Chapter 6

Investigation into the Electrical Conductivity of Carbon Nanosphere-Based Green Nanofluids

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Abstract Electrical conductivity measurements of green nanofluids prepared from carbon nanospheres dispersed in 60:40 ethylene glycol and water (60:40 EG/W) based nanofluids have been studied. In order to investigate the effect of temperature and volume concentration on the electrical conductivity of the nanofluids, the temperature was varied from 15 to 60 °C and volume fractions of 0.04, 0.1, 0.12, and 0.2 vol% were used. The results show that the electrical conductivity is greatly enhanced with an increase in temperature and volume fraction. The highest enhancement is seen at 0.2 vol% with 1470% increase in electrical conductivity. The high conductivity enhancement indicates a potential for cooling applications.

Keywords Activated carbon · Carbon nanospheres · Coconut fibre · Electrical conductivity · Green nanofluids · Green nanoparticles · Temperature · Volume concentration

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6.1 Introduction

Synthesis of nanoparticles from “green” bio-precursors has environmental advantages over other conventional methods because of their low-costs and low-toxicity [1, 2]. Nanomaterials synthesized from plants already have their surfaces functionalized; an advantage which is absent in synthetic nanomaterials and this enables them to have better dispersability and stability in base-fluids and subsequently enhanced properties [3]. A detailed review by Buzea et al. [4] outlines the numerous effects of nanoparticle exposure on the human body and environment. These effects can be reduced by investing more into “green” nanotechnology.

A study by Kumar et al. [5] investigated the use of natural sources such as fossil hydrocarbons, waste natural products and botanical hydrocarbon precursors as a means of synthesizing carbon nanomaterials and graphene. It was revealed that those based on fossil hydrocarbon are mostly expensive and not readily accessible. In addition, a lot of the liquid and gaseous fossil hydrocarbons are explosive or toxic in nature and are not acceptable due to atmospheric pollution and its negative effect on human health. On the other hand, carbon nanomaterials derived from carbon based natural precursors have the advantage of producing scalable amounts, they are safe to use in the environment, cheap and allows for fast production techniques.

Thermophysical properties of fluids are those properties that vary with temperature and yet do not have any impact on the chemical structure of the fluid. Just like other thermo-physical properties, electrical conductivity of fluids needs to be enhanced as this can improve the overall working efficiency of their applications relating to cooling, such as in proton electron membranes (PEM) [6]. They can also improve the life span of the electrodes used in metallic cathodes and nozzles [7]. To deal with emission issues, PEM fuel cells are starting to be used in place of batteries as they are light-weight, quiet, have exceptional storage density and possess high fuel energy efficiency [8]. The life span of electrodes is influenced by the electrical conductivity of the liquids flowing through them.

The concept of electrical conductivity arises from the movement of ions is a medium. When an electric field is applied to the medium or nanofluids, the central ion will be attracted and the result is an asymmetric field from a formerly symmetric field [9].

From Stokes law, the hydrodynamic force needed for the movement of a spherical body with radius r and a velocity ν through a fluid with viscosity μ is given as [9]:

$$F_s = 6\pi \mu r \nu \tag{6.1}$$

For microscopic particles with relatively same size as the base fluid, the hydrodynamic drag force on an ion moving under the influence of a chemical potential gradient is [9]:

$$-F_d = 6\pi \mu r_i \upsilon_i \tag{6.2}$$

where r_i and υ_i is the radius and velocity of i ion respectively. The Stokes equation is given as [9]:

$$D_i = \frac{kT}{6\pi \mu r_i} \tag{6.3}$$

where k and T are the thermal conductivities and temperatures respectively. When there is movement of ions in a solution, the local solvent molecules are dragged along. For electric current to be created in a fluid, the positive and negative ions move in opposite directions under the influence of an electromagnetic force (e.m.f). This results in an electrophoretic effect with a countercurrent velocity ν_e [9]. If the number of positive ions is denoted as n_{+ve} and the number of negative ions as n_{-ve} both having drift velocities of ν_{+ve} and ν_{-ve} respectively with charge q_{+ve} and q_{-ve} respectively, then the current density will be [10]:

