JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Performance Evaluation of Different Nano Fluids in a Horizontal Shell and Tube Heat Exchanger Using Computational Fluid Dynamics(CFD)

Deepak Kumar Verma[1], Dr. B.K. Chourasia [2]

1. Research Scholar, Department of Mechanical Engineering, JEC Jabalpur (M.P.)
2. Professor, Department of Mechanical Engineering, JEC Jabalpur (M.P.)

Abstract: The Shell and Tube heat exchangers are most widely used heat exchangers in various industries such as chemical processing, power generation, oil refining, refrigeration and air conditioning. The Cooling system's thermal performance is mainly based on the Performance of the heat exchanger and working fluid. One method of enhancement of heat transfer rate in different types of heat exchangers is possible with the use of nano fluids instead of plain fluids. The present analysis is carried out for analyzing the nano fluids as heat transfer fluid for shell and tube heat exchanger. The Al_2O_3 and CuO are the nanoparticles that are introduced with a mixture of water and Ethylene Glycol as a base fluid. Al_2O_3 and CuO nanoparticles of concentration 0.05%, 0.15% and 0.3% were added to the base fluid. The analysis has been carried out using Ansys as the tool having CFD method. The enhancement of overall heat transfer coefficient, heat transfer rate and temperature drop are the basic parameters are considered for the assessment of results. The maximum value of Overall Heat Transfer Coefficient and Heat Transfer rate of the base fluid were obtained 11.01 kw/m^2 °C and 22.81 kw, 0.3% Al_2O_3 nanofluid were obtained 26.51 kw/m^2 °C and 34.43 kw and 0.3% CuO nanofluid were obtained 16.2 kw/m^2 °C and 27 kw respectively. The results show that the overall heat transfer coefficient and Heat Transfer rate of Al_2O_3 and CuO nanofluids is higher than that of the base fluid at the same mass flow rate.

Keywords: Shell and Tube heat exchanger, Nano fluids, NTU analysis, Heat Transfer Rate, Computational Fluid Dynamics (CFD) etc.

1. Introduction:

The Heat transfer is an important aspect to reduce the temperature of the working bodies in various industries. Many new techniques have been introduced for reducing the temperature of the machines used in industries and also to reduce the temperature of the working fluids. Heat transfer fluids such as water, Oil, Ethylene Glycol are used in this process for reduction of temperature. These fluids are passed into the system which absorbs the heat from the hot bodies and come out with a slight increase in temperature. Based on the properties of the fluid the heat transfer rate and efficiency of heat transfer differs. The poor heat transfer properties of these fluids when compared with those of most solids are the primary hindrance of high compactness and the effectiveness of the heat exchanger. The primary reason for these solid particles to be used in heat transfer is their high thermal conductivity compared to liquids. Initially the thought was to suspend these solid particles in small amount in the liquids used for heat transfer. Various types of materials such as metallic, non-metallic, polymeric materials can be added to these liquids to form slurries. Even though these solid particles are suspended in size of micrometers and millimeters, many problems raised causing coagulation of particles, erosion of material and a pressure drop in practical applications.

2. Literature Review:

Jaafar Albadr et al; presents an experimental study on the heat transfer through heat exchanger using Al_2O_3 nanofluid at different concentrations [1]. Alhassan Salami Tijani et al; aims to evaluate the Thermos-physical properties and heat transfer characteristics of water/anti-freezing and Al_2O_3/CuO based nanofluid as a coolant for car radiator [2]. Arun Kumar et al; presented the study on the particle concentration levels of various nanofluids in plate heat exchanger for best performance [3]. B. Farajollahi et al; reports an experimental study on the heat transfer of nanofluids in a shell and tube heat exchanger [4]. M.M. Sarafraz et al; presents an experimental study on the thermal performance of a counter-current double pipe heat exchanger working with COOH-CNT/water nanofluids [5]. K. Goudarzi et al; presents an experimental study on the Aluminium's Oxide (Al_2O_3) in Ethylene Glycol (EG) as nanofluid was used for heat transfer enhancement in car radiator together with wire coil inserts [6]. K.Y. Leong et al; gives the Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator) [7]. M.M. Elias et al; presents in this study on the effect of different nanoparticle shapes on shell and tube heat exchanger using different baffle angles and operated with nanofluid [8]. S.M. Peyghambarzadeh et al; reports the improving the cooling performance of automobile radiator with Al_2O_3/water nanofluid [9]. Cong Wang et al; presented the study on the Intelligent optimization design of shell and helically coiled tube heat exchanger based on genetic algorithm [10]. Hasan Kücük et al; presents this study investigated experimentally the shell side heat transfer and pressure drop of a mini-channel shell and tube heat exchanger (MC-STHE) designed and manufactured using Kern's method [11]. Hardik V. Patel et al; gives the numerical study on Ansys workbench platform to evaluate heat transfer through the radiator for water based CuO nano fluid [12]. G. Jamuna Rani et al; reports of this work is Nano fluids effect on crossflow heat exchanger characteristics [13]. Jonn Are Myhren et al; study the Performance evaluation of ventilation radiators [14]. Rajashekhar Pendyala et al; gives the CFD Analysis of Heat Transfer Performance of Nanofluids in Distributor Transformer [15].

