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A review on the application of nanofluids in vehicle engine cooling system☆

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ABSTRACT

This paper reviewed the application of nanofluids in vehicle engine cooling system. So far, nanoparticles have been used in engine oil, transmission oil, and radiator coolant to enhance heat transfer removal from vehicle engine. The heat transfer performance of nanofluids has been reported to perform better compared to pure fluid. This review focused on the experimental and numerical studies by previous researchers and their suggested amount of nanoparticles for optimum performance in vehicle engine cooling system. Finally, the conclusions and important summaries were presented according to the data collected.

1. Introduction

The last few decades have witnessed vast research on the new types of heat transfer fluids, namely nanofluids. A nanofluid is a fluid which contains nanometer-sized solid particles. Nanofluids were introduced by Choi [1] and they have been proven to provide efficient heat transfer compared to conventional fluids. Detailed reviews on the physical and thermal properties of nanofluids have been reviewed by several authors [2–5]. Since its first introduction to actual engineering applications [6–9], a nanofluid has been successfully applied to enhance heat transfer in many applications such as electronic components [10–12], nuclear reactor [13–15], building heating and cooling systems [16–19], water boiling [20], and many more [21–26].

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 presence of nanoparticles in the base fluids contributes better flow of mixing and higher thermal conductivity compared to pure fluid. A novel study by Masuda [27] revealed that the dispersion of γ-Al_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 for other potential nanoparticles. Eastman et al. [28] experimentally proved that 5 vol.% of nanocrystalline copper oxide particles suspended in water resulted in an improvement of thermal conductivity for almost 60% compared to pure water. For the purpose of measuring the performance of nanofluids with oxide nanoparticles, Lee and his co-workers [29] have conducted a transient hot-wire experimental technique to determine the thermal conductivity of Al_2O_3 and CuO nanofluids. Good agreements were obtained when compared with Hamilton and Crosser's thermal conductivity model. Using the same experimental set-up, Li et al. [30] measured the thermal conductivity of boron nitride/ethylene alcohol nanofluids. They concluded that thermal conductivity enhancement of nanofluids increased with the increment of nanoparticle volume fraction, aspect ratio of nanoparticles, the size of nanoparticles, and temperature of nanofluids. Ho et al. [31], Godson et al. [32], Duangthongsuk and Wongwises, [33], Lee et al. [34], Mahbubul et al. [35], Lelea and Laza [36], and Zakaria et al. [37] also found similar results indicating the enhancement of thermal conductivity of various nanofluids. However, surprisingly, a few researchers have found insignificant improvement of thermal conductivity as shown by Putnam et al. [38], Zhang et al. [39], Eapen et al. [40] and Timofeeva [41]. Recently, Wang et al. [42] have provided an excellent review on the effects of several parameters to determine the effective thermal conductivity of nanofluids.

Some literature has 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 has 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 has 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

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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 a boundary layer formed along the surface.

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 Table 1 and Table 2.

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) 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, which consists of the dispersion of nanomaterials in a traditional coolant, has been considered in actual applications since early 2000s. Interestingly, the literature records show that automotive radiator was the pioneer complex system that used nanocoolant for cooling technology [43]. Choi and his co-workers [43] 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. [44] who measured the thermal conductivity of water and ethylene glycol/water-based metal oxide nanofluids using a transient planar source method. However, the problems of agglomeration and oxidation of metallic nanoparticles remain unsolved. A year later, by using differential scanning calorimetry, Goldenstein et al. [45] proved that the addition of nanoparticles to water leads to high thermal diffusivity of nanofluid. This excellent characteristic as a coolant can be applied to any system that needs a quick response to thermal changes, such as a vehicle radiator.

3. Experimental research on real vehicle engine

Experimental investigation on the performance of nanofluid in vehicle cooling system of an actual car engine was initiated by Tzeng et al. [46]. They investigated the performance of CuO, Al_2O_3 nanoparticles, and antifoam when added to transmission oil. The engine run at four different rotating speeds (400 rpm, 800 rpm, 1200 rpm, and 1600 rpm) and Mazda's four-wheel-drive (4WD) transmission system was used as the test vehicle. They found that among the tested nanoparticles and antifoam, CuO gave the best heat transfer effect and had the lowest heat transfer distribution for all rotating speeds.

