Effect of mesoporous cerium oxide nanofluids on the thermal conductivity

Montes de Oca LM(1)*, Borjas-García SE(1), Vargas Correa AJ(2), Alvarado-Gil JJ(3), Martínez-Torres P(1)

(1) Institute of Physics and Mathematics, Universidad Michoacana de San Nicolás de Hidalgo, Edificio C-3, Ciudad Universitaria, 58040 Morelia, Michoacán, Mexico
(2) Facultad de Ciencias Físico-Matemáticas, Universidad Michoacana de San Nicolás de Hidalgo, Edificio xxx, Ciudad Universitaria
(3) Department of Applied Physics, Cinvestav-Unidad Mérida, Carretera Antigua a Progreso, Km. 6, 97310 Mérida, Yucatán, Mexico

*Corresponding author's email: luismontesdeocafis@gmail.com

Nanofluids are suspensions formed by a liquid matrix, containing nanoparticles as a dispersed phase. There is a high interest in the study of the thermal properties of nanofluids due to their applications in the thermal energy storage or heat dissipation of electronic devices. To enhance and control the thermal properties of the nanofluids, nanoparticles like alumina, diamond, silver, gold, among others have been used [1]. It is known that the thermal conductivity of nanofluids depends upon the concentration and the collective aggregation of nanoparticles, even though, several factors remain misunderstood, such as the effect of size and porosity of nanoparticles. In this work, we used the thermal wave resonator cavity (TWRC) technique to obtain the thermal diffusivity of nanofluids loaded with cerium oxide mesoporous nanoparticles [2,3]. We also used mathematical effective thermal models to study the effect of these parameters.

Mesoporous cerium oxide nanoparticles were synthesized by the sol-gel method with a soft hydrothermal treatment. In a typical sample preparation, two solutions were prepared, the first one was obtained by dissolving 0.05 mol cerium chloride heptahydrated and 0.02 milimol of Pluronic F127 in 5 grs of distilled water (S1). The second solution was obtained by dissolving 0.04 mol sodium hydroxide in 4 grs of distilled water (S2). Later the two solutions were mixed, S2 was added slowly to S1, which was kept under constant stirring at 350 rpm at room temperature while S2 was added. Once S2 was added to S1, the xerogel obtained was stirred around 60 rpm for 24 h inside closed flask with cap at room temperature. The molar ratio was precursor: surfactant: NaOH: H2O = 1: 0.004: 8: 100. Subsequently, the xerogel was hydrothermally treated in static condition at 80 °C, for 24 h. After hydrothermal treatment, the sample was washed with distilled water and centrifuged. Finally, the resulting material was dried at 80 °C for 24 h. The powders were calcinated at 560 °C for 1 h to eliminate organic waste. Critical synthesis parameters such us amount of alkaline material, surfactant, temperatures of synthesis and hydrothermal treatment were changed in order to get better surface area and mesoporosity in samples.

The TWRC technique was used to determine the thermal diffusivity of the nanoparticle suspensions as is described in reference [4]. In this technique, the liquid sample is heated at a fixed frequency by a modulated laser diode. The signal of the modulated laser is driven by a Lock-in amplifier. The temperature changes are detected by a pyroelectric sensor that is connected to a lock-in amplifier, used to read the amplitude and phase of the signal as the length of the cavity varies. Under the thermally thick regime, it is possible to estimate the complex voltage of the pyroelectric sensor, as was measured by the Lock-in amplifier, using the following equation [5]:

$$V(L,\alpha,f) = F(f)e^{-L(i+1)/\sqrt{\pi f \alpha}} \qquad \text{Eqn. 1}$$

where *F(f)* is a transfer function that depends on the modulation frequency of the thermal wave.

Plots of ln(voltage) and phase versus length can be obtained. From Eqn. 1, the amplitude is $ln|V| = C_V - \sqrt{\pi f \alpha}L$ and the phase is $\varphi = C_\varphi - \sqrt{\pi f \alpha}L$, both equations follow a linear behaviour. Therefore, from the slopes m_V and m_φ of the experimental data, the thermal diffusivity of the samples is determined by

$$\alpha = \frac{\pi f}{m_V^2} \text{ and } \alpha = \frac{\pi f}{m_\varphi^2} \qquad \text{Eqn. 2}$$

References

[1] B. Bakthavatchalam, K. Habib, R. Saidur, B.B. Saha, K. Irshad, Comprehensive study on nanofluid and ionanofluid for heat transfer enhancement: A review on current and future perspective, J. Mol. Liq, 305 (2020) 112787. https://doi.org/10.1016/j.molliq.2020.112787.

[2] A. Taghizadeh, M. Taghizadeh, M. Azimi, A.S. Alsagri, A.A. Alrobaian, M. Afrand, Influence of cerium oxide nanoparticles on thermal conductivity of antifreeze: Preparation and stability of nanofluid using surfactant, J. Therm. Anal. Calorim, 139:1 (2020) 225–236. https://doi.org/10.1007/s10973-019-08422-2.

[3] Y. Yan, M. Li, S. King, T. Galy, M. Marszewski, J.S. Kang, L. Pilon, Y. Hu, S.H. Tolbert. Controlling Thermal Conductivity in Mesoporous Silica Films Using Pore Size and Nanoscale Architecture, J. Phys. Chem. Lett, 11:9 (2020) 3731–3737. https://doi.org/10.1021/acs.jpclett.0c00464.

[4] J. Shen, A. Mandelis, Thermal-wave resonator cavity, Rev. Sci. Instrum, 66:10 (1995) 4999–5005.

[5] C. Vales-Pinzon, D. Gonzalez-Medina, J. Tapia, M.A. Zambrano-Arjona, J.A. Mendez-Gamboa, R.A. Medina-Esquivel, Thermal diffusivity of compounds loaded with carbon nanofibers, Int J Thermophys, 39:7 (2018) 1–10.