06.1

Nanofluids based on carbon nanomaterials for direct absorption solar collectors

© M.A. Morozova, A.V. Zaikovsky

Kutateladze Institute of Thermophysics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
E-mail: morozova.itp@gmail.com

Received February 15, 2024
Revised March 27, 2024
Accepted March 28, 2024

In this work the results of an experimental study of nanofluids based on various carbon nanomaterials (carbon nanoparticles, carbon nanotubes and graphene nanoparticles) for use in direct absorption solar collectors were obtained. Analysis of optical properties showed that the studied nanofluids are effective absorbers of sunlight. Compared with other nanofluids, nanofluid based on carbon nanoparticles showed the highest light absorption capacity, thermal conductivity value and the lowest viscosity, which makes it most promising for use as a working fluid in direct absorption solar collectors.

Keywords: nanofluids, carbon nanoparticles, carbon nanotubes, graphene, solar collectors

DOI: 10.61011/TPL.2024.07.58725.19895

The use of solar energy is one of the main approaches to „green" energy. Direct absorption solar collectors (DASCs), which harvest solar energy, convert it into heat, and transport it in coolant fluids [1], are of great interest in this regard. Water, ethylene glycol, paraffins, or oils may be used as a base liquid in this context. The addition of nanoparticles to the base fluid allows one to alter and tune the properties of the resulting nanofluid. Nanofluids based on carbon nanostructures attract much attention due to their profound capacity for absorption of light. Nanofluids with carbon nanoparticles, multi-walled carbon nanotubes, graphene, or graphene oxide raise the efficiency of DASC systems, have a higher thermal conductivity, and reach higher temperatures under illumination, although the viscosity of the studied nanofluid also increases [2–5]. A considerable number of studies focused on nanofluids based on various carbon nanostructures have already been published, but experimental data on a direct comparison of nanofluids with different types of carbon nanomaterials are virtually lacking at the moment. In the present study, we report the results of examination of nanofluids based on different carbon nanomaterials: spherical carbon nanoparticles, multi-walled carbon nanotubes, and graphene flakes.

An electric arc reactor was used to produce carbon nanomaterials. An electric arc discharge in this reactor induced congruent evaporation of a composite electrode, triggering the formation of a heterogeneous gas-plasma system that propagated in the reactor chamber. The processes of mixing with a buffer gas, cooling of the mixture, and interaction of its components with each other potentially initiated chemical reactions and condensation of vapors into clusters (nanoparticle nuclei), which then grew into nanoparticles of a certain size. The produced material was deposited from the gas phase onto a screen for collection of synthesis products. A solid graphite electrode with a diameter of 8 mm and a length of 80 mm was used to form spherical carbon nanoparticles (CNPs) in the present study. Helium under a pressure of 3 Torr served as the buffer gas. The current strength of the electric arc discharge was 100Å. Transmission electron microscopy (TEM) images revealed that the obtained carbon nanoparticles have an approximately spherical shape and are grouped into chain clusters (Fig. 1, *a*) [5]. It was found after statistical processing that the average particle diameter is 14 nm.

Graphene flakes (graphene) were also produced in the electric arc reactor via sputtering of a composite electrode (a graphite rod with silicon powder). Helium under a pressure of 12 Torr served as the buffer gas. The current strength was 100 A. Our previous experiments have demonstrated that multilayer graphene flakes form at these process parameters [6]. The produced flakes have an average lateral size of 50 nm, and the number of sheets ranges from 1 to 7 (Fig. 1, *b*). Commercial multi-walled carbon nanotubes (CNTs) (Kaina Carbon New Material Co, Ltd, China) with an average diameter of 30 nm were also used (Fig. 1, *c*).

