THERMOPHYSICAL PROPERTIES OF NANOCARBON PARTICLES IN ETHYLENE GLYCOL AND DEIONIZED WATER

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Article History: Received 20.4.2017; Revised 30.4.2018; Accepted 30.6.2018

ABSTRACT

The recent research has demonstrated that nanofluids have provided significantly better thermophysical properties than the base fluids because of its novel properties. The nanofluids proved to have higher heat transfer property and specific heat capacity at a very low particle concentration than conventional heat transfer fluid. Generally, the available base fluid such as ethylene glycol (EG) and deionized water (DI) has a limitation in terms of thermophysical properties like thermal conductivity and heat transfer. An innovative way to overcome this limitation is by adding nanoparticles to the base fluid to form nanofluid. In this paper, the proposed objective is to formulate a stable nanofluid from HHT24 carbon nanofiber (CNF) and –OH functionalized multiwalled carbon nanotubes (MWCNT-OH) in a base fluid with the presence of polyvinylpyrrolidone (PVP) as the stabilizer through two-step preparation process. Then, the thermal conductivity and heat transfer were investigated at three different temperatures (6°C, 25°C and 40°C). Nanofluids tested for thermal conductivity and heat transfer shows that most of the samples achieved an enhancement in EG and DI based nanofluids when CNF HHT24 and MWCNT-OH particle was added. Overall, this studies shows that nanocarbon material is a great alternative to being used in conjunction with ethylene glycol and deionized water as a heat transfer media in a cooling application.

KEYWORDS*: Thermal conductivity; heat transfer; nanofluids; carbon nanofiber; cooling*

1.0 INTRODUCTION

Nanofluids are widely used as heat transfer media for many applications such as microelectronics, a cooling process, heating process, thermal management (Kamel et al., 2016) and others. However, nanofluids are commonly used as a coolant in heat transfer equipment such as electronic cooling system. The recent research has demonstrated that nanofluids have exhibited better heat transfer properties than the base fluids because of its novel properties (Khanafer et al., 2013). The nanofluids proved to have a much higher and strongly temperature-dependent thermal conductivity (Das et al., 2003) at very low particle concentrations than conventional radiator coolants without the nanoparticles. The amazing properties of nanocarbon such as carbon nanotube and carbon nanofiber have gained attention among the researchers as the addition of the small number of suspending nanoparticles has the potential to enhance the thermo-physical properties of the base fluid. These nanoparticles which have high surface area and high thermal conductivity (Singh, 2008) are potential to be used as a superior medium for a heat transfer media. This shows that prospect of nanofluids as future coolants for industrial applications and the development of the nanofluids should be widely enhanced in nanotechnologies area.

Nanocarbon materials, for instance, CNT and CNF, has a nanometer-sized diameter and specifically molecularly smooth surfaces (Guo et al., 2013) which offer an interesting framework for molecular transport in nanofluidic (Choi et al., 2011). Since the discovery of the nanocarbon materials, CNT and CNF have received a considerable attention around the world because of its amazing electronic properties which possess excellent mechanical and thermal properties. Apart from the excellent thermal and mechanical properties that possess, nanocarbon materials prove to have physiochemical properties that make them suitable for a conventional heat transfer fluid in the industrial cooling application. Thus, the first aim of this present work is to formulate a stable nanofluid produced from the mixture of nanocarbon particles (CNT and CNF), base fluids (EG and DI) and dispersing agent. Then, the thermophysical properties of the formulate nanofluids will be studied in terms of thermal conductivity and heat transfer.

2.0 MATERIALS AND METHOD

2.1 Material Selection

The nanocarbon particles used in this study is multiwalled carbon nanotube (MWCNT-OH) from the industrial grade multiwalled CNT that has been functionalized with –OH, purchased from Nanostructured & Amorphous Materials, Inc. (Nanoamor). Meanwhile, CNF used in this research is from Pyrograf III Carbon Nanofiber, High Heat Treated 24 (CNF HHT24) grade, which has been treated to high heat treatment temperature up to 3000°C. For morphological examinations of the nanoparticles, a JEOL JSM-6010PLUS/LV Scanning Electron Microscopy (SEM) was utilized.The properties of CNT and CNF is shown in Table 1 below.