P.B. Maheshwary et al; presents this study the Effect of Shape on Thermophysical and Heat Transfer Properties of ZnO/R-134a Nanorefrigerant [16]. I.M. Mahbubul et al; study the Thermal conductivity, viscosity and density of R141b refrigerant based nanofluid [17].

The discussed literature review study demonstrated that the implementation of nano fluids in engineering era possess substantial potential in regards to the significant improvement in thermo-hydraulic performance of engineering thermal devices. The paramount significance and innumerable applications of indirect channels in almost every sector of industries. numerical and analytical studies to fully acknowledge the prominent influence of decisive parameters on thermo-hydraulic performance of engineering thermal devices. This has eventuated in implementation of nano fluids as new generation heat transfer medium and immaculate coolant in helix, spiral and serpentine channels. The preliminary focus has been given in this study on investigation of thermal and pressure drop performance of various straight section lengths of serpentine tube with Al_2O_3 and CuO nano fluids.

Thus, The objective of this work is "To determine the heat transfer performance of different nano fluids (i.e., Al_2O_3 and CuO nano particles) in a horizontal shell and tube heat exchanger under a turbulent flow condition".

3. Research Methodology:

The various researchers have been studying the cooling performance of shell and tube heat exchangers. The analysis has been divided into three sections comprising: Model validation, nanofluid side and heat transfer performance for shell and tube heat exchanger. The heat transfer takes place between Hot water and nanofluids. The volume concentration used in this analysis was from 0 to 1 volume %. Mass flow rate was deemed constant all the time. The study is carried out by two parts i.e., Mathematical Analysis for model validation and Finite Element Analysis (FEA) for different Nano fluids. Mathematical Analysis is used for the validation of Finite Element Analysis (FEA) model used in ANSYS FLUENT analysis. The design specification of shell and tube heat exchanger are presented in Table 1. It is horizontal type shell and tube heat exchanger with single tube pass. The dimensions of shell and tube heat exchanger are presented in Table 1.

Table1. The Specification of Shell and Tube Heat Exchanger.

Sr. No.	Description	Unit	Value
1.	Cross Sectional Area of the Shell	mm^2	4534.16
2.	Shell diameter	mm	76
3.	Tube diameter	mm	11
4.	Number of tubes		9
5.	Shell/Tube length	m	1.2
6.	Thickness of the Shell	mm	04

3.1. *Finite Element Analysis (FEA):*

ANSYS Workbench 15.0 is used for Finite element analysis (FEA). In ANSYS software the Computational Fluid Dynamics (CFD) is used as platform for the study.

3.2. *Mathematical background:*

The flow is governed by the continuity equation, the energy equation and Navier-Stokes momentum equations. Transport of mass, energy and momentum occur through convective flow and diffusion of molecules and turbulent eddies. All equations are set up over a control volume where i; j; k = 1; 2; 3 correspond to the three dimensions.

The continuity equation defines the conservation of mass and is inscribed as in equation:-

$$\frac{\partial p}{\partial t} + \frac{\partial pU_1}{\partial x_1} + \frac{\partial pU_2}{\partial x_2} + \frac{\partial pU_3}{\partial x_3} = 0 \qquad \text{………… (1)}$$

$$\frac{\partial p}{\partial t} + \frac{\partial pU_i}{\partial x_i} = 0, i = 1,2,3 \qquad \text{………… (2)}$$

The momentum equation in tensor notation for a Newtonian fluid can be written as:-

$$\frac{\partial U_i}{\partial t} + U_j \frac{\partial U_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \vartheta \frac{\partial}{\partial x_j}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) + g_i \qquad \text{………… (3)}$$

Where:- ρ is density of fluid.

t is time.

