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Investigations on the thermo-physical properties of nanofluid-based carbon nanofibers under modified testing conditions

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Abstract

Rod shaped carbon nanofibers with 1wt%, 3wt% and 5wt% of iron catalyst loadings are developed by Chemical Vapour Deposition (CVD) and the morphology of the carbon nanofibers are characterized. Nanofluids are prepared by dispersing 0.5wt% of carbon nanofiber in the mixture of Sodium Dodecyl Sulfate (SDS) and deionized water to measure the thermal conductivity at varying temperature conditions. The results show that the thermal conductivity of nanofluid-based carbon nanofiber decreases with the increment in catalyst loading. The morphology examination indicates an increment in the diameter of carbon nanofiber during catalyst loading. Further surface area study for the nanofibers, based on nitrogen absorption analysis, confirms the possible mechanisms that scale down the thermal transport in nanofluid.

Keywords: Nanofluids; Carbon Nanofibers; Thermal Conductivity.
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1. Introduction

In recent times, there has been great attention among the researchers for using solid particles as additives in modifying fluids in order to improve the overall heat transfer performance. Suspension of solid materials in a fluid offers a huge potential for enhancement of heat transfer, since thermal conductivity of solid is generally higher than fluids. However, developing an effective heat transfer fluid depends on the particle size of the base material. Bigger particle size will lead to precipitation, abrasion and clogging [1]. Therefore, nanomaterials seem to have a better chance in developing nanofluid containing conductive filler which can be well dispersed in fluid. Nanomaterials such as carbon nanotube and carbon nanofiber attract lot of interest among researchers due to their amazing electronic and mechanical properties [2-4].

Heat transfer through fluid is essentially convection dominated, which strongly depends on the thermal onductivity of the fluid [5-10]. For this reason, thermal conductivity is very important in the development of energy-efficient heat transfer and nanofluid containing nanomaterials are already proven to have improved the thermal conductivity and heat transfer [2, 5].

Early studies reported to have found that nanomaterials such as carbon nanotube

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(CNT) and carbon nanofiber (CNF) have high thermal conductivity and with the potential to be ideal components for heat transfer media [4-6]. Many researches on nanofluid-based carbon nanotube have been proven to be enhancing the thermal conductivity as well as heat transfer efficiency [11-16]. In some research, carbon nanofiber proves to be great alternative for carbon nanotube. Studies conducted by K.J. Lee et al. showed that the suspension of nanofluid-based CNF had a better thermal conductivity enhancement compare to nanofluid-based CNT [15].

In the current work, carbon nanofiber was developed with different morphology for nanofluid formulation. The morphology of the prepared carbon nanofiber was studied by using scanning electron microscopy (SEM) and the surface area was confirmed from nitrogen adsorption analysis. Nanofluid was formulated by addition of carbon nanofiber and sodium dodecyl sulphate surfactant in deionized water solution. Three different nanofluids were formulated and thermal conductivity was measured at three different temperature 6°C, 25°C and 45°C. The results of the investigations on nanofluids show an enhancement in thermal conductivity as compared with standard deionized water. The nanofluids added with the smallest diameter CNF contributed the highest thermal conductivity with ±8% enhancement when measured at 45°C.

2. Experimental Procedure

Carbon nanofibers (CNF) were developed by using chemical vapour deposition (CVD) method. Activated carbon (AC) derived from palm kernel shell was used as a substrate. The preparation of CNF/AC was initiated by pre-treating the activated carbon with nitric acid, followed by impregnation of 1 wt%, 3 wt% and 5 wt% of iron acetate solutions in absolute ethanol. The catalyst precursor was calcined at 250°C and reduced at 700°C for an hour in each step. The catalytic growth of carbon nanofiber in C_2H_4/H_2 was carried out at temperature of 700°C for 2 hours with continous different rotating angle in the fluidization system using universal temperature programmed reactor (UTP).

Nanofluids were prepared by mixing the carbon nanofiber and sodium dodecyl sulphate (SDS) in deionized water solution. The samples were homogenized using Digital Homogenizer LHG-15 for one minute at 10000 rpm and then ultrasonicated with portable JAC ultrasonic-model 4020 for 60 minutes, 25°C at highest frequency. The samples were homogenized again for another five minutes at 10000 rpm.

