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Eco-friendly and low-cost nanofluid for direct absorption solar collectors

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A R T I C L E   I N F O

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A B S T R A C T

Nanofluids are promising receivers for solar collectors with volumetric absorption. These solar collectors are 1.2…1.4 times more efficient than conventional technology. However, most of the considered nanofluids are expensive and toxic. This work demonstrates how to treat instant coffee to produce inexpensive and environmentally friendly nanofluids for solar collectors. Our nanofluid contains particles with an average size below 100 nm. The nanofluid extinction coefficient is up to 300 1/m when 2% wt. of coffee is used. The toxicity of the nanofluid is of the same order as for the conventional coolants.

1. Introduction

Direct absorption solar collectors (DASC) use nanofluids for simultaneous absorption and transport of solar heat [1]. Due to the volumetric absorption of thermal radiation, the existing DASC prototypes are up to 1.4 times more efficient than solar collectors with surface absorption [2,3]. Various types of nanoparticles were tested in the prototypes: metal oxides [4], semiconductors [5], and noble metals [6]. Based on their performance data, we identify three main problems with the existing nanofluidic solutions for DASCs. The stability of the nanofluid is important in static conditions as most of the studied cases report agglomeration of nanoparticles in base fluids to sizes over 200 nm [6]. Due to the large density difference with the base, the metal-based nanofluids are least stable. However, the concentration of nanoparticles in the DASC is relatively low. Therefore, there is a significant progress towards a better stability. Sharaf et al. [7] reported a successful stabilization of gold particles in water where an average particle size remained at 15 nm for 16 months. Market prices for the commercial "solar" nanofluids may go up to 2570 EUR/l [8]. This is much beyond the prices of many conventional heat transfer fluids.

However, the most important problem is nanotoxicity [9]. EC50 is the effective concentration for 24-h exposure by nanoparticles. For *Daphnia magna*, EC50 is below $1.5 \cdot 10^{-4}$% wt [10] for the exposure by the metal-based nanoparticles (size$\sim$200 nm). The carbon-based nanofluids impose a similar toxicity with EC50 $< 1.0 \cdot 10^{-4}$% wt for a 48-h exposure of *Daphnia magna* [11]. These concentrations are very low as compared to the standard heat transfer fluid, e.g. EC50 = 5.6% wt. for ethylene glycol [12].

There were so-named "green" nanofluids produced with organic base fluids [13] and Jackfruit peel [14]. These nanofluids still contained toxic nanoparticles. In addition, several articles reported brewed coffee [15] and *Azadirachta Indica* [16] used as the eco-friendly absorbers of solar radiation. However, as follows from our previous experiments, the static stability of these fluids is rather questionable due to the high content of micro-sized particles [17]. None of the mentioned "green" fluids were examined using a standard toxicity test.

In this work, we demonstrate how instant coffee can be used to produce a stable, low-cost, and eco-friendly nanofluid for DASC applications.

2. Production

The production of our nanofluid goes in 3 steps: (I) dissolution of 0.1…2.0% wt. commercial instant coffee in tap water at 90 °C; (II) stirring the sample with 0.1% wt. of sodium dodecyl sulfate (SDS) surfactant at 60 °C; (III) ultrasonic treatment of the sample. We used 10 different sorts of instant coffee from the following countries: Norway, France, Italy, and the US. Using MEF93.T ultrasonic probe from MELFIZ, we sonicated the sample at 600 W and 22 ś 1.65 kHz for 20 min. The rheology of the nanofluid did not significantly differ from water at standard conditions. As measured by NDJ-8S viscometer (Baoshishan), the dynamic viscosity was 0.9 mPa·s at 24 °C.

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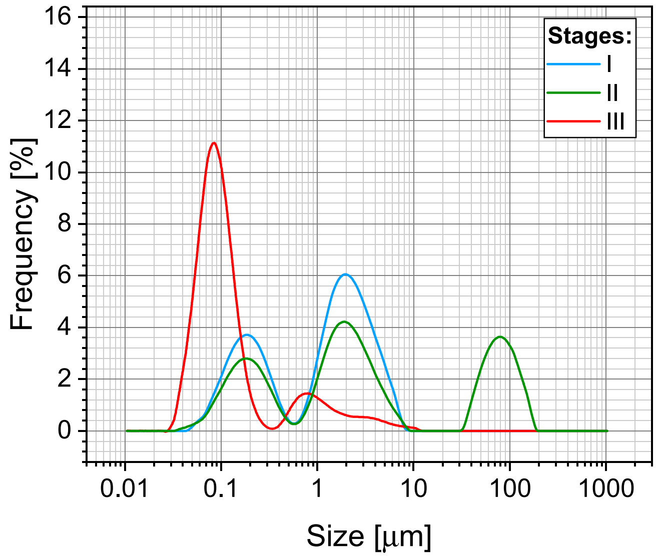

Fig. 1. PSDs of samples with 0.1% coffee particles: stage (I) dissolution, stage (II) surfactant, stage (III) sonication.

