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Experimental investigation of conduction and convection heat transfer properties of a novel nanofluid based on carbon quantum dots

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ABSTRACT

So far, many studies have been conducted on heat transfer nanofluids and various nanofluids have been synthesized and evaluated by different nanoparticles. In the present research, the use of biodegradable carbon quantum dots (CQDs) to synthesize heat transfer nanofluids was investigated for the first time. In fact, CQDs are a new generation of carbon nanoparticles and one of the advantages of which is their very small size that facilitates the prepared of nanofluids at very low concentrations with high stability. In the present research, CQDs were synthesized based on microwave method using commercial ammonium hydrogen-citrate as precursor. The nanofluid samples were synthesized based on car radiator coolant and CQDs at the concentrations of 100, 200, 500, and 1000 ppm. Thermal conductivity (k) and convection heat transfer (h) coefficients were investigated as the main features of the fluid's heat transfer characteristics. The obtained results for 200-ppm concentration indicated the improvement of k and h by 5.7% and 16.2%compared to the base fluid, respectively. Besides, the synthesized nanofluids had also significant stability and very low cost which are of great importance for industrial applications. Finally, the heat transfer process in the 200-ppm nanofluid was simulated by Ansys Fluent software.

1. Introduction

Nanofluids are the suspensions obtained by mixing solid nanoparticles with a liquid fluid, which could improve the properties or lead to novel properties. Over the past two decades, numerous scientific studies have been conducted on nanofluids [1–27]. The general objective of these studies has been to investigate the effect of various carbon, metal, metal oxide, and polymer nanoparticles, such as Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Cu, Au, Fe, C_{60}, MWCNT, SWCNT, graphene, etc., on various fluids such as water, ethylene glycol, lubricant oils, liquid fuels, as well as a variety of heat transfer fluids. Although significant progress has been achieved of in this field, there are concerns on the potential risks of the products and applications of this technology [28–32]. Since metal and metal oxide nanoparticles might have toxic effects on the environment, the use of biodegradable carbon nanoparticles can partly reduce such concerns.

Carbon quantum dots, as a new generation of carbon nanoparticles, have exhibited a great potential for being used as multi-purpose nanomaterials for a wide range of applications. CQDs are a newly emerged class of carbon nanomaterials that have gained much interest among researchers. Beside fluorescent and optical properties, CQDs have favorable advantages such as low toxicity, environmentally friendly, low cost, and simple synthesis methods [33–36]. Furthermore, the possibility of passivation and surface functionalization of CQDs facilitates controlling their physicochemical properties. Since being accidently discovered by Xu et al. [37] during separation and purification of single-walled nanotubes, CQDs have found several applications in the fields of chemical sensors, biosensors, biological imaging, nano-medicine, photocatalyst, and electrical catalysts [38–42].

Among the challenges in the field of nanofluids, lack of long-term stability, base fluid properties variations, high cost of nanomaterials, and possible environmental risks can be mentioned. Thus, the present research is aimed to introduce the biodegradable carbon quantum dots as a new type of nanoparticles to overcome the problems of nanofluids. Accordingly, for the first time in the present research, biodegradable carbon quantum dots was used to synthesize heat transfer nanofluids

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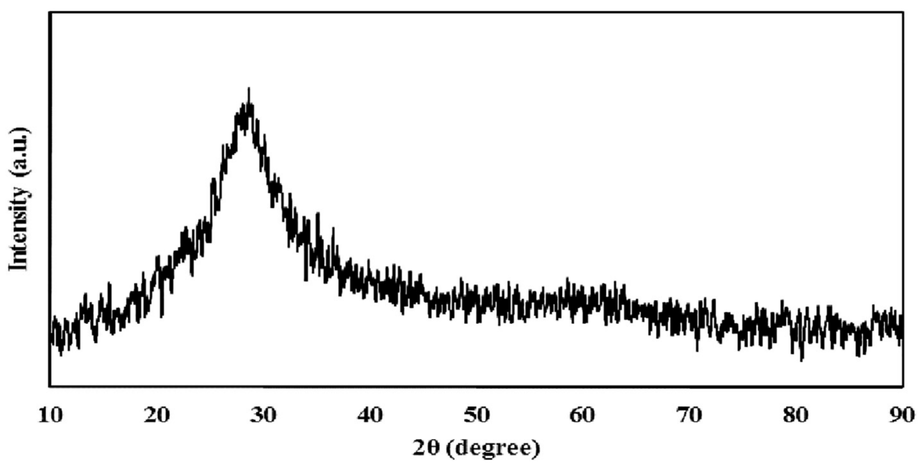

Fig. 1. X-ray diffraction (XRD) pattern of CQDs.

and the heat transfer capability of the radiator coolant-CQDs nanofluids was investigated.

