CFD INVESTIGATION INTO ENHANCEMENT OF HEAT TRANFER IN COILED TUBE HEAT EXCHANGER USING NANOFLUID

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Abstract: This paper studies the heat transfer properties of a helical coiled heat exchanger by the use of nanofluids to enhance these properties. The analysis compares these properties for two different nanoparticles suspended in water to determine which gives a better result and also economical to use. Copper oxide and aluminum oxide nanoparticles suspended in water were used and the results were also compared with water as a working fluid for the heat exchanger.

Analysis was carried out using CFD software, Ansys fluent 16.0, and the heat exchanger was also modeled using Solidworks 2016. The results were validated by carrying out the CFD analysis of a heat exchanger with known results, the CFD results were compared to prove that it is a reliable tool for thermal analysis.

***IndexTerms* -** nanofluids, Heat Exchanger, Thermal analysis, CFD.

1.0 INTRODUCTION

Helical coil is widely known for its numerous advantages when used as heat exchangers. These advantages ranges from compact size of the device, which makes it less bulky to handle to enhanced heat transfer characteristics of the heat exchanger due to bigger heat transfer surface area and enhanced flow characteristics of the fluid. Due to better performance of coiled tube in heat transfer, when compared to other heat exchangers, great attention has been paid to helical coiled tube heat exchangers, and many researchers have carried out various investigations to study the various characteristics of this heat exchanger and find out ways of improving its performance.

1.1 Aim & Objective

This study compares the rate of heat transfer in a coiled heat exchanger given water and nanofluid at different concentrations of 5%, 10% and 15%. These concentrations compares with water without any particle. The validation of CFD software isalso carried out to prove that ansys fluent is a good thermal analysis program.

1.2 Methodology

The main aim of this paper is to study the thermal properties of a coiled tube heat exchanger with data obtained from CFD software and compare these data for various working fluid properties.

The result can be obtained from the ansys software; however, given the temperature values of the heat exchanger, the following equations can be used to obtain the necessary results.

$$U_0 = \frac{q}{A_0 \Delta T_{LM}} \tag{1}$$

$$q_h = m_h C_{p,h} (T_{in} - T_{out})_h \tag{2}$$

$$q_c = m_c C_{p,c} (T_{in} - T_{out})_c \tag{3}$$

$$q = \frac{q_c + q_h}{2} \tag{4}$$

$$\Delta T_{LM} = \frac{\Delta T_1 + \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} \tag{5}$$

$\Delta T_{LM} = Log\ mean\ temp.difference$; ΔT_1 = inlet temp difference; ΔT_2 = outlet temp difference; $q = heat\ transfer\ rate$; $m_h = mass\ flow\ rate$; $C_p = specific\ heat$; $U_0 = overall\ heat\ transfer\ coefficient.$

2.0 Literature Review

[1] Jamshidi et al (2013) used the Taguchi method to investigate the best design parameters for optimum heat transfer characteristics of helical coiled heat exchanger experimentally. It was observed that increase in the coil diameter, pitch and mass flow-rate positively affects the heat transfer rate.

Results from the experimental analysis showed that the pitch, coil diameter and shell and tube flow rates are very important parameters in design of a coiled tube heat exchanger. It was agreed that the best design parameters for optimum performance of a coiled tube heat exchanger are 116mm coil diameter,18mm coil pitch with both cold and hot fluid inlet flow rate at 3LPM.

Similarly, [2] Sibel et al (2011) used the parameter design stage of the Taguchi method to identify the parameter setup which will minimize variation in performance characteristics of the coiled tube heat exchanger. This analysis was performed on a tube with equilateral triangular cross-sectioned coiled wire inserts.

[3] Ghorbain et al (2010) studied the mixed convection heat transfer characteristics of a vertically coiled tube heat exchanger. The experimental analysis was carried out by varying the Reynold’s number, tube to coil diameter ratio and dimensionless coil pitch. This study concentrates mainly on the effect of the coil pitch and tube diameter on the shell side heat transfer coefficient of the heat exchanger.

The experimental analysis was performed for both turbulent and laminar flow in the coil side fluid flow of the heat exchanger. The result showed that given the same dimensionless pitch, the tube diameter effect on the heat transfer coefficient is negligible. The tube diameter therefore does not influence the heat transfer coefficient. Result also showed that the heat transfer coefficient is largely affected by the coil surface area.

[4] Salimpour M. R. (2009) experimentally investigated the heat transfer coefficient of shell and helically coiled tube heat exchanger by using three different coil pitches. The experiment was conducted for both parallel and counter-current fluid flow in the system. The result showed that the shell side heat transfer coefficient of the heat exchanger with tubes of higher pitch is higher than those with smaller tube pitches. It was also observed that the shell side Nusselt number increases with pitch number increase.

