



Thermos-physical properties and heat transfer characteristics of water/anti-freezing and $\text{Al}_2\text{O}_3/\text{CuO}$ based nanofluid as a coolant for car radiator



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ABSTRACT

In recent times conventional heat transfer fluids such as water and engine oil are widely used in the automobile radiator. However, to improve the thermal performance of the system, a lot more is required from the aspect of the heat transfer fluid. Major improvements in cooling capabilities have been constrained because of poor thermal conductivities of the working fluids, which is vital in the enhancement of heat transfer. The use of nano-sized (1–100 nm) solid particles as an additive suspended in the base fluid is one of the technique to enhancement heat transfer. This study aims to evaluate the performance of the heat transfer characteristics of water/anti-freezing based nanofluid as a coolant for car radiator. For the based fluid, a mixture of water and Ethylene Glycol were used with concentration of 50% for each of the fluid. Al_2O_3 and CuO nano particles of concentration 0.05%, 0.15% and 0.3% were added to the base fluid and then evaluate the heat transfer characteristics of the nanofluid. The mass flow rate of nanofluid in the flat tube was kept constant. The heat transfer models are simulated using ANSYS fluent solver. The performance of the heat transfer characteristics were evaluated based on certain parameters which are the heat transfer coefficient, thermal conductivity, Nusselt number, and rate of heat transfer of the nanofluids. It was found that the nanofluid that exhibited the highest heat transfer performance was the CuO nanofluid. The heat transfer coefficient was recorded at $36384.41 \text{ W/m}^2 \text{ K}$, the thermal conductivity was 1.241 W/m K , Nusselt number was 208.71 and the rate of heat transfer was at 28.45 W. The Al_2O_3 nanofluid had a heat transfer coefficient of $31005.9 \text{ W/m}^2 \text{ K}$, thermal conductivity of 1.287 W/m K , Nusselt number was 173.19 and the rate of heat transfer was at 28.25 W.

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1. Introduction

The cooling system of a car engine is important in maintaining its performance. The engine produces a lot of heat that must be removed in order for it to function optimally. The present cooling system that is available uses water and anti-freezing agent as the coolant for the radiator to remove the heat from the engine via conduction and convection. The heat transfer performance of the coolant is not adequate to remove more heat that may be produced in the engine. With the use of nanoparticles, the surface area of heat transfer of coolant can be increased, thus increasing the heat transfer performance of the coolant. However, the concentration of the nanoparticles of Al_2O_3 and CuO that can optimally transfer heat must be determined.

In the past decades, research efforts have been conducted to improve the performance of cooling system in cars, specifically

the radiator and coolant fluid. A research conducted by Ali et al. [1] suggested that conventionally, modifying the fins and microchannels of the radiator in order to increase cooling effect has reached its limits. The past decade has seen rapid efforts spent to modify the radiator in terms of its geometry [2–4]. Heat transfer fluids such as water and engine oil are widely used in the industry for low and high temperature applications, these fluids, however have some limitations due to their poor thermal conductivities. In the cooling system of a car, water and anti-freezing agents have been widely used as heat transfer fluids [5]. In cold countries anti-freezing agents such as ethylene glycol is added to the cooling fluid in order to reduce the freezing point of the coolant and increase the boiling point [6]. Fluids such as water and ethylene glycol used as coolant in radiators have poor heat transfer performance, this therefore requires a compact and effective heat transfer system to meet the required heat transfer [7].

Nanofluids, which is a mixture of nanoparticles and base fluid have the potential to increase the heat transfer as compared to water and ethylene glycol [8]. Nanofluids contained suspended nanoparticles that are significantly smaller than 100 nm, and have

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Nomenclature

ρ	density	h	heat transfer coefficient
ϕ	particle sphericity	$\dot{Q}$	rate of heat transfer
C_p	specific heat capacity	$\dot{m}$	mass flow rate
k	thermal conductivity	T	temperature
Φ	empirical shape factor		
μ	viscosity	Subscript	
Pr	Prandtl number	nf	nanofluid
Nu	Nusselt number	bf	base fluid
Re	Reynold's number	p	nanoparticle
d	hydraulic diameter	EG	ethylene glycol

