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Enhanced heat dissipation of a radiator using oxide nano-coolant

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ABSTRACT

This study adopts an alumina (Al_2O_3) and titania (TiO_2) nano-coolant (NC) to enhance the heat dissipation performance of an air-cooled radiator. The two-step synthesis method is used to produce different concentrations of Al_2O_3 and TiO_2/water (W) nanofluid by using a 0.2 wt.% chitosan dispersant, and the nanofluid is mixed with ethylene glycol (EG) at a 1:1 volume ratio to form NC_1 to NC_6. The experiments were conducted to measure the thermal conductivity, viscosity, and specific heat of the NC with different concentrations of nanoparticles and sample temperatures, and then the NC was used in an air-cooled radiator to evaluate its heat dissipation capacity, pressure drop, and pumping power under different volumetric flow rates and heating temperatures. Finally, this study evaluates the relationship of the heat dissipation capacity and pumping power by using the efficiency factor (EF). The experimental results show that the heat dissipation capacity and the EF of the NC are higher than EG/W, and that the TiO_2 NC is higher than the Al_2O_3 NC according to most of the experimental data. The maximum enhanced ratios of the heat dissipation capacity, pressure drop, pumping power, and EF for all the experimental parameters are approximately 25.6%, 6.1%, 2.5%, and 27.2%, respectively, compared with EG/W. Overall, the NC improves the heat dissipation capacity and EF of the cooling system; however, the enhanced ratio of the pressure drop and pumping power is not obvious in this study.

1. Introduction

Rising petroleum prices and energy-saving awareness have focused attention on the issue of how to enhance vehicle fuel efficiency. Numerous mechanical experts are committed to developing a new type of engine or vehicle to enhance the performance of a vehicle heat dissipation system, to reduce the weight of the cooling equipment to save fuel for vehicles [1]. The use of a coolant with a high heat dissipation performance to enhance the cooling efficiency is the easiest method for enhancing the heat dissipation performance. Numerous researchers have added nanomaterials to the working fluid to form a stable suspension and called this stable suspension as "nanofluids" [2], the purpose of which is to obtain excellent thermal conductivity and heat transfer performance. Therefore, using nanofluids with a high thermal performance in a vehicle cooling system is worthy of research.

The nano-additives of nanofluids primarily contain metal nanoparticles [3–5], carbon nanotubes (CNTs) [6–9], and oxide nanoparticles [10–17]. Metal nanoparticles dispersed in water make it prone to oxidation and drastically change the thermal performance. CNTs with high thermal conductivity enable significant improvements in the thermal properties of working fluid. However, CNTs are expensive, and because the aspect ratio is large and prone to agglomeration, it is not easily dispersed. Although the thermal conductivity of oxide nanoparticles is low, the oxide material is stable and less prone to chemical changes under long-term use. Therefore, oxide nanoparticles have been primary nano-additives for producing nanofluids for heat transfer application.

Most research on nanofluids for heat exchange or heat dissipation by forced convection has focused on a small area or a single pipe [10–12,18,19]. Numerous investigators have recently conducted applied research for microchannel or miniature heat sinks [13,14,20–22], plate heat exchangers [23,24], air-cooled heat exchangers [5,15,16,25,26], double-tube or tube-in-shell heat exchangers [27,28], and solar collectors [29]. The related results indicate that the nanofluids, compared with the base liquid under convection heat transfer, were used to reach four important conclusions: 1) Nanofluids enhance the heat transfer coefficient or the heat exchange capacity [5,10–22,25–29]; 2) The viscosity of the nanofluid is higher than that of the base liquid [13,23]; 3) Pumping power of nanofluid is higher under forced convection [13,15,20,21]; and 4) The use of nanofluids results in a higher pressure drop or a pipeline friction factor [8,10–13,18,19,23,27]. The improved dispersion technique, low-concentration nanofluids, and adding a

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Nomenclature

ϕ	volume fraction (vol.%)
ω	weight fraction (wt.%)
ρ	density (kg/m^3)
$\dot{m}$	mass flow rate (kg/s)
P_p	pumping power (kW)
c_p	specific heat (kJ/kg °C)
μ	viscosity (mPa s)
$\dot{G}$	volumetric flow rate (m^3/s)
$\dot{Q}_H$	heat dissipation capacity (kW)
A	cross-section area of tube (mm^2)
D	minimum of experimental parameters
ΔD	deviation range of experimental parameters
dP	pressure drop (kPa)
ER_{EF}	enhanced percentage of average EF
k	thermal conductivity (W/m °C)
PP	pumping power (kW)
R	ratio of test data
Re	Reynolds number
R_w	hydraulic radius (mm)
T	temperature (°C)
u_D	experimental uncertainty
v_m	mean velocity of fluid
WP	wetter perimeter of tube (mm)

Subscripts

bf	base fluid
i	inlet
l	liquid
nc	nano-coolant
nf	nanofluid
np	nanoparticle
o	outlet
H	heat dissipation capacity

suitable dispersant can be used for mitigating these problems of viscosity, pipeline pressure drop, and pumping power.

