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To Study the Effect of Aluminium and Copper Based Nano Fluid in Double Pipe U-Bend Heat Exchanger

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Abstract

Heat exchanger is used for heat transfer from one hot fluid to cold fluid. The performance of heat exchanger is analyzed by of the heat transfer rate and heat transfer coefficient. The main objective of this research work is increased the performance of the heat exchanger by using Nano fluid. CFD analysis is performed for the estimation of heat transfer rate and heat transfer coefficient of Nano-fluid flow in a double pipe U-bend heat exchanger. The prototype of U-bend heat exchanger was developed using ANSYS 15.0 workbench. In this study Copper oxide (CuO), Aluminum oxide (Al_2O_3,), Silicon dioxide (SiO_2), and Ethylene Glycol are used as a Nano fluids. The volume fraction of Nano fluids are 0.2%, 0.3% and 0.4% were used in this analysis. The mass flow rate of hot fluid kept constant and the mass flow rate of Nano-fluids are varies from 0.155 kg/sec. The temperatures of Nano-fluids flow in a heat exchanger are kept at 342 K. The results revealed that as volume fraction are increased the heat transfer rate and heat transfer coefficient are increased, and Velocity and pressure are decreased. Based on the numerical results, the highest value of heat transfer coefficient and heat transfer rate is obtain from CuO Nano-fluids with 0.02% volume fraction. Al_2O_3 Nano fluids is the second best Nano fluids and its shows the good heat transfer coefficient and heat transfer rate as compare to other Nano fluids.

Keywords: Nano fluid, Numerical analysis, Volume fraction, heat exchanger, heat transfer rate, enhancement of heat transfer

I. Introduction

The thermal conductivity plays an important role for the development of energy efficient heat transfer equipment. In all the processes which involves heat transfer, the thermal conductivity of the fluid is among one of the major important properties taken in to consideration while designing and controlling the processes. Nano fluids are engineered colloids which are made of a base fluid and nano particles of (1-100) nm. It has been studied by many researchers that the Nano-fluids provide higher thermal conductivity compared to base fluids. It increases with the increase in particle concentration in base fluid, temperature, particle size, dispersion and stability. Nevertheless, it is expected that other factors like density, viscosity, and specific heat are also responsible for the convective heat transfer enhancement of Nano-fluids. Nano-fluids are having high thermal conductivity and high heat transfer coefficient compared to single phase fluids.

Heat transfer of fluid flow in annular channel occurred due to change in pressure gradient caused by an increase or decrease of cross-sectional area of annular channel. Fluid flow in annular channels can be found in several heat exchange devices, such as heat exchangers, nuclear reactors, evaporators, condensers, etc. Generally, many experimental and numerical studies are concerned with the phenomena of separation and reattachment flow.

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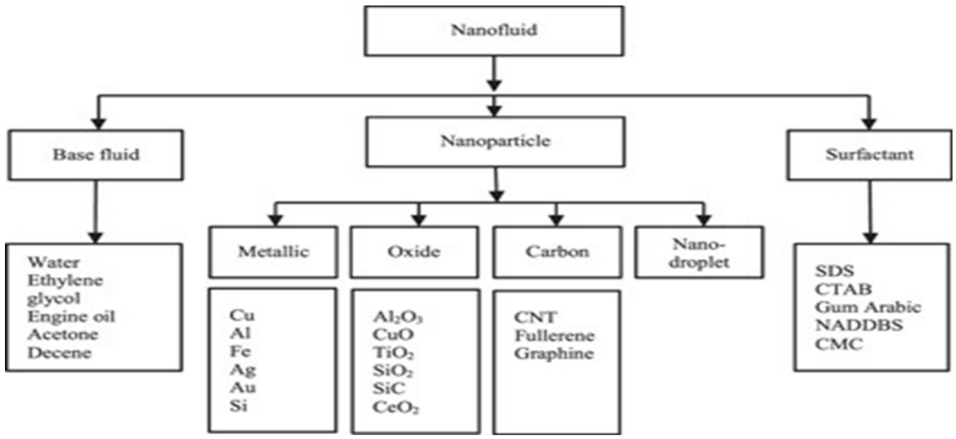

Figure 1 Classification of Nano fluids

II. Literature Review

Kim et al [1] experimentally studied the effect of nano fluid on heat transfer flowing through a circular horizontal tube under both laminar and turbulent flow regimes. In this research, alumina oxide nano particles were used because this was very environment friendly. It was observed that adding Al2O3 nano particles in the base fluids had helped to enhance the heat transfer rate. The maximum enhancement was observed to be 15% and 20% respectively at 3% under both the laminar and turbulent flow conditions.

