



PROPERTIES OF SILICA NANOFLUID IN GLYCEROL-ETHYLENE GLYCOL MIXTURE AS BASE LIQUID

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ABSTRACT

Base liquid properties are critical in heat transfer due to their flexible capabilities to suit a wide range of applications. The addition of two pure miscible liquids alters thermo-physical properties, which could in turn influence the desired heating or cooling performance. A binary mixture of engineered base liquid with nanoparticle dispersions results in enhanced properties as compared to base fluid mixture. In this paper, thermophysical properties viz. viscosity, density and thermal conductivity are evaluated for silica nanofluid in glycerol/ethylene glycol mixture in 60:40 ratio for particle concentration in the range of 1.0 to 4.0% vol. and temperatures of 20 °C–80 °C. The experimental results showed that the properties of density and viscosity decreased whilst specific heat capacity and thermal conductivity of the nanofluid both increased with temperature. The property enhancement ratio for flow under turbulent conditions indicates heat transfer enhancements at low concentrations and high temperature for the SiO₂ nanofluid.

Keywords: glycerol, ethylene glycol, base liquid, silica nanofluid, thermophysical properties.

1. INTRODUCTION

Heat transfer fluids are integral to the performance of various thermal systems in energy, chemical, metallurgical, and manufacturing industries. When selecting a heat transfer fluid for a specific application, the thermophysical properties such as boiling point, heat capacity, thermal conductivity, viscosity factors must be considered. Moreover, corrosiveness and chemical stability can be other influencing parameters in the selection of working fluids. For example, arctic regions are characterized with extreme cold conditions; hence fluids with a low freezing point should be used as coolants for heating systems and automobile engines. Likewise, fluids with high boiling point are preferred in tropical climates since they are constantly subjected to high temperatures. Properties of viscosity and heat capacity can be used to estimate the amount of pumping power required.

The effectiveness of thermally driven cooling technologies, in particular, energy recovery heat exchangers requires thermo-physical and transport properties of the carrier fluid that have high boiling temperature, heat capacity, density, thermal conductivity and low viscosity. Glycerol possesses all these favourable properties except lower viscosity. Too high fluid viscosity means increased flow resistance with possible pumping retardation. In order to minimize this undesirable effect and its consequent pumping consumption demands, viscosity of glycerol needs to be reduced. Ethylene glycol can be mixed with glycerol in certain proportion to decrease the viscosity of the resulting mixture. Studies have pointed that pure ethylene glycol and glycerol behave as Newtonian fluid at temperatures between 20°C and 70°C [1-3].

Nanofluids connotes a two-phase engineered heat transfer fluid which comprises of solid particle with sizes lower than 100nm and base liquid such as water, glycerol (GC), ethylene glycol (EG), engine oil (EO). Nanofluids exhibit enhanced properties than pure base liquids, and are

regarded as the next generation heat transfer carrier fluid. The heat transfer enhancement capabilities of nanofluids depend on the thermophysical properties, particle shape, size, surface charge and above all the stability of the suspension [2]. The relevance of these parameters on the thermophysical properties of nanofluids have been confirmed through experiments available in the literature [4, 5].

To date, large number of experimental works have been reported on nanofluid characteristics [1-6]. The measured values of density can be used in the determination of pumping power, thermal capacity and diffusivity. Yet studies of density and specific heat of nanofluids are limited in the literature. Vajjha and Das [6] observed that the addition of 2.0% vol. SiO₂ in ethylene glycol and water mixture 60:40 wt.% increase the density of the nanofluid by 2.15% at 50 °C compared to water. Further, the authors noted modest increases in the specific heat with increasing temperature. Thermal conductivity and viscosity are fundamental properties used in evaluating the performance of a nanofluid. Enhancement in the thermal conductivity and viscosity can be a function of particle concentration, material and size. For instance, Tadjarodi *et al.* [2] investigated the thermal conductivity of mesoporous SiO₂/GC, and reported enhancement of 9.24% at a maximum concentration of 4.0% vol. measured at 25 °C. On the other hand, the nanofluid demonstrated Newtonian behaviour and the viscosity decremented with temperature between 20-50 °C. Rudyak *et al.* [7] investigated the influence of particle size and temperature on the viscosity of SiO₂/EG nanofluid. It is observed that viscosity decreases with increase in particle size undertaken between 20-60nm and temperatures between 25 °C-60 °C.

