Thermal Conductivity of Carbon Nanofiber in Mixed Ethylene Glycol/ Deionized Water Based Nanofluids

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ABSTRACT

The objective proposed in this work is to find the best formulation of a stable nanofluids with the addition of Pyrograf III HHT24 carbon nanofibers (CNF) in a base fluid consisting of deionized water (DI) and ethylene glycol (EG). The dispersion of nanofibers was enhanced with the presence of polyvinylpyrrolidone (PVP) as the stabilizing agent through two-step preparation process. The experiment was conducted by setting the variable weight percentage of CNF from 0.1wt% to 1.0wt%, with the base fluid ratio of 70:30 (DI:EG) of weight percent. Then, the thermal conductivity analysis was investigated for the stable nanofluids at three different temperatures (6°C, 25°C and 40°C). Significant increases of the thermal conductivity were observed with the volume concentration of CNF addition. The highest thermal conductivity was gained at 1.0wt% volume concentration at 40°C with value

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of 0.499 W/m.K and maximum enhancements of 6.62%. Overall, nanofluids proved to have a greater potential to be commercialized as conventional heat transfer fluids due to its good thermal properties.

Keywords: *Carbon Nanofiber, Thermal Conductivity, Nanofluids.*

Introduction

High thermal conductor material such as carbon nanotubes, metal and metal oxides which possess high thermal conductivity have concerned many researchers to investigate the performance of existing heat transfer system [1]. These materials were added into a heat transfer fluid to improve the thermal conductivity [2]. Scientists at Argonne National Laboratory was the first one who invented nanofluids. The thermal conductivity values of about 20-150% higher than the conventional heat transfer fluids has been improved with the dilution mixture of liquid and particles of the fluids [3].

Materials such as carbon nanofibers (CNF) and carbon nanotube (CNT) have been proposed to be used as thermal interface materials to improve contact thermal conductance in electronic packaging applications [4]. Besides that, some researchers have also revealed the large improvements in the thermal contact conductance due to the CNTs and CNFs [5-6]. Numerous studies had been reported in literature on the enhancement of thermal conductivity of nanofluids which was prepared by mixing these CNTs and CNFs with conventional base fluids such as water and ethylene glycol. However, only a few studies regarding the addition of CNF into a base fluid have been reported.

The first carbon fiber (CF) was initiated in 1879 by Thomas Edison as it was used as the filament of a light bulb which was prepared by carbonizing cotton and bamboo [7]. The early works established by Thomas Edison causes these materials to be established vastly in both theoretical and real-world applications [8-9]. CNF as one of the most prominent variants of CFs, possess excellent mechanical properties, high electrical and thermal conductivity [10] which makes these materials driven as a promising material in extensive range of application [7].

This study is concerned with nanofluids prepared by dispersing CNF in base fluid consisting of water and ethylene glycol to enhance their performance as a heat transfer fluid in a host of applications. Therefore, the focus is to formulate a stable nanofluids produced from the mixture of carbon nanofiber (CNF HHT24), a mixture of deionized water/ethylene glycol as the base fluid and stabilizing agent. Then, the thermal performance of the formulated nanofluids in terms of its thermal conductivity were studied.

Methodology

Nanofluids sample preparation

Carbon nanofiber (CNF), deionized water (DI), ethylene glycol (EG) and polyvinylpyrrolidone (PVP) were used to produce nanofluids. CNF used in this study were supplied by Pyrograf Products, Inc. from Pyrograf III Carbon Nanofibers, High Heat Treated 24 (CNF HHT24) grade. The nanofiber had a specified fiber diameter of 100 nm and specific surface area of 41 m^2/g produced by chemical vapor deposition (CVD) process. The properties of CNF HHT24 are shown in Table 1.

Table 1: Pyrograf III CNF HHT24 properties

Properties	**Description**
Density	2.0 g/cm^3
Moisture	< 5 wt%
Purity	> 98 wt%
Fiber Diameter	100 nm
Color	Black
Specific Surface Area	41 m^2/g

DI with a density of 1.0 g/cm^3, which was used as the base fluid, was prepared in the laboratory using an ELGA LabWater purification system, while ethylene glycol, with a density of 1.1 g/cm^3, was purchased from Quality Reagent Chemical (QRëC). The polyvinylpyrrolidone (PVP) from Sigma-Aldrich was chosen as a stabilizing agent.

