CFD Analysis of Shell & Serpentine Heat Exchanger using CuO/Water & Al_2O_3/Water Nano Fluid

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Abstract— The serpentine tube in tube arrangement is very effective for various applications such as heat exchangers and chemical reactors. The serpentine tube in tube arrangement can provide large heat transfer area occupying lesser space with high heat transfer coefficients. The heat exchanger geometry contains one serpentine tube of outer diameter 30 mm and shell of diameter 200 mm, shape of tube is serpentine and heat exchanger is analyzed by using nano fluids CuO/water and Al_2O_3/water. ANSYS CFX solver has been used for CFD analysis using the CAD model developed in Creo 2 software. The changes in temperature profiles in each of the cases are taken into consideration for calculating effectiveness of heat exchanger. The turbulence model used for CFD analysis is k-epsilon.

Key words: CFD, ANSYS CFX, Shell & Tube, Nano Fluids

I. Introduction

Nanofluids, fluid suspensions of nanometer-sized particles, have recently been demonstrated to have thermal conductivities far superior to that of the liquid alone. This and their other distinctive features offer unprecedented potential for many applications in various fields including energy, bio and pharmaceutical industry, and chemical, electronic, environmental, material, medical and thermal engineering. Nanofluids is the next exciting frontier of technology. The excitement can be attributed to the shear brilliance of the idea and application of technology. Over the past decade, nanofluids, which are liquids containing suspensions of nanoparticles, have been reported to possess substantially higher thermal conductivity than anticipated from the effective medium theories. This makes them very attractive as heat transfer fluids in many applications. For example, nanofluids would be useful as coolants in the automobile and electronics industries. However, the reported high thermal conductivity sometimes cannot be reproduced, and the potential mechanisms leading to the enhancement are still under scrutiny. Due to these reasons, nanofluids have been a controversial topic.

II. Literature survey

Keblinski et al. [1], in its study, talked about the properties of nanofluids and future difficulties. The advancement of nanofluids is still thwarted by a few factors, for example, the absence of assention between results, poor portrayal of suspensions, and the absence of hypothetical comprehension of the components.

Keblinski et al. and Eastman et al. [2] proposed four conceivable systems, e.g., Brownian movement of the nanoparticles, sub-atomic level layering of the fluid at the fluid/molecule interface, the nature of heat transport in the nanoparticles, and the impacts of nanoparticle bunching They hypothesized that the impact of Brownian movement can be disregarded, since the commitment of thermal diffusion is significantly more noteworthy than Brownian dispersion. Notwithstanding, they just analyzed the instances of stationary nanofluids.

Wang et al. [3] contended that the warm conductivities of nanofluids ought to be subject to the microscopic movement (Brownian movement and between molecule powers) and molecule structure.

Xuan and Li[4] likewise talked about four conceivable explanations behind the enhanced powerful thermal conductivity of nanofluids: the expanded surface region because of suspended nanoparticles, the expanded thermal conductivity of the fluid, the interaction among particles, the intensified fluctuations and turbulence of the fluid, and the scattering of nanoparticles.

Yu and Choi [5] proposed models, in view of traditional hypothesis, which consider a fluid sub-atomic layer around the nanoparticles. In any case, an investigation of Xue et al.[6] utilizing sub-atomic elements reproduction demonstrated that basic monatomic fluids had no impact on the heat exchange attributes both typical and parallel to the surface. This implies thermal transport in a layered fluid may not be sufficient to clarify the expanded thermal conductivity of suspensions of nanoparticles.

Khaled and Vafai [6] investigated the effect of thermal dispersion on heat transfer enhancement of nanofluids. These outcomes demonstrated that the nearness of the dispersive components in the core locale did not influence the heat transfer rate. Be that as it may, the relating dispersive components brought about 21% change of the Nusselt number for a uniform tube provided by a settled heat flux when contrasted with the uniform conveyance for the dispersive components. These outcomes give a conceivable clarification to the expanded thermal conductivity of nanofluids, which might be resolved incompletely by the dispersive properties.