It is apparent that few papers have been presented in the literature regarding the thermophysical properties of GC and EG based nanofluids. In addition, there are limited studies about properties of silica in high viscosity base liquids. Therefore, the present work is aimed to evaluate



the thermophysical properties of density, specific heat, thermal conductivity and viscosity of silica nanoparticles dispersed in a single-phase fluid mixture. Glycerol and ethylene glycol in 60:40% wt. ratio was chosen as base liquid over pure glycerol for its lower viscosity.

2. PREPARATION OF BASE FLUID AND SILICA NANOFLUID

Silica powder purchased from Sigma-Aldrich of specific surface area 590-690 m²/g and density 2.2-2.6 g/cm³ was used in this work. The variation of particle size is between 15-25nm. Pure glycerol and ethylene glycol were purchased from R&M Chemicals, Malaysia. The properties of the base fluids and nanoparticle given by [8] are listed in Table-1.

Table-1. Material properties specifications at 25°C [8].

Material	ρ (kg/m ³)	C_p (J/kg K)	k (W/mK)
Ethylene glycol	1109	2428	0.2530
Glycerol	1261	2416	0.2886
Silica @27°C	2220	745	1.380

The required quantity of the nanoparticles for a given concentration is evaluated based on the law of mixtures as follows:

$$\phi = \left(\frac{m_{\text{SiO}_2} / \rho_{\text{SiO}_2}}{m_{\text{SiO}_2} / \rho_{\text{SiO}_2} + m_{\text{GC+EG}} / \rho_{\text{GC+EG}}} \right) \quad (1)$$

where, ϕ is the particle volume concentration.

Formulation of the nanofluid was initiated with preparation of the base liquid. First, 60g of glycerine and 40g of ethylene glycol were weighted on analytical balance (GX-400, A&D, Japan) of ± 0.0001 g precision. Then, samples are transferred into an empty beaker, and thoroughly mixed by using magnetic stirring system. Next, samples of nanofluid in the concentration range of 1.0-4.0% vol. were prepared in two steps process by dispersing the nanoparticles in the base liquid and stirred for 30 mins. It is worth noting that neither ultrasonic agitation nor chemical treatments with dispersant has been applied in the nanofluid preparation steps as use of these techniques depends on the dispersibility of the nanoparticles in the base liquid media [9]. Moreover, the stability of the nanofluid was checked through electrical conductivity measurements with (Con 11, Eutech Scientific, USA). The electrical conductivity drift for the period of 48hrs is summarized in Table-2.

Table-2. Electrical conductivity of silica nanofluid.

ϕ	0pH	^{48}pH	0E_c	$^{48}E_c$
0.0	6.95	7.2	0	0
1.0	7.4	7.21	3.09	3.03
4.0	8.8	8.65	8.21	8.03

The measured electrical conductivity of the nanofluid and pH remained almost constant, immediately on preparation and 48hrs thereafter. In addition, the nanofluid stability was quantitatively evaluated based on macroscopic appearance of the samples. On this perspective, visual inspection of the sample vials was undertaken and there was no any form of phase separation or sediments detected in each of the vials for 48 hrs. after preparation. The photographic images of stable nanofluid samples are shown in Figure-1.



Figure-1. Photograph of silica nanofluid in various concentrations after 48 hrs preparation time.

3. PROPERTY MEASUREMENT

The density of the silica nanofluid was measured using a densitometer (DA-645, KEM, Japan) with an accuracy of $\pm 0.005\%$ kg/m³. The density data of the nanofluid was recorded at least five times for different volume concentrations of 1.0–4.0% vol. in the temperature range from 20 °C to 60 °C. The nanofluid's specific heat was measured using standard differential scanning calorimeter (DSC1, Mettler-Toledo AG, Switzerland). The sample measurements were carried out for heating ramps from 30 to 60 °C at steps of 5 °C. The thermal conductivity was determined based on transient hot wire method by using a thermal property meter (KD2-Pro, Decagon, USA). Temperature control was facilitated by a refrigerated and heating water bath (Vivo-RT2 Julabo, Germany). Thermal conductivity of the silica nanofluids was measured for temperatures from 30 °C to 60 °C with the device operated in auto-mode. The uncertainty in the thermal conductivity measurements was about $\pm 3\%$. At least three consecutive readings have been recorded at each temperature and the average values reported. Rheological and viscosity data was taken on a combined motor-transducer rheometer (AR-G2, TA, USA), which is equipped with plate-cone geometrical arrangement. 60mm cone-plate geometry with upper cone angle of 2° was used. The viscosity measurements were carried out for shear rates ranging from 0.1 to 100 s⁻¹ and temperature of 15 °C to 75 °C with a tolerance of 1 °C.