G.Murali et al [2] studied the heat transfer and friction factor characteristics of a circular tube fitted with full length twisted tape trapezoidal cut for the Reynolds number range of 2000– 12,000. They used twisted tape with water as the working fluid and compared with Fe3O4 Nanofluid as working fluid at a volume concentration of 0.06%. The secured experimental data from plain tube were validated with standard correlations to make sure the authorization of experimental results. They found that the thermal performance of trapezoidal cut twisted tape increase significantly than the plain tube. Performance ratio is more than unity is reasonable for trapezoidal cut twisted tape.

M.Awais et al [3] investigate the thermo-hydraulic performance of serpentine tube heat exchanger (STHX) by using CFD analysis. The effect of various flow rates varying from 1L/min to 5L/min and different arrangements of tubes such as uniform, high-to-low-to- high (H-L-H), low-to-high-to-low (L-H-L) and low-to –high (L-H) were considered to study the effect on heat transfer rate and pressure drop. Also the addition of Al2O3 /nano fluid with different (1%, 3% and 5%) concentration at flow rate of 5L/min. It was noticed that L-H serpentine tube provided comparatively higher heat transfer performance than the other cases.

P.C. Mukesh Kumar et al [4] investigate the heat transfer and pressure drop of the double helically coiled heat exchanger handling MWCNT/water Nano fluids. The properties are analyzed by the computational software ANSYS 14.5 version. Laminar flow condition was studied. Simulation studies were conducted on helically coiled shell and tube heat exchanger with the variation of Nano fluids addition in base fluid by 0.2%, 0.4%, and 0.6% volume concentrations. Pressure drop and heat transfer rate was studied with the change in volume concentration. It is found that the Nusselt number of 0.6% MWCNT/water Nano fluids is 30% higher than water. and Pressure drop is 11% higher than water. It is found that the simulation data hold good agreement with the experimental data.

T. Hussein,et al [5] studies shows the effect of addition of nano fluids to viscosity, thermal conductivity and cooling efficiency. Addition of nano particles and its phases were also The systems engineering approach was applied to nanofluid design resulting in a detailed assessment of various parameters in the multivariable nanofluid systems. The relative importance of nanofluid parameters for heat transfer evaluated in this article allows engineering nanofluids with desired set of properties.

III. Methodology

In this research the effect of moist content of different Nano fluids of pipe on the overall performance of system will be studied numerically under the climatic conditions, which considered one of most hot spots around the world. This facilitates the transfer of heat, and greatly increases the rate of the temperature change.

- Evaluating the existing heat exchanger working characteristics, effectiveness, effectiveness, efficiency, losses etc.
- Generating 3D model of existing heat exchanger using Solid-works software.
- Theoretical calculations for new models.
- Selecting of parameters for CFD analysis.
- Obtaining its CFD model and simulating its working condition.
- Implementing methods that are ought to improve the performance of heat exchanger.
- Performing CFD analysis in ANSYS Fluent on new models
- Comparing the results with the original model.

A. Modeling

Figure represents the schematic diagram of double pipe U-bend heat exchanger. The analysis is performed on a 2-pass double pipe heat exchanger with the inner diameter of inner pipe is 0.019 m & outer diameter of inner pipe is 0.025 m, similarly for annulus pipe, the inner diameter of outer pipe is 0.05 m & outer diameter of outer pipe is 0.056 m and the total length of heat exchanger is 2.36 m (2-pass). The mass flow rate of hot water is kept constant over annulus section, with different temperatures and the mass flow rate of cold water 0.155 (kg/s). There is insulation for outer wall of annulus pipe with asbestos rope to minimize the heat losses.