[6] Hussein et al (2013) used cfd software to study the thermal properties of nanofluids inside a heated flat tube. It was found that the thermal conductivity and viscosity increases with increasing volume concentration of nanofluid, with a maximum deviation of19% and 6% respectively. Nusselt number and friction factor also increased with volume concentration. Al_2O_3 was found to have the highest value of thermal conductivity.

[7] Mostafa Keshavarz Moraveji (2014) performed cfd analysis to compare heat transfer and pressure drop on helically coiled and straight tube heat exchanger with both pure oil and CuO/oil base nanofluid. The volume concentration was and the effect of shape of tube was studied. Result showed that heat transfer increased by 28% when comparing the nanofluid to oil. Pressure drop slightly rose with the adjustment of nanoparticle concentration.

3.0 Design Model

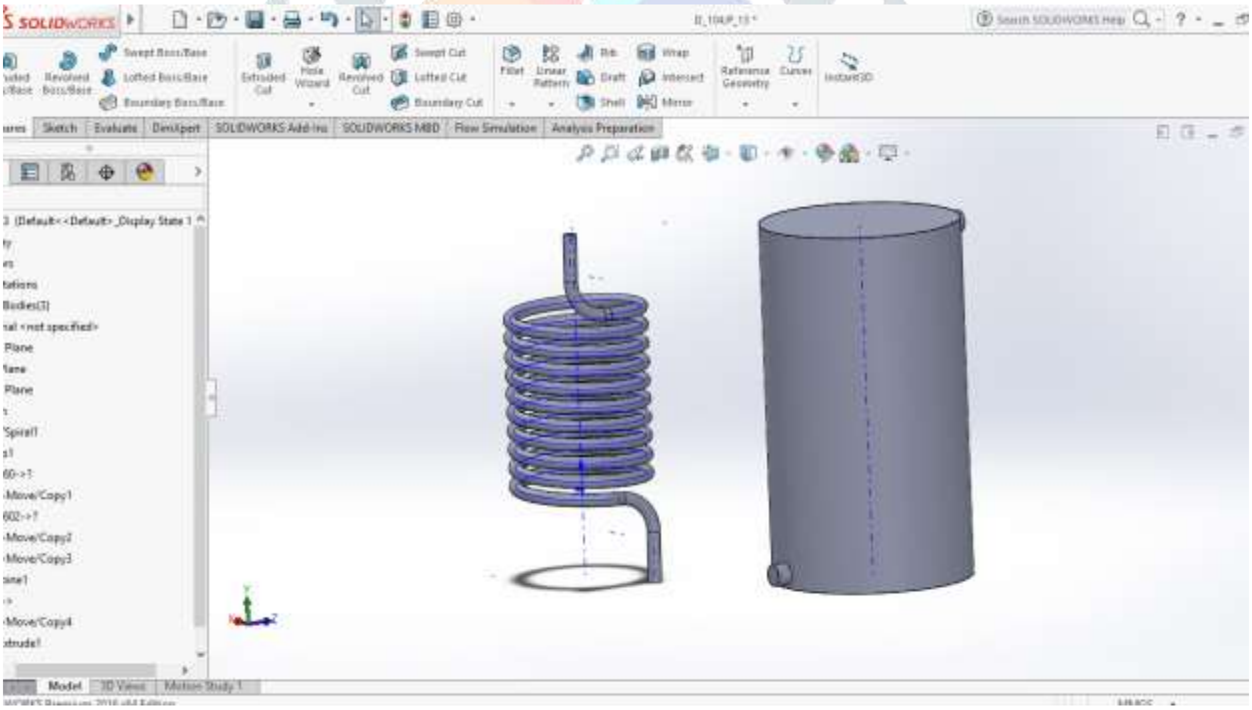


Fig. 1. Design of coiled tube heat exchanger with Solidworks 16

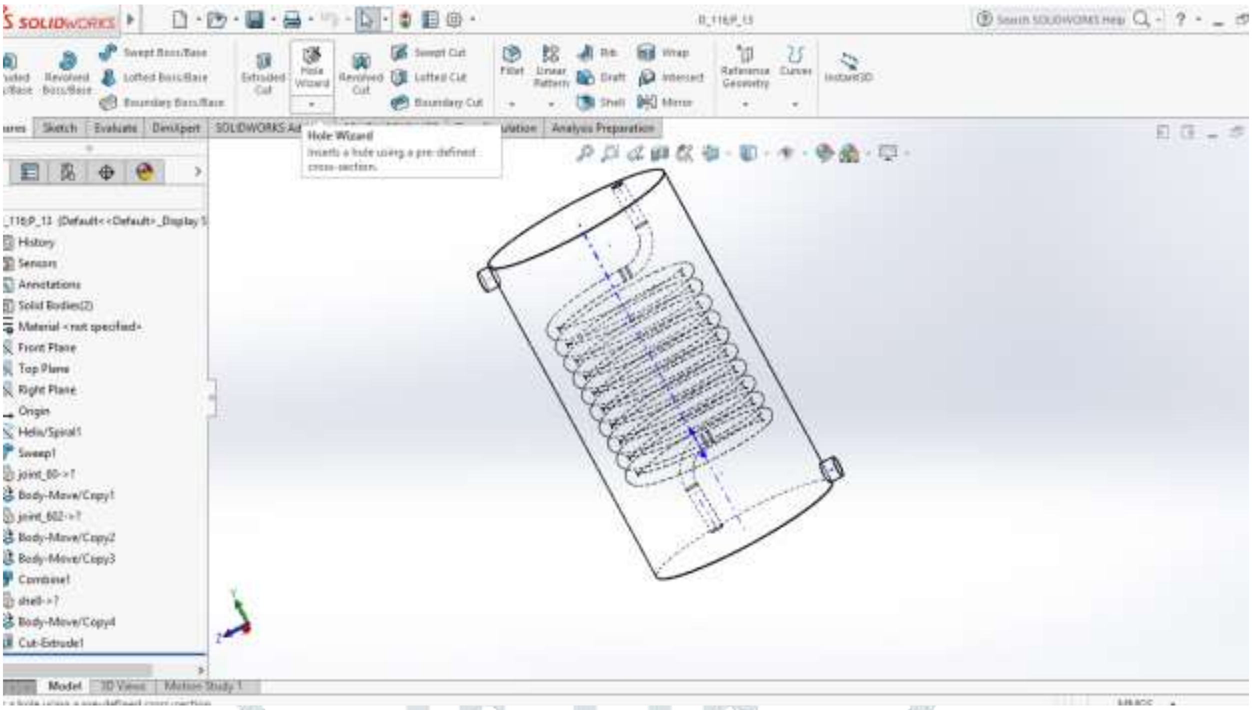


Fig. 2. Image of assembled heat exchanger

The modeling of the heat exchanger was done using the solidworks program 2016 version and later imported to Ansys fluent for computational analysis.

3.1 Computational analysis

A steady state heat transfer analysis was carried out for the present research, to study and compare the thermal properties of helical coiled tube heat exchanger with two various nanofluid as the working fluid. The analysis was performed using ansys fluent 16.0 on a computer with the following configuration; intel core i5, 4GB ram and a CPU speed of 2.20GHz.

The models were meshed with a minimum of 140,000 nodes and 240,000 elements using the fluent mesh tool. The standard k-epsilon model was applied for the analysis and the material properties were kept constant.

A simple algorithm was used for the pressure-velocity coupling. Second-order upwind scheme was applied for solving the momentum and energy equation. The convergence criterion was set at $1.0e^{-05}$ for continuity and velocity in all direction; and $1.0e^{-08}$ for energy equation. A total of 2000 iterations were done for each analysis an lasted for 28 hours.