U_1, U_2, and U_3 are velocity of the fluid in x,y and z directions respectively.

g is acceleration due to gravity.

ϑ is kinematic viscosity of the fluid.

3.3. CFD Analysis:

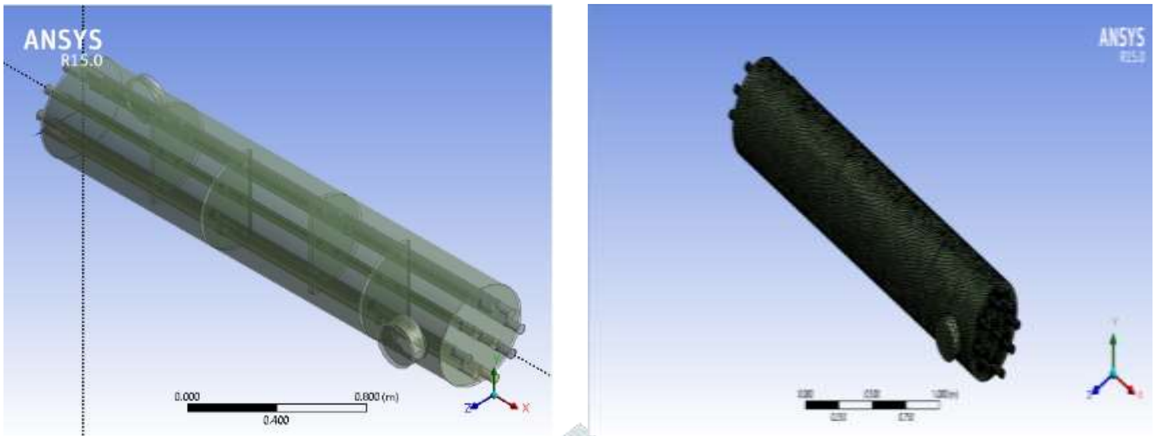

Figure 1. Geometry and meshing of the shell and tube heat exchanger.

The Heat exchanger geometry is built in the AutoCAD inventor and thus it is imported as iges file in ANSYS workbench design module. It is a counter current flow shell and tube heat exchanger. The tube side is built with 9 separate tubes inlets comprising of 9 complete tubes. Initially a relatively coarser mesh is generated with 591944 nodes and 2314819 elements. This mesh contains mixed cells (Tetra and Hexahedral cells) having both triangular and quadrilateral faces at the boundaries.

3.4. Boundary Conditions:

Table 2. Boundary Conditions.

	Boundary Condition	Shell	Tube
Outlet Pressure	Outlet	1 bar	1bar
Wall	No slip condition	No heat flux	Coupled

Table 3. Material Property used for the study.

Material Property					
Material	Nano Particles Concentration (%)	Density (kg/m^3)	Specific Heat Capacity (J/kg-K)	Thermal Conductivity (W/m-K)	Viscosity (kg/m-s)
Base Fluid (Water+ Ethylene Glycol)	0	1027.01	3570	0.415	0.00076
Base Fluid (Water+Ethylene Glycol)+Al_2O_3	0.05	1156.1	3461.123	0.668	0.0019
	0.15	1452.3	2685.322	0.874	0.0019
	0.3	1896.6	1975.971	1.287	0.0019
Base Fluid (Water+ Ethylene Glycol)+ CuO	0.05	1282.6	3137.082	0.664	0.0019
	0.15	1831.8	2165.382	0.858	0.0019
	0.3	2655.6	1461.414	1.241	0.0019

4. Result and Discussions:

The Computational Fluid Dynamics (CFD) results for various nano particles concentrations of nano fluids is employed for different nano fluids to find out the Heat transfer performance. The some variables have been considering constant i.e Hot Fluid mass flow rate 1 kg/s, Cold fluid mass flow rate 0.5kg/s, Hot fluid inlet temperature 57°C. Firstly, the result is obtained for Water+Ethylene Glycol considering as base fluid thereafter the nanoparticles Al_2O_3 and CuO at different concentrations has been added to the base fluid. Figure depicts the Computational Fluid Dynamics (CFD) results for Water+Ethylene Glycol as a base fluid and for both Al_2O_3/water+Ethylene Glycol and CuO/water+Ethylene Glycol nano fluids in a shell and tube heat exchanger.