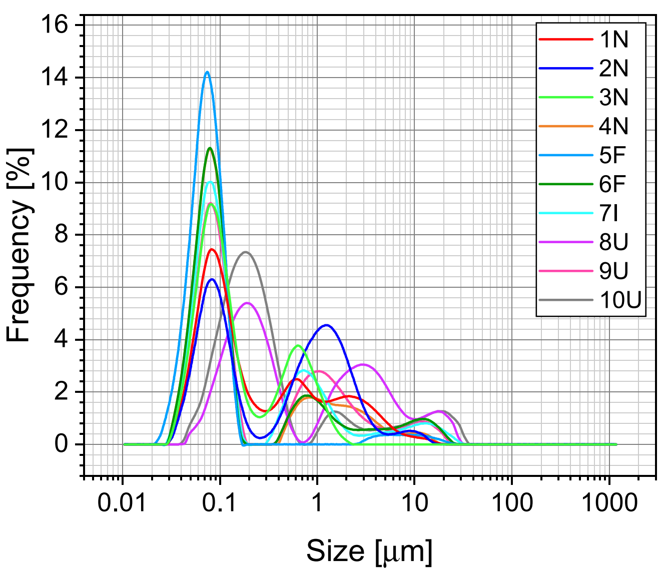

Fig. 2. PSD in nanofluids. Letters denote of origin: (N) Norway, (F) France, (I) Italy, (U) the US; and numbers denote producers.

3. Characterization

3.1. Particle size distribution

To examine the granulometry of the samples, we used the standard laser diffraction technique available in Malvern Mastersizer 2000 (measurement range 0.02…2000 µm). The particle size distribution (PSD) of a typical nanofluid sample is shown in Fig. 1 for different production stages. The dissolved instant coffee at stage (I) produces two peaks at 2000 and 200 nm. The SDS does not change the granulometry of the nanofluid at stage (II). The third peak at about 100 µm appeared due to the occasional formation of foam bubbles caused by the SDS; the sample is unstable. After the sonication, at stage (III), a single maximum of the PSD appears at ~80 nm.

Fig. 2 present PSDs from the samples produced with instant coffee from different countries and producers. Reading the figure, we conclude that over 70% of the studied samples have an average size below 100 nm. Therefore, the proposed production method is not entirely dependent on a specific sort of instant coffee. We also tested the nanofluid in a long-term stability test. The results are in Fig. 3. The PSD did not change significantly for a two-weeks old sample kept in static conditions at room temperature.

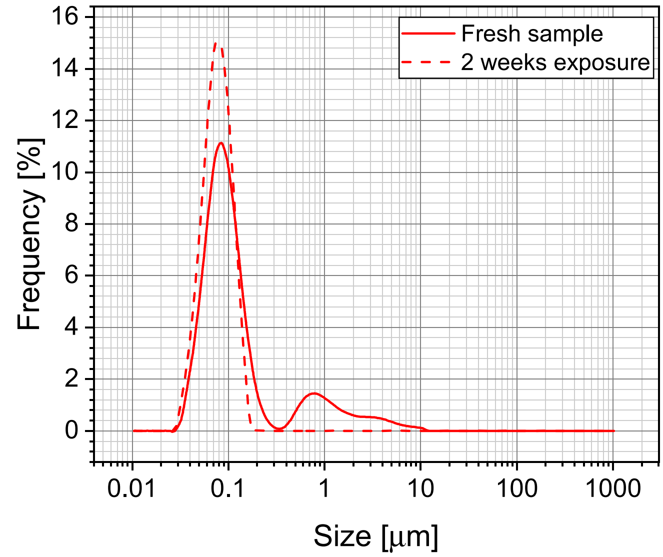

Fig. 3. PSD for a 2-week old sample with 0.2% coffee particles.

Table 1
Extinction coefficient.

concentration [% wt.]	0.1	0.2	0.5	1.0	2.0
extinction [1/m]	30	52	98	159	270

3.2. Extinction coefficient

The optical depth of the nanofluid and, respectively, the extinction coefficient should correspond to the receiver thickness for a given DASC. The literature shows that the thickness is in the range 0.2…2.0 cm [5,4,18]. Therefore, the extinction coefficient should be at 50…500 m^{-1}.

To tune up the extinction for our composition, we conducted a series of UV–vis measurements using UV-5100B spectrophotometer from Metash (wavelength range 190…1000 nm). The results of the measurement are given in Table 1 for different concentrations of coffee. As the table shows, 0.2% wt. of particles results in absorption required in a DASC. A relative dispersion of the extinction is below 15% for coffee samples of different origins.

3.3. Toxicity

The *Daphnia magna* toxicity test was carried out following the standard procedure described in OECD 202 [19]. The standard test was ordered at the Norwegian Institute of Water Research. The effective concentration of nanofluid in freshwater (Isklar) for 24-h exposure was from 5.15 to 7.06% wt. with an average of 6.03% wt.

4. Conclusion

In this communication, we present an eco-friendly coffee-based nanofluid for direct absorption solar collectors [20]. The production method can be also applied to synthesize arbitrary nanofluids for model studies. The average particle size in the nanofluid is below 100 nm, and the stability does not deteriorate after two weeks in normal static conditions. The extinction coefficient of the nanofluid is up to 300 1/m though at a relatively high concentration of 2% wt. With EC50 = 6.03% wt., the toxicity of the nanofluid is of the same order as for most conventional heat transfer fluids. To our knowledge, this is the first documented nanofluid with low toxicity. Our estimate of the production cost for this nanofluid is about 10 EUR/l. The properties of the nanofluid do not significantly change depending on the sort of coffee.

CRediT authorship contribution statement

Boris V. Balakin: Conceptualization, Methodology, Supervision. **Pavel G. Struchalin:** Methodology, Data curation.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Boris Balakin has patent #Nanofluid for use in solar collectors. UK Patent Application no. GB 2208368.7 pending to Vestlandets Innovasjonsselskap AS.

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