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Heat dissipation performance of MWCNTs nano-coolant for vehicle

Tun-Ping Teng *, Chao-Chieh Yu

Department of Industrial Education, National Taiwan Normal University, No. 162, Sec. 1, He-ping E. Rd., Da-an District, Taipei City 10610, Taiwan, ROC

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ABSTRACT

This study demonstrates the heat dissipation performance of a motorcycle radiator filled with multi-walled carbon nanotubes (MWCNTs) nano-coolant (NC). The two-step synthesis method was used to produce different concentrations of MWCNTs/water (W) nanofluid (0.1, 0.2, and 0.4 wt.%) using a 0.4 wt.% cationic chitosan dispersant, and the MWCNTs/W nanofluid was mixed with ethylene glycol (EG) at a 1:1 volume ratio to form the NC_1, NC_2, and NC_3. The experiments in this study measured the thermal conductivity, viscosity and specific heat of NC with weight fractions and sample temperatures (80, 85, 90, and 95 °C), and then used the NC in an air-cooled radiator for a motorcycle to assess its heat exchange capacity, Nusselt number and pumping power under different volumetric flow rates (4.5, 6.5, and 8.5 L/min) and sample temperatures (80, 85, 90, and 95 °C). Considering the overall efficiency of the heat exchange system, this study evaluates the relationship of heat exchange capacity and the pumping power using the efficiency factor (EF). Experimental results show that the NC_1 has a higher heat exchange capacity and EF than EG/W. The maximum enhanced ratios of heat exchange, pumping power, and EF for all the experimental parameters in this study were approximately 12.8%, 4.9%, and 14.1%, respectively, compared with EG/W. NC with high concentrations of MWCNTs cannot achieve a better heat exchange capacity because the uneven density of NC in the flow state increases the thermal resistance of the solid–liquid interface, effectively decreasing the contact area between the MWCNTs and the EG/W.

1. Introduction

The cooling of a vehicle is one of the key factors in maintaining normal engine operation. Improving the cooling efficiency of a vehicle radiator makes it possible to decrease the size and weight of the cooling system. This in turn enhances the vehicle's use of space and reduces its loading weight, thus improving the vehicle's comfort and reducing fuel consumption. Typical methods of enhancing cooling performance include using micro-structures to enhance the effective area of the radiator, improving the coolant flow rate, using high thermal conductivity materials to manufacture the radiator, and using cooling fluid with high heat transfer performance. However, the harsh working conditions of vehicles often prevent the application of micro-structure technology to improve the heat transfer performance of a radiator. Increasing the coolant flow rate increases the pumping power and reduces the overall efficiency of the vehicle. Existing radiators are typically made of copper, aluminum, and other metals with high thermal conductivity, offering little improvement in the material of the radiator. Therefore, improving the heat transfer performance of the working fluid is the most promising method of improving cooling performance. With the on-going development of nanotechnology, using nano-materials to improve the thermal conductivity of working fluid and the heat transfer performance of traditional working fluids has shown vigorous and concrete results [1–3].

Carbon nanotubes (CNTs) have a high thermal conductivity, high aspect ratio, low specific gravity, and large specific surface area (SSA). Because CNTs have excellent thermal properties, adding them to traditional working fluid to form CNTs nanofluid can effectively enhance the thermal properties of traditional working fluid. Choi et al. [4] added CNTs to oil at a concentration of 1.0 vol.% to enhance the thermal conductivity by 2.5 times compared to oil at room temperature. Biercuk et al. [5] used a comparative method to measure the thermal conductivity of polymers with single-walled carbon nanotubes (SWCNTs) and vapor phase growth carbon fiber (VGCF). The thermal conductivity of polymers with the SWNTs and VGCFs at a concentration of 1.0 wt.% was enhanced 125% and 45%, respectively. Xie et al. [6] stably dispersed multi-walled carbon nanotubes (MWCNTs) in deionized water and ethylene glycol (EG), showing that the increase in the ratio of thermal conductivity depends on the concentration, size, and shape of MWCNTs. Assael et al. [7] made a MWCNT nanofluid with the addition of 0.1 wt.% of sodium dodecyl sulfate (SDS) to strengthen suspension. This enhanced the maximum thermal conductivity by 38% for a MWCNTs nanofluid with a MWCNTs concentration of 0.6 vol.%. Liu et al. [8] added CNTs to EG and synthetic engine oil

* Corresponding author. Tel.: +886 2 77343358; fax: +886 2 23929449.
E-mail addresses: tube5711@ntnu.edu.tw, tube.t5763@msa.hinet.net (T.-P. Teng).