Morphology investigations were carried out on the prepared carbon nanofibers with Scanning Electron Microscopy (SEM) using FEI Quanta 200F FESEM. Surface area analysis was conducted through Sorptometric 1990 instrument. The thermal conductivity of nanofluids was measured at three difference temperatures 6°C, 25°C and 45°C using KD2 Pro-thermal properties analyzer. All the samples were then tested for thermal conductivity after homogenization so as to prevent the impending sedimentation, which could otherwise affect the end results.

3. Results and Discussion

3.1 SEM Characterization

From the SEM analysis, the morphology of the three difference carbon nanofiber with catalyst loading of 1wt% (CNF-19), 3wt% (CNF-20) and 5wt% (CNF-21) are shown in Fig. 1. All images illustrate agglomerated carbon nanofibers with mainly non-uniform tubular fibers structure. However there are differences found in the diameter of the fibers which indicated in Table 1. Incrementing the amount of catalysts causes the agglomeration between metal particles on the substrate surface. Agglomerated metal particle had increased the diameter size of carbon nanofiber which is observed from Fig. 1.

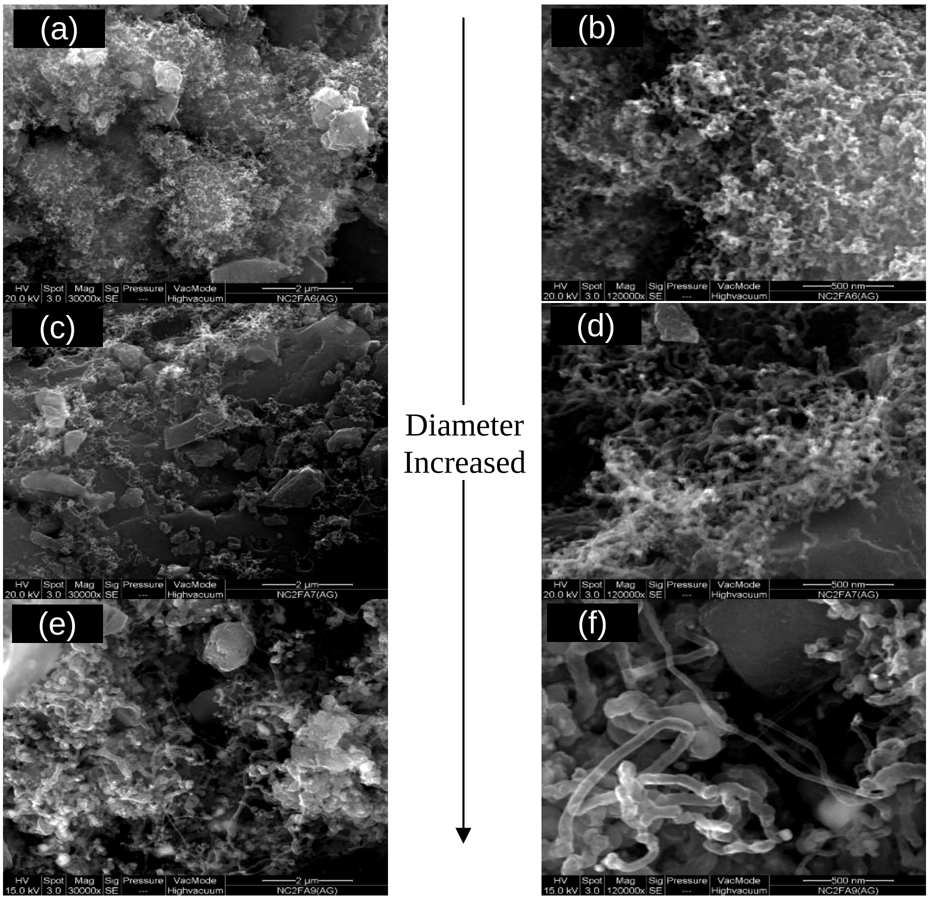

Fig. 1: SEM images for CNF-19 (a,b), CNF-20 (c,d) and CNF-21 (e,f) at 2 micron and 500 nm magnification.

