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A Comparative analysis of Viscosity and Thermal Conductivity for Al_2O_3/CuO Hybrid Nanofluid in Binary Base Fluids

Rashmi Rekha Sahoo[1*], **Vikash Kumar**[2]

[1]Department of Mechanical Engineering, Indian Institute of Technology (BHU),Varanasi 221005, India

***Corresponding author:** Rashmi Rekha Sahoo, Department of Mechanical Engineering, Indian Institute of Technology (BHU), Varanasi 221005, India Tel: +91-9628721155; Email: rrsahoo.mec@itbhu.ac.in

Abstract

Thermal conductivity and viscosity analysis of Al_2O_3/CuO (50/50) hybrid nanofluid in EG and PG binary base fluid of various mass fraction has been investigated in present work. Thermal conductivity and viscosity of hybrid nanofluid with vol. fraction range limited to 1.5% with a higher temperature range (50^{o}C-70^{o}C) is considered. Impact on viscosity and conductivity models with various shape *i.e.* spherical, cylindrical, brick, platelets, and blades have been discussed and were compared for hybrid nanofluid in EG and PG binary base fluids. Also, the analysis extends to the prediction for the stability with zeta potential and synthesis of spherical shape Al_2O_3/CuO hybrid nanofluid with XRD and SEM.

Theoretical analysis revealed that thermal conductivity of Al_2O_3/CuO hybrid nanofluid in EG binary base fluid is lower compared to in PG binary base fluid. The thermal conductivity is observed to be higher in spherical and cylindrical nanoparticle shape compared to bricks, blades and platelets shape nanoparticles. Optimum viscosity of Al_2O_3/CuO hybrid nanofluid is observed at 50% EG and 30% PG of binary base fluid. Hybrid nanofluid in 30% of PG as binary base fluid results 16.2% higher dynamic viscosity compared to pure PG base fluid for a vol. concentration of 2%. Zeta potential measurement results in the stability of spherical Al_2O_3-CuO/ (50/50) EG/W hybrid nanofluid and it may be considered as a heat transfer fluid.

Keywords: Propylene glycol; Hybrid nanofluid, Viscosity; Thermal conductivity; Particle shape

Introduction

Due to the rapid growth of power producing devices, more power needed as an output and therefore results in more heat generation. So it is very much needed of the time for the thermal management of such devices, like in *i.e* engines thermal management results in better performance of the engine, either in terms of fuel consumption, size, thermal efficiency *etc*. Only Conventional fluids like EG, PG will not serve the purpose as it is a poorer heat transfer fluid. Therefore, a mixture of EG, PG, water, and nanoparticles can serve the purpose as it results in the reduction of pumping pressure and better thermophysical properties compared to EG, PG[1]. Nanofluid is a colloidal mixture made up of an nanoparticle and a base fluid. Nanofluids are a modern nanotechnology-based heat transfer fluids which are derived from the stably suspended of nanometre-sized particles (of typical length from 1 to 100 nm) in ordinary heat transfer fluids, usually liquids. Nanofluids consisting of such small particles which are suspended in the ordinary liquids (typically ordinary heat transfer liquids) have been shown to improve the thermal conductivity positively and the convective heat transfer performance of the base or ordinary liquids[2,3]. It is a modern generation of heat transfer fluids become a high potential fluid in heat transfer applications due to enhanced thermal conductivity. This technology nowadays has a new dimension of mixing two or more nanoparticles in base fluids, namely composite or hybrid nanofluid. It is a mixture in

