side of the pipes the velocity and pressure values were higher in comparison to the inner values. It may be concluded that by increasing pitch size of cone helically coiled heat exchanger, the heat transfer rate increases as Nusselt no. and Overall heat transfer increases.

Index terms- **Volume concentration of nanoparticle, Cone helically coiled tube, MWCNT /water nanofluids, Computational fluid dynamics, Pressure drop, Thermal conductivity, Nanofluid viscosity, Pitch size.**

I.INTRODUCTION

The design of heat exchangers and heat transfer enhancement techniques are picking up momentum nowadays because of the challenging in meeting our current cooling demand. Heat transfer enhancement techniques generally reduces the thermal resistance either by increasing the effective surface area or by generating turbulence in the fluid flowing inside the heat exchanger.

Mainly heat transfer augmentation techniques can be grouped into three categories: active, passive and compound technique. In Active techniques, heat transfer enhancement is done by employing external forces while in the case of Passive techniques, needs a special surface geometric face or fluid additives and various tube inserts. Many researchers worked on the passive heat transfer enhancement techniques rather than the active heat transfer enhancement techniques. However, the work on curved tubes and helically coiled tubes need more knowledge about the flow of primary and secondary flow formation.

Helically coiled tube heat exchangers are used in power plants, nuclear plants, process plants, automobile, refrigeration, heat recovery units, processing industries and steam generation in marine due to their compact shape and effective heat transfer. The flow pattern in helical coiled tube is complicated due to the formation of secondary flows induced by the centrifugal force. Secondary flow provides better thermal contact between the surface of the tube and fluids due to the creation of vertex and resulting the mixture of fluid which improve the temperature gradient.

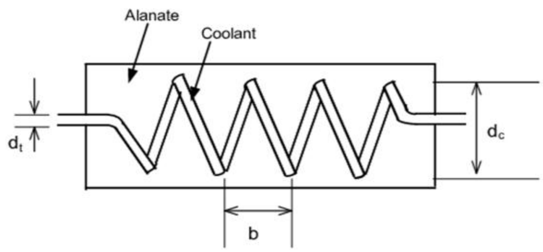

Figure 1: Helical Coil tube configuration

II. LITERATURE REVIEW

Dean [1927, 1928] suggested that the helically coiled tubes are better than straight tubes in view of heat transfer rate as the coiled tube forms strong secondary flow and named the vortex as Dean Vortex. Dean found that the secondary flow in coiled tubes (Dean Vortex) is a function of Reynolds number and the d/D ratio [1, 2].

Dean [1928] investigated the steady-state condition of incompressible fluid flow through the helically coiled tubes. He reported that the mass flow rate decreases with respect to the coil ratio [2].

Vimal Kumar et al. [2006] revealed that there is a poor circulation of a fluid in the shell region of the shell and single helically coiled heat exchanger [3].

Ferng et al. [2012] worked on the effect of changing the Dean Number and pitch of the helically coiled tube on heat transfer. They revealed that the creation of secondary flow becomes weaker when increasing the coiled tube pitch [4].

Narrein and Mohammed [2014] numerically studied the effect of Al2O3, SiO2, CuO, ZnO concentration and size of the nanoparticles, different base fluids such as water, ethylene glycol and engine oil on the heat transfer and fluid flow characteristics. They suggested the nanofluids based on the SiO2 has higher pressure drop than other Al2O3, SiO2, CuO, ZnO nanofluids. They found that the pressure drop increases when increasing particle concentration and decreasing particle diameter as a result of improved viscosity. The nanofluid based on the engine oil has highest pressure drop when compared with the nanofluids based on the ethylene glycol and water [5].

Bahiraei et al. [2017] investigated the entropy generation due to particle migration for biologically produced nanofluids in a mini double pipe heat exchanger. They found that the nanofluid at higher concentration and Reynolds number gives higher migration which generates more entropy. They studied that the heat transfer contribution increases when the inlet water temperature raises to 360K. They also found that the entropy generation at the wall has smaller contribution to the total entropy generation [6].

K. Palanisamy et al. [2019] numerically investigated the heat transfer and the pressure drop of cone helically coiled tube heat exchanger using (Multi wall carbon nano tube) MWCNT/water nanofluids. The tests was conducted under the turbulent flow in the Dean number range of $2200 < De < 4200$. The experiments was conducted with experimental Nusselt number is 28%, 52% and 68% higher than water for the nanofluids volume concentration of 0.1%, 0.3% and 0.5% respectively. It was found that the pressure drop of 0.1%, 0.3% and 0.5% nanofluids are found to be 16%, 30% and 42% respectively higher than water. It is also studied that there is no immediate risk of handling MWCNT and studied that there is no significant erosion of coiled tube inner wall surface even after several test runs. Therefore the MWCNT/water nanofluids are the alternate heat transfer fluids for traditional fluids in the cone helically coiled tube heat exchanger to improve the heat transfer with considerable pressure drop [7].