Nanofluids were prepared by stabilizing the obtained nanoparticles in a base fluid. Ultrapure water produced using a Millipore Direct-Q3 UV water purification system served as the base fluid. A surfactant (sodium dodecyl sulfate, SDS; Helicon, Russia) in a mass concentration of 1% was added to all samples in order to stabilize carbon materials. The mass concentration of carbon materials was 0.01% in each sample. A mixture of water, surfactant, and carbon nanoparticles was processed in a Stegler 6DT ultrasonic bath (frequency, 40 kHz; power, 180 W) for 3 h. This processing resulted in disintegration of agglomerates of carbon structures and their stabilization in the base liquid [7].

Transmission spectra of the prepared nanofluids were studied using an SF-2000 (OKB Spektr, Russia) spec-

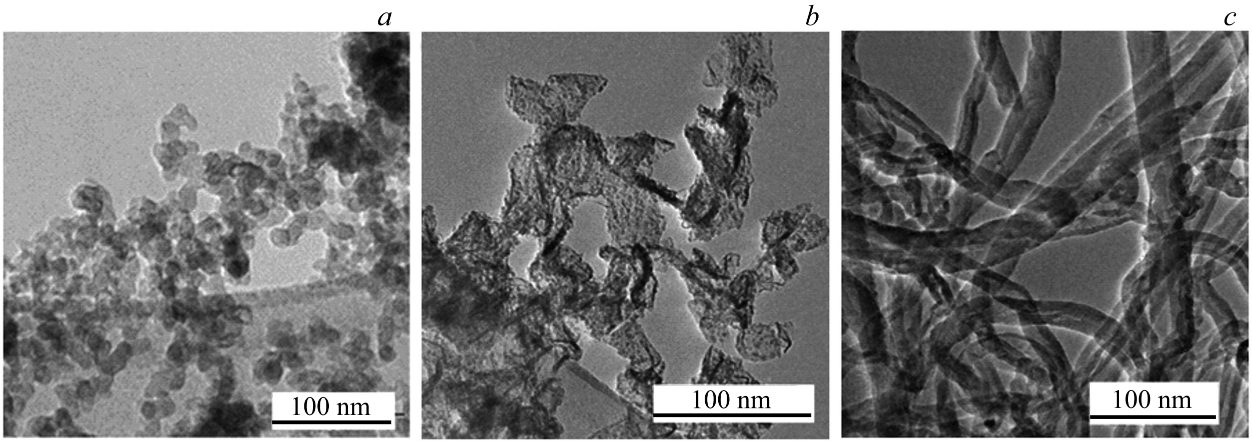

Figure 1. TEM images of carbon nanoparticles (a), graphene flakes (b), and multi-walled carbon nanotubes (c).

