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Numeric and Experimental Study of CO_3O_4 – Water/Ethylene glycol-based Nanofluid for Car Radiator Application

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Abstract: **Advanced heavy-duty engines are being employed to provide a better experience to the people as technology advances. For heavy-duty engines, we can't expand the heat transfer area to enhance the heat transfer rate. Nanofluids are widely employed as a coolant in automotive radiators as a replacement for conventional base fluid to fulfil current needs for better heat transfer rates in the smallest possible heat transfer area. Co3O4 – Water/Ethylene Glycol mixture based nanofluids are employed in this work to investigate the improvement in automotive radiator performance for better cooling. The obtained results are compared to a base fluid that does not contain nanoparticles. The input temperature was maintained at 63° C, and output temperatures were monitored at varied radiator inlet flow rates and cobalt oxide volume concentrations. ANSYS FLUENT software is used to model the experimental setup, and the results are compared. The increase in heat transfer rate recorded for 0.3 vol. percent of nanoparticles at 4 lpm velocity is 29.5 percent, according to this study.**

***Keywords*: Nanofluid, Cobalt oxide, Car Radiator, Computational Fluid Dynamics (CFD)**

Nomenclature

Re Reynolds Number
SEM Scanning Electron Microscopy
Cp Specific heat capacity
H Heat transfer coefficient
T Temperature
Nu Nusselt Number
Nf Nanofluid
Dh Hydraulic diameter
Pr Prandtl Number
EG Ethylene Glycol
Lpm Litre per minute

I. INTRODUCTION

A nanofluid is a fluid that contains nano-sized solid particles that are spread in a base fluid. Any of the Area, temperature difference, or heat transfer co-efficient can be increased to improve heat transfer. R. Saidur et al. conducted a thorough investigation in this area. Because of their large surface area to volume ratio, nanofluids outperform basic fluids. This allows for more heat transfer between the particle and the fluid. Because gravity's effect on a particle is negligible, it can stay in suspension for a long time. When compared to other particles, nanoparticles cause the least amount of blockage. To suit different applications, variable particle concentrations can be used to change the thermal characteristics. M. Peyghambarzadeh et al. investigated the heat transfer performance of an automobile radiator using pure water and an EG mixture with Al_2O_3 nanoparticles. With various concentrations, the flow rate was changed between 2 and 6 lpm. The best solution yielded a 40 percent increase in enhancement. The heat transfer behaviour was found to be significantly reliant on particle concentration and scarcely dependent on temperature. S.A. Ahmed et al. investigated TiO_2 –water-based nanofluid use for automobile radiators at 0.1, 0.2, and 0.3 volume concentrations with laminar flow rates. The Reynolds number ranged between 560 and 1650.

The author discovered that a concentration of 0.2 vol percent can increase the efficacy of a car radiator by 47 percent. TiO_2 has a higher aspect ratio, lower specific gravity, higher thermal conductivity, thermal resistance, and a larger specific area than other oxides. For an automobile radiator, Hafiz Muhammad Ali et al. employed a ZnO-based nanofluid. Various volumetric concentrations of ZnO are applied (0.01 percent, 0.08 percent, 0.2 percent and 0.3 percent). The fluid flow rate ranged from 7 to 11 lpm. At 0.2 percent volumetric concentration, nanofluids showed up to 46 percent better heat transmission than base fluid. In comparison to the 0.2 percent concentration, an increase in concentration to 0.3 percent resulted in a decrease in heat transmission. The fluid inlet temperature was controlled between 45 and 55 degrees. C.M. Naraki et al. investigated the use of CuO-based nanofluids to improve heat transmission in automotive radiators. The content of CuO nanofluid was changed from 0-0.4 vol percent. At 0.4 vol percent concentration and 0.4 m3/hr flow rate, an enhancement of 8% is seen. Hussein et al. conducted an experimental investigation employing TiO_2 and SiO_2 nanopowders suspended in pure water to improve automotive radiator efficiency. The volumetric flow rate was varied between 2 and 8 lpm, the inlet temperature was varied between 60 and 80°C, and the nanofluid content was varied between 1-2 percent. For TiO_2 and SiO_2, the maximum boost was determined to be 11 percent and 22.5 percent, respectively.

For vehicle radiators, Hashemabadi et al. employed Al_2O_3/water based nanofluids. When compared to water as a coolant, the author saw a 45 percent increase. Using copper-based nanofluids, Saidur et al. increased heat transmission by 3.8 percent. Using SiC-based nanofluids and a 0.5 percent nanoparticle concentration, Zou et al. achieved a 53.81 percent thermal conductivity improvement over the basic fluid. Al_2O_3/water-mono ethylene glycol nanofluids were employed by Subhedar et al. Ethylene glycol and water are mixed in a 50:50 ratio. The heat transfer rate increased by 30%, according to the author. Oliveira et al employed MWCNT/water nanofluid in a car radiator and discovered that at 0.16 wt percent concentration, the heat transfer rate drops by 17 percent. This demonstrates that a constant increase in heat transfer rate is not required. In an automobile radiator with wire coil inserts, Goudarzi et al. employed Al_2O_3/Ethylene Glycol as a nanofluid. The rate of heat transfer increased by 9%. In addition, using a heat coil insert in conjunction with a 1% nanofluid concentration results in a 5% increase over using the coil alone. Tijani et al. investigated the thermophysical properties and heat transport characteristics of an Al_2O_3/CuO based nanofluid that was used as a coolant. The ANSYS fluent solver is used to create heat transfer models. CuO-based nanofluid was shown to be more efficient than Al2O3-based nanofluid. Filho et al. used a water/Ethylene glycol combination to make silver and graphene nanoparticles in varied proportions. The water/glycol mixture is held at a 50:50 ratio. Experiments are carried out at different mass flow rates and inlet temperatures. The rest of the parameters remain unchanged. Thermohydraulic performance of silver nanoparticles increased by 4.4 percent, but that of graphene nanoparticles decreased. Elbadawy et al. investigated enhancement utilising numerical approaches using Al_2O_3/water and CuO/water-based nanofluids. Ali et al. looked into the performance of a ZnO/water nanofluid in a car radiator. The author achieves a 46 percent improvement. The -NTU approach was utilised by Peyghambarzadeh et al. to examine heat transfer performance using Al_2O_3/water and CuO/water-based nanofluids. In this study, a 9 percent improvement was achieved. Ali et al. examined all recent achievements in the application of nanofluids in a car radiator. All of the critical characteristics, such as size, shape, nanoparticle concentration, nanofluid flow rate, and so on, were discussed by the author. In this study, the use of Co3O4 is not explored. When compared to the base fluid, Reddy et al. employed TiO_2/water nanofluid and found a 37 percent improvement at optimal operating settings. f-MWCNT nanoparticles with water and ethylene glycol as a base fluid were employed by Shashishekar et al. Heat transfer performance has been improved by 45 percent. Yang et al. examined all of the current developments in utilising ANN to model vehicle radiators. Experimental achievements in nanofluid applications in an automobile engine were reviewed by Sidik et al. Using graphene-based suspension in a car radiator, Harish et al. showed a 20 to 51 percent increase in heat transfer rate at optimal conditions of mass flow rates and nanoparticle concentration. Chiavazzo et al. and Sidik et al. both looked at transport processes in nanofluid coolants, with an emphasis on automotive applications. Sidik et al. investigated the thermal performance of MWCNT-based nanoparticles for Perodua Kelisa 1000cc radiators in an experimental setting. This paper claims a 196.3 percent improvement over the control fluid. When compared to the base fluid, Hussein et al. employed SiO_2 nanoparticles and showed a 50% increase in heat transfer rate.

