1st European Symposium on Nanofluids (ESNf2017)
8-10 October 2017, Lisbon, Portugal

Transport properties of water-based nanofluids with dispersion of graphene-oxide nanoparticles

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Keywords: Nanofluids, Graphene-oxide, Thermal conductivity, Viscosity.

Introduction

Enhancement of thermal properties of heat transfer fluids is presently the most promising way to increase the performance of heat exchangers and in general of systems where heat transfer is a significant part of the energy flow. Nanofluids, dispersions of solid nanoparticles in a common fluid like water, glycol or oil, are widely studied due to their possibility to strongly increase the thermal properties of the base fluid [1]. However, the results available in the literature are still controversial and several problems (e.g. nanoparticles stability inside the fluid) have to be overcome [2]. Among the possible materials for nanoparticles, carbon nanostructures seem to exhibit the highest potential with respect to other materials, such as metal oxides or metals [3]. In particular, graphene, a graphite carbon allotrope, is one of the most interesting due to its remarkable mechanical, structural, thermal, and electrical properties [4, 5, 6]. Here, commercial nanofluids based on graphene-oxide (GO) nanostructure have been considered as potential substitutes for water as heat transfer fluids in ground source heat pumps (GSHP). Stability along time have been evaluated and transport properties (thermal conductivity and viscosity) have been measured as a function of temperature.

The study has been performed within the research activities of the European Project “Cheap and efficient application of reliable Ground Source Heat exchangers and Pumps” Cheap – GSHPs Grant Agreement Number 657982.

Experimental

Materials: two commercial nanofluids provided by Sigma Aldrich have been used for the experiments. Both fluids are based on water and graphene-oxide platelets, but with two different concentrations of nanoparticles: 1 mg/ml (WG1) and 2 mg/ml (WG2). Nanoparticles are constituted by a structure formed by 15-20 sheets of graphene, edge-oxidized at 4-10%. No information are available about the presence of dispersants.

Nanofluids Stability Characterization: nanoparticles stability in the dispersion has been evaluated applying a method based on the Dynamic Light Scattering (DLS) using a Zetasizer Nano ZS (Malvern) [7]. A sample of fluid is put into a proper cell, which is illuminated by a laser and the particles scatter the light which is measured using a detector. The particles move randomly and their speed is used to determine the particles dimension. The particle size measured in a DLS instrument is the diameter of the ideal sphere that diffuses at the same rate of the considered particle. This instrument can detect particle size from 0.6 nm to 6 μm using the DLS process, with a declared accuracy better than ±2%. All size measurements were made at 25 C° with a scattering angle of 173°. In order to verify the dependency of the diameter size from the concentration of the solution, each nanofluid was sonicated and the nanoparticle size was measured three times.

Thermal Conductivity apparatus: the thermal conductivity measurements were performed using a TPS 2500 S (Hot Disk), an instrument based on the hot disk technique which can measure thermal conductivity and thermal diffusivity of several materials [8]. The main parts of the instrument are the sensor, made of a double spiral of thin nickel wire that works as a continuous plane heat source and as a temperature sensor, a proper box containing the sensor and the fluid and a thermostatic bath to reach the test temperature. The conductivity data were measured at ambient pressure and in a temperature range between 10 and 70°C. The power supplied for each measurement was 30 mW and the time of the power input was 4 s. The declared instrument uncertainty is 5%.

Dynamic Viscosity apparatus: dynamic viscosity data were measured by means of an AR-G2 rheometer (TA Instruments), a rotational rheometer with magnetic bearing which permits ultra-low nanotorque control [9]. A plate-cone geometry with a 1° cone and diameter of 40 mm was employed and a proper device (Upper Heated Plate) was used to stabilize the measurement temperature. A constant quantity of sample, about 0.34 mL, was considered optimal for the analysis. Before the measurements, the rheometer was carefully calibrated at each temperature, as fully described in Bobbo et al. The dynamic viscosity data were measured at ambient pressure and in a temperature range between 10 and 70°C, with steps of 10°C. All the measurements were performed at constant temperature and variable shear rate. The declared instrument uncertainty is 5%.

