BAOJ Nanotechnology

Venu Gopal VR and Susmita Kamila, BAOJ Nanotech 2016, 3: 1
3: 013

Review

Thermo-Acoustics and Rheological Properties of Various Heat Transfer Fluids Blended with Cuo Nanoparticles

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Abstract

The purpose of the present investigation is to study the effect of adding copper oxide nano powder to the conventional heat transfer fluids for their thermal and acoustics properties. CuO nano powder was synthesized and subsequently different nanofluids were prepared in various base fluids such as water, ethylene glycol (EG), tri-ethylene glycol (TEG) by ultrasonication technique. Synthesized CuO nano powder was characterized for its shape and size from X-ray diffraction analysis (XRD), Energy dispersive X-ray analysis (EDXA) and Scanning electron microscopy (SEM) analysis. Besides, thermo-acoustical properties such as isentropic compressibility and acoustic impedance of prepared nanofluids have been studied from measured ultrasonic velocity, density data to understand the molecular environment of the dispersed phases at different temperature. The dynamic viscosity shows the nanofluids to be non-Newtonian fluids at very less shear rate. Moreover, the enhanced thermal conductivities and ultrasonic velocities for all nanofluids at different temperatures from their base fluids suggests the nanofluids to be better heat transfer fluids from their respective base fluids.

Keywords: Cuo Nanofluids; Thermo-Acoustical Properties; Ultrasonic Velocity; Thermal Conductivity

Introduction

Heat management in industries and automobile sectors is becoming a challenging task for the investigators due to the continuous strive to impress the efficient utilization of energy. Heat transfer fluids have been an integral part of this process for many years. The heat transfer capacity of a fluid can be enhanced by changing flow geometry, boundary conditions, or by increasing the thermal conductivity. Varieties of heat transfer fluids both organic and aqueous origin were being used to meet the operating needs of diverse applications. Apart from water, ethylene glycol has better heat transfer properties including high density and low viscosity in comparison to many other fluids. However, TEG is non-toxic and more eco-friendly to be used as heat transfer fluid [1]. Researchers have also tried to increase the thermal conductivity of base fluids by suspending micro- or larger-sized solid particles in fluids, since the thermal conductivity of solid is typically higher than that of liquids. Study is being carried out by using nano particles in heat transfer fluids, where these nano particles found to boost the heat transfer capacity of base fluids [2]. Review of literature shows that metals and metallic oxides in their nano scale are utilized for the preparation of nanofluids [3-5]. Because of their unique physical, chemical, thermal and structural properties from bulk materials, these nano particles have extensive applications in various frontier areas like optoelectronics [6,7], sensing [8], catalysis [9], solar cells etc,. In the area of nano research, investigations on nanofluids are quite demanding field apart from nanoparticles. These are the most modern class of fluids engineered by Choi et al [10].

Out of many metal oxides, CuO nanoparticles are the promising materials due to their applications in various technologies both as solid form as well as in fluids. CuO nanoparticles blended with fluids have many potential applications in the industries and instruments especially with heat transfer systems. Dispersivity of nanoparticles in fluid is the key factor to be considered for choosing a nanofluid for heat transfer applications. This dispersion behaviour can be better understood from the thermal, rheological and acoustic properties of the nanofluids.

So the major objectives of the present investigation were to synthesize CuO nano particles and to prepare different nanofluids by blending these nanoparticles with various conventional base fluids such as water, EG and TEG to study different thermo-acoustics and rheological parameters. All these parameters shed light on the molecular environment as well as the dispersed phase of the nanofluids with respect to the temperature.

Materials and Methods

The reagents used for the synthesis and preparation were of analytical grade and procured from Merck, India. These reagents were used as it is without further purification. Deionized double distilled water was used throughout the experiment.

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Rec Date: March 10, 2017, **Acc Date:** March 27, 2017, **Pub Date**: March 27, 2017.

Citation: Venu Gopal VR and Susmita Kamila (2016) Thermo-Acoustics and Rheological Properties of Various Heat Transfer Fluids Blended with Cuo Nanoparticles. BAOJ Nanotech 3: 013.

Synthesis of Cuo Nano Particles and Preparation of Nanofluids

Copper oxide nanoparticles are synthesized from copper chloride dihydrated and sodium hydroxide pellets as precursors in aqueous media [11]. To the solution of copper chloride (0.5g $CuCl_2$ dissolved in 100ml deionized water), 1g of sodium hydroxide pellets were added to make the pH of the solution from 4 to 11 by maintaining the temperature 60^0C. A brownish-black precipitation of copper hydroxide was obtained and the stirring was continued for one more hour to complete the precipitation reaction. The solution was neutralized by adding few drops of hydrochloric acid. The precipitate was centrifuged and washed 3 to 4 times with deionized water and was dried in oven at 90^0 C for 4hour to get Copper Oxide nanoparticles. The synthesized nanoparticles were then characterized for their properties using XRD, EDX and SEM.

$$CuCl_2 + 2NaOH/KOH \longrightarrow Cu(OH)_2 + 2NaCl$$

$$Cu(OH)_2 \xrightarrow{\Delta} CuO + H_2O$$

Preparation of Nanofluids

Different nanofluids have been prepared by using the synthesized CuO nano particles in water, EG, 60% EG-water and Tri ethylene glycol [0.005% (w/V)]. These solutions were properly stirred for 15-20mins by a magnetic stirrer before subjecting to ultra-sonication for 2 hr using ELECTROSONIC MAKE Ultrasonic Processor [EI-250 UP]. After dispersing, the Zeta potential, electrical conductivity, thermal conductivity along with acoustic and rheological properties have been measured. These measured values were utilized to evaluate acoustic parameters.