Table 1. Geometrical specification and characteristics of CNT and CNF

Properties	CNF	CNT
CNT Type	Carbon Nanofiber	Carbon Nanotube
Manufacturer	Pyrograf Products	Nanoamor
Density	2.0 g/cm^3	2.1 g/cm^3
Purity	>98 %	>90 %
Diameter	100 nm	10-30 nm
Color	Black	Black
Form	Powder	Powder

Deionized water (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 (EG), with a density of 1.1 g/cm^3, was purchased from Quality Reagent Chemical (QRëC). The polyvinylpyrrolidone (PVP) from Sigma-Aldrich Co. was chosen as a stabilizer to allow the easy dispersion of nanoparticles in nanofluids, lower the surface tension, increases the particle immersion and may prevent fast sedimentation in the mixture.

2.2 Preparation of Nanofluid

The nanofluids were prepared using two-step method with several different concentrations of CNFs and CNTs that were used in the base fluids. Weight percentage were varying from 0.1wt% up to 1.0wt% with the interval of 0.1wt% and were added to a 40ml of the base fluids EG and DI with the presence of polyvinylpyrrolidone (PVP). These suspensions are then homogenized for five minutes by using Digital Homogenizer LHG-15 at 10000 rpm rotational speed. The homogenization is important to ensure the solid particles inside the suspension are uniformly dispersed. Then, the nanofluids sample undergoes sonication at 25°C using Elmasonic S30H ultrasonicator for 5 minutes at 37 kHz wave frequency. The nanofluid dispersion and stability are then be observed by Stability Test Rig (STR) as to make sure the nanofluid retain in the stable condition and well homogenized for further analysis.

2.3 Thermal Conductivity Measurement

All the samples which achieved the stability then were tested for thermal conductivity test. KD2 Pro Thermal Properties Analyser (Decagon Devices, Inc.) was used to measure the thermal conductivity of nanofluids at three different temperatures of 6°C, 25°C and 40°C. 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. The best three samples of CNT and CNF in each base fluid which enhance the highest thermal conductivity were chosen to undergo heat transfer test. The experimental set-up for thermal conductivity measurement was shown in Figure 1.

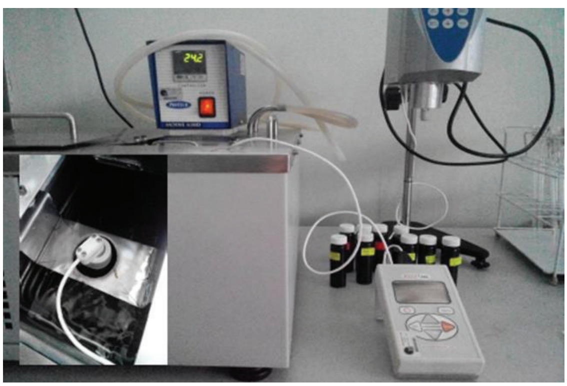

Figure 1. Experimental set-up for thermal conductivity measurement

2.4 Heat Transfer Test

A mini heat transfer test rig, as shown in Figure 2 was designed to study the thermal performance of the formulated nanofluids as efficient coolants that can be used in liquid cooling systems. A copper coil with an outer diameter of

6.65 mm, an inner diameter of 4.35 mm, a thickness of 1.15 mm, and heat exchange length of 81.40 mm, was used as a heating source, which was drenched inside a refrigerated water bath. A liquid pump with a flow rate of 8 L/min was used to circulate the nanofluids and base fluid during the test. A K-type thermocouple was used to measure the inlet and outlet temperatures of the nanofluids as they flowed through the copper coil. The temperature difference of nanofluids was measured by using thermocouple wire that is placed in the inlet and outlet of the copper coil. Nanofluid undergoes heat transfer when it flows to the outlet of copper coil. The pump ensures the constant flow of the nanofluid through the passageways. In this experiment, the thermocouples were attached to the data logger and the result is directly shown in the PicoLog data acquisition software. Reading were taken at 6°C, 25°C and 40°C temperature of the water bath in collectively five minutes after the constant flow of nanofluids.

