NANOFLUID-BASED NANOCARBONS: AN INVESTIGATION OF THERMAL CONDUCTIVITY PERFORMANCE

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ABSTRACT

This paper presents a study of thermal conductivity performance, using a nanofluid-based nanocarbon formulate, with three different types of nanocarbons. NC300, NC200, and commercial carbon nanotube (CNT) were used together with Sodium Dodecyl Sulphate (SDS) as a dispersant, and deionized water as a solvent. A weighted ratio of the nanocarbons (0.4 - 1.0wt%) was set-up and the thermal conductivity was measured at 6°C, 25°C, and 45°C using a KD2 Pro thermal properties analyser. The results showed that NC300 with 1wt% of nanocarbons at 45°C gave the highest improvement of almost 30%, compared to deionized water. Meanwhile, the best nanofluid, based on prepared nanocarbons (NC200) and commercial CNT, showed improvement of more than 9% and 12%, respectively, with the addition of 0.6wt% nanocarbons at 45°C. Morphology analysis using electron microscopy, revealed the structural properties of the nanocarbons. NC300 showed a loose CNT with an average diameter of 70-150nm. NC200 are supported by nanocarbons with an average diameter of 10-30nm. Meanwhile, the commercial CNT showed a similar characteristic to that of NC300. Even though NC200 had the smallest diameter of all nanocarbons, (which should provide the highest surface area), the larger sizes of the activated carbons, as a nanocarbon support, are expected to reduce thermal conductivity performance.

***KEYWORDS**: Thermal conductivity, nanofluid, nanocarbon*

1.0 INTRODUCTION

Nanofluids can be used in a wide variety of industries, from transportation, Heat Ventilation and Air Conditioning (HVAC), and energy production; which contributes to electronics, textiles, and paper manufacture. The impact of this new heat transfer technology is expected to be enormous, when considering that heat exchangers are used in all types of industrial applications and that heat transfer performance is crucial in many industries.

High thermal conductivity is expected to affect heat transfer performance (Hong *et.al.*, 2007). Recently, numerous worldwide studies have been performed to improve the thermal conductivity of nanofluids. What are nanofluids? Nanofluids are recognized as nanoparticles suspended in a liquid (Hong *et.al.*, 2007). The suspension of nanoparticles in a fluid provides the advantages of better dispersion behaviour, less clogging, and a larger total surface area (Yang *et.al.*, 2005). Therefore, nanofluids have a great potential to improve the efficiency of heat transfer behaviour (Yang *et.al.*, 2005; Wongcharee *et.al.*, 2011)

Heat transfer through fluid is essentially convection dominated, which strongly depends on the thermal conductivity of the fluid (Chopkar *et.al*., 2006). For this reason, thermal conductivity is very important in the development of energy-efficient heat transfer. Nanofluids containing nanomaterial have already proved their ability to improve the thermal conductivity and heat transfer (Chopkar *et.al*., 2006; Lia *et.al*., 2005). Nanocarbons, such as carbon nanotube and carbon nanofibre, have gained lots of attention from researchers, due to their amazing electronic and mechanical properties (Nakashima , 2006; Dubey *et.al*., 2005). They have the potential to be ideal components for a heat transfer media (Che *et.al*., 2000; Saidura *et.al*., 2011) These nanoparticles, with a high surface area and high thermal conductivity, are potentially a superior medium for heat exchangers. They will also enable further advanced investigation in the field of thermal-fluids or electrochemical applications, by introducing thermal conductivity and temperature sensitivity using nanocarbons (Boskovic *et.al*., 2005). However, applications of these nanocarbons are limited, due to their insolubility in many solvents (Nakashima *et.al*., 2006; Ghadimi *et.al*., 2011).

Many different approaches to disperse nanocarbons in fluid have been carried out. Two of the most popular methods have already been proven to disperse nanocarbons in liquid very well (Ko *et.al*., 2007). One used a surfactant to disperse the nanocarbons and the other, by attaching the hydrophilic functional group onto the surface of the nanocarbon, using an acid treatment method (Ko *et.al*., 2007).