Experiments were carried out using base water, Co_3O_4 – Water Ethylene glycol combination, and Co_3O_4 – Water in this article. And the findings are compared to the performance of just the base fluid. Nanofluid with 0.1, 0.2, and 0.3 percent volume concentrations were explored in these studies, with flow rates ranging from 2 to 4 litres per minute. Differential light scattering was used to characterize the particles, yielding a particle size of 56.71 nm.

II. EXPERIMENTAL SETUP

Preparation of nanofluids

For the preparation of cobalt oxide nanoparticles, firstly cobalt nitrate $Co.(NO_3)_2.6H_2O$ (0.6M) was dissolved in 100ml deionized water. Then 100ml KOH aqueous solutions (3.2 M) dropped wise added to the precursor solution.10 ml oleic acid was added as a surfactant and was kept for mixing for 30 min. at 50°C in magnetic stirrer. The pink precipitate was noticed immediately which got oxidized by air easily and low heat or weak oxidizing agents to $Co(OH)_3$. The obtained dark brown precipitate was separated and washed with deionized water and was thus dried in an oven at 110°C for 20 hours. The obtained cobalt hydroxide was ground and preserved in a decanter. The cobalt oxide (Co_3O_4) was prepared by heating dark brown cobalt hydroxide at 450°C. The obtained black cobalt oxide was then crushed in crushing mortar to get cobalt oxide nanoparticles [7]. The cobalt oxide nanoparticles are taken in the desired fraction in 300 ml water and kept for sonication for 1 hr. This resulted in nanofluid formation.

Experimental Setup

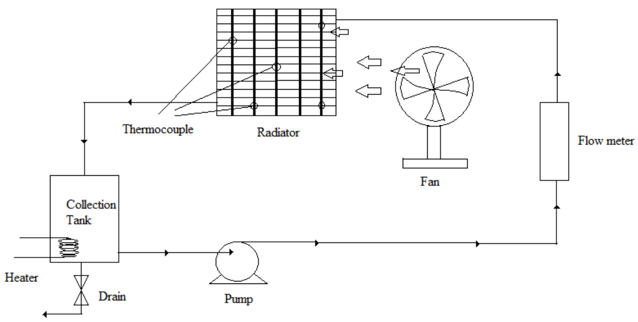

Figure 1: Schematic Representation of Experimental Setup

Required setup is shown in figure 1. The setup consists of a car radiator, two water tanks (one with a heater to act as engine), pipe fittings, pipe connections, valve, thermocouples, a fan, water pump. Basic dimensions of car radiator are tabulated in table 1. In the setup car radiator is connected to the tank with the heater at the inlet side and outlet of a car radiator is connected to another tank to collect water. The thermocouples are connected such that they calculate the inlet temperature of the fluid and the outlet temperature. The digital reading is thus obtained. One thermocouple is used to measure the wall temperature. The flow rate is varied from 2-4 litres per minutes with an interval of 0.5 lpm and the concentration of nanoparticles is varied as 0.05, 0.1, 0.2, 0.25 and 0.3 vol. %. Firstly base water is used as a fluid and is experimented with free and forced convection. Then a mixture of ethylene glycol and water for 50% ethylene glycol is made and is used as the base fluid for nanofluid for observations. In actual cars, a mixture of water and ethylene glycol is used. Outlet temperature, wall temperature, and inlet temperature are measured for all the cases using thermocouples. The inlet temperature is maintained constant at 63°C and ensured using a thermocouple.

TABLE 1
Geometrical details of the car radiator design

Tube length	29 cm
Tube thickness	0.5 cm
Tube height	0.14 cm
Tube width	0.2 cm
Number of fins	125
Space between tubes	1.5 cm
Tube hydraulic diameter	0.261 cm
Material used	Aluminum
Cell count	16,47,980

III. Theoretical Background

The car radiator geometry necessary for the simulation was prepared using ANSYS ICEM-CFD software. The blocking feature of this software was used in order to get structured hexahedral mesh. This feature provides a projection-based mesh-generation environment. The final mesh generated was then imported into ANSYS FLUENT software. Single radiator tube with its louvered fins on both sides was modeled. Figure 2 shows the details of geometrical configurations of a car radiator. All the necessary dimensions of geometry are illustrated in Figure 2 A. While, Figure 2 B gives the glimpses of the meshed domain of the radiator. A computational model of the radiator is given in Figure 2 C.