It is studied from the literature review that most of the experimental works on double helically coiled tube heat exchanger have been done by using oxide nanofluids. Very little works have been done on cone helically coiled tube heat exchanger by using MWCNT/water nanofluids with CFD software. With advances in numerical techniques and computation power, Computational Fluid Dynamics (CFD) can be used to predict the performance of machines in design phase only without manufacturing them. Conventional methods are found to be very expensive and time consuming. CFD has emerged as boon for researchers. With the help of CFD, one can determine effectiveness, heat transfer rate detailed parameters easily. Much commercial software are available in the market. By using CFD, information about the output temperature, velocity, pressure and other non-dimensional parameters can be obtained. CFD is not only useful to predict the performance but it also helpful to determine the effect of change in any design parameter on its output.

Therefore this investigation deals with the thermal and flow behavior of cone helically coiled tube heat exchanger handling MWCNT/water nanofluids at three different pitch numbers by varying pitch of helical coil.

III.METHODOLOGY

The geometry of cone helically coiled tube heat exchanger performing the simulation study is taken from the one of the research scholar's K. Palanisamy et al. [2019] with exact dimensions. The part of the model designed in ANSYS (fluent) workbench 14.5 software. The geometric dimension and test setup is shown in Table 1 and figure 2 respectively.

Table 1. Dimensions of cone coil tube

Cone coil angle (θ)	8 degree
Cone inner tube dimeter (d_i)	0.08 cm
Cone outer tube diameter (d_o)	0.1 cm
Diameter of the shell	11.4 cm
Effective length of the coil	470 cm
Pitch of the coil	1.8, 2.0, 2.2 cm
Calming section length	11 cm
Cone coil diameter	6.4 cm
Number of turns	16

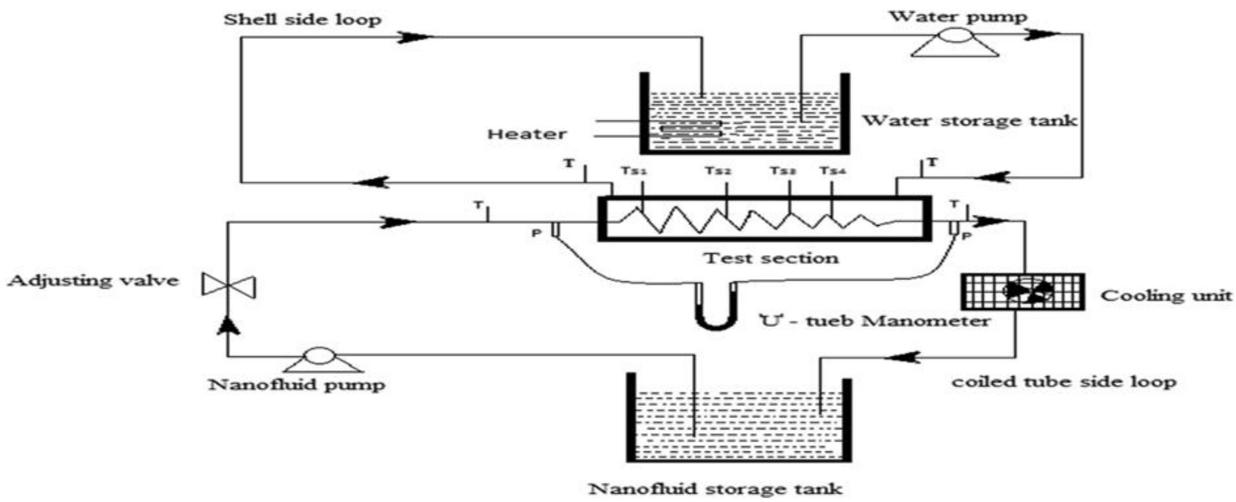

Figure 2. layout of the experimental setup [9]

The test setup has two loops. The first one is cone helically coiled tube side which handles nanofluids. The second loop is the shell side which handles hot water.

