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Experimental investigation on thermo physical properties of single walled carbon nanotube nanofluids

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ABSTRACT

This experimental study is aimed to measure and analyze the thermal conductivity, viscosity, and specific heat of water based single walled carbon nanotube (SWCNT) nanofluids in presence of sodium dodecyl sulfate (SDS) surfactant. The surfactant was used to prepare stable nanofluids and the stability of SWCNT nanofluids of five volume concentrations (0.05–0.25 vol%) is observed good. The measured values of thermal conductivity in the range of 0.615–0.892 W/m K, viscosity in the range of 0.67–1.28 mPa s, and the specific heat in the range of 2.97–3.90 kJ/kg °C, were observed for temperature rising from 20 to 60 °C with an interval of 10 °C as the volume concentration increased from 0.05 to 0.25 vol%. The maximum thermal conductivity enhancement of 36.39% compared to water is observed for 0.25 vol% at 60 °C. The viscosity of SWCNT nanofluids exhibited a non-Newtonian shear-thinning behavior due to the alignment of nanotube clusters and agglomerates with increasing shear rate. The temperature and volume concentrations have effect on specific heat as well and it decreases with particle loadings while increases with temperature.

1. Introduction

Carbon nanotube (CNT), a wonder material in multidisciplinary fields including material science, automotive, optical, electrical, aerospace, and energy conversion, possess outstanding electrical, thermal, mechanical, chemical and optical features. Carbon nanotubes (CNTs) have the capability to conduct electricity and heat efficiently and can act like metals or semiconductors. CNTs are fascinating as they can be used in lithium ion batteries; polymer based composite materials; nanoelectronics as diodes and transistors, and in super-capacitors like electromechanical actuators and sensors [1]. Advanced membrane technology is another field where CNTs are used for water desalination process. Due to the unique structure, high surface to volume ratio and high chemical stability, carbon nanotubes have emerged as new class nanomaterials which possess properties of individual components with synergistic effect when integrated with some other materials [2]. Thus research on carbon nanotubes has become essential to accelerate the innovation of advanced technologies in diversified fields.

CNTs are tubular in shape as they are composed of cylindrical sheet form with carbon which is rolled up in a tube like structure with the appearance of lattice work fence. There are three types of CNTs for instance single walled, double walled and multi walled. Single-walled carbon nanotube (SWCNT) consists of one cylindrical graphite sheet whereas multi-walled carbon nanotube (MWCNT) contains multiple layers of graphene sheets.

Experimental and theoretical studies have demonstrated high thermal conductivity of cylindrical structured nanoparticles compared to spherical nanoparticles [3]. Spherical nanoparticles are the metallic and oxide nanomaterials such as aluminum and aluminum oxide have thermal conductivity of 237 W/m K and 40 W/m K respectively [1]. In contrast, CNTs have thermal conductivity in a range of 2000–6000 W/m K. Specifically, the values for thermal conductivity of single walled carbon nanotube (SWCNT), double walled carbon nanotube (DWCNT) and multi walled carbon nanotube (MWCNT) are 6000 W/m K, 3986 W/m K and 3000 W/m K, respectively [4,5]. The thermal conductivity of DWCNT and MWCNT decreases respectively due to the increase of nanotube wall layers [6].

High thermally conductive materials have attracted researchers to investigate the performance of existing heat transfer system by adding highly thermally conductive particles like carbon nanotubes, metal, metal oxides into heat transfer fluid to improve

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Abbreviations and Nomenclature

SWCNT	single walled carbon nanotube
MWCNT	multi walled carbon nanotube
SDS	sodium dodecyl sulfate
TC	thermal conductivity
EG	ethylene glycol
wt%	weight percent
THWM	transient hot wire method
D	diameter of nanoparticle, nm
L	length of nanoparticle, μm
m	weight, kg
μ	viscosity, mPa s
C_p	specific heat, kJ/kg °C
K	thermal conductivity, W/m K
ρ	density, kg/m^3
ϕ	volume concentration, vol%

Subscript

Nf	nanofluid
Np	nanoparticle
Bf	base fluid
eff	effective

the overall thermal conductivity. In 1995, researchers at Argonne National Laboratory first demonstrated the dilute liquid particle mixtures, called nanofluids, can exhibit thermal conductivity values of about 20–150% higher than the base heat transfer fluids [4]. The term introduced as 'nanofluid' because the particles dispersed in the base fluid are in range of 1–100 nm size.