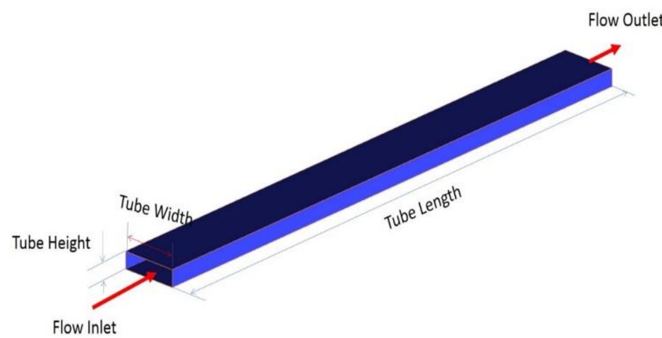

Figure 2 A) Schematic of the flat radiator tube

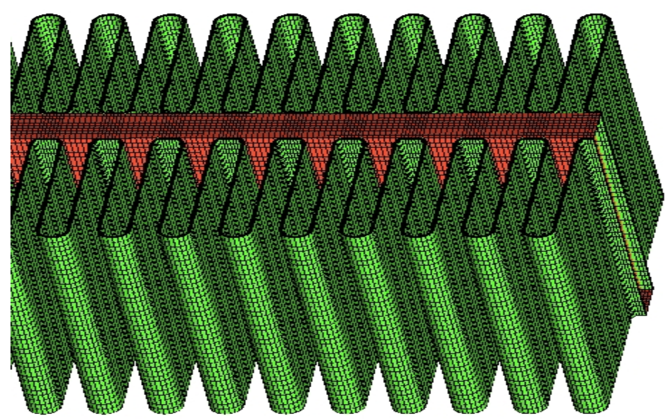

Figure 2 B) Details of structured hexahedral mesh

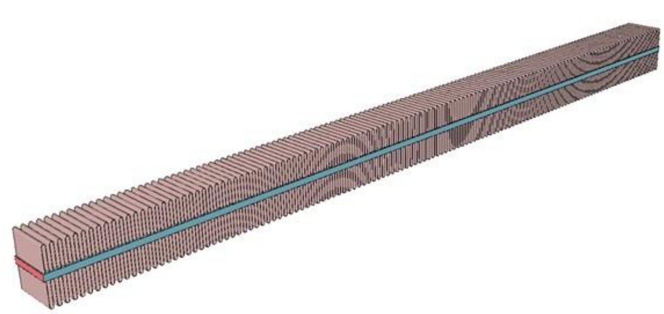

Figure 2 C) Computational model of the Radiator

Estimation of nanofluid physical properties and model equations

Mathematical models illustrated below were used in order to determine the thermophysical properties of the base fluid and nanofluid. These properties were utilized for numerical computation. Co_3O_4 nanoparticles were mixed with the base fluid (water) and nanofluids of different volume percentages were prepared. The nanoparticles were assumed to be well dispersed in the mixture and uniform throughout the system.

TABLE 2
Physical Properties of Nanoparticles and base fluid at 25^{0}C

Working Fluid	**Density (Kg/m^3)**	**Specific Heat Capacity (J/Kg K)**	**Viscosity (Pa.sec)**	**Thermal Conductivity (W/m K)**
Co_3O_4	6081	225	-	8.69
Water	995	4180	0.00089	0.609
Ethylene Glycol	1110	2200	0.0161	0.256
Base fluid [14]	1027.01	3570	0.00076	0.415

Physical properties used for calculation are tabulated in Table 2. And calculation formulae are given below.

Viscosity is calculated by the following formula

$$\mu_{nf} = (1 + 2.5\varphi)\mu_{bf} \text{ [29]} \qquad (1)$$

Where, μ_{nf} means viscosity of nanofluids, μ_{bf} stands for the viscosity of base fluids

ϕ : Particle volume fraction

$$\rho_{nf} = \varphi\rho_p + (1 - \varphi)\rho_{bf} \text{ [30]} \qquad (2)$$

Where, ρ_{nf} stands for a density of nanofluid, ρ_p means density of the particle, ρ_{bf} is the density of the base fluid and ϕ represents volume fraction of particle

$$(\rho C_p)_{nf} = \phi(C_p\rho)_p + (1 - \phi)(C_p\rho)_{bf} \text{ [31]} \qquad (3)$$

$$K_{nf} = \frac{K_p + 2K_{bf} + \phi(K_p - K_{bf})}{K_p + 2K_{bf} - \phi(K_p - K_{bf})} K_{bf} \text{ [32]} \qquad (4)$$

K_{nf} Represents thermal conductivity of nanofluid, K_p stands for thermal conductivity of particle, K_{bf} is thermal conductivity of the base fluid

For calculating Prandtl number for car radiator, the following equations are used

$$\text{Pr} = \frac{C_p * \mu}{k} \qquad (5)$$

Dittus and Boelter's equation is used for this geometry

$$Nu = 0.023 \times (Re)^{0.8} \times (Pr)^{0.3} \qquad (6)$$

$$\text{h} = \frac{Nu * k}{d} \qquad (7)$$

Where, h = heat transfer co-efficient and k represents thermal conductivity of the fluid.

Boundary Condition

CFD simulation was performed using ANSYS FLUENT simulation package of version 16.2.

- Turbulence model used for the simulation was realizable k-epsilon.
- Inlet: Volumetric flow rate of 2 L/min, 2.5 L/min, 3 L/min, 3.5 L/min and 4 L/min of coolant was specified in terms of velocity inlet boundary condition of 0.1832 m/s, 0.229 m/s, 0.2749 m/s, 0.3207 m/s and 0.3665 m/s respectively.
- Outlet: Pressure outlet boundary condition was specified at the outlet. Outlet pressure was specified to be atmospheric.
- Wall: Both the radiator tube as well as louvered fin walls were specified with convective boundary condition (varying convective heat transfer coefficients in W/m^2K for varying volumetric flow rates) and ambient air temperature of 35°C.
- The flow was assumed to be turbulent, steady and incompressible. The thermophysical properties of the coolant were constant throughout the flow. System pressure was set at atmospheric (101.325 kPa).
- It was assumed that the flow through each radiator tube is constant & temperature drop through each tube is the same. Based on this assumption, only single tube along with its louvered fins on both sides was selected as our computational domain for numerical analysis. Moreover, the radiation heat loss effect was assumed to be negligible.