Discussion and Results

Stability analysis: mean values of the nanoparticles nominal diameters at the starting time were 428 nm and 214 nm for WG1 and WG2, respectively. With the purpose to determine the tendency of the particles in suspension to settle down along time, two samples of the fluid were put in two different measurement cuvettes. The first sample was measured almost every day for thirty days, without shaking the fluid, to evaluate the changes in size distribution due to natural sedimentation. The second sample was measured almost every day for thirty days after sonication of the fluid to evaluate the changes in size distribution after mechanically removing the sedimentation [7]. The variations along time of the GO nanoparticles mean diameters are shown in Figure 1. The shaken WG1 sample average size slowly decrease along time stabilizing after 15 days at around 350 nm, while the static WG1 sample, after a quite fast decrease along the first 15 days, stabilizes at around 250 nm. This probably means that agglomerates with size over 250 nm are not stable and can

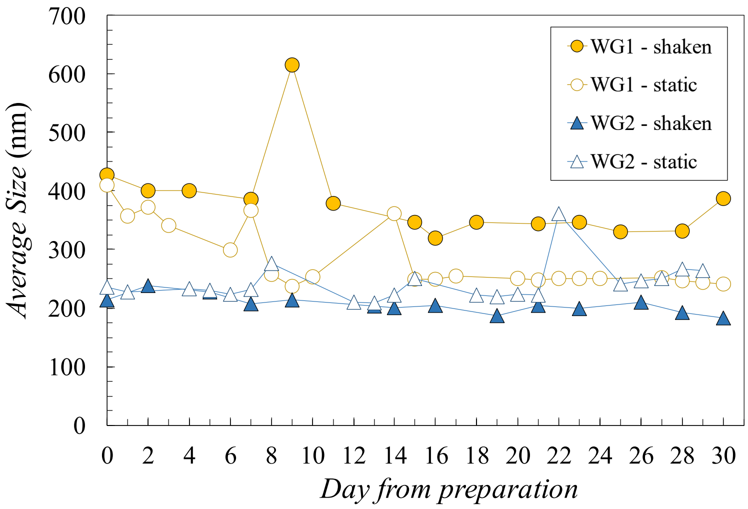

Figure 1. Variation along time of GO nanoparticles mean diameters.

be partially re-dispersed only after sonication. The starting average diameter of WG2 is below 250 nm and this is probably the reason why both shaken and static samples showed a quite constant size, in the range between 190 and 250 nm for all the thirty days of analysis. In any case, for both WG1 and WG2, no micrometric peaks were recorded in the period considered, suggesting there is no tendency of nanoparticles to further agglomerate.

Thermal Conductivity (λ): thermal conductivity data of the two nanofluids, measured from 283 to 333 K and 343 K for WG1 and WG2 respectively, are represented in Figure 2 and compared with the thermal conductivity of water, calculated with the database Refprop 9.1 [10]. For both nanofluids the thermal conductivity increases with temperature, as expected, and is very similar for both nanofluid, thus suggesting a very weak dependence on GO nanoparticles concentration. The fluctuation of λ with temperature are probably due to some instability of the nanofluids and anyway the differences shown by the two nanofluids are within the measurements uncertainties. Moreover, the increments with respect to water, more evident at the highest temperatures, are very moderate and do not suggest any special effect due to the presence of solid nanoparticles inside the base fluid. This is clearly represented in Figure 3, that shows the ratio ($\lambda_{nf}/\lambda_{water}$) between the thermal conductivities of the nanofluids and water. The ratio is practically constant for WG1 and weakly dependent on temperature for WG2, but in any case never exceeds 1.04, *i.e.* the maximum observed increment of thermal conductivity is 4%.

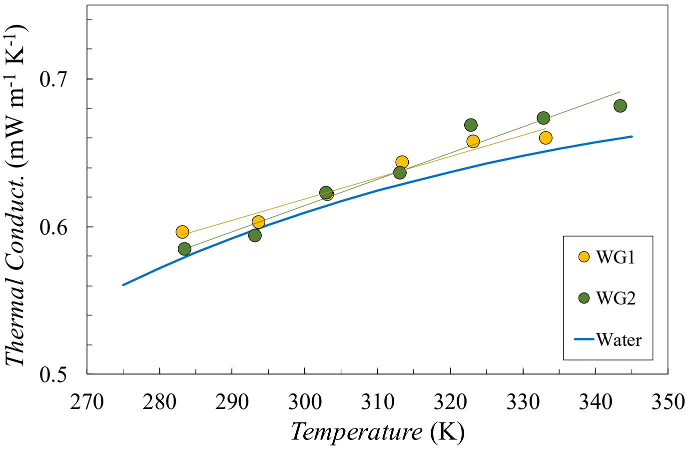

Figure 2: Thermal conductivity of the nanofluids as a function of temperature

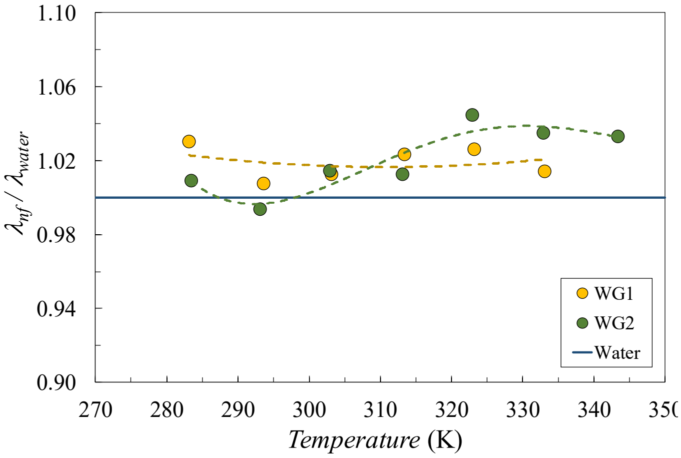

Figure 3: Thermal conductivity ratio between WG1 and WG2 nanofluids and water as a function of temperature