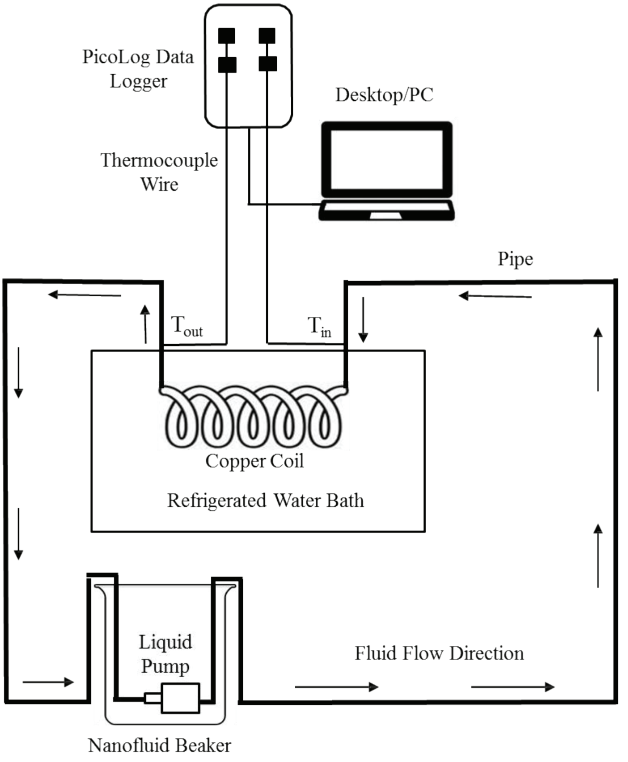

Figure 2. Schematic diagram for heat transfer set-up

3.0 RESULTS AND DISCUSSION

3.1 SEM Characterizations of CNT/CNF Nanoparticles

SEM analysis is valuable for visualizing and measuring macroscopic features up to the nanoscale dimension. Figure 3 shows the morphology of the CNT and CNF. From the SEM images, the morphology is clearly distinguished from each other. All the resolution images were obtained with an acceleration voltage of 12 kV.

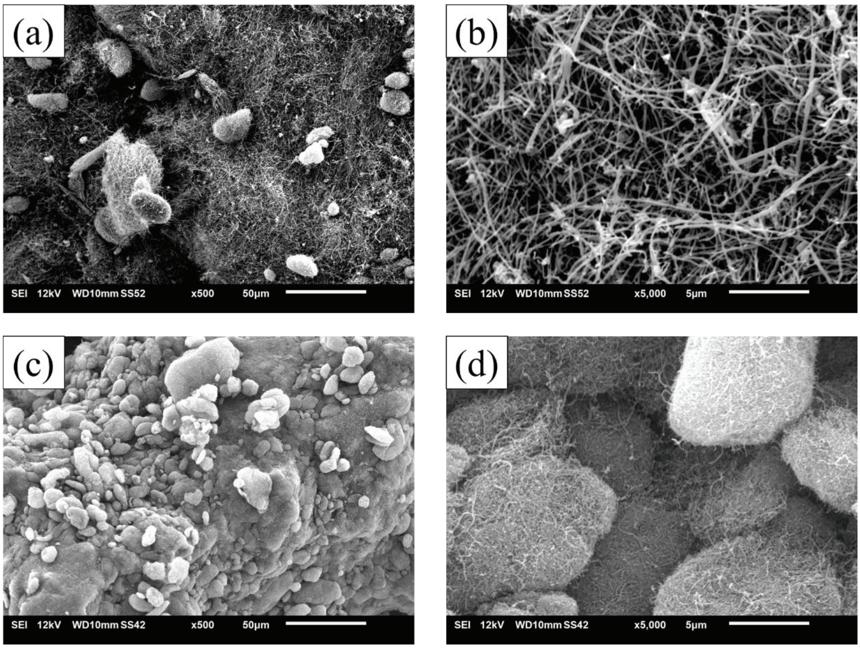

Figure 3. SEM images at 500x and 5000x magnification for (a, b) CNF HHT24 and (c, d) MWCNT-OH

Generally, from the SEM images, the nanotubes morphology is randomly entangled and highly interconnected, probably due to the van der Waals forces. Whilst, the structural properties of CNF HHT24 convert the fiber to a fully graphitized form and creates a highly conductive carbon nanofiber. All the SEM images illustrated agglomerate carbon nanotube and nanofibers, primarily with non-uniform tubular structure.

3.2 Thermal Conductivity

The thermal conductivity test was conducted at three different temperatures which are 6°C, 25°C and 40°C. Different temperature settings used are intended to demonstrate the effects of several factors such as the results of Brownian motion related to the thermal conductivity which consists of conventional static particles. Nanofluid formulation without CNFs and CNT were used as a standard or datum to calculate the thermal conductivity enhancement. The result of thermal conductivity is represented clearly in Figure 4, Figure 5, Figure 6 and Figure 7.

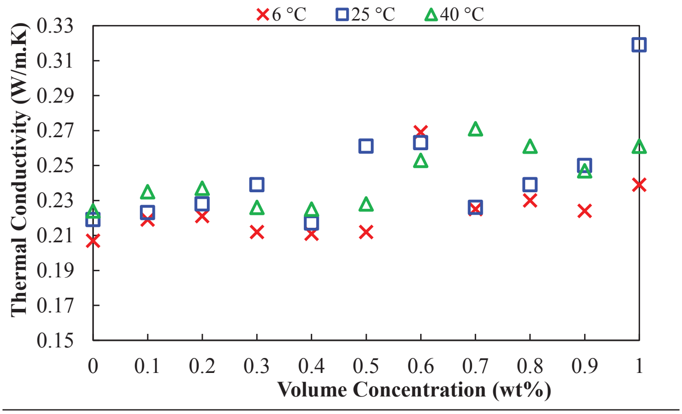

Figure 4. Thermal conductivity of CNF HHT24 EG-based nanofluid

Referring to Figure 4, the results for thermal conductivity of CNF HHT24 EG-based nanofluid fluctuate at all temperatures but for most of the results the thermal conductivity increase with the increment of nanoparticles percentage. The highest thermal conductivity at all temperature was recorded at 0.6 wt.%, 0.8 wt.%, and 1.0 wt.% concentration. For MWCNT-OH EG-based nanofluid, Figure 5 shows that the thermal conductivity of most nanofluids is directly increased with the increase of weight percent of CNT. The highest thermal conductivity at all temperature was noted at 0.8 wt.%, 0.9 wt.%, and 1.0 wt.%. When comparing both CNF HHT24 and MWCNT-OH, the highest thermal conductivity was recorded by 1.0 wt.% of CNF HHT24 at temperature 25°C with 0.319 W/m.K values. Meanwhile, the highest thermal conductivity value for MWCNT-OH was observed at 1.0 wt.% with 0.256 W/m.K values at 40°C.

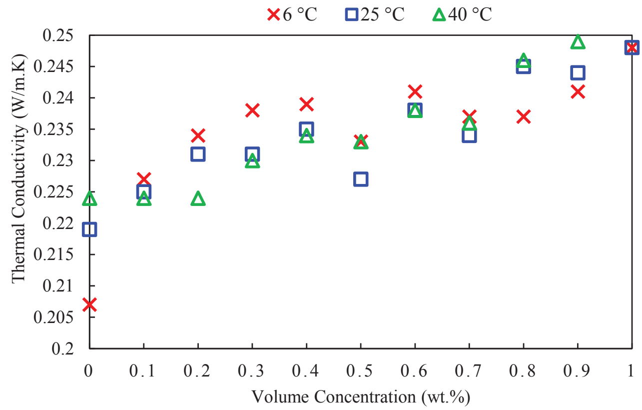

Figure 5. Thermal conductivity of MWCNT-OH EG-based nanofluid

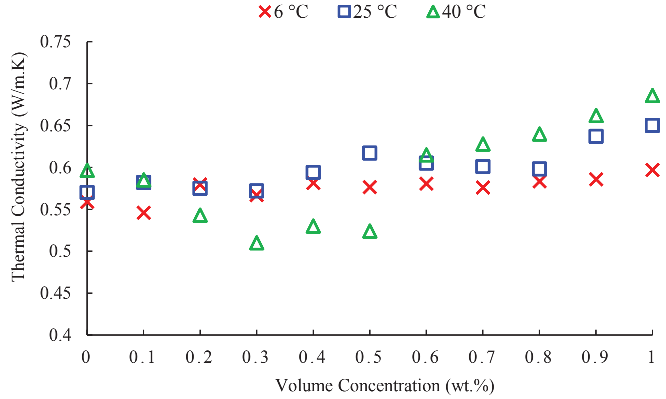

Figure 6. Thermal conductivity of CNF HHT24 DI-based nanofluid

From the Figure 6, CNF HHT24 DI-based nanofluid recorded an increase in thermal conductivity and the value is above the standard as the temperature increase from 6°C to 25°C. However, there are few samples recorded a decrement of thermal conductivity as the temperature increases to 40°C which are at concentration 0.1 wt.%, 0.2 wt.%, 0.3 wt%, 0.4 wt.% and 0.5 wt.%. While the other samples continuously perform an increment in thermal conductivity as temperature increases to 40°C. The highest thermal conductivity at all temperature was recorded at 0.8 wt.%, 0.9 wt.%, and 1.0 wt.%.

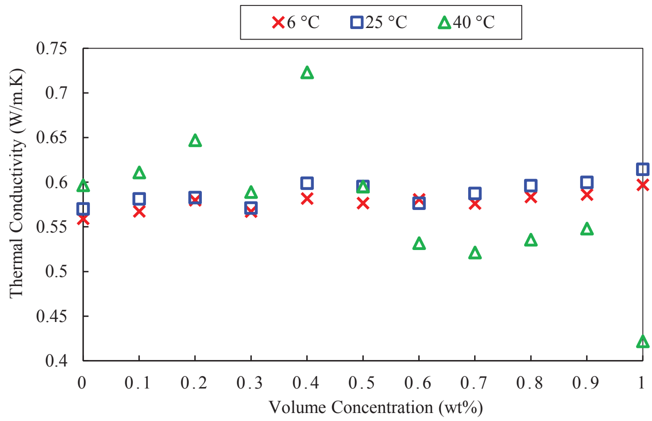

Figure 7. Thermal conductivity of MWCNT-OH DI-based nanofluid

The similar trend was also observed with MWCNT-OH DI-based nanofluid as shown in Figure 7, where all the sample recorded an increase in thermal conductivity as the temperature rises from 6°C to 25°C. However, there are few samples shows a decrease in thermal conductivity after the temperature reaches to 40°C which includes the concentration of 0.3 wt.%, 0.6 wt.%, 0.7 wt.%, 0.8 wt.%, 0.9 wt.% and 1.0 wt.%. While the other samples continuously perform an increment in thermal conductivity as the temperature rises to 40°C. The highest thermal conductivity at all temperature was recorded at the concentration of 0.8 wt.%, 0.9 wt%, and 1.0 wt%. When comparing both CNF HHT24 and MWCNT-OH, the highest thermal conductivity is 0.723 W/m.K for 0.4 wt% of MWCNT-OH at temperature 40°C. Meanwhile, the highest thermal conductivity value for CNF HHT24 is 0.686 W/m.K for 1.0 wt% at 40°C.

The enhancement analysis is done to see the trend and was later compared to the fluid standard. The enhancement can be calculated by using the formula in Equation (1). The enhancement percentages of the nanofluids are shown in Table 2, Table 3, Table 4 and Table 5.

$$Enhancement = \left| \frac{Experimental\ Reading - Standard\ Reading}{Standard\ Reading} \right| X\,100\% \quad (1)$$

Table 2. Enhancement percentage for CNF HHT24 EG-based nanofluid

Coding	CNF HHT24 (wt%)	Percentage enhancement (%) at temperature		
		6 °C	25 °C	40 °C
NF01	0.1	5.79	1.83	4.91
NF02	0.2	6.76	4.10	5.80
NF03	0.3	2.42	9.13	0.89
NF04	0.4	1.93	-1.10	0.45
NF05	0.5	2.42	19.18	1.79
NF06	0.6	29.95	20.09	12.95
NF07	0.7	8.69	3.20	20.98
NF08	0.8	11.11	9.13	16.51
NF09	0.9	8.21	14.15	10.27
NF10	1.0	15.45	45.66	16.52