$$J = n_{+ve}q_{+ve}\nu_{+ve} - n_{-ve}q_{-ve}\nu_{-ve} \tag{6.4}$$

Equation (6.4) can also be written as:

$$J = \frac{nq^2\tau_f E}{m} \tag{6.5}$$

where τ_f, E, and m are the mean free time, electric field and mass respectively. From Ohms law, the electrical conductivity σ is:

$$\sigma = \frac{J}{E} \tag{6.6}$$

Combining Eqs. (6.5) and (6.6),

$$\sigma = \frac{nq^2\tau_f}{m} \tag{6.7}$$

The electrical conductivity in nanofluids can be assumed to be governed by the number of ions present per unit of volume and their respective drift velocities [10].

From past research [7, 11–14], conclusions can be made that the electrical conductivity of nanofluids depend on temperature, volumetric concentration and particle diameter. Increasing the volumetric concentration increases the conducting pathway hence, increasing the electrical conductivity. Similarly, increasing the temperature of the nanofluids will result in a decrease in viscosity thereby enhancing the mobility of ions in the nanofluids. In addition, the numbers of ions are increased due to molecular dissociation, resulting in an enhanced electrical conductivity [11]. The interface effect was considered by [15] as a factor that could enhance the electrical conductivity in carbon nanotubes as the electrical conductivity of complex CNTs in their study decreased rapidly with increasing interfacial layer thickness depending on the percolation threshold.

Coconut fibre (CF) is obtained from the pericarp of coconut fruit and a coconut is made up of 33–35% of husk. Presently, CF are being used as fuel in the processing of coconut-based products, as a fibre source for manufacturing ropes and mats and as a fuel for domestic application [16]. To benefit from this plentiful and low-cost agricultural waste, coconut fibre has been transformed into a carbon nanomaterial in the present study. The conversion of CF into carbon nanomaterials will function as an important raw material obtained from agricultural waste as they are bacteria and fungi resistant. Carbon is a group 14 element that is distributed very widely in nature. It also has a remarkable ability to bond with several other elements as a result of its polyvalent properties creating structures with distinct properties. Recent research has tuned carbon into nanoscale, resulting into carbon nanospheres, carbon nanotubes and carbon nanofibres. Heptagonal and pentagonal pairing of carbon atoms can result in the creation of carbon nanospheres. The graphite sheets in nanospheres occur as waving flakes instead of closed shells which takes the form of the sphere, hence having several open ends at the surface and establishing carbon nanospheres (CNS) as suitable materials for catalytic and adsorption application [17].

Laboratory fabrication of carbon nanospheres involve methods such as chemical vapour deposition (CVD) [18–21], hydrothermal treatment [22], pyrolysis of polymers [23], ultrasonic treatments and chlorination of cobaltocene [24]. Generally, chemical vapour deposition (CVD) occurs when rare earth metal oxides or metal oxides are used as catalysts which results in a need for purification of the synthesized carbon spheres in order to get rid of the catalyst. This makes the process limited to a small scale [25]. Various sources of biomass are being used for the production of nanomaterials derived from carbon [26, 27] because of their low toxicity and availability. These biomasses are often first carbonized, and then activated before being converted to carbon nanomaterials using different methods [28–33]. The method of activation used can either be physical (thermal), chemical or a combination of both physical and chemical processes [16]. The physical process involves the use of CO_2, steam or air and takes place at higher temperatures while the chemical process which is one-step, takes place at lower temperatures and involves the co-carbonization of a parent feedstock with a suitable chemical compound.

