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Effects of surface modification on the suspension stability and thermal conductivity of carbon nanotubes nanofluids

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Abstract

The composite carbon nanotubes (CCNTs) were synthesized by surface modification of the as-synthesized carboxyl-functionalized carbon nanotubes (f-CNTs) with the polyethylene glycol, and the composite carbon nanotubes-based nanofluids (CCNTs-based nanofluids) were prepared with the as-synthesized CCNTs and ethylene glycol. The surface molecular structure, surface morphology of the CCNTs were characterized by Fourier Transform Infrared Spectroscopy, Field Emission Scanning Electron Microscope and Transmission Electron Microscopy. The suspension stability and thermal conductivity enhancement ratio of the CCNTs-based nanofluids were characterized via the thermal conductivity variation method. The results show that suspension stability of the CCNTs-based nanofluids was greatly improved by surface modification of the carbon nanotubes; the thermal conductivity of the CCNTs-based nanofluids was further enhanced and became more stable by surface modification.

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Keywords: carbon nanotubes nanofluids; surface modification; suspension stability; thermal conductivity.

1. Introduction

Carbon nanotubes-based nanofluids (CNTs-based nanofluids) are very promising composite fluids applied in solar thermal power generation to enhance heat transfer capabilities [1], because of their enhanced thermal performance [2], stable chemical property and high temperature stability [3]. However, pristine carbon nanotubes have strong tendency to rapidly aggregate and precipitate to the bottom of the container, which can clog any flow

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channels, seriously decay heat transfer effectiveness, and render practical engineering applications infeasible [4,5]. Therefore, improving suspension and heat transfer enhancement stability of CNTs-based nanofluids is the key challenge to enable successful engineering applications of these CNTs-based nanofluids [6]. To efficiently mitigate these disadvantages, a novel method has been developed to controllably modify the surface characteristics of CNTs through in-situ grafting organic molecular chains on the surface of CNTs, so that composite CNTs (CCNTs) and CCNTs-based nanofluids have been prepared using ethylene glycol carrier fluid. The effects of surface modification on the suspension stability and thermal conductivity enhancement ratio of CCNTs-based nanofluids were investigated. Moreover, the mechanisms that increase the suspension stability, or reduce sedimentation rate, were studied.

Nomenclature

f	base fluid
nf	nanofluid
k_{nf}	thermal conductivity of nanofluids
k_f	thermal conductivity of the base fluid ethylene glycol
$\triangle k=k_{nf}-k_f$	thermal conductivity enhancement of nanofluids
$\triangle k/k_f$	thermal conductivity enhancement ratio
$Ø$	volume fraction of CCNTs
T	temperature

2. Experimental procedure

2.1. Preparation of the CCNTs-based nanofluids

Firstly, carboxyl-functionalized carbon nanotubes (f-CNTs) were synthesized with carbon nanotubes and a mixed acid composed of nitric and sulfuric acid for 5 hours [7,8]; then the composite carbon nanotubes (CCNTs) were synthesized via esterification reaction between the as-synthesized f-CNTs and polyethylene glycol. Finally, CCNTs-based nanofluids were prepared by suspending CCNTs in ethylene glycol for five different volume fractions (0.1, 0.3, 0.5, 0.7 and 0.9 vol%) by means of mechanical agitation and ultrasonic mixing.

2.2. Characterization of CCNTs-based nanofluids

The structure and properties of both CNTs and CCNTs were characterized by Fourier Transform Infrared Spectroscopy (FT-IR), Field Emission Scanning Electron Microscope (FE-SEM), and Transmission Electron Microscopy (TEM). The suspension stability of the CCNTs-based nanofluids was evaluated via the thermal conductivity variation method [9]. Thermal conductivity of nanofluids were measured using a thermal properties analyzer, which complies with ASTM and IEEE Standards [10].

3. Results and discussion

3.1. The surface molecular structure of CCNTs

To judge whether the surface modifier polyethylene glycol was successfully grafted onto the surface of the as-synthesized CCNTs, the surface molecular structure of the as-synthesized CCNTs and pristine CNTs were analyzed by FT-IR spectra, because the FT-IR spectra can reflect the changes of the surface molecular structure of the CCNTs as the organic surface modifier polyethylene glycol (PEG) 200 was grafted on the surface [11]. So the FT-IR spectra of as-synthesized CCNTs and pristine CNTs (for comparison) were collected, as shown in Fig. 1. The infrared characteristic absorbing peaks of the CCNTs can be assigned to $-COO^-$stretch (1642.48 cm^{-1}), -OH stretch (1383.49 cm^{-1}), and CH_2 stretch(702.72 cm^{-1}). In contrast, FT-IR spectrum of the pristine CNTs does not exhibit these