Experimental Study of Thermal Characteristics of ZrO2/EG nanofluid for Application of Heat Transfer

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Experimental study of thermal characteristics of ZrO_2/EG nanofluid for Application of Heat Transfer

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Abstract

In thermal management system nanofluids will act as robust elements in future for coolants. Nanofluids have remarkable potential during the heat transfer increase reported by researchers from all over the world. Nanofluids have attracted many researchers and there have been tremendous advances because of the high thermal characteristics and possible applications in certain areas such as the transport sector, aerospace, medical regions and microelectronics. This current study reports on the thermal characteristics of nanofluid based on ZrO_2/EG. The nanoparticles characterized by XRD and SEM techniques. Nanofluid was prepared by a two-step method in ethylene glycol (EG) using ultra sonication. The thermal conductivity of ZrO_2/EG nanofluid was investigated experimentally at various volume concentrations (0.02-0.1vol. %) and temperature range between 35-55^{o}C. The enhancement in thermal conductivity was observed to be 26.2 % at 0.1vol. % which exhibits superior performance as compared to base fluid (EG). The results of the experiment were compared with the three most often utilised model in the literature. The behavior of ZrO_2/water based nanofluid thermal conductivity, viscosity and stability in various concentrations was studied.

Key words: Zirconia, ethylene glycol, Nanofluid, thermal conductivity, viscosity, Stability

Introduction

As world competition increases, industry needs to develop advanced heat transfer fluids that have considerably higher thermal conductivity than is currently available. The thermal conductivity of the heat transfer fluid plays an essential role in developing energy-efficient heat transfer equipment. However, inherently poor heat transfer fluids, are the traditional heat transfer fluids such as ethylene glycol and water mixtures, ethylene glycol (EG), water, and oil.

Nanofluids are the most efficient fluids for heat transfer applications in transportation, electronic cooling, industrial cooling, aerospace, and defense cooling systems, and renewable energy (Kakac et al. 2002). To improve the convective heat transfer properties of conventional fluids, the fundamental concept is to improve the thermal conductivity of these base fluids. Numerous factors contribute to improving thermal conductivity such as volume fraction, particle size, shape, material, base fluid, temperature, Brownian motion, and aggregation of nanoparticles (Simpson et al.2019). The thermal conductivity of nanofluid is a property that can straightforwardly impact heat transfer ability of nanofluid (Choi 2008). A nanofluid is a fluid that contains nanometer-sized (1-100nm) nanoparticles. These liquids are engineered nanoparticles' colloidal suspensions in a base fluid. Superior thermo physical properties of nanofluid such as thermal conductivity, viscosity, and coefficients of convective heat transfer compared to base fluids (Kulkarni et al. 2008; Vajjha et al. 2010; Peyghambarzadeh et al. 2011; Leong et al. 2010).

A property that can have a direct impact on the heat transfer capacity of nanofluid is its thermal conductivity (Choi and Eastman 1995). The most common additives used in order to enhance thermal conductivity are the metal oxides (Al_2O_3, TiO_2, MgO, Fe_2O_3, SiO_2, CuO, ZnO), metal nitrate, carbid (ACS, SiC), metals (Cu, Ag, Ni, Au) and the carbon (diamond, graphite, CNT, MWCNTs) (Sajid and Ali 2018). The researchers have been interested in Zirconia (ZrO_2) due to their inert chemical existence, thus imparting long-term stability and lower cost of production (Elwahed and Mesilhy 2020).

(Ettefaghi et al. 2013) studied the thermal properties by adding MWCNTs with a different concentration in engine oil. They found that thermal conductivity was 13.2% at 0.5wt%. It has been investigated that, higher stability is achieved with lower concentration. (Li et al. 2016) experimentally studied the silicon carbide (SiC) nanofluids thermal conductivity and viscosity dependent on motor coolants. They found that thermal conductivity was 53.81% at 0.5 vol. %. (Maheshwary et al. 2017) has been investigated TiO_2/water-based nanofluid's thermal conductivity based on particle size, shape, and concentration. It was found that concentration is the main cause in the augmentation of thermal conductivity. (Batmunkh et al. 2014) showed an intensification in the thermal conductivity from (0.619 - 0.627 W/mK) at 40^{o}C with the addition of 0. 5wt. percent Ag into 3 wt. percent TiO_2/water nanofluid. (Munkhbayar et al.

