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Performance dependence of thermosyphon on the functionalization approaches: An experimental study on thermo-physical properties of graphene nanoplatelet-based water nanofluids

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ABSTRACT

Graphene Nanoplatelets (GNP) were stably dispersed in aqueous media by covalent and non-covalent functionalization. Covalent functionalization was performed by a rapid microwave-assisted approach. Surface functionality groups and morphology of acid-treated GNP were analyzed by Fourier transform infrared spectroscopy and transmission electron microscopy. The GNP-based water nanofluids were then prepared with different concentrations of GNP to evaluate the thermo-physical and rheological properties. It was found that the rheological and thermo-physical properties of all treated samples were significantly enhanced compared to the pure water. The amount of enhancement also increased as the weight concentration increased. Thermo-physical results also confirmed that the thermal conductivity varied significantly depending on the functionalization approaches. At a constant concentration, the measurement showed that the thermal conductivity of covalent nanofluid (GNP-COOH/water) is larger than the non-covalent nanofluid (GNP-SDBS/water), which is larger than distilled water. The GNP-COOH/water nanofluids were found to be especially more effective in the thermosyphon in terms of overall thermal properties such as net heat transfer, entropy, and thermal efficiency, and rheological property such as effective viscosity, as well as, total pressure drop in comparison to GNP-SDBS/water nanofluids and certainly distilled water. The relative degradation of thermal conductivity and heat transfer efficiency of non-covalent nanofluids (GNP-SDBS/water) is due to the reduction of effective heat transfer surface of GNP nanoparticles in suspension, implying lower formation of surface nanolayers. Since the covalent functionalization with microwave radiation is a fast and cost-effective, it would provide an economical approach for industrial applications, an environmentally friendly alternative to the surfactant methods.

1. Introduction

Different kinds of heat pipes are essential equipment in the electronics, thermal and electrical appliances. Also, heat pipes are commonly energy-efficient vehicles with minimal maintenance requirements for a long period of time [1–5]. Heat pipes are commonly design based on the characteristics of the apparatus including working fluid, temperature of basefluid, the dimension and heat flux [5]. In terms of design, heat pipes can be categorized into four groups: heat pipe with wick, loop heat pipe, thermosyphon heat pipe and thermosyphon loop. Each type of heat pipes is appropriate for special application based on the thermal performance, rate of heat transfer, the objective device to be cooled and the installation reason [6–8].

Previous researches showed that various factors such as right filling ratio to the evaporator volume, basefluids, design, bent position and bend angle play key roles in the thermal performance of the thermosyphon heat pipe [9–11]. Finding optimal filling ratio, working fluids, the geometry, diameters and bend angles, applying vibration and rotation system have been considered as the main essential subjects to increase the performance of thermosyphons. Although all mentioned novelties have appropriate influence on the thermal performance of thermosyphon heat pipe, employing new basefluids seems to be most cost-effective, especially for systems that are already manufactured.

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Nomenculture

Q	power (W)
D	diameter (m)
L	length (m)
I	current (A)
V	voltage (V)
$\dot{m}$	water mass flow rate (kg s^{-1})
C_p	specific heat of water (J kg^{-1} K^{-1})
R	resistance (°C W^{-1})
S	entropy (W K^{-1})
U	overall heat transfer coefficient (W m^{-2} K^{-1})
e	exergy
$\overline{T}$	average temperature (°C)
T	temperature (°C)

Greek letters

η	efficiency of TPCT
μ	viscosity (kg m^{-1} s^{-1})