Characterization of Cuo Nanoparticles and Nanofluids

The nanoparticles have been characterized for structural determination from XRD by using RIGAKU smart lab X-ray Diffractometer with CuK alpha radiation (λ= 1.5405 Å). Both, the elemental composition (EDX analysis) and the particle shapes (SEM morphology) of CuO nano particles and nanofluids have been carried out by using GEMINI ULTRA 55 instruments. In addition, zeta potentials and particle size of nanofluids were determined by using MICROTRAC W3231 make and BROOKHAVEN Instruments, respectively.

Acoustics and Rheological Properties of Nanofluids

The Ultrasonic velocities for all the nanofluids were measured at different temperatures by single-crystal variable-path multi frequency nanofluid interferometer (MITTAL-NF-10X) at 2MHz frequency by circulating water from a thermostatically regulated bath around the sample holder for constant temperature (within ±0.01 K). The velocity measurements were precised to $0.1\pm ms^{-1}$. The densities of the fluids were measured by a bicapillary pyknometer with deionised doubled distilled water with $0.9923 \times 10^3 kg\ m^{-3}$ as its density at temperature 303.15 K. The precision of density measurement was within $0.0003\pm kg\ m^{-3}$. These measured values of ultrasonic velocity and density were utilized to evaluate other related acoustic parameters like isentropic compressibility, b_s and specific acoustic impedance, Z, to study the particles effect in fluids by using the following relations [12-15].

$$bs = 1/rU^2$$

$$Z = rU$$

where ρ and U are the density and ultrasonic velocity of the fluids, respectively. The dynamic viscosity was determined by using BROOKFIELD viscometer (DV-III Ultra) [16,17] having a small adaptor that consists of a cylindrical sample holder and a spindle for immersing in the test fluid. When the spindle is rotated, the viscous drag of the fluid against the spindle is measured by the deflection of the calibrated spring. The range of spindle speeds available in this viscometer is from 0–250 rpm. The kinematic viscosities of the solutions were measured with a calibrated Ostwald viscometer immersed in a constant temperature water bath maintained within ±0.01 K, and the time of flow was determined at three different temperatures. Besides, the thermal conductivity of all the fluid samples were measured experimentally using KD-2 Pro KS-1 sensor instrument, where it uses transient hot wire source method for the conductivity measurement.

Results and Discussions

From XRD diffractogram, it is observed that the intensity and position of peaks are indicative of the presence of copper oxide in the sample and the particles are of monoclinic crystal system (literature: JCPDS, File No 01-080-1916). The average crystallite size (D) has been calculated from the line broadening using the following Debye-Scherrer's relation [18] and the average crystal size is found to be 11.23 nm

$$D = \frac{K\lambda}{\beta \cos\theta}$$

where K is the crystallite shape factor and a good approximation is 0.9, λ is the wavelength of X-ray, β is full width at half the maximum (FWHM) in radians of the X-ray diffraction peak and θ is the Braggs angle.

The EDX images for the samples show the presence of copper and oxygen elements in the prepared nano powder [% weight composition of copper and oxygen are 67.73 and 25.60, respectively]. The SEM images are the evidence for the nano scale sizes of CuO particles in range of 43 to 73nm. In addition, it also reveals the shapes of copper oxide particles to be spherical.

Zeta potential is an important property and it shows the difference between the dispersion medium and the stationary layer of fluid attached to the dispersed particle. Therefore, colloids with high zeta potential are electrically stabilized whereas colloids with low value of zeta potentials tend to coagulate. Larger the values of zeta potential better will be the dispersion. pH of a colloidal solution is found to be one of the main parameters influencing the particle aggregation and the stability of the suspension. In the present investigation, zeta potential has been studied with the variation of pH of the nanofluids and it has been observed that the potentials of all the nanofluids increase with pH values. However, it decreases after pH 8 in most of the fluids with negative mV. This variation may be due to more anionic dispersant [19]. Besides, there is an exception in tri-ethylene glycol, where all values are found to be negative without much variation in potentials. Heat transfer and stability are the two major phenomena of nanofluids, where both the parameters depend on the ability of dispersion of particles in the fluid media. The agglomeration of nanoparticles results not only in settlement but also in decrement of thermal conductivity of nanofluids. In the present study, there is increment of thermal conductivity for all the nanofluids from their respective base fluids. Thermal conductivity increases with temperatures appreciably for the CuO nanofluids in water, though there is not any remarkable change for other systems. Electrical conductivity is another parameter that is related to the ability of charged particles or ions in the suspension to carry the charges towards respective electrodes when an electric potential is applied [20]. There are no such appreciable variations in electrical conductivity with pH except for the nanofluid with water, where the conductivity shows maxima at pH 4. This enhanced conductivity is assumed to be presence of more charged particles at this range.

Viscosity is an essential parameter that describes the internal resistance of a fluid to flow and, in case of a nanofluids, it depends on the morphology and size of nanoparticles. However, it due to its certain impact on overall performance of a heat transfers fluid. The dynamic viscosity is found to be decreased with increased shear rate. However, it is independent of the shear rate for pure EG and pure water evidencing a Newtonian behaviour [21]. The observed behavior of dynamic viscosity is supposed to be shear-thinning type at lower shear rate from 0 to 10 s^{-1} [22, 23]. This shows non-Newtonian flow at less shear rate. But however, the fluids show Newtonian flow at high shear rate. Besides, the kinematic viscosities of nanofluids are more than that of their base fluids and it decreases with temperature (Table1). This might be due to the increased disturbance in particles with temperature that makes the fluids to move fast. The enhanced viscosity is indicative of increased particulate-solvent association in fluids. It also shed light on better dispersion of CuO nanoparticles [24].