Table 1: Average diameter and surface area of prepared carbon nanofiber

Sample Code	Catalyst loading (wt%)	SEM Images (Fig. 1)	Average Diameter (nm)	Surface Area, A_{BET} (m^2/g)
CNF-19	1	(a) and (b)	12-20	789
CNF-20	3	(c) and (d)	20-45	744
CNF-21	5	(e) and (f)	35-120	613

3.2 Thermal Conductivity Analysis

The results of the thermal conductivity measurements are shown in Fig. 2. Thermal conductivity of de-ionized water without the addition of carbon nanofibers was carried out as a standard as well as a benchmark. The data was taken at three different temperatures which are at 6°C (0.572 W/m.K), 25°C (0.591 W/m.K) and 45°C (0.616 W/m.K).

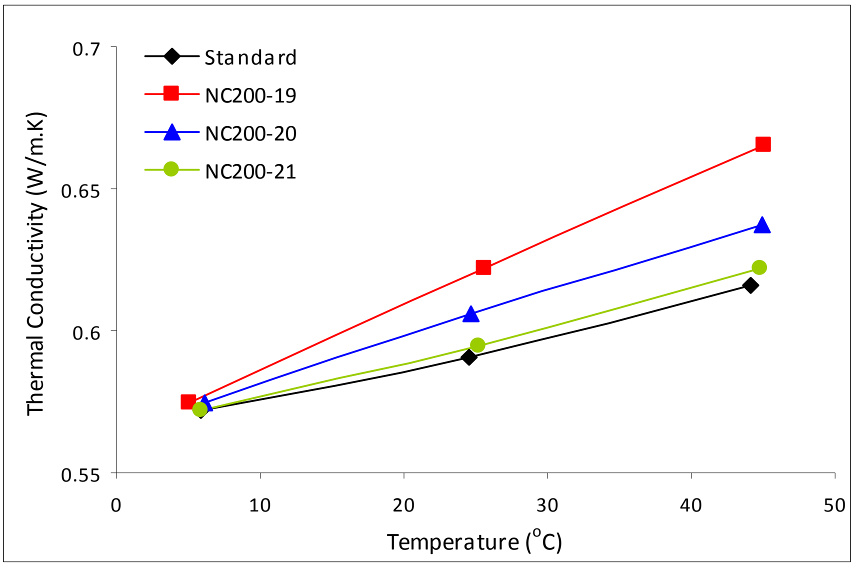

Fig. 2: Thermal conductivity of nanofluids

Addition of carbon nanofibers in the nanofluid showed significant enhancement in thermal conductivity at all temperature levels and positively improving thermal transport properties of the nanofluid. However, bigger diameter carbon nanofibers cause lowering off the thermal conductivity of nanofluid. Table 2 shows the thermal conductivities of NC200-19, NC200-20 and NC200-21 respectively. The data showed a trend of enhancement from lower temperature to higher temperature, which is attributed to the increased particle activity and movement.

However, addition of smallest diameter of carbon nanofiber (CNF-19) in the nanofluid gave the highest thermal conductivity at all temperature levels followed by addition of CNF-20 and CNF-21. Among the three combinations, NC200-19 shows the best thermal conductivity recorded at 0.665 W/mK when measured at 45°C. Addition of smaller diameter nanofibers such as CNF-19 provides highest surface area as compared to the surface area of the nanofibers that have bigger diameters of CNF. Surface area study using nitrogen adsorption analysis confirmed that increase in diameter of nanofibers will reduce the surface area, (Table 1). Higher surface areas are expected to have provided a better media for thermal transport in nanofluid.

Table 2: Data of thermal conductivity for nanofluid prepared

Sample Code	Type of CNF	CNF (wt%)	SDS (wt%)	Temperature (°C)		
				6	25	45
Standard	-	-	0.2	0.572	0.591	0.616
NC200-19	CNF-19	0.5	0.2	0.575	0.622	0.665
NC200-20	CNF-20	0.5	0.2	0.575	0.606	0.637
NC200-21	CNF-21	0.5	0.2	0.572	0.595	0.622

3.3 Percentage enhancement of all the nanofluid-based carbon nanofiber

The percentage of thermal conductivity enhancement is clearly summarized in Fig. 3. NC200-21 nanofluid with biggest diameter size (35-120) nm of CNF-21 gives the lowest thermal conductivity with only 0.19% to 1.36% enhancement. The enhancement however, is improved with the addition of comparatively smaller diameter CNF. NC200-20 with 20-45 nm diameters CNF-20 shows slightly higher enhancement in thermal conductivity at 0.68% to 3.79%.