a higher thermal conductivity as compared to the base fluids [9,10]. The nanoparticles used in nanofluids are usually metals, oxides, carbides or carbon nanotubes [11]. Recent studies shows that a radiator that is able to withstand higher thermal load could reduce the size of the radiator by approximately 30%. Furthermore, the drag force, fuel pumping and fan power could be reduced as well, resulting in 10% fuel savings [12]. Elias et al. [13] studied the thermos-physical properties of Al_2O_3 nanoparticles suspended in car radiator coolant and found that the maximum enhancement of the nanofluid was 8.3% with the use of 1% concentration of nanoparticles at 50 °C. Raja et al. investigated the performance of alumina water at different ranges of nanoparticles volume fractions. They concluded that the maximum heat transfer enhancement of heat transfer coefficient was 25% at 2 vol% of alumina nanoparticles [14]. Bozorgan et al. conducted a numerical study on the characteristics of 7 nm Al_2O_3 /water nanofluid with volume concentrations up to 2% under turbulent conditions. Hussein et al. [15] studied the heat transfer enhancement of nanopowders suspended in pure water using TiO_2 and SiO_2 nanopowders under laminar condition. Their results showed that the Nusselt number increases as the volume flow rate, inlet temperature and nanofluid volume concentration increases. Hwang et al. [16] conducted a research on the stability and thermal conductivity characteristics of nanofluids. From the results they obtained, they concluded that the enhancement of thermal conductivity depends on the volume fraction of the nanoparticles, thermal conductivities of the nanoparticles and base fluids. Al_2O_3 nanoparticles were also used by Mukesh et al. [17] to conduct a CFD analysis of heat transfer and pressure drop in helically coiled heat exchangers. The enhancement of the Nusselt number at 0.1%, 0.4% and 0.8% nanofluid concentration were 20%, 24% and 30% respectively. The enhancements were due to the higher thermal conductivity of the nanofluid and collision among the nanoparticles and fluid particles. Asmaie et al. [18] analyzed the thermal performance of nanofluids in thermosiphon heat pipe using CFD modelling. The fluid that was used were deionized water and CuO /water. In a related research conducted by Asmaie et al., their results showed that maximum heat flux of the nanofluid was about 46% higher than that of water, and by increasing the concentration of the nanofluid, the wall temperature decreases.

This paper focuses on the heat transfer performance of nanofluid by varying the concentration of nanoparticles (Al_2O_3 and CuO) to be added to the base fluid, which is a mixture of water and ethylene glycol, to be used as coolant in a car radiator. The concentration of the nanoparticles varied at 0.05%, 0.15%, and 0.3%. The base fluid will be set as a mixture of water and ethylene glycol. This project will be conducted using Computational Fluid Dynamics (CFD) simulation in ANSYS software. In this study, only a section of the radiator was considered for the analysis. The heat transfer performance of the nanofluids was evaluated based on

the thermal conductivity, Nusselt number, heat transfer coefficient, and rate of heat transfer.

2. Modelling and simulation

The modelling of the car radiator was designed in Catia software which was later imported into ANSYS Fluent software, based on the design parameters collected from other literatures. The car radiator consisted of flat tubes and louvered fins. The material of the radiator, which is aluminium, was also applied to the design. Due to the limitations of the ANSYS software itself, only a portion of the flat tube and fins were imported into the ANSYS software to be analysed further. Fig. 1 shows the detail illustrations of the geometrical configurations of the car radiator. Fig. 1A shows the dimensions of the flat tube, Fig. 1B shows how the hydraulic diameter was estimated and Fig. 1C and D illustrates the meshed and catia model respectively of the proposed geometry of the radiator. Table 1 shows the geometrical configurations of the car radiator used in this study [5].

2.1. Mode of operation of set up

Fig. 2 illustrate the schematic diagram of the mode of operation of the car radiator integrated with other components such as water tank, a heating coil, a feed pump, liquid flow meter, a blower to induce forced draft, radiator, temperature indicators, power source and reflux line. Initially the coolant inlet temperature to the radiator is set at a desire value by means of a heater in the water tank. A reflux line connected to a valve is used to adjust the flow rate. As the hot coolant passes through the radiator flat tube, induced air is blown across it, the result is that, the coolant is cooled to a desire temperature. The cooled fluid is sent back to the water tank and the process can be repeated for different flow rates. The fins attached to the radiator flat tubes are used to increase the surface area of the heat exchange and this increases the cooling effect. The set up mimics the actual operating condition of car radiator.

3. Theoretical background

3.1. Model equations of the nanofluid physical properties

The thermophysical properties of the basefluid and nanofluid were first determined using the mathematical models below. Using these properties, the computation fluid dynamics analysis was conducted in ANSYS Fluent software. The Al_2O_3 and CuO nanoparticles were mixed with the base fluid that is water and ethylene glycol. The nanoparticles were assumed to be well dispersed in the mixture and uniform throughout the system. Over the years, there have been several formulas applied by other

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