Applied Thermal Engineering 87 (2015) 344–351

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research paper

Thermo-physical properties of water-based single-walled carbon nanotube nanofluid as advanced coolant

Meibo Xing [a], Jianlin Yu [a, *], Ruixiang Wang [b]

[a] Department of Refrigeration & Cryogenic Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an, 710049, PR China
[b] Beijing Engineering Research Centre of Sustainable Energy and Buildings, School of Environment and Energy Engineering, Beijing University of Civil Engineering and Architecture, Beijing, 100044, PR China

HIGHLIGHTS

- The SWCNTs-nanofluids were prepared with highly dispersion stability.
- The thermo-physical properties of SWCNTs-nanofluids were measured and discussed.
- Thermal conductivity of SWCNTs-nanofluid is enhanced by 16.2%.
- The SWCNTs-nanofluid exhibits good heat transfer enhancement in laminar regime.
- The viscosity increase worsens heat transfer performance in turbulent regime.

ARTICLE INFO

Article history:
Received 22 December 2014
Accepted 6 May 2015
Available online 22 May 2015

Keywords:
Carbon nanotube
Nanofluid
Thermal conductivity
Viscosity
Heat transfer enhancement

ABSTRACT

In this paper, the thermo-physical properties of water-based single-walled carbon nanotube nanofluids (SWCNTs-nanofluids) are experimentally studied. The effect of mass concentration, varying from 0.1 to 1 wt%, on the thermal conductivity, viscosity and density of nanofluids is investigated at the temperatures of 10–60 °C. The results show that the thermal conductivity, viscosity and density of nanofluids are higher than that of the base fluid, and increase with an increase in nanotubes concentration. The thermo-physical property variation of SWCNTs-nanofluids with temperature is similar to that of pure water, i.e. thermal conductivity increases, whereas the viscosity and density decrease with an increase in the temperature. When the concentration is 1 wt%, at 60 °C, the maximum thermal conductivity and viscosity enhancements increase by up to 16.2% and 35.9%, respectively. Furthermore, the heat transfer performance of SWCNTs-nanofluids as advanced coolants is evaluated in both laminar and turbulent flow regimes based on the measured data. The evaluated results indicate that SWCNTs-nanofluids have good heat transfer performance in laminar flow regime. For the case of turbulent flow regime, however, the viscosity increase worsens the heat transfer performance at the lower temperature and higher concentration.

1. Introduction

The developments of energy-efficient heat transfer fluids have been advanced over the past several decades. Various techniques have been proposed to enhance the heat transfer performance of fluids. Among them, the use of additives is a technique applied to enhance the heat transfer performance of base fluids, i.e. nanofluids. Nanofluids exhibit enhanced thermal properties by dispersing nanometer-sized materials into base fluids such as water, ethylene glycol and refrigerant [1–3]. Therefore, nanofluids with higher thermal conductivity and heat transfer coefficients compared to the base fluid can be potentially useful in many applications in heat transfer, including electric cooling, heat exchanger, refrigerator, and so on [4–7]. For example, application of nanofluids in a heat exchanger exhibits an increased heat transfer coefficient compared to its base fluid [8,9]. Due to the nanometer-size, nanofluid also can be used in the microchannel heat sinks to enhance the heat transfer performance [10,11]. In addition, the nanofluids can be employed to the solar collectors for improved efficiency [12,13].

Basically, a nanofluid is created when nanoparticles are controllably dispersed into a base fluid to enhance its properties. With

* Corresponding author. Tel.: +86 29 82668738; fax: +86 29 82668725.
E-mail address: yujl@mail.xjtu.edu.cn (J. Yu).

http://dx.doi.org/10.1016/j.applthermaleng.2015.05.033
1359-4311/

Nomenclature

C	specific heat (kJ kg^{-1} K^{-1})
C_μ	viscosity enhancement coefficient
C_k	thermal conductivity enhancement coefficient
k	thermal conductivity (W m^{-1} K^{-1})
K	shape factor
n	empirical shape factor
q	heat flux (W m^{-2})
R	electric resistance (Ω)
T	temperature (K)
t	time (s)
Greek symbols	
μ	viscosity (Pa s)
ρ	density (kg m^{-3})
α	temperature-resistance coefficient
ϕ	nanoparticle volume fraction (%)
ω	nanoparticle mass fraction (wt%)
ψ	particle sphericity
Subscripts	
0	specified value
bf	base fluid
nf	nanofluid
P	nanoparticle

