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COMPARISON OF THERMAL CONDUCTIVITY FOR HHT-24-CNF-BASED NANOFLUID USING DEIONIZED WATER AND ETHYLENE GLYCOL

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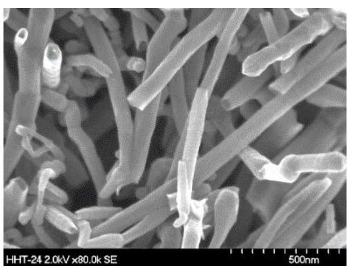
Graphical abstract



Abstract

Carbon nanofibers (CNF) is one of potential nanoparticles that possess superior thermal conductivity. In this study, nanofluids with suspension of CNF in deionized water (DI water) and ethylene glycol (EG) are prepare. Thermal conductivity (TC) of the nanofluids are measured at 6°C, 25°C and 40°C using KD2 Pro Thermal Properties Analyser. The results show that, TC increases with increasing of temperature and CNF loading. Best TC is recorded by 36.7 % enhancement at 40 °C for EG based fluid with 0.9 wt% CNF loading. Meanwhile, for DI water based fluid, best TC enhancement (39.6 %) can be achieved with CNF loading of 0.7 wt% at 40°C. Overall, both based fluid show a promising enhancement in thermal conductivity. However, DI water based fluid show higher TC in comparison to EG based fluid due to the higher TC in standard DI water itself.

Keywords: Carbon nanofibers, deionized water, ethylene glycol, thermal conductivity

Abstrak

Karbon nanofiber (CNF) merupakan salah satu partikel nano berpotensi yang mempunyai kekonduksian termal yang tinggi. Dalam kajian ini, bendalir nano yang mengandungi CNF disediakan di dalam air ternyahion dan etilena glikol (EG) sebagai bendalir asas. Kekonduksian termal (TC) bendalir nano di ukur pada suhu 6°C, 25°C dan 40°C menggunakan alat Penganalisa Pencirian Termal KD2 Pro. Hasil kajian menunjukkan TC meningkat dengan peningkatan suhu dan penambahan CNF. Peningkatan TC terbaik direkodkan sebanyak 36.7 % pada suhu 40 °C untuk bendalir EG dengan penambahan 0.9 wt% CNF. Sementara itu, untuk bendalir berasaskan air ternyahion, peningkatan TC terbaik (39.6 %) dicapai dengan penambahan CNF sebanyak 0.7 wt% pada suhu 40°C. Secara keseluruhan, kedua-dua bendalir asas tersebut menunjukkan peningkatan kekonduksian termal yang memberangsangkan. Walaubagaimanapun, bendalir berasaskan air ternyahion mencatatkan TC yang lebih tinggi berbanding bendalir berasaskan EG disebabkan air ternyahion piawai mempunyai nilai kekonduksian termal yang lebih tinggi.

Kata kunci: Karbon nanofiber, air ternyahion, etilena glikol, kekondusian termal

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1.0 INTRODUCTION

Researchers from all over the world have demonstrated interesting uses of dispersions of nanoparticles mixed or suspended in conventional fluids. The trend of using nanocarbon as nanoparticles started to highlight and there is gradually growth in research articles. Currently, most of the research studies were done on multi-walled carbon nanotubes (MWNTs) with the addition of dispersant agent in water-based fluids [1,2]. Some of them worked on the effects of dispersant [3], acidity [4] and diameter [5] and also aspect ratio [6]. Majority of them focused on the thermal conductivity enhancement as a function of particle volume concentration [7], base fluids [8], and temperature [9]. Several experimental studies on nanofluids have been reported in the literature using single-walled carbon nanotubes (SWNT)[10], double-walled carbon nanotubes (DWNT) [11] and multi-walled carbon nanotubes (MWCNT) [12] together with dispersant agent to achieve stability and thermal conductivity but fewer works have been using modified carbon nanofibers [13].

The major attraction of using nanocarbon for preparation of nanofluid materials is due to their intensive thermal and electrical properties. However the process to produce homogeneous water base nanocarbon nanofluids is hindered by the nanocarbon particle surface hydrophobicity that promotes agglomeration and obstructing their dispersion in polar liquid. Nanocarbon particle dispersion in polar liquid can be achieved by physical or chemical means. The best technique to produce stable suspensions was a combination of both physical and chemical method [14]. Therefore, in this paper we demonstrate the thermal conductivity properties of carbon nanofiber suspensions in water deionized water and ethylene glycol using polyvinylpyrrolidone (PVP) as dispersing agent.

