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Transient measurement of the thermal conductivity as a tool for the evaluation of the stability of nanofluids subjected to a pressure treatment

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ABSTRACT

Nanofluids are a type of composite material with a demonstrated potential for improving heat transfer processes present in industries such as computers, electronics, and automobile. However, they have a limitation, which is that the suspended nanoparticles tend to agglomerate and in that way decrease their thermophysical properties. The present work studies experimentally the stability of a nanofluid synthesized with TiO_2 nanoparticles (6 nm) dispersed by continuous ultrasonication in water, determining the effect that exposure of the nanofluid to an atmosphere pressurized with N_2 at 1000 kPa has on its stability. A method is proposed for the quantitative measurement of the stability of a nanofluid based on the transient study of its thermal conductivity and the implementation of a model that describes such behavior. The results allow inferring statistically that the pressure treatment improves the stability of the nanofluid due to a presumed decrease of the average diameter of the agglomerations of the suspended nanoparticles. However, this improvement depends on the temperature.

1. Introduction

The increasing need of the refrigeration industry to generate high heat yield systems brings with it the dissipation of high energy rates, as in the case of electronic and computational devices whose tendency is to function at higher speeds, increasing the generated heat loads, which must be dissipated efficiently [1]. This represents a challenge to the existing heat transfer technologies, which are limited by the low thermal conductivity of the refrigerants that are used [2]. To solve this problem, nanofluids, solid-liquid composite materials, have been shown to have the potential to improve the heat transfer processes by increasing the thermal conductivity of traditional refrigerant fluids by the addition of low concentrations of nanoparticles (< 1 vol%) [3].

The dispersion of nanometric solid particles in the base fluid, and therefore the synthesis of a nanofluid, is currently carried out by two methods: the one-step and the two-step methods. In general, the one-step method combines the preparation of the nanoparticles with their dispersion in a single physicochemical procedure [4]. In this classification, cathodic spraying or sputtering [5], synthesis by plasma arc [6,7] and pulsed laser ablation in liquid (PLAL) [8] stand out.

The preparation of nanofluids by the two-step method is carried out with nanomaterials which are initially made as dry powders that are then dispersed in the base fluid [9]. For this purpose many studies use ultrasonication as a disperson method, either by means of an ultrasonic bath or probe [10–12]. The aim of this last step is to generate a stable solution, i.e., to reduce the agglomeration of nanoparticles [13], a phenomenon associated with decrease of the thermal conductivity of the nanofluids [14,15]. In this sense, the preparation of a stable and homogeneous suspension is a technical challenge due to the Van der Waals interactions present between the nanoparticles, which favor their agglomeration [16]. To improve the stability of a nanometric suspension, some of the methods used are based on the modification of the surface of the nanoparticles by the application of surfactants, as in the case of Xia et al. [17], who in addition to finding an improvement of the stability of the studied nanofluid with the addition of two surfactants (SDS and PVP), also concluded that with their addition the improvement of the thermal conductivity of the nanofluid decreases. Another process that allows improving the stability of nanofluids is by controlling the sample's pH, which modifies its electrokinetic properties. This process is the one applied by Li et al. [18], who, studying the behavior of an aqueous dispersion with copper nanoparticles, concluded that at pH of 9.5 the stability of the nanofluid is optimized.

Although the stability of a nanofluid is very important for its industrial application, there are limited studies on the methods for the quantitative estimation of the stability of a nanometric suspension, among which UV-VIS spectrophotometry [19,20] (measuring process based on determining the fluid's absorbance), measurement of the Zeta potential [21–23] (which relates the stability of the nanofluid to the electrostatic repulsion between the particles), and the light dispersion method [24] (based on the relation that there is between the intensity

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of the light dispersed by a suspended particle and its volume) stand out. On the other hand, the studies that describe the transient behavior of the thermophysical properties of nanofluids are also few. That is the case of Karthikeyan et al. [25], who by suspending CuO nanoparticles in water, determined that the thermal conductivity drop recorded in 20 min is due to the progressive increase of the number and size of the nanoparticle agglomerates, which are formed minutes after the applied sonication, and whose size depends on both the size and the concentration of the nanoparticles, because as the latter increases, the shorter is the distance between them, increasing the probability of agglomeration. Responding to two fundamental problems of nanofluids, like their stability and their quantitative determination, the present paper proposes the transient study of thermal conductivity as a quantitative method for the evaluation of the stability of nanofluids by the determination of a characteristic parameter of the mathematical model formulated to describe that phenomenon, which we believe represents a significant simplification with respect to the traditional methods used for that purpose. The studied nanofluids have been prepared with TiO_2 (6 nm) nanoparticles suspended in water by the two-step method of ultrasonication, making a modification that consists in subjecting the nanofluid to a pressure treatment prior to the ultrasonic irradiation, aimed at improving its stability, based on the hypothesis that exposure of the nanofluid to a pressurized atmosphere would decrease the average size of the nanoparticle agglomerations, and in this way delay the drop of the thermal conductivity, achieved by the addition of nanoparticles, due to their increase in size and not in number. A statistical validation is then made of the effect of that modification on the stability of the nanofluids, together with a quantitative measurement of its stability by means of the proposed method.