Ultrasonic velocity is another significant parameter that provides information about the molecular environment in a fluid system. And in case of nanofluids, it is dependent on its density, temperature, size and dispersion of nano particles in it [25]. The ultrasonic velocity varies slightly with the temperature for all the fluids. However, the temperature influence of nanoparticles dispersion that varies on the velocity of ultrasonic propagation. Randomness of dispersed particles increases with the temperature. This is the reason when the ultrasonic vibration is propagated in the nanofluids, the Brownian motion stops the particles in suspension and thus there is decrease in the velocity. However, increase in velocity can be explained due to the raise in surface area of nano particles that helps for adsorption of base fluid molecules (EG, TEG or water) on them, which possibly makes a free movement.

The acoustic parameter, isentropic compressibility, b_s is found to decrease with increase in temperature for water as well as for nanofluid in water. But the trend is reverse for both EG and TEG systems. The decrease in compressibility indicates the molecular association, which makes the nanofluid to be less compressed. Whereas the dispersion of nanoparticles enhances the compressibility. Specific acoustic impedance, Z, is another acoustic parameter that shed light on the molecular association present in two phase systems. It is the ratio of the instantaneous pressure at any particle in the system to the instantaneous velocity of that particle. This factor is governed by the inertial and elastic properties of the medium and depends directly on velocity and density values. In the present study impedance increases with temperature for water systems Literature shows that the enhancement in impedance is indicative of strong association among the particulates [13,15]. However, there is decrease in impedance in EG and TEG systems with temperature. This might be due to the presence of H-bonds in the base fluids that allow the nanoparticles to be more dispersed in the systems.

Conclusion

From the present investigation, the following conclusions have been drawn:

- Copper oxide nanoparticles have been synthesized successfully by using chemical precipitation technique and stable CuO nanofluids have been prepared by taking base fluids such as

Table 1: Experimentally determined density, ρ, viscosity, η and ultrasonic velocity, U of Water, EG, TEG (basefluid) & 0.005% CuO nanofluids in Water, EG, TEG at 303.15K, 308.15K and 313.15K

Solvents	$\rho \times 10^{-3}$ kg.m^{-3}			$\eta \times 10^{3}$ kg.m^{-1}s^{-1}			U m.s^{-1}		
Basefluids									
	303.15K	**308.15K**	**313.15K**	**303.15K**	**308.15K**	**313.15K**	**303.15K**	**308.15K**	**313.15K**
Water	0.9945	0.9943	0.9931	0.7877	0.7112	0.6531	1506.1	1518.3	1524.9
EG	1.1030	1.1008	1.0975	11.9231	10.0474	8.4412	1645.3	1639.0	1626.6
TEG	1.1121	1.1091	1.1071	21.1615	18.0889	13.6685	1667.3	1654.4	1640.2
0.005% CuO in different basefluids									
Water	0.9953	0.9942	0.9930	0.7952	0.7260	0.6603	1509.4	1519.2	1526.3
EG	1.1014	1.0998	1.0974	12.5736	10.1041	8.9594	1651.7	1642.4	1631.1
TEG	1.1135	1.1133	1.1125	29.6908	21.8496	18.8393	1633.7	1608.9	1596.1