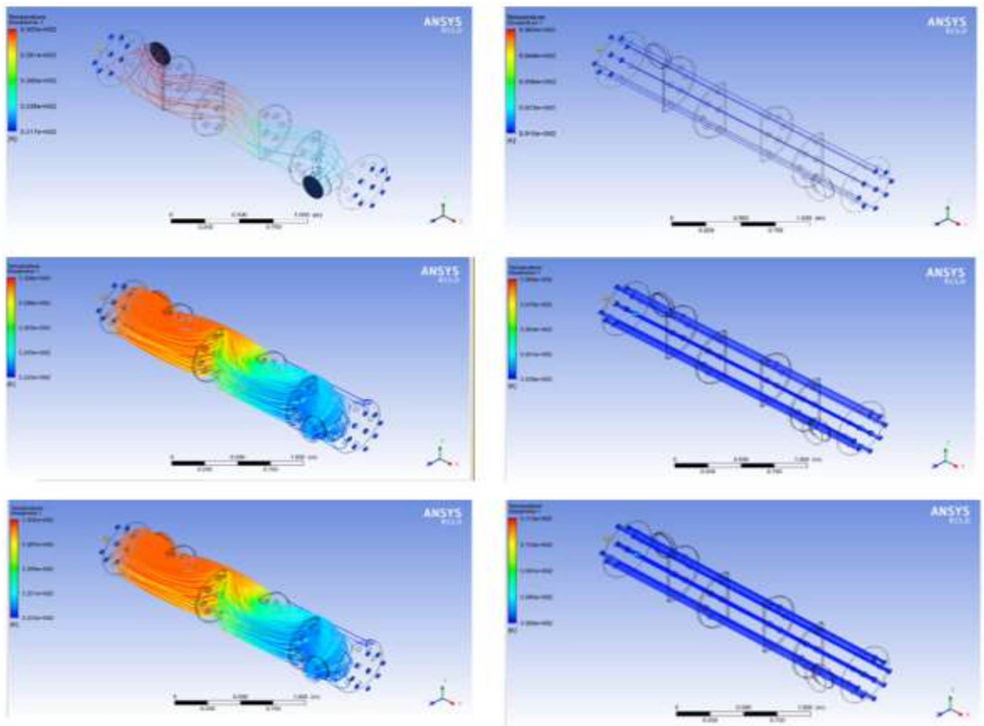

Figure 2. Temperature Distribution streamline for Hot Fluid and cold fluid with Cold Fluid Inlet temperature (a) 28°C (b) 31°C and (c) 34°C, when only [Water+Ethylene Glycol] used as Cold Fluid.

