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Experimental study on thermal performance of MWCNT nanocoolant in *Perodua Kelisa* 1000cc radiator system☆

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ABSTRACT

Latest advances in nanotechnology have allowed development of new applications of nanofluids in vehicle engine cooling. In this study, the heat transfer enhancement of vehicle radiator by using water/ethylene glycol based multi-walled carbon nanotube (MWCNT) nanocoolant was studied experimentally. A car engine system (*Proton Kelisa* 1000cc) was utilized to test the heat transfer performance using this nanocoolant as a substitute to the conventional coolant. Different nanoparticle volume concentrations (0.1%, 0.25%, 0.50%) in 50:50 water/ethylene glycol have been prepared and tested. Liquid flow rate has been regulated in the range of 2, 4 and 6 l/min and the experimental analysis was carried out in laminar flow region. Our experimental results revealed that the average heat transfer coefficient is directly proportional to the volume concentration of nanofluids and Reynolds number. In addition, the maximum average heat transfer coefficient enhancement was found to be 196.3% for 0.5% nanoparticle volume concentration compared with base fluid.

1. Introduction

Last few decades have witnessed rapid development of vehicle engine performance. Engine manufacturers have been competing with each other to meet customers' demands in producing high-efficiency engine at low cost. However, engine overheating has been a primary concern for many manufacturers. Vehicle engine cooling system takes care of excess heat produced during engine operation. However, low thermal conductivity of engine coolant limits the cooling efficiency of a vehicle radiator, which makes it difficult in maintaining the compact size of the cooling system. In addition, increasing the cooling rate by traditional technologies (i.e. fins and microchannel) has already reached their limits. One of the innovative efforts to enhance heat transfer in an automotive car radiator is by using a new type of coolant which is called nanocoolant.

Nanocoolant, dispersion of nanomaterials in traditional coolant, has been considered in real applications since early 2000s. Interestingly, literature record shows that automotive radiator was the pioneer complex system that used nanocoolant for cooling technology [1]. Choi et al. [1] measured the thermal conductivity of metallic and oxide, ethylene glycol based nanofluids using transient hotwire method. They claimed that the measured thermal conductivity is much higher than the predicted ones. This finding is consistent with the study by Maranville et al. [2], who measured the thermal conductivity of water and ethylene glycol/water based metal oxide nanofluids using transient planar source method. However, agglomeration and oxidation of metallic nanoparticles remains unsolved problem. A year later, using differential scanning calorimetry, Goldstein et al. [3] proved that the addition of nanoparticles in water leads to high thermal diffusivity of nanofluid. This excellent characteristic as a coolant can be applied for a system that need quick respond to thermal changes like a vehicle radiator.

It may be noted that the addition of nanoparticles to a standard engine coolant may improve the cooling performance of automotive radiator and engine. This improvement in heat removal rate by utilizing nanofluids could reduce the size of the cooling system resulting in increase in the fuel economy. In addition, the smaller size of a radiator could reduce the drag and leading to lesser fuel consumption. Peyghambarzadeh et al. [4] used Al_2O_3–water nanofluids in car radiator to determine the tube side heat transfer coefficient. The heat transfer coefficient was determined for different volume concentrations of nanofluid in the range of 0.1–1%, mass flow rate of 2–5 l/min and inlet temperature in the range of 37–49 °C. The heat transfer enhancement was found to be 45% higher compared to pure water for turbulent flow condition. In another study, Peyghambarzadeh et al. [5] used various fluids, namely, pure water, pure ethylene glycol and their binary mixtures with Al_2O_3 nanoparticles and observed that nanofluids improved the cooling performance of the car radiator. The heat transfer

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enhancement in nanofluids was found approximately 40% higher compared to the base fluid. Naraki et al. [6] obtained the overall heat transfer coefficient of CuO–water nanofluids under a laminar flow regime in a car radiator through experimental investigation. The overall heat transfer coefficient was found to decrease with the increasing nanofluid inlet temperature from 50 to 80 °C. For the 0.4% of volume concentration, nanofluid exhibited the increase in the overall heat transfer coefficient up to 8% compared to water.

Experimental investigation on the performance of nanofluid in vehicle cooling system of car engine has been initiated by Tzeng et al. [7]. They investigated the performance of CuO, Al_2O_3 nanoparticle and antifoam when added into engine oil and the engine run at four different rotating speeds (400 rpm, 800 rpm, 1200 rpm and 1600 rpm). They found that among the tested nanoparticles and antifoam, CuO gave the best heat transfer effect and has the lowest heat transfer distribution for all rotating speeds.

Zhang et al. [8] tested the effect of addition of nano-graphite in heavy-duty-diesel engine coolant. They found that the cooling capability increases 15% when 3 vol.% of nano-graphite was added into the coolant. The effect of nanocoolant in a truck engine has been studied by Saripella and his team [9]. 50/50 mixture of ethylene-glycol and water was used as base fluid and 2 vol.% and 4 vol.% of CuO particles were added to investigate the effect on the engine temperature, pump's speed and power. They inferred that the addition of nano-graphite contributed to the reduction of pump speed up to a factor of two to give the same amount of heat rejection without nano-graphite. This results in reduction of power consumption of truck engine.

Mohammadi et al. [10] have studied the enhancement of thermal conductivity when γ-Al_2O_3 and CuO were dispersed in engine oil. They claimed that addition of 2 vol.% could increase the thermal conductivity up to 5% and 8% for γ-Al_2O_3 and CuO respectively. Kole [11] extended the study by varying the temperature and found the enhancement of thermal conductivity of 4.2% and 4.5% when temperature at 30 °C and 50 °C. Their experiment was restricted to 1.5 vol.% of Al_2O_3 nanoparticles.

