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Photothermal properties of graphene nanoplatelets nanofluid for low-temperature direct absorption solar collectors

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ABSTRACT

Today's population growth and increasing dependency of industry and technology on fossil energy encounters all countries and communities with challenge of energy for future. Hence researches about renewable energies, especially solar energy are considered. Among all types of solar systems, the optimization of direct absorption solar collector performance which the solar radiation received by the fluid medium, have been investigated. Since nanofluids are considered as an appropriate environment to absorb solar energy as well as increase in heat transfer coefficient, in present work, the morphological structure, the stability, the optical properties and thermal conductivity of nanofluid have been investigated by preparing nanofluid containing graphene nanoplatelets on the bases of deionized water by 0.00025, 0.0005, 0.001 and 0.005 wt%. Finally, by investigating the effect of weight percent and temperature of nanofluids on optical properties and thermal conductivity, this nanofluid with strong absorption band in the range of 250–300 nm as a suitable environment is offered to be used in direct absorption collectors.

1. Introduction

Since sun is available in most parts of the world it is considered as a source of renewable energy. The amount of solar energy absorbed by Earth's atmosphere, land surface and the ocean is about 4×10^{24} J per year, due to the amount of energy absorbed by the Earth during one hour it can provide energy consumption more than a year of a world [1]. In 1970s, there was an oil crisis and considerable researches have been done in relation to solar energy by various researchers [2]. In 1980s and 1990s, by reducing the oil crisis, the investigation slope went slower than the past, so that in recent years, according to the crisis of energy supply, again using solar energy as an attractive area is taken into attention of researchers. According to the investigation of the types of technologies of solar energy, it is clear that the conversion and use of photo-thermal are important because apart from using in heating systems [3], it is used in electricity generation [4] and chemical technologies [5]. In solar heating systems, collectors are the most important part in conversion of photo-thermal. Among all types of solar collectors, volumetric absorption or direct absorption collector have high efficiency due to the light from volume of fluid instead of limiting it to the surface and also receiving the heat emitted by the heated surfaces [6]. Among the benefits of volumetric absorptions in comparison with surface absorber, it can be noted that the solid particles suspended in suspension used in volumetric collectors are able to absorb the solar energy and since these particles are in contact with fluid, they transfer their receiving energy to the surrounding fluid. Existing particles in fluids cause increased levels that can absorb more energy and transfer convection heat [7]. A century ago, in order to increase heat transfer and thermo-physical properties of fluid, the idea of dispersing solid particles in fluid was discussed [8]. Nanofluid is the fluid containing metallic or non-metallic solid particles with an average diameter less than 100 nm. It should be noted that the term “nanofluids” was first used by Choi for a new group of fluids containing solid particles [9]. Studies show that nanofluids have better thermo-physical properties than basic fluids such as water or ethylene glycol and oil [10–12]. Another advantage of the nanoparticles is radiative properties of basic fluid and improving their ability to absorb radiant energy [13]. This advantage beside thermal properties causes that using nanofluids in direct solar absorption collectors is taken into attention [14–17]. Otanicar et al. [18] have done the first experimental study on direct absorption collectors by using nanofluids of graphite, carbon nanotubes and silver on the bases of water and the results showed that using nanofluids increase optical properties of fluid and it can also increase the efficiency of the solar collector to be about 5%. Taylor et al. [19] showed that in different situations nanofluids are able to absorb 95% of radiant energy by investigating the optical properties

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of nanofluids containing particles of graphite, gold, copper, aluminum and silver. Mu et al. [20] considered the importance of using nanofluid in volumetric collectors by using nanofluids of Titanium Oxide, Silicon Oxide, Zirconium Carbide on the bases of water. The results showed that using Zirconium Carbide nanoparticles in water has a significant impact in increasing the amount of solar energy compared with other nanofluids. In experimental study which Bandera et al. [21] have done by using silver nanoparticles in a direct absorption of solar, they concluded that nanofluids with the volume fraction of 6.5 ppm can increase system performance up to 144%. Liu et al. [22] with numerical and experimental study investigated the use of graphene in ionic fluid in direct absorption collector at high temperature. Their research results showed that receiver with weight percent of 0.0005 at a height of 5 cm of nanofluids and under radiation of $20 \times 1000\ \mathrm{W\,m^{-2}}$ at a temperature of 600 K has a performance of 0.7. Said et al. [23] showed that Titanium Oxide compared to Aluminum Oxide has a better optical properties by experimental measurements and investigating optical properties of nanofluids with metal oxide particles. Karami et al. [24] by introducing new applications of nanofluids containing Carbon Nanotubes in direct solar absorption collectors at low temperature investigate an optical properties of nanofluids and the results of their research showed that using these nanoparticles in volume fraction of 150 ppm will increase thermal conductivity up to 32%. Zhang et al. [25] introduced suitable nanofluid for using direct absorption collectors at medium to high temperature by investigating the optical properties of nanofluids on the bases of ionic fluid. Their research results show that nanofluids with the volume fraction of 10 ppm containing Nickel nanoparticles has better performance than nanofluids containing Copper with the same volume fraction. They also investigated nanofluid properties containing Carbon particles coated with Nickel compared to nanofluid containing pure Nickel concluded that nanofluids containing Carbon coated with Nickel in volume fraction of 40 ppm can absorb nearly 100% energy and has better performance than pure Nickel. Shende et al. [26] used nanofluids particles containing Multi-Walled Carbon Nanotubes and Graphene Oxide which is strengthened by nitrogen in order to use direct absorption collectors in low-temperature. Their research results show that using this type of particle in water with volume fraction of 0.02 percent increase 17.7 percent thermal conductivity and also using these particles in Ethylene Glycol with volume fraction of 0.03 percent increase up to 15.1 percent. Due to the importance of base fluid and suspended particles in a volumetric collectors or direct absorption, the optimization of solar collectors will happen by directly absorbed mechanism when suitable base fluid is used. Thus, the importance of using graphene nanoplatelets as an agent particle in water has been investigated.