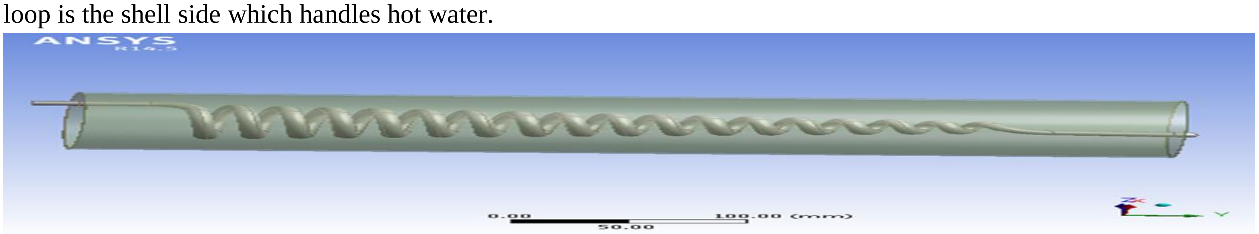

Figure 3. Geometry of Cone helically coiled tube heat exchanger in design modular

The modelling of the test section is meshed with ANSYS 14.5.The coarser meshing is created throughout the effective length of the tube. Figure 3 represents the meshing of cone helically coiled heat exchanger used in the CFD analysis.

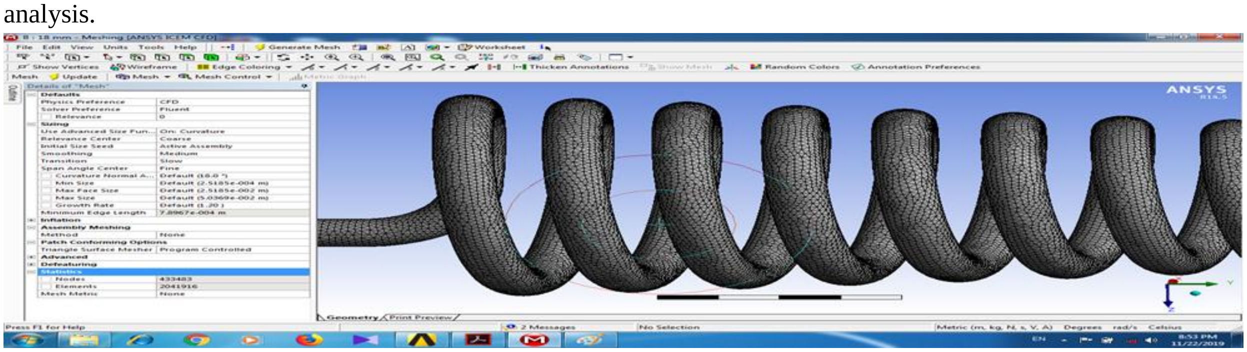

Figure 4. Meshing of cone helically coiled tube

The meshing contains the collaborated cells for triangular and quadrilateral expressions at boundary conditions. Much effort has been given to the structure hexahedral cells. The smooth meshing is created, edges as well as region of pressure and temperature constraints, meshed.

Table 2. meshing information of the test section.

Meshing Detail		
Pitch	No. of Nodes	No. of Elements
18mm	433483	2041916
20mm	412140	1565568
22mm	384315	1829431

The analysis type is change into heat transfer analysis type. The problem type is 3-D and type of solver is pressure based. The velocity is changed to absolute velocity and gravity is set to -9.81 m/s2.

Model Selection:

- The numerical simulation performed by the steady state with pressure oriented methods.
- The k-epsilon model is chosen for the analysis as the k-epsilon equation model predicts well far from the boundaries (wall) and k-omega model predicts well near wall.
- Continuity, energy and Navier-stokes equations are used for find the condition of fluid flowing in the helically coiled tube.
- Flow is hydrodynamic.
- Effect of radiation and net convection are neglected.

Governing Equations:

The continuity equation gives the conservation of mass and given as:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho U_1}{\partial x_1}+\frac{\partial \rho U_2}{\partial x_2}+\frac{\partial \rho U_3}{\partial x_3}=0$$

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial x_1}=0$$

$$\frac{\partial \rho}{\partial t}=0 \text{ (for incompressible fluids)}$$

The momentum balance follows Newton's second law. Two forces acting on the bod y and surface pressure. The momentum equation is given by:

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

The governing energy equation is given by:

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

Where ρ is density Kg/m^3 , t is the time in s, U and V are the velocity components, C_p is the specific heat in J/Kg-K, u and v are the velocity along x and y directions, K is the thermal conductivity in W/m-K , T is the temperature in Kelvin.