2. Material and methods

2.1. Synthesis and characterization of CQD nanoparticles

First, the CQD nanoparticles were synthesized using microwave method. For this purpose, 2 g of commercial ammonium hydrogen-citrate precursor ($C_6H_{14}N_2O_7$) was completely dissolved in 10 mL of deionized water. Then, the suspension was put into a domestic microwave at 180 °C for 8 min. After the completion of reaction, the obtained dried product was cooled down to ambient temperature. The final product contained 1.65 g of CQDs collected from the reaction container. The X-ray powder diffraction (XRD) of the synthesized CQDs is shown in Fig. 1, which indicates the amorphous nature along with very low crystallinity of CQDs. Fig. 2 shows the infrared spectrum of CQDs, which has a completely different pattern from bulk graphite or other merely carbonic structures. With regard to the presence of oxygen and nitrogen heteroatoms in the structure of CQDs, the absorptions associated with tensile and bending vibrations special for the bonds formed between carbon and heteroatoms are predictable. With regard to Fig. 2, the absorption band of 1730 cm^{-1} region is related to C═O tensile vibration. Wide absorption in 2700–3600 cm^{-1} region is due to the presence of O—H groups related to HO—C═O or C-OH; however, it seems that the N—H tensile absorption has also been overlapped in this region. Specification absorption of C—O has also appeared in 1192 cm^{-1} region corresponding to tensile C—N bond. Tensile absorptions related to C═C and N—H bending are also observed in 1635–1680 cm^{-1} region.

Also, spectrum of the CQDs' emission under 360-nm excitation wavelength is shown in Fig. 3. As can be seen, the emission wavelength at around 460 nm, is in the range of blue spectrum. The image specified at the right corner of Fig. 3 represents the fluorescence property of CQDs compared to the base solvent (deionized water) under UV lamp with wavelength of 365 nm.

The size of CQD nanoparticles was investigated using DLS and HRTEM tests. Figs. 4 and 5 show the results of DLS test and HRTEM imaging of the CQDs, respectively. As can be seen, the mean size of the synthesized nanoparticles is estimated to be about 1.5 ± 0.5 nm.

2.2. Preparing CQDs nanofluids

In the present research, the CQDs-based nanofluid samples were synthesized using the car radiator coolant (CRC) used in the vehicles as the base fluid. In fact, due to the importance of heat transfer in vehicles and internal combustion engines (ICE), one of the objectives of the present research was to improve heat transfer capability of radiator coolant. The radiator coolant was prepared by mixing Caspian Antifreeze (Foumanchimie-under licence of Caspian International Ltd. England) and distilled water at the ratio of 1:1. The CRC-CQDs nanofluid samples were synthesized at four different nanoparticle concentrations, including 100, 200, 500, and 1000 ppm. The nanoparticles within the base fluid were stabilized using merely the bath ultrasonic (P120h. Elmasonic. Germany) and no chemical surfactant was used. For this purpose, a certain amount of CQDs was added to the base fluid and, then, the sample container was put in the bath ultrasonic at the frequency of 37 KHz for 5 min.

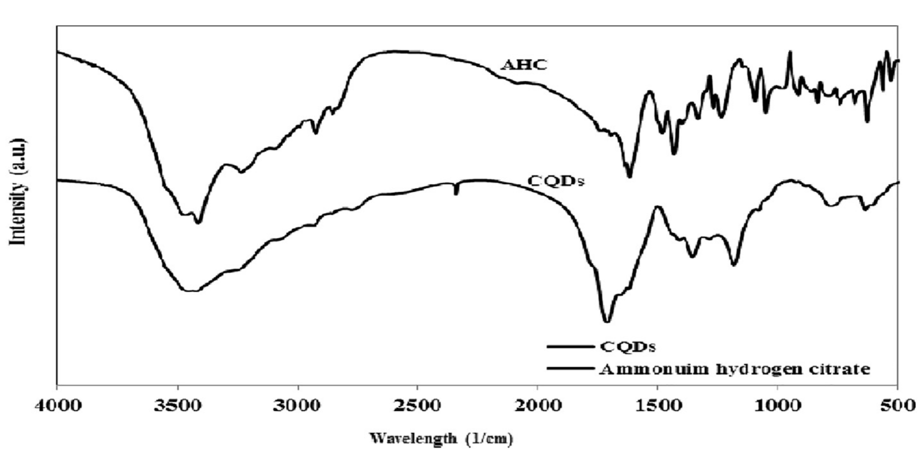

Fig. 2. Infra-red spectra of CQDs and ammonium hydrogen citrate.