Wen and Ding[7] contemplated hypothetically the impact of molecule movement on heat move qualities in nanofluids coursing through smaller than normal channels (D 1 = mm). They examined the impact of shear instigated and thickness slope actuated molecule movement and the self-dispersion because of Brownian movement. Their outcomes demonstrated a noteworthy no uniformity in molecule focus and thermal conductivity over the tube cross-area because of molecule relocation. Contrasted with the uniform conveyance of thermal conductivity, the no uniform circulation caused by molecule movement actuated a higher Nusselt number.

Koo and Kleinstreuer [8] talked about the impacts of Brownian, thermo-phoretic, and osmo-phoretic movements on the successful thermal conductivities. They found that the part of Brownian movement is significantly more essential than the thermo-phoretic and osmo-phoretic movements. Moreover, the molecule collaboration can be dismissed when the nanofluid focus is low (< 0.5%). Be that as it may, these discoveries have not been approved by experimental methods.

III. OBJECTIVE

The aim of this research is to investigate effect of nano fluids like CuO/water nano fluid in heat transfer rate and effectiveness of heat exchanger using serpentine tube in tube arrangement and comparing results with water as fluid. The CAD model is developed using Creo parametric software and CFD analysis is performed using ANSYS CFX.

IV. METHODOLOGY

The CAD model of shell and serpentine heat exchanger is developed using Creo 2 software as per the dimensions given in table 5.1 below. CAD model is prepared using part modeling and assembly. Creo is sketch based, feature based parametric 3d modeling software developed by PTC having properties of bidirectional associativity and parent child relationship as shown in fig 1.

HEAT EXCHANGER LENGTH	1300mm
SHELL OUTER DIAMETER	200mm
SHELL THICKNESS	3.2mm
TUBE OUTER DIAMETER	30mm
TUBE THICKNESS	1.5mm
NUMBER OF SERPENTINE TUBE	1

Table 1: Dimensions of Heat Exchanger

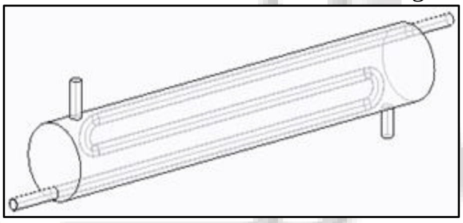

Fig. 1: CAD Model of Shell and Serpentine Heat Exchanger

The CAD model developed in Creo software is converted in .iges file and imported in ANSYS as shown in fig 2 below. The model is checked for geometric clean up and hard edges.

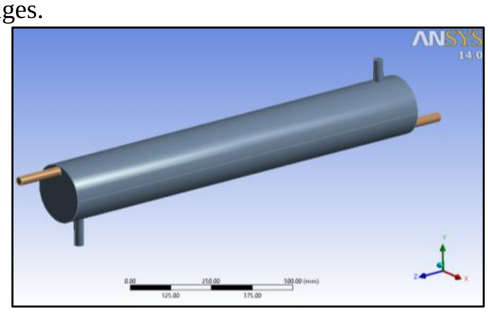

Fig. 2: Imported CAD Model

The model is meshed using tetra elements and fine sizing with curvature fine as shown in fig 3 below. Nodes generated is 201623 and number of elements generated is 622079.

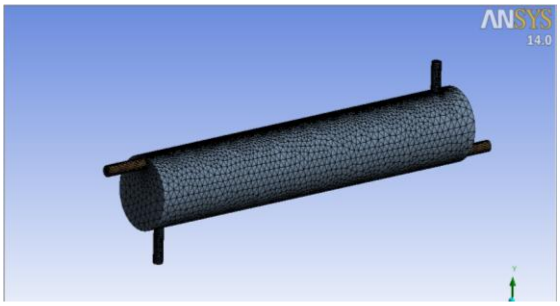

Fig. 3: Meshed Model

The model is applied with appropriate boundary conditions and domain definitions along with interface generation with constant thermal interface between two diffeent domains as shown in fig 4 below.