2013) have studied the enhancement of CNTs surface properties by using silver nanoparticles. Volume concentration (0-3%) and temperature range 15-40°C were used in the preparation of nanofluids. It was observed that improvement in thermal conductivity 14.5 percent contrasted with the base liquid. (Hung et al. 2012) found that adding 1.5 wt. % Al_2O_3 nanoparticles to water improved heat transfer by 40%. It is also demonstrated that lower operating temperatures result in better heat transfer performance. (Guo et al. 2018) studied SiO_2/ (EG-Water) nanofluid's thermal conductivity. They observed that the thermal conductivity of nanofluid increased with rising in temperature. Also found to be volume concentration is an important factor for the enhancement of thermal conductivity. (Thrush et al. 2020) have been studied the enactment of tribological applications and the stability of ZrO_2 nanofluids. The dispersion's stability was tested over a period of twenty-five months to ensure that the nanoparticles did not clump together or settle out of the solution. It has been found that for concentration equal to or more than 0.1% wt., the tribofilm growth rate swift and stability more than two years. As a result, tribological performance of ZrO_2 nanofluids has been reported as a function of nanoparticle concentration.

The available literature reveals that there have been few studies on the thermal conductivity and viscosity of ZrO_2/EG nanofluid. Mostly, concentration of the nanoparticles normally used in the preparation of the nanofluid is above 0.1 vol. %. When volume concentration of the nanoparticle increases in base fluid then there is problem of clogging, sedimentation and settling down the nanoparticle. Therefore, the objective of present work to study experimentally thermal characteristics of ZrO_2 nanoparticle has been suspended in base fluid ethylene glycol at lower volume concentrations i.e. (0.02-0.1vol. %) with interval of 0.02vol. % and temperature range between 35-55°C. The results of the experiment were compared with the three most often utilised model in the literature.

Preparation process of nanofluids

The two-step approach for preparing nanofluids is the most often used in the literature (Starace et al. 2011; Chen et al. 2011). Two-step methods are used in the current study for heat transfer purposes. This method to be an economic method for mass production. In particular, Equations (1) calculated and re-evaluated in measuring the precise equilibrium of the nanoparticles to be used at five different volume concentrations of nanofluids 0.02%, 0.04%, 0.06%, 0.08% and 0.1% (Kannaiyan et al. 2017).

$$\% \text{ Volume concentration} = \left[\frac{\frac{W_{np}}{\rho_{np}}}{\frac{W_{np}}{\rho_{np}} + \frac{W_f}{\rho_f}} \right] \quad (1)$$

Where, ρ_{np}, W_{np} → density and weight of nanoparticles

ρ_f, W_f → density and weight of base fluid (EG)

To make sample nanofluids, 100 ml of the base fluid (ethylene glycol) were distributed in preweighed amounts of zirconia nanoparticle. After 30 minutes the sample was stirred in a magnetic stirrer before it was placed 3 hours in an ultrasound bath. Ultrasonic and mechanically agitated stirring are used to break the agglomeration of nanoparticles to keep them intact for a longer period of time.

Measurement of thermal conductivity and viscosity

Nanofluid's thermal conductivity was evaluated by using the thermal properties analyzer KD2 Pro (Decagon Devices, USA). The transient hot-wire method of functioning is used. Single-needle sensors assess thermal conductivity and resistivity, while dual needle sensors measure thermal conductivity, volumetric specific heat capacity, resistivity, and diffusivity using this instrument. The accuracy of this device is ±5.0 percent. ZrO_2/EG nanofluid's thermal conductivity measurement device as shown in figure 1. To increase precision, the data was collected in triplicate, and the average value was utilized for analysis.

