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Experimental Investigation of Heat Transfer in Automotive Radiator Using CuO Nanofluids

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Abstract

This paper focuses on the thermal analysis of an automotive radiator within the content of an engine cooling system. The cooling system plays a crucial role in regulating the temperature of a car's engine. One of the essential components of the car's cooling system is the cooling fluid. An efficient cooling system is vital in preventing engine overheating and ensuring the vehicle operates at its optimal performance level. A range of different approaches can be utilized to enhance heat transfer performance. To enhance heat transfer in radiator design, increasing the number of fins is a common approach, but this method has limitations, and current technology has already maximized its effectiveness. Nanofluid has been identified as a potential candidate for the automobile sector. Compared to water and water-ethylene glycol mixtures, the heat transfer coefficient of the nanofluid is significantly higher. This thesis investigates the performance of copper oxide nanofluids when mixed with a base fluid. In this study, the outlet temperature of copper oxide nanofluid is compared with ethylene glycol coolant in an automobile radiator. The nanofluid is tested at five different volume concentrations ranging from 0.1to0.5%.

A. Introduction

Radiators serve as heat exchangers designed to transfer heat and thermal energy between two mediums, facilitating either cooling or heating purposes. The radiator assembly comprises essential components such as the radiator itself, an electric cooling fan, water pump, thermostat, and radiator pressure cap. Inadequate heat dissipation within the car radiator can lead to engine overheating, cylinder deformation, and increased wear between engine parts [4]. A radiator serves the purpose of storing cooling water, which is circulated around the cylinder, and is provided with fins to enhance air venting. Conventional fluids, including refrigerants, water, engine oil, and ethylene glycol, exhibit poor heat transfer performance. Consequently, heat transfer systems must be highly compact and effective to meet the necessary heat transfer requirements. The substitution of pure water with ethylene glycol/copper oxide (CuO) nanofluid as a coolant in the radiator. Since copper oxide offers significantly better cooling performance, a mixture of copper oxide and ethylene glycol has been employed. The effectiveness of the radiator is enhanced by employing copper oxide as a nanofluid, and we proceed to examine how various operating conditions affect its heat transfer performance[5].

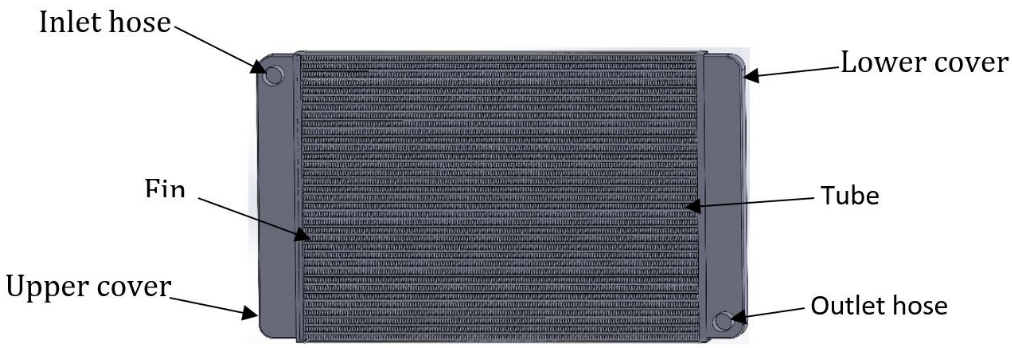

Figure 1. Toyota 2Y Radiator

Hot water enters the radiator and exits as cold water due to the use of copper oxide nanofluid as a coolant, which flows through the radiator tubes [5]. Nanofluids, consisting of nano-sized particles (1 nm - 100 nm) suspended in a base fluid, are used to enhance the heat transfer rate [7].. Results show that nanofluids enchance the thermal performance of a radiator. nanoparticles volume concentration The larger the nanoparticles volume concentration, the higher the cooling performance.

B. Research Method

There are three steps to solve the cooling performance of the radiator. The first step is to calculate the heat transfer rate by using ε-NTU (Number of Heat Transfer Units) Method. The second step is to calculate the heat transfer characteristics by using systhesis of nanoparticles theoretically. The third step is to experiment with Toyota2Y with different volume concentration.