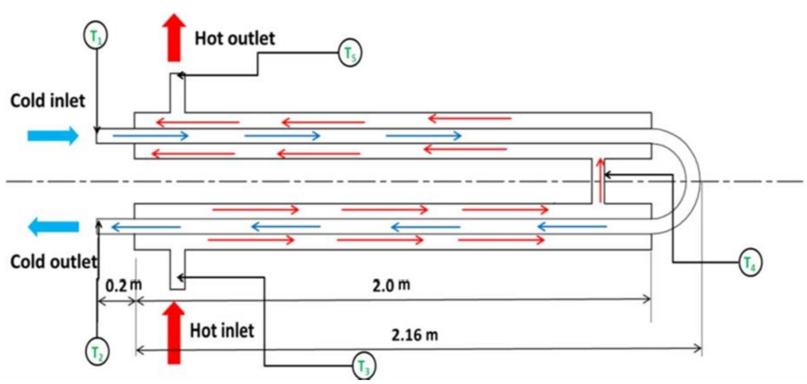

Figure 2 Schematic representation of double pipe U-bend heat exchanger

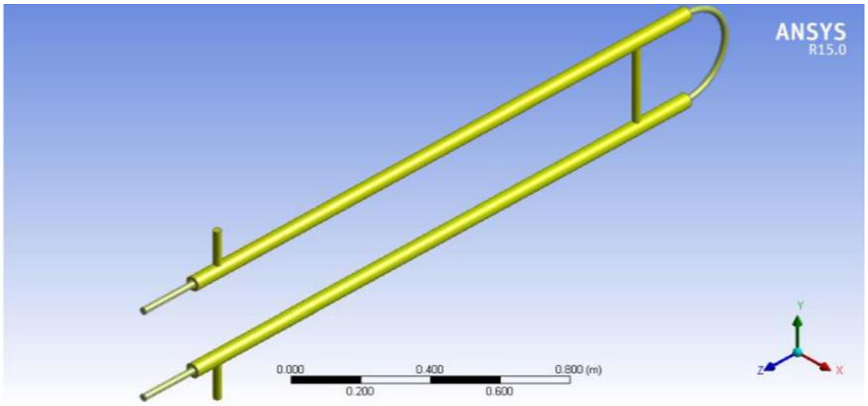

Figure 3 Geometry modeling of 2-Pass Double Pipe in ANSYS work bench

B. Meshing

Structured meshing method in ANSYS WORKBENCH was used for the geometry. The element for meshing considered is hexahedral shape with number of elements of 876874 to 1240000. Naming selections were also done at required places.

Grid Independence is the term used to designate the enhancement of results by using successively smaller cell sizes for the calculations. A calculation should reach the correct result so the mesh becomes smaller; hence the term is known as grid Independence. The ordinary CFD technique is, to start from coarse mesh and gradually improve it until the changes detected in the values are smaller than a pre-defined acceptable error. There are 2 problems with this. Firstly, it can be quite difficult with other CFD software to gain even in a single coarse mesh resulting for some problems. Secondly, refining a mesh by a factor two or above can lead to take more time.

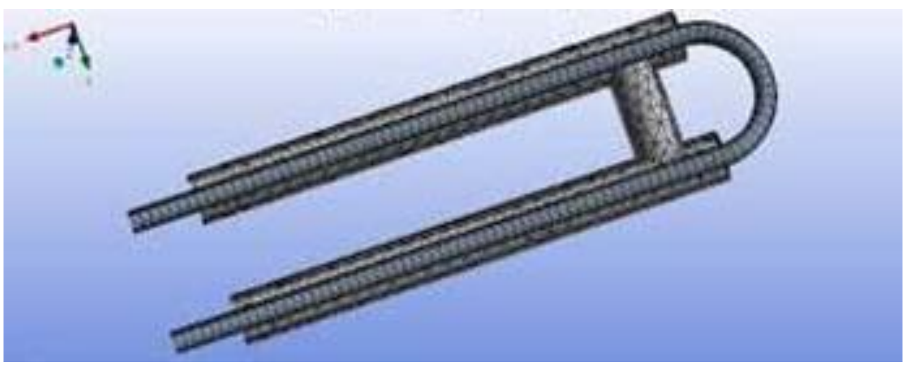

Figure 4 Geometry of Meshing

Table 1 Grid test results & Final mesh elements of 1124397 have been used for simulation

No. of Elements	Cold water outlet temp (^{0}C)	Hot water outlet temp (^{0}C)
876874	31.458	53.970
895812	31.625	53.625
856253	30.256	44.325

C. Boundary Condition

This is clearly offensive for software intended to be used as an engineering tool design operating to constricted production limits. In addition to that the other issues have added significantly to the perception of CFD as an extremely difficult, time consuming and hence costly methodology. Finally grid independence test has been conducted at a flow rate of 8 LPM hot water, 10LPM cold water flow rates in ANSYS-FLUENT, by decreasing and increasing the size of the elements. The gained results are tabulated in Table, for outlet temperatures of cold water and hot water of 2-pass double pipe heat exchanger.