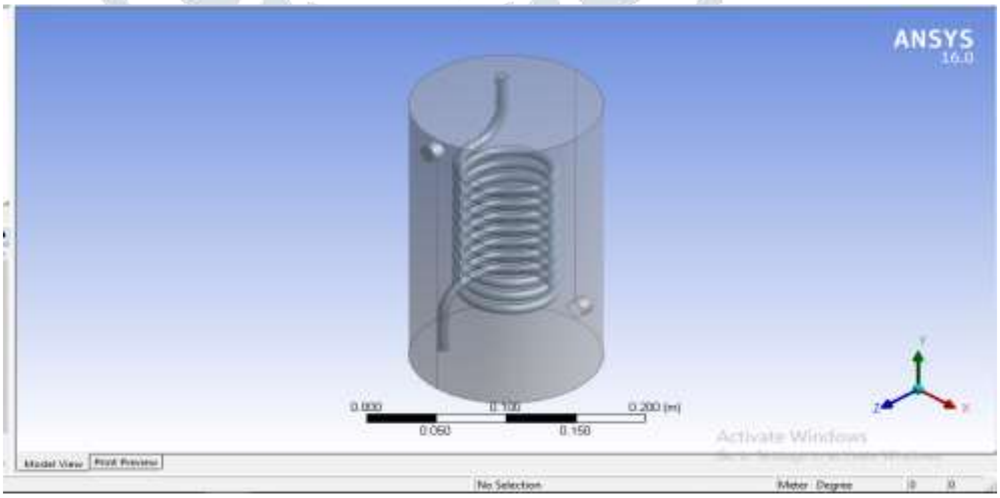
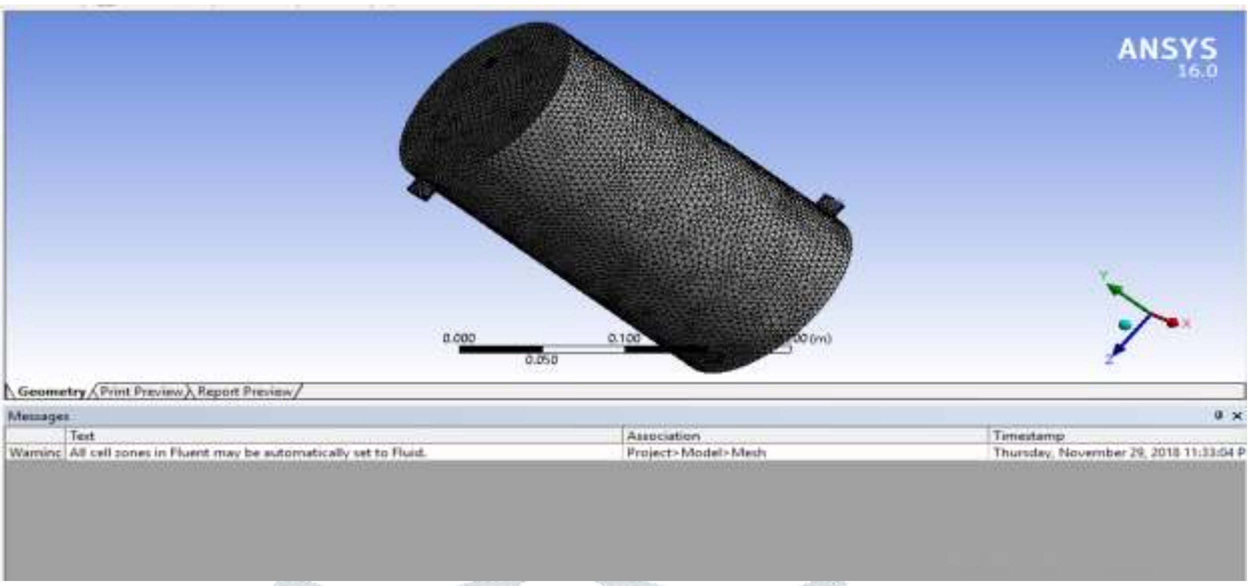


Fig. 3. image of imported heat exchanger model in ansys design modeler



	Text	Association	Timestamp
Warninc	All cell zones in Fluent may be automatically set to Fluid.	Project>Model>Mesh	Thursday, November 29, 2018 11:33:04 P

Fig. 4 image of meshed heat echanger model in ansys mesh tool

3.3 Working Fluid:

Thermo physical properties of the nanofluids are defined by the equations below, and then input in the Material option of the ansys fluent setup window.

i) Density (ρ)

$$\rho_{nf} = \rho_{bf}\left(1 + \frac{\phi(\rho_p - \rho_{bf}}{\rho_{bf}}\right) \tag{6}$$

ii) Specific Heat (C_p)

$$(C_p)_{nf} = (C_p)_{bf}\frac{1-\left(\frac{\phi\left((C_p)_{bf}\,\rho_{bf}-(C_p)_p\rho_p\right)}{(C_p)_{bf}\rho_{bf}}\right)}{(1+\frac{\phi(\rho_p-\rho_{bf}}{\rho_p})} \tag{7}$$

iii) Viscosity (μ)

$$\mu_{nf} = (1 + 2.5\phi)\mu_{bf} \tag{8}$$

iv) Thermal Conductivity (k)