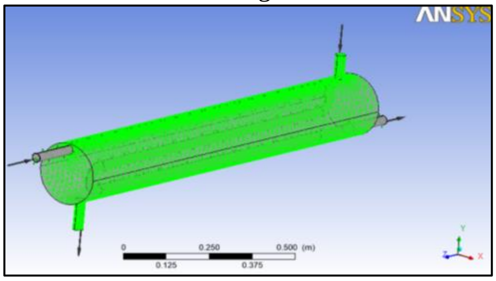

Fig. 4: Boundary Condition

Three different domains are defined for shell, tube and tube coating. The shell domain is defined with reference pressure as 1 atm and turbulence model set to k-epsilon, domain definition set to fluid, material water and for subsequent analysis is set to nano fluid 1%, 2%,3%,4% and 5% The nano fluid used for analysis is CuO/water and its thermal properties are defined in ANSYS CFX. The properties of CuO/water nano fluid is given table 2 below.

MATERIAL	DENSITY (Kg/m^3)	SPECIFIC HEAT(J/Kg.K)	THERMAL CONDUCTIVITY (W/m.K)	DYNAMIC VISCOSITY Kg/m.s
PURE WATER	981.3	4189	.643	.000598
CuO(1%)-water	1061	4150.9	.662	.000612
CuO(2%)-water	1140.7	4112.8	.682	.000627
CuO(3%)-water	1220.4	4074.8	.702	.000642
CuO(4%)-water	1300.2	4036.7	.723	.000657
CuO(5%)-water	1378	3998	.744	.000672

Table 2: CuO/Water Nano Fluid Properties

MATERIAL	DENSITY	SPECIFIC	THERMAL CONDUCTIVITY	DYNAMIC

	(Kg/m^3)	HEAT(J/ Kg.K)	(W/m.K)	VISCOSITY Kg/m.s
PURE WATER	981.3	4189	.643	.000598
Al_2O_3 - water C=1%	1007.4	4154.7	.661	.000612
Al_2O_3 - water C=2%	1033.6	4120.5	.68	.000627
Al_2O_3 - water C=3%	1059.8	4086.2	.699	.000642
Al_2O_3 - water C=4%	1086	4052	.719	.000657
Al_2O_3 - water C=5%	1112.2	4017.8	.739	.000672

Table 3: Al_2O_3/Water Nano Fluid Properties

Effectiveness calculation: Effectiveness of a heat exchanger is defined as ratio of actual heat transferred to maximum possible heat that can be transferred. It denotes the degree to which heat exchanger is successful in producing desired heat transfer between different fluids. It is a parameter showing feasibility of a heat exchanger installation.

$$\text{Effectiveness} = Q_{actual}/Q_{max\ possible}$$

$$\varepsilon = m_c C_{pc}(T_{co} - T_{ci}) / C_{min}(T_{hi} - T_{ci}) = C_c(T_{co} - T_{ci}) / C_{min}(T_{hi} - T_{ci}) \quad (1.1)$$

V. RESULTS & DISCUSSION

CFD analysis is conducted using ANSYS CFX 14.0 version, velocity and temperature plots are extracted for different cases of fluids. The analysis has 11 cases comprising of different combination of base fluids and nano fluids. The effectiveness of heat exchanger is calculated in each case.

FLUID TYPE	MASS FLOW RATE (Kg/s)	SPECIFIC HEAT (J/Kg K)
COLD FLUID	.05	4179.725
HOT FLUID	.04	4197.178

Table 4: Reference Fluids for Analysis

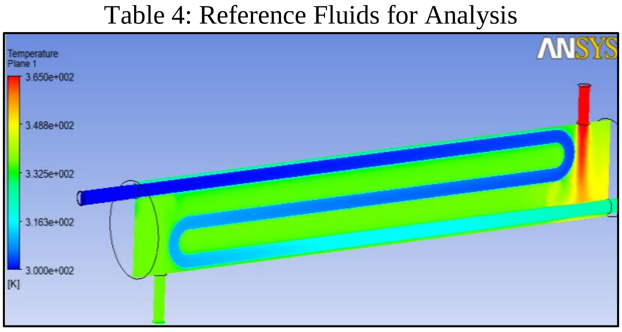

Fig. 5: Temperature Plot

The temperature contour shown in fig 5 above heated fluid entering in shell shown by dark red color on upper right portion of contour and temperature of hot fluid decreases as we move towards left of shell. The cold fluid entering the tube is shown by dark blue in color (tube domain) and fluid at exit is shown by light blue color.