A Velocity inlet, uniform mass flow inlets and a constant inlet temperature were assigned at the channel inlet. At the exit, pressure was specified.

Table 2 Boundary Conditions

S.No.	Boundary Condition	Outer Pipe	Inner Pipe
1	Mass flow rate in inlet	0.155 kg/s	0.261 kg/s
2	Temperature	342 K	300 K

D. Thermo-Physical Properties of Materials

Pure water is used as base fluid, and Nano particles of Al2O3, SiO2 and ethylene glycol fluid used as working fluid, the properties are shown in below.

Table 3 Thermo-Physical Properties of Nano particles

Material	Thermal conductivity (W/m-k)	Specific heat (j/kg-k)	Density (kg/m3)	Viscosity (kg/m-s)
Water	0.605	4195	997.1	0.001003
Al2O3	31.922	873.336	3950	----------
SiO2	1.300	680	2650	----------
CuO	400	385	8933	
Ethylene Glycol	0.2580	837	1110	----------

The thermo physical properties of Al2O3 Nano fluid such as density (ρ), specific heat (Cp), thermal conductivity (k) and viscosity (μ) are calculated by using following correlations developed to determine these properties. The particle size of the CuO nanoparticles is considered as 40 nm to 50 nm.

Table 4 Thermo-Physical Properties of nano fluids in different volume fraction.

Fluid	Volume fraction $	Thermal conductivity W/m-k)	Specific heat Cpnf (j/kg-k)	Density (kg/m^3)	Viscosity (kg/m- s)
Copper Oxide (CuO)	0.2	1.062062	1561.018	2584.28	0.001505
	0.3	1.441362	1172.261	3377.87	0.001755
	0.4	2.034516	931.4203	4171.46	0.002006
Aluminium Oxide (Al_2O_3)	0.2	1.031229	2542.202	1587.68	0.001505
	0.3	1.37354	2104.594	1882.97	0.001755
	0.4	1.889237	1785.632	2178.26	0.002006
Silicon Dioxide (SiO_2)	0.2	0.705878	2791.838	1327.68	0.001505
	0.3	0.762587	2323.278	1492.97	0.001755
	0.4	0.824199	1948.127	1658.26	0.002006
Ethylene Glycol	0.2	0.529953	3463.912	1019.68	0.001505
	0.3	0.495665	3110.377	1030.97	0.001755
	0.4	0.463294	2764.501	1042.26	0.002006

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IV. Result and Discussion

The temperature contours of inside pipe of double pipe U-bend heat exchanger are shown in Figure 4.1. From the figure it was observed that temperature of inside fluid, Nano fluid gradually increased from inlet to the outlet of pipe. Fig. 4.2 shows the temperature contours of annulus pipe of double pipe U-bend heat exchanger. From the figure it was observed that temperature of annulus fluid i.e., pure water gradually decreased from inlet to the outlet of annulus pipe.