The objective of the research is to develop new nanofluid additive using indigenous carbon materials which will improve thermal conductivity thus will enhance the heat transfer efficiency. In this research, we present a study of the thermal conductivity of nanocarbon, which disperses well with Sodium Dodecyl Sulphate (SDS) surfactant in a deionized water solution. Three different nanocarbons were used and a series of nanocarbon loadings were varied, in order to measure thermal conductivity.

Overall, the test results were promising, where almost all samples prepared showed some enhancement of thermal conductivity, when compared to standard deionized water.

2.0 EXPERIMENT

NC300 and NC200 nanocarbons were produced by Nanoc Sdn. Bhd. Commercial carbon nanotube (CNT) was purchased from Materials and Electrochemical Research (MER) Corporation.

To investigate the as-prepared nanocarbons morphology, Scanning Electron Microscopy (SEM) was performed using a FEI Quanta 200F FESEM. The microstructure of the nanocarbons was further investigated by Transmission Electron Microscopy (TEM) using a Phillips CM200 through LaB6 emitter.

Nanofluids were prepared by mixing the nanocarbon and Sodium Dodecyl Sulphate (SDS) in a deionized water solution. The samples were homogenized (using a Digital Homogenizer LHG-15) for one minute at 10000rpm and then ultrasonicated (using a Portable JAC Ultrasonic-Model 4020) for 60 minutes, at 25°C at the highest frequency. The samples were homogenized once more for five minutes at 10000rpm.

The thermal conductivity of the nanofluids was measured at three different temperatures (6°C, 25°C, and 45°C) using a KD2 Pro Thermal Properties Analyser from Decagon Devices Inc. All samples were tested for thermal conductivity after being well homogenized to avoid sedimentation, which can affect the results.

3.0 RESULTS AND DISCUSSION

3.1. SEM and TEM characterization

SEM analysis is useful for visualizing and measuring macroscopic features up to the nanoscale dimension. FIGURE 1 shows the morphology of the three different nanocarbons. NC300 images (FIGUREs 1a and 1b) illustrate the agglomerate nanocarbon with an average diameter of 70 to 150nm. It mainly shows a tubular fibre structure with a polygonal cross section (Tessonnier *et.al*., 2009)

FIGURES 1c and 1d, show images of a non-uniform type of fibre NC200. This is the smallest size of nanocarbon with an average diameter of approximately 10 to 30nm. However, the larger size of activated carbon, which acts as a nanocarbon support, is also clearly seen in these micrographs. For the commercial CNT, FIGURES 1e and 1f show that the structures are quite similar when compared with NC300, where the average diameters are in the range of 60 to 140nm.

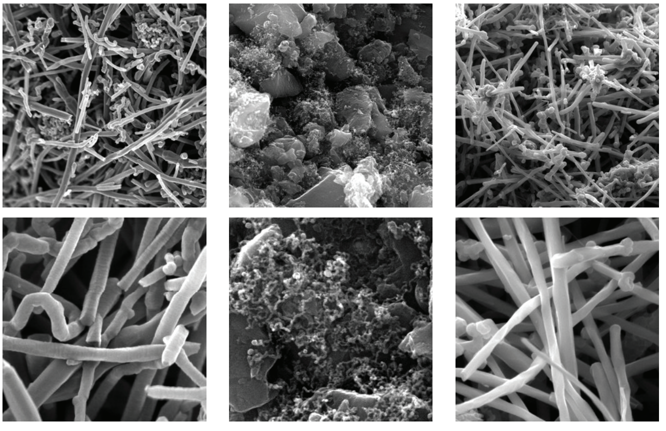


FIGURE 1 SEM images at 2 micron and 500nm scale for NC300 (a, d), NC200 (b, e), and Commercial CNT (c, f)

The high resolution TEM images of all three as-prepared nanocarbons are shown in FIGURE 2. The NC300 image (FIGURE 2a) shows straight graphene sheets, whilst the curve and disorganized graphene layer is observed for NC200 in FIGURE 2b. For commercial CNT, the nanocarbon structures are well graphitized with 10-20 concentric layers; where the outer layers are smooth, as seen in FIGURE 2c (Verdejo *et.al*., 2007)