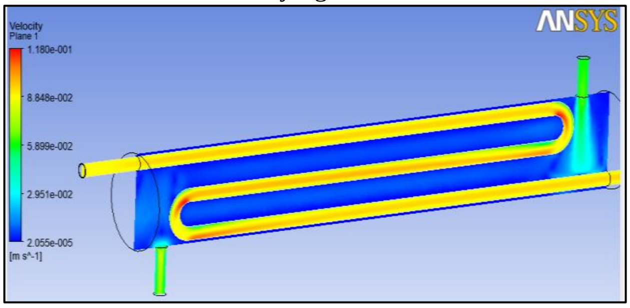

Fig 6: Velocity Plot

The velocity contour plotted above shows high magnitude at inlet and consequently decreases as we move towards exit of shell shown by green color. The cold fluid velocity is almost constant except on U tube bends where velocity increases due to centrifugal forces.

COLD FLUID IN	300K
COLD FLUID OUT	326.83K
HOT FLUID IN	365K
HOT FLUID OUT	334.9K

Table 5: Temperature Output Using Water

– Effectiveness Calculation

Heat capacity of cold fluid, Cc = mc * Cpc = 0.05*4179.725 = 208.98 W/K

Heat capacity of hot fluid, Ch = mh * Cph =0.04*4197.178 = 167.887 W/K

Ch < Cc, Cmin = Ch

Effectiveness = C_C (T_{co}-T_{ci})/ C_h (T_{hi}-T_{ci})

= 208.98*26.83/167.88*65=.513

COLD FLUID IN	300K
COLD FLUID OUT	327.51K
HOT FLUID IN	365K
HOT FLUID OUT	335.8K

Table 6: Temperature Output Using Nano Fluid 1%

– Effectiveness Calculation

Heat capacity of cold fluid, Cc = mc * Cpc = 0.05* 4179.7 = 208.98 W/K

Heat capacity of hot fluid, Ch = mh * Cph =0.04*4154.7 = 166.18W/K

Ch < Cc, Cmin = Ch Effectiveness,

Effectiveness = C_C (T_{co}-T_{ci})/ C_h (T_{hi}-T_{ci})

= 208.98*27.5/166.18*65= .532

COLD FLUID IN	300K
COLD FLUID OUT	327.52K
HOT FLUID IN	365K
HOT FLUID OUT	335.8K

Table 7: Temperature Output Using Nano Fluid 2%

– Effectiveness Calculation

Heat capacity of cold fluid, Cc = mc * Cpc = 0.05* 4179.7 = 208.98 W/K

Heat capacity of hot fluid, Ch = mh * Cph =0.04*4120.5 = 164.82W/K

Ch < Cc, Cmin = Ch Effectiveness,

Effectiveness = C_C (T_{co}-T_{ci})/ C_h (T_{hi}-T_{ci})

= 208.98*27.5/164.82*65= .536

COLD FLUID IN	300K
COLD FLUID OUT	327.56K

HOT FLUID IN	365K
HOT FLUID OUT	335.8K

Table 8: Temperature Output Using Nano Fluid 3%

– Effectiveness Calculation

Heat capacity of cold fluid, Cc = mc * Cpc = 0.05* 4179.7 = 208.98 W/K

Heat capacity of hot fluid, Ch = mh * Cph =0.04*4086.2 = 163.44 W/K

Ch < Cc, Cmin = Ch Effectiveness,

Effectiveness = C_C (T_{co}-T_{ci})/ C_h (T_{hi}-T_{ci})