Material Selection

Table 3. Thermo-physical properties of Water

Water properties	
Density	997 Kg/m^3
Specific heat capacity	4181 J/Kg-K
Thermal conductivity	0.613 W/m-K
Viscosity	0.0007 Kg-m/s

Table 4. Thermo-physical properties of MWCNTs

MWCNT Nano powder properties	
Form	Solid
Outer Dia.	50-80 nm
Inner Dia.	5-15 nm
Length	10-20 μm
Specific surface area	32-40 m^2/g
True Density	2.1 g/cm^3
Bulk Density	0.18 g/cm^3
Purity	99.5%
Thermal conductivity	3000 W/m-K

Pak and cho [8], Patel [9] and Ebrahmnia- Bajestan [10] suggested the below equations for determining density, thermal conductivity, specific heat and viscosity of nanofluids.

$$\rho_{nf}=\emptyset\rho_p+(1-\emptyset)\rho_f$$

$$\left(\rho C_p\right)_{nf}=(1-\emptyset)(\rho C_p)_f+\emptyset(\rho C_p)_p$$

$$K_{nf}=K_f\left[1+\frac{K_p\emptyset\ r_f}{K_f(1-\emptyset)r_p}\right]$$

$$\mu_{nf}=\mu_f(1+22.7184\emptyset-9748.4\emptyset^2+1000000\emptyset^3)$$

Table 5. Thermo-physical properties of carbon nanotubes/ water nanofluids at 0.5% volume concentration

MWCNT/ water nanofluids at 0.5% volume concentration	
Density	1660 Kg/m^3
Specific heat capacity	1014 J/Kg-K
Thermal conductivity	0.635 W/m-K
Viscosity	0.00085 Kg-m/s

Boundary Conditions

- Flow is turbulent and counter flow conditions.
- The nanofluid of 0.5% volume concentration are supplied for cone helically coiled tube and hot water is supplied to the shell side.
- The mass flow rate of shell side is maintained constant at 0.15 Kg/s.
- The inlet temperature of hot fluid (shell) is 338 K whereas the inlet temperature of cold fluid (for cone helically coiled tube) is 305 K.

- The flow rate of the cone tube which handled nanofluid is varies from 0.05-0.07 Kg/s.The corresponding Dean number (De) range is 2200 < De < 4200.

$$De = Re_i\left(\frac{d_i}{2R_c}\right)^{0.5}$$

IV. RESULTS AND DISCUSSIONS

After putting all the boundary conditions, the solution is initialized and then the iteration is applied so the value of all parameter can be seen in a line curve graph. As the iteration gets completed final results could be seen. The result can be viewed in the form of graph, contours, value, animation etc.

The average heat transfer, Nusselt number, Pressure drop, Overall heat transfer coefficient are calculated by the equations given below:

$$Q_w = \dot{m}_w \times c_{p,w} \times (T_{in} - T_o)_w$$

$$Q_{nf} = \dot{m}_{nf} \times c_{p,nf} \times (T_{in} - T_o)_{nf}$$

$$Nu_i = \frac{h_i d_i}{k_{eff}}$$

$$Q = h_i \times A_i \times (T_{wall} - T_{bulk})$$

$$Q = U_o \times A_O \times (\Delta T)_{LMTD}$$

$$\Delta P = \rho \times g \times \Delta h$$

In order to validate the CFD model of cone helically coiled tube heat exchanger for initial case we considered hot water is supplied to the shell side and nanofluid of 0.5% volume concentration are supplied for cone helically coiled tube (pitch= 20 mm) at different Dean number.

The values of Nusselt no. calculated from the CFD modeling were compared with the values obtained from the experimental analysis performed by K. Palanisamy et al. [2019].

Table 6. Comparison of values of Nusselt no. at different Dean no. (Pitch=20mm)

S. No	Dean Number	Nusselt no. obtained from base paper	Nusselt no. obtained from CFD analysis	Percentage Error
1	2200	74	74.84	1.13
2	3025	97	97.9	0.92
3	4200	119.5	126.99	6.26

The values of Overall heat transfer coefficient calculated from the CFD modeling were compared with the values obtained from the experimental analysis performed by K. Palanisamy et al. [2019].

Table 7. Comparison of values of overall heat transfer coefficient at different Dean no. (Pitch=20mm)

S. No	Dean Number	Overall heat transfer coefficient (W/m^2-K) from base paper	Overall heat transfer coefficient (W/m^2-K) from CFD analysis	Percentage Error
1	2200	860	872	1.39
2	3025	970	983	1.34
3	4200	1140	1156	1.40

The values of Pressure drop calculated from the CFD modeling were compared with the values obtained from the experimental analysis performed by K. Palanisamy et al. [2019].