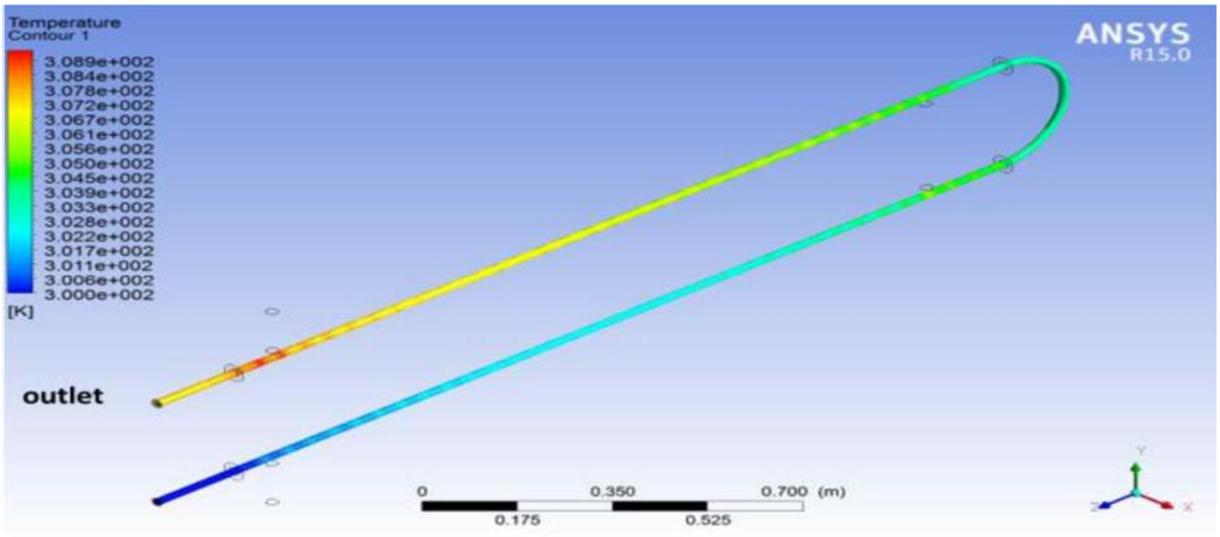

Figure 5 Temperature contours of inside pipe

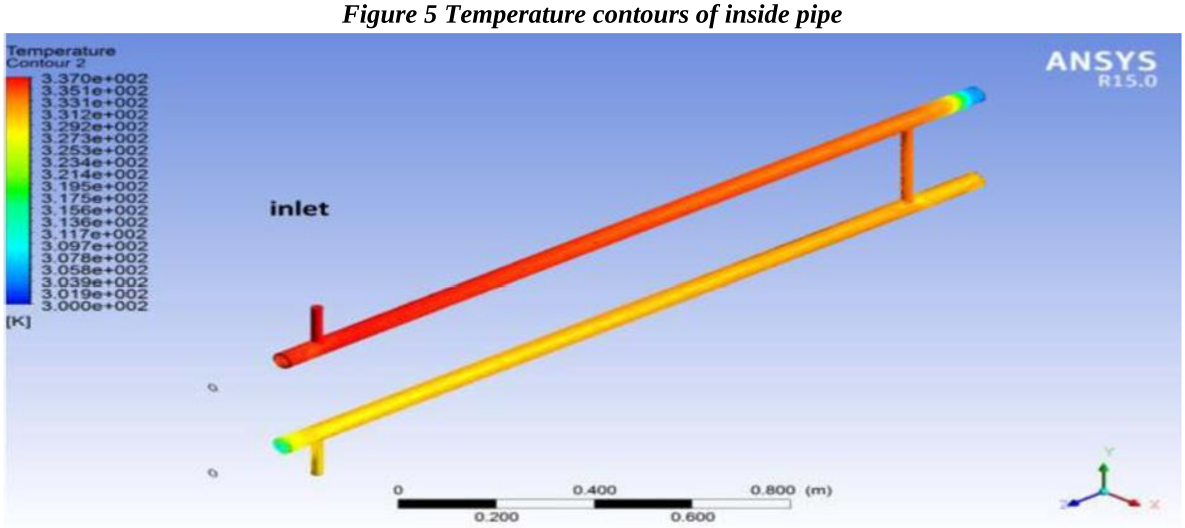

Figure 6 Temperature contours of annulus pipe

A. Computational Fluid Dynamics (CFD) Analysis

As mentioned above, four types of Nano fluids (Al_2O_3, CuO, SiO_2 and Ethylene Glycol) were used at three volume fractions as shown in Tables. In order to study the thermal performance of the heat exchanger the mass rate flow was 2Kg/s and the inlet temperature was 353K. For each Nano fluid, experiments were conducted for three volume fractions. As an example in this paper, Figures show the computational fluid dynamics (CFD) analysis of the heat exchanger by using all Nano fluids at three volume fractions (0.2, 0.3 and 0.4). Figure 8 shows the plot of the pressure against Nano fluid types at different volume fractions.

Table 5 CFD analysis results of Nano fluids at volume fraction (0.2, 0.3 and 0.4)

Fluid	Volume fraction Ø	Inlet Temperature (k)	Velocity (m/s)	Pressure (Pa)	Heat Transfer Coefficient (W/m²-k)	Mass Flow Rate (Kg/s)	Heat Transfer Rate (W)
Aluminium Oxide (Al_2O_3)	0.2	353	0.0032	0.0195	84.024	0.0033913	236.8281
	0.3	353	0.0026	0.0161	67.1	0.00389	300.345
	0.4	353	0.0023	0.0141	77.9	0.00282	192.362
Copper Oxide (CuO)	0.2	353	0.0019	0.0115	78.3442	0.0034658	310.0293
	0.3	353	0.0018	0.091	66.8	0.00389	551.2265
	0.4	353	0.0016	0.0294	77.3	0.00282	439.937
Silicon Dioxide (SiO_2)	0.2	353	0.0037	0.0224	43.0295	0.0033913	217.4531
	0.3	353	0.0033	0.0201	36.824	0.00389	179.9843
	0.4	353	0.003	0.0183	51.6	0.00282	248.429
Ethylene Glycol	0.2	353	0.0048	0.029	66.669	0.0034657	93.9687
	0.3	353	0.0045	0.0089	61.853	0.00389	121.196
	0.4	353	0.0042	0.0073	55	0.00282	137.546