The nanofluids were prepared using a two-step method with several different concentrations of CNFs which were used in the base fluids. Weight percentage of CNFs were varied from 0.1wt% up to 1.0wt% with the interval of 0.1wt%. The ratio used between DI and EG are set to 70:30. These mixtures are then homogenized using the mechanical homogenizer for five minutes by using a Digital Homogenizer LHG-15 at 10000 rpm rotational speed. To ensure homogenous and uniformity of the nanofluids, sonication was carried out using Elmasonic S30H ultrasonicator at 25°C for 5 minutes at 37 kHz frequency. The nanofluid dispersion and stability of a 100 hours of aging was observed using Stability Test Rig (STR) to make sure the nanofluid retain its dispersion before further analysis. The nanofluids that were formulated are shown in Figure 1.

Thermal conductivity measurement of nanofluids

All stabilised and adequately dispersed nanofluids were tested for their thermal conductivity. KD2 Pro Thermal Properties Analyser (Decagon Devices, Inc.) was used to measure the thermal conductivity at three different temperatures

of 6°C, 25°C and 40°C. These three temperatures were selected to study the temperature effect on the thermal conductivity of nanofluids. A single-needle KS-1 sensor, with a length of 60 mm and a diameter of 1.3 mm, was inserted into the sample vertically with the purpose of reducing the possibility of inducing convection. This device meets the standards of ASTM D5334 and IEEE 442-1981 regulations. In this experiment, to ensure accurate results, the testing was carried out three times for each nanofluid sample to obtain an average reading. The schematic diagram of thermal conductivity measurement is shown in Figure 2.

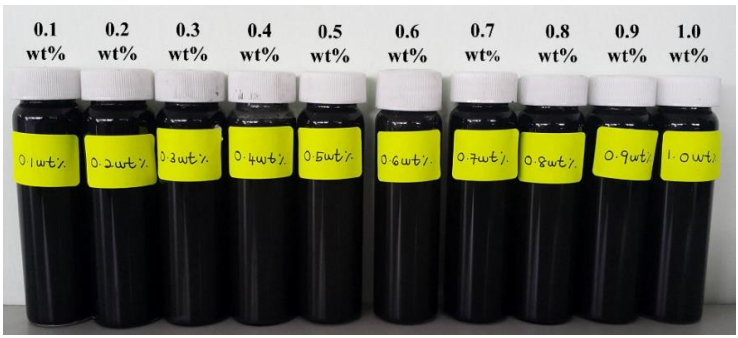

Figure 1: Sample of prepared nanofluids

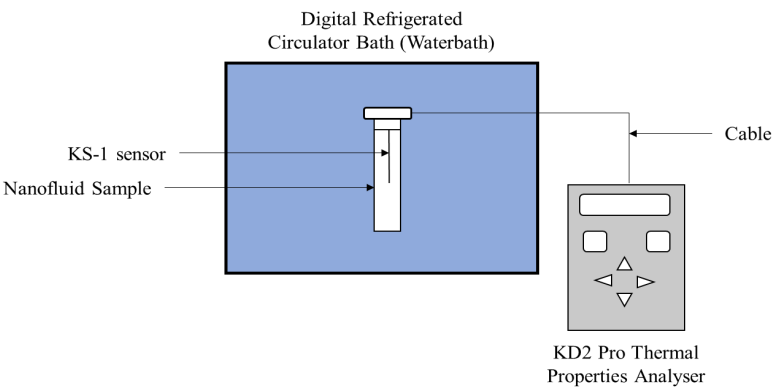

Figure 2: Schematic diagram for thermal conductivity measurement of nanofluids

Result and Discussion

Preliminary experimental study was performed to establish the reliability and accuracy of the measurement data in comparison with the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). Table 2 represent the experimental data from our work and those from ASHRAE.

Table 2: Standard data comparison between ASHRAE and experimental data from this work.

Temperature (°C)	**Thermal Conductivity (W/m.K)**		**Percentage Difference (%)**
	ASHRAE	**This Work**	
6	0.430	0.437	0.40
25	0.450	0.456	0.33
40	0.463	0.468	0.27

Thermal conductivity value from our preliminary experiment at three different temperature were in good agreement with the value given by ASHRAE. At temperature of 6°C and 25°C, the thermal conductivity value gains increments of about +0.006 whereas at 40°C the value increases to +0.005 as compared to ASHRAE which is acceptable in this work. This value is established as the basis for the formulation of different weight loading of CNF and test at temperature of 6°C, 25°C and 40°C.