In this experiment, we use a Red wood viscometer to determine viscosity. A preset amount of fluid may flow through a capillary tube of specific dimensions in these viscometers under a predetermined set of parameters and the flow rate at a certain temperature is measured. The viscosity of oil thus determined in the units is sometimes referred to as relative viscosity. As the instruments used are kinematic in the standard dimension of the oil in the centistokes, it can be calculated by using the following equation (2) as the oil passes through the standard orifice of the instrument.

$$\nu = C * t \quad (2)$$

ν → kinematic viscosity

t → time of flow in second

C = viscometer constant (value of C depends on t)

Fig. 1 Measurement of thermal conductivity of ZrO_2/ EG nanofluid

The measured thermal conductivity values ZrO_2/EG nanofluids compared with the predicted values from already presented models. For this three models have proposed the most frequently used model to find out nanofluids' thermal conductivity.

(Hamilton and Crosser 1962) model was used to estimate the nanofluid's thermal conductivity:

$$K_{nf} = \frac{k_p + k_{bf} \times (n-1) + (n-1)\left(k_p - k_{bf}\right)\emptyset}{k_p + k_{bf} \times (n-1) - \left(k_{bf} - k_p\right)\emptyset} k_{bf} \tag{3}$$

(Maxwell 1891) model was utilized to ascertain nanofluids' thermal conductivity:

$$K_{nf} = \left[\frac{k_p + 2 \times k_{bf} - 2 \times \emptyset\left(k_{bf} - k_p\right)}{k_p + 2 \times k_{bf} + \emptyset\left(k_{bf} - k_p\right)} \times k_{bf}\right] \tag{4}$$

(Yu and Choi 2003) was also utilized to determine thermal conductivity of the nanofluid:

$$K_{nf} = \left[\frac{k_p + 2 \times k_{bf} - 2 \times \emptyset\left(k_{bf} - k_p\right) \times (1+\beta)^3}{k_p + 2 \times k_{bf} + \emptyset\left(k_{bf} - k_p\right) \times (1+\beta)^3} \times k_{bf}\right] \tag{5}$$

Here, K_p, k_{bf} → thermal conductivity of nanoparticle and base fluid

Ø → volume concentration and β=0.1 was used by Yu and Choi for nanofluids.

Results and Discussion

Characterization of sample

By X-ray diffractometer (Bruker AXS D8 advance), the crystallinity and phase pureness of the synthesized ZrO_2 was determined. XRD pattern (Figure 2) of the zirconia exhibits high crystallinity with sharp peaks at 2θ, 31.23° and 51.32°, respectively. A JEOL appliance has been used with the Scanning Electron Microscope (SEM) (Model – JEOL 6380A for identification of microstructures. Figure 3 SEM image reveals the presence of ZrO_2 spherical nanoparticles with an average range of <100 nm in particle size.

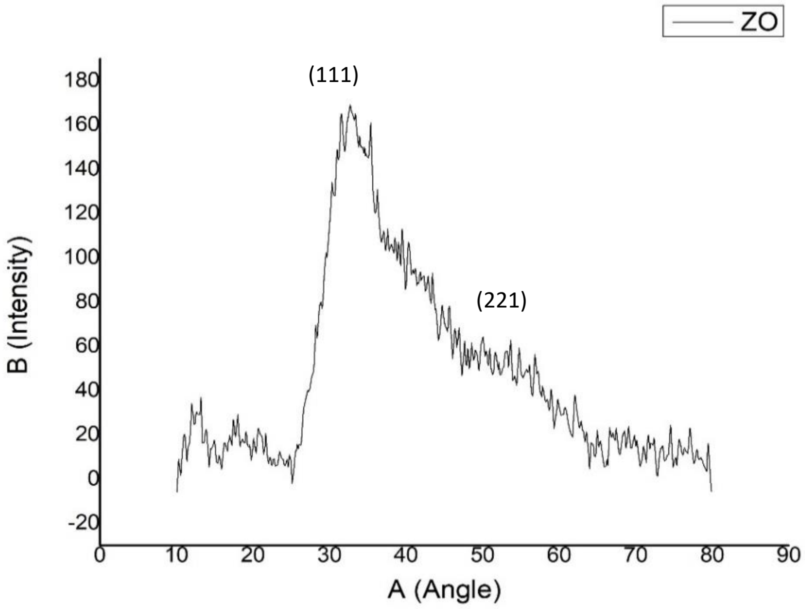

Fig. 2 XRD images of ZrO_2 nanoparticles

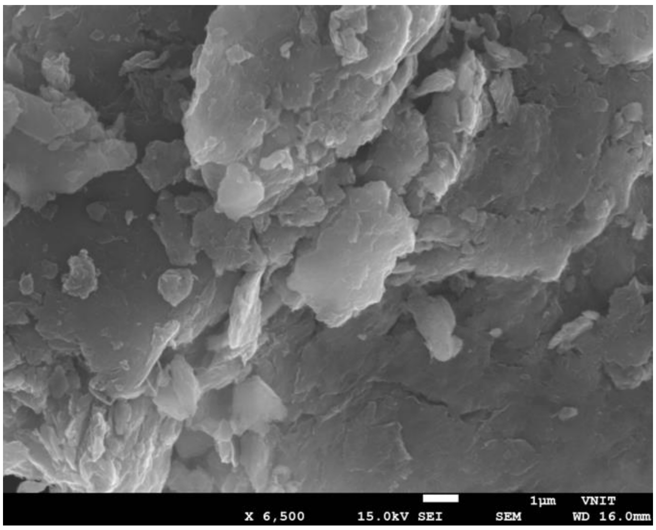

Fig. 3 SEM image of ZrO_2 nanoparticle

Monocline nanoparticles ZrO_2 (111) and (221) were discovered respectively as highest diffractive diffraction levels at 2θ 31.23º and 51.32º. The typical JCPDS file (88-2390) of monoclinic ZrO_2 (Singh et al. 2015; Wang et al. 2014; Das et al. 2019) was found to be quite similar to these diffraction peaks.

Thermal conductivity and viscosity

The thermal conductivity of ZrO_2/EG nanofluids was evaluated with varying volume concentrations of nanoparticles (0.02 to 0.1 vol. %) at temperatures ranging from 35 to 55°C, as shown in figure 4. It reveals that nanofluids boost the thermal conductivity as their volume concentration and temperature rise. Thermal conductivity of the base fluid, Ethylene glycol (EG), was first calculated (0.244W/m-K), and then ZrO_2 nanoparticles were introduced to the base fluid (EG) in varied volume concentrations (i.e.0.02 to 0.1vol. percent) at temperatures ranging from 35 to 55 degrees Celsius.

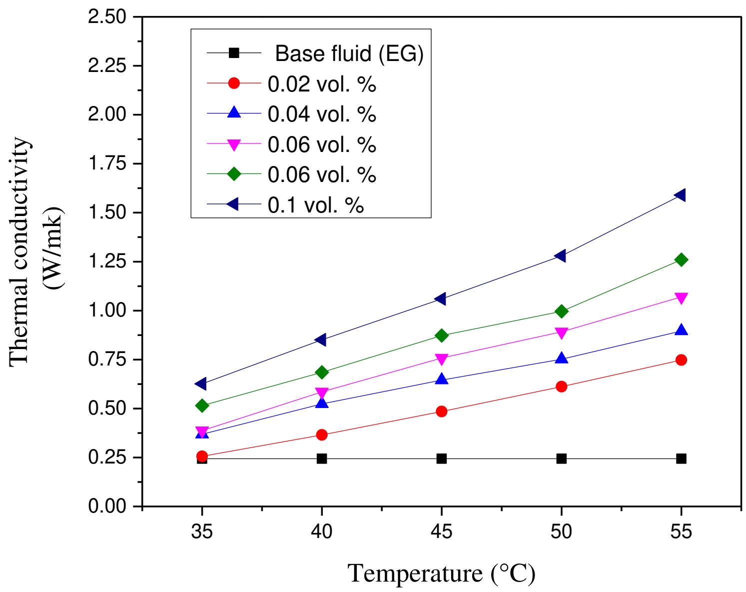

Fig. 4 Thermal conductivity of ZrO_2/EG nanofluid at different temperatures

In the analysis of the effect on thermal conductivity of nanofluid that five different volume concentration and temperature interval of 0.02% and 5°C was taken. It shows an improvement in the thermal conductivity with increasing volume concentration and temperature. Figure 5 illustrated that thermal conductivity of ZrO_2/EG nanofluid in aspects of volume concentration at different temperature. According to this figure, adding ZrO_2 nanoparticles to the base liquid leads to increases in thermal conductivity levels at any temperature. Figure 6 shows the thermal conductivity of ZrO_2 /EG nanofluid at various volume concentrations. It may be understood that, with the increased volume of nanoparticles in base fluids, the thermal conductivity of all nanofluid has been improved. For different nanofluids, similar cases had been reported before (Paul et al. 2011; Mostafizur et al.2014; Ijam et al. 2015).

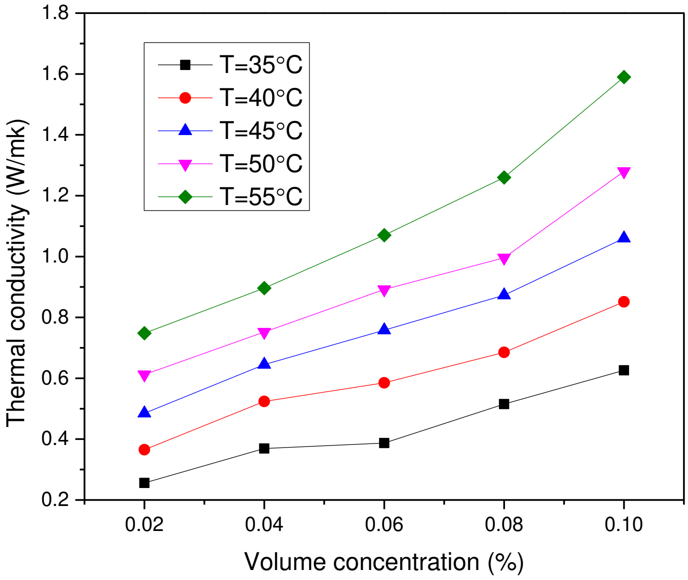

Fig. 5 Thermal conductivity of ZrO_2/EG nanofluid in aspects of volume concentration at different temperature

A variety of parameters influence the thermal conductivity of nanofluids, including nanoparticle volume concentrations in base fluid, nanoparticle type and morphology, basic fluid type, base fluid temperature, and method of preparations (Murshed et al. 2008; Murshed et al. 2005).

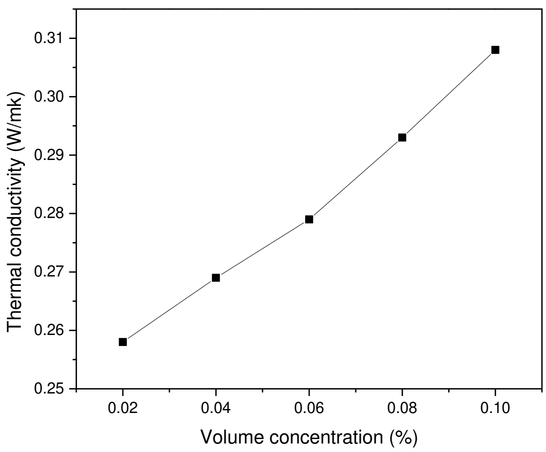

Fig. 6 Thermal conductivity (ZrO_2/EG nanofluid) at various volume concentration.

Nanofluids were computed using the following equation for thermal conductivity improvements (Senthilraja et al. 2015).

$$\text{Thermal conductivity enhancement } (\%) = \left[\frac{K_{nf} - K_f}{K_f}\right] \times 100$$

Where,

K_f, K_{nf} → thermal conductivity base fluid and nanofluid

Figure 7 shows the percent enhancement in the thermal conductivity of ZrO_2/EG nanofluids at different volume concentrations. Significant enhancement in the thermal conductivity were recorded for ZrO_2/EG nanofluids (5.73%, 10.24%, 14.34%, 20.08%, and 26.2%) for various volume concentrations of (0.02 vol. %, 0.04 vol. %, 0.06 vol. %, 0.08 vol. %, and 0.1vol. %) respectively, which exhibits superior performance as compared to base fluid (EG)

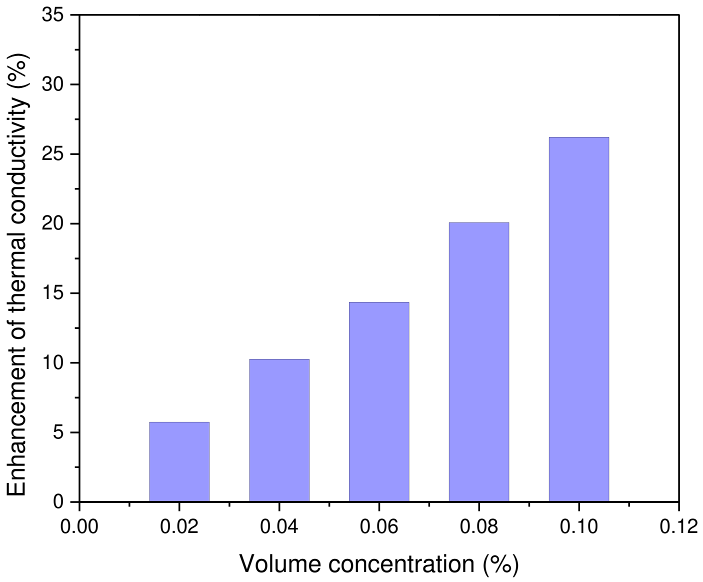

Fig. 7 Enhancement of thermal conductivity (ZrO_2/EG nanofluid) at various volume concentration.

Thermal conductivity has been enhanced because of Brownian mobility and collisions between nanoparticles in base fluid (Hojjat et al. 2009). The thermal efficiency of the energy system is due to the large nanoparticles surface area per unit volume that allows more transfer of heat between solid particles and base fluids (Yin et al. 2018). Figure 8 illustrates the experimental viscosity of ZrO_2/EG nanofluid as well as base fluid. It has been revealed that when the temperature rises, the viscosity of nanofluid reduces.

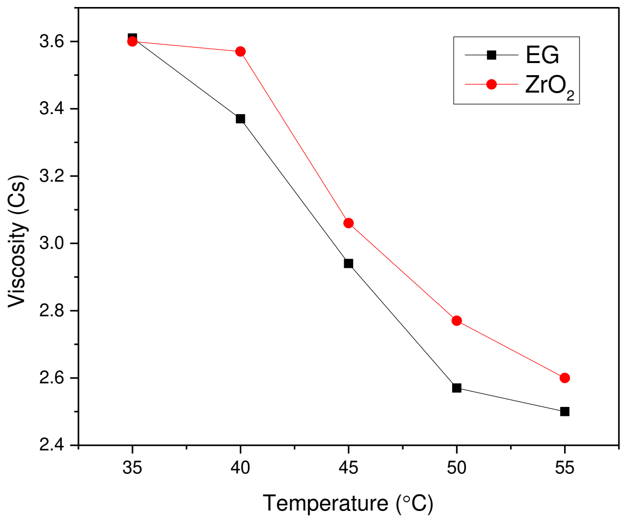

Fig. 8 Viscosity of ZrO_2/EG nanofluid at different temperature

The measuring ZrO_2/EG nanofluid thermal conductivity values compared to the values predicted in the previous models. Figure 9 compare these experimental values with predicted values using conventional models at different volume concentrations ranging between 0.02 and 0.1%.

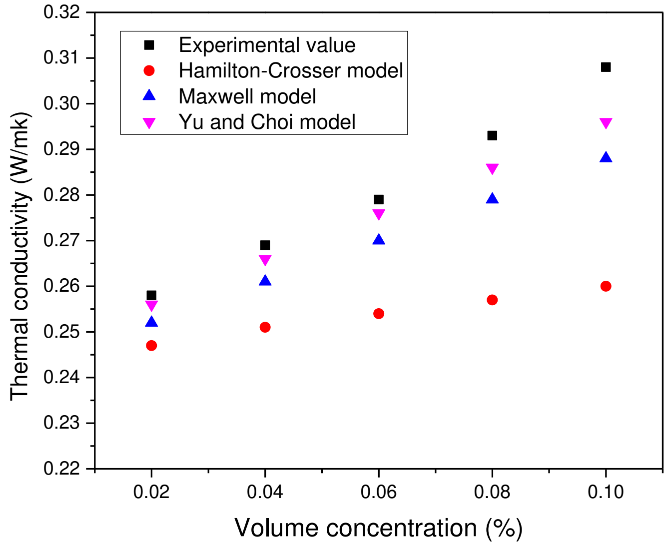

Fig. 9 Experimental thermal conductivity of ZrO_2/EG nanofluid compared to theoretical model at various volume concentration.