Survey from literature indicates that thermal conductivity is closely related to their heat transfer properties. Choi et al. [15] proposed that thermal conductivity of nanofluid is higher compared to those conventional heat transfer fluids. Thus, the discovery of nanofluid had improved the heat transfer capabilities of conventional heat transfer fluids and has a greater potential in industrial cooling media such as cooling towers, oil & water heaters, tool heaters and HVAC systems.

2.0 EXPERIMENTAL

In this study, carbon nanofibers (CNF) HHT-24 was puchased from Pyrograf Product, Inc. The code of HHT indicates high heat treatment in which this CNF was heated up to 3000 °C. The nanofibers have 41 m^2/g specific surface area with diameter of 100 nm. One of the characteristics of nanoparticles that causes problems in synthesizing of nanofluids is its hydrophobic characteristic. To overcome this problem, a dispersing agent polyvinylpyrrolidone (PVP) purchased from Sigma-Aldrich was chosen in order to decrease the surface tension between CNF and the base fluids.

For the preparation of nanofluids, CNF was dispersed in sampling bottle contains 40 ml of the based fluids (deionized water/ethylene glycol) with an addition of PVP. Then the mechanical homogenizer was used to homogenize the nanofluids with 10000 rpm for 60 seconds. The steps continue by placing the sampling bottles in ultrasonic and undergo ultrasonication for 60 minutes at temperature of 25 °C. The mixture of nanofluids was again homogenized at 10000 rpm for another 5 minutes.

The suspension nanofluids were being left for 100 hours prior to stability test using Stability Test Rig (Figure 1). Whereas, thermal conductivity (TC) test was analyse using KD2-Pro Thermal Properties Analyser at three different temperature of 6°C, 25°C and 40°C. Field Emission Scanning Electron Microscope (FESEM) was carried out using FEI Quanta 200F to investigate the morphology of carbon nanofibers.

Figure 1 Stability Test Rig.

3.0 RESULTS AND DISCUSSION

3.1 CNF Morphology

The morphology of HHT-24 CNF are shown in Figure 2. From the image we can observed that the received CNF was in uniform size, 60-90 nm in diameter and less entangle.

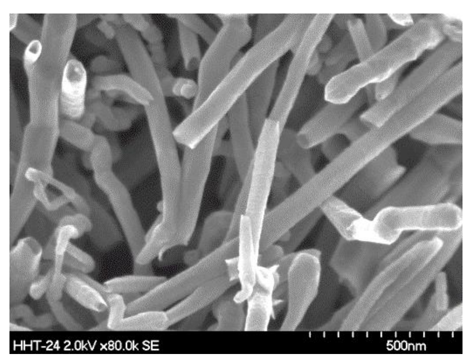

Figure 2 FESEM image of HHT-24 CNF at 80K magnification.

3.2 Effect of Temperature and CNF loading

Thermal properties has been identified as one of the major elements that should be determined in order to identify the heat transfer coefficient of any fluids. Thermal conductivity and stability test of nanofluids CNF were carried out at three different temperatures, 6°C, 25°C, 40°C with percentage loading of CNF varies from 0.1 wt% up to 1.0 wt%. From the experimental data, it was found that TC of our fluids is influenced by three factors; temperature, CNF loading (wt%) and type of based fluids.

The effect of temperature on the TC value can be seen in Figure 3 (a) – (b). Both TC value at 0 wt% CNF are use as standard. As the temperature of the nanofluids increase, the TC increases. For water based CNF nanofluid (Figure 3 (a)) thermal conductivity slightly increase in comparison to the original based fluid from 0.579 W/m.K to 0.675 W/m.K. These can be achieved when the amount of CNF used in the formulations ranging from 0.1 wt% up to 0.6 wt% at temperatures 25°C and 40°C. When the amount of CNF loading is higher in the formulations, the TC value increase drastically. However, at lower temperature (6 °C), there is no significant influence of CNF amount on the TC value. The highest amount of TC at 6 °C is 0.612 W/m.K. Whereas, at 25°C the highest TC has the reading of 0.79 W/m.K followed by 0.835 W/m.K at 40°C.

Results for EG based CNF nanofluids is shown in Figure 3 (b). The trend is somehow different from water-based CNF nanofluids. At temperature 6°C and 25°C, TC value is negligible for lower CNF loading, however when CNF loading in the based fluids is higher than 0.3 wt%, the TC start to increases accordingly from 0.244 W/m.K up to 0.309 W/m.K. At temperature 40°C, TC show improvement at lowest possible CNF loading of 0.3 wt% (0.274 W/m.K)up to 1 wt% (0.335 W/m.K). Hamilton-crosser model [16] shows that TC ratio increase nonlinearly with an increase in solid concentrations that is in line with our data here.