Grid Independence Study

In order to reduce computational time, it is essential to perform the simulation on optimum grid size. Adoption of the grid independence study proves to be an effective tool to achieve this objective. Five cases of simulations with different grid resolution are used.

The lowest number of elements is 1647980 elements. Highest element count is 3376132 elements. Same output temperatures were recorded for all of the grid independence cases.

IV. Results & Discussion

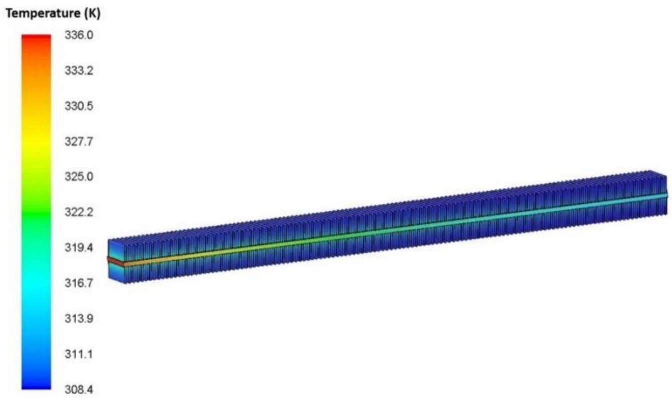

Figure 3. Temperature profile over the wall of radiator for coolant (pure water) at 3 L/min.

Simulation results

To ensure accuracy of results obtained from simulation; simulation results are compared with experimental values, Table 3 illustrates validation of simulation results of Nusselt number with experimental data obtained for pure water as base fluid. From the table, it is clear that the average error is near to 8.02%. As we took the only section of radiator and experimentations are done by using the whole radiator. Thus there is a possibility of this error. Thus, we can continue with this simulation approach for other studies where the composition of water and ethylene glycol is taken 50-50%.

Results obtained from ANSYS FLUENT for water-Ethylene glycol-based nanofluid

Table 4 represents results obtained from ANSYS FLUENT for 50-50% of water–ethylene glycol mixture. Figure 3 shows the temperature profile of the car radiator model for 3 lpm and 0.1 % conc. The outlet temperature is an important parameter to study, from the figure, it can be seen that a temperature drop of 20 K is achieved. While, in case of the pure base fluid, temperature drop achieved is 16 K. Thus, heat transfer is achieved is more in nanofluids than base fluid.[33-38] Conduction through walls and fins can be seen in this figure.

While in Figure 4 A & B, velocity pathlines of the radiator are shown. In 4A, Velocity counter of base fluid at 4 lpm is shown and in 4 B, Velocity of 4lpm in 0.3% nanofluid concentration is shown. Because Highest Reynolds number is at high velocity of 4 rpm and a concentration of 0.3% nanoparticles and the lowest value of Reynolds number is recorded at 2 lpm of the pure base fluid.

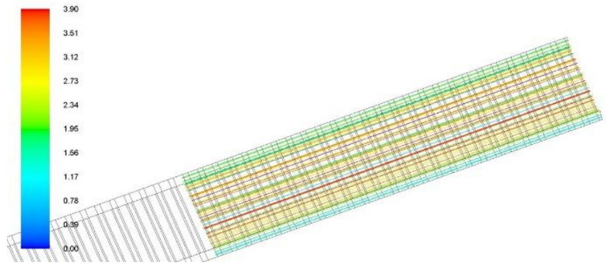

Figure 4 A. Velocity pathlines at the exit of the radiator tube (released from the imaginary plane) for coolant pure water at 4 L/min.

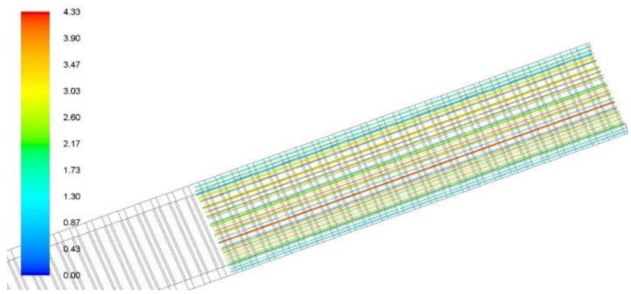

Figure 4B. Velocity pathlines at the exit of radiator tube (released from the imaginary plane) for highest Reynolds number value (N_{Re}=62184)

Figure 5 represents the Nusselt number at different concentration for different flow rates for CO_3O_4. Highest Nusselt number is recorded as 0.1 vol % of Co_3O_4. After this value heat performance of car radiator goes on decreasing due to the decreasing value of Prandtl number, This leads to a decrease in Nusselt number. As the flow rate of nanofluid increases, Reynolds number also increases, This increases Nusselt number value because the Reynolds number and Nusselt number are related by equation no. 6.[39-44].

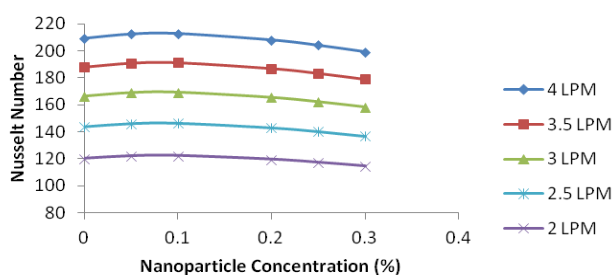

Figure 5: Nusselt number variation with respect to nanoparticles concentration at various flow rates

Figure 6 represents Heat transfer co-efficient for different concentrations at different flow rates for CO_3O_4 calculated from simulations. As we are increasing nanoparticle concentration thus, thermal conductivity increases in nanofluids and this increased thermal conductivity leads to an increase in heat transfer coefficient. Increased flow rate increases Reynold number and this leads to an increase in Nusselt number.