= 207.54*27.5/163.44*65=.537

COLD FLUID IN	300K
COLD FLUID OUT	327.53K
HOT FLUID IN	365K
HOT FLUID OUT	335.8K

Table 9: Temperature Output using Nano Fluid 4%

– Effectiveness Calculation

Heat capacity of cold fluid, Cc = mc * Cpc = 0.05* 4179.7 = 208.98 W/K

Heat capacity of hot fluid, Ch = mh * Cph =0.04*4052 = 162.08 W/K

Ch < Cc, Cmin = Ch Effectiveness,

Effectiveness = C_C (T_{co}-T_{ci})/ C_h (T_{hi}-T_{ci})

= 208.98 * 27.53/162.08 * 65=.546

COLD FLUID IN	300K
COLD FLUID OUT	327.54K
HOT FLUID IN	365K
HOT FLUID OUT	335.8K

Table 10: Temperature Output using Nano Fluid 5%

– Effectiveness Calculation

Heat capacity of cold fluid, Cc = mc * Cpc = 0.05* 4179.7 = 208.98 W/K

Heat capacity of hot fluid, Ch = mh * Cph =0.04*3998 = 159.92 W/K

Ch < Cc, Cmin = Ch Effectiveness,

Effectiveness = C_C (T_{co}-T_{ci})/ C_h (T_{hi}-T_{ci})

= 207.54*27.5/159.92*65=.549

After conduction of CFD analysis on shell and serpentine heat exchanger using CFX solver, effectiveness is calculated for different percentages of nano fluids using temperature output from ANSYS CFX. The table number 11 below provides effectiveness values for different composition of nano fluids.

FLUID	EFFECTIVENESS
WATER	0.513
NANO FLUID 1%	0.532
NANO FLUID 2%	0.536
NANO FLUID 3%	0.537
NANO FLUID 4%	0.546
NANO FLUID 5%	0.549

Table 11: Effectiveness for CuO/Water Nano Fluid

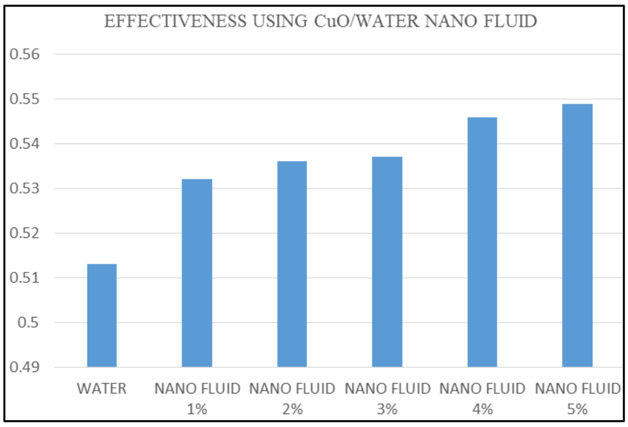

Fig 7: Effectiveness comparison using CuO/water

The effectiveness value increases with increase in nano particle concentration. The bar graph of effectiveness vs nano particle concentration is shown in fig 7.

After performing CFD analysis using CuO/water nano fluid subsequent analysis is done for Al_2O_3/water nano fluid with different concentration of nano particles and effectiveness is determined. The results obtained are discussed in table 12 below.

