International Communications in Heat and Mass Transfer 77 (2016) 159–164

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Experimental study on the thermo-physical properties of car engine coolant (water/ethylene glycol mixture type) based SiC nanofluids☆

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ARTICLE INFO

Available online 16 August 2016

Keywords:
Nanofluids
SiC nanoparticles
Thermal conductivity
Viscosity
Overall effectiveness

ABSTRACT

The engine coolant (water/ethylene glycol mixture type) becomes one of the most commonly used commercial fluids in cooling system of automobiles. However, the heat transfer coefficient of this kind of engine coolant is limited. The rapid developments of nanotechnology have led to emerging of a relatively new class of fluids called nanofluids, which could offer the enhanced thermal conductivity (TC) compared with the conventional coolants. The present study reports the new findings on the thermal conductivity and viscosity of car engine coolants based silicon carbide (SiC) nanofluids. The homogeneous and stable nanofluids with volume fraction up to 0.5 vol.% were prepared by the two-step method with the addition of surfactant (oleic acid). It was found that the thermal conductivity of nanofluids increased with the volume fraction and temperature (10–50 °C), and the highest thermal conductivity enhancement was found to be 53.81% for 0.5 vol.% nanofluid at 50 °C. In addition, the overall effectiveness of the current nanofluids (0.2 vol.%) was found to be ~1.6, which indicated that the car engine coolant-based SiC nanofluid prepared in this paper was better compared to the car engine coolant used as base liquid in this study.

1. Introduction

In recent decades, the rapid developments of nanotechnology have led to emerging of a relatively new class of fluids called nanofluids. It is defined as suspension of nanoparticles (1–100 nm) in a base fluid [1]. Growing attention has been recently paid to nanofluid because it could enhance the thermal conductivity (TC) significantly and eventually increase heat transfer coefficient of the fluid [2]. This desirable characteristic ensures application prospect of nanofluids in heat transfer systems such as radiators, electronic devices, nuclear reactors and car engines [3–6].

Thermal conductivity and viscosity are two critical parameters for the application of nanofluids [7]. Thermal conductivity represents the ability of nanofluids directly to conduct or transmit heat. And the fluid viscosity is related to pumping power or pressure drop directly [8,9]. Therefore, numerous published studies focused on the two aspects of various nanofluids. Estellé et al. [10] observed a great enhancement of TC of carbon nanotube nanofluids and it increased as volume fraction and temperature increased. The improved transient heat transfer performance of ZnO–propylene glycol nanofluids was reported by Rajan et al. [11]. Zyła et al. [12] studied the rheological properties of diethylene glycol-based $MgAl_2O_4$ nanofluids and found an unexpected behavior. Li et al. [13] focused on the effect of volume fractions and temperature on the viscosity of ethylene glycol-based silicon carbide (SiC) nanofluids and observed an increase in viscosity with increasing of particle volume fraction, but it decreased with the increase of temperature. A similar experimental phenomenon on viscosity of water-based SiC nanofluids was reported by Bang et al. [14]. In addition, the enhanced thermophysical properties of nanofluids containing SiO_2, Al_2O_3, and CuO, etc. have attracted some more attention in recent years [15–20]. However, for the base fluid, most of the researches have focused mainly on water or glycols, and very limited literatures were available on the car engine coolant-based nanofluids.

Car radiators are essential accessories for automobiles. The higher heat transfer performance of radiators ensures a higher efficiency engine, which leads to smaller engine size, better fuel economy and less emission. The most commonly used method to enhance the heat transfer performance of radiators is increasing the size and heat transfer area of the heat exchanger, but it will inevitably lead to unwanted increases in weight [21]. Besides, development of this method has already reached its limit [22]. Therefore, engine coolant becomes one of the most commonly used commercial fluids in cooling system of automobiles. Generally, the car engine coolants are economically available in the market. And the water/ethylene glycol mixture type of car engine coolant is the most popular one, whose main component is the mixture of water and ethylene glycol, because it has lower freezing point and

☆ Communicated by P. Cheng and W.-Q. Tao.

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http://dx.doi.org/10.1016/j.icheatmasstransfer.2016.08.009
0735-1933/

Nomenclature

Symbols

k	Thermal conductivity [W/(m K)]
φ_v	Volume fraction of nanofluids [%]
m	Mass [g]
ρ	Density [g/cm^2]
μ	Viscosity [mPa·s]
μ_r	Relative viscosity
C_k	Conductive enhancement coefficient
C_μ	Viscosity enhancement coefficient

Subscripts

n	Nanoparticle
b	Base liquid
nf	Nanofluids

higher boiling point. However, the heat transfer coefficient of this kind of engine coolant is very limited.

