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THERMAL CONDUCTIVITY COMPARISONS OF ORIGINAL AND OXIDIZED MULTIWALLED CARBON NANOTUBES-WATERBASED FLUIDS

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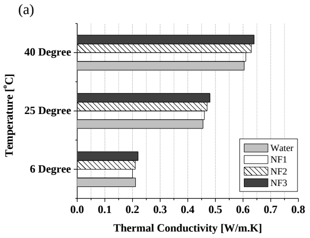
Graphical abstract



Abstract

Nanofluids are a new class of fluids engineered by dispersing nanoparticles in base fluids. The addition of small amount nanoparticles may enhance the thermo-physical properties of the original liquids. In this study, thermal conductivity of pristine and modified multiwalled carbon nanotubes (MWCNT) in water-based fluids was prepared and investigated at various temperatures ranging from 6°C to 45°C. Stable and homogeneous MWCNT nanofluids were successfully produced with an addition of polyvinylpyrrolidone (PVP) as the dispersing agent using physical agitation process. The addition of MWCNT into a fluid leads to the enhancement of its thermal conductivity. The prepared nanofluids, with good fluidity, stability, and high thermal conductivity, is a potential advanced coolant in thermal energy engineering and energy consumption saving.

Keywords: Nanofluids, nanoparticles, multiwalled carbon nanotubes, thermal conductivity

1.0 INTRODUCTION

The cooling of electrical parts has become a major challenge in recent year due to the rapid development in the design of faster and decreasing components that results in more energy consumption and higher heat capacities. Different cooling technologies have been developed to efficiently remove the heat from these components [1, 2]. There are many requirements for a liquid coolant for electronics applications. The requirements may differ depending on the type of application. Some common requirements are high thermal conductivity, low viscosity, good thermal stability for the life of the electronics system, non-corrosive to materials of construction and the most important is low-cost and economic. Suspended nanosize particles in conventional fluids, such as water and ethylene glycol have been the subject of intensive study worldwide since pioneering researchers recently discovered the anomalous thermal behavior of these fluids [3, 4]. The Thermal conductivity of these fluids was found to exhibit such dramatic enhancement. Among the various nanosize particles available, carbon nanotubes (CNTs) are those which have attracted the greatest interest [5]. However, it remains extremely difficult to prepare stable suspensions of pristine CNT, since they easily tend to agglomerate. The aggregation of the CNT will cause the settlement, clogging of the flow channels and the decay of their overall effectiveness properties. In order to obtain stable dispersion, it is necessary to disentangle the pristine CNT, which can be achieved by physical or chemical approaches [6]. Therefore, this work attempts to study the effect of physical and chemical method on the thermal conductivity of multiwalled carbon nanotubes-waterbased fluids.

2.0 EXPERIMENTAL METHOD

2.1 Preparation of Oxidized MWCNT

Original Multiwalled Carbon Nanotubes (MWCNTs) was purchased from China with diameter and length of 0.0070 µm, ~5-15 µm. For the preparation of oxidized MWCNTs, concentrated nitric acid was used at two different temperatures. About 4 g of pristine MWCNTs was added to 40 ml concentrated nitric acid in a round bottom flask. The flask equipped with a reflux condenser and a magnetic stir bar was kept at 40°C (CNT-1) and 150 °C (CNT-2) with vigorous mixing for 4 h. The resulting mixture was filtered and washed several times with distilled water until the pH of the filtrate was neutral.

2.2 Preparation of Nanofluids

Deionized water (DI) and polyvinylpyrrolidone (PVP) were used as base fluid and polymer dispersant. The nanofluids were prepared by mixing together the MWCNT, PVP and DI using homogenizer with rotation of 1000 rpm for about 10 minutes. Then each of the samples will undergo 60 minutes of intensive ultrasonication to disperse the nanoparticles. Nanofluids were then visualized by using a metallurgical microscope (Olympus BX41M) to observe the form of nanocarbon suspension in the fluids. Thermal conductivity of the nanofluid analysis was conducted at three different temperatures which were 6 °C, 25 °C and 45 °C. For thermal conductivity test, the KD2 Pro thermal analyser (Decagon, USA) was used to measure the nanofluids thermal conductivity. Table 1 shows the specification of nanofluids used in this work.