Viscosity (μ): the viscosity of the two nanofluids, measured from 283 to 313 K and 323 K for WG1 and WG2 respectively. Viscosity data are represented in Figure 4 and compared with the viscosity of water, calculated with the database Refprop 9.1 [10]. As shown, the viscosity of WG1 was close to that of water up to 303, with a more significant increase at 313 K, while the viscosity of WG2 is generally higher especially at the lowest and the highest temperatures. Figure 5 shows the viscosity ratio (μ_{nf}/μ_{water}) between the viscosities of the nanofluids and water. The ratio for WG1 is almost constant and below 1.04 in the range of temperatures between 283 and 303 K, but suddenly increases to 1.24 at 313 K. For WG2, the ratio tends to increase with temperature from 293 and 323 K, ranging from 1.07 to 1.32, while an unexpected increase to 1.26 is obtained at the lowest temperature (283 K).

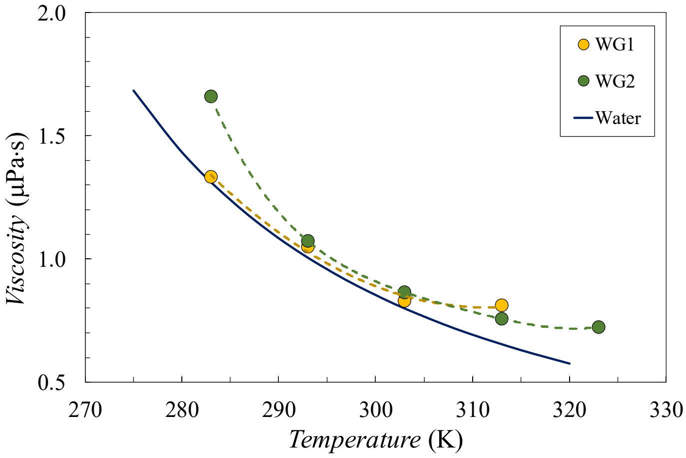

Figure 4: Viscosity of the nanofluids as a function of temperature in comparison with water

Summary/Conclusions:

Stability, dynamic viscosity and thermal conductivity for two commercial nanofluids (named WG1 and WG2) formed by water and graphite-oxide nanoparticles at two different concentrations (1 mg/ml and 2 mg/ml) were analysed as a function of temperatures. Even if the nanofluids shown to be quite stable at ambient temperature along time, measured thermal conductivity and viscosity behaviour do not suggest any potentiality of the nanofluids to enhance the heat transfer efficiency of the nanofluids with respect to water: thermal conductivity is similar or only slightly higher than that of water in all the temperature range for both nanofluids, despite the very high thermal conductivity of graphene-oxide; at the same time, dynamic viscosity enhancement is negligible for WG1 but suddenly increases by 24% at 313 K, while it is quite significant for WG2, increasing from 7% to 32 % from 283 to 323 K, while is anomalously high (32) at the low temperature of 283 K.

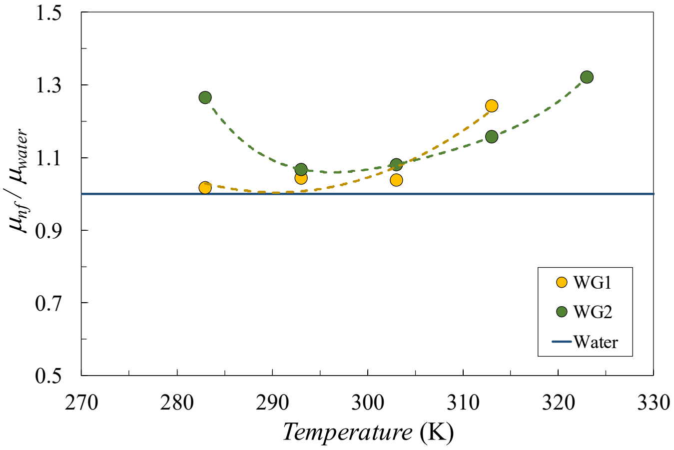

Figure 5: Viscosity ratio between WG1 and WG2 nanofluids and water as a function of temperature

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