The results obtained enables an analysis of the trend of thermal conductivity at different heat and at various concentration. Nanofluid formulation without CNFs was used as a standard or datum to calculate the thermal conductivity enhancement.

Figure 3 shows that generally most of the nanofluid samples exhibited an increasing thermal conductivity higher than the standard suspension. Relating to temperature dependence, the thermal conductivity of all nanofluids also increases with the increase in temperature. As per observed, the addition of CNF thoroughly increases the thermal conductivity of the nanofluid as compared with the standard suspension. The highest thermal conductivity value of 0.499 W/m.K can be achieved using 1.0wt% of CNF loading and the temperature/heat applied was at 40°C. Whilst, the highest thermal conductivity at all temperatures was recorded for 0.8wt%, 0.9wt% and 1.0wt% samples. The highest thermal conductivity at 6°C was gained at 0.461 W/m.K, whereas at 25°C, the highest thermal conductivity reading was 0.474 W/m.K, followed by 0.499 W/m.K at 40°C. The observation of this trend seems to be related to the Brownian motion where the addition of small suspended particle cause the increasing in particle collision with molecules of base fluid at high temperatures [11]. Various reviews and studies covering factor which effect the thermal conductivity of nanofluids have been reported. Gao et al. has revealed the increase in cluster size of nanoparticles has significant impact on

the enhancement of thermal conductivity [12]. Some previous studies also reported a linear relation between the increase of thermal conductivity relative to the increase in particle volume fraction. The result reported in this study agrees with the other researchers that encounter the same trends for based fluid in such a mixture by using carbon nanofiber HHT24 in a mixture of water and ethylene glycol [10].

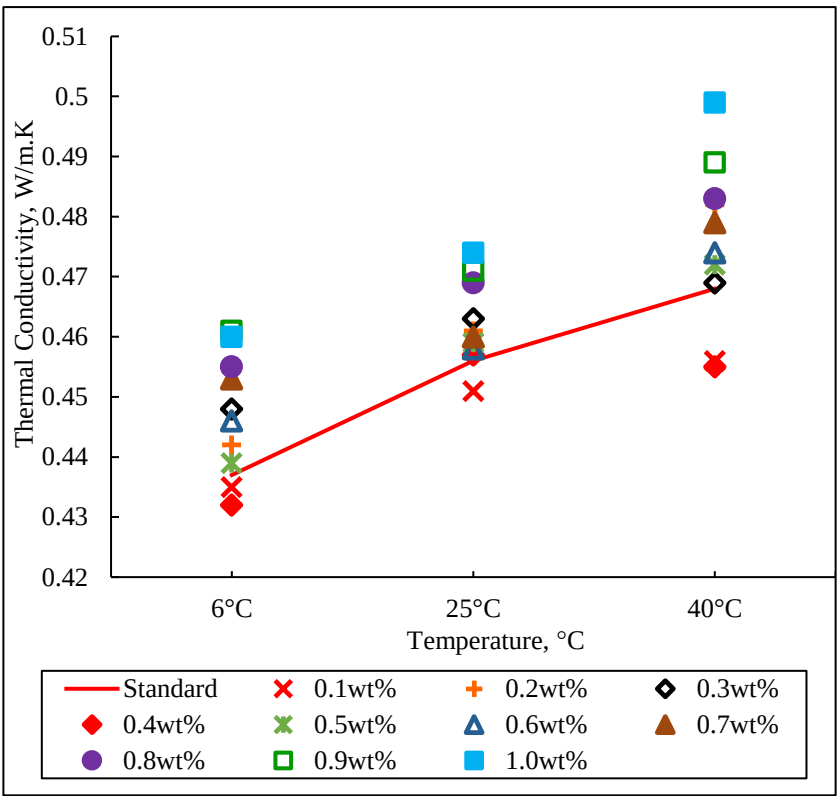

Figure 3: Graph of thermal conductivity value for CNF based nanofluids at variables of concentration and temperatures

However, there were two samples with conductivities that were exceptionally lower than the standard value, and these were the 0.1wt% and 0.4wt%, samples. The lowest thermal conductivities of 0.432 W/m.K and 0.451 W/m.K were noticed in the 0.4wt% and 0.1wt% sample at 6°C and 25°C, respectively.