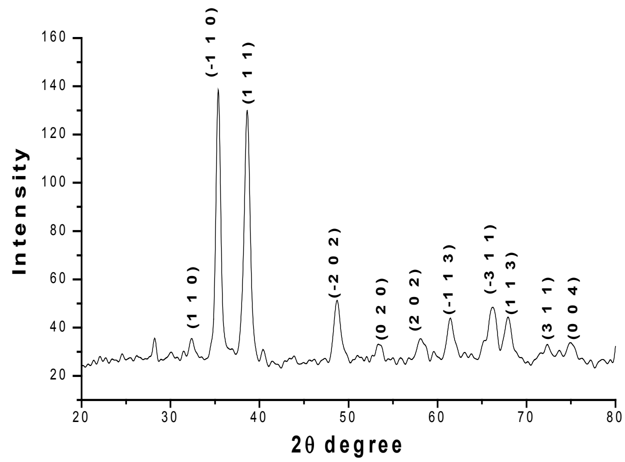

Figure – 1: X-ray diffractograms of CuO Nanoparticles

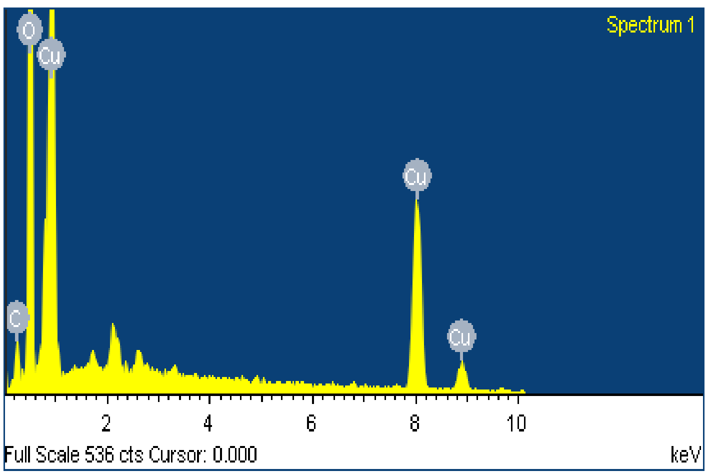

Figure –2: EDAX images of CuO Nanoparticles

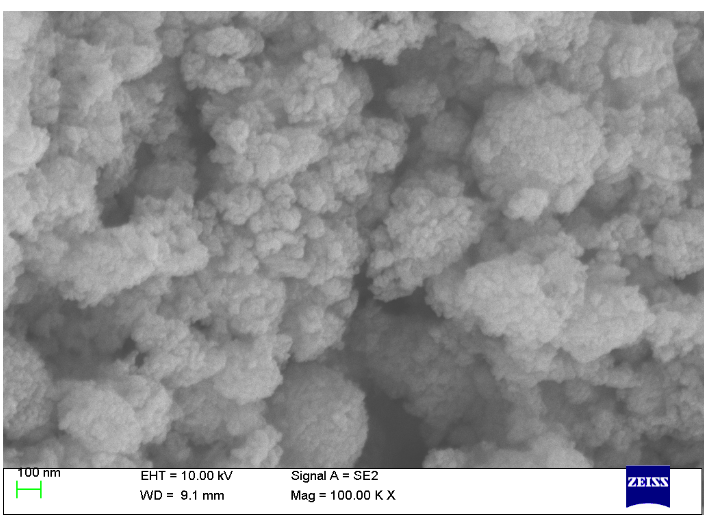

Figure – 3: SEM morphologies of CuO Nanoparticles

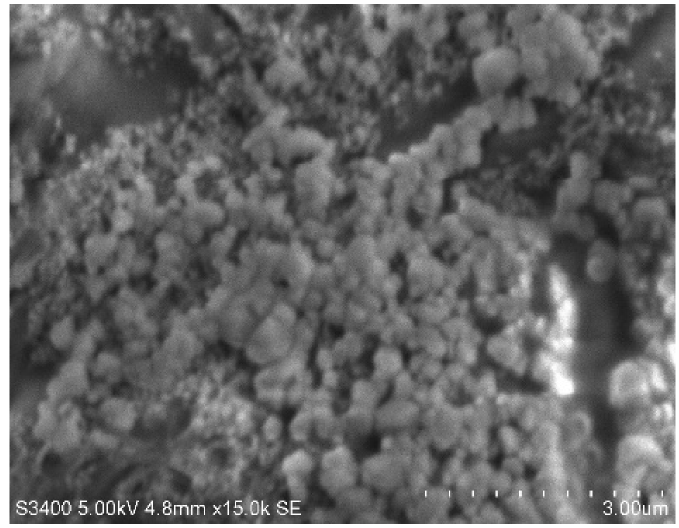

Figure – 4 SEM morphologies of CuO Nanofluid in Water

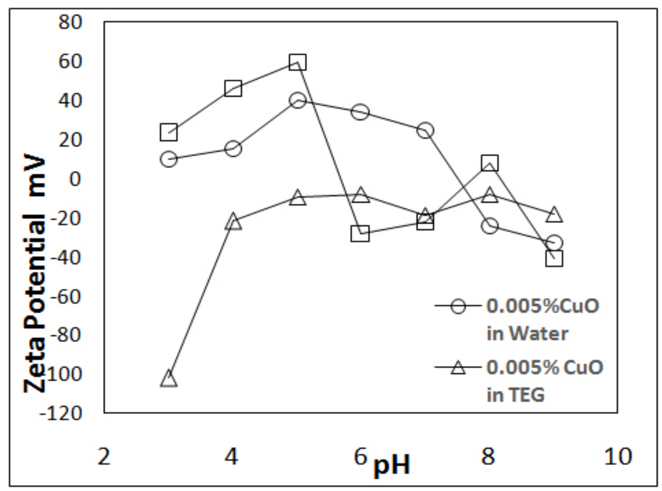

Figure – 5: Plot of Zeta Potential of CuO Nanofluids in water, EG and TEG vs pH

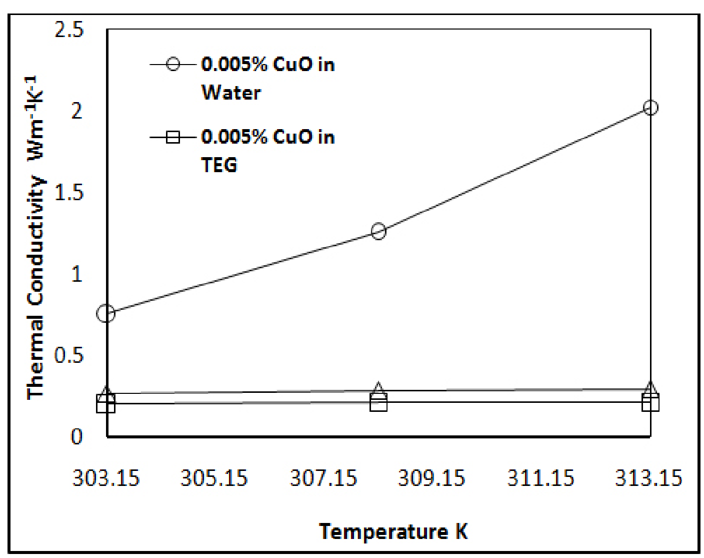

Figure – 6: Plot of Thermal Conductivity of CuO Nanofluids in water, EG and TEG vs Temperature

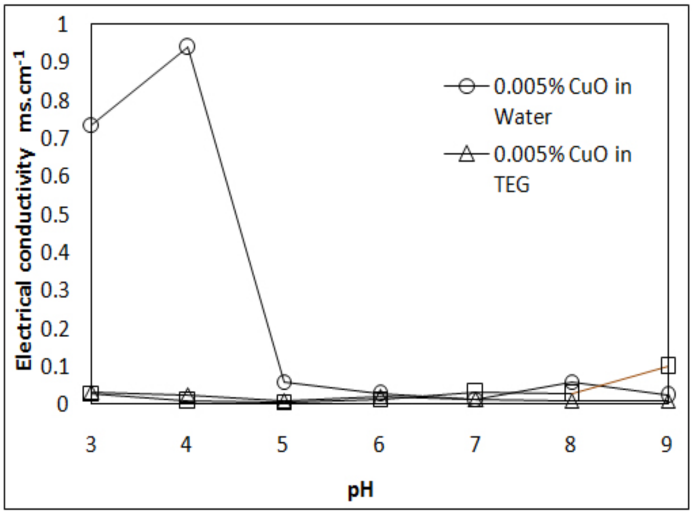

Figure – 7(a): Plot of Electrical conductivity of CuO Nanofluids in water, EG and TEG vs pH

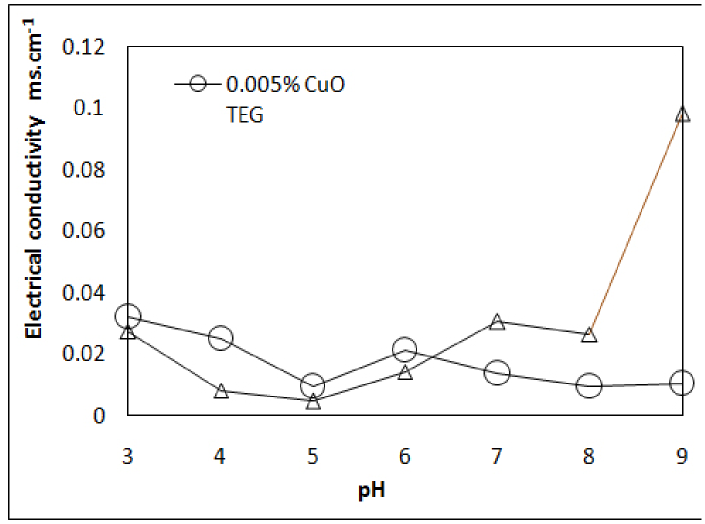

Figure – 7(b): Plot of Electrical conductivity of only CuO Nanofluids in EG and TEG vs pH (enlarged view)

