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Properties of glycerol and ethylene glycol mixture based SiO_2-CuO/C hybrid nanofluid for enhanced solar energy transport

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ABSTRACT

Hybrid nanofluids are a novel class of colloidal fluids which have drawn significant attention due to potential tailoring of their thermo-physical properties for heat transfer enhancement by a combination of more than one nano-additive to meet specific requirements of an application. In the present work, ceramic copper oxide/carbon (SiO_2-CuO/C) nanoparticles in 80:20 (wt%) composition were prepared by ultrasonic-assisted wet mixing technique. The hybrid nanofluid was formulated by dispersing the nanoparticles into a base fluid mixture of 60:40 (% by mass) glycerol and ethylene glycol (G/EG) using the two-steps method. The influence of nanoparticles on the augmentation of specific heat, thermal conductivity and viscosity was examined in the volume concentration range of 0.5–2.0% in the temperature range of 303.15–353.15 K. The results demonstrate that the synthesized SiO_2-CuO/C hybrid nanoparticles enhanced the thermo-physical properties of the base fluid mixture which is higher than using SiO_2 alone. In the case of SiO_2–G/EG nanofluid, the specific heat capacity decremented by a maximum value of 5.7% whereas the thermal conductivity and viscosity incremented by 6.9% and 1.33-times as compared with G/EG at maximum volume concentration of 2.0% at a temperature of 353.15 K. Comparatively, a reinforcement of 80% SiO_2 with 20% CuO/C in G/EG mixture led to thermal conductivity and viscosity enhancement by 26.9% and 1.15-times, respectively with a significant reduction of specific heat by 21.1%. New empirical correlations were proposed based on the experimental data for evaluation of thermo-physical properties.

1. Introduction

Over the past two decades, there have been an increased interest to optimize the performance of thermal systems due to their high power consumption coupled with escalation in energy prices. Potential solutions for improving the effectiveness of thermal systems, solar devices in particular have focused on solar collector absorber area exposed to radiation, inclination angle, absorber geometry, integration of energy storage material and working fluids etc. [1–3]. Improving the properties of working fluid could substitute to expanding collector area or absorber surface which adds weight and size to the collector. Moreover seeding the working fluids with solid additive components have contributed effectively toward increased solar absorption and have since been implemented globally as reported in the review of Javadi et al. [4]. The idea to develop energy efficient fluids is not new, Maxwell [5] way back in 1881 was the first to propose the concept of thermal conductivity enhancement in slurries. The advancement in nanomaterial production technologies has created new avenues for designing fluids with excellent heat transfer capabilities. Nanofluids are engineered colloidal suspensions of nanoparticles in conventional base fluids, which are characterized by ultra-high thermal conductivity and convective heat transfer performance [6]. Hence, nanofluids were considered as the working medium for solar thermal collectors [7], solar thermoelectric [8,9], solar photovoltaic [10], solar stills [11] and thermal energy storage systems [12].

Thermophysical properties of nanofluid such as specific heat, thermal conductivity and viscosity depend on influencing parameters viz., base fluid, particle concentration, particle size, temperature and nanoparticle material. Some commonly used nano-additives in nanofluids are metal additives w7hich include Ag, Al_2O_3, Cu, CuO, MgO, SiO_2, TiO_2 and ZnO. Liquids such as water (W), ethylene glycol (EG), propylene glycol (PG), glycerol (G), oils and other lubricants are typically used as the base medium for dispersion [13]. It is a fact that dispersing small amount of nanoparticles could significantly alter the

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Nomenclature

d	diameter [nm]
c_p	specific heat capacity [KJ/kg K]
$c_{p,r}$	specific heat ratio, $c_{p,r} = c_{p,bf}/c_{p,nf}$ [dimensionless]
e	electron charge [C]
E	calibration factor
k	thermal conductivity [W/m K]
k_r	thermal conductivity ratio, $k_r = k_{nf}/k_{bf}$ [dimensionless]
k_B	Boltzmann constant
n	shape factor
n_o	ionic concentration [mol/L]
q	[W/m^2]
Q_o	heat flow [W]
r	particle radius
t	time (s)
T	temperature [K]
T_o	reference temperature
w	weight [g]
z	charge of ion [dimensionless]

Greek symbols

ε_r	dielectric constant [dimensionless]
ε_o	electrical permittivity [F/m]
$\dot{\gamma}$	shear rate [1/s]
φ	particle volume concentration (%)
μ	viscosity [Pa s]
μ_r	viscosity ratio, $\mu_r = \mu_{nf}/\mu_{bf}$ [dimensionless]
κ	Debye–Hückel parameter [m]
τ	shear stress [Pa]
ρ	density [kg/m^3]
θ	angle [degree]
ν_E	electrophoretic mobility [cm/s]
ζ	zeta-potential [mV]

Subscripts

bf	base fluid
nf	nanofluid
nc	nanocomposite
p	particle
ref	reference

properties of base fluid specifically the thermal conductivity, specific heat and viscosity. Stability of the dispersion is important for successful application of nanofluids, since nanoparticles have the tendency for agglomeration due to high surface energy. This agglomeration of nanoparticles is a serious problem limiting the surface area to volume ratio of nanoparticles and thermal transport potential of the nanofluids [14]. Convenient methods such as control of pH and addition of dispersants could be used to achieve good stability of the suspension against high surface energies of the nanoparticles. In addition, physical methods such as mechanical homogenization, sonication and ultra-sonication could repel the sticking together effect by increasing the separation distance between dispersed nanoparticles for longer duration [15,16].

Researchers have made some attempts to improve thermal properties of fluids using different nano-additives in several base fluids [17–19]. These earlier studies of single-component nanofluids have shown a huge potential for thermal conductivity augmentation. However, progress in such research has been limited due to the pressing need for enhanced properties of heat transfer fluids. Obviously, thermal conductivities of ceramic oxides such as Al_2O_3, SiO_2 and TiO_2 are lower than those of metals like silver, copper and gold or carbon compounds such as diamond, carbon nanotubes and graphene. In recent years, as nanotechnology has rapidly developed, low thermal conductivity limitation of ceramic oxides nanoparticles could be overcome by combination of more than one component nanoparticle which is termed as composite/hybrid nano-additive. A suspension with compositions of hybrid nano-additives termed as 'hybrid nanofluid' leads to an increased thermal conductivity which facilitates heat transfer enhancement [20].

Till date, continued research efforts and their findings have been reported in the literature on the characterization of hybrid nanofluids. The preparation of hybrid nanofluids using different particle combinations of metal-ceramic [21–25], ceramic-ceramic [26–29] and ceramic-carbon (derivative) [30–32] have been reported. It is noteworthy to mention that, all the outcomes revealed substantial increase of thermal conductivity with hybrid nano-additives [21–34]. A combination of metal-metal hybrid nano-additive was reported by Chopkar et al. [33] using high energy planetary mechanical milling to produce Al–Cu powder. A stable nanofluid was formulated using two-step method, by dispersing Al_{70}-Cu_{30} (~10 nm) particles in ethylene glycol. Their results disclose about 30% thermal conductivity increment for particle concentration of 0.5% volume. Similarly, Paul et al. [34] obtained for a blend of a metal-metal combination of Al_{95}-Zn_5 (15 nm) an enhancement of 16% at 0.1% volume concentration. Summary of thermo-physical property enhancement of hybrid nanofluid is shown in Table 1.

Seemingly, different nano-additives of metal-ceramic material combination have been investigated and reported in the literature. However, there are fewer studies reported using ceramic-ceramic nano-additive for heat transfer fluids in solar thermal applications. Among the oxides of metals, copper oxide (CuO) has a high thermal conductivity compared to other metal oxides whereas Silica (SiO_2) exhibits high thermal stability (up to 1728 °C), low density and superior corrosion resistance compared to CuO. The combination of the two metal

Table 1
Summary of thermophysical property enhancement of hybrid nanofluids.

Authors	Nano-additive	Base fluid	Maximum thermal conductivity enhancement (%)	Maximum viscosity enhancement (%)
Suresh et al. [22]	Al_2O_3/Cu	W	12.1	205
Hemmat Esfe [23]	Cu/TiO_2	W/EG 60:40	40	–
Madhesh et al.[24]	Cu/TiO_2	W	19.3	–
Nabil et al. [28]	TiO_2/SiO_2	W/EG 60:40	22.8	62.5
Nikkam et al. [29]	SiC/SiO_2	W/EG 50:50	20	14
Chopkar et al. [33]	Al/Cu	EG	30	–

– Data not provided.