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### PHOTOTHERMAL CONVERSION USING GRAPHENE/WATER NANOFLUIDS

**Carolina Lau Lins Beicker**

Universidade Federal de Uberlândia. Av. João Naves de Ávila, 2121, Santa Mônica. Uberlândia-MG, Brasil  
carolina.beicker@ufu.br

**Enio Pedone Bandarra Filho**

Universidade Federal de Uberlândia. Av. João Naves de Ávila, 2121, Santa Mônica. Uberlândia-MG, Brasil  
bandarra@ufu.br

**Abstract.** *The dispersion of particles in the nanometer range - 1 to 100 nm - in a liquid medium, known as nanofluids, has been shown by several authors as an optimization alternative for conventional solar absorption systems and heat transfer systems due to its unique properties. The present study experimentally investigated the behavior of Graphene/Water nanofluids under realistic conditions of photothermal conversion using direct absorption solar collector (DASC). Nanofluids at low volumetric concentrations – 1 to 300ppm - were obtained by dilution and sonication process. An apparatus was built for the simultaneous exposure of different concentrations of nanofluids and the base fluid to solar radiation without any solar concentrating device. The results showed that nanoparticles have excellent photo-thermal conversion capacity, even at low concentrations, however, the Specific Absorption Rate (SAR) decreased with nanoparticle's addition to the base fluid. After ten hours of testing, the samples showed agglomeration and precipitation problems, a challenge for future applications.*

**Keywords:** *Nanofluids, Graphene, DASC, Photothermal Conversion.*

#### 1. INTRODUCTION

Usual fluids used in thermal systems, like water and ethylene-glycol have been very useful in energy generation. However, these fluids have limitations due to its relative low thermal conductivity. In this way, recently were developed techniques to produce a new class of fluids, called nanofluids. Nanofluids are colloidal dispersions where the solid particles are sized between and 100 nm (Choi 1995).

The main advantage of nanofluids is the enhanced thermal conductivity compared to base fluid. Thus, the principal studies involving nanofluids are related to the synthesis and characterization of thermal and transport properties, like thermal conductivity, viscosity and density (Li et al., 2009; Lee et al., 2010; Ghadimi et al., 2011; Ramesh e Prabu, 2011; Khanafer et al., 2011; Fan e Wang, 2011; Vajjha et al., 2012; Trisaksri et al., 2007).

Another characteristic of nanoparticle dispersions is the improvement of fluid's optical properties, like higher radiation absorption capacity and better energy storage ability.

These characteristics has motivated the search for applications of nanofluids as solar radiation absorbers, such as its use as working fluid in direct absorption solar collectors (DASC's). DASC's, known for having, instead of selective surfaces, transparent coating and a fluid responsible for the photothermal conversion, became promising substitutes to the traditional solar collector design, which has efficiency limitations due to heat loss in the absorbing surface with temperature rise. This substitution would lead to the reduction of the heat losses and consequently increasing device efficiency.

Natarajan et al. (2009) investigated the possibility of increasing efficiency of conventional solar water heaters using nanofluids as a heat transfer medium and concluded that nanofluids are more effective than conventional fluids. Otanicar et al. (2010) investigated experimentally the performance of solar thermal collectors using nanofluids as the absorption method, and concluded that it is possible an enhancement up to 5% in the collector efficiency.

The use of carbon-based nanoparticles has also been reported by many authors as great candidates for use in solar collectors due to their high spectral absorptivity over the entire solar range, good photothermal conversion efficiency even at low concentrations and the low cost compared with noble nanoparticle materials (He et al., 2011; Taylor et al., 2011a; Taylor et al. 2011b; Ladjevardi et al., 2013; Hordy et al., 2014; Sabiha et al., 2015; Delfani et al., 2016; Vakili et al., 2016).

To understand the influence of nanoparticle concentration in nanofluids used as direct absorbers of solar radiation, this work investigates Graphene/water samples at different volume fractions and its base fluid under realistic conditions, using natural solar radiation without concentration and exposing the samples to sunlight for about 10 hours. The influence of particle concentration on the photothermal conversion efficiency and the samples stability after test are also discussed.

## 2. EXPERIMENTAL PROCEDURE

The sonication process preceded by successive dilutions was the preparation method used to obtain eleven different volumetric concentrations (1-300ppm) of graphene nanoplatelets dispersed in distilled water. A concentrated graphene nanoplatelet-water paste (5-10 $\mu$ m, 50 layers,  $\phi$ =10 wt%) was bought and diluted to obtain the tested sample with higher concentration (300 ppm) and then, the sample was sonicated to guarantee the homogeneity of the obtained fluid. After the obtainment of the 300 ppm sample, by successive dilutions and sonication of each sample, lower concentrations samples were obtained.