Table 8. Comparison of values of Pressure drop at different Dean no. (Pitch=20mm)

S. No	Dean Number	Pressure drop obtained from base paper	Pressure drop obtained from CFD analysis	Percentage Error
1	2200	10520	11180	6.27
2	3025	14750	15717	6.55
3	4200	16950	17469	3.06

From the above it is found that the value calculated from CFD analysis is close to the value obtained from the base paper. So here we can say that the CFD model of cone helically coiled heat exchanger is correct.

Comparison of Nusselt number, Pressure drop and Overall heat transfer coefficient at different dean number for different pitch number

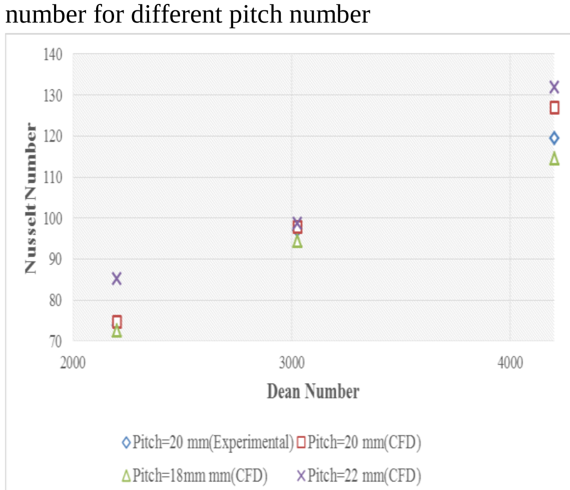

Figure 5. Comparison of values of Nusselt no. at different Dean No. for different pitch number

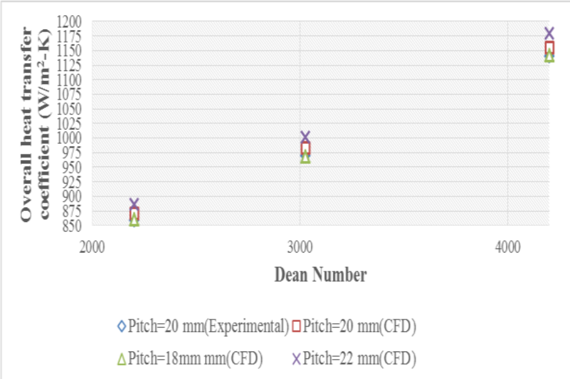

Figure 6. Comparison of values of Overall heat transfer coefficient at different Dean No. for different pitch number

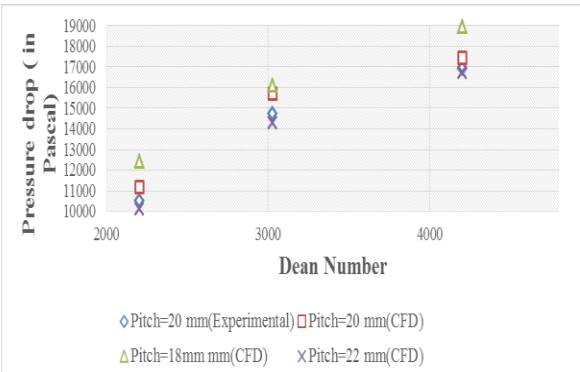

Figure 7. Comparison of values of Pressure drop at different Dean No. for different pitch number

V. CONCLUSIONS

In this analysis, the heat transfer and pressure drop of a cone helically coiled tube heat exchanger handling MWCNT/water nanofluids have been studied with CFD software package. Initially, hot and cold water are used to check the simulation and recorded the pressure and temperature of MWCNT/water of nanofluids at 0.5% volume concentrations with the Dean number range of 2200–4200.

- CFD data were compared with experimental data and hold good agreement with the deviation of CFD Nusselt number and pressure drop are 2.5 % and 1.5 % with the experimental data.
- It is found that the maximum overall heat transfer coefficient for pitch=22 mm is 32.23% higher than the pitch=18mm in the Dean number 4200.
- It is found that the maximum Nusselt number for pitch=22 mm is 14.91% higher than the pitch=18mm in the Dean number 4200.
- From the pressure and temperature contours it was found that along the outer side of the pipes the velocity and pressure values were higher in comparison to the inner values.
- In present case it may be concluded that by increasing pitch size of cone helically coiled heat exchanger, the heat transfer rate increases as Nusselt no. and Overall heat transfer increases.

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