2. Experimental method

2.1. Material and method of preparing nanofluids

Deionized water and graphene nanoplatelets with diameter less than 2 μm and the thickness of graphene nanoplatelets is 2 nm with the surface area of $750\mathrm{m}^2\ \mathrm{gr}^{-1}$ were used to produce nanofluids and provided by Grade C, XG Sciences, Inc., Lansing, MI, USA. Preparing stable nanofluids with uniform distribution is essential for measuring thermo-physical and radiative properties. Among the existing methods for preparing nanofluids, the two-step method is used. In this method, a certain amount of nanoparticles with 0.00025, 0.0005, 0.001 and 0.005 wt%. is dispersed by using ultrasonication probe (Q700 Sonicator, Qsonica, LLC.,USA) which has a power of 700 W and a frequency of 20 kHz in deionized water. Ultrasonic time length for making samples is an hour with power of 95% and for preventing extra heat of fluid, the mixture is alternately ultrasonic probe. In Fig. 1 the prepared samples are shown.

2.2. Method of investigating the properties

Two methods are used for analyzing materials and investigating the structure of prepared ones. One of the methods which was chosen to investigate the morphology of graphene nanoplatelets structure is the method of transmission electrons microscopes. This method used the transmission electrons microscopes (TEM,EM900, Zeiss,Germany), with an acceleration voltages of 80 kW. Fig. 2 shows the image of graphene nanoplatelets layer in specific surface area 750 $\mathrm{m}^2\ \mathrm{gr}^{-1}$. The graphene nanoplatelets include sheet-like structure with a lateral size at the micrometer length scale that is shown in Fig. 2 as well. The graphene nanoplatelets sheets only contain a few number of Graphene layers, which are compatible with the manufacturer parameters. When graphene nanoplatelets were dispersed by ultrasonic probe, the lateral size of graphene nanoplatelets was decreased. With nanofluids defined preparation method, the edges of GNP layers are clearly seen. The ultrasonic process tends to break the flake, therefore; the longer process time improves dispersion of nanoparticle in base fluid.

Another way which is used to evaluate chemical composition and crystalline structure of material is X-Ray Diffraction. In this way, X-Ray Diffraction (PANalytical, XPert Pro MPD,Netherlands) with an angle range of measure 0.6–157° is used. Fig. 3 shows the XRD pattern of Garphene Nanoplatelets. The maximum value of the peak in diagram is related to sample preparation and measurement equipment. The peak position appears at $2\theta = 26.31$, which is close to that of single crystalline graphite ($2\theta = 26.5$). This peak is different from turbostratic graphite ($2\theta = 25.8$). These results clearly demonstrate that this material possesses a crystalline structure.

There are several ways to assess the stability of prepared nanofluids: deposition methods, zeta potential and absorption spectrum method. Here zeta potential is used to seek stability of nanofluids. Zeta potential of nanofluid is measured, by using Zetasizer Nano devices (ZEN 3600, Malvern Instruments Ltd, UK). Optical properties and the

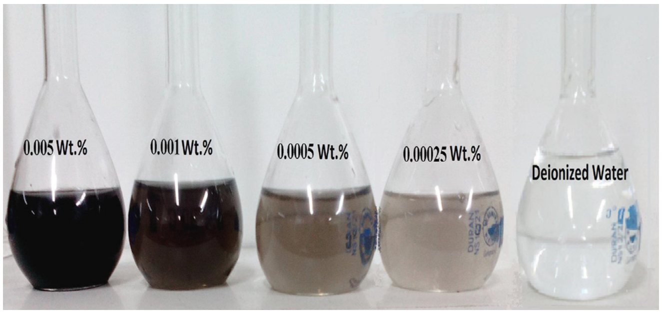

Fig. 1. Samples of the nanofluids by different weight percent.

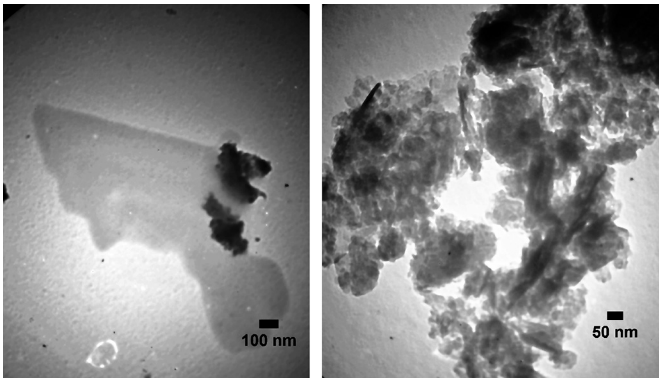

Fig. 2. TEM images of graphene nanoplatelets.