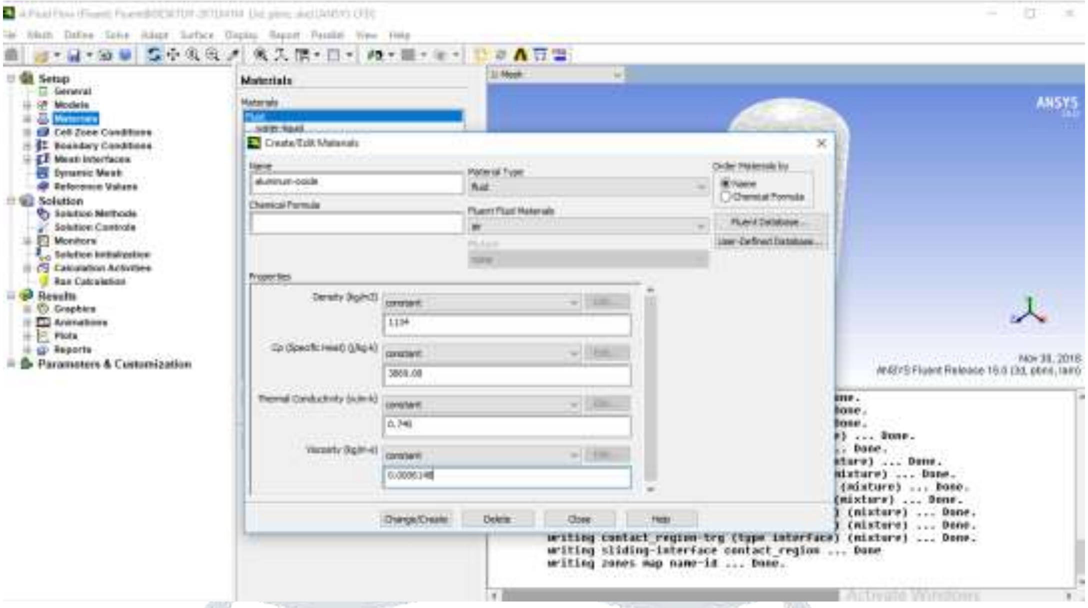
$$k_{nf} = \frac{k_p+(n-1)k_{bf}-(n-1)\phi(k_{bf}-k_p)}{k_p+(n-1)k_{bf}+\phi(k_{bf}-k_p)}k_{bf} \tag{9}$$

The subsets above represents, nf - nanofluid; bf - base fluid; ϕ - concentration; p – particle.

The boundary conditions were set for inlet flow rate at the inlet of both tube and shell, and pressure outlet set at the outlets of the model. The temperature of the tube and shell fluid region was also set. The table below shows the boundary inputs in the heat exchanger.

Properties	value
Mass flow inlet (l/min)	3
Hot fluid temp (C)	50
Cold fluid temp (C)	20
Nanoparticle concentration (%)	5-15

Table 1 fluid boundary inputs



Name: aluminum-oxide
Material Type: fluid
Fluent Fluid Materials: air
Order Materials by: ● Name ○ Chemical Formula
Density (kg/m3): constant 1134
Cp (Specific Heat) (j/kg-k): constant 3869.08
Thermal Conductivity (w/m-k): constant 0.746
Viscosity (kg/m-s): constant 0.0006148

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writing contact_region-trg (type interface) (mixture) ... Done.
writing sliding-interface contact_region ... Done
writing zones map name-id ... Done.
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Fig.4. Material creation for nanofluid

4.0 RESULTS

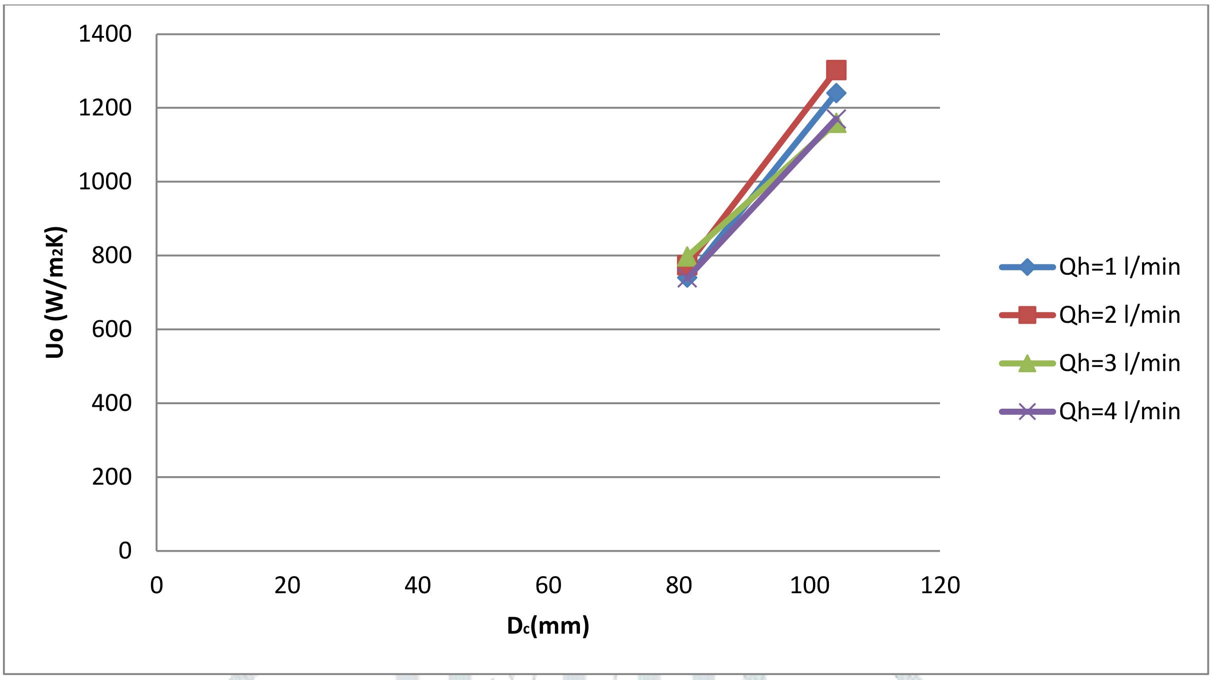
CFD analysis was performed for 3different concentration for both copper oxide and aluminum oxide. The parameters for analysis are in the table above. The overall heat transfer coefficient and rate of heat transfer were calculated using equations (1) – (5), results and graphs are represented below:

mass flow inlet(l/min)	inlet hot temp(K)	outlet hot temp(K)	inlet cold temp(K)	outlet cold temp(K)	log mean temp.	Overall heat transfer coefficient(W/m^2k)
1	323	315	293	297	23.4	739.99
2	323	319	293	298	25.16	774.37
3	323	320	293	298	25.79	797.22
4	323	321	293	298	26.35	739.42

Table 2 table of result for tube diameter 81.3mm

mass flow inlet(l/m)	inlet hot temp(K)	outlet hot tem(K)	inlet cold temp(K)	outlet cold temp(K)	log mean temp	overall heat transfer coefficient(W/m^2k)
1	323	310	293	299	18.94	1240.13
2	323	315	293	300	21.64	1302.26
3	323	318	293	300	23.49	1159.78
4	323	319	293	300	24.08	1170.34

Table 3 table of result for tube diameter 104.1mm



Graph 1. Effect of coil diameter on overall heat transfer coefficient

The table and graph above confirms to that in the base paper, given the losses in the experimental data due heat loss to the surrounding, roughness of tube and other losses during the analysis. These losses are however not present in CFD analysis, giving rise to slight deviation between experimental and computational datas.

Qh in the graph above represents the flow rates and ranges from 1- 4 litres/minute.

4.1 Enhanced Model

Having confirmed that the ansys fluent is a reliable program for thermal analysis , the heat transfer analysis was carried out for a coiled tube heat exchanger having coil diameter of 116mm and coil pitch of 18. The flow rate for both hot and cold fluid region was set at 3l/min. varying the concentration of the nanofluid used as the working fluid gives the result:

	mass flow inlet	inlet tube temp	outlet tube temp	inlet shell temp	outlet shell temp	log mean temp
Water	3	323	317	293	299	23.49
Aluminium oxide						
5% conc	3	323	311	293	303	16.65
10% conc	3	323	312	293	302	18.2
15% conc	3	323	311	293	303	16.65
Copper oxide						
5% conc	3	323	312	293	302	18.2
10% conc	3	323	312	293	302	18.2
15% conc	3	323	310	293	303	15.8

Table 4. Table of temperature in tube an shell boundaries with different nanofluid concentration

	overall heat transfer coefficient	Q
Water	961.64	1287.2

Aluminium oxide		
5% conc	1422.69	2250.34
10% conc	1102.42	1906.08
15% conc	1361.74	2153.93
Copper oxide		
5% conc	1180.19	2040.54
10% conc	1152.12	1992.01
15% conc	1485	2228.98