To enable adequate solar exposure and test different volumetric concentrations of nanofluids and its base fluid it was built a support with capacity up to twelve test cells simultaneously, as shown in Fig. 1.

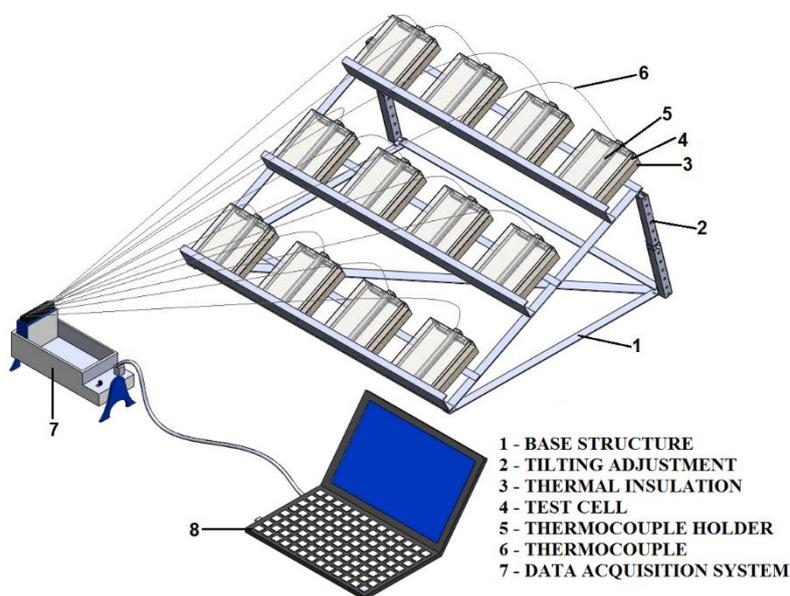


Figure 1. Schematic experimental bench.

The test cells are acrylic made and have dimensions according to Fig. 2, with the back surface thermally insulated from the surroundings and one thermocouple placed inside each container at the central position of the fluid volume to monitor the fluid heating process. Each test cell was filled with 100 ml of fluid and the temperature data was acquired at 1 Hz rate.

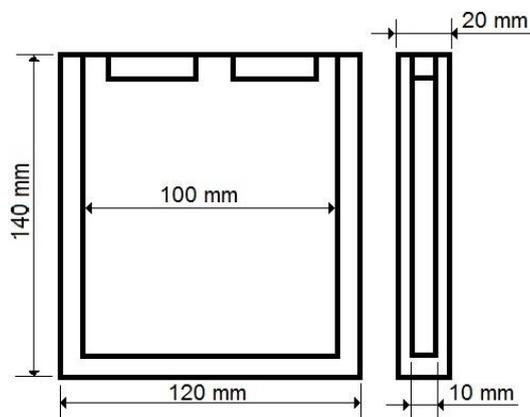


Figure 2. Acrylic containers used in the tests: views and dimensions.

The tested fluids were exposed to solar radiation according to the configuration exposed on Fig. 3 from 7AM to 5PM (GMT-3). The orientation and tilt angle adjustment of the system was made considering the geographic coordinates of the experimental bench location (18°55'23"S 48°17'19"W), according to ABNT NBR 15569:2008 standard for maximum collector efficiency on a whole year use installation.

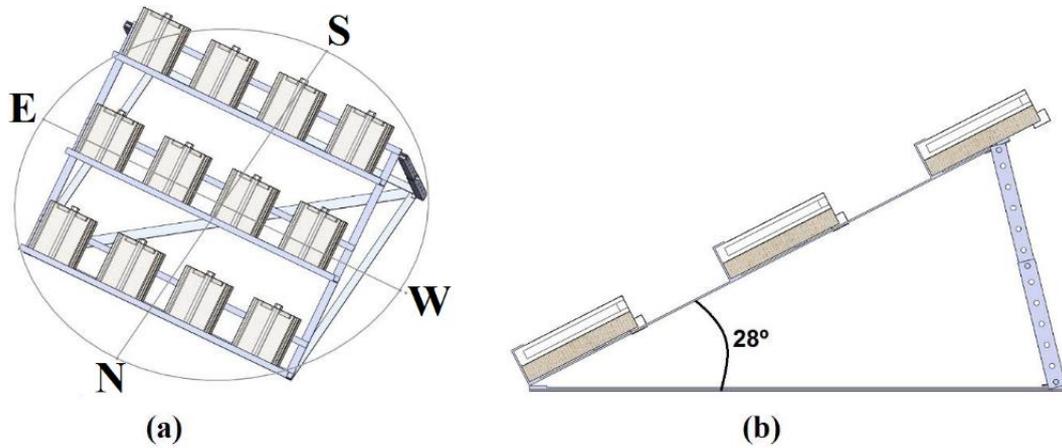


Figure 3. Experimental bench (a) orientation and (b) tilt angle.