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C. Design Consideration of Radiator Dimensions

The overall dimensions of radiators depend on their arrangement in the vehicle, the quantity of heat to be dissipated, the air velocities, the coolant flow in the tubes, and the design parameters of the radiator. The size of the radiator is determined by the engine height and the shape of the front portion of the bonnet. When the engine height is small, the radiator must be designed as a less favorable rectangular shape instead of a square one. After confirming the geometry of radiator tubes and fins, particle volume concentration in the fluid are changed in this research [6].

Calculation of Heat Transfer Rate and Outlet Temperature

In this paper, the design data is obtained from Toyota 2Y engine. These specifications are as follows;

Table 1. Specifications of the Radiator

No.	Descriptions	Symbols	Dimensions
1	Core Width	W	529mm
2	Core Height	H	400mm
3	Tube Length	L_t	529mm
4	Tube Height	H_t	2.25mm
5	Tube Width	W_t	18mm
6	Fin Length	b	9.5mm
7	Fin Pitch	c	2.5mm
8	Fin Thickness	t_f	0.1mm
9	Number of Tubes	N_t	34

In studying the thermal analysis of engine radiator, design data of petrol engine on Toyota2Y and radiator specification have to be collected. Engine power is 57kW and speed is 4200rpm. To calculate heat transfer coefficient for air side , air velocity is 18.05m/s. Air inlet temperature, $T_{a,in}$ =30˚C. And, thermophysical properties of air are as follows ;

Table 2. Thermophysical Properties of Air[7]

Properties	Values	Units
Thermal Conductivity, k_a	0.02588	W/m. K
Specific Heat Capacity, $C_{p,a}$	1007	J/kg. K
Density, ρ_a	1.164	kg/m³
Dynamic Viscosity, μ_a	1.872×10^{-5}	kg/m.s

Hydraulic diameter of air can be calculated by using Equation [1] [8],

$$D_{h,a}=\frac{2b(c-t_f)}{b+c} \tag{1}$$

Reynolds number of air can be calculated by using Equation [2][8].

$$Re_a=\frac{\rho_a v_a D_{h,a}}{\mu_a} \tag{2}$$

Prandtl number of air can be calculated by using Equation [3][8]

$$Pr_a = \frac{\mu_a C_{p,a}}{k_a} \quad (3)$$

Nusselt number of air can be calculated by using Equation [4][12]

$$Nu_a = 0.664 Re_a^{1/2} Pr_a^{1/3} \qquad \text{For } Re<5\times10\text{^}5 \quad (4)$$

Heat transfer coefficient of air can be calculated by using Equation [5][8].

$$h_a = \frac{Nu_a k_a}{D_{h,a}} \quad (5)$$

Table3. Results of heat transfer coefficient for air side

Calculated Parameter	**Symbol**	**Result**	**Units**
Hydraulic diameter of air	$D_{h,a}$	3.8	mm
Reynolds number of air	Re_a	4264.89	-
Prandtl number of air	Pr_a	0.728	-
Nusselt number of air	Nu_a	39.01	-
Heat transfer coefficient of air	h_a	265.68	W/m^2K

The coolant flows inside the radiator tubes. To calculate heat transfer coefficient for coolant side, mass flow rate of coolant is 1.47kg/s and Coolant inlet temperature is 363K. For non-circular channels, the hydraulic diameter is also called cross sectional non-circular tube diameter which the coolant flows in radiator.

Thermophysical properties of coolant are as follows;

Table 2. Thermophysical Properties of coolant [1]

Properties	**Values**	**Units**
Thermal Conductivity, k_c	0.4108	W/m. K
Specific Heat Capacity, $C_{p,c}$	3499	J/kg. K
Density, ρ_c	1050.44	kg/m^3
Dynamic Viscosity, μ_c	0.001538	kg/m.s

Hydraulic diameter of coolant can be calculated by Equation [9][11] [6]

$$D_{h,c} = \frac{4Ac}{P}$$

Where, A_c= cross sectional area of tube

P= parameter of tube cross sectional area

Velocity of coolant can be calculated by the following Equation [7][8]

$$V_c = \frac{2\dot{m}_c}{\rho_c N_t Ac} \quad [7]$$

Reynolds number of coolant can be calculated by Equation [8][8]

$$Re_c = \frac{\rho_C v_c D_{h,c}}{\mu_c} \qquad [8]$$

Prandtl number of coolant can be calculated by Equation [9][8]

$$Pr_c = \frac{\mu C_{p,c}}{k_c} \qquad [9]$$

Nusselt number of coolant can be calculated by Equation [10][11]

$$Nu_c = 0.023 Re_c^{0.8} Pr_c^{n} \qquad \text{For } 2500<Re<1.25\times10^5 \qquad [10]$$