To the best of the authors' knowledge, there has been no study carried out on the behavior of electrical conductivity of green nanofluids from coconut fibre based nanospheres. In this study, the authors present the results from the dispersion of already synthesized carbon nanospheres from coconut fibre in 60:40 ethylene glycol/water (EG/W) and finally electrical conductivity measurements. The effect of volume concentration and temperature on the electrical conductivity was also reported.

6.2 Experimental Method

6.2.1 Materials and Stable Nanofluid Preparation

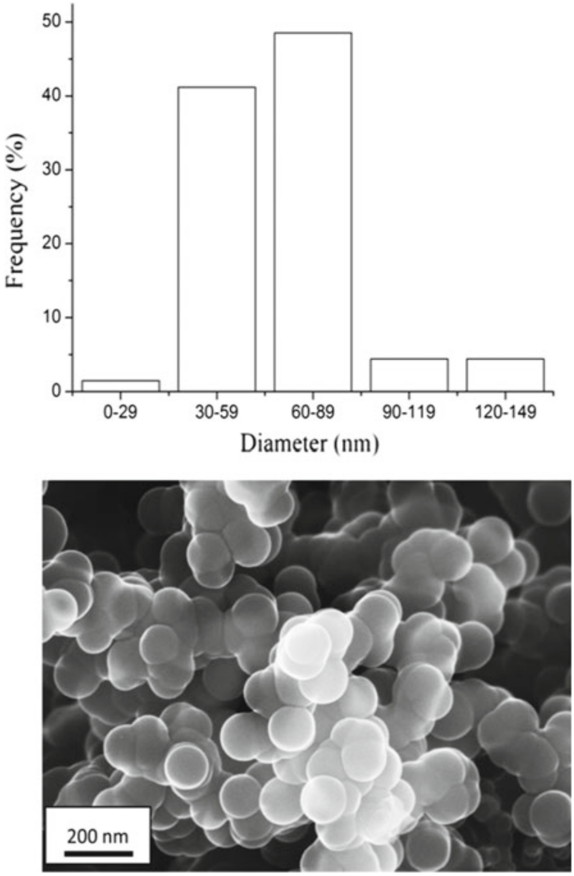
Nanoparticles used in this study were synthesized from coconut fibre. They were first carbonized followed by physical activation in the presence of CO_2 and then treated with ethanol vapour at 800 °C. The procedure is outlined in our previous study of the synthesis procedure in [34]. A known weight of the nanoparticles were measured using a digital weight balance (RADWAG model: AS 220. R2 Max: 220 g Min: 10 mg) and dispersed in 60:40 EG/W (Merck (Pty) Ltd.), gum arabic (GA) acquired from Fluka Analytical and deionized water was used for the nanofluid preparation. The nanotubes were dispersed in a base fluid consisting of 60:40% EG/W in the volume fractions of 0.04, 0.1, 0.12 and 0.2% respectively. The mixture of the nanoparticles, GA and 60:40 ethylene glycol/water (EG/W) was magnetically stirred using a hotplate stirrer (Lasec from Benchmark Scientific Inc., model-H4000-HSE) and sonicated with a 20 kHz, 700 W, QSonica ultrasonic processor. The nanofluid was kept in a programmable temperature bath (LAUDA ECO RE1225 Silver temperature bath) the whole time of sonication and the temperature maintained at 15 °C.

The nanospheres are in the size range of 10–150 nm and the size with the highest occurrence is 60–89 nm. From Fig. 6.1, nanospheres of diameter in the range 60–89 nm constituted almost 50% (48.5%) while nanospheres of diameter 30–59 nm constituted 41%. This shows uniformity in the size range of the nanospheres. The particle size distribution and morphology of the green nanoparticles is given in Fig. 6.1. The morphology indicates smooth round nanospheres with some degree of aggregation due to strong Van der Waals forces. These aggregates can lead to reduced stability and electrical conductivity, hence the need to break the agglomerates.

