Study on the Heat Transfer Capability of Silicon Carbide - Ethylene Glycol Nanofluid

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ABSTRACT

Ethylene glycol-based (EG) nanofluids containing silicon carbide (SiC) in the concentrations 0.1, 1 and 5 wt% were characterized, in order to understand their potentiality to improve the heat transfer efficiency of the base fluid.

First of all, the stability was verified almost every day for 30 days using a Dynamic Light Scattering (DLS) technique.

Then, nanofluids thermal conductivities and dynamic viscosities were measured, analysing their dependence on temperature and nanoparticle concentration.

The fluids show an increment in thermal conductivity (λ) more than proportional to the increment of nanoparticle concentration at a given temperature. Moreover, λ increases with temperature. The dynamic viscosity (μ) increment is small at low nanoparticle concentrations and quite significant at 5%wt concentration. Increasing the temperature, the absolute value of viscosity decreases but the increment is increasing.

Keywords: nanofluid, thermal conductivity, viscosity, silicon carbide, ethylene glycol

1 INTRODUCTION

Nanofluids, *i.e.* suspensions of nanoparticles in liquids [1], seem to be very promising as thermal vectors in systems where secondary fluids are applied. It has been found [2-3] that it is possible to get an unproportional increase in thermal conductivity and heat transfer coefficient also at relatively low nanoparticle concentrations. Moreover, nanoparticle material, dimension and shape can affect the efficiency of nanofluids as thermal vectors [4]. Particular attention must be put on the suspension stability, considering its Zeta potential, pH, type and concentration of dispersants [5-6].

Obviously, the addition of nanoparticles can determine a change in viscosity. Then the study of the rheological properties of nanofluids is fundamental to determine the possible increase in energy required to pump the nanofluid.

In the last years, several papers have been published in the literature on thermal properties and/or viscosity for nanofluids with various kinds of added nanoparticles, showing different behaviours [*e.g.*, 7, 8, 9].

Here, an ethylene-glycol (EG) based nanofluid with silicon carbide (SiC) nanoparticles has been studied.

EG can be used as a heat-transfer fluid in heating applications with maximum operating temperatures higher than water boiling temperature.

SiC is characterized by high thermal conductivity, *i.e.* 490 W/mK [10] (*e.g.* common oxides) and it is supposed to enhance the thermal properties of EG more than other common materials such as metal oxides.

Only few data are available for thermal conductivity of EG-SiC nanofluids, while no rheological properties were found in the literature.

First of all, the stability of three considered suspensions, at 0.1, 1 and 5 wt%, was studied. Then, thermal conductivity and dynamic viscosity were measured in the temperature ranges between 10°C and 70°C and 10°C and 90°C, respectively.

These measurements will be preliminary to future analysis of the heat exchange coefficient for this fluid. Both thermal conductivity and viscosity are necessary to properly evaluate fluid-dynamic regimes and heat transfer behaviour (*e.g.* to calculate non-dimensional numbers such as Re, Pr, Nu).

2 EXPERIMENTAL

2.1 Materials

EG-based nanofluids containing SiC at concentrations 0.1, 1 and 5 wt% were supplied by Nanograde Llc. An anionic dispersant (not specified by the manufacturer) was added to the suspensions at concentrations 0.008, 0.08 and 0.4 wt%, respectively.

2.2 Nanofluids stability characterization

The stability of the EG-SiC suspensions was studied by means of a Zetasizer Nano ZS (Malvern), based on Dynamic Light Scattering (DLS). It was used to check the actual average dimension of the nanoparticles in solution and verify the dependency of the diameter size from the concentration of the solution. The declared nanoparticle size by the supplier is 10-50 nm.

The actual mean particle diameter was measured every day for a period of 30 days to evaluate its stability. Two samples were analysed for each nanofluid: one static and the other one shaken before each measurement to evaluate the presence of deposited agglomerated. As shown in figure 1, both static and shaken samples showed a similar and practically constant values, around 100-120 nm for all nanoparticle concentrations, along the 30 days period. Only the shaken sample at 5% wt nanoparticle concentrations showed higher mean diameters, increasing with time, denoting progressive agglomeration and deposition of part of the nanoparticles.