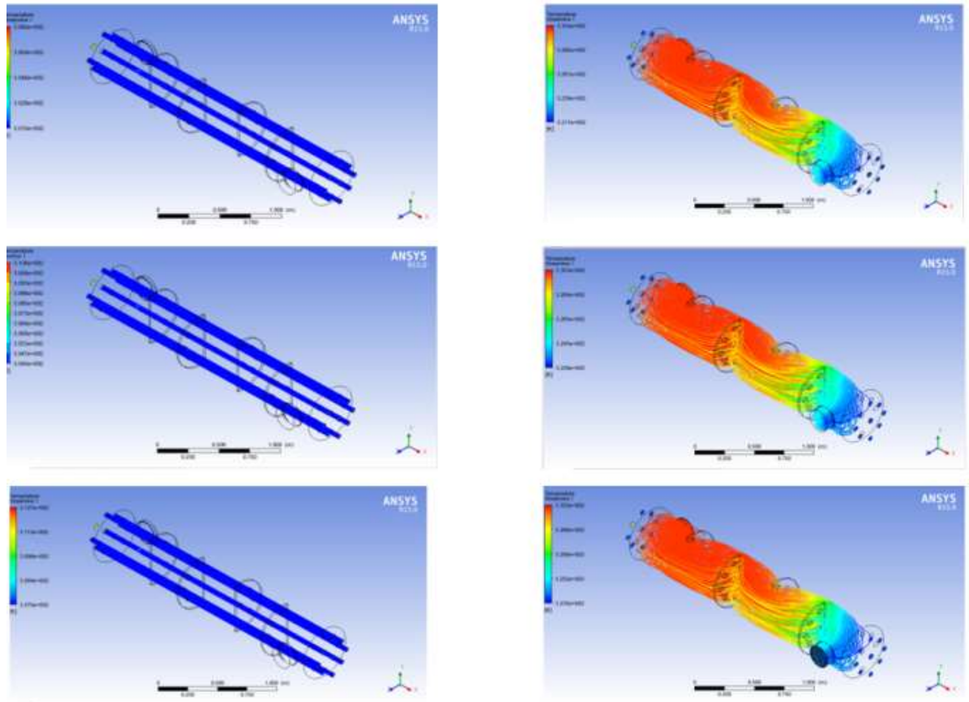

Figure 3. Temperature Distribution streamline for Hot Fluid and cold fluid with Cold Fluid Inlet temperature (a) 28°C (b) 31°C and (c) 34°C, when only [Water+Ethylene Glycol +Al_2O_3] used as Cold Fluid.

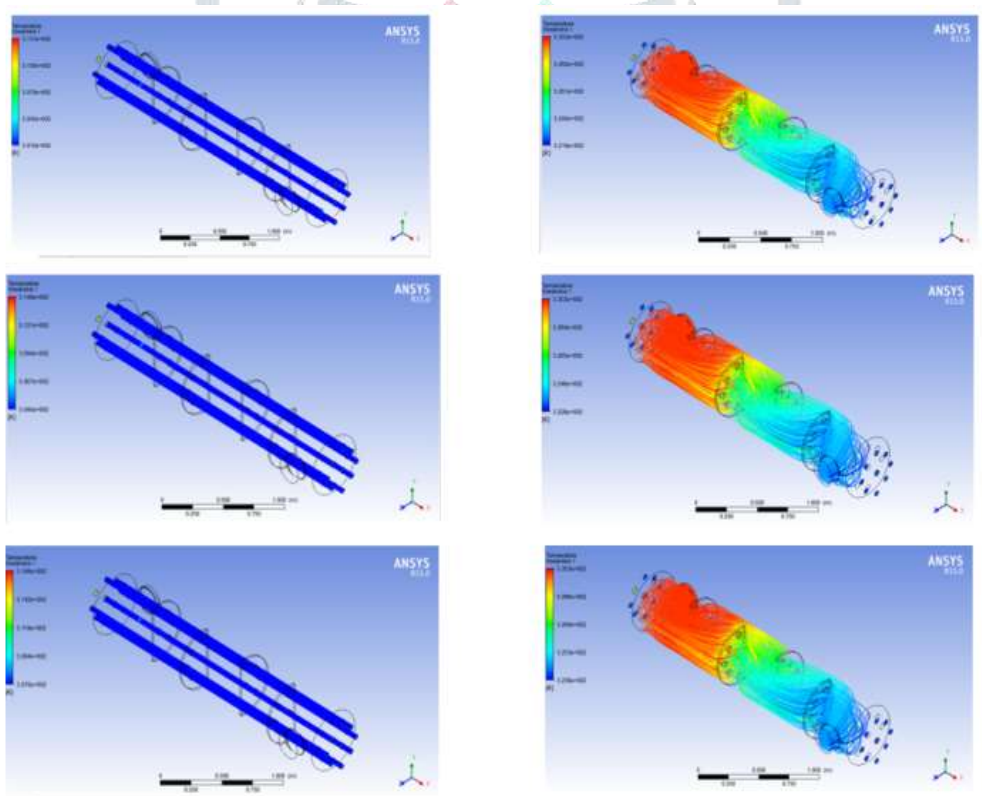

Figure 4. Temperature Distribution streamline for Hot Fluid and cold fluid with Cold Fluid Inlet temperature (a) 28°C (b) 31°C and (c) 34°C, when only [Water+ Ethylene Glycol +CuO] used as Cold Fluid.

The overall heat transfer coefficient increases with the increase of volume concentration of Nano particles. The maximum value of Overall Heat Transfer Coefficient can be obtained by having 0.3% and 0.05% particles concentration nanofluids with Al_2O_3 and CuO respectively. The maximum enhancement of the overall heat transfer coefficient of nanofluid occurs at 0.3% volume concentration of Al_2O_3 nano particles as clearly shown in figure 5. The maximum value of heat transfer rate can be obtained by having 0.3% and 0.05% particles concentration of Al_2O_3 and CuO nanofluids respectively. The heat transfer rate is found higher for nanofluid containing 0.3 % volume concentration of Al_2O_3 nano particles as clearly shown in figure 6. For both nanofluids the overall heat transfer coefficient and Heat Transfer rate at a constant Hot Fluid Inlet Temperature increases with increasing of the nanoparticles concentration compared to the base fluid only except the condition of having 0.15% concentration Al_2O_3 nanofluid. The heat transfer rate is minimum for both nanofluids at nano particles concentration 0.15% by volume. It is observe that the Temperature drop is maximum at nano particles concentration 0.15% by volume. The Temperature Drop is maximum at 0.15% volume concentration of Al_2O_3 nano particles.