The thermal conductivity of 3 vol.% of aluminum components in engine oil have been determined by Vasheghani [12]. He reported that the aluminum nitride behaves exceptionally with thermal conductivity enhancement of 75.23% followed by γ-Al_2O_3 and α-Al_2O_3 with 31.47% and 26.1% respectively. Earlier than that, Kole [13] found enhancement of thermal conductivity of 10.4% when 3.5 vol.% of Al_2O_3 nanoparticles were dispersed in engine coolant.

Knowing that excessive volume fraction of nanoparticles tends to deteriorate the heat transfer performance, Elias et al. [14] conducted experimental research on 1 vol.% of Al_2O_3 nanoparticles dispersed into water and ethylene glycol based coolant in car radiator. 8.3% of thermal conductivity enhancement was obtained in their study. More recently, Chougule and Sahu [15] studied the cooling performance of automobile radiator using Al_2O_3–water and carbon nanotube-water nanofluid. They summarized that the thermal conductivity can be enhanced up to 38% with only 0.6 vol.% of nanoparticles.

Dispersion of nanoparticles in base fluid not only contributes to enhancement of thermal conductivity but also due to greater heat transfer area, superior convective heat transfer coefficient can be achieved which also lead to enhancement of heat transfer. To prove this, Raja et al. [16] and Zhong et al. [17] examined the performance of alumina water at different range of nanoparticles volume fraction. Raja et al. [16] demonstrated that the maximum enhancement of heat transfer coefficient of 25% was obtained at 2 vol.%. However, Zhong et al. [17] found enhancement of only 6.52% at 5 vol.% compared to water. Again this indicates the deterioration of heat transfer at high volume fraction of nanoparticle.

Experimental researches on nanocoolant with ethylene glycol as base fluid have been conducted by many researchers. Nieh et al. [18] reported that the efficiency factor for 0.2 vol.% of TiO_2 nanofluid in ethylene glycol with 50/50 ratio was 27.2%. Investigations of heat transfer enhancement for nanoparticles dispersed directly in ethylene glycol were conducted by Leong et al. [19] and Sarkar et al. [20]. Leong et al. [19] considered 2 vol.% of Cu nanoparticles and found only 3.8% enhancement of heat transfer compared to pure ethylene glycol. In contrast, the study by Sarkar et al. [20] indicated heat transfer enhancement of 40% for 1 vol.% of Al_2O_3 nanoparticles.

Many previous researches reported that the carbon nanotubes (CNTs) nanocoolants contribute to higher thermal conductivity, aspect ratio, specific surface area (SSA) and lower specific gravity and thermal resistance compared to CuO–water, Al_2O_3–water nanofluid and many other nanofluids [21–23]. Because of their excellent thermal properties, CNTs nanocoolants have been reported to have enormous enhancement in heat transfer [23]. Ding and his co-workers [24] reported the heat transfer performance of multi-wall CNT (MWCNT)-water nanofluids with concentration of 0.5 wt.% in a horizontal tube. The authors obtained maximum enhancement in heat transfer of 350% for Reynolds number 800. The enhancement in heat transfer was due to particle rearrangement, shear-induced thermal conduction and reduction of the thermal boundary layer by nanoparticles, and the high aspect ratio of MWCNTs. Ettefaghi et al. [25] investigated the effect of only 0.1 vol.% of multi-walled carbon nanotube dispersed in engine oil. Enhancement of 13.2% of thermal conductivity was reported. Teng and Yu [26] investigate the performance MWCNT nanocoolant and found efficiency factor (heat exchange capacity/pumping power) of 14.1%. In their study, the ratio of nanofluid and ethylene glycol was 50/50 and limited to low volume fraction of nanoparticles. They also found that high concentration of nano-coolant cannot achieve better performance due to uneven distribution of nanoparticles.

A brief review on the literature shows that there is no work on the mixture of water/Ethylene-Glycol with MWCNT nanoparticles as a coolant in a vehicle radiator. For this purpose, an attempt has been made to study the thermal performance of automobile radiator using MWCNT–water–glycol as a new coolant. An experimental test rig has been setup to evaluate the heat transfer coefficient and thermal performance of *Perodua Kelisa* 1000cc radiator system operated with water/ethylene glycol based MWCT nanocoolant.

2. Preparation and evaluation of nanocoolant

The effectiveness of heat transfer is controlled by the convective heat transfer coefficient, which is a function of a number of physical properties of the nanofluid: density, viscosity, thermal conductivity and specific heat. For the present research, multiwalled carbon nanotubes were supplied by Nova Scientific Resources Sdn Bhd, Malaysia. The physical properties of MWCNT nanoparticles were recorded in Table 1.

MWCNT nanocoolant with different volume concentrations (0.1%, 0.25%, 0.50%) was prepared by the technique proposed by Sundar and Sharma [27]. As described by this technique, acid treatment gives great stability in water to carbon nanotubes suspension. This was brought on by a hydrophobic state to the hydrophilic state transformation of the surface nature because of the production of a group called hydroxyl group. In this procedure, MWCNTs were treated in a mixture of H_2SO_4/HNO_3 (1:1) at room temperature (30 °C) to attach functional groups to improve the suspendability of MWCNTs in base fluid. The

Table 1
Geometrical specification and characteristics of MWCNT.

Material	Specification	Remarks
MultiWalled Carbon Nanotube (MWCNT)	Appearance	Black
	Purity	>99.5%
	Diameter	20–30 nm
	Length	3–8 μm
	Specific surface area	90–350 m^2/g
	Density	3.250 g/cm^3