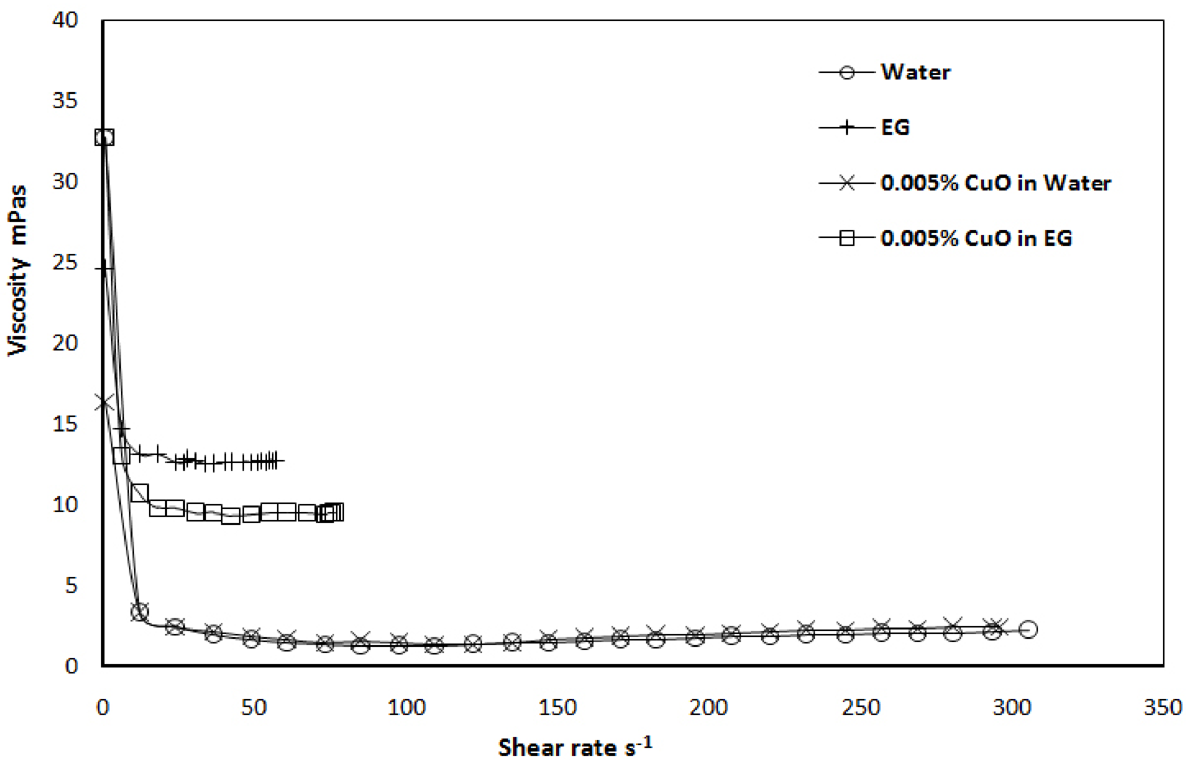

Figure –8: Plot of Dynamic Viscosity vs Shear Rate

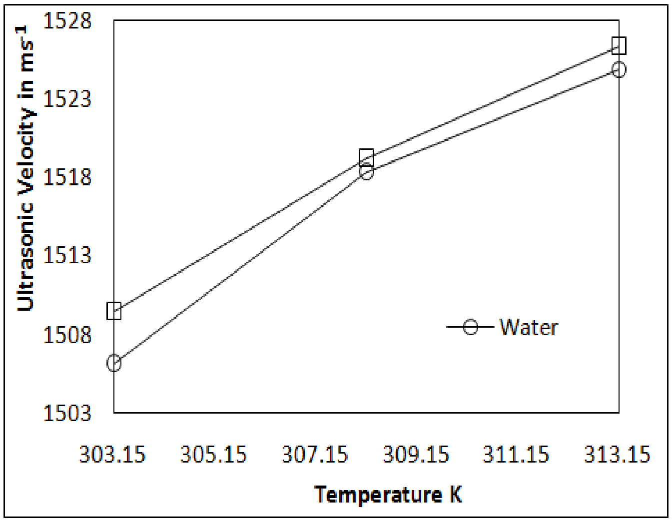

Figure – 9 (a): Plot of Ultrasonic Veloctiy vs Temperature of Water and 0.005% CuO in Water

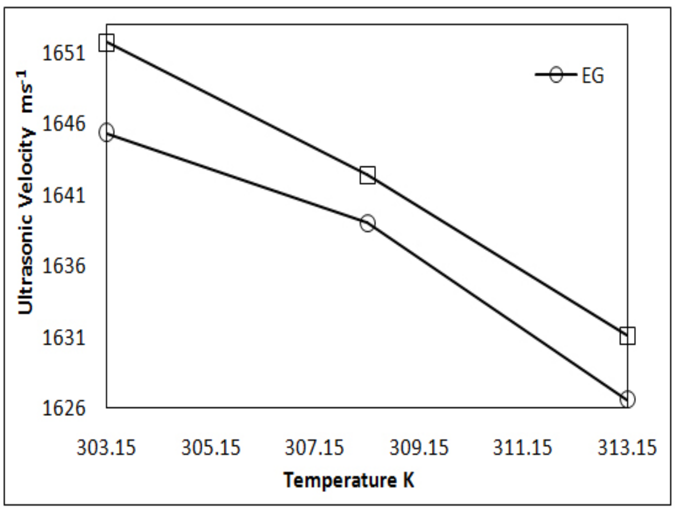

Figure – 9 (b): Plot of Ultrasonic Veloctiy vs Temperature of EG and 0.005% CuO in EG

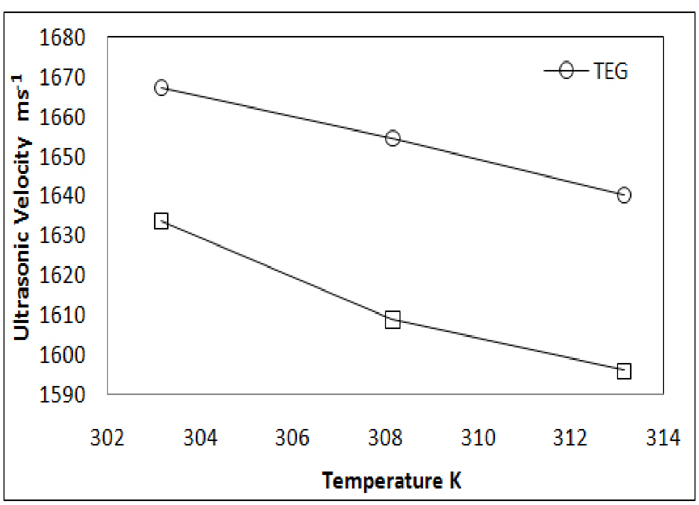

Figure – 9 (c): Plot of Ultrasonic Veloctiy vs Temperature of TEG and 0.005% CuO in TEG.

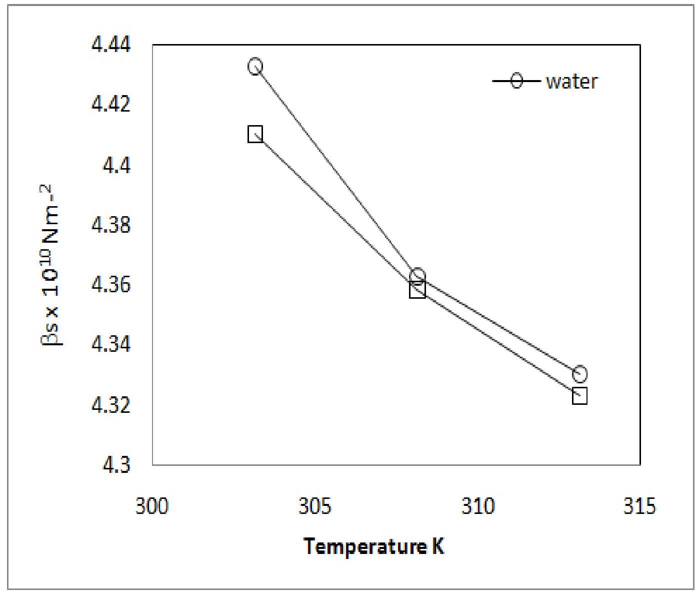

Figure – 10 (a): Plot of isentropic compressibility vs Temperature of Water and 0.005% CuO in Water