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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, W
c_p	specific heat, kJ/kg °C
$\dot{G}$	volumetric flow rate, m^3/s
$\dot{Q}_{ex}$	heat exchange capacity, kW
h	heat transfer coefficient, W/m^2 °C
k	thermal conductivity, W/m °C
L	characteristic length, m
Nu	Nusselt number
T	temperature, °C
w	weight, kg
μ	viscosity, mPa s

Subscripts

bf	base fluid
c	cross-section
i	inlet
l	liquid
nc	nano-coolant
nf	nanofluid
np	nanoparticle
o	outlet

(SEO) to form CNTs nanofluid and measured the resulting thermal conductivity. The thermal conductivity of CNTs/EG with 1.0 vol.% CNTs and CNTs/SEO nanofluid with 2.0 vol.% CNTs increased 12.4% and 30% compared with the base fluid, respectively. Hwang et al. [9] compared the difference of thermal conductivity for MWCNTs/water (W), CuO/W, SiO_2/W, and CuO/EG nanofluids. The highest thermal conductivity was MWCNTs/water nanofluid with 1.0 vol.% MWCNTs, offering a thermal conductivity enhancement of approximately 11.3%. Phuoc et al. [10] prepared MWCNTs/W nanofluids with different concentrations of cationic chitosan as a dispersant (0.1, 0.2, and 0.5 wt.%). The measured thermal conductivity of the MWCNTs/W nanofluids showed an enhancement of 2.3–13% for nanofluids containing from 0.5 wt.% to 3 wt.% MWCNTs. Harish et al. [11] prepared a SWCNTs/EG nanofluid using a bile salt as the surfactant and performed thermal conductivity measurements using the transient hot-wires technique. The enhancement of thermal conductivity increased with respect to nanotube loading. The maximum enhancement in thermal conductivity of SWCNTs/EG nanofluid was 14.8% at a SWCNTs concentration of 0.2 vol.%.

Faulkner et al. [12] demonstrated the convective heat transfer of a CNTs/W nanofluid in a micro-channel with a hydraulic diameter of 0.355 mm, a Reynolds number between 2 and 17, and CNTs concentrations of 1.1, 2.2, or 4.4 wt.%, respectively. Their results show an enhanced heat transfer coefficient of the CNTs/W nanofluid at the highest CNTs concentration. Ding et al. [13] tested the heat transfer performance of MWCNTs/W nanofluids with a CNTs concentration of 0.5 wt.% in a horizontal tube, and obtained a maximum enhancement of heat transfer of 350% at a Reynolds number of 800. The reasons for enhanced heat transfer include particle re-arrangement, shear-induced thermal conduction, the reduction of the thermal boundary layer by nanoparticles, and the high aspect ratio of MWCNTs. Ding et al. [14], who experimentally analyzed forced convective heat transfer using aqueous-based titania, carbon, and titanate nanotube nanofluids, showed that the convective heat transfer coefficient enhancement greatly exceeded the extent of the thermal conduction enhancement. The reasons for this heat transfer enhancement include the competing effects of particle migration on the thermal boundary layer thickness and on the effective thermal conductivity. Lotfi et al. [15] studied the heat transfer enhancement of MWCNTs/W nanofluid in a horizontal shell and tube heat exchanger. They synthesized MWCNTs using the catalytic chemical vapor deposition (CCVD) method over a Co–Mo/MgO nanocatalyst. These results were obtained under two heating powers of 280 W and 630 W. The maximum overall heat transfer coefficient was higher 8.3% than water at a heating power of 630 W. Although many studies have shown that adding CNTs to working fluid enhances the thermal conductivity and heat convection performance of working fluid, adding CNTs to the working fluid also increases the viscosity of the original working fluid [16–18]. Thus, using CNTs nanofluids in an actual heat exchange system may decrease the overall efficiency of the heat exchange system because of increased pump power consumption and pipeline pressure decrease caused by a working fluid with a higher viscosity [18,19].

Most studies on the use of nanofluids for heat dissipation consider temperatures below 60 °C. Therefore, this study focuses on the coolant temperature range of a general vehicle to research the heat dissipation performance of nanofluid (nano-coolant) and extend the range of applications for nanofluids. Employing the two-step synthesis method, this study uses MWCNTs and chitosan dispersant to make the MWCNTs nano-coolant (NC) as a working fluid for the radiator of a motorcycle. This study focuses on how the volumetric flow rate of the working fluid, heating temperature, and MWCNTs weight fraction affect the heat exchange capacity and pumping power. This study also evaluates the overall efficiency of using NC in a motorcycle radiator by calculating its efficiency factor (EF).

2. Calculation of nano-coolant heat exchange

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

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

A flow meter was 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):

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

Adding MWCNTs to a base fluid changes its density and specific heat. Based on the concept of solid–liquid mixture, Eqs. (3) and (4) show the density (ρ_{nf}) and specific heat ($c_{p,nc}$) of the NC. These terms are related to volume fraction (ϕ), base fluid density (ρ_{bf}), nanoparticle density (ρ_{np}), base fluid specific heat ($c_{p,bf}$), and nanoparticle specific heat ($c_{p,np}$) [20–23]:

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

$$c_{p,nc} = (1 - \phi)c_{p,bf} + \phi c_{p,np} \quad (4)$$