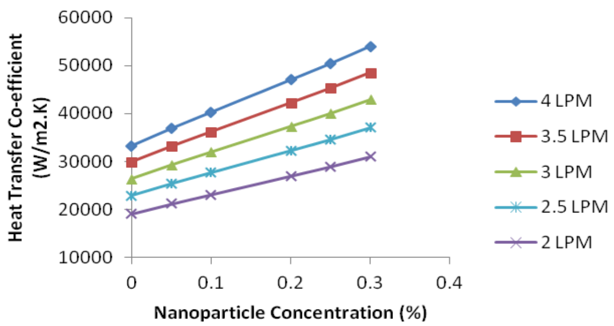

Figure 6: Heat Transfer Co-efficient Variation with respect to nanoparticles concentration at various flow rates

Experimental values have an average of 10 % more than simulation values because we do not consider experimental errors while developing a CFD model. Table 5-10 represents comparative values of simulation results and experimental results of output temperatures at various concentrations of nanoparticles.[45-48]

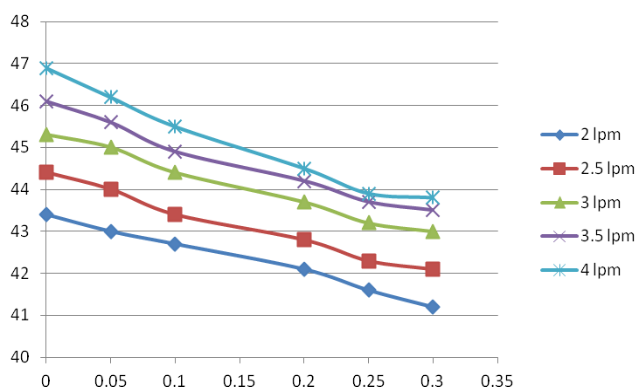

Figure 7: Outlet Temperature variation with respect to nanoparticles concentration at various flow rates

Figure 7 shows outlet temperature with respect to nanoparticle concentration. With an increase in flow rate, outlet temperature increases and less temperature difference is obtained. But for lower flow rates, temperature difference increases. Because of increased residence time. Temperature difference increases with increase nanoparticle in concentration. Because, at higher nanoparticle concentration, the thermal conductivity increases and becomes a dominant parameter for heat transfer.[49-52]

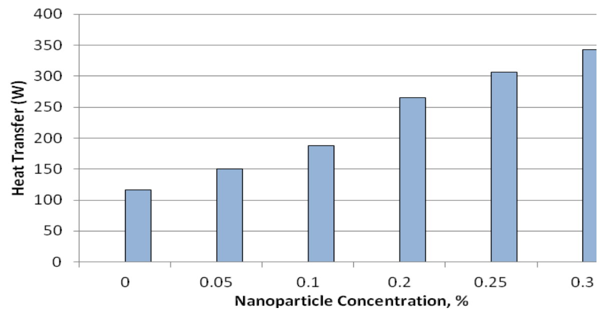

Figure 8: Heat Transfer Enhancement with respect to Nanoparticles concentration in the base fluid

From figure 8, it is clear that the maximum amount of heat transfer occurred is 29.50 % compared to the base fluid. Heat transfer rate increases with an increase in nanoparticle concentration.

V. Conclusion

The use of ethylene glycol decreases the overall heat transfer rate compared with only water as base fluid. The use of ethylene glycol is still necessary as it acts as an anti-freezing agent. Use of nanoparticles as a coolant in car radiator is beneficial as it reduces the overall size of the car radiator for the same duty requirements or we can get higher duty work done with the same size of a car radiator. The heat transfer rate is determined for various volume fractions of Cobalt Oxide nanoparticles in the base fluid of water and Ethylene Glycol of 50-50% composition. The addition of nanoparticles showed enhancement in heat transfer rate as compared to the base fluid. Highest heat transfer rate enhancement recorded is 29.5 % compared to the base fluid of 50-50% of water and ethylene glycol. The experimental and theoretical heat transfer coefficients are almost equal with the highest error of 14.35% due to experimentation. Effect of flow rate and concentration of nanoparticles is studied on Nusselt number, Prandtl number and Reynolds number and results are tabulated in Table 4-10.

VI. Acknowledgement

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TABLE 3

Mathematical modeling comparison with experimental values

Flow Rate (lpm)	Experimental				Simulation				Percentage Error			
	Nanoparticles concentration (v/v)				Nanoparticles concentration (v/v)				Nanoparticles concentration (v/v)			
	0	0.05	0.2	0.3	0	0.05	0.2	0.3	0	0.05	0.2	0.3

2	106.55	110.18	111.62	130.67	101.24	103.32	103.78	119.25	5.25	6.64	7.56	9.58
2.5	128.66	131.17	134.77	152.40	121.02	123.51	124.06	135.42	6.32	6.21	8.64	12.54
3	150.46	148.92	151.23	173.46	140.03	142.91	143.54	151.7	7.45	4.21	5.36	14.35
3.5	165.07	163.68	177.38	186.09	158.41	161.66	162.38	170.3	4.21	1.25	9.24	12.35
4	190.73	187.71	203.11	211.83	176.26	179.89	180.69	185.3	8.21	4.35	12.41	14.32
					Total Average Error				8.0225 %			