0.6<Pr<100
Where, n=0.4 for heating of the fluid
n=0.3 for cooling of the fluid

Heat transfer coefficient of coolant can be calculated by Equation [11][8]

$$h_c = \frac{Nu_c k_c}{D_{h,c}} \qquad [11]$$

Table4. Results of heat transfer coefficient for coolant side

Calculated Parameter	**Symbol**	**Result**	**Units**
Hydraulic diameter of coolant	$D_{h,c}$	4	mm
Velocity of coolant	V_c	1.01	m/s
Reynolds number of coolant	Re_c	2777.6	-
Prandtl number of coolant	Pr_c	13.099	-
Nusselt number of coolant	Nu_c	28.3	-
Heat transfer coefficient of coolant	h_c	2906.41	W/m²K

In order to calculate the overall heat transfer coefficient of radiator Equation [12] [8] is used.

Overall heat transfer coefficient, $U = \left[\frac{1}{\eta_0 h_a} + \frac{1}{h_c \times \frac{A_i}{A}}\right] = 90.38\ W/m^2K$ [12]

Where, A_i = Total internal cross sectional surface area of tube
A =Total heat transfer area
η_o = Overall surface effectiveness

To investigate the heat transfer rate of radiator mass flow of air can be calculated by the following Equation [13][8]

Mass flow rate of air, $\dot{m}_a = \rho_a A_{fr} v_a = 4.445 kg/s$

Where, A_{fr}= Frontal area of the radiator

Actual heat transfer rate of radiator can be calculated by using effectiveness- NTU method [8].

Minimum heat capacity rate, $C_{min} = \dot{m}_a C_{p,a} = 4476.88 W/K$ [13]

Maximum heat capacity rate, $C_{max} = \dot{m}_c C_{p,c} = 5143.53 W/K$ [14]

Number of heat transfer unit, $NTU=\frac{UA}{C_{min}}=0.254$ [15]

Heat capacity ration, $C_r=\frac{C_{min}}{C_{max}}=0.87$ [16]

Effectiveness for cross flow unmixed fluid,

$$\varepsilon=1-\exp\left[\frac{NTU^{0.22}}{C_r}\left\{\exp(-C_r NTU^{0.78})-1\right\}\right]=0.197 \quad [17]$$

Heat transfer rate of radiator,

$$Q=\varepsilon C_{min}(T_{c,in}-T_{a,in})=52.916\ kW \quad [18]$$

The outlet temperature of coolant,

$$T_{c,out}=T_{c,in}-\frac{Q}{\dot{m}_c C_{p,c}}=352.72K \quad [19]$$

The outlet temperature of air,

$$T_{a,out}=T_{a,in}+\frac{Q}{\dot{m}_a C_{p,a}}=314.32K \quad [20]$$

Effect of Nanofluid and Nanoparticle Concentration on Heat Transfer Enhancement when Compared to Coolant

The heat transfer coefficient of nanofluid depends upon the Nusselt number of nanofluid, thermal conductivity of nanofluid, density of nanofluid. The thermophysical properties of nanoparticle, base fluid and nanoparticle volume concentration are needed in calculation. In this study copper oxide nanoparticle is used, so thermophysical properties of copper oxide are as follows ;

Table 5. Thermophysical Properties of Copper Oxide Nano Particles[9]

Properties	Values	Units
Thermal Conductivity, k_{nf}	32.9	W/m. K
Specific Heat Capacity, $C_{p,nf}$	540	J/kg. K
Density, ρ_{nf}	6310	kg/m^3

Nanoparticle volume concentrations (0.1% ,0.2%,0.3%,0.4%,0.5%) are considered. For copper oxide nanoparticles volume concentration 0.1%, φ=0.001
Density of nanofluid can be calculated by using Equation [21][9]

Density of nanofluid, $\rho_{nf}=(1-\varphi)\rho_{bf}+\varphi\rho_p=1055.699kg/m^3$ [21]

Specific heat of nanofluid, $C_{p,nf}=\frac{(1-\varphi)\rho_{p,nf}+\varphi\rho_{p,p}}{\rho_{nf}}=3481.31J/kgK$ [22]

Thermal conductivity of nanofluid,

$$k_{nf}=\frac{k_p+2k_{bf}+2(k_p-k_{bf})\varphi}{k_p+2k_{bf}-(k_p-k_{bf})\varphi}k_{bf}=0.41 \quad [23]$$