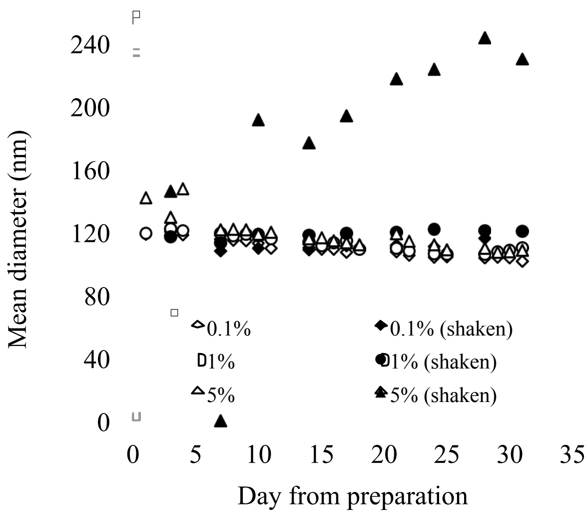

Figure 1. Dimensional stability analysis along 30 days for static samples (empty symbols) and shaken samples (full symbols).

2.3 Thermal Conductivity apparatus

The thermal conductivity data were measured, by means of a TPS 2500 S (Hot Disk), between 10°C and 70°C at ambient pressure. The instrument is based on the hot disk technique and can measure thermal conductivity and thermal diffusivity of several materials. The hot disk sensor is made of a double spiral of thin nickel wire and works as a continuous plane heat source. In case of liquids, the sensor is immersed in the fluid by a specifically built aluminium box, made up of two parts containing a cylindrical cavity, providing a full contact. The filled box is put in a water thermostatic bath to reach the test temperature. Temperature stability is achieved in at least 2 hours. The power supplied for each measurement was 30 mW and time of power input was 4 s. The declared instrument uncertainty is 5%, even if the tests performed on water showed an uncertainty around 1%.

2.4 Viscosity apparatus

The dynamic viscosity was measured at ambient pressure and in a temperature range between 10°C and 90°C by means of a AR-G2 rheometer (TA Instruments). It is a rotational rheometer, with a plate-cone geometry. A 1° cone, with a diameter of 40 mm, was employed. In order to stabilize the measurement temperature, an Upper Heated Plate (UHP) was used. Before the measurements, the rheometer was carefully calibrated at each temperature.

All the measurements were performed at constant temperature and variable shear rate, starting from 80 s^{-1} to 1200 s^{-1}, at constant step of about 124 s^{-1}. A conditioning step of 2 seconds and a pre-shear rate at 80 1/s were performed before the measurements to remove any possible fluid "memory" due to the sample preparation, storage and loading.

The apparatus was tested with water, finding deviations from the dynamic viscosity literature data lower than 1.5%, even if the declared accuracy of the instrument is 5%.

3 RESULTS AND DISCUSSION

3.1 Thermal conductivity experimental data

The thermal conductivity of EG-SiC nanofluids was measured at ambient pressure in the temperature range between 10°C and 70°C, at steps of 20°C. All the measured data are summarised in Table 1, while Figure 2 shows the ratio between the thermal conductivity of nanofluids and that of EG, indicating the enhancement given by the nanoparticles adding. Pure EG thermal conductivity was calculated on the base of [11].

Thermal conductivity ratio ($\lambda_{nf}/\lambda_{EG}$) increases with temperature and concentrations. Suspensions at 0.1% and 1% do not show large differences in thermal conductivity, probably due to the presence of the dispersant, that should have thermal conductivity lower to EG. The ratio ranges from around 1.05 at 10°C to around 10% at 70°C.
Higher enhancements are shown by the nanofluid at 5%, up to 21% at 70°C.

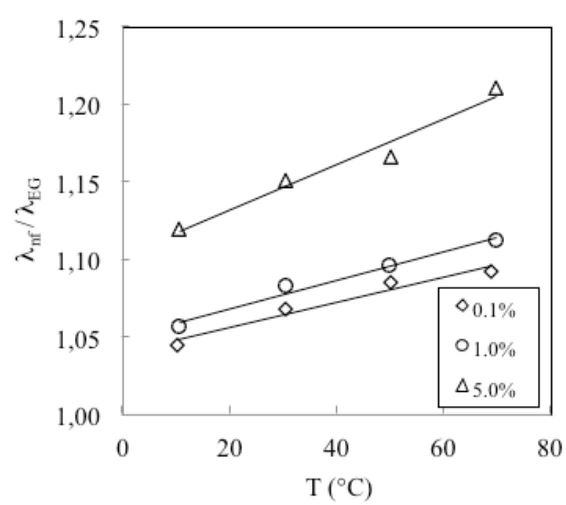

Figure 2. Thermal conductivity ratio for the EG-SiC nanofluids.