4. NANOFLUID HEAT TRANSFER MERIT

The performance of nanofluid for turbulent heat transfer duty can be estimated using the property enhancement parameter. According to Garg *et al.* [10], the heat transfer enhancement of nanofluids under turbulent flow is possible when the enhancement in the



viscosity is lower by a factor of five compared to the increase in thermal conductivity as follows:

$$C_{\mu} = 5 C_k \quad (2)$$

5. RESULTS AND DISCUSSIONS

Experimental values of the thermophysical properties of base liquid have been summarized in Table-3:

Table-3. Measured data for the thermophysical properties of base liquid GC+EG 60:40 wt.% at different temperatures.

Property	Temperature		
	30 °C	60 °C	80 °C
ρ , (kg/m ³)	1192	1174	-
C_p (J/ kgK)	2310	2490	-
k , (W/ mK)	0.264	0.273	-
μ @ 10 s ⁻¹ , (cP)	95.7	32.7	10.4
Average particle size (SEM), 21nm			

Validation of the experimental data for the nanofluid properties could not be established due to unavailability of relevant data. For this reason, comparison with pure base liquid data was the only option for result verification.

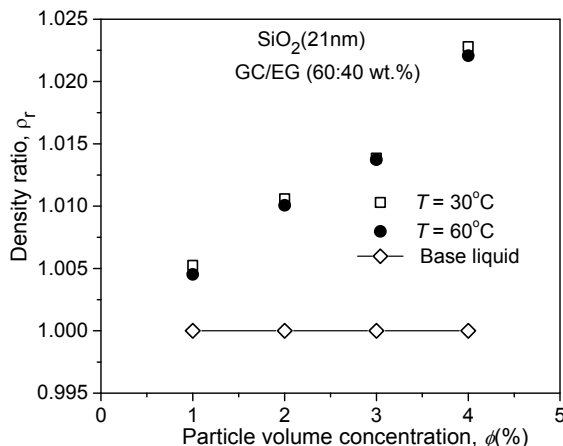


Figure-2. Density enhancement ratio of silica nanofluid as function of particle volume fraction.

The properties of glycerol (GC) have been considered here. Accordingly, overall the properties of density and thermal conductivity for GC matched closely within $\pm 3\%$ of the standard reference data [11], while those of specific heat and viscosity deviated by about $\pm 1\%$ and $\pm 2\%$ from the literature values of Rigetti *et al.* [12] and Segur [13], respectively. From the results, since the obtained values of the base liquid properties are consistent with the literature, the reliability of the measuring instruments is thus proven.

Figure-2 shows density enhancement ratio of the nanofluid as a function of the volume fraction of silica nanoparticles at different temperatures. The density ratio increased linearly with particle concentration. However, the ratio slightly decreases with temperature. For example, about 2.0% maximum diminution of the density occurred at 4.0% vol. concentration when the temperature decreased from 60 °C to 30 °C. This is due to the fact that when nanofluid is heated, the molecules move further apart due to their acquired kinetic energy.

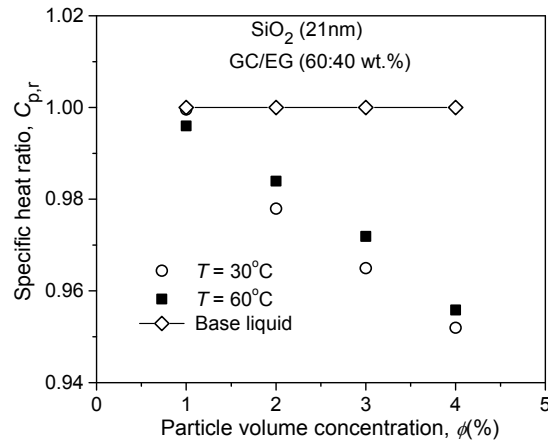


Figure-3. Specific heat detrimental ratio of silica nanofluid as function of particle volume fraction.