the aid of the surface area effect, volume effect and other exceptional properties of nanoparticles, the addition of nanoparticles can remarkably improve the thermo-physical properties and heat transfer coefficient of a base fluid [14]. To develop nanofluids for heat transfer, different materials have been used for nanoparticles, including oxides such as alumina, silica, titanium and copper oxide, and metals such as copper and gold [15]. Popular base fluids include water, oil, refrigerant and organic fluids such as ethanol and ethylene glycol. As known, water has been widely used as a heat transfer fluid in many fields of industry such as transportation, refrigeration, power generation, electronic, etc. Due to this fact, many studies on various water-based nanofluids have been carried out in the past years [16]. For example, the graphene nanofluid added to distilled water has outstanding properties as heat transfer media due to their excellent thermal conductivity [17]. Application of water-based nanofluids in a heat exchanger exhibits an increased heat transfer coefficient compared to pure water [5,7]. Rimbault et al. [18] presents an experimental investigation of CuO–water nanofluid flow and heat transfer inside a microchannel heat sink. The thermal properties and rheological behavior of water based Al_2O_3 nanofluid are also investigated as the heat transfer fluid [19]. A two-phase theoretical study of Al_2O_3-water nanofluid flow is given inside a concentric pipe with heat generation/absorption [20]. Seyf and Feizbakhshi [21] study on a numerical investigation of the application of CuO–water nanofluids in micro-pin-fin heat sinks and found a significant enhancement in heat transfer. Hajmohammadi et al. [22] consider Cu and Ag water based nanofluids for the flow and heat transfer of nanofluids over a permeable flat plate with convective boundary condition. In the cases of injection and impermeable surface, increasing the nanoparticles volume fraction result in augmentation of convection heat transfer rate. However, in the case of suction, adding Cu and Ag particles reduces the convection heat transfer coefficient at the surface. Overall, many researchers have been devoted to exploiting water-based nanofluids.

In recent years, carbon nanotubes (CNTs) with high thermal conductivity have attracted particularly close attention from researchers, which have also been used to realize nanofluids. For examples, CNTs-nanofluids can enhance of bubble absorption process in the thermal driven absorption system [23], boost boiling heat transfer and decrease the Leidenfrost effect in the quenching process [24], and enhance the heat-transfer utility of the heat pipe in a solar collector [25]. CNTs with a very high aspect ratio have unusual heat transfer properties. Along the length direction, they show an excellent heat transfer performance. Besides, they possess a remarkable thermal property with ultra-high thermal conductivity (2000–6000 W m^{-1} K^{-1}) which is much higher than those of the metallic (hundreds times) or their oxide nanomaterial used in nanofluids (tens times). Ding et al. [26] found that thermal conductivity of CNT based aqueous nanofluid increases significantly with the temperature by 15% at 20 °C, 30% at 25 °C and by 79% at 40 °C for the same volume fraction. Khoshmehr et al. [24] investigated MWCNT-water with four different concentrations heat transfer in boiling phenomenon. Moreover, Lotfi et al. [27] discovered heat transfer enhances in the presence of multi-walled nanotubes in comparison with the pure water. From the recent researches, it is demonstrated there is a substantial increase in the heat transfer performance of different CNTs-nanofluids in comparison to their base fluids. In general, CNTs-nanofluids research has blossomed in many different directions, and has attracted a great deal of attention to researchers. Further research on various thermal features of CNTs-nanofluids is clearly essential to advance their potential applications in industrial and civil fields.

In this study, the single-walled carbon nanotubes (SWCNTs) with remarkable thermal conductivity properties are used to prepare the water-based nanofluid. Further, the thermo-physical properties of this nanofluid, including thermal conductivity, viscosity and density, are investigated experimentally. Finally, the heat transfer enhanced characteristics of the SWCNTs-nanofluids in both laminar and turbulent flow regimes are evaluated based on the experimental data of their thermo-physical properties. The aim of this study is to provide a guide for selecting the SWCNTs-nanofluid as a potential coolant of heat sinks in electric and thermoelectric cooling applications [28–30].

2. Experimental procedures and apparatus

2.1. Materials

De-ionized water (DIW) was used as the base fluid for nanofluid preparation, which was purchased from Sinopharm chemical Reagent Co., Ltd, China. The SWCNTs with long cylindrical tubular shape was utilized. The CNTs were purchased from Chengdu Organic Chemicals Co. Ltd., China. They were synthesized by catalytic decomposition of methane with cobalt catalyst, and then oxidized in air to remove the activated carbon. The detailed properties of SWCNTs product are given in Table 1. The morphological characterization was obtained using transmission

Table 1
Properties of SWCNTs.

Properties	Value
Outer diameter (nm)	1–2
Inner diameter (nm)	0.8–1.6
Length (um)	5–30
Aspect ratio	2500–30,000
Special surface area (m^2/g)	>380
Thermal conductivity (W/m K)	~4000
Pure density (g/cm^3)	2.1
Purity	>90%