6.2.2 Measurement of Electrical Conductivity

CON700 conductivity meter was used to measure electrical conductivity (EUTECH instruments). The CON700 conductivity meter is comprised of an electrode with a nominal cell constant of k = 1.0, built-in temperature sensor, and 1 m cable. The electrode design offers fast temperature response and reduces air entrapment, ensuring accurate, repeatable, and stable readings. Measurements were taken at temperatures ranging from 15–60 °C at 5 °C intervals. This temperature control was done using a temperature control bath. The conductivity meter was initially calibrated at room temperature with a 1413 μS standard fluid from the supplier.

Fig. 6.1 Nanosphere particle size distribution



6.3 Results and Discussion

6.3.1 XRD and Stability of Nanofluid

The graphitization and crystallinity of the synthesized nanospheres is studied through XRD analysis. Figure 6.2 is the XRD results which shows two Bragg diffraction peaks at 30.34° and 50.44°. These peaks can be assigned to typical graphite (003) and (101) planes [35]. The d-spacing calculated is 0.342 nm which is close to graphite 3R given as 0.340 nm. The broadening peaks suggest a low graphitization degree and the possibility of the presence of amorphous carbon. These results fall in the range of values from authors [36] and [37] with d-spacing of 0.33 nm and 0.36 nm respectively. No other peaks are visible in the XRD pattern, which could be due to the high purity of the product.

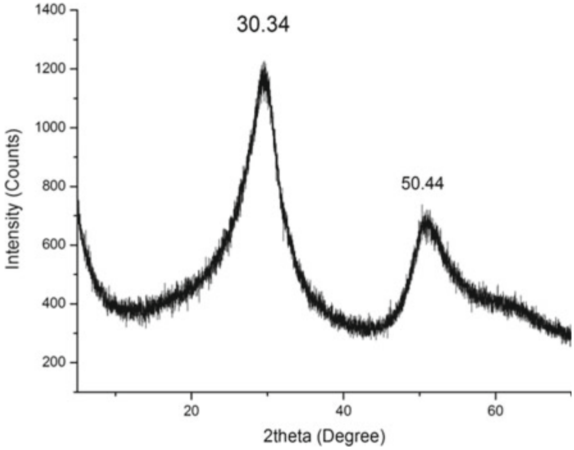


Fig. 6.2 XRD pattern of carbon nanospheres synthesized at 1100 °C

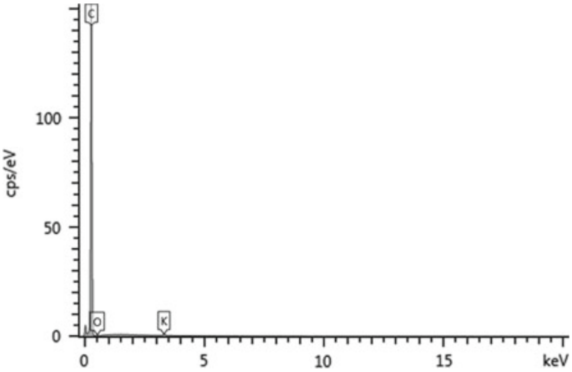


Fig. 6.3 EDX of CNS

Figure 6.3 confirms the purity of the material with a well-defined presence of carbon (98.59%) with a trace of oxygen and potassium.

The stability of the green nanofluids was determined by observing the viscosity at a constant temperature (20 °C) for 720 min. Figure 6.4 is the result of the observation from stability of nanofluids which shows that the viscosity values were hardly changed for the whole duration. This is an indication that the fluids were stable for more than 720 min which is more than sufficient time to take the electrical conductivity measurements. It was therefore determined that a ratio of 1:3.5 CNS/GA gave a good stability and this ratio was maintained throughout this study.