3.0 RESULTS AND DISCUSSION

Digital images of nanofluids suspensions 10 minutes after sonication, after 1 and 7 days of preparation are shown in Figure 1. As can be seen from the images in Figure 1(a) that modified CNT-2 and CNT-3 in NF2 and NF3 show possibility to deposit in deionized water 10 minutes after sonication, whereas, CNT-1 in NF1 retains it stability and homogeneity. After prolonged to 1 and 7 days (Figure 1(b)-(c), obviously nanofluids using CNT-1 and CNT-2 started to deposit at the bottom of suspension in de-ionized water. However, the modified CNT-3 with more functional group attached on it's the surface showed improved stability in water due to the chemical affinity between the polar modified groups and water. In fact, the CNT-3 remains stable in water for a prolonged time span up to 7 days without further agglomeration or sedimentation. This observation strongly suggests that proper chemical oxidation treatment can improved the dispersion of CNTs in water. However, when PVP was added into the suspension, the CNTs dispersed well and homogeneous suspension was achieved. The prepared nanofluids were further investigated using an optical metallurgical microscope to visualize its aggregation state of the suspension with nanocarbon on a micron scale. It can be seen in Figure 2 that there are a numbers of CNTs cluster and aggregated were observed for CNTs in water, while the breakup of this aggregates occurs only after addition of PVP. Besides the role of acid treatment that changes the properties of CNTs into hydropilicity, ultrasonication also plays a significant role on the dispersion of nanofluids. Ultrasonication is an extremely common method used to break up agglomerates in solution processing techniques [7]. It can be observed that with the aid of ultrasonic treatment large agglomerates are separated into smaller units with further dispersed in water when one compared with original CNTs in water without any chemical and physical treatment (Figure 2(a)-(d)). We also observed that, addition of PVP followed by ultrasonication process, dispersion give many smaller units and predictable to form a uniform suspended phase (Figure 2(e)-(g)).

Table 1 Specification of MWCNTs Nanofluids

Sample Coding	Specification
NF-1	0.5 % original CNT + Water
NF-2	0.5 % CNT-1 + Water
NF-3	0.5 % CNT-2 + Water
NF-4	0.5 % original CNT + 0.2% PVP + Water
NF-5	0.5 % CNT-1 + 0.2% PVP + Water
NF-6	0.5 % CNT-2 + 0.2% PVP + Water

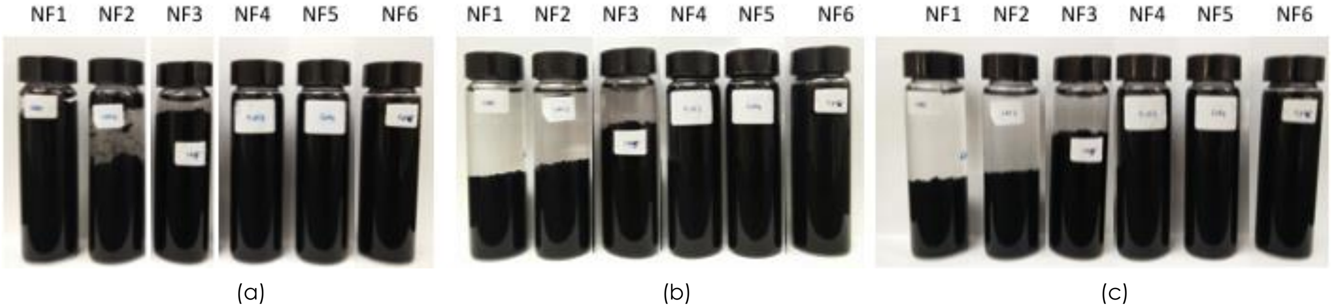


Figure 1 Digital pictures of MWCNTs waterbased-fluids after 10 minutes (a), after 1 day (b) and after 7 days (c), of preparation