Table 3. Enhancement percentage for MWCNT-OH EG-based nanofluid

Coding	MWCNT-OH (wt%)	Percentage enhancement (%) at temperature		
		6 °C	25 °C	40 °C
NT01	0.1	9.95	2.51	-
NT02	0.2	13.30	5.24	-
NT03	0.3	14.89	5.56	2.85
NT04	0.4	15.50	7.06	4.32
NT05	0.5	12.70	3.55	3.88
NT06	0.6	16.60	8.56	6.24
NT07	0.7	14.60	6.92	5.35
NT08	0.8	14.60	11.62	9.67
NT09	0.9	16.60	11.16	11.01
NT10	1.0	20.10	13.12	14.27

Table 4. Enhancement percentage for CNF HHT24 DI-based nanofluid

Coding	CNF HHT24 (wt%)	Percentage enhancement (%) at temperature		
		6 °C	25 °C	40 °C
NF11	0.1	1.09	2.10	-
NF12	0.2	4.12	5.82	-
NF13	0.3	7.63	0.35	-
NF14	0.4	5.47	4.20	-
NF15	0.5	9.18	8.24	-
NF16	0.6	10.04	6.14	3.36
NF17	0.7	10.18	5.80	5.54
NF18	0.8	12.16	4.90	7.56
NF19	0.9	18.45	11.75	11.26
NF20	1.0	20.17	14.04	15.29

Table 5. Enhancement percentage for MWCNT-OH DI-based nanofluid

Coding	MWCNT-OH (wt%)	Percentage enhancement (%) at temperature		
		6°C	25 °C	40 °C
NT11	0.1	1.48	1.98	2.69
NT12	0.2	3.68	2.23	8.74
NT13	0.3	1.43	0.18	-
NT14	0.4	4.04	5.04	-
NT15	0.5	3.15	4.39	-
NT16	0.6	3.86	1.11	0.84
NT17	0.7	3.04	3.04	-
NT18	0.8	4.35	4.56	-
NT19	0.9	4.83	5.21	-
NT20	1.0	6.80	7.77	-

The results obtained in Table 2, Table 3, Table 4 and Table 5 was observed to be irregulars in term of the enhancements at all temperature. At temperature 6°C, 25°C and 40°C, most of the sample exceeds the standard samples in thermal conductivity enhancement excepting for NF11, NF12, NF13, NF14, NF15, NT13, NT16, NT17, NT18, NT19, and NT20. The highest recorded enhancement is at temperature 25°C by NF10.

In conventional suspensions of solid particles with sizes on the order of millimeters or micrometers in liquids, the thermal conductivity of the mixture depends on temperature only due to the dependence of thermal conductivity of base liquid and solid particles on temperature. However, in case of nanofluids, change of temperature affects the Brownian motion of nanoparticles and clustering of nanoparticles, which results in dramatic changes of thermal conductivity of nanofluids with temperature (Babu et al., 2013).

From the result, it can be seen that deionized water recorded the higher thermal conductivity compared to ethylene glycol. However, in term of percentage enhancement, ethylene glycol recorded more percentage enhancement of thermal conductivity compared to deionized water. Differences in enhancement performance may be attributable to differences of the thermal boundary resistance around the nanoparticles occurring for different base fluids. In addition, the role of Brownian motion of particles in nanofluids may be an important parameter in determining the thermal conductivity enhancement and also an important factor, when the viscosity of a base fluid changes significantly with temperature, which is certainly the case for EG.

3.2 Heat Transfer

A heat transfer test was conducted through heat convection as fluid is used as the medium. Three selected samples for CNF HHT24 and MWCNT-OH from both base fluids which have the best enhancement in thermal conductivity were tested for heat transfer test. The results of heat transfer test were shown in Table 6 and Table 7.

Table 6: Temperature of inlet and outlet for heat transfer test

Sample	Inlet and Outlet Temperature					
	6°C		25°C		40°C	
	T_{in}	T_{out}	T_{in}	T_{out}	T_{in}	T_{out}
Pure EG	6.95	5.96	25.64	25.04	39.50	40.15
Pure DI	6.17	6.13	25.55	25.05	40.65	40.87
NF06	6.33	5.98	25.23	24.97	39.77	40.21
NF08	6.38	6.03	25.10	24.88	40.24	41.03
NF10	6.66	6.01	24.83	24.01	40.22	40.96
NF18	6.04	5.98	24.71	24.04	39.98	40.15
NF19	6.18	5.68	25.65	25.20	39.70	40.24
NF20	6.22	6.01	25.81	25.39	39.38	40.22
NT08	6.95	6.00	25.75	25.02	39.76	40.05
NT09	6.78	6.01	25.42	25.07	39.62	40.20
NT10	6.55	6.02	25.34	25.03	40.18	40.42
NT18	6.15	6.11	25.22	24.98	40.58	40.91
NT19	6.25	6.15	25.37	25.03	40.34	40.67
NT20	6.07	6.02	25.37	25.04	40.25	40.79