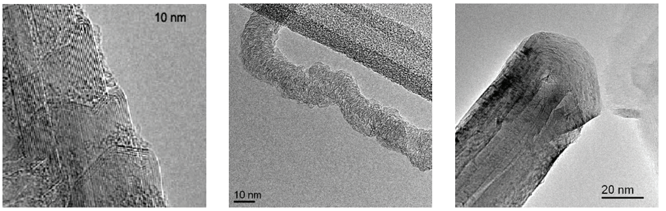
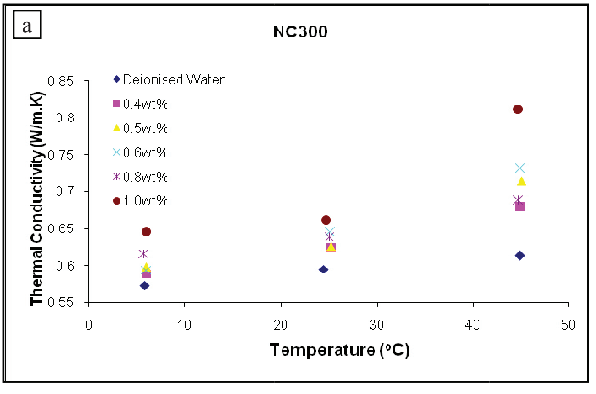


FIGURE 2 TEM images for a) NC300, b) NC200, and c) Commercial CNT

3.2. Thermal Conductivity Analysis

The results of the thermal conductivity measurements are shown in FIGURE 3. The thermal conductivity of deionized water, without the addition of nanocarbon, was carried out as standard. Data was captured at three different temperatures, which were 6°C (0.573W/m.K), 25°C (0.595W/m.K), and 45°C (0.613W/m.K).

The addition of nanocarbon showed a significant enhancement of thermal conductivity at all levels of temperature and positively improved thermal transport properties of nanofluids (Yang *et.al*., 2005). Overall, it showed a trend of enhancement from lower temperatures to higher temperature, due to the increments of particle activity and movement. However, nanofluids containing 1.0wt% of NC300 showed the highest enhancement of thermal conductivity at 0.812W/m.K, when tested at 45°C.



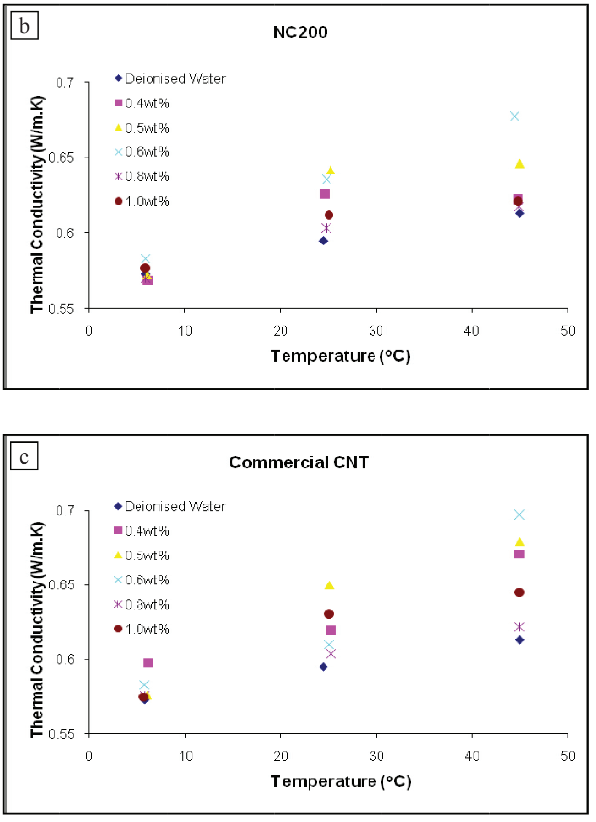


FIGURE 3 Thermal conductivity test for a) NC300, b) NC200, and c) Commercial CNT

3.3. Percentage enhancement of all nanofluid based nanocarbons

The percentage of thermal conductivity enhancement is clearly summarized in FIGURE 4 and TABLE 1.