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which the properties of the solid nanoparticles and the primary base fluid grant to the enhance in the thermal and transport properties of the base fluid. These are fundamentally featured by the fact that Brownian agitation over-comes any settling motion due to gravity. Thus, for a stable nanofluid, the solid particle needs to stay as small enough (usually 100 nm). Hence nanofluid contains Nano powders with average dimensions of a solid particle smaller than 100 nm and is suspended in a base fluid such as water or ethylene glycol etc. Nanofluids are capable of enhancing the heat transfer rate of the base fluids and hence the mixture[4,5]. On Addition of very small amount, less than 6% of high thermal conductivity solid nanoparticles into the base fluid is enhanced the thermal conductivity, thus, as a result, as a result increasing the heat transfer rate. Nanofluids were first used by Choi et al., at the Argon national laboratory[6]. It is observed that there is a decrement in the thermal boundary layer thickness due to the presence of the solid nanoparticles and also due to its random motion within the base fluid may have important contributions to the heat transfer improvement. On increasing the amount of solid nanoparticles concentration as a result of it there is an increase in heat transfer rate because under such conditions the collision and interaction of nanoparticles are greatly improved. Also due to the diffusion of solid nanoparticles as well as its relative movement near the wall leads to a rapid increase in heat transfer from interface surface to the nanofluid. For an energy efficient heat transfer equipment, the thermal conductivity of fluid plays an important role therefore, nanofluid is introduced, which is a new type of heat transfer fluid developed by suspending the solid particle of size <100 nm into the conventional base fluid. Since the metal of solid form is having high thermal conductivity than those of conventional fluid[7]. Properties like specific heat, viscosity and thermal conductivity of the nanofluid depends upon the temperature , Particle volume fraction, base fluid, nanoparticle size ,shape, and it's material, most commonly used metal additives in nanofluid is Cu, Ag, CuO, Al_2O_3, MgO, TiO_2, ZnO and SiO_2[8,9]. Das et.al[10] experimentally investigated the effect of temperature dependency on the nanofluid (Al_2O_3,CuO) conductivity enhancement. The result showed that increase in thermal conductivity value occurs in the temperature range (21-51°C). Therefore, nanofluid can act as an alternative fluid which can be used as a cooling medium, where high energy density is developed and cooling fluid is likely to use at a higher temperature. Moreover, CuO of lower particle size will have a higher enhancement of conductivity at a higher temperature when compared to greater particle size[11] experimentally examined the TiO_2-Ag/Engine Oil, Al_2O_3-Ag/Engine oil, and observed that viscosity decreases on increase in solid particle volume fraction. However, result also shown that materials having different morphology results in a reduction in viscosity when compared to dissimilar nanoparticles of one material. D. Toghraiel., et al[12]. Investigated the thermal properties of ZnO-TiO_2/EG hybrid nanofluid and varied the temperature 25- 50°C and particle volume fraction from 0 to 3.5%. It was observed that at higher temperature thermal conductivity enhancement was more when compared to lower temperature. In addition, the enhancement was observed to be more at higher solid concentration when compared to low concentration[13] experimentally determined the thermal conductivity value and finally proposed a correlation which is a function of volume fraction and temperature and found that the thermal conductivities of the solid particle materials are basically is of higher magnitude than compared to those of the base fluids such as ethylene glycol, water, and light oils. Nanofluids, even at low volume concentrations, show a significant increase in thermal performance[14-19] given viscosity for two metallic oxides which is suspended in water of nanoparticle size 13 and 27 nm of Al_2O_3, TiO_2 respectively. Thermal conductivity of hybrid nanofluid by a mixture model approach derived from modified Maxwell model[20]. Therefore thermophysical study is carried out on Al_2O_3–CuO(50%-50%)/water-EG/PG at lower particle volume fraction and at a higher temperature for different shape by varying the EG/PG concentration in order to ensure the fluid to be used as a cooling agent. Maxwell[24] was the first one to study analytically the behaviour of nanofluid by injecting nanoparticles into the base fluid and considered the shape of the particle to be a sphere and didn't take the interaction among nanoparticle and host fluid. Hamilton and Crosser[25] proposed a model for the effective thermal conductivity which is an expand version of Maxwell, by introducing a new term called shape factor[26] estimated the thermal conductivity experimentally as a function of volume fraction of particle within a range of (0.125 – 2%) and temperature for spherical particles, proposed a model with the margin of deviation 1.3%[27] proposed a model to determine thermal conductivity for a temperature (25-60), nanoparticle volume fraction (0-0.75%) for a binary base fluid[28] proposed a new model to determine the thermal conductivity of alumina nanofluid[29] experimentally determined the thermal conductivity of hybrid nano binary base fluid (ZnO-MWCNT / Water-Ethylene glycol) by varying temperature(30°C-50°C) and solid vol. fraction (up to 1%) and found maximum increment of thermal conductivity of mixture by 28.1% at 50 and 1% volume fraction and finally proposed a correlation with 0.98 of determination coefficient. Dynamic viscosity is an important parameter of a nanofluid, not enough study available for the hybrid nanofluid compared to thermal conductivity. Different models and empirical correlation have been investigated, considered as a function of volume fraction and temperature[30] proposed a correlation for viscosity which is dependent on the nanoparticle concentration[31] proposed a correlation to determine effective viscosity of the mixture which depends upon the concentration of nanoparticle and mixture temperature[32] proposed a viscosity correlation for hybrid nanofluid investigated experimentally, CuO-TiO_2/c suspended into EG as a base fluid. The equation of effective viscosity as a function of concentration and temperature[33] investigated the thermal conductivity and viscosity correlations with shape and surface factor. Researchers[34-38] showed the effect of thermal conductivity and viscosity of nanofluid and hybrid nanofluid by addition of nanoparticle in base fluids and reported that enhancement in thermal conductivity occurred due to particle size and vol. fraction of nanoparticles. Present literature survey summarized that the nanofluid was prepared by addition of nanoparticles to a single base fluid like water, EG or PG. However, the present analysis focused on the effect of thermal conductivity and viscosity of Al_2O_3-CuO hybrid nanofluid in EG and PG binary base fluids. Also, comparison of viscosity and thermal conductivity for various models and shape of nanoparticles *i.e* brick, cylindrical spherical and platelet have been focused. Also, present analysis extends to the prediction for the stability with zeta potential and synthesis of spherical shape Al_2O_3/CuO hybrid nanofluid with XRD and SEM.