TABLE 4
Heat Transfer Performance of nanofluids as a coolant from ANSYS FLUENT

%CO_3O_4 Conc.	**Velocity**	**Heat Transfer Coefficient (W/m^2K)**	**Prandtl number**	**Reynolds number**	**Nusselt number**
0	2	19110.42	6.5378	21972.5658	120.1884
0	2.5	22845.37	6.5378	27465.7072	143.6781
0	3	26432.8	6.5378	32958.8487	166.2400
0	3.5	29902.02	6.5378	38451.9901	188.0585
0	4	33273.17	6.5378	43945.1316	209.2601
0.05	2	21181.11	5.2380	24336.8935	122.0368
0.05	2.5	25320.76	5.2380	30421.1169	145.8877
0.05	3	29296.9	5.2380	36505.3403	168.7967
0.05	3.5	33142.03	5.2380	42589.5637	190.9507
0.05	4	36878.45	5.2380	48673.7871	212.4784
0.1	2	23134.33	4.3127	26228.3557	122.2279
0.1	2.5	27655.71	4.3127	32785.4447	146.1162
0.1	3	31998.52	4.3127	39342.5336	169.0609
0.1	3.5	36198.22	4.3127	45899.622	191.2497
0.1	4	40279.2	4.3127	52456.7115	212.8111
0.2	2	27010.31	3.0405	29065.5490	119.4863
0.2	2.5	32289.23	3.0405	36331.9363	142.8387
0.2	3	37359.64	3.0405	43598.3236	165.2689
0.2	3.5	42262.98	3.0405	50864.7108	186.9599
0.2	4	47027.69	3.0405	58131.0981	208.0377
0.25	2	28965.02	2.5846	30156.7772	117.2072
0.25	2.5	34625.96	2.5846	37695.9715	140.1143
0.25	3	40063.31	2.5846	45235.1659	162.1166
0.25	3.5	45321.49	2.5846	52774.3602	183.3939
0.25	4	50431.02	2.5846	60313.5545	204.0697
0.3	2	31038.76	2.1989	31092.1157	114.4225
0.3	2.5	37105	2.1989	38865.1446	136.7853
0.3	3	42931.64	2.1989	46638.1735	158.2649
0.3	3.5	48566.28	2.1989	54411.2025	179.0367
0.3	4	54041.63	2.1989	62184.2314	199.2212

TABLE 5
Temperature measurement for base fluid (water+EG)

		Outlet Temp. (deg C)		**Bulk Temp. (deg C)**		**Wall Temp. (Deg C)**	
Flow rate (Lpm)	**Inlet Temp**	**From Experiment**	**From Simulation**	**From Experiment**	**From Simulation**	**From Experiment**	**From Simulation**

	(^{o}C)						
2	63	46	43.4	54.5	50.7	41.2	37.7
2	63	47.3	44.4	55.1	51.5	42.5	37.6
2	63	48.5	45.3	56.0	52.1	43.9	37.6
2	63	50	46.1	56.8	52.8	45.4	37.5
2	63	51.4	46.9	57.3	53.3	46.7	37.5

TABLE 6
Temperature measurement for base fluid + Co_3O_4 nanofluid (0.05 vol%)

		Outlet Temp. (deg C)		Bulk Temp. (deg C)		Wall Temp. (Deg C)	
Flow rate (L/min)	**Inlet Temp. (deg C)**	**Experimental**	**Simulation**	**Experimental**	**Simulation**	**Experimental**	**Simulation**
2	63	44.8	43.0	54	50.2	40.2	37.5
2.5	63	46.1	44.0	54.5	51.0	41.3	37.5
3	63	47.7	45.0	55.4	51.8	42.5	37.5
3.5	63	49.4	45.6	56.3	52.4	44.6	37.5
4	63	50.6	46.2	56.8	53.9	46.1	37.4

TABLE 7
Temperature measurement for base fluid + Co_3O_4 nanofluid (0.1 vol%)

		Outlet Temp. (deg C)		Bulk Temp. (deg C)		Wall Temp. (Deg C)	
Flow rate (L/min)	**Inlet Temp. (deg C)**	**Experimental**	**Simulation**	**Experimental**	**Simulation**	**Experimental**	**Simulation**
2	63	44	42.7	53.8	49.9	39.6	37.4
2.5	63	45.3	43.4	54.1	50.6	40.7	37.4
3	63	47.2	44.4	54.9	51.4	41.7	37.5
3.5	63	48.7	44.9	55.8	51.8	44.2	37.3
4	63	50.2	45.5	56.2	52.3	45.7	37.3

TABLE 8
Temperature measurement for base fluid + Co_3O_4 nanofluid (0.2 vol%)

		Outlet Temp. (deg C)		Bulk Temp. (deg C)		Wall Temp. (Deg C)	
Flow rate (L/min)	Inlet Temp. (deg C)	Experimental	Simulation	Experimental	Simulation	Experimental	Simulation
2	63	43.1	42.1	53.4	49.3	39.1	37.2
2.5	63	44.4	42.8	54.0	49.9	40.4	37.2
3	63	46.5	43.7	54.8	50.7	41.1	37.4
3.5	63	48.1	44.2	55.6	51.2	43.2	37.3
4	63	49.3	44.5	56.2	51.4	45.5	37.1

TABLE 9
Temperature measurement for base fluid + Co_3O_4 nanofluid (0.25 vol%)

		Outlet Temp. (deg C)		Bulk Temp. (deg C)		Wall Temp. (Deg C)	
Flow rate (L/min)	Inlet Temp. (deg C)	Experimental	Simulation	Experimental	Simulation	Experimental	Simulation
2	63	41.9	41.6	52.5	49.1	37.3	37.1
2.5	63	42.3	42.3	52.8	49.4	39.1	36.9
3	63	45.1	43.2	54.2	50.2	40.6	37.1
3.5	63	46.9	43.7	55.0	50.7	42.4	37.1
4	63	48.2	43.9	55.7	50.9	44.7	37.0

TABLE 10
Temperature measurement for base fluid + Co_3O_4 nanofluid (0.3 vol%)

		Outlet Temp. (deg C)		Bulk Temp. (deg C)		Wall Temp. (Deg C)	
Flow rate (L/min)	Inlet Temp. (deg C)	Experimental	Simulation	Experimental	Simulation	Experimental	Simulation
2	63	42.6	41.2	52.9	49.0	37.8	37.1
2.5	63	43.5	42.1	53.3	49.4	39.6	36.9
3	63	45.9	43.0	54.5	50.0	41.2	37.1
3.5	63	47.5	43.5	55.3	50.5	42.8	37.1
4	63	49.1	43.8	56.2	50.7	45.3	37.0

VII. References

Saidur, R., Leong, K. Y., & Mohammad, H. A. (2011). A review on applications and challenges of nanofluids. *Renewable and sustainable energy reviews*, *15*(3), 1646-1668.

