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Recent advancement of nanofluids in engine cooling system

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ABSTRACT

Engine cooling system using nanofluids provides a new foundation for technological integration and innovation. Nanofluids are suitable coolant due to its high thermal diffusivity and can be applied to any system that needs a quick response to thermal changes such as vehicle engine. The presence of nanoparticles in nanofluids contributes better flow of mixing and higher thermal conductivity compared to pure fluid. The current review begins with the overview of preparation methods and thermal conductivity improvement of fluids with nanoparticles. Then, the thermal performance of vehicle engine using nanofluids is highlighted. It has also given emphasis on the major applications of nanofluids in radiator system and as lubricants for improving heat removal efficiency from vehicle engine.

1. Introduction

The last few decades have witnessed a vast research on the new types of heat transfer fluids, namely nanofluids. Nanofluid is a fluid which contains nanometer-sized solid particles. Nanofluid was introduced by Choi [1] and it has been proven to provide efficient heat transfer compared to conventional fluids. Since its first introduction to actual engineering applications [2–5], nanofluid has been successfully applied to enhance heat transfer in many applications such as electronic components [6–8], nuclear reactor [9–11], building heating and cooling system [12–15], water boiling [16], and many more [17–22].

A nanofluid can be produced by dispersing a typical size of less than 100 nm of metallic or non-metallic nanoparticles or nanofibers in a base liquid. The preparation of nanofluids is the key step to improve the thermal conductivity of fluids. Two kinds of methods have been employed in producing nanofluids. One is a single-step method and the other is a two-step method [23]. Nanoparticles, the additives of nanofluids, play an important role in changing the thermal transport properties of nanofluids. At present, various types of nanoparticles, such as metallic nanoparticles and ceramic nanoparticles, have been used in nanofluid preparation.

Table 1 shows the summary of preparation method of various nanofluids.

The presence of nanoparticles in the base fluids contributes better flow of mixing and higher thermal conductivity compared to pure fluid. A novel study by Matsuda [45] revealed that the dispersion of γ-$A1_2O_3$ particles at 4.3 vol% can increase the effective thermal conductivity of water by almost 30%. Since then, many studies have been carried out to investigate the enhancement of thermal conductivity with different nanoparticle volume fractions, materials and dimensions in several base fluids. Most of the findings show that thermal conductivity of nanofluid is higher than the base fluids. Among them, Lee et al. [46] demonstrated that oxide ceramic nanofluids consisting of CuO or Al_2O_3 nanoparticles in water or ethylene-glycol exhibit enhanced thermal conductivity. For example, using Al_2O_3 nanoparticles having mean diameter of 13 nm at 4.3% volume fraction increased the thermal conductivity of water under stationary conditions by 30% [47]. On the other hand, larger particles with an average diameter of 40 nm led an increase of less than 10% [47]. Vajjha et al. [48] investigated the thermal conductivity enhancement of three different nanofluids CuO, ZnO_2 and Al_2O_3 nanofluids. Also, thermal conductivity increases with increasing temperature and volume concentration. A model was proposed by Murshed et al. [49] to predict the thermal conductivity theoretically under dynamic and static processes taking into account the effect of Brownian motion, particle size, nanolayer and particle surface. They concluded that thermal conductivity is due to both static and dynamic mechanisms. In a different study, Hong et al. [50] reported a nonlinear model of thermal conductivity enhancement of 18% at volume fraction of 0.05 vol% using Fe-ethylene glycol nanofluid. Eastman et al. [51] compared the thermal conductivity between Cu-ethylene glycol nanofluid and pure ethylene glycol. The result indicated 40% increase in thermal conductivity of Cu-ethylene nanofluid at volume fraction of 0.3 vol%. Liu et al. [52] recorded 23.8% thermal conductivity enhancement of Cu-water nanofluid using chemical reduction method. The enhancement of thermal conductivity as reported by various researchers is presented in Table 2 (adapted from

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Table 1
Summary of preparation method of nanofluids (adapted from ref [24]).

