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# Preparation and investigation of the heat transfer properties of a novel nanofluid based on graphene quantum dots

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ABSTRACT

In the present research, the biocompatible graphene quantum dots were used to prepare heat transfer nanofluids for the first time. Graphene quantum dots are a new generation of carbon nanoparticles capable of being synthesized from biodegradable and non-toxic resources. In this research, graphene quantum dots were produced by hydrothermal method using citric acid and urea as precursor. Nanofluid samples were synthesized based on car radiator coolant and graphene quantum dots at very low concentrations including 100, 200, 500, and 1000 ppm. One of the advantages of the graphene quantum dots was their long-term stability within the base fluid without using any chemical surfactants. In order to investigate the nanofluids' heat transfer properties, thermal conductivity (k) and convection heat transfer (h) coefficients of the samples were measured. The results for 100 ppm concentration indicated 5.2% and 17% improvement of k and h, compared to the base fluid, respectively. Further, the results demonstrated that the nanofluids containing graphene quantum dots had better stability and performance at low concentrations. Thus, it can be concluded that heat transfer nanofluids based on graphene quantum dots not only reduce probable environmental risks, but also are economically appropriate options for industrial applications; leading to reducing the energy consumption.

## 1. Introduction

These days, the issue of energy has become a key issue in the world. High and growing costs of fossil fuels and concerns about the problem of depletion of these non-renewable resources have made the owners of large industries make great efforts to find solutions to the reduction of energy consumption and improve its efficiency. Advanced materials and nanomaterials have found applications in the area of energy including the sectors of generation, storage, and saving. For example, in the sector of energy saving one can mention the issues of nanofluids in which reduction in the volume of heat exchanger and also in the consumption of energy. Although significant progress has been achieved in the field of nanofluids, there are still some problems. Actually, development of nanotechnology and its various applications have caused inevitable interactions between nanomaterials and the environment. Most of the studies have indicated the positive effects of nanoparticles on the physicochemical function of different systems and; on the other hand, the concerns resulted from the emission of different metal and metal oxide nanoparticles in the environment are expressed [1]. In fact, since common metal and metal oxide nanoparticles can remain in different environments for a long time without any physicochemical changes [2], there are many concerns on their potential risks for human health as well as the environment [3]. Hristozov and Malsch [4] studied the hazards of engineered nanoparticles for the environment and human health. Also, Joo and Zhao [5] reviewed the factors that affect the fate, transformation and toxicity of metal oxide nanoparticles.

Nanotechnology is making rapid progress and has entered many scientific fields. In this regard, one of the most applicable fields of nanotechnology is the improvement of fluids' heat transfer properties [6]. The heat-transfer processes have an effective role in most of the industries, represented in the air conditioning, energy generation, solar collector and chemical processors. For instance, Balaji et al. [7] used nanofluids to improve performance of air conditioning systems. Li et al. [8] employed to improve efficiency of solar collectors and increase the energy generation rate. Also, Anin Vincely and Natarajan [9] conducted experimental studies on the performance of flat plate collectors using graphene oxide-containing nanofluids. They dispersed graphene oxide nanoparticles in deionized water at three different concentrations and, then, measured thermal properties of the produced nanofluids. The results demonstrated that use of nanofluids led to an increase of 7.3% in

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efficiency of the collectors. Sonawane et al. [10] used $Al_2O_3$-Fuel nanofluids to improve performance of aviation turbines.

So far, researchers have been attempting to produce stable nanofluids with high capability of heat transfer based on different nanoparticles. Sarsam et al. [11] investigated effect of various chemical surfactants, including sodium dodecyl benzene sulfonate (SDBS), sodium dodecyl sulfate (SDS), cetyltrimethylammonium bromide (CTAB), and gum Arabic (GA), on the stabilization of the graphene nanoplatelets in water. They used ultrasonic to homogenize the nanofluid. The obtained results showed that the sample containing SDBS surfactant with the ratio of 1:1 and ultrasonic duration of 60 min had good stability for 60 days. Leela Vinodhan et al. [12] produced a nanofluid based on water and copper oxide (CuO) nanoparticles and, then, investigated its heat transfer performance in a U-shaped tube. The results showed that the nanofluid' heat transfer rate and the Nusselt number were higher than those of pure water. Also, Hemmat et al. [13] experimentally investigated thermophysical properties of the nanofluid based on water and silver (Ag) nanoparticles. Although they did not use surfactants to stabilize the nanoparticles within the base fluid, the sample underwent ultrasonic waves with power of 400 W for 3 h. The obtained results indicated the 11.8% increase in the Nusselt number at volume concentration of 1%. Imani-Mofrad et al. [14] applied the nanofluid based on water and zinc oxide (ZnO) nanoparticles to improve thermal performance of a wet cooling tower. They added the nanoparticles to water at concentration of 0.02–0.1 wt%, the results of which indicated the improved performance of the wet cooling tower using the nanofluid. In another study, Umer Ilyas et al. [15] investigated stability and thermal properties of the nanofluids based on thermal oil and alumina ($Al_2O_3$) nanoparticles in advanced cooling systems. They used oleic acid to stabilize alumina nanoparticles within the base oil. Furthermore, Ettefaghi et al. [16] studied thermal and rheological properties of the nanofluids based on engine oil and various carbon nanoparticles, including carbon nanotubes, graphene, carbon nanoball, and fullerene. They also used probe ultrasonic to stabilize the nanoparticles within the base fluid, the results of which indicated an increase of 18% in thermal conductivity coefficient of the carbon nanoball particles-containing nanofluid. Also, few studies have been conducted on the car radiator coolant (CRC) nanofluids based on different nanoparticles. Muhammad Ali et al. [17] used zinc oxide nanoparticles to improve performance of car radiator. They added the nanoparticles to water at concentrations of 0.01, 0.08, 0.2 and 0.3 vol% and, then, investigated the radiator's heat transfer performance using the produced nanofluids. The obtained results indicated improvement of 46% in the heat transfer coefficient for the nanofluid containing 0.2% volumetric concentration nanoparticles compared to the base fluid. In another work, Sandhya et al. [18] added titanium dioxide ($TiO_2$) nanoparticles at different concentrations to a mixture of water and ethylene glycol; afterwards, the convection heat transfer ability of the nanofluids was measured on a car radiator, the results of which indicated an increase of 37% in the heat transfer rate using the nanofluids. Elias et al. [19] studied the thermo-physical properties of $Al_2O_3$ nanoparticles suspended in car radiator coolant; thermal conductivity, viscosity, density, and specific heat have been measured at different volume concentrations (i.e. 0–1 vol%) of nanoparticles and various temperature ranges (i.e. from 10 °C to 50 °C). They found that thermal conductivity, viscosity, and density of the nanofluid have increased with increasing the concentration of nanoparticles. However, specific heat of nanofluid was found to be decreased with the increase of nanoparticle volume concentrations. Also, the highest thermal conductivity enhancement was found to be 8.30% for 1 vol% of $Al_2O_3$–RC nanofluid. However, in general, the use of metal and metal oxide nanoparticles at high concentrations as well as chemical surfactants to stabilize the nanoparticles would have negative effects on the human health and environment. Besides, they would damage the mechanical systems, increase the costs and become non-cost-effective for industrial applications. Therefore, in the present research, it has been attempted to use biocompatible graphene quantum dots (GQDs), instead of common metal and metal oxide nanoparticles, to prepare high quality and cost-effective heat transfer nanofluids.

Graphene quantum dots have currently found increasing attention in wide range of biological applications [20] due to their unique properties and low cost of production. GQDs consist from single to ten-layered graphene sheets with lateral dimensions smaller than 100 nm with zero dimensions (0D) [21]. Further, GQDs provide special advantages such as low cytotoxicity, excellent solubility [22], good surface grafting properties, large surface area, robust chemical inertness, tunable band gap, quantum confinement and edge effects [23]. Therefore, GQDs have been extensively used in different fields. For instance, Li et al. [24] have reviewed the recent progress in GQD-based optoelectronics and energy devices, indicating the wide potential application of GQDs for development of communication and energy functional devices. Also, Zhang et al. [25] have considered the achievements obtained in energy and charge transfer devices such as fuel cells and light-emitting diodes via using GQDs. Zhu et al. [26] have used GQDs as biocompatible and low toxicity material for bioimaging. Chen et al. [27] have investigated the potential of GQDs for sensors with promise selectivity and response. However, to the best of our knowledge, the potential of GQDs for enhancing the properties of heat transfer nanofluids has not been explored. Hence, in this research, the properties of GQDs as additive in nanofluids have been investigated.

A variety of methods have been reported for synthesizing GQDs which can be divided to two main categories including "top-down" and "bottom-up" methods. In the "top-down" method, the carbonaceous materials are cut into graphene dots by hydrothermal treatment, chemical or electrochemical oxidation, electron beam, and microwave process [28]. In this regard, Lin and Zhang [29] have used an effective method based on intercalation and exfoliation of carbon nanotubes and graphite for synthesizing GQDs via "top-down" procedure. Moreover, Shinde and Pillai [30] have prepared GQDs from multiwall carbon nanotube by electrochemical method. However, the most important disadvantage of "top-down" method is expensive starting materials and extremely low reaction yields [31]. On the other hand, on the "bottom-up" method, GQDs are synthesized from organic compounds [32]. The "bottom-up" methods are efficient routes to produce fluorescent quantum dots in large scale [28]. Therefore, in this research, GQDs are synthesized via "bottom-up" method with high production yield.

The main aim of the present research is to introduce nanofluids that are environmentally friendly and cost-effective with high stability and suitable heat transfer capability which leads to energy conservation. Thus, GQDs were selected for the first time and their effects as nano additive on the properties of nanofluids were investigated. Also, the prepared GQDs were carbonized, activated, and functionalized. It should be mentioned that the main aim of activation process is to increase the specific surface area, enrich the pore structure, and enhance thermal stability and conductivity. Since the content of nitrogen and oxygen atoms would be reduced during carbonization and activation procedures, the products of activation method are functionalized (FGQDs) to improve their dispersibility in solvent [33]. In this regard, the synthesis of GQDs, the production of stable CRC-GQDs nanofluids, and heat transfer properties of the samples were studied.

## 2. Material and methods

As mentioned in Table 1, all chemicals used in this research were purchased from Sigma Aldrich or Merck and these chemicals were used without further purification. The steps of conducting the experiments are shown in Fig.1.

### 2.1. Synthesis of graphene quantum dots and functionalized graphene quantum dots

In this research, citric acid and urea were used as the precursor for the synthesis of GQDs. Accordingly, 0.21 g citric acid and 0.18 g urea