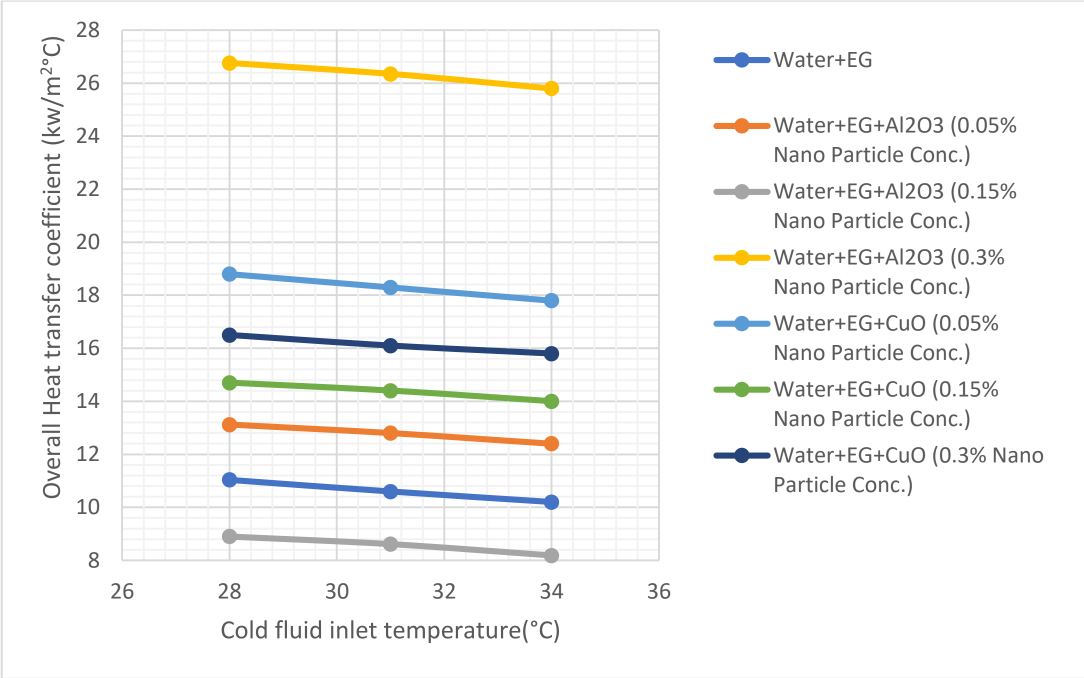

Figure 5. Overall Heat Transfer Coefficient variation with respect to cold Fluid Inlet Temperature for various fluids.