Peyghambarzadeh, S. M., Hashemabadi, S. H., Hoseini, S. M., & Jamnani, M. S. (2011). Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators. *International Communications in Heat and Mass Transfer*, *38*(9), 1283-1290.

Ahmed, S. A., Ozkaymak, M., Sözen, A., Menlik, T., & Fahed, A. (2018). Improving car radiator performance by using TiO2-water nanofluid. *Engineering science and technology, an international journal*, *21*(5), 996-1005.

Ali, H. M., Ali, H., Liaquat, H., Maqsood, H. T. B., & Nadir, M. A. (2015). Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids. *Energy*, *84*, 317-324.

Naraki, M., Peyghambarzadeh, S. M., Hashemabadi, S. H., & Vermahmoudi, Y. (2013). Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator. *International Journal of Thermal Sciences*, *66*, 82-90.

Hussein, A. M., Bakar, R. A., Kadirgama, K., & Sharma, K. V. (2014). Heat transfer enhancement using nanofluids in an automotive cooling system. *International Communications in Heat and Mass Transfer*, *53*, 195-202.

S. L. Sharifi et. al., Characterization of Cobalt Oxide Co_3O_4 Nanoparticles Prepared by Various Methods: Effect of Calcination Temperatures on Size, Dimension and Catalytic Decomposition of Hydrogen Peroxide, *Int. J. Nanosci. Nanotechnol*., Vol. 9, No. 1, pp. 51-58, March 2013.

Peyghambarzadeh, S. M., Hashemabadi, S. H., Jamnani, M. S., &Hoseini, S. M. (2011). Improving the cooling performance of automobile radiator with Al2O3/water nanofluid. *Applied Thermal Engineering*, *31*(10), 1833-1838.

Leong, K. Y., Saidur, R., Kazi, S. N., & Mamun, A. H. (2010). Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator). *Applied Thermal Engineering*, *30*(17-18), 2685-2692.

Li, X., Zou, C., & Qi, A. (2016). Experimental study on the thermo-physical properties of car engine coolant (water/ethylene glycol mixture type) based SiC nanofluids. *International Communications in Heat and Mass Transfer*, *77*, 159-164.

Subhedar, D. G., Ramani, B. M., & Gupta, A. (2018). Experimental investigation of heat transfer potential of Al2O3/Water-Mono Ethylene Glycol nanofluids as a car radiator coolant. *Case Studies in Thermal Engineering*, *11*, 26-34.

Oliveira, G. A., Contreras, E. M. C., &Bandarra Filho, E. P. (2017). Experimental study on the heat transfer of MWCNT/water nanofluid flowing in a car radiator. *Applied Thermal Engineering*, *111*, 1450-1456.

Goudarzi, K., & Jamali, H. (2017). Heat transfer enhancement of Al2O3-EG nanofluid in a car radiator with wire coil inserts. *Applied Thermal Engineering*, *118*, 510-517.

Tijani, A. S., & bin Sudirman, A. S. (2018). Thermos-physical properties and heat transfer characteristics of water/anti-freezing and Al2O3/CuO based nanofluid as a coolant for car radiator. *International Journal of Heat and Mass Transfer*, *118*, 48-57.

Contreras, E. M. C., Oliveira, G. A., &Bandarra Filho, E. P. (2019). Experimental analysis of the thermohydraulic performance of graphene and silver nanofluids in automotive cooling systems. *International Journal of Heat and Mass Transfer*, *132*, 375-387.

Elsebay, M., Elbadawy, I., Shedid, M. H., &Fatouh, M. (2016). Numerical resizing study of Al2O3 and CuO nanofluids in the flat tubes of a radiator. *Applied Mathematical Modelling*, *40*(13-14), 6437-6450.

Ali, H. M., Ali, H., Liaquat, H., Maqsood, H. T. B., & Nadir, M. A. (2015). Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids. *Energy*, *84*, 317-324.

Peyghambarzadeh, S. M., Hashemabadi, S. H., Naraki, M., &Vermahmoudi, Y. (2013). Experimental study of overall heat transfer coefficient in the application of dilute nanofluids in the car radiator. *Applied Thermal Engineering*, *52*(1), 8-16.

Sajid, M. U., & Ali, H. M. (2019). Recent advances in application of nanofluids in heat transfer devices: a critical review. *Renewable and Sustainable Energy Reviews*, *103*, 556-592.

Devireddy, S., Mekala, C. S. R., &Veeredhi, V. R. (2016). Improving the cooling performance of automobile radiator with ethylene glycol water based TiO2 nanofluids. *International communications in heat and mass transfer*, *78*, 121-126.

Jadar, R., Shashishekar, K. S., &Manohara, S. R. (2017). f-MWCNT Nanomaterial Integrated Automobile Radiator. *Materials Today: Proceedings*, *4*(10), 11028-11033.

Zhao, N., Li, S., & Yang, J. (2016). A review on nanofluids: Data-driven modeling of thermalphysical properties and the application in automotive radiator. *Renewable and Sustainable Energy Reviews*, *66*, 596-616.

Sidik, N. A. C., Yazid, M. N. A. W. M., &Mamat, R. (2017). Recent advancement of nanofluids in engine cooling system. *Renewable and Sustainable Energy Reviews*, *75*, 137-144.

Selvam, C., Lal, D. M., & Harish, S. (2017). Enhanced heat transfer performance of an automobile radiator with graphene based suspensions. *Applied Thermal Engineering*, *123*, 50-60.

Bigdeli, M. B., Fasano, M., Cardellini, A., Chiavazzo, E., &Asinari, P. (2016). A review on the heat and mass transfer phenomena in nanofluid coolants with special focus on automotive applications. *Renewable and Sustainable Energy Reviews*, *60*, 1615-1633.

Sidik, N. A. C., Yazid, M. N. A. W. M., &Mamat, R. (2015). A review on the application of nanofluids in vehicle engine cooling system. *International Communications in Heat and Mass Transfer*, *68*, 85-90.