6.3.2 *Electrical Conductivity Evaluation*

Temperature effects on the electrical conductivity of prepared green nanofluids from coconut fibre nanosphere are shown in Fig. 6.5. The results indicate the dependence

Fig. 6.4 Stability test using viscosity at a constant temperature for 720 min

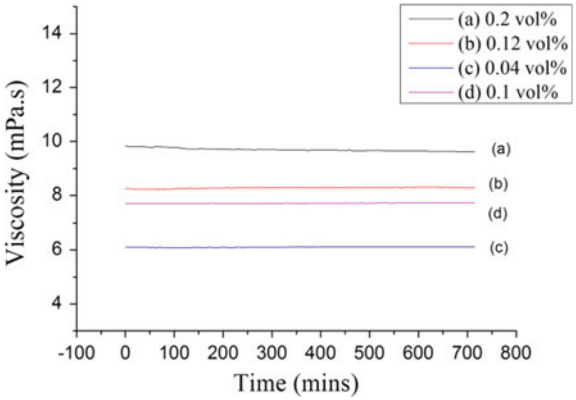
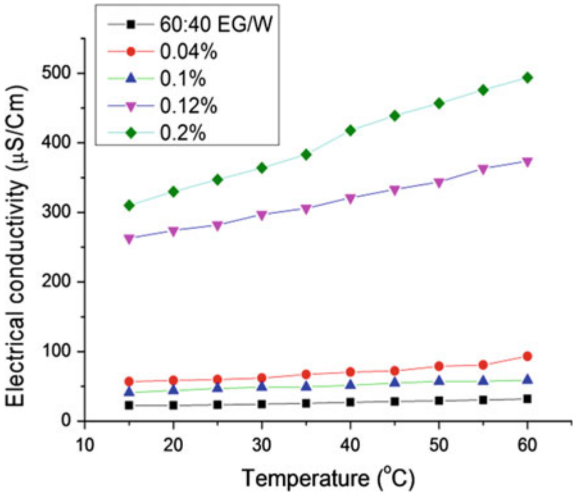


Fig. 6.5 Electrical conductivity at different temperatures for different volume concentrations



of electrical conductivity on temperature. From Fig. 6.6 the effect of the nanosphere volume concentration on the electrical conductivity is reported. The result reveals that an increase in the nanosphere loading impacted greatly on the electrical conductivity as this led to a change in the ionic configuration [38].

At 0.2% volume fraction, the highest electrical conductivity was observed at all temperatures. This is in line with results from recent studies on nanofluids electrical conductivity [38]. With an increase in particle volume concentration, the availability of conducting pathways is increased in the nanofluids consequently leading to a rise in electrical conductivity.

The electrophoretic mobility in nanofluids is also increased when it is stable thereby reducing equivalent particulate masses resulting in an increased electrical conductivity [12]. It is therefore safe to say increasing the temperature of nanofluids

Fig. 6.6 Electric conductivity at various mass fractions

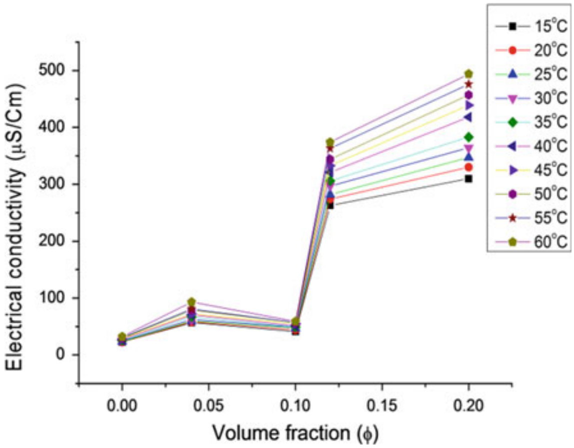
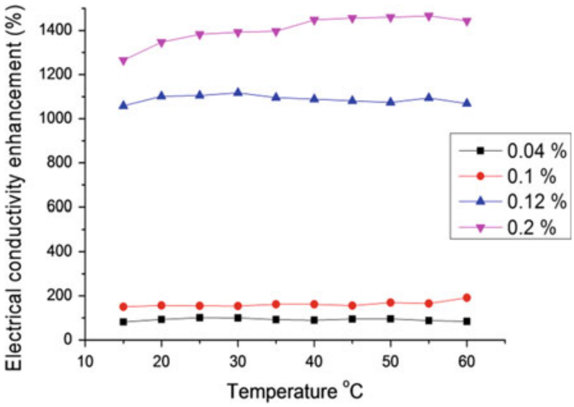