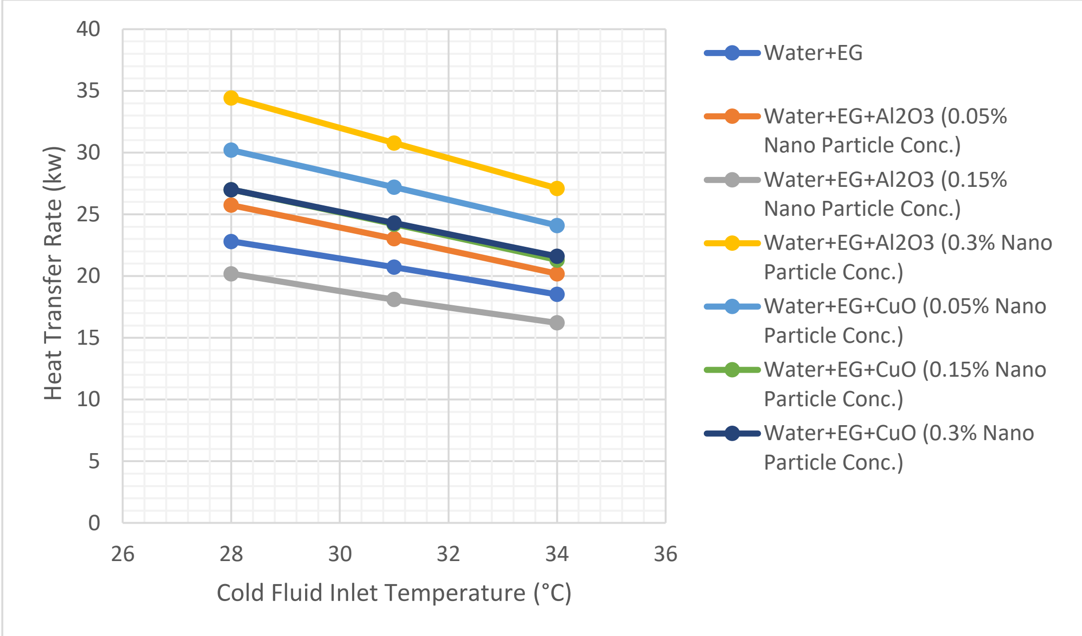

Figure 6. Heat transfer rate variation with respect to cold Fluid Inlet Temperature for various fluids.

5. Conclusion:

In this paper the study of heat transfer performance of both Al_2O_3/water+Ethylene Glycol and CuO/water+Ethylene Glycol nano-fluids in a shell and tube heat exchanger was investigated. The following observation has been made; The overall heat transfer coefficient is varying from 10.8 kw/m^2 °C minimum value to the 11.01 kw/m^2 °C maximum value for Water+Ethylene Glycol as a base fluid. The overall heat transfer coefficient is varying from 12.92 kw/m^2 °C minimum value to the 13.12 kw/m^2 °C maximum value for Water+ Ethylene Glycol as a base fluid with 0.05% concentration of Al_2O_3 as Nano Particles. It can be observed that the overall heat transfer coefficient is varying from 8.817 kw/m^2 °C minimum value to the 8.982 kw/m^2 °C maximum value for Water+Ethylene Glycol as a base fluid with 0.15% concentration of Al_2O_3 as Nano Particles. It can be observed that the overall heat transfer coefficient is varying from 25.93 kw/m^2 °C minimum value to the 26.51 kw/m^2 °C maximum value for Water+Ethylene Glycol as a base fluid with 0.3% concentration of Al_2O_3 as Nano Particles. It can be observed that the overall heat transfer coefficient is varying from 18.5 kw/m^2 °C minimum value to the 18.7 kw/m^2 °C maximum value for Water+Ethylene Glycol as a base fluid with 0.05% concentration of CuO as Nano Particles. It can be observed that the overall heat transfer coefficient is varying from 14.4 kw/m^2 °C minimum value to the 14.5 kw/m^2 °C maximum value for Water+Ethylene Glycol as a base fluid with 0.15% concentration of CuO as Nano Particles. It can be observed that the overall heat transfer coefficient is varying from 16 kw/m^2 °C minimum value to the 16.2 kw/m^2 °C maximum value for Water+Ethylene Glycol as a base fluid with 0.3% concentration of CuO as Nano Particles. The overall heat transfer coefficient increases with the increase of volume concentration of Nano particles. For both nanofluids the overall heat transfer coefficient and Heat Transfer rate at a constant Hot Fluid Inlet Temperature increases with increasing of the nanoparticles concentration compared to the base fluid only except the condition of having 0.15% concentration Al_2O_3 nanofluid. The maximum value of Overall Heat Transfer Coefficient of the base fluid was 11.01 kw/m^2 °C. With the addition of 0.3% of Al_2O_3 and 0.3% of CuO nanoparticles, the Overall Heat Transfer Coefficient increased to 26.51 kw/m^2 °C and 16.2 kw/m^2 °C respectively. The maximum value of Heat Transfer rate of the base fluid was 22.81 kw, 0.3% Al_2O_3 nanofluid was 34.43 kw and 0.3% CuO nanofluid was 27 kw respectively. The maximum value of Overall Heat Transfer Coefficient and Heat Transfer rate of nanofluids can be obtained by having 0.3% and 0.05% particles concentration nano fluids with Al_2O_3 and CuO respectively. The maximum enhancement of the overall heat transfer coefficient and Heat Transfer rate of nanofluids occurs at 0.3% volume concentration of Al_2O_3 nano fluid. The heat transfer rate is minimum for both nanofluids at nanoparticles concentration 0.15% by volume. And the Temperature drop is maximum For both nanofluids at nanoparticles concentration 0.15% by volume. It can be concluded that the overall heat transfer coefficient and Heat Transfer rate of Al_2O_3 nanofluid is higher than that of CuO nanofluid at the 0.3% volume concentration of nanoparticles.