The capacity of energy absorption by nanoparticles is well represented by the specific absorption rate, calculated as:

$$SAR = \frac{(m_{bf}c_{bf} + m_{np}c_{np})\Delta T_{nf} - m_{bf}c_{bf}\Delta T_{bf}}{1000m_{np}\Delta t} \quad (1)$$

Where:

- *SAR* - specific absorption rate (kW/g);
- *m*- mass (g);
- *c* - specific heat (kJ/g°C);
- $\Delta T$  - temperature variation (°C);
- $\Delta t$  - time variation (s);

And the subscripts:

- *bf* - base fluid (water);
- *np* - nanoparticle;
- *nf* - nanofluid.

Considering the diluted nature of the tested nanofluids,  $m_{np}c_{np} \ll m_{bf}c_{bf}$ . Then, the equation can be simplified as:

$$SAR = \frac{m_{bf}c_{bf}}{1000m_{np}} \left( \frac{\Delta T_{nf}}{\Delta t} - \frac{\Delta T_{bf}}{\Delta t} \right) \quad (2)$$

### 3. RESULTS AND DISCUSSION

For better visualization, the graph of temperature in function of the elapsed test time was divided in two parts: the lowest concentrations (1-20 ppm; 0,0001%-0,002% by vol.) and the highest concentrations (20-300 ppm; 0,002%-0,03% by vol.). Fig. 4 and Fig. 5 shows the results of the lowest and highest concentrations, respectively. It was observed a remarkable change in temperature of all nanofluids at the first hour of experiment and better results compared with distilled water. The heating behavior of graphene nanofluid with higher concentration (>0,003%) showed to be very similar, both temperature variation and maximum temperature.

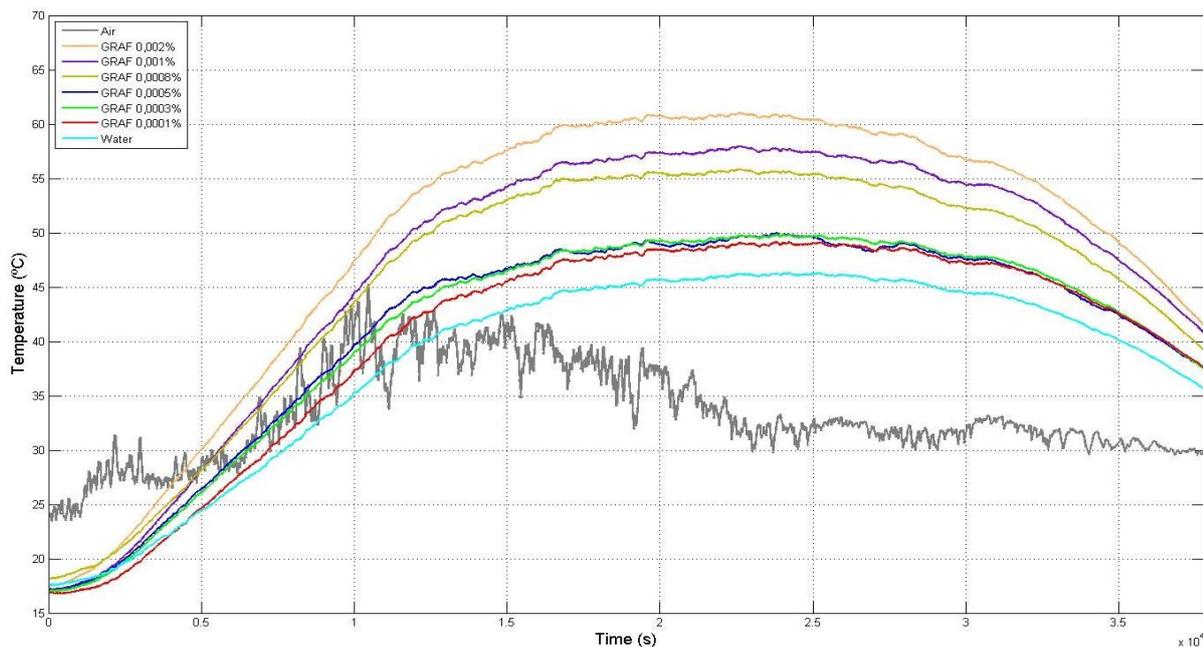


Figure 4. Temperature profile of water/graphene nanoplatelets nanofluids (1-20 ppm) and the base fluid.