B. Velocity Compression

In order to test the effect of Nano fluid types on the outlet velocity of the heat exchanger, the figure shows the heat exchanger outlet velocity as a function of Nano fluid types. As can be seen, the highest value was recorded within Ethylene Glycol at volume fraction 0.2 while the smallest value was documented within copper oxide Nano fluid at volume fraction 0.4. This might be because the density of the Ethylene Glycol Nano fluid has the smallest value at 0.2 volume fraction while the density of Copper oxide Nano fluid has the greatest value as per the tables.

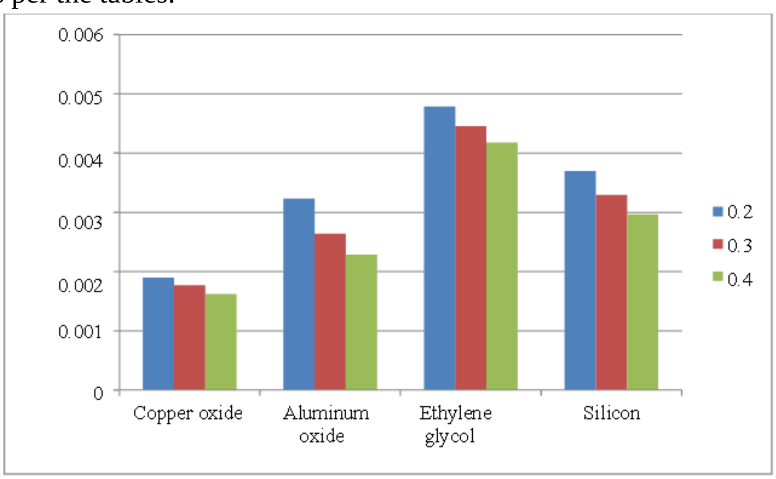

Figure 7 Velocity vs different Nano fluids

C. Pressure Comparison

Figure shows the plot of the pressure against Nano fluid types at different volume fractions. As can be seen in the value of pressure increased dramatically when copper oxide was used at volume fraction 0.4. There are very small different between silicon oxide and aluminium oxide. Other volume fraction of Nano fluids shows the lower pressure. The lowest pressure was recorded when Ethylene Glycol was used at volume fraction 0.4.

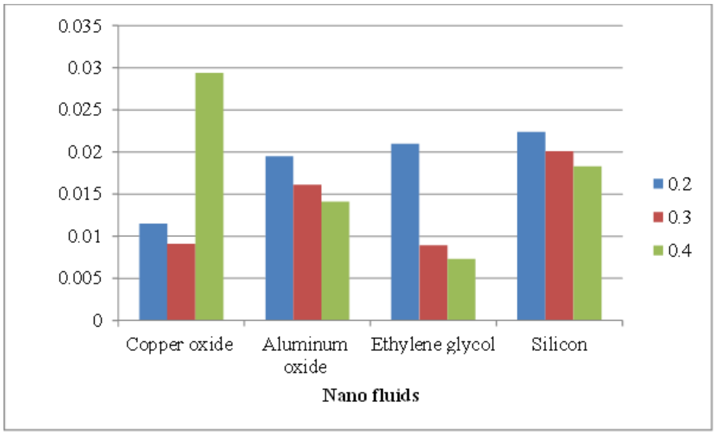

Figure 8 Pressure vs. different Nano fluids

D. Heat Transfer Coefficient Comparison

The heat transfer coefficient value of Nano fluids will effect of the movements of the fluids inside the heat exchanger. Graph presents the heat transfer coefficient as a function of Nano fluids at different volume fractions. The highest value was recorded when Al2O3 was used at volume fraction 0.2 while the smallest value was documented when SiO2 was used at volume fraction 0.3. Copper oxide Nano fluids with 0.2 volume fraction shows the second highest value of heat transfer coefficient.