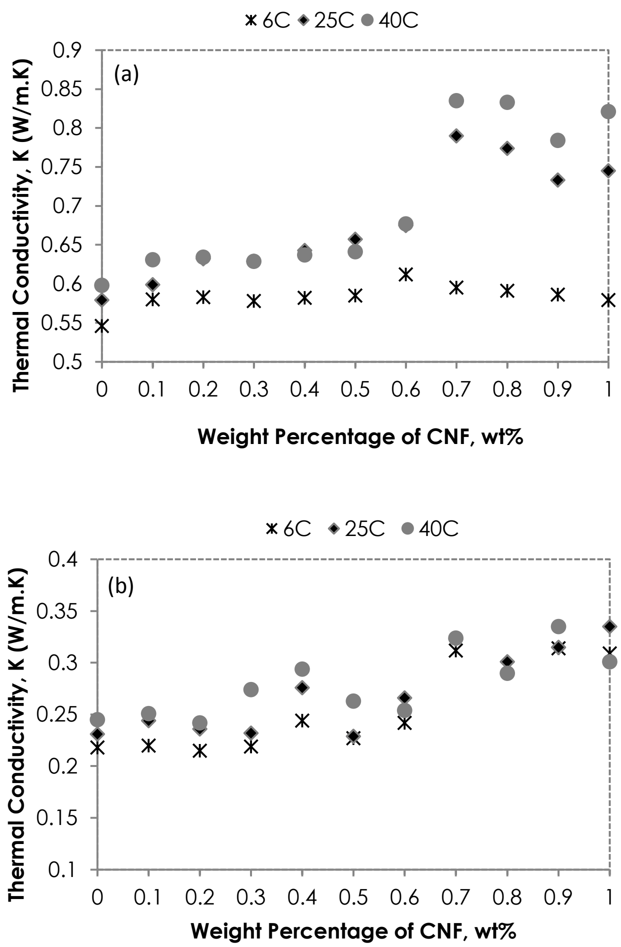

Figure 3 Thermal conductivity of (a) water-based and (b) ethylene glycol based of CNF nanofluids at temperature of 6°C, 25°C and 40°C.

As the temperature increases, significant increases in thermal conductivity are evident for all solid volume fractions, especially at high concentrations. Significant increase of relative thermal conductivity with respect to increasing temperature indicates that thermal conductivity is strongly dependent on temperature [16]. From overall results, both the nanofluids are exhibiting higher TC in comparison to their original base fluid (standard). TC of DI-water based CNF nanofluid is always superior than EG based CNF nanofluid at all tested parameters.

3.3 Stability

Stability of nanofluids is the condition where the nanoparticles are fully dispersed in the based solution. The stability nanofluids can improve the heat transfer and thermal activities. Besides that, good stability will prevent settling and reduce clogging in heat transfer devices. Polymer dispersant agent (PVP) used in this formulation has been found to prevent the agglomeration of CNF in both fluids by steric effect. From the stability test results shown in Table 1, we observed that, stability of nanofluids influence by the ratio between CNF to PVP during the formulation. When the ratio of CNF to PVP is 1 to 0.1, the stability of EG-based CNF nanofluids is stable up to 24 hours. The maximum stability up to 72 hours can be achieved with ratio CNF : PVP (1 : 0.3) and the minimum ratio to achieved more than 100 hours stability is CNF : PVP (0.1 : 0.4). However, when deionized water was used as the based fluids, only minimum ratio is needed CNF : PVP (1 : 0.1) in order to obtain best formulation that can give better stability. Adding dispersing agent such as PVP is an easy and economic method to enhance the stability of nanofluids for longer periods.

Table 1 Stability analysis of deionized water (DI-water) and ethylene glycol (EG) based CNF nanofluids.

CNF (wt%)	PVP (wt%)	Based Fluids	Stability		
			24 hrs	72 hrs	100 hrs
0.1	0.01	EG	Stable	Unstable	Unstable
0.1	0.03		Stable	Stable	Unstable
0.2	0.08		Stable	Stable	Stable
0.1	0.004	DI Water	Unstable	Unstable	Unstable
0.1	0.01		Stable	Stable	Stable
0.1	0.02		Stable	Stable	Stable

4.0 CONCLUSION

In general, adding carbon nanofibers (HHT-24) has been found to increase the thermal conductivity of water based and ethylene glycol based nanofluids. Nanofluids with higher CNF loading possess high thermal conductivity compared to the original base fluids. The degree of stability can be achieved with the usage of PVP as the dispersant agent at lowest possible ratio to CNF in the formulation. From the results, these nanofluids have huge potential yet to be explored in many applications such as automotive engine cooling system and military devices.

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