For all volume concentrations, the experimental results of the nanofluid revealed higher thermal conductivities than the models developed by Hamilton- Crosser, Maxwell, and Yu and Choi. The thermal conductivity increases with increasing volume concentration, according to both experimental data and models. The anticipated models had not taken into consideration the impact of particle size and interfacial layer formed at the interface of the particle and fluid.
The zeta potential method determines the difference in potential between the bulk fluid and the stationary layer of fluid in contact with nanoparticles. To estimate formulation stability, zeta potential measurement was taken into consideration. Figure 10 shows that zeta potential of ZrO_2/EG nanofluid at various volume concentration.

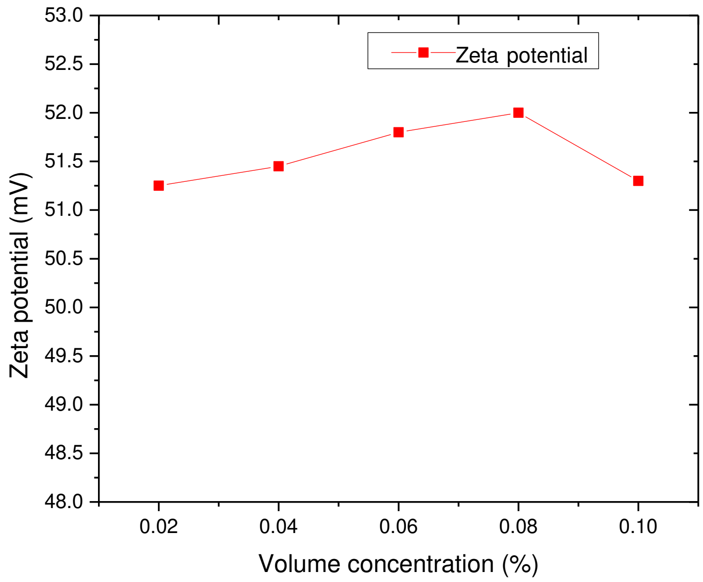

Fig. 10 Zeta potential of ZrO_2/EG nanofluid at various volume concentration.

After a week, the nanofluid was found to be stable, with zeta potential values larger than 50mv.

Conclusions

In this work, A KD2 Pro thermal property analyser was used to estimate the thermal conductivity of ZrO_2/EG nanofluid with five different volume concentration (0.02%, 0.04%, 0.06%, 0.08%, and 0.1%). Nanofluid was prepared by a two-step method in ethylene glycol (EG) using ultra sonication. Enhancement of thermal conductivity was obtained by 26.2% compared with base fluid ethylene glycol at 0.1vol. %. The impact of concentration and temperature of nanoparticles on improvements in thermal conductivity was deemed. Its shows that the enhancement in thermal conductivity of nanofluid is influenced by volume concentration and temperature. For all volume concentrations, the experimental results of the nanofluid revealed higher thermal conductivities than the predicted models' value. A significant increase in thermal conductivity has been seen in nanofluids. Zeta potential method use to formulate stability of nanofluid and found to be stable, with zeta potential values larger than 50mv. As a result, ZrO_2 nanoparticles are likely to play a substantial role in heat transfer, and this aspect of nanofluid was further investigated. This reveals that nanofluids are the future generation's most promising heat transfer fluids.

Ethics declarations

Ethical approval and consent to participate

Not applicable.

Consent to publish

Not applicable.

Availability of data and materials

Not applicable.

Competing Interests

The authors declare no competing interests.

Funding

Not applicable.

Authors Contributions

Rohinee M. Barai: investigation, methodology, writing, review and editing; Devesh Kumar: conceptualization, supervision and formal analysis; Atul V.Wankhade: conceptualization, supervision and formal analysis; Aamir R.Sayed: review and editing; Anup A. Junankar: writing, review and editing.

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