Mathematical Modelling: For analysis thermal conductivity and viscosity of Al_2O_3/CuO (50/50) hybrid nanofluid in EG and PG binary base fluid of various mass fraction at a higher temperature, the total volume fraction of hybrid nanofluid can be considered as,

$$\varnothing_{\mathrm{hnf}} = \varnothing_{\mathrm{np1}} + \varnothing_{\mathrm{np2}} \tag{1}$$

Thermophysical properties of nanoparticles shown in Table 1.

Table 1: Thermophysical properties of nanoparticles[22].

Particle	ρ (kg/m³)	k (W/m.K)	C_p (J/kg.K)	β (1/K)	Particle size (nm)
Al_2O_3	3970	40	765	5.80E-06	53
CuO	6500	20	535.6	4.30E-06	29

Maxwell[24] thermal conductivity model as

$$k_{eff} = \left[\frac{k_p + 2k_{\mathrm{bf}} - 2\varphi(k_{bf} - k_p)}{k_p + 2k_f + \varphi(k_f - k_p)}\right]k_{bf} \tag{2}$$

Hamilton and Crosser [25] thermal conductivity model as

$$k_{eff} = \left[\frac{k_p + (j-1)k_{\mathrm{f}} - (j-1)\varphi(k_f - k_p)}{k_p + (j-1)k_f + \varphi(k_f - k_p)}\right]k_{bf} \tag{3}$$

where j is a shape factor and equal to 3 for spherical nanoparticles

Modified Maxwell[20] thermal conductivity model expressed as

$$k_{hnf} = k_{bf}\left[\frac{\dfrac{\phi_1 k_1 + \phi_2 k_2}{\phi_1 + \phi_2} + 2k_{\mathrm{bf}} + 2(\phi_1 k_1 + \phi_2 k_2) - 2\phi_{hnf}k_{bf}}{\dfrac{\phi_1 k_1 + \phi_2 k_2}{\phi_1 + \phi_2} + 2k_{\mathrm{bf}} - 2(\phi_1 k_1 + \phi_2 k_2) + \phi_{hnf}k_{bf}}\right] \tag{4}$$