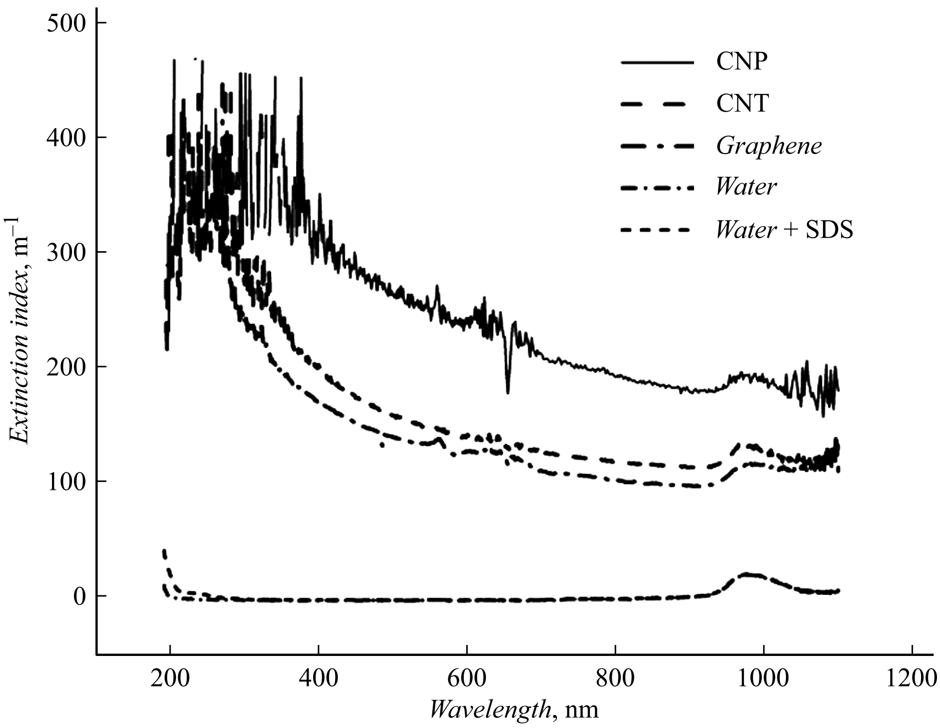

Figure 2. Extinction index spectra of nanofluids.

trometer within the 190–1100 nm wavelength range. The obtained data allowed us to plot the extinction index spectra of nanofluids (Fig. 2, a) and calculate the specific power of solar radiation absorbed by a nanofluid layer:

$$P = \int_{\Lambda} I_{solar}(\lambda)(1 - e^{-k(\lambda)x})d\lambda,$$

where $I_{solar}(\lambda)$ is the intensity of the solar spectrum at wavelength λ [8], Λ is the examined spectral range, $k(\lambda)$ is the nanofluid extinction index, and x is the nanofluid layer thickness, which was set to 25 mm (close to the tube diameter in common commercial solar collectors).

The power of solar radiation on the surface of the Earth within the 190–1100 nm wavelength range is estimated at 772 W/m^2 [8]. According to calculated data, water in this system has the capacity to absorb 29 W/m^2, and water with SDS may absorb 37 W/m^2. The studied nanofluids with carbon nanostructures have similar levels of absorbed energy; however, the highest value of 750 W/m^2 corresponds to the nanofluid based on spherical carbon nanoparticles, while nanofluids based on multi-walled carbon nanotubes and graphene flakes absorb 732 and 723 W/m^2, respectively.

The thermal conductivity of nanofluids was measured by the transient hot-wire method with an instrument discussed