Fig. 6.7 Electrical conductivity enhancements at various temperatures for different volume concentrations

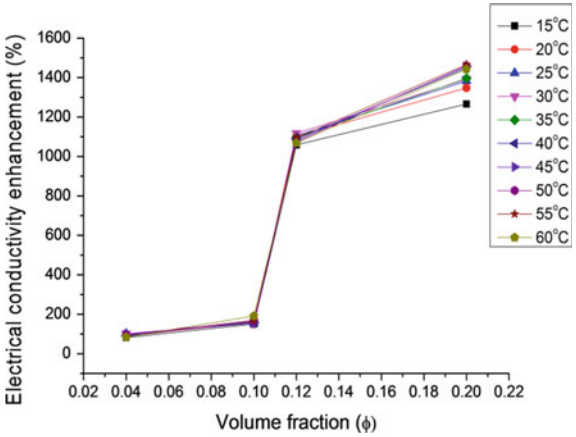


reduces the equivalent particulate masses and increases the electrophoretic mobility. The enhancement in electrical conductivity was calculated based on Eq. 6.3 [13]:

$$\frac{\sigma_{nf} - \sigma_{bf}}{\sigma_{bf}} \times 100 \tag{6.8}$$

where σ_{nf} is the nanofluids electrical conductivity and σ_{bf} is the base fluid electrical conductivity. From Figs. 6.7 and 6.8, the percentage enhancement in electrical conductivity increases with an increase in temperature and volume fraction. At 0.04 vol% an enhancement of about 100% is seen while an enhancement of 1470% is observed at 55 °C for 0.2 vol%.

Fig. 6.8 Electrical conductivity enhancement at different volume fractions



6.4 Conclusion

This study presents the results on the electrical conductivity behavior of green nanospheres synthesized from coconut fibre dispersed in 60:40 EG/W and 1:3.5 nanosphere/GA. The measurement of electrical conductivity was varied with volume concentration and temperature. The results obtained show an improved electrical conductivity with increase in temperature and volume concentration. At 0.2 vol%, a maximum electrical conductivity of 1470% was achieved at a temperature of 55 °C. The results presented show the potentials of carbon nanosphere-based green nanofluids as heat transfer fluid for cooling applications. Due to its less toxic nature, it can also be used in applications where human contact is required.

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References

1. B. Orhevba, M. Umaru, I.A. Garba, B. Suleiman, M.U. Garba, N. Ernest, Synthesis of composite biomass briquettes as alternative household fuel for domestic application, in *Proceedings of the World Congress on Engineering and Computer Science 2016, WCECS 2016*, 19–21 October 2016, San Francisco, USA. Lecture Notes in Engineering and Computer Science (2016), pp. 696–700
2. J.D. Bayani, J.R.M.D. Pena, E.R. Magdaluyo Jr., Infrared spectra and mechanical properties of corn oil-based polyurethane reinforced with silica nanoparticles from rice husk ash, in *Proceedings of the World Congress on Engineering 2016, WCE 2016*, 29 June–1 July 2016, London, U.K. Lecture Notes in Engineering and Computer Science (2016), pp. 998–1002
3. V. Makarov et al., "Green" nanotechnologies: synthesis of metal nanoparticles using plants. Acta Naturae (англоязычная версия) **6**(1)(20) (2014)