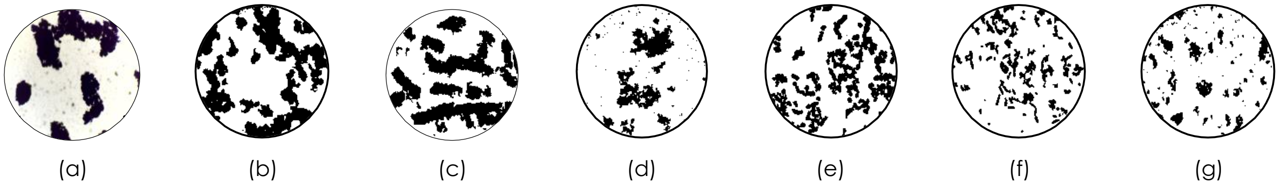


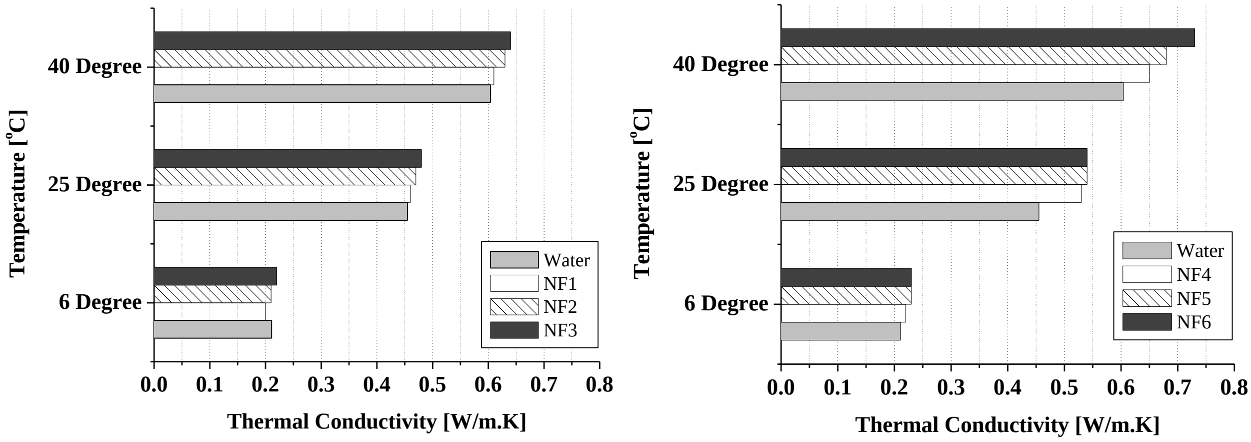
Figure 2 Optical Microscopy pictures of MWCNTs waterbased-fluids with and without PVP addition; a) Original MWCTs in water, b) NF1, c) NF2, d) NF3, e) NF4, f) NF5, g) NF6

To understand the thermal properties of MWCNTs in deionized water, thermal conductivity and thermal conductivity enhancement have been measured for all nanofluids at temperature of 6°C, 25°C and 45°C. As can be seen in Figure 3(a) thermal conductivity of nanofluids without addition of PVP are slightly higher than that of the base fluid and are a function of stability and temperature. Better stability and dispersion due to anchoring the functional group on CNTs surface increases the level of thermal conductivity on NF2 and NF3. Similarly, with the addition of PVP, better stability and dispersion in NF4-NF6 in which results in higher thermal conductivity as compared to nanofluids without PVP addition. Many mechanisms such as particle clustering, Brownian motion, ordered liquid layering were considered to be responsible for the thermal conductivity enhancement [8]. Loosely packed cluster gives higher thermal conductivity than that of closely packed clusters. As the cluster and aggregates decreased, the random motion (Brownian motion) is larger and, consequently, the convection like effects becomes dominant, while the nanofluid conductivity in- creases. Therefore, the smaller the nanoparticles, the better for increasing the conductivity [9].

Table 2 displays the thermal conductivity enhancement of the nanofluids contain 0.5% MWCNTs. There is a trend of enhancement of nanofluids with and without addition of PVP. The similar trends are observed from lower temperature to higher temperature level with enhance thermal conductivity. The highest enhancement was achieved at temperature of 45°C for NF6 containing 0.5% treated MWCNTs with 20.86%. Some data from this experimental work show anomalous behavior, this might due to inhomogeneous medium (solid/liquid) in nanofluids during preparation. In overall thermal conductivity enhancement is affected by dispersion of nanosize particle in basefluids and the strong interaction between fluid and clusters of nano-particles. Well-dispersed nanofluids results in percolating paths for thermal conduction at clusters interface, leading to an enhanced thermal conductivity of such nanofluids beyond the 3φ Maxwell limit, with φ as concentration of nanoparticles [10].

Table 2 Thermal conductivity enhancement data of MWCNTs waterbased-fluids

Sample Coding	**Thermal Conductivity Enhancement (%) at different Temperature**		
	6°C	**25°C**	**45°C**
NF1	-7.58	1.10	0.83
NF2	0.47	3.30	4.97
NF3	6.16	5.49	5.79
NF4	4.75	16.92	7.62
NF5	9.00	18.46	11.92
NF6	8.53	18.68	20.86



(a) (b)

Figure 3 Thermal Conductivity Data of MWCNTs Waterbased-fluids

4.0 CONCLUSION

Proper chemical treatment of multiwalled carbon-nanotubes have a great potential to disperse in water without the addition of dispersing agent. However, the aqueous suspensions of multi-walled carbon nanotubes prepared by using PVP as dispersant and ultrasonication technique were found to be stable for more than 7 days. The thermal conductivity analysis of the prepared fluids revealed that the thermal conductivity enhancement can reached up to 20.86% for sample NF6 which attributed from defect of MWCNTs during aggressive chemical treatment. These promising properties of MWCNTs in water-based fluids would enable the nanofluids to be used as a heat transfer fluids in coolant technology.

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