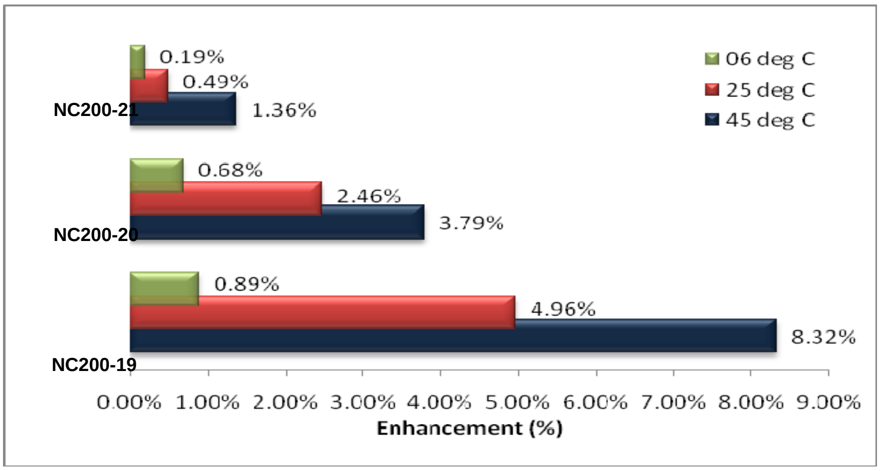

Fig. 3: Percentage of thermal conductivity enhancement for nanofluid-based carbon nanofiber

Addition of the smallest diameter of CNF-19 (12-20 nm) which provides highest surface area (789 m^2/g) generates the maximum enhancement in thermal conductivity. NC200-19 offers the best potential, as a media for thermal transport in nanofluids with the highest increase in thermal conductivity at 0.89% to 8.32%.

4. Conclusion

Nanofluid-based carbon nanofibers were investigated for their influence in enhancing the thermal conductivity using three carbon nanofibers. CNF-19, CNF-20 and CNF-21 were developed through chemical vapour deposition (CVD) method and introduced with deionized water and SDS to formulate nanofluid. Morphology of prepared carbon nanofibers with catalyst loading of 1wt% (CNF-19), 3wt% (CNF-20) and 5wt% (CNF-21) were studied with SEM. All images illustrated agglomerate carbon nanofibers, primarily with non-uniform tubular fibers structure. Increment in the amount of catalyst causes the agglomeration between metal particles on the substrate surface, thus increased the diameter of carbon nanofibers.

The study of surface area of the prepared CNF, from nitrogen adsorption analysis showed decrement of surface area with the increment of diameter size. The thermal conductivity analysis for all the three prepared CNF show an enhancement, due to decrement of diameter size of CNF. Overall, NC200-19 with the addition of smallest diameter of CNF-19 generates the best enhancement in thermal conductivity which is attributed to highest surface area among all the prepared CNF. High surface area of the CNF offers a better media for thermal transport in nanofluids.

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References

[1] Soumen Jana *et al*, Thermochimica Acta **462** (2007) 45
[2] Min-Sheng Liu *et al*, Int. Communi. Heat and Mass Trans. **32** (2005) 1202
[3] Naotoshi Nakashima *et al*, Techno. Advan. Mater. **7** (2006) 609
[4] J. Che *et al*, Nanotechnology **11** (2000) 65
[5] M. Chopkar *et al*, Scripta Materialia **55** (2006) 549
[6] Jie Li and Clement Kleinstreuer: Int. J. Heat and Fluid Flow **29** (2008) 1221
[7] Weiting Jiang *et al*, Int. J. Therm. Sci. **48** (2009) 1108
[8] H. A. Mintsa *et al*, Intl. J. Therm. Sci. **48** (2009) 363
[9] S.M.S. Murshed *et al*, Int. J. Therm. Sci. **47** (2008) 560
[10] F. Frusteri *et al*, Appl. Therm. Eng. **25** (2005) 1623
[11] H. Xie *et al*, J. Appl. Phys. **94** (2003) 4967
[12] M. J. Assael *et al*, Int. J. Thermophys. **25** (2004) 971
[13] A. Cherkasova, J. Shan, Carbon Nanotubes, **222** (2006) 235
[14] D. Wen, Y. Ding, J. Thermophys. Heat Trans. **18** (2004) 481
[15] K. J. Lee *et al*, Small **3** (2007) 1209
[16] L. Chen, H. Xie, Collo. Surf. A, **352** (2009) 136