It has been well validated that nanofluids could be potential replacement of conventional car engine coolants. R. Saidur et al. [22] reported that about 3.8% of heat transfer enhancement could be achieved with the addition of 2% copper nanoparticles in ethylene glycol. Significant increases of the total heat transfer rates in water and ethylene glycol based Al_2O_3 nanofluids were also recorded by Hashemabadi [23]. Teng et al. [24] reported that the heat dissipation capacity of the cooling system could be improved by using oxide nanofluids as nano-coolants. However, to the best of the authors' knowledge, there are only two literatures available on the engine coolant based nanofluid [25,26]. And both of them dispersed Al_2O_3 nanoparticles into the car engine coolant. In addition, Dey et al. [25] only focused on the viscosity of car engine coolant based Al_2O_3 nanofluids.

On the other hand, SiC is one of the most promising non-oxide ceramic materials and has high thermal conductivity, strong corrosion resistance and chemical inertness [27]. Moreover, the SiC nanofluids were found to have better stability compared with other nanofluids [13,28]. Therefore, in order to fill the research gap in the literatures, the TC and viscosity of car engine coolant based nanofluids containing SiC nanoparticles were investigated. The effects of volume fractions and temperature on the TC and viscosity were also examined, analyzed, and discussed in this study.

2. Experimental methods

2.1. Materials and preparation

Nanofluids were prepared by the well-known two-step method [29]. The SiC nanoparticles (30 nm) used in this paper were purchased from C.W. Nanotechnology Company (Shanghai, China). And its basic information is provided by the supplier. The transmission electron microscope (TEM) (HRTEM, TECNAI, Titan) was used to identify the morphology of isolated SiC nanoparticles. As shown in Fig. 1, the dry SiC nanoparticles have spherical shape and they are in the form of agglomerates. The car engine coolant ($\rho = 1.17$ g/cm^3) used as base liquid in this study is commercially available and its main components are 40:60 mixture (mass ratio) of ethylene glycol and water.

The process of two-step method was conducted as follows. Firstly, nanoparticles were suspended into the base fluid to give the required concentration ranging from 0.1 to 0.5 vol.%. The magnetic stirring was used for 1 h on samples and a specific amount of oleic acid as dispersant was added to ensure its stability. Then, an ultra-sonication homogenizer Sonifier 250 (Branson Ultrasonics, Danbury, USA) was continuously used for 6 h to get homogeneous and stable nanofluids. All the processes were conducted at the room temperature. The volume fractions of nanofluids were calculated using Eq. (1).

$$\varphi_v = \frac{m_n/\rho_n}{(m_n/\rho_n) + (m_b/\rho_b)} \tag{1}$$

where φ_v means the volume fraction of nanofluids (%), m stands for mass and ρ determines the density. The subscripts n and b represent nanoparticle and base liquid, respectively.

2.2. Measurement of thermal conductivity

A KD2-Pro thermal analyzer (Decagon Devices Inc., USA) was used to measure the thermal conductivity of car engine coolant based SiC nanofluids. This instrument measures thermal conductivity by transient hot wire method. In thermal conductivity measurements, an isothermal water bath was used to control the temperature of the nanofluid. The vessel containing test sample was placed in the isothermal water bath

Material*	SiC nanoparticles
Average diameter	30 nm (>98%)
Bulk density	0.11 g/cm^3
Surface area	39.8 m^2/g
Thermal conductivity	220 W/m K

*Data provided by the supplier

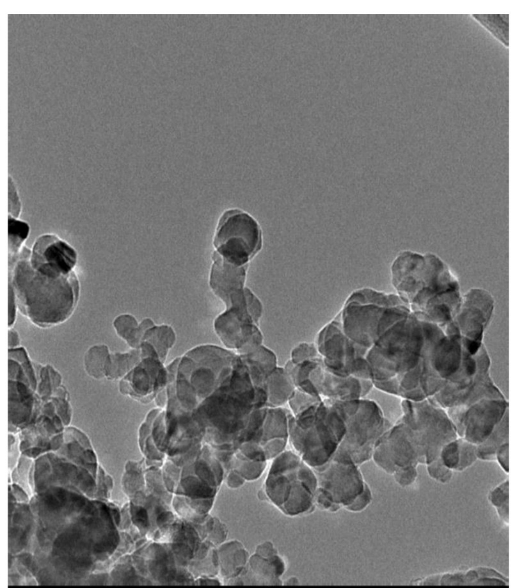

Fig. 1. Basic information and TEM micrograph of SiC nanoparticles.