WATER	0.513
NANO FLUID 1%	0.5325
NANO FLUID 2%	0.5378
NANO FLUID 3%	0.5428
NANO FLUID 4%	0.5479
NANO FLUID 5%	0.5536

Table 12: Effectiveness for Al_2O_3/Water Nano Fluid

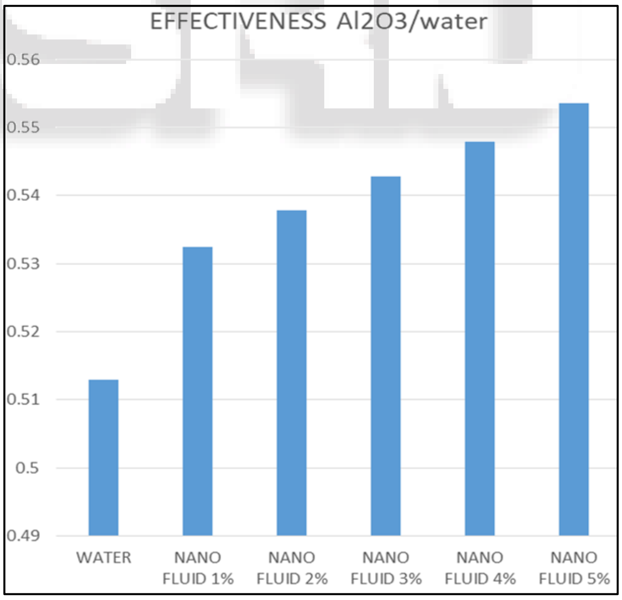

Fig 8: Effectiveness comparison using Al_2O_3/water

As it can be seen from figure 8 above effectiveness value increases with increase in Al_2O_3 concentration.

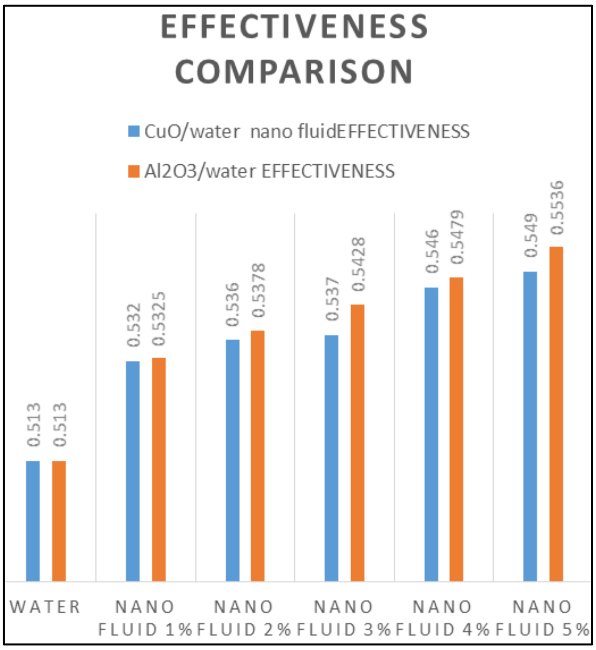

Fig 9: Effectiveness Comparison between Al_2O_3/Water and CuO/Water

VI. CONCLUSION

Nanofluids are colloidal mixtures of nanometric metallic or ceramic particles in a base fluid, such as water, ethylene glycol or oil. Nanofluids possess immense potential to enhance the heat transfer character of the original fluid due to improved thermal transport properties. CFD analysis of shell and serpentine heat exchanger is performed using CuO/water nano fluids at different concentration of CuO nano particles and Al_2O_3/water at different concentrations of Al_2O_3 nano particles. Effectiveness value shows an increasing trend with increase in nano particles concentration for both cases. The numerical results reveal the enhancement in heat transfer, with respect to the base fluid, identified to characterize nanofluid. On comparison with Al_2O_3/water nano fluid and CuO/water nano fluid heat transfer and effectiveness is found to be more when Al_2O_3/water nano fluid is used for analysis. Therefore Al_2O_3/water nano fluid is best suited for this application.

This can be attributed to greater heat transfer rate with increase in nano-particle concentration. Also turbulence kinetic energy associated with nano fluid is higher as compared to water resulting in increase of turbulent flow heat transfer.

1) Using of nanofluids lead to increase the effective- ness and cooling performance of a shell and serpentine heat exchanger.
2) There is no extra increase in pressure drop across serpentine heat exchanger associated with using of nanofluid as a coolant due to ultra-fine particles and small volume fractions.
3) The effect of nanofluids is larger for low velocities while in flow with high velocities this effect is small because the flow will be dominated by the flow rate.
4) The effect of nanofluids is high in the entrance region due to the effect of solid particles on the developing of boundary layer.

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