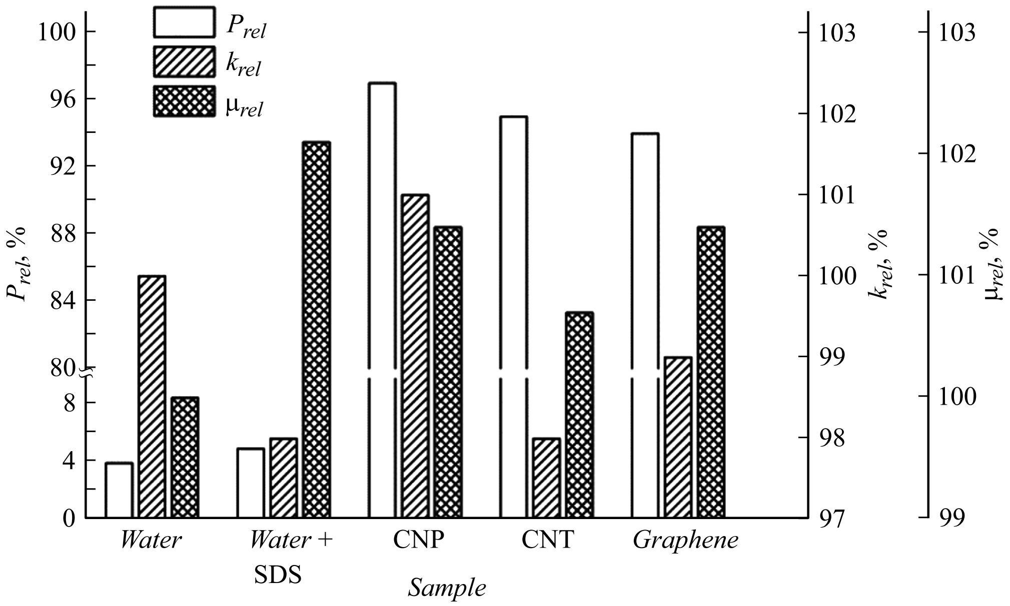

Figure 3. Relative values of the absorbed light power (P_{rel}), thermal conductivity coefficient ($k_{rel} = k_{nf}/k_{water}$), and viscosity ($\mu_{rel} = \mu_{nf}/\mu_{water}$) of the examined nanofluids (nf).

in detail in [9]. Viscosity measurements were performed using a Fungilab Expert L rotational viscometer. Figure 3 presents a summary of experimental data on the relative values of absorbed light power, thermal conductivity, and viscosity for nanofluids based on carbon nanoparticles, graphene nanoparticles, and carbon nanotubes. The results for water and a water solution with a mass SDS content of 1% are shown for comparison. Although SDS is one of the most widespread stabilizers of carbon nanoparticles in water-based nanofluids [10], its use leads to a reduction in thermal conductivity of water and an increase in viscosity. The CNP-based nanofluid have the highest energy absorption capacity and thermal conductivity among the nanofluids studied, and its relative viscosity is lower than the one of the aqueous SDS solution. The CNT-based nanofluid has the capacity to absorb a greater amount of solar energy and has a lower viscosity than the graphene-based nanofluid, but its thermal conductivity is lower than that of the other examined nanofluids and does not exceed the thermal conductivity of the aqueous SDS solution. It follows from a comparison of the obtained results that the nanofluid based on carbon nanoparticles is the one most suited for use in a DASC.

Funding

This study was supported by a grant from the Russian Science Foundation, project № 22-79-00139 (https://rscf.ru/project/22-79-00139/).

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] M. Hussain, S.K.H. Shah, U. Sajjad, N. Abbas, A. Ali, Energies, **15** (19), 7101 (2022). DOI: 10.3390/en15197101

[2] S.P. Yu, T.P. Teng, C.C. Huang, H.K. Hsieh, Y.J. Wei, Energies, **16** (3), 1157 (2023). DOI: 10.3390/en16031157

[3] B. Sun, X. Xu, D. Yang, H. Li, Appl. Therm. Eng., **230**, 120786 (2023). DOI: 10.1016/j.applthermaleng.2023.120786

[4] Z. Li, A. Kan, K. Wang, Y. He, N. Zheng, W. Yu, Appl. Therm. Eng., **203**, 117948 (2022). DOI: 10.1016/j.applthermaleng.2021.117948

[5] A.V. Zaikovskii, S.A. Novopashin, Phys. Status Solidi A, **214** (10), 1700142 (2017). DOI: 10.1002/pssa.201700142

[6] D.V. Smovzh, I.A. Kostogrud, S.Z. Sakhapov, A.V. Zaikovskii, S.A. Novopashin, Carbon, **112**, 97 (2017). DOI: 10.1016/j.carbon.2016.10.094

[7] M.A. Morozova, A.A. Osipov, E.A. Maksimovskiy, A.V. Zaikovskii, E3S Web Conf., **459**, 08005 (2023). DOI: 10.1051/e3sconf/202345908005

[8] *Standard solar constant and zero air mass solar spectral irradiance tables*, ASTM standard E490-00, 2006a (ASTM International, West Conshohocken, PA, 2006).

[9] P.V. Skripov, A.A. Smotritskiy, A.A. Starostin, A.V. Shishkin, J. Eng. Thermophys., **16** (3), 155 (2007). DOI: 10.1134/S1810232807030071

[10] A.O. Borode, N.A. Ahmed, P.A. Olubambi, Phys. Fluids, **31** (7), 071301 (2019). DOI: 10.1063/1.5105380

Translated by D.Safin