Figure-3 depicts the measured values of silica nanofluid specific heat as a function of temperature for different particle concentrations. It was observed that the specific heat decrease with the increase of the particle volume concentration. This behaviour is in agreement with the observations of Namburu *et al.* [3] and O'Hanley *et al.* [14]. Moreover, the specific heat was increased with the temperature.

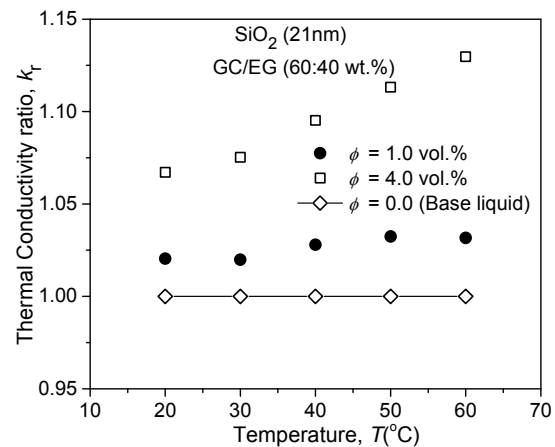


Figure-4. Thermal conductivity enhancement ratio of silica nanofluid as function of temperature.

As observed the specific heat increased by about 2% between 30 °C and 60 °C for particle volume



concentrations less than 4.0% vol. In contrast, the effect of temperature on specific heat is reported by Shin and Banerjee [15] to be a constant. Similar behaviour is exhibited by silica nanofluid with concentration as shown in Figure-3.

The variation of thermal conductivity ratio of silica nanofluid with temperature for two concentrations is shown in Figure-4. A linear increase in thermal conductivity ratio was observed with temperature at nanofluid concentrations of 1.0 and 4.0% vol. Tadjarodi *et al.* [2] reported that the thermal conductivity of mesoporous silica in glycerol increased approximately by 9.0% for particle concentration between 2.0-4.0% wt. in the temperature range of 20 °C to 50 °C. The enhancement is attributed to the low Brownian motion of the particles due to high viscosity of glycerol. The reduction of viscosity of the glycerol with the addition of ethylene glycol in 60:40 ratio had most probably improved the Brownian motion of the particles in the fluid resulting in the enhancement of 13% in thermal conductivity. The enhancement capabilities of nanofluids follow the conductivity trend of the base fluid [16].

Figure-5 shows the variation of silica nanofluid viscosity with temperature and concentration. The viscosity of the nanofluid increases with particle concentration from 1.0 to 4.0% vol. The results are consistent with the behaviour of SiO₂ in EG/W base liquid [3]. On the other hand, the viscosity of the nanofluid decreases with increase in temperature from 20 °C to 80 °C. The viscosity exhibited constant values at 4.0% vol. whereas a decrease of about 4% was observed at 1.0% vol. over the limited range of the temperature shown. Rate of decrease in the viscosity is highly pronounced at 1.0% vol. concentration. The decrease factor is almost 4 times compared to that at 4.0% vol. concentration in the same temperature range. The viscosity decrease with temperature may be due to the disruption in the particle/fluid intermolecular attraction force [17-19]. This phenomenon is highly critical as considerable savings in the pumping power can be achieved at higher operating temperatures.

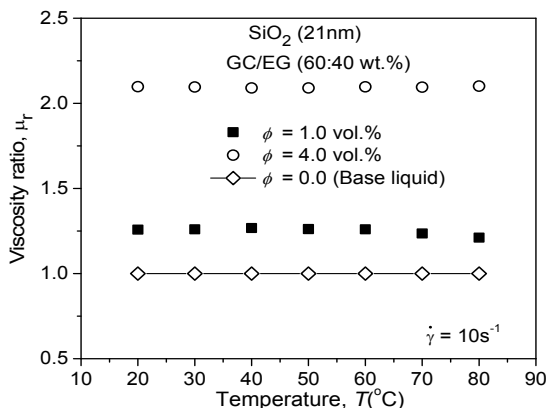


Figure-5. Viscosity enhancement ratio of silica nanofluid as function of temperature for different particle volume concentrations.