Table 5. Table of thermal properties for different nanofluid concentrations

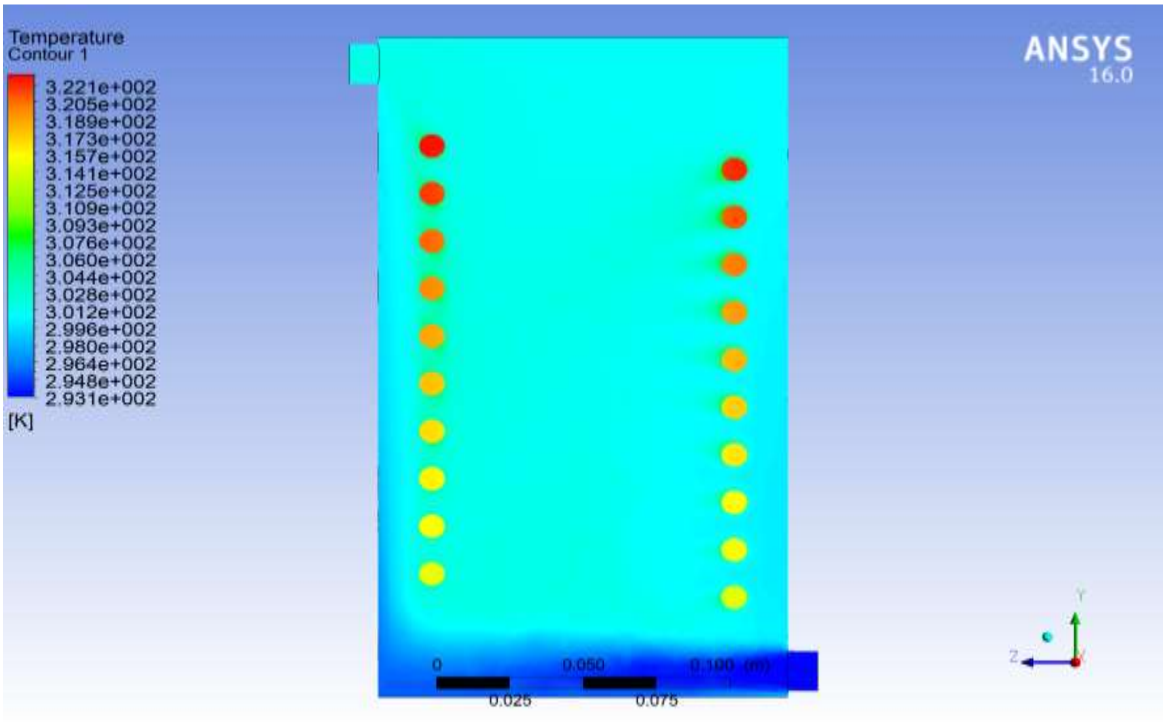
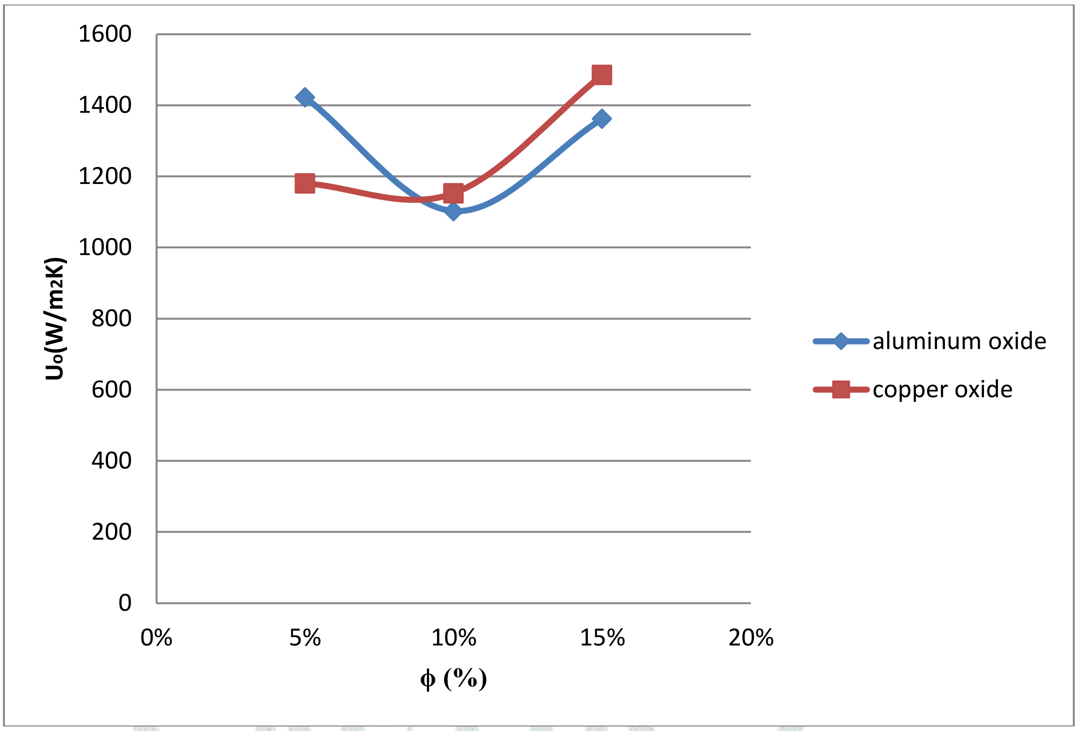


Fig 5. Temperature contour for 5% conc. Of copper oxide

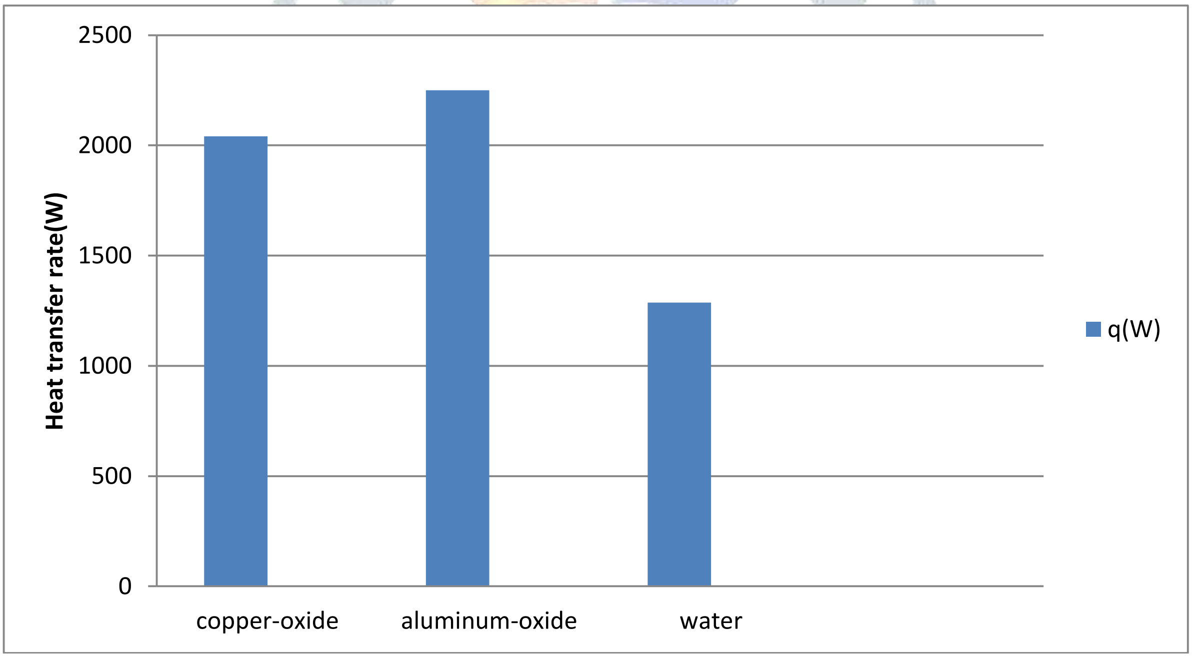
The figure above shows the temperature distribution of nanofluid and water in the heat exchanger. The inlet of the tube could be seen to show more temperature value than the outlet as it has loss the heat to the cold shell fluid. The opposite however occurs in the old fluid region as the hot fluid shows more temperature value due to the counter current flow in the heat exchanger.

The graphical representations of the above data are represented below with a plot of thermal properties against nanoparticle concentrations. The results are plotted to compare a better result between the two nanofluids used for this research. Comparism is also made between the nanofluid and plain water without any particle.



Graph 2. Effect of nanofluid concentration on overall heat transfer coefficient

The graph above shows the effect of concentration on the heat exchanger with respect to the overall heat transfer coefficient. The graph shows an increase in overall heat transfer coefficient as the concentration increase. The overall heat transfer coefficient even though dropped as the concentration rose to 10%, it increase on higher concentration of 15%.



Graph 3. Comparing the difference between the heat transfer rates of nanofluids (5% concentration) and water as working fluid.

The above graph shows that the rate of heat transfer improves rapidly with the use of nanofluid. It can be seen to almost double with aluminum oxide/base nanofluid. This goes to prove the improvement in heat exchangers with the use of nanofluids.

5.0 CONCLUSION

In this study, CFD analysis was conducted to first validate the Ansys fluent software as a good and reliable analysis tool for thermal processes. The result showed good agreement and the slight difference in result is as a result of losses in the experimental data, which is not present in CFD data.

A second analysis was conducted to study the enhancement of heat transfer in coiled tube heat exchanger, by using nanofluid. Copper and aluminum oxide in water base fluid were used, and showed great improvement in heat transfer rate of the tube.

Result showed an increase in heat rate and overall heat transfer coefficient as the concentration of the nanoparticles increased. The difference in heat rate and overall heat transfer coefficient for both nanofluid is very small, and it is therefore believed that aluminum oxide/water base nanofluid is a better choice because it is cheaper and more economical.

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