Subscripts

in	input
out	output
th	thermal
e	evaporator
c	condenser

As mentioned above, the effects of working fluids on the performance of thermosyphon heat pipes were investigated extensively [12–16]. In addition, previous studies [5,17] confirmed that nanofluids made of the mixture of basefluids and nanoparticles with good thermal conductivity could enhance the thermal performance of the heat pipes. Choi [18] reported enhancement of thermal conductivity by adding copper nanoparticles into the basefluids. Zeinali Heris et al. [19] investigated the convective heat transfer coefficient of nanofluid made of suspension of CuO nanoparticles and compared the results with the Al_2O_3–water nanofluid. Their results confirmed that Al_2O_3–water nanofluids showed higher convective heat transfer coefficient in comparison with the CuO–water nanofluids. This observation showed that the thermal conductivity of nanoparticles play an essential role in heat transfer characteristics of nanofluids. A maximal reduction of the thermal resistance of about 24% was reported in the presence of water based titanium dioxide and gold nanofluids by Buschmann and Franzke [20]. As another example, Shanbedi et al. [13] studied the influence of multiwalled carbon nanotubes (MWCNT) on the efficiency of two-phase closed thermosyphon (TPCT). They observed about 11% enhancement in the thermal efficiency of the TPCT at 90 kW in the presence of functionalized MWCNT. The recent results also showed that the thermophysical properties like thermal conductivity of nanoparticles play a key role in their applications especially in heat transfer equipments [21–24]. The thermal conductivity of graphene nanoparticles (GNP) is much higher than the value presented by other carbon allotropes like MWNT, SWNT and diamond [12]. Due to the promising properties, GNP may have numerous applications in different scientific fields for making some equipment such as sensors, and batteries [25]. A majority of these applications, however, cannot fully be realized because of insignificant interaction between GNP and other materials. Thus, in order to increase the interactivity of carbon nanostructures, covalent (aminoacids) and non-covalent (GA) functionalizations were proposed as the common solutions elsewhere [26]. Covalent and non-covalent functionalizations are two possible methods to increase the GNP dispersibility in aqueous/organic solvents. Non-covalent functionalization of carbon nanostructures is performed by employing various surfactants [17,26–31]. In order to increase the dispersibility of carbon nanostructures in aqueous media, four common surfactant of gum Arabic (GA), sodium dodecyl sulphonate (SDS), sodium dodecyl benzene sulphonate (SDBS) and triton X-100 are commonly utilized. SDBS and triton X-100 have a benzene function, which produce powerful π–π interaction with the surface of carbon nanostructures. It is noteworthy that SDBS has higher dispersibility than that of Triton X-100. This is attributed to the steric hindrance of tip chains in triton X-100, which resulted in low concentration of triton on the carbon nanostructures surface [32]. On the other hand, although GA can provide better condition for dispersion of carbon nanostructures in comparison with SDBS and triton X-100, it significantly increases the viscosity of mixture, which may cause numerous problems including increase in pressure drop in thermal equipment [13]. Thus, SDBS was selected as a suitable candidate for synthesizing non-covalent nanofluid. Also, covalent functionalization comprises the addition of hydrophobic or hydrophilic groups on the high energy features such as edges of GNP. To compare the effect of functionalization, in the present study, we functionalized the GNP with two methods based on covalent and non-covalent reactions. These include rapid non-covalent functionalization of GNP with SDBS and the covalent functionalization with carboxyl groups. The samples were then characterized and the thermal performance in a thermosyphon was evaluated. The covalent and non-covalent functionalization effects on the thermal conductivity, viscosity, and thermosyphon performance were studied for various operating temperatures and concentrations. In the presence of non-covalent groups, a significant increase in viscosity of suspension vitiates the enhancement in the heat transfer characteristics of GNP nanofluids. The presented results showed that thermophysical property of covalent nanofluids (GNP-COOH/water) was more enhanced compared to those of non-covalent nanofluids (GNP-SDBS/water) and water. Overall heat transfer, entropy, thermal efficiency, thermal resistance and pressure drop showed significant increases in the presence of covalent nanofluids even at low concentrations. SDBS as an additive had some negative influences on the thermal parameters in thermosyphon. The presented results also showed that the covalent functionalization under microwave radiation was sufficiently fast and cost-effective to replace the surfactant in synthesizing nanofluids.

2. Material and methods

2.1. Materials

The pristine Graphene Nanoplatelet (GNP) with diameter of 0.5–3 μm and thickness of 0.55–3.74 nm were obtained from Neutrino Company. Sodium dodecylbenzenesulfonate (SDBS), sulfuric acid (H_2SO_4, 98%), and nitric acid (HNO_3, 68%), all with ACS quality were purchased from Sigma–Aldrich. SDBS used as a surfactant for synthesizing non-covalent nanofluids and mixture of HNO_3 and H_2SO_4 for covalent samples.

2.2. Covalent functionalization of GNP

Based on the technique explained by Wang et al. [33] with slight modification, carboxylation of GNP was performed. In order