In Figure-6, the Enhancement Ratio (ER) of the nanofluid with temperature for two concentrations are shown. The ER is defined as the ratio of viscosity to thermal conductivity enhancement. Moreover, from the experimental data, the equations for the viscosity and thermal conductivity enhancements ratios given by Equations. (5) and (6), respectively are developed.

$$\mu_r = 0.05963 (1 + (\phi/100))^{2.198} (1 + (T/80))^{0.2005} (\alpha_p / \alpha_{bf})^{1.178} \quad (5)$$

$$k_r = 0.0491 (1 + (\phi/100))^{2.192} (1 + (T/60))^{0.218} (\alpha_p / \alpha_{bf})^{1.245} \quad (6)$$

These correlating equations are incorporated as functions of particle concentration, temperature and thermal diffusivity to facilitate the evaluation of ER. Following the analysis of Garg [10] that heat transfer enhancement would cease, if the value of ER > 5. It can be observed that the ER for silica nanofluid for 4.0% vol. is greater than 5.0 in the range of temperatures undertaken. However, the values of the enhancement ratio for 1.0% vol. is lower than 5 for temperatures greater than 70 °C. A comparable results have also been reported by Azmi *et al.* [20] for silica nanofluid dispersions in water. The authors showed that the ideal conditions for heat transfer benefits with the use of nanofluid in the turbulent regime occurred when the particle volume concentration of the nanofluid was below 3.0% vol. and temperatures higher than 40 °C.

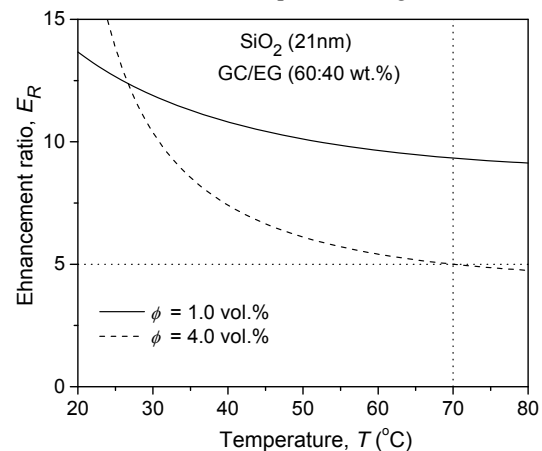


Figure-6. Influence of particle concentration and temperature enhancement ratio of silica nanofluid.

6. CONCLUSIONS

The following conclusions can be drawn from the experimental work:

- (1) The density ratio of the silica nanofluid decrease by 2% with concentration. The density remained almost unaltered irrespective of rise in temperature from 30 °C to 60 °C.
- (2) The experimental values of specific heat remained almost constant with concentration but decreased by 0.1% with temperature.



- (3) The thermal conductivity reflected low enhancements with concentration. Significant increase in thermal conductivity results at high temperatures with maximum values of 13% with 4.0% vol. concentration at 60 °C.
- (4) The thermal conductivity reflected low enhancements with concentration. Significant increase in thermal conductivity results at high temperatures with maximum values of 13% for 4.0% vol. concentration at 60 °C.
- (5) The viscosity increases with particle loading but remain almost constant with the increase of temperature. The average enhancement in the viscosity between 1.0 to 4.0% at fixed temperatures between 20° and 80 °C is approximately 85%. Effect of temperature on the nanofluid viscosity is more significant at low concentration. The nanofluid of 1.0% vol. exhibited viscosity decrement of 4%.
- (6) The nanofluids performance merit for a turbulent flow conditions is attained with particle concentration below 1.0% vol. and temperatures greater than 70°C.

NOMENCLATURE

α	thermal diffusivity, m^2/s
E_c	electrical conductivity, $\mu S/cm$
E_R	enhancement ratio, $(\mu_r - 1)/(k_r - 1)$
$c_{p,r}$	specific heat ratio, $c_{p, nf}/c_{p, bf}$
C_μ	viscosity enhancement ratio, $(k_{nf} - k_{bf})/(k_{bf})$
C_k	conductivity enhancement ratio, $(\mu_{nf} - \mu_{bf})/(\mu_{bf})$
γ	shear rate, s^{-1}
k_r	thermal conductivity ratio, k_{nf}/k_{bf}
m	mass, g
μ_r	dynamic viscosity ratio, μ_{nf}/μ_{bf}
ϕ	particle volume concentration, $\phi = \phi / 100$
ρ_r	density ratio, ρ_{nf}/ρ_{bf}
T	temperature, °C
τ	shear stress, $dyne/cm^2$

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