Table 1. Thermal conductivity data for EG-SiC nanofluids.

$\Delta\% = (\lambda_{exp}-\lambda_{EG})/\lambda_{EG}*100$

ω	T (°C)	λ_{exp} (W/mK)	λ_{EG} (W/mK) [11]	Δ%
0.1%	10.3	0.2562	0.2453	4.43
	30.3	0.2672	0.2503	6.74
	50.0	0.2770	0.2552	8.52
	69.0	0.2838	0.2599	9.16
1%	10.4	0.2592	0.2453	5.65
	30.3	0.2711	0.2503	8.32
	50.0	0.2796	0.2552	9.57
	69.7	0.2894	0.2601	11.26
5%	10.4	0.2746	0.2453	11.93
	30.3	0.2881	0.2503	15.09
	50.0	0.2975	0.2552	16.56
	69.8	0.3150	0.2601	21.07

3.2 Viscosity experimental data

Dynamic viscosity data of GE-SiC nanofluids were measured between 10°C and 90°C by steps of 10°C.

All the data measured at shear rate 830 s^{-1} are summarized in Table 2, while Figure 3 shows between the dynamic viscosity ratio (μ_{nf}/μ_{EG}), *i.e.* the enhancement obtained by by adding the nanoparticles.

The dynamic viscosity of the nanofluids at 0.1 and 1 wt% is lower or similar to that of ethylene glycol. This is may be due to the presence of the dispersant or to the interactions between the nanoparticles. However, the differences are of the same order of the experimental uncertainties.

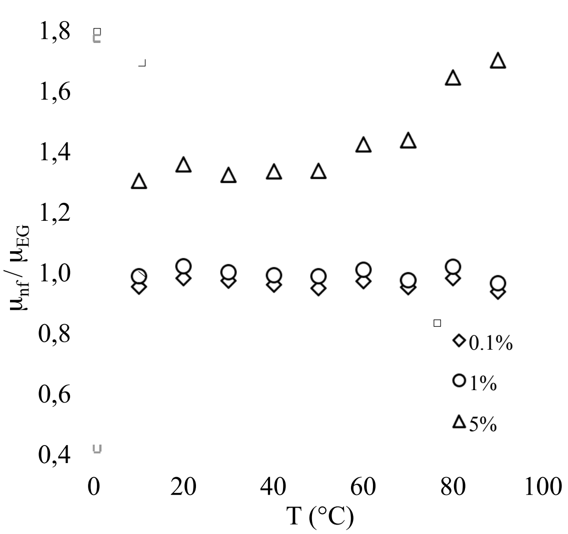

Figure 3. Dynamic viscosity ratio for the EG-SiC nanofluids.

For the suspension at 5 wt%, the dynamic viscosity enhancement is around 30% from 10°C to 50°C and than rapidly increases up to 70% at 90°C. This behaviour could be due to nanoparticles aggregation at elevated temperatures.

It should be noted that the nanofluids at 0.1% and 1% show a Newtonian behaviour, as pointed out in Figure 4.

On the contrary, the suspension at 5% presents a non-Newtonian behaviour.

Table 2. Dynamic viscosity data for EG-SiC nanofluids.