Zhang et al. [47] tested the effect of the addition of nanographite in heavy-duty diesel engine coolant. They found that the cooling capability increased by 15% when 3 vol.% of nanographite was added to the coolant. The effect of nanofluid coolant in a truck engine has been studied by Saripella et al. [48]. 50/50 mixture of ethylene-glycol and water was used as the base fluid and 2 vol.% and 4 vol.% of CuO particles were added to investigate the effect on engine's temperature, pump's speed, and power. The authors inferred that the addition of nanographite contributed to the reduction of pump speed up to a factor of two to give the same amount of heat rejection without nanographite. This resulted in the reduction of power consumption of a truck engine.

The most recent experimental investigation on an actual vehicle cooling system was conducted by Ali and his co-workers [49]. They attempted to investigate the characteristics of forced convection heat transfer in Toyota Yaris radiator filled with Al_2O_3–water nanofluid. They concluded that the heat transfer coefficient reached its optimum only when the volume fraction was 1%. Increasing the volume fraction would deteriorate the performance of the radiator cooling system.

3.1. Other experimental research on nanofluid for engine cooling

Other than the experimental studies on the actual car engine discussed above, many researchers have set up experimental test rig and performed experimental research which are similar to the condition of actual engine vehicles. Mohammadi et al. [50] studied the enhancement of thermal conductivity when γ-Al_2O_3 and CuO are dispersed in engine oil. They claimed that the addition of 2 vol.% γ-Al_2O_3 and CuO could increase the thermal conductivity up to 5% and 8% respectively. Kole [51] extended the study by varying the temperature and found the enhancement of thermal conductivity was 4.2% and 4.5% for the temperature at 30 °C and 50 °C respectively. However, their experiment was restricted to 1.5 vol.% of Al_2O_3 nanoparticles.

The thermal conductivity of 3 vol.% of aluminum components in the engine oil has been determined by Vasheghani [52]. The researcher reported that 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. Prior to that, Kole [53] found that the enhancement of thermal conductivity was 10.4% when 3.5 vol.% of Al_2O_3 nanoparticles was dispersed in the engine coolant.

Knowing that excessive volume fraction of nanoparticles tends to deteriorate the engine performance, Ettefaghi et al. [54] investigated the effect of the dispersion of precisely 0.5 vol.% multi-walled carbon nanotube in engine oil. As much as 22.7% of thermal conductivity enhancement was reported. With the same objective, Elias et al. [55] conducted an experimental research on the dispersion of 1 vol.% of Al_2O_3 nanoparticles in water and ethylene glycol-based coolant used in a car radiator. 8.3% of thermal conductivity enhancement was achieved in their study. More recently, Chougule and Sahu [56] studied the cooling performance of an automobile radiator using Al_2O_3–water and carbon nanotube–water nanofluid. They summarized that the thermal conductivity could be enhanced up to 38% with 0.6 vol.% of nanoparticles.

The dispersion of nanoparticles in a base fluid does not only contribute to the enhancement of thermal conductivity, but also due to a greater heat transfer area, superior convective heat transfer coefficient can be achieved, which will also lead to the enhancement of heat transfer. To

Table 1
Properties of pure ethylene glycol and water.

	Ethylene glycol	Water
Density (g/cm^3)	1.1132	1.0
Molar mass (g/mol)	62.07	18.02
Freezing point (°C)	−12.9	0
Boiling points (°C)	197.3	100
Viscosity (Ns/m^2)	1.61×10^{-2}	1.002×10^{-3}
Thermal conductivity (Wm/K)	0.258	0.609

Table 2
Freezing and boiling points of water/EG vs. concentration of EG.

Percentage of EG in water	Freezing point (°C)	Boiling point (°C)
0	0	100
10	−4	102
20	−7	102
30	−15	104
40	−23	104
50	−34	107
60	−48	110
70	−51	116
80	−45	124
90	−29	140
100	−12	197