CNT nanoparticles have high thermal conductivity, large specific surface area (SSA), high aspect ratio and low specific gravity. Therefore, CNT nanofluids expected to exhibit excellent thermal features, long term stability and rheological properties compared to traditional working fluids [7]. The first study regarding CNT nanofluid was conducted by Choi et al. [8] by dispersing MWCNT nanoparticles in synthetic poly oil base fluid. They reported 160% enhancement in thermal conductivity for 1.0 vol% of MWCNT nanoparticles. According to literature, no further studies have reported such improvement in thermal conductivity using MWCNT nanofluid. Xie et al. [9] dispersed 1.0 vol% MWCNT nanoparticles in three different base fluids and the enhancement of thermal conductivity was observed as 7.0%, 12.7%, and 19.6% for distilled water (DW), ethylene glycol (EG), and decene (nonpolar liquid) respectively. Though a small amount of CNT nanoparticles in nanofluid is capable of enhancing thermal conductivity significantly, the CNT nanoparticles tend to agglomerate due to hydrophobic nature of CNTs, high surface area and the van der waals forces. Sonication is the most common method used by the researchers to improve the stability of CNT nanofluids by breaking the agglomerations of nanoparticles. Beside sonication, various surfactants such as sodium dodecyl sulfate (SDS), sodium dodecyl benzene sulfonate (SDBS), cetyltrimethyl ammonium bromide (CTAB), hexamethyldisi loxane (HMDS), sodium deoxycholate (DOC), poly-vinyl pyrrolidone (PVP) and gum Arabic (GA) have been used to obtain desired stability of sample nanofluids. Functionalization of CNT nanofluid is another way to achieve better stability with higher thermal conductivity [10].

Most of the studies in literature used water or EG to disperse MWCNT nanoparticles and mainly focused on their stability. Experimental studies to determine the thermal conductivity of CNT nanofluid using different methods, different base fluids, different surfactants, and different volume concentrations of nanoparticles having different length and diameter have been conducted which is summarized in Table 1.

Due to outstanding thermal conductance capability, CNT nanofluid is privileged nowadays as an excellent heat transfer fluid in different applications. Kathiravan et al. [11] used MWCNT nanofluid for pool boiling to investigate the heat transfer behavior of the fluid. The MWCNT nanoparticles were dispersed by 0.25, 0.5, and 1.0 vol% with water and also with the suspension of water and SDS. The heat transfer coefficients of nanofluid were enhanced 1.7 times compared to water.

Park and Kim [12] used nanofluid, formulated with hydroxyl radicals combined with oxidized multi-walled CNTs (MWCNTs) to enhance the heat-transfer utility of the heat pipe in a solar collector. The thermal conductivity is found to be 12.6% higher at 90 °C than that of the base fluid and the viscosity is 11% lower due to oxidation. Therefore, oxidized MWCNT nanofluid as working fluid can provide increased operating temperature range as well as total heat in a heat pipe of a collector.

Karami et al. [13] introduced CNT nanofluid as an excellent working fluid for direct absorption solar collector (DASC) due to high thermal conductivity, good optical properties, and dispersion stability. Functionalized CNT (f-CNT) nanoparticles were dispersed in water and the thermal conductivity, optical property and stability were observed for six different volume concentration (5, 10, 25, 50, 100, 150 ppm) of f–CNT particle. The extinction coefficient of nanofluid having 150 ppm CNT increased by 4.1 cm^{-1} and thermal conductivity increased by 32.2% compared to water. They also found that the thermal conductivity is mainly dependent on temperature than the volume concentration which is an advantage for solar collector applications. Therefore, they reported CNT nanofluid as a very suitable working fluid for increasing overall efficiency of DASC.

Chougule [14] conducted a study on FPC consists of heat pipe and compared the performance using water and CNT nanofluid. The performance of collector using nanofluid found to be better. The average collector efficiencies using water and nanofluid for tilt angle 31.5° are 25% and 45%, for tilt angle 50° are 36% and 61% respectively. The maximum instantaneous efficiency obtained by using CNT nanofluid is 69% for 50° tilt angle.

To investigate the effect of nanofluid on heat transfer characteristics of an intertube falling film, Ruan and Jacobi used MWCNT nanofluid based on water and EG due to very high thermal conductivity (3000 W/m K) of MWCNTs [15]. Nanofluids using both base fluids were prepared with volume concentration of 0.05, 0.14, and 0.24. About 9% enhancements in thermal conductivity were observed for 0.24 vol% MWCNT nanofluid based for both base fluids. However, 0.24 vol% MWCNT nanofluid based on EG were capable of enhancing the heat transfer up to 20%.

Compared to MWCNT and DWCNT nanoparticles, SWCNT nanoparticles exhibit higher thermal conductivity and better optical properties such as raman, fluorescence and absorption spectra. Therefore, it is necessary to conduct more studies on SWCNT nanofluid to find out their suitability in various heat transfer applications.

Table 1 summarizes the previous studies regarding thermal properties of CNT nanofluid and it is remarkable that most of the studies conducted on MWCNT and mainly focused on thermal conductivity. Viscosity and specific heat capacity are the key parameters to calculate enthalpy in various thermal processes, to determine heat transfer rates under flow conditions and other heat transfer properties, and to evaluate heat storage capacity of thermal management systems. However, Table 1 illustrates that only