Meanwhile, at 40°C, the lowest thermal conductivity of 0.455 W/m.K was recorded by the 0.4wt% sample. A plausible reason was due to physical

properties of ethylene glycol which had a lower thermal conductivity as compared to deionized water. Therefore, when these two conventional fluids were mixed together, it may have led to a decrease in thermal conductivity value. The explanation behind these phenomena was due to the increase in nanofluids concentration which causes the viscosity of base fluid to increase and consequently causes a reduction in thermal conductivity of nanofluids [13]. The viscosity of the base fluid affects the Brownian motion of the nanoparticles thus reduces thermal conductivity of the nanofluid [14].

The thermal conductivity enhancement analysis which correspond to 6°C, 25°C and 40°C temperature was calculated using equation 1 to observe the trend, which was compared to the standard fluid. The enhancement percentages of the nanofluids are shown in Table 3.

$$\%\ Enhancement = \frac{\text{Nanofluid Reading - Standard Reading}}{\text{Standard Reading}} \text{x}100\% \qquad (1)$$

Table 3: Enhancement percentage of nanofluids subjected to varying CNF weight loading and temperature.

Nanofluids weight loading (wt%)	**Percentage of Enhancement (%) at different temperature**		
	6°C	**25°C**	**40°C**
0.1	-	-	-
0.2	1.14	1.10	2.99
0.3	2.52	1.53	0.21
0.4	-	0.22	-
0.5	0.46	0.65	0.85
0.6	2.06	0.44	1.28
0.7	3.66	0.88	2.35
0.8	4.12	2.85	3.20
0.9	5.49	3.29	4.48
1.0	5.26	3.94	6.62

At temperature of 6°C, nanofluid sample with 0.9wt% CNF loading gives the highest enhancement in thermal conductivity with 5.49% percent enhancement. Meanwhile, at temperature of 25°C and 40°C, the highest enhancement in thermal conductivity was represented by 1.0wt% with 3.94% and 6.62% respectively. It can be clearly seen from Table 3 that there was no enhancement for the 0.1wt% and 0.4wt% samples. The probable reason to which there is no enhancement in thermal conductivity is the structural characteristics of nanoparticles used such as the diameter size, particle size distribution and shape. These characteristics for nanoparticles in suspensions are not easily measured. This fact could be accounted for some of the

discrepancies in thermal conductivity result as reported in this study. Other than the use of ultrasonic and homogenizer, the use of stabilizing agents could change the surface properties of the suspended particles and thus causes a tendency to form particle clustering which lead to a reduction in thermal conductivities. Some techniques such as adjustment of pH value, addition of dispersant and ultrasonic vibrator was developed which aims at changing the surface properties of suspended particles and suppressing formation of particle clusters to obtain stable suspensions. Surprisingly, these techniques can affect the thermophysical properties of the nanofluids, especially when sample were tested at high temperature [15].

It was noted that there are several factors that plays a significant role in affecting the percentage enhancement of nanofluids in terms of thermophysical properties which was discussed earlier. By and large, the use of nanofluids in an extensive range of applications is promising but the commercialization potential was hindered due to the inconsistent agreement between experimental results from a different researcher. Further systematic research is necessary to obtain a whole map for the thermal conductivities of nanofluids. From the aforementioned discussion, we find that the available experimental data from different research groups vary widely. Hence, further investigations are necessary to clarify the current predicament.

Conclusion

Thermal conductivities of nanofluids containing carbon nanofiber in mixture of deionized water and ethylene glycol have been determined experimentally as a function of volume concentration and temperature. Significant increase of the thermal conductivity was observed with the volume concentration of CNF addition. The highest thermal conductivity was observed at 1.0wt% volume concentration at 40°C with thermal conductivity value of 0.499 W/m.K and maximum enhancements increases to 6.62%. In overall, nanofluids is proven to have a wide prospect to be commercialized as conventional heat transfer fluids due to its good thermal capability. Nanofluids is prominently beneficial in almost every aspect of application which utilizes heat transfer fluid.

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