$\Delta\% = (\mu_{exp}-\mu_{EG})/\mu_{EG}*100$

ω	T (°C)	μ_{exp} (Pa s)	μ_{EG} (Pa s) [12]	Δ%
0.1%	10.0	0.03304	0.03491	-5.35
	20.0	0.02089	0.02143	-2.50
	30.0	0.01357	0.01404	-3.38
	40.0	0.00925	0.00971	-4.77
	50.0	0.00660	0.00701	-5.96
	60.0	0.00506	0.00525	-3.64
	70.0	0.00384	0.00406	-5.49
	80.0	0.00314	0.00322	-2.48
	90.0	0.00243	0.00261	-6.65
1%	10.0	0.03426	0.03491	-1.86
	20.0	0.02175	0.02143	1.51
	30.0	0.01395	0.01404	-0.67
	40.0	0.00956	0.00971	-1.59
	50.0	0.00687	0.00701	-2.11
	60.0	0.00526	0.00525	0.18
	70.0	0.00393	0.00406	-3.17
	80.0	0.00326	0.00322	1.35
	90.0	0.00250	0.00261	-4.12
5%	10.0	0.04521	0.03491	29.51
	20.0	0.02893	0.02143	35.02
	30.0	0.01849	0.01404	31.66
	40.0	0.01288	0.00971	32.66
	50.0	0.00932	0.00701	32.90
	60.0	0.00743	0.00525	41.36
	70.0	0.00581	0.00406	43.14
	80.0	0.00527	0.00322	63.90
	90.0	0.00442	0.00261	69.63

3.3 Comparison with literature

Xie *et al.* [10] studied the thermal conductivity of two kinds of Sic nanoparticles, with average size of 26 nm and 600 nm, respectively, in water and ethylene glycol.

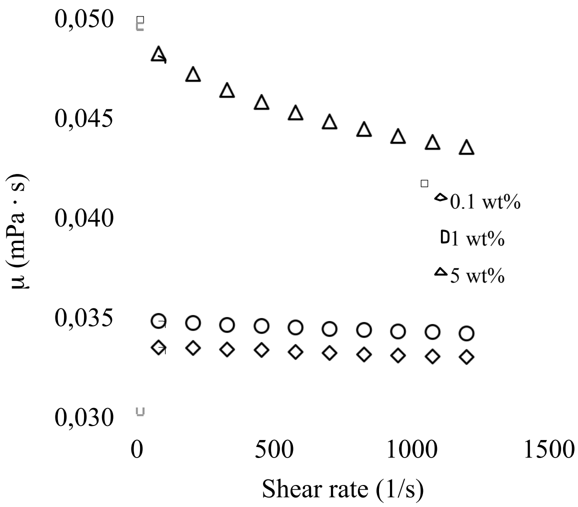

Figure 4: dynamic viscosity of EG-SiC nanofluids as a function of shear rate

Considering the dimensions of the nanoparticles employed for the preparation of the suspensions here studied, a comparison can be done only with the suspension containing the smaller particles.

In [10] thermal conductivity of suspensions with concentrations up to 4% by volume were measured only at 4°C. Considering that compositions and temperatures are different from those studied in this paper and that in [10] no data are explicitly written, but only graphically represented in the figures, a quantitative comparison is quite difficult.

However, the suspension at roughly 2% vol. could be compared to that at 5wt%, *i.e.* 1.82% vol. In [10], the suspension at 2% shown an enhancement of about 7% in thermal conductivity at 4°C, that can be considered in reasonable agreement with the increase of about 12% found with the suspension at 5wt% at 10°C.

4 CONCLUSIONS

Viscosity and thermal conductivity for nanofluids formed by ethylene glycol (EG) and SiC nanoparticles were measured at various concentrations and temperatures. The thermal conductivity enhancement is relatively high at all the concentrations and is increasing with temperature up to more than 20% for the 5%wt nanofluid. The viscosity enhancement is negligible or negative at concentrations up to 1%wt. Viceversa, it is quite significant for the 5%wt nanofluid, with a strong increase at temperatures higher than 50°C, suggesting aggregation of the nanoparticles.

The main objective in developing nanofluids as secondary fluid is obtaining high heat transfer coefficients coupled to not too penalising pressure drops (i.e low viscosity enhancements), so to ensure an overall increase of energy efficiency of system were the fluid are applied. The results of the present study suggest that EG-SiC nanofluids could be actually energy efficient at the lower concentrations (up to 1%), while with higher concentrations the thermal conductivity enhancement could be vanished by an unproportional increase of viscosity.

In any case, considering that heat transfer coefficient enhancement is not trivially related to thermal conductivity and viscosity behaviour, heat transfer and pressure drop measurements in a dedicated experimental loop installed at ITC-CNR laboratory will be performed to evaluate the actual potentiality of EG-SiC nanofluids.

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