4. C. Buzea, I.I. Pacheco, K. Robbie, Nanomaterials and nanoparticles: sources and toxicity. Biointerphases **2**(4), MR17-MR71 (2007)
5. R. Kumar, R.K. Singh, D.P. Singh, Natural and waste hydrocarbon precursors for the synthesis of carbon based nanomaterials: graphene and CNTs. Renew. Sustain. Energy Rev. **58**, 976–1006 (2016)
6. M.R. Islam, B. Shabani, G. Rosengarten, Electrical and thermal conductivities of 50/50 water-ethylene glycol based TiO_2 nanofluids to be used as coolants in PEM Fuel cells. Energy Procedia **110**, 101–108 (2017)
7. H. Konakanchi, R. Vajjha, D. Misra, D. Das, Electrical conductivity measurements of nanofluids and development of new correlations. J. Nanosci. Nanotechnol. **11**(8), 6788–6795 (2011)
8. J.W. Pratt, L.E. Klebanoff, K. Munoz-Ramos, A.A. Akhil, D.B. Curgus, B.L. Schenkman, Proton exchange membrane fuel cells for electrical power generation on-board commercial airplanes. Appl. Energy **101**, 776–796 (2013)
9. S.I. Smedley, *The Interpretation of Ionic Conductivity in Liquids* (Springer Science & Business Media, 2012)
10. H. Semat, R. Katz, *Physics, Chapter 28: Electrical Conduction in Liquids and Solids* (1958)
11. I. Nurdin, Satriananda, Investigation on electrical conductivity enhancement of water based maghemite (γ-Fe_2O_3) nanofluids. Int. J. Mater. Sci. Appl. J. **6**, 32–36, Art. no. 1 (2017)
12. M. Zawrah, R. Khattab, L. Girgis, H. El Daidamony, R.E.A. Aziz, Stability and electrical conductivity of water-base Al_2O_3 nanofluids for different applications. HBRC J. **12**(3), 227–234 (2016)
13. T.T. Baby, S. Ramaprabhu, Investigation of thermal and electrical conductivity of graphene based nanofluids. J. Appl. Phys. **108**(12), 124308 (2010)
14. M. Kole, T. Dey, Investigation of thermal conductivity, viscosity, and electrical conductivity of graphene based nanofluids. J. Appl. Phys. **113**(8), 084307 (2013)
15. K. Yan, Q. Xue, Q. Zheng, L. Hao, The interface effect of the effective electrical conductivity of carbon nanotube composites. Nanotechnology **18**(25), 255705 (2007)
16. I. Tan, A. Ahmad, B. Hameed, Preparation of activated carbon from coconut husk: optimization study on removal of 2,4,6-trichlorophenol using response surface methodology. J. Hazard. Mater. **153**(1), 709–717 (2008)
17. A. Nieto-Márquez, R. Romero, A. Romero, J.L. Valverde, Carbon nanospheres: synthesis, physicochemical properties and applications. J. Mater. Chem. **21**(6), 1664–1672 (2011)
18. H.-S. Qian, F.-M. Han, B. Zhang, Y.-C. Guo, J. Yue, B.-X. Peng, Non-catalytic CVD preparation of carbon spheres with a specific size. Carbon **42**(4), 761–766 (2004)
19. Y.Z. Jin et al., Large-scale synthesis and characterization of carbon spheres prepared by direct pyrolysis of hydrocarbons. Carbon **43**(9), 1944–1953 (2005)
20. J.-Y. Miao et al., Synthesis and properties of carbon nanospheres grown by CVD using Kaolin supported transition metal catalysts. Carbon **42**(4), 813–822 (2004)
21. M. Ibrahim Mohammed, R. Ismaeel Ibrahim, L.H. Mahmoud, M.A. Zablouk, N. Manweel, A. Mahmoud, Characteristics of carbon nanospheres prepared from locally deoiled asphalt, in *Advances in Materials Science and Engineering*, vol. 2013 (2013)
22. X. Yu et al., Synthesis of activated carbon nanospheres with hierarchical porous structure for high volumetric performance supercapacitors. Electrochim. Acta **182**, 908–916 (2015)
23. Y. Wang, F. Su, C.D. Wood, J.Y. Lee, X.S. Zhao, Preparation and characterization of carbon nanospheres as anode materials in lithium-ion secondary batteries. Ind. Eng. Chem. Res. **47**(7), 2294–2300 (2008)
24. N. Katcho et al., Structure of carbon nanospheres prepared by chlorination of cobaltocene: experiment and modeling. Phys. Rev. B **77**(19), 195402 (2008)
25. P. Zhang, Z.-A. Qiao, S. Dai, Recent advances in carbon nanospheres: synthetic routes and applications. Chem. Commun. **51**(45), 9246–9256 (2015)
26. A.A. Arie, H. Kristianto, M. Halim, J.-K. Lee, Biomass based carbon nanospheres as electrode materials in lithium ion batteries. ECS Trans. **66**(11), 13–19 (2015)
27. H. Kristianto, C.D. Putra, A.A. Arie, M. Halim, J.K. Lee, Synthesis and characterization of carbon nanospheres using cooking palm oil as natural precursors onto activated carbon support. Procedia Chem. **16**, 328–333 (2015)

28. X.-W. Chen, O. Timpe, S.B. Hamid, R. Schlögl, D.S. Su, Direct synthesis of carbon nanofibers on modified biomass-derived activated carbon. Carbon **47**(1), 340–343 (2009)
29. J. Zhu, J. Jia, F.L. Kwong, D.H.L. Ng, S.C. Tjong, Synthesis of multiwalled carbon nanotubes from bamboo charcoal and the roles of minerals on their growth. Biomass Bioenerg. **36**, 12–19 (2012)
30. H. Li, X. He, Y. Liu, H. Yu, Z. Kang, S.-T. Lee, Synthesis of fluorescent carbon nanoparticles directly from active carbon via a one-step ultrasonic treatment. Mater. Res. Bull. **46**(1), 147–151 (2011)
31. J.O. Alves, C. Zhuo, Y.A. Levendis, J.A. Tenório, Catalytic conversion of wastes from the bioethanol production into carbon nanomaterials. Appl. Catal. B **106**(3), 433–444 (2011)
32. K. Shi, J. Yan, E. Lester, T. Wu, Catalyst-free synthesis of multiwalled carbon nanotubes via microwave-induced processing of biomass. Ind. Eng. Chem. Res. **53**(39), 15012–15019 (2014)
33. A. Melati, E. Hidayati, Synthesis and characterization of carbon nanotube from coconut shells activated carbon. J. Phys. Conf. Ser. (IOP Publishing) **694**(1), 012073 (2016)
34. G.A. Adewumi, N. Revaprasadu, A.C. Eloka-Eboka, F. Inambao, C. Gervas, A facile low-cost synthesis of carbon nanosphere from coconut fibre, in *Proceedings of the World Congress on Engineering and Computer Science 2017, WCECS 2017*, 25–27 October 2017, San Francisco, USA. Lecture Notes in Engineering and Computer Science (2017), pp. 577–582
35. P. Debye, P. Scherrer, Interference on inordinate orientated particles in X-ray light. III. Physikalische Zeitschrift **18**, 291–301 (1917)
36. A. Nath, D.D. Purkayastha, M. Sharon, C.R. Bhattacharjee, Catalyst free low temperature synthesis and antioxidant activity of multiwalled carbon nanotubes accessed from ghee, clarified butter of cow' s milk. Mater. Lett. **152**, 36–39 (2015)
37. A.D. Faisal, A.A. Aljubouri, *Synthesis and Production of Carbon Nanospheres Using Noncatalytic CVD Method*
38. S.A. Adio, M. Sharifpur, J.P. Meyer, Investigation into effective viscosity, electrical conductivity, and pH of γ-Al2O3-glycerol nanofluids in Einstein concentration regime. Heat Transf. Eng. **36**(14–15), 1241–1251 (2015)