Table 7: Temperature difference of sample

Sample	Temperature Difference, ΔT		
	6°C	25°C	40°C
Pure EG	0.99	0.60	0.65
Pure DI	0.03	0.50	0.22
NF06	0.35	0.26	0.44
NF08	0.35	0.22	0.79
NF10	0.65	0.82	0.74
NF18	0.06	0.67	0.17
NF19	0.50	0.45	0.54
NF20	0.21	0.42	0.84
NT08	0.95	0.73	0.29
NT09	0.77	0.35	0.58
NT10	0.52	0.31	0.24
NT18	0.03	0.24	0.33
NT19	0.09	0.34	0.33
NT20	0.04	0.33	0.54

The presence of nanoparticles does enhance some of the results for heat transfer test. From the result, CNF HHT24 and MWCNT-OH nanofluid experienced enhancement in heat transfer as opposed to the standard solution of ethylene glycol and deionized water.

Favorably, nanofluids sample mostly recorded the temperature difference above the standard temperature difference and this result shows that the heat transfer properties of formulated nanofluid are higher compared to the standard solution. The high- temperature difference between inlet and outlet is due to the properties of the fluid that can transfer heat proficiently. A previous study conducted by some investigator reveals that a large surface area encourages high heat transfer from two mediums (Chopkar et al., 2006). The reduction of particle size which is represented by the nanoparticles affects the surface area. When the particle size is decreased, the surface area per unit volume will increase, thus the heat transfer that is related directly to the surface area will increases, resulting in a good efficiency of nanoparticles to transfer heat to the base water (Hussein et al., 2014).

A broader perspective has been adopted by Duangthongsuk and Wongwises (2010) who investigated the effect of thermophysical properties models on the prediction of the heat transfer coefficient and concluded that the heat transfer coefficient of nanofluid is higher than water. This statement had met an agreement with most of the result obtained where the percentage of enhancement is positive. However, there are some results shows a negative value of percentage. This result is because of several factors such as gravity, Brownian forces, friction between the fluid and solid particles, sedimentation and dispersion that may present in the main flow of a nanofluid.

4.0 CONCLUSION

The present study examines the thermal conductivity and heat transfer performance of CNF and CNT in EG/DI based nanofluids. These nanofluids are synthesized by using a two-step preparation process.Tests have been carried out for the varied range of nanoparticle concentration from 0.1wt% to 1.0wt% volume concentration. In the meantime, all the tested samples mostly exhibit enhancements above the standard samples at all three temperatures of 6°C, 25°C and 40°C. From the results and analysis of the thermophysical properties test for the formulated nanofluids, several improvements are seen in terms of enhancement percentages by comparison to the standard mixture of ethylene glycol and deionized water as the base fluid. In thermal conductivity test, the highest value was recorded at 0.723 W/m.K for MWCNT-OH DI-based nanofluids at temperature 40°C. For heat transfer results, nanofluids sample mostly recorded the temperature difference above the standard temperature difference and this result shows that the heat transfer properties of formulated nanofluid are higher compared to the standard solution. It was noted that there are several factors that play an important role in affecting the percentage enhancement of nanofluids in terms of thermophysical properties and has been discussed in result and discussion section. 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. Hence, experimental studies are desired to understand the thermophysical features of nanofluids and recognize innovative and unique applications for these fields.

ACKNOWLEDGEMENT

Many thanks to Universiti Teknikal Malaysia Melaka (UTeM), Universiti Pertahanan Nasional Malaysia (UPNM) and the Ministry of Higher Education (MOHE) for supporting this research under the grants of FRGS/2010/FKM/SG03/1-F0076, FRGS/2/2013/ST05/UPNM/03/1, and FRGS/2/2013/SG02/FKP/02/2/F00176.

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