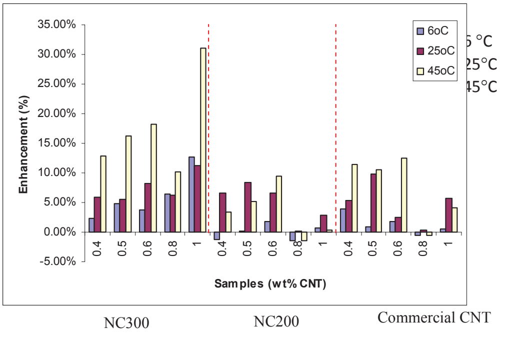


FIGURE 4 Percentage enhancement of nanofluid based nanocarbon

We observed that during thermal conductivity testing at 45°C, nanofluids containing 1.0wt% and 0.6wt% NC300 nanocarbon, showed the best enhancement of 31.15% and 18.18%. Nanofluid based NC200 showed its best enhancement of thermal conductivity of 9.40% with a 0.6wt% nanocarbon loading. For commercial CNT, a 12.51% enhancement was similarly observed with a 0.6wt% loading at 45°C. When the thermal conductivity of nanofluid is lower than deionized water, negative value show there is no improvement on the thermal conductivity, this maybe because of the human error or error on the apparatus. Overall, we concluded that a nanofluid based NC300 nanocarbon loading of 1.0wt%, gave the best enhancement of all temperatures tested. Meanwhile, for NC200 and commercial CNT based nanocarbons, their best enhancements were observed with a 0.6wt% nanocarbon loading, at 45°C.

TABLE 1 Data of percentage enhancement of nanofluid based nanocarbons

Samples	CNT loading	Temperature		
	wt%	6°C	25°C	45°C
NC300	0.4	2.34%	5.95%	12.82%
	0.5	4.75%	5.56%	16.29%
	0.6	3.73%	8.29%	**18.18%**
	0.8	6.46%	6.19%	10.15%
	1	12.67%	11.27%	**31.15%**
NC200	0.4	-1.16%	6.53%	3.37%
	0.5	0.18%	8.43%	5.23%
	0.6	1.84%	6.69%	**9.40%**
	0.8	-1.51%	0.24%	-1.38%
	1	0.80%	2.79%	0.30%
Commercial CNT	0.4	3.89%	5.44%	11.48%
	0.5	0.88%	9.80%	10.61%
	0.6	1.84%	2.41%	**12.51%**
	0.8	-0.47%	0.33%	-0.61%
	1	0.48%	5.79%	4.14%

4.0 CONCLUSION

The thermal conductivity of the three different nanofluid based nanocarbons was investigated. NC300, NC200, and commercial CNT were used as a based nanocarbon and the nanofluid was prepared with the addition of nanocarbons by weight ratio, from 0.4wt% -1.0wt%, in order to obtain a series of thermal conductivity. Thermal conductivity was then measured at 6°C, 25°C, and 45°C using a KD2 Pro thermal properties analyser.

Most results showed an enhancement of thermal conductivity. Nanofluid based NC200 and commercial CNT gave the best results at a

0.6wt% nanocarbon loading, when tested at 45°C, with enhancements of 9.40% and 12.51%, respectively. However, nanofluid based NC300 nanocarbon, with a 1wt% ratio, gave the highest thermal conductivity when measured at 45°C, with an enhancement of 31.15% (thermal conductivity at 0.812W/m.K). Morphology analysis of NC300 nanocarbon, illustrates an average diameter between 70 to 150nm, a tubular fibre structure with a polygonal cross section, and straight graphene sheets. These characteristics of the nanocarbons are expected to provide the best features for improving the thermal conductivity of the nanofluids, and therefore, have a potential to be a medium for a heat transfer fluid.

5.0 ACKNOWLEDGEMENTS

We thank the Ministry of Higher Education for the FRGS/2010/FKM/SG03/1-F00076 research grant, NANOCEN, Nanoc Sdn. Bhd., OYL R&D Sdn. Bhd., and Universiti Teknikal Malaysia Melaka (UTeM), for providing financial, infrastructure, and support for this research.

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