Nasajpour et.al.[26] thermal conductivity model expressed as

$$k_{hnf9} = (0.0008794\, \varnothing_{hnf}^{0.5899}\, T^{1.345} + 1)\, k_{\mathrm{bf}} \tag{5}$$

Kakavandiet al.[27] thermal conductivity model expressed as

$$k_{hnf} = (0.0017\, \varnothing_{hnf}^{0.698}\, T^{1.396} + 0.981)\, k_{bf} \tag{6}$$

Timofeevaet al.[28] thermal conductivity model expressed as

$$k_{hnf} = k_{bf}\,(1 + 3\varnothing_{hnf}) \tag{7}$$

Compared to experimental results Esfe et al. [29] gives the more accurate result, hence thermal conductivity model expressed for the present model as,

$$k_{hnf} = \left[1.024 + 0.5988\, \phi_{hnf}^{\ 0.6029}\, e\left(\frac{\phi_{hnf}}{T}\right) - \left(\frac{8.059\phi_{hnf}T^{0.2} + 2.24}{6.052\,\phi_{hnf}^{\ 0.2} + T}\right)\right]k_{bf} \tag{8}$$

Wang et al. [30], viscosity model expressed as

$$\mu_{\mathrm{hnf}} = \mu_{\mathrm{bf}}\,(1 + 7.3\, \varnothing_{\mathrm{hnf}} + 123\, \varnothing_{\mathrm{hnf}}^{\ 2}) \tag{9}$$

Compared to experimental results Akilu et al. [31] showed the accurate viscosity value for the present model as

$$.\mu_{hnf} = \mu_{bf}\left(0.9894\left(1 + \frac{\phi_{hnf}}{100}\right)^{6.6301}\left(\frac{T}{273}\right)^{0.064}\right) \tag{10}$$

Pak and Cho et al [19] viscosity model expressed as

$$\mu_{\mathrm{hnf}} = \mu_{\mathrm{bf}}\,(1 + 39.11\, \varnothing_{\mathrm{hnf}} + 533.9\, \varnothing_{\mathrm{hnf}}^{\ 2}) \tag{11}$$

Sharma et al.[32] viscosity model expressed as

$$\mu_{hnf} = \mu_{bf}\left(0.9653 + 77.4567\left(\frac{\phi_{hnf}}{100}\right)^{1.1558}\left(\frac{T}{333}\right)^{0.6801}\right) \tag{12}$$

To study the effect of shape on thermophysical properties of nanofluid, bricks, spherical, cylindrical, platelets and blade shape of nanoparticles have been considered. Thermal conductivity and viscosity correlations with shape and surface factor expressed as.

Effective thermal conductivity

$$k_{\mathrm{eff}} = k_{\mathrm{bf}}\,(1 + (C_k^{\mathrm{Surface}} + C_k^{\mathrm{Shape}})\varnothing) \tag{13}$$

where Ck thermal conductivity enhancement coefficient which depends upon the shape and surface of the nanoparticle shown in Table 2.

Table 2: Effect of particle shape and surface resistance of nanoparticle

Type	Aspect Ratio	C_K	C_k^{Shape}	$C_k^{Surface}$
Platelets	1:1/8	2.61	5.72	-3.11
Blades	1:6:1/12	2.74	8.26	-5.52
Cylindrical	1:8	3.95	4.82	-0.87
Bricks	1:1:1	3.37	3.71	-0.35

Dynamic viscosity can be expressed as

$$\mu_{\mathrm{eff}} = \mu_{\mathrm{bf}}\,(1 + A_1\, \varnothing + A_2\, \varnothing^2) \tag{14}$$

Effective viscosity depends upon the volume fraction and coefficient; viscosity enhancement coefficient can be obtained from the Table 3.

Table 3: Viscosity enhancement coefficients

Coefficient	Platelets	Blades	Cylindrical	Bricks
A_1	37.1	14.6	13.5	1.9
A_2	612.6	123.3	904.4	471.4

For implementing the theoretical analysis, an EES (Engineering Equation Solver) code is developed to study the comparative results of thermal conductivity and viscosity for Al_2O_3/CuOhybrid nanofluid in EG and PG binary base fluