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Heat Transfer Performance of ZnO- Ethylene Glycol-Water Nanofluid Using Thermal Lens Technique

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Abstract

Nanofluids are engineered fluids used in advanced electronic systems for thermal management. Fluids with dispersed nanoparticles have exhibited remarkable thermal properties. Ethylene glycol (EG) and water mixtures are widely used in many industrial areas. This study investigates the synthesis and heat transfer performance of ZnO-EG, ZnO-water, and ZnO-EG-water nanofluids using a dual-beam thermal lens technique. ZnO is a widely used inorganic, UV-absorbing, multifunctional semiconducting material with applications in various fields due to its electrical, optical, and mechanical properties. Good transparency, high electron mobility, a wide band gap, and strong room-temperature luminescence are the favorable properties of ZnO, which have led to its application in numerous scientific fields. ZnO nanoparticles were synthesized using a simple solution method followed by ultrasonication, where ethylene glycol dispersed in zinc acetate dihydrate and NaOH were used as precursors. ZnO nanopowder was obtained and dispersed in water, ethylene glycol, and ethylene glycol-water to prepare a 0.1 mg/ml concentrated stable ZnO nanofluid. The morphology of the synthesized nanoparticle was found using HRTEM, which concluded the spherical shape of the nanoparticles. The thermal diffusivity of the solvent and solvent-ZnO nanofluids was investigated using the dual-beam thermal lens technique. Significant enhancement in thermal diffusivity is observed when ZnO nanoparticles disperse in EG-water fluid. This enhancement in thermal diffusivity was observed due to the phonon scattering at the liquid-solid interface and the excellent stability of the nanofluid. The superior heat transfer performance of ZnO-EG-water nanofluid could be used as a coolant in optoelectronic devices instead of EG and water.

Keywords: ZnO, ethylene glycol, nanofluids, thermal diffusivity, coolant

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INTRODUCTION

Thermal nanofluids, one of the newly emerged engineered fluids have been curiously studied in both industrial academic fields. Nanofluid is a fluid suspended by 1-100nm-sized particles with increased surface area. They are heat transfer fluids with excellent thermal conductivity and convective heat transfer performance. Since the formation of the concept of nanofluid by Choi[1], numerous experimental and theoretical studies have been carried out to study optoelectronic devices[2,3,4]. Most frequently used are water, oil, and ethylene glycol, which can be classified as either oil-based nanofluids or water-based nanofluids. Commonly added nanoparticles include metal oxides, metallic particles, ceramics, and different forms of carbon.

Nowadays researchers have tried to enhance the photothermal properties of fluids typically for water, ethylene glycol, and its binary mixtures. Water and ethylene glycol are conventional heat transfer fluids in the industrial sector due to their excellent heat transfer capabilities. However, their binary mixtures exhibit superior heat transfer properties and emerge as a more effective solution in industrial applications. The binary mixtures of water and EG show many advantages such as high boiling temperature, and low melting temperature which encourages the usage of the mixtures in cold and high-temperature areas. Based on these excellences these base fluids have been used in fuel cells, air conditioning, antifreeze in car engines, and solar energy utilization[5,6]. Thermal conductivity is the primary thermo-optical properties for fluids influencing the heat transfer ability used in optoelectronic devices. So, it is essential to enhance the thermal conductivity of the EG-water binary mixture. For studying the enhancement of thermal conductivity, we dispersed ZnO nanoparticles in selected fluids such as water, EG, and EG-water binary mixture.

Zinc oxide (ZnO) is a multifunctional semiconducting material used in various fields [7,8]. Several works have reported on the thermal parameters of Al_2O_3, TiO_2, CuO, and metallic nanoparticles dispersed in water or EG or water-EG. Very few works have been reported and studied the heat transfer properties of ZnO in EG-water mixture. D Cabaleiro et al.[9] experimentally investigated the ZnO concentration effect in an EG-water base fluid using the transient plane source technique and showed that increasing the concentration of ZnO increased the dynamic viscosity. Our group previously examined the particle size and concentration effect of ZnO dispersed in water using the thermal lens technique. Results showed that there is an optimum size (∼17nm) and concentration (0.01mg/ml) for the enhancement of thermal diffusivity[10]. In the present work, we determined the thermal diffusivity of water, EG, and EG-water binary mixture and their ZnO nanofluids with a particle size of 17nm and a concentration of 0.01mg/ml.

EXPERIMENTAL

The solution method was employed in the preparation of ZnO nanoparticles. Ethylene glycol dispersed zinc acetate dihydrate (0.1M) and NaOH (0.5M) are mixed under ultrasonication and heated at 150°C for 2 hours using an oil bath. The ZnO nanosol thus obtained was kept to rest for a day for the aging process. After centrifugation and drying, ZnO nanopowder was obtained are shown in Figure 1. More synthesis and characterization details are explained in our previously published paper [10]. The morphology of synthesized nanoparticles was examined using HRTEM (JEM2010) analysis and shown in Figure 2. The particle shows spherical-shaped nanoparticles with an average size of nearly 17nm. Generally, nanofluids are prepared using a one-step and two-step approach. In the one-step approach simultaneously preparing and dispersing nanoparticles in the fluid and ensuring a high uniformity and dispersion stability. In a two-step approach, first synthesizing the nanoparticles and dispersing them in the base fluid. This ensures greater control over particle size [11-15]. The two-step method is widely used in the synthesis of metal oxide nano/microfluids on an industrial scale. In this method, initially we prepare the nanoparticles using physical, chemical, or biological methods and then disperse them in fluids using ultrasonication. Schematics of nanofluid preparations are shown in Figure 3.

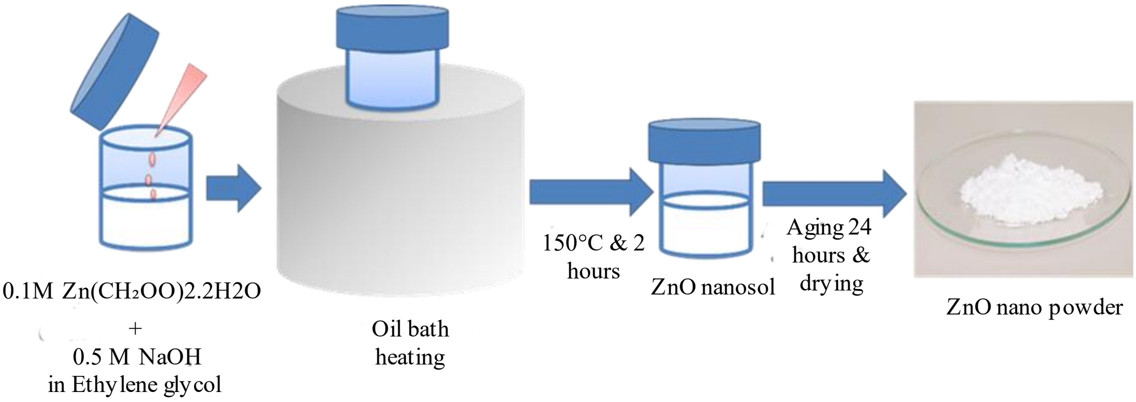

Figure 1. Schematics of ZnO nanoparticle synthesis method.

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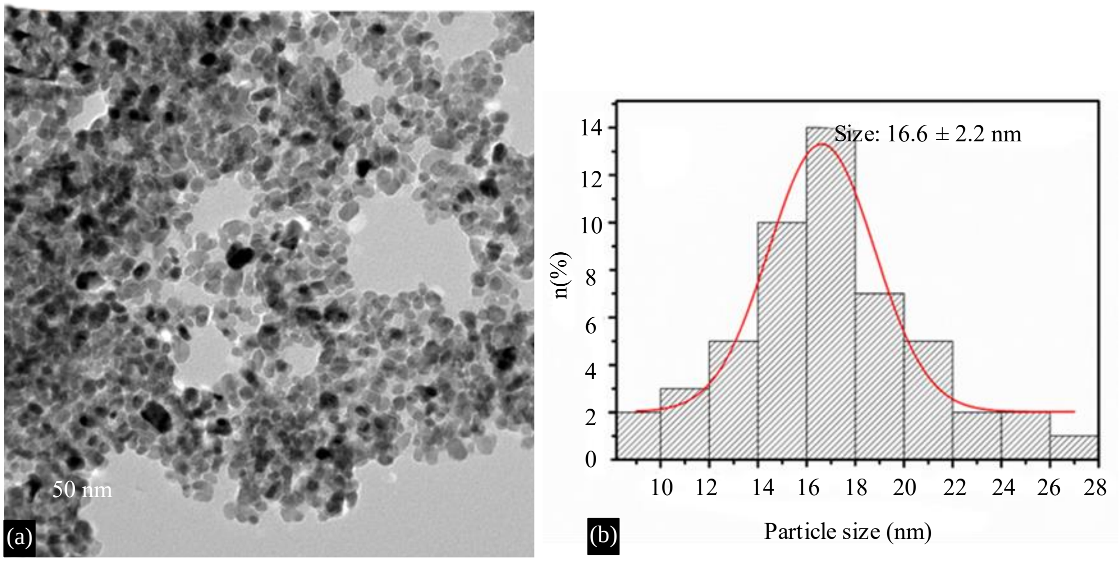

Figure 2. TEM image and particle size distribution of ZnO nanoparticles.

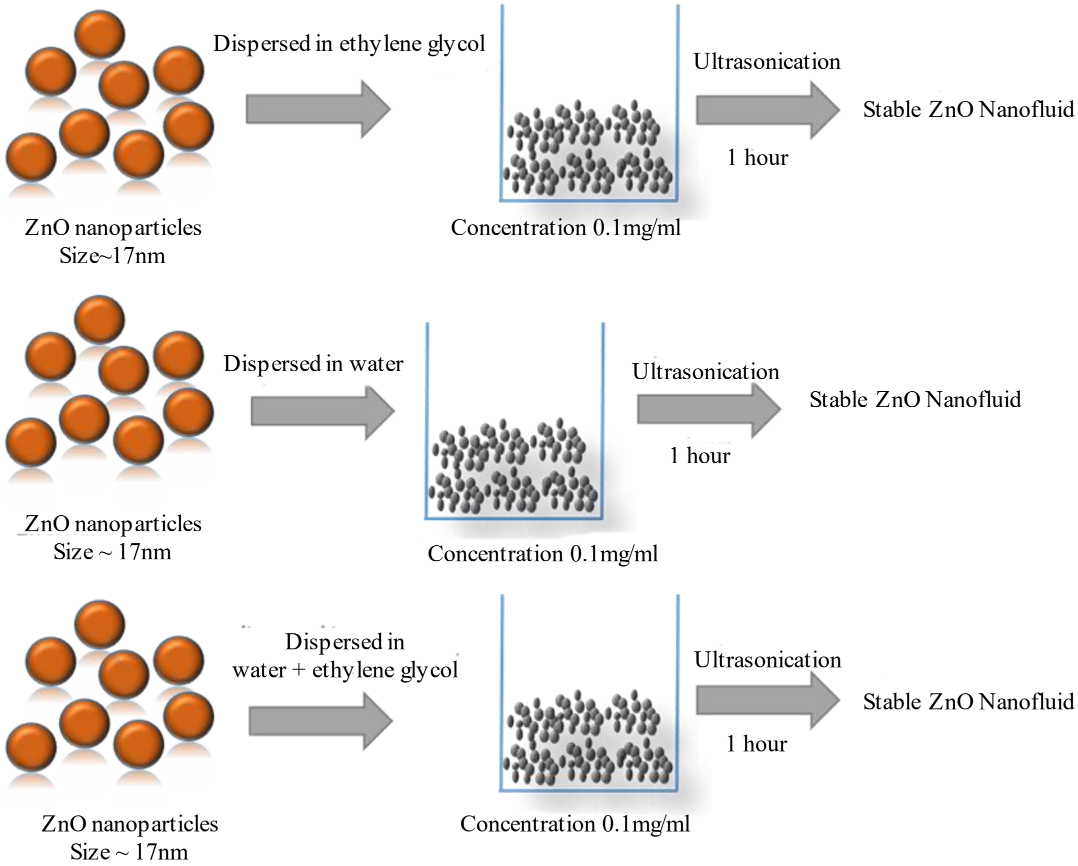

Figure 3. Schematics of the two-step method of ZnO-nanofluid preparation.

The stability of the nanofluids is the prime factor for any device or industrial application. When we add nanoparticles in fluids, there is a strong tendency to form aggregates. These aggregated nanofluids lose their heat-transferring properties. Therefore, the primary challenge in nanofluid preparation is to achieve stable and dispersed nanofluids. In the time of nanofluid preparation, we employed ultrasonication treatment which helps to increase the stability. The colloidal stability of the nanofluids was estimated by measuring the zeta potential (ζ) using Horiba SZ 100 particle size analyzer. If the ζ is greater than ±30mV, the colloids are stable otherwise colloids are agglomerated. The estimated zeta potential values were -45.3mV, -45.2mV, and -49.6mV for ZnO particles dispersed in water, EG, and EG-water mixture respectively.

The thermal lens (TL) is a nondestructive laser photothermal technique used to find the thermal conductivity of nanofluids. Here we used, mode-matched collinear thermal lens configurations, where DPSS CW laser (λ = 403nm, power = 100mW) acts as pump laser and He-Ne (λ = 632.8nm, power = 4mW) as probe laser. More descriptions of the thermal lens experimental setup and theoretical backgrounds are explained in our previous publications[10,16,17].

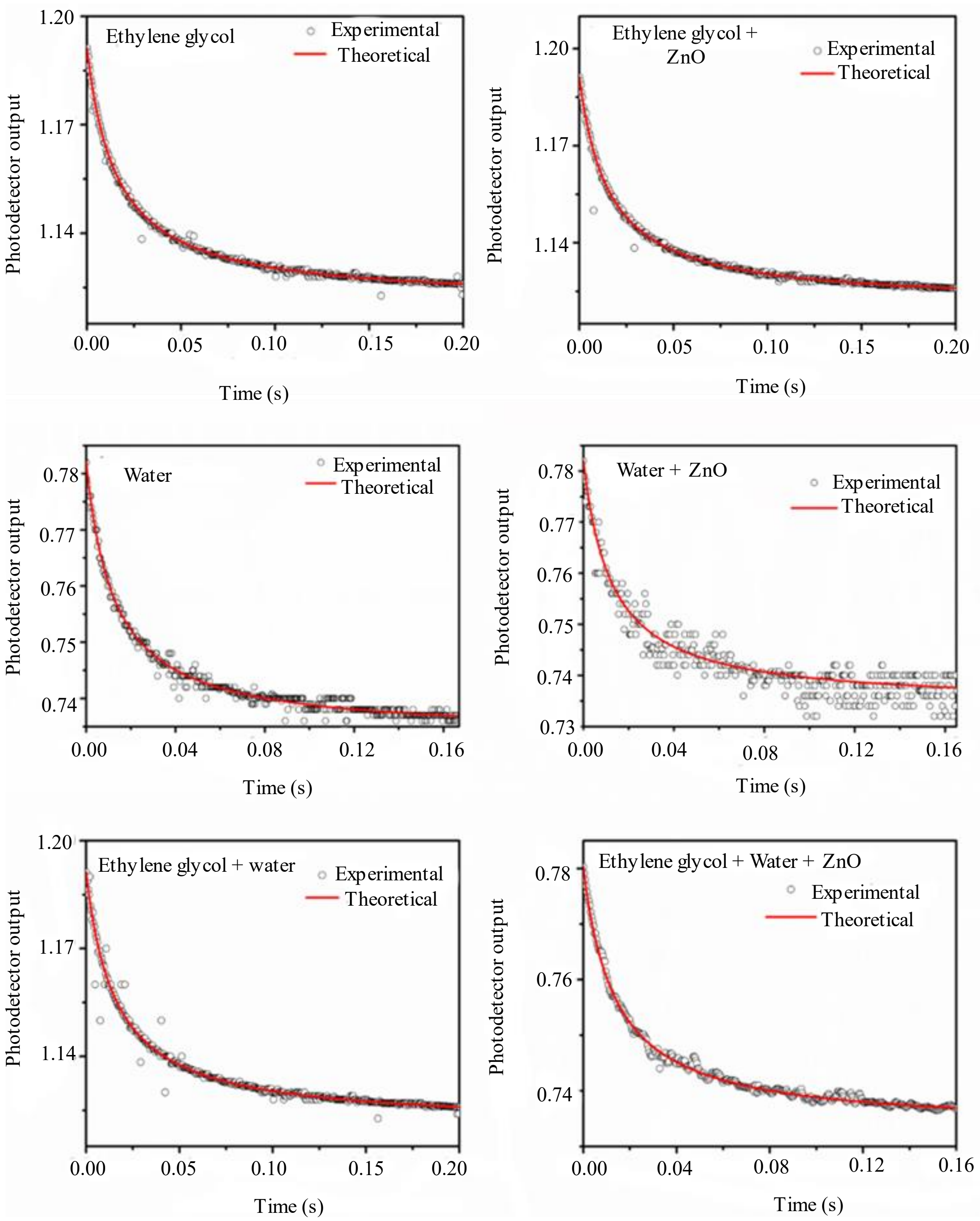

Figure 4. Thermal lens signal recorded for solvents and solvent - ZnO nanofluids.

Table 1. Tabulated thermal diffusivity values of solvent and solvent-ZnO nanofluids.

Solvents	**Thermal Diffusivity (∝) × $10^{-3}cm^2/s$**	
	Solvent only	***Solvent + ZnO nanofluid***
Water	1.40	1.42
Ethylene glycol	0.96	1.06
Ethylene glycol + Water	1.03	1.70

RESULTS AND DISCUSSION

To understand the thermal diffusivity (α) of selected fluids and their ZnO nanofluids, we have conducted the thermal lens experiment and chose water as a reference sample. The thermal diffusivity of an unknown nanofluid can be measured using Equation 1.

$$\alpha_{sample} = \alpha_{water} \, {t_c^{water}} \Big/ {t_c^{sample}} \quad (1)$$

The recorded thermal lens signals are shown in Fig.4 and the calculated α values are summarized in Table 1. From this, it is clear that ZnO nanoparticle addition effectively influences the thermal diffusivity of the fluids, significantly for the EG-water binary mixture. This is due to the higher stability of ZnO in the EG-water mixture. This higher stability enhances the thermal diffusivity of the nanofluids compared to other samples. Apart from this stability phonon scattering, formation of nanolayer structure, and interfacial thermal contact between solvent - solute are the main reasons for the heat transfer increment. When the nanoparticle's size reaches the order of phonon mean free path, it reduces scattering and increases the thermal diffusivity. In the case of large particles interfacial thermal resistance is reduced which also positively contributes to thermal diffusivity[10,18]. Here we used 17 nm-sized nanoparticles, which offer low interfacial resistance and good thermal contact between the nanoparticles and fluid.

CONCLUSIONS

This work investigated the thermal diffusivity of ZnO nanoparticles dispersed in selected solvents such as water, EG, and EG-water binary mixture. Thermal diffusivity was found to increase with the addition of ZnO nanoparticles especially for nanoparticles dispersed in an EG-water binary mixture. This increment in thermal diffusivity is due to lower interfacial thermal resistance, good contact between nanoparticles and surrounding liquids, and, excellent stability. So, this work suggested that ZnO-EG-water nanofluids be used as a medium in solar heating installation and as an antifreeze in car engines.

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