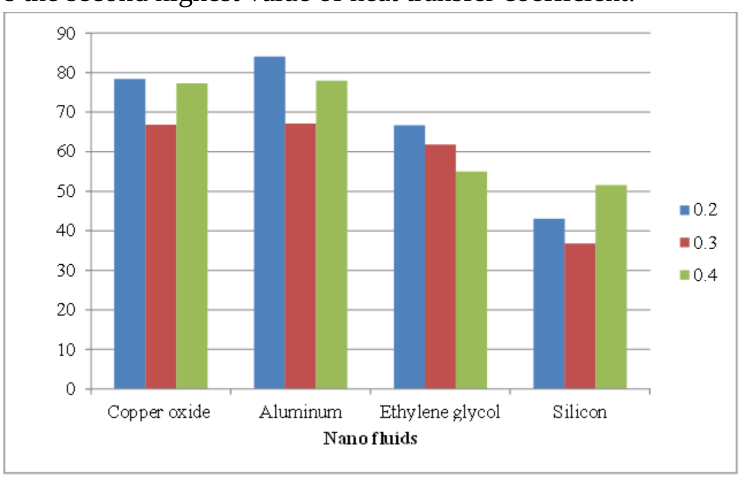

Figure 9 Heat Transfer Coefficient vs. different Nano fluids

E. Heat Transfer Rate comparison

The effect of Nano fluids types on the heat transfer rate of the heat exchanger was also studied as shown in Figure. As can be seen, adding CuO Nanoparticles to the base fluid increased heat exchanger heat transfer rate in comparison with other nanoparticles. It may be because the CuO Nano fluid has greatest thermal conductivity compared to other types Nano fluid as per the table. It may be also because the CuO Nano fluid had the lowest values of outlet velocity; there for, the fluid had sufficient time for contacting with air so the heat transfer rate increased.

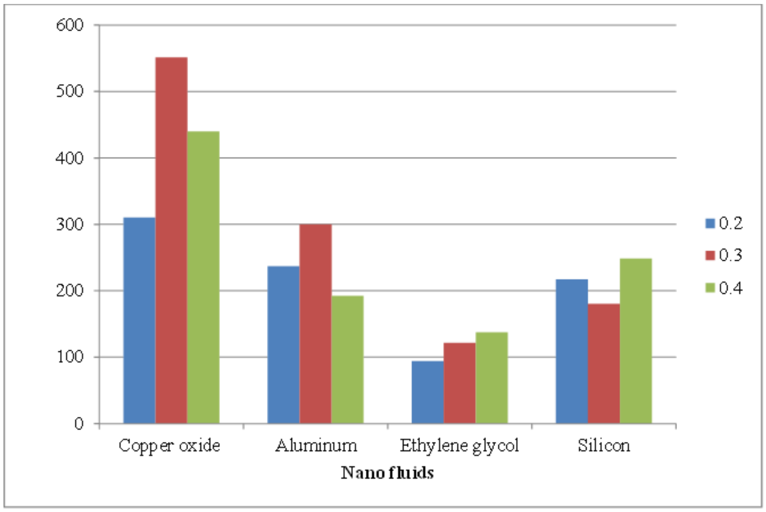

Figure 10 Heat Transfer Rate Vs. different Nano fluids

V. CONCLUSION

Computational Fluid Dynamics (CFD) analysis was conducted for four types of Nano fluids (Al_2O_3, CuO, SiO_2, and Ethylene Glycol) with varying VF (0.2, 0.3 and 0.4). It was established that increasing the heat transfer rate for any cooling system will also indicate to better thermal performance of the cooling system. It can be concluded that,

- The highest value of the heat exchanger outlet velocity was recorded within Ethylene Glycol at volume fraction 0.2 and lowest value of velocity is CuO with 0.2 volume fraction.
- The highest values of the heat transfer coefficient was recorded when Al_2O_3 is used with 0.2 volume fraction. CuO Nano fluids with 0.2 volume fraction shows almost similar value of heat transfer coefficient.
- The heat transfer rate was more when CuO Nanoparticles were added to the base fluid in comparison with other nanoparticles.
- The high value of heat transfer rate is indicated to better thermal performance of the cooling system.

Overall, it can be said that CuO Nano fluid shows the best performance in comparison with other Nano fluids. Al_2O_3 Nano fluids is the second best Nano fluids.

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