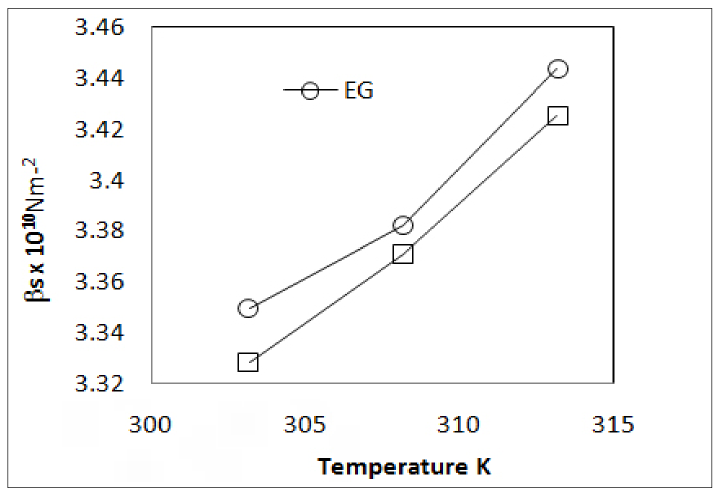

Figure –10 (b): Plot of isentropic compressibility vs Temperature of EG and 0.005% CuO in EG

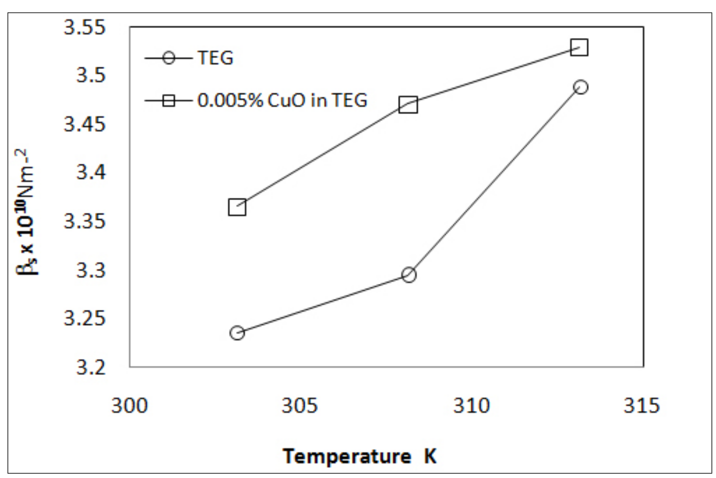

Figure –10(c): Plot of isentropic compressibility vs Temperature of TEG and 0.005% CuO in TEG.

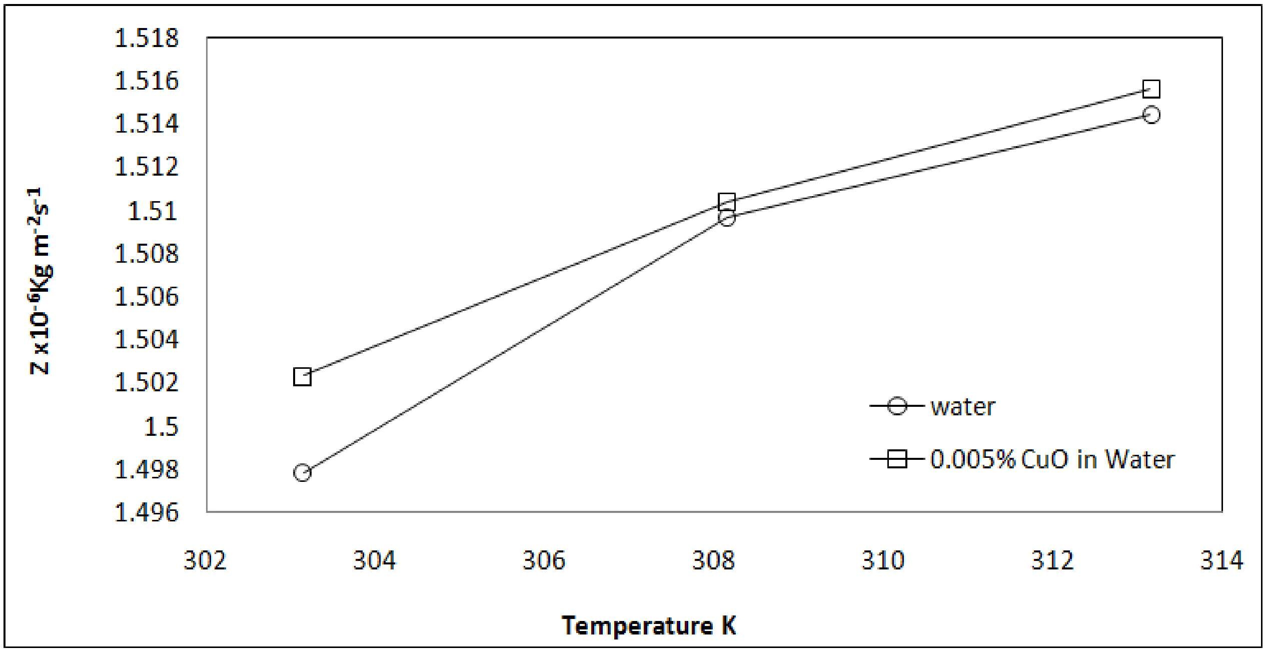

Figure –11 (a): Plot of Acoustic impedance vs Temperature of Water and 0.005% CuO in Water