Viscosity of nanofluid,

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\varphi)^{2.5}} = 1.54\times10^{-3} \qquad [24]$$

Nusselt number of nanofluid, $Nu_{nf} = 0.0059(1+7.6\times\varphi^{0.4}\times\frac{k_{nf}}{k_{bf}})\times Re^{0.9}\times Pr^{0.4}$ [25]

For $1.5<Pr<500$ and $2300<Re<10^6$

Where, φ= Volumetric coefficient
bf= Base fluid
nf= Nanofluid

Table 6. Theoretical Results Data for Copper oxide Nanofluid

Particle Volume Concentration (%)	**U (W/m^2K)**	**Q(kW)**	**$T_{nf,out}$(K)**
0.1	94.54	54.90	352.32
0.2	99.42	57.11	351.89
0.3	102.85	58.63	351.60
0.4	105.53	59.81	351.37
0.5	107.76	60.78	351.18

The results of Table 6 shows that the Heat Transfer Characteristics of Copper Oxide Nanofluid coolant increase with the improvement particle volume concentration.

Experimental setup

Toyota 2Y engine type with a complete cooling system settled in front of the engine . The four-cylinder, four stoke engine has a compression ratio of 8:8 and produces a power of 57 horsepower at 4200RPM. The volume of coolant is 5 liters (5000cc). The radiator has been made of copper. It is of a horizontal type, so the working fluid flows inside the horizontal radiator from the right to the left. Electronic fan is used for cooling the radiator. If the engine coolant temperature reaches 96C, the fans are placed in a series circuit by the ECU unit. The water temperature sensor is used to bring the engine water temperature information to the ECU unit. Two Infraerd Rey thermometers are used for measuring the inlet and output coolant temperature. The amount of coolant in the radiator tank is 5000CC, so we added 5CC copper oxide nanoparticles for 0.1%. Infrared Ray Thermometer indicator is used to indicate the range of temperature of inlet, and outlet. Also with that we are using OBD (On Board Diagnosis)Scanner Tool to investigate the coolant temperature which is connected to Toyota Engine's ECU(Electronics Control Module). Temperature changes noted both inlet and out Infrared Thermometer and OBD Scannar Tool. Experimental investigation of nanofluid (CuO-ethylene glycol) tested with 0.1 to 0.5.

Required Equipment

1. Two Infrared Thermometer
2. OBD Scanner Tool

Figure 2. Infrared Thermometer

Figure 3. OBD Scanner Tool

Figure 4. 1% Copper Oxide Nanoparticle

Figure 5. Temperature measurement

Table 5. Comparison of Theoretical and Experimental Result of Outlet temperature with different volume concentration

Particle Volume Concentration (%)	Theoretical Result(K)	Experimental Result(K)	Deviation (%)
0.1	352.32	353	0.19
0.2	351.89	352.5	0.17
0.3	351.60	352.2	0.17
0.4	351.37	351.9	0.15
0.5	351.18	351.7	0.14

D. Result and Discussion

The results obtained in this study are consistent with the use of nanofluids in automotive radiators. Nusselt number enhancement of 8-12% improvement with CuO nanofluids. The overall trend of improved heat transfer performance with the use of nanofluids is well-established in the literature. This study demonstrates the promising potential of CuO nanofluids for enhancing the thermal management and cooling efficiency of automotive radiators. The observed improvements in heat transfer performance can contribute to better engine cooling, reduced coolant operating temperatures, and potentially improved fuel economy and emissions. Future studies should focus on the long-term effects of CuO nanofluids on radiator materials and performance. Additionally, exploring hybrid nanofluids combining CuO with other nanoparticles may yield even better heat transfer properties.

E.Conclusion

In this study, the heat transfer performance of an automotive radiator using copper oxide (CuO) nanofluid was experimentally investigated. The results demonstrated a significant enhancement in heat transfer compared to the base fluid, with the heat transfer coefficient increasing by up to 12% at a 0.5% concentration of CuO nanofluid. The findings highlight the potential of CuO nanofluids to enhance the thermal performance of automotive cooling systems. Additionally, exploring the use of different nanoparticles or hybrid nanofluids could provide insights into achieving even better heat transfer properties. The findings of this study have important implications for improving engine cooling efficiency, reducing coolant operating temperatures, and potentially contributing to enhanced fuel economy and emission reductions in automotive applications.

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