6. References:

[1] Jaafar Albadr, Satinder Tayal, Mushtaq Alasadi, Heat transfer through heat exchanger using Al_2O_3 nanofluid at different concentrations, Studies in Thermal Engineering 1 (2013) 38-44.

[2] Alhassan Salami Tijani, Ahmad Suhail bin Sudirman, Thermos-physical properties and heat transfer characteristics of water/anti-freezing and Al_2O_3/CuO based nanofluid as a coolant for car radiator, Int. J. of Heat and Mass Transfer 118 (2018) 48–57.

[3] Arun Kumar Tiwari, Pradyumna Ghosh, Jahar Sarkar, Particle concentration levels of various nanofluids in plate heat exchanger for best performance, Int. J. of Heat Mass Transfer 89 (2015) 1110–1118.

[4] B. Farajollahi, S.Gh. Etemad, M. Hojjat, Heat transfer of nanofluids in a shell and tube heat exchanger, Int. J. of Heat and Mass Transfer 53 (2010) 12–17.

[5] M.M. Sarafraz, F. Hormozi, V. Nikkhah, Thermal performance of a counter-current double pipe heat exchanger working with COOH-CNT/water nanofluids, Exp. Therm. and Fluid Sci. 78 (2016) 41-49.

[6] K. Goudarzi, H. Jamali, Heat transfer enhancement of Al_2O_3-EG nanofluid in a car radiator with wire coil inserts, Applied Thermal Engineering 118 (2017) 510-517.

[7] K.Y. Leong, R. Saidur, S.N. Kazi, A.H. Mamun, Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator), Applied Thermal Engineering 30 (2010) 2685-2692.

[8] M.M. Elias, I.M. Shahrul, I.M. Mahbubul, R. Saidur, N.A. Rahim, Effect of different nanoparticle shapes on shell and tube heat exchanger using different baffle angles and operated with nanofluid, Int. J. of Heat and Mass Transfer 70 (2014) 289–297.

[9] S.M. Peyghambarzadeh, S.H. Hashemabadi, M. Seifi Jamnani, S.M. Hoseini, Improving the cooling performance of automobile radiator with Al_2O_3/water nanofluids, Applied Thermal Engineering 31 (2011) 1833-1838.

[10] Cong Wang, Zhengyu Cui, Hongmei Yu, Kai Chen, Jianli Wang, Intelligent optimization design of shell and helically coiled tube heat exchanger based on genetic algorithm, Int. J. of Heat and Mass Transfer 159 (2020) 120140.

[11] Hasan Kücük, Murat Ünverdi, Mehmet SenanYılmaz, Experimental investigation of shell side heat transfer and pressure drop in a mini-channel shell and tube heat exchanger, Int. J. of Heat and Mass Transfer 143 (2019) 118493.

[12] Hardik V. Patel, Dattatraya G. Subhedar, Dr.Bharat Ramani, Numerical Investigation of performance for Car Radiator Oval Tube, Material Today: Proceedings 4 (2017) 9384-9389.

[13] G. Jamuna Rani, G. Sai Rani, Anchupogu Praveen, Nano fluids effect on crossflow heat exchanger characteristics – Review, Materials Today: Proceedings (2020).

[14] Jonn Are Myhren, Sture Holmberg, Performance evaluation of ventilation radiators, Applied Thermal Engineering 51 (2013) 315-324.

[15] Rajashekhar Pendyala, Suhaib Umer Ilyas, Lian Rui Lim, Narahari Mar neni, CFD Analysis of Heat Transfer Performance of Nanofluids in Distributor Transformer, Procedia Engineering 148 (2016) 1162 – 1169.

[16] P.B. Maheshwary, C.C. Handa, K.R. Nemade, Effect of Shape on Thermophysical and Heat Transfer Properties of ZnO/R-134a Nanorefrigerant, Materials Today: Proceedings 5 (2018) 1635–1639.

[17] I.M. Mahbubul, R. Saidur, M.A. Amalina, Thermal conductivity, viscosity and density of R141b refrigerant based nanofluid, Procedia Engineering 56 (2013) 310 – 315.