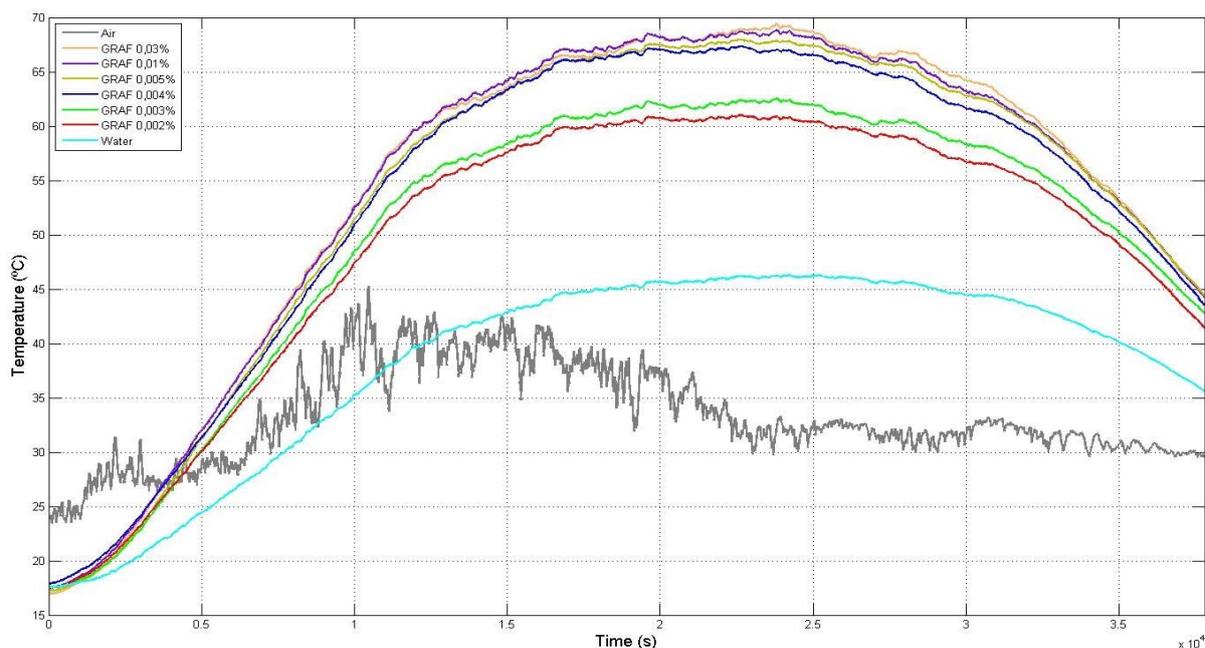


Figure 5. Temperature profile of water/graphene nanoplatelets nanofluids (20-300 ppm) and the base fluid.

The extreme temperature points of each tested fluid and the maximum temperature variation are presented in Tab. 1, showing that all nanofluids presented higher maximum temperature variation compared to the reached by the base fluid, varying from 12% (0,0001% by vol.) to 82% (0,03% by vol.) higher than distilled water.

Table 1 – Extreme temperature points and maximum temperature variation during day test.

$\phi_v$ (%)	Tmin (°C)	Tmax (°C)	$\Delta T_{max}$ (°C)
0,03	16,9	69,4	52,5
0,01	17,5	68,9	51,3
0,005	17,3	68,0	50,7
0,004	17,8	67,3	49,5
0,003	17,5	62,6	45,0

0,002	17,5	61,0	43,5
0,001	17,2	57,9	40,8
0,0008	18,1	55,8	37,7
0,0005	17,1	49,9	32,8
0,0003	17,0	49,8	32,8
0,0001	16,8	49,1	32,4
0 (Water)	17,6	46,3	28,7

Fig. 6 presents the maximum SAR values for each nanofluids volumetric concentrations tested, which was observed at the first minutes of testing. The lowest nanofluid concentration ( $\Phi_v = 0.0001\%$ ) showed the highest SAR value and the highest concentration ( $\Phi_v = 0.03\%$ ), the lowest value. The observed behavior implies that the difference between the temperature variation rate of nanofluids and water does not increase at the same ratio as the nanoparticle concentration and that the photothermal conversion capability per nanoparticle decreases at higher particle loadings.