Certain researchers have used nanofluids in a car radiator to evaluate the heat dissipation performance. Leong et al. [5] applied Cu/ethylene glycol (EG) nanofluids with different concentrations at 0–2 vol.% and an inlet temperature of 70–95 °C in an automotive cooling system. The results showed that approximately a 3.8% heat transfer enhancement and 18.7% reduction of the air frontal area were achieved with 2 vol.% Cu/EG nanofluid at the 6000 and 5000 Reynolds number for the air and coolant, respectively, and an additional 12.13% pumping power was needed for a radiator at a 0.2 m^3/s coolant volumetric flow rate compared to the pure EG coolant.

Peyghambarzadeh et al. [25] added Al_2O_3 nanoparticles with different concentrations (0.1, 0.3, 0.5, 0.7, and 1 vol.%) into pure water, EG, and EG/water mixtures (5, 10, and 20 vol.% EG) to form the Al_2O_3 nanofluid, and adopted these nanofluids in a car radiator to evaluate the nanofluid heat transfer performance. The liquid flow rate changed from 2 to 6 L/min, and the fluid inlet temperature (water: 35–50 °C; EG: 45–60 °C) changed for all the experiments. The heat transfer improved by approximately 40%, compared to the base fluids in the best conditions.

Peyghambarzadeh et al. [16] evaluated the heat transfer performance of an automobile radiator with CuO and Fe_2O_3/water nanofluids by calculating the overall heat transfer coefficient by using the conventional 3-NTU technique. The concentrations were 0.15, 0.4, and 0.65 vol.% after considering the best pH for longer stability. The liquid-side Reynolds number varied in the range of 50–1000, and the inlet liquid changed at 50, 65, and 80 °C. The results indicated that the overall heat transfer coefficient of nanofluids increased to 9% compared with the water. Increasing the nanoparticle concentration, air velocity, and nanofluid velocity enhanced the overall heat transfer coefficient. In contrast, increasing the nanofluid inlet temperature reduced the overall heat transfer coefficient.

Naraki et al. [26] used CuO/water nanofluids (0–0.4 vol.%) in a car radiator to investigate the overall heat transfer coefficient under the laminar flow regime ($100 < Re < 1000$). The nanofluids had been stabilized with a variation in pH and the use of sodium dodecyl sulfonate (SDS) as a surfactant. The results demonstrated that the overall heat transfer coefficient decreased with an increase in the nanofluid inlet temperature from 50 to 80 °C. The overall heat transfer coefficient increased to 8% at a nanofluid concentration of 0.4 vol.%, compared with the base fluid.

This study adopts a nano-coolant (NC) to examine the thermal performance of a vehicle cooling system at a temperature of 80–95 °C to refer the general engine temperature of the coolant. To reduce the pressure drop and pumping power of a cooling system with an NC, this study uses a low-concentration of the NC. The two-step synthesis method is used to produce an alumina (Al_2O_3) NC and a titania (TiO_2) NC with chitosan dispersant as a working fluid for the air-cooled radiator. This study focuses on how the volumetric flow rate of the working fluid, heating temperature, and weight fraction of nano-additives affects the heat dissipation capacity, pressure drop, and pumping power. This study also evaluates the overall efficiency of using an NC in an air-cooled radiator by calculating its efficiency factor (EF).

2. Calculation of heat exchange

This section presents the evaluation of the heat dissipation capacity of the working fluid for a radiator based on the measure inlet and outlet temperature difference ($T_i - T_o$) for different mass flow rates ($\dot{m}_l$) and specific heat ($c_{p,l}$) of the working fluid. The heat dissipation capacity ($\dot{Q}_H$) of the radiator can be written as follows:

$$\dot{Q}_H = \dot{m}_l c_{p,l}(T_i - T_o) \quad (1)$$

A flow meter is used to measure the volumetric flow rate of the working fluid. The mass flow rate in Eq. (1) can be further expressed as the volumetric flow rate ($\dot{G}_l$) multiplied by the density of the liquid (ρ_l).

$$\dot{m}_l = \dot{G}_l \times \rho_l \quad (2)$$

The specific heat ($c_{p,nc}$) of the NC in this study was measured using a differential scanning calorimeter (DSC). The NC density was calculated using the mixing theory concept for ideal gas mixtures, as expressed in Eq. (3). These terms are related to the volume fraction (ϕ), base fluid density (ρ_{bf}), and nanoparticle density (ρ_{np}) [3,5,15,16,25,30,31].

$$\rho_{nc} = (1 - \phi)\rho_{bf} + \phi\rho_{np} \quad (3)$$

where ϕ of the nanoparticles can be converted to the weight fraction (ω) of the nanoparticle by using ρ_{bf} and ρ_{np}.

The fluid flow condition of pipes is assessed using the Reynolds number (Re). When Re is smaller than 2000, it is regarded as a laminar flow, whereas when Re is greater than 4000, it is regarded