Authors	Nanofluid	Dispersing Equipment	Stabilizers/ pH control
Duangthongsuk and Wongwises [25]	TiO_2/water	Ultrasonic vibrator for 3–4 h	CTAB/-
Lotfi et al. [26]	MWNTs (MWNTs)/water	Ultrasonic bath for 60 min and magnetic stirrer for 3 h	COOH functional groups/-
Zhu et al. [27]	Al_2O_3/water	Ultrasonic bath for least 1 h	SDBS 0.1 wt %/pH=8.0–9.0
Phuoc et al. [28]	MWNTs/water	Ultrasonic processor for 10 min and magnetic stirrer for 20 min (repeated two times	Chitosan/-
Kumeresan and Velraj [29]	MWNTs/water-ethylene glycol (EG) mixture	Magnetic stirrer for 30 min, followed by ultrasonication for 90 min	SDBS 0.1 vol %/-
Teng et al. [30]	Carbon/water	Magnetic stirrer for 1 h, homegenizer for 30 min, and ultrasonic liquid processor for 30 min(repeated five times)	Water-soluble chitosan/-
Ding et al. [31]	MWCNTs/water	Ultrasonic bath for 24 h, high shear homogenizer for 30 min	Gum Arabic (GA)pH=6
Peng et al. [32]	Cu/R113 (refrigerant-based)	Ultrasonic processor for 1 h	SDS, CTAB Span-80/-
Yousefi et al. [33]	MWCNTs/water	Ultrasonic disruptor for 30 min	Triton X100/ Ph=3.5,6.5, and 9.5
Raveshi et al. [34]	$A1_2O_3$/water-Eg mixture	Ultrasonic bath for 4 h and magnetic stirrer for 5 h	SDBS/-
Li et al. [35]	CuO/water	Ultrasonic cleanser for at least I h	TX-10, CTAB, and SDBS/ Ph=9.5
Nieh et al. [36]	$A1_2O_3$ and TiO_2/ water-EG mixture	Magnetic stirrer for 1.5hr, homogenizer for 30 min, and ultrasonic liquid processor for 30 min (repreated five times)	Water-soluble chitosan/-
Li et al. [37]	Cu/water	Ultrasonic bath for a least 15 min	SDBS 0.02 wt %./Ph=8.5–9.5
Hwang et al. [38]	Multiwalled carbon nanotubes (MWNCTs)/water	Ultrasonic disruptor for 2 h	SDS/-
Ho et al. [39]	Al_2O_3/water	Ultrasonic bath for at least 2 h	-/pH=3
Kathiravan et al. [40]	Cu/water	Ultrasonic bath for about 10 h	SDS/-
Yousefi ei al. [41]	Al_2O_3/water	Ultrasonic disruptor for 30 min	Triton X-100/-
Byrne et al. [42]	CuO/water	High intensity ultrasonic processor for 7–8 h	CTAB/-
Wang et al. [43]	Single-walled carbon nanotubes (SWNTs)/heavy water (D_2O)	Ultrasonicated for 24 h	Trixon X-100/-
Dong et al. [44]	CuPc-U (unsulfonated and hydrophobic) and CuPc-S (surface sulfonated and hydrophilic)/ (water-$NaNO_3$ mixture)	Ultrasonic bath for 30 min	Trixon X-100/-

(continued on next page)

Table 1 [53]).

Some literature have investigated the applicability of nanofluids in vehicle engine cooling system. With the purpose to increase the efficiency of heat removal from the engine, nanoparticles have been dispersed into conventional coolants (water, ethylene glycol, and glycerol) and their performance have been acknowledged by many researchers.

However, there are some discrepancies in the reported findings, especially in the optimum amount of nanoparticles, percentage of improvement, novel type of nanoparticles, and others. Therefore, in the present paper, we attempt to thoroughly review the application of nanofluids in vehicle cooling system that have been published previously. To the best of authors' knowledge, there is no comprehensive literature on the subject.

2. Engine coolant and vehicle radiator system

Radiator system plays a vital role in preventing the vehicle engine from overheating due to friction. Conventionally, a car radiator pumps water as the heat transfer medium through the chambers within the engine block to absorb the heat and spread it away from other important parts. A radiator is designed with louvered fins so that additional heat transfer at the surface area can be created and interrupt the growth of boundary layer formed along the surface (Fig. 1).

In countries with extreme weather conditions, antifreeze is used as an additive to lower the freezing point or elevate the boiling point of a liquid. Since water has good properties as a coolant, the mixture of water as a base liquid with glycol family, especially ethylene glycol (EG) at various percentages depends on the weather conditions. The properties of pure EG and water, and water-based EG with various mixing ratios are shown in Tables 3 and 4.

The last few decades have witnessed a 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, 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) have 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, which consists of the dispersion of nanomaterials in a traditional coolant, has been considered in actual applications since early 2000. Interestingly, the literature records show that automotive radiator was the pioneer complex system that used nanocoolant for cooling technology [84]. Choi et al. [84] have experimentally measured the thermal conductivity of metallic and oxide, ethylene glycol-based nanofluids using a transient hot wire method. They claimed that the measured thermal conductivity was much higher than the predicted ones. Their finding is in agreement with the study by Maranville et al. [85] who measured the thermal conductivity of water and ethylene