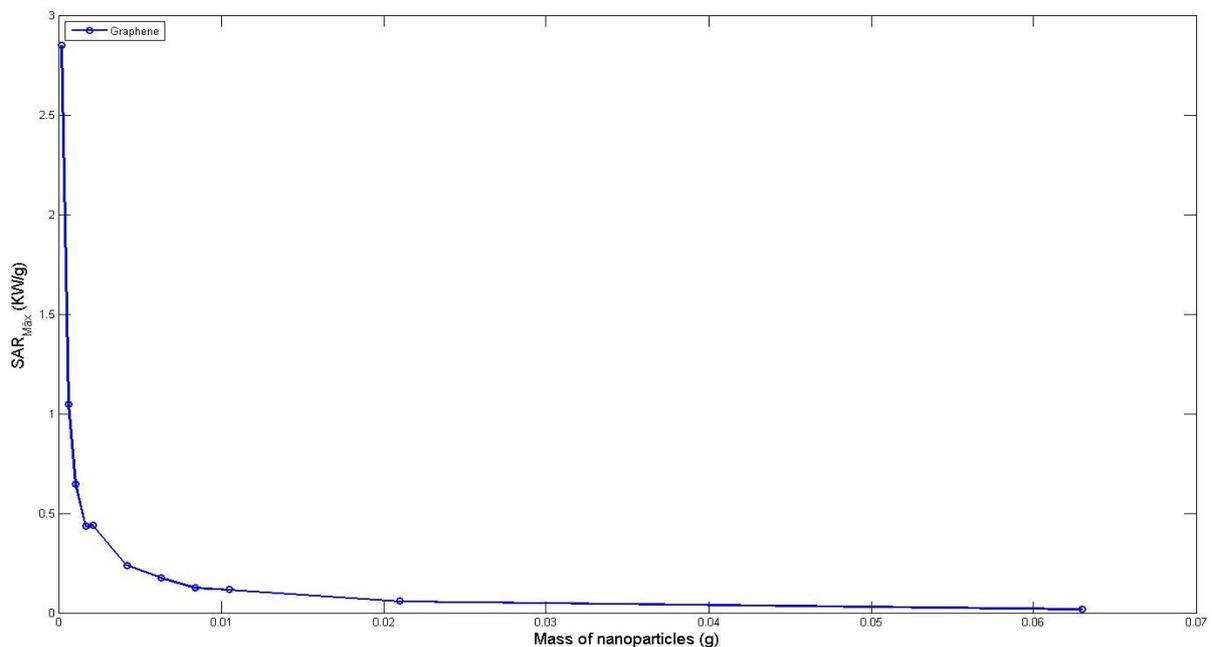


Figure 6. Specific Absorption Rate (SAR): maximum values for each volumetric concentration of graphene-nanoplatelets nanofluids in water

The decrease in the maximum SAR at higher nanoparticle loadings can be explained by two hypotheses:

- The existence of agglomerations in the nanofluid:
  - the increase in nanoparticle volumetric concentration could be just virtual, without a real increase in the amount of individual particles dispersed in the fluid;
  - agglomerations have higher surface area and, in their presence, the photothermal conversion process does not behave like occurs with individual nanoparticles.
- The increase in the number of nanoparticles near the collector surface:
  - at each fluid depth, the intensity of incident radiation on the fluid is different, decreasing along the radiation path;
  - with a great number of nanoparticles near the collector surface, a thin film of nanofluids receives almost all the incident radiation and the heat loss to the surrounding are intensified.

The samples were exposed to solar radiation for ten hours, what caused agglomeration and precipitation problems, as seen in Fig. 7 It is important to note that no chemical components were added in the nanofluids preparation and that sonication method was the only one applied to make the samples stable before the testing stage.



Figure 7. Agglomeration and precipitation problem observed in a nanofluid sample at the end of ten-hour solar radiation exposure.

#### 4. CONCLUSIONS

In this work nanofluids were experimentally investigated as volumetric receivers in solar collectors. The nanofluids showed a large potential to increase the radiation absorption and energy storage. It was found an increase of 82% in the maximum temperature variation for the nanofluid with higher concentration (300 ppm) compared to base fluid.

The effect of nanoparticle concentration were also investigated, and it was found that for concentrations higher than 30 ppm the temperature profile and the maximum SAR are very similar, suggesting that further increase does not provide results that could justify the higher costs.

The exposure of nanofluids samples to solar radiation for ten hours has caused agglomeration and precipitation problems, showing the need of further investigation about the influence of the production method, time of exposure and maximum temperature reached on the stability of the studied nanofluids.

#### 5. ACKNOWLEDGEMENTS

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