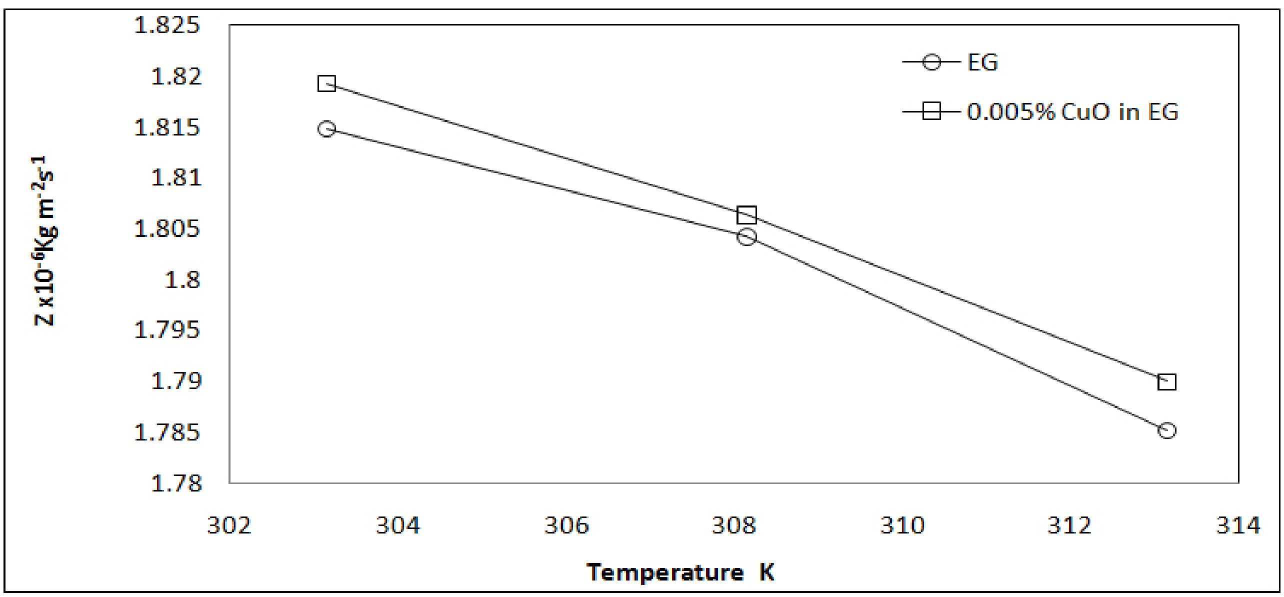

Figure –11 (b): Plot of Acoustic impedance vs Temperature of EG and 0.005% CuO in EG

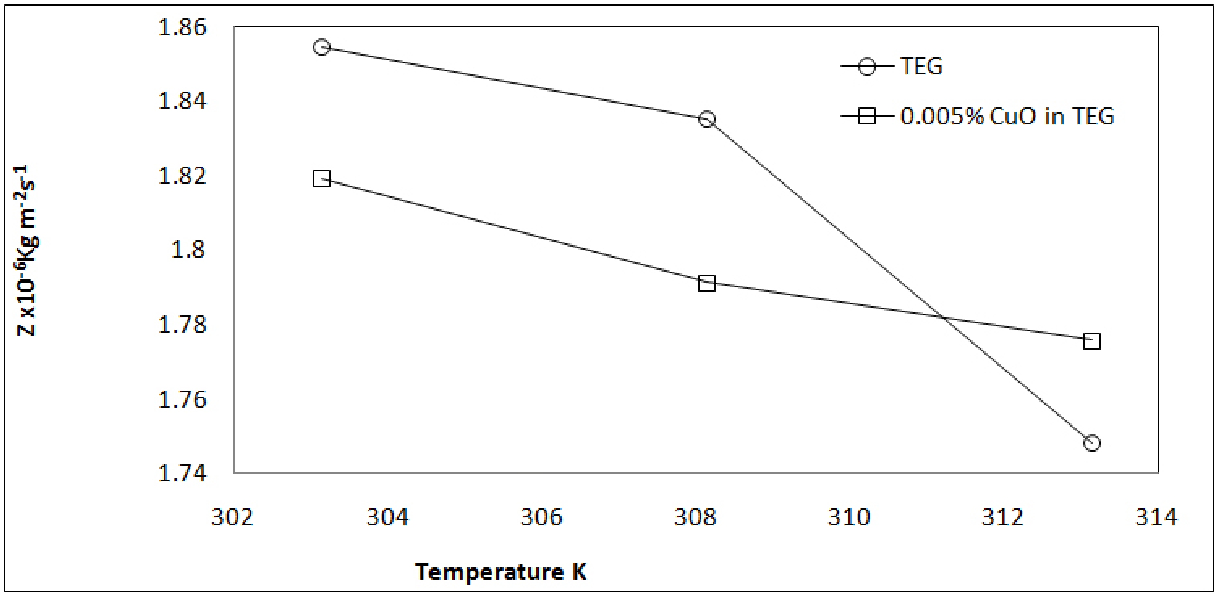

Figure –11 (c): Plot of Acoustic impedance vs Temperature of TEG and 0.005% CuO in TEG.

water, EG and TEG

- Enhanced thermal conductivity was observed for the nanofluids from their respective base fluids
- From the rheological studies, it reveals that the nanofluids behave like non-Newtonian fluids at lower shear rate but there is change in fluidity as the shear rate increases
- Zeta potential, which is the important parameter for the stability and dispersibility also shows enhancement with the variation of pH
- Ultrasonic velocity and its related parameters such as isentropic compressibility and acoustic impedance indicate the presence of particulate association and dissociation among the dispersed phase with temperature for nanofluids

Acknowledgement

Susmita Kamila is thankful to SERB-DST, New Delhi for the award of Start-up Research Grant. The authors are also thankful to Dr B M Satish, Principal, East Point College of Engineering and Technology for his constant support and encouragement.

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