2. Materials and methods

2.1. Materials

Titanium oxide nanoparticles, Anatase (TiO_2), of 99.9% purity, with an average diameter of 6 nm and a specific surface area of 356 m^2/g, supplied by Mknano (Toronto, Canada) in the form of a dry powder, were used for the synthesis of the nanofluids. A transmission electron microscope, TEM (Hitachi HT7700), was used to identify the morphology of the isolated nanoparticles (Fig. 1), showing nanoparticle agglomerates. The base fluid used was double distilled water.

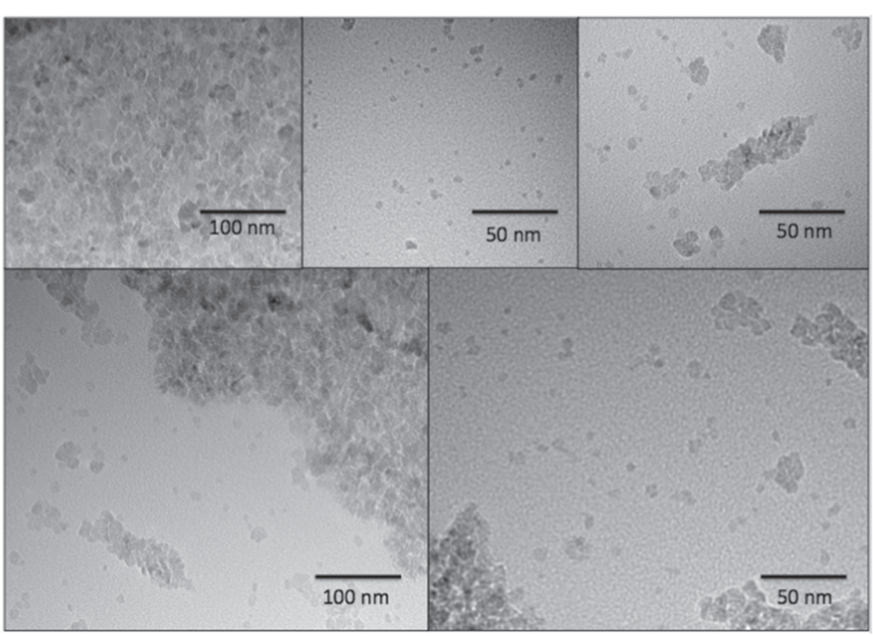

Fig. 1. TEM image of nanoparticles.

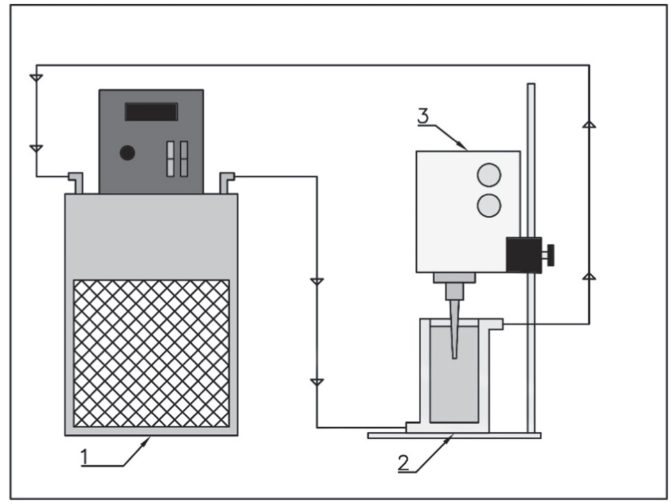

Fig. 2. Experimental setup for the ultrasonication. 1) Cooled circulation bath, 2) double wall container, and 3) ultrasonic probe.

2.2. Preparation of TiO_2 nanofluids

The preparation of the nanofluids was made by the two-step method of ultrasonication (Fig. 2), starting by defining the volume of base fluid to be used, and then weighing it on an analytical balance (BOECO, modelBas 32). The mass of nanoparticles to be dispersed was determined from the mass of water used, by means of Eq. (1).

$$m_{np} = \frac{\varphi \cdot m_{bf}}{(1 - \varphi)} \tag{1}$$

where φ corresponds to the fraction of the mass of nanoparticles to be dispersed with respect to the mass of solution, m_{np} is the mass of nanoparticles, and m_{bf} is the mass of base fluid.

Once the mass of nanoparticles had been determined, they were dispersed in the base fluid by means of a vertical axis ultrasonic probe (Hielscher GmbH, model UP50H), working at a frequency of 30 kHz, irradiating during 60 min at a constant temperature kept by a cooled circulation bath (JSR, model JSRC-13C).