M'hamed, B., Sidik, N. A. C., Akhbar, M. F. A., Mamat, R., & Najafi, G. (2016). Experimental study on thermal performance of MWCNT nanocoolant in PeroduaKelisa 1000cc radiator system. *International Communications in Heat and Mass Transfer*, *76*, 156-161.

Hussein, A. M., Bakar, R. A., &Kadirgama, K. (2014). Study of forced convection nanofluid heat transfer in the automotive cooling system. *Case Studies in Thermal Engineering*, *2*, 50-61.

Einstein, A. (1906). Eine neue bestimmung der molekuldimensionen. *Annalen der physik*, 324(2), 289-306.

Pak, B. C., & Cho, Y. I. (1998). Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Experimental Heat Transfer an International Journal*, *11*(2), 151-170.

Xuan, Y., & Roetzel, W. (2000). Conceptions for heat transfer correlation of nanofluids. *International Journal of Heat and Mass Transfer*, *43*(19), 3701-3707.

Hamilton, R. L., & Crosser, O. K. (1962). Thermal conductivity of heterogeneous two-component systems. *Industrial & Engineering chemistry fundamentals*, *1*(3), 187-191.

Kumar, N., & Sonawane, S. S., Experimental study of Fe2O3/water and Fe2O3/ethylene glycol nanofluid heat transfer enhancement in a shell and tube heat exchanger. International Communications in Heat and Mass Transfer, 2016; 78, 277-284.

Sonawane, S. S., & Juwar, V., Optimization of conditions for enhancement of thermal conductivity and minimization of the viscosity of ethylene glycol based Fe3O4 nanofluid. Applied Thermal Engineering, 2016; 109, 121-129.

Nishant, K., & Sonawane Shriram, S., Influence of CuO and TiO2 nanoparticles in enhancing the overall heat transfer coefficient and thermal conductivity of water and ethylene glycol based nanofluids. Research Journal of Chemistry and Environment, 2016; Vol, 20, 8.

Kumar, N., & Sonawane, S. S., Experimental study of thermal conductivity and convective heat transfer enhancement using CuO and TiO2 nanoparticles. International Communications in Heat and Mass Transfer, 2016; 76, 98-107.

Khedkar, R. S., Shrivastava, N., Sonawane, S. S., &Wasewar, K. L., Experimental investigations and theoretical determination of thermal conductivity and viscosity of TiO2–ethylene glycol nanofluid. International Communications in Heat and Mass Transfer, 2016; 73, 54-61.

Nishant Kumar, Shriram S. Sonawane, Shirish H. Sonawane, Experimental study on pool boiling and Critical Heat Flux enhancement of metal oxides based nanofluid, International Communications in Heat and Mass Transfer 2018; 96 37-42.

Vijay, J., & Sonawane Shriram, S., Investigations on rheological behaviour of paraffin based Fe3O4 nanofluids and its modelling. Research Journal of Chemistry and Environment, 2015; Vol, 19, 12.

Sonawane, S. S., Khedkar, R. S., &Wasewar, K. L., Effect of sonication time on enhancement of effective thermal conductivity of nano TiO2–water, ethylene glycol, and paraffin oil nanofluids and models comparisons. Journal of Experimental Nanoscience, 2015; 10(4), 310-322.

Khedkar, R. S., Sonawane, S. S., & Wasewar, K. L., Heat transfer study on concentric tube heat exchanger using TiO2–water based nanofluid. International communications in Heat and Mass transfer, 2014; 57, 163-169.

Sonawane, S. S., Khedkar, R. S., & Wasewar, K. L., Study on concentric tube heat exchanger heat transfer performance using Al2O3–water based nanofluids. International communications in heat and mass transfer, 2013; 49, 60-68.

Khedkar, R. S., Kiran, A. S., Sonawane, S. S., Wasewar, K. L., &Umare, S. S., Thermo-physical properties measurement of water based Fe 3 O 4 nanofluids. Carbon-Sci. Technol., 2013; 5, 187-191.

Khedkar, R. S., Sonawane, S. S., &Wasewar, K. L., Synthesis of TiO2–water nanofluids for its viscosity and dispersion stability study. In Journal of Nano Research, 2013; Vol. 24, pp. 26-33.

Khedkar, R. S., Sonawane, S. S., &Wasewar, K. L., Water to Nanofluids heat transfer in concentric tube heat exchanger: Experimental study. Procedia Engineering, 2013; 51, 318-323.

Khedkar, R. S., Kiran, A. S., Sonawane, S. S., Wasewar, K., &Umre, S. S., Thermo–Physical Characterization of Paraffin based Fe3O4 Nanofluids. Procedia Engineering, 2013; 51, 342-346.

Sonawane, S., Thakur, P., & Paul, R. Study on thermal property enhancement of MWCNT based polypropylene (PP) nanocomposites. Materials Today: Proceedings,2020; 27(1), 550-555.

Kumar, N., Urkude, N., Sonawane, S. S., & Sonawane, S. H. (2018). Experimental study on pool boiling and Critical Heat Flux enhancement of metal oxides based nanofluid. *International Communications in Heat and Mass Transfer*, *96*, 37-42

Thakur, P., & Sonawane, S. S., Application of Nanofluids in CO2 Capture and Extraction from Waste Water. Journal of Indian Association for Environmental Management (JIAEM), 2019; 39(1-4), 4-8.

Thakur, P., Sonawane, S. S., Sonawane, S. H., & Bhanvase, B. A. (2020). Nanofluids-based delivery system, encapsulation of nanoparticles for stability to make stable nanofluids. Encapsulation of Active Molecules and Their Delivery System, 141.

Sonawane, S. S., Thakur, P. P., & Paul, R. (2020). Study on visco-elastic properties enhancement of MWCNT based polypropylene nanocomposites. Materials Today: Proceedings, 29, 929-933.

Thakur, P. P., Khapane, T. S., & Sonawane, S. S., Comparative performance evaluation of fly ash-based hybrid nanofluids in microchannel-based direct absorption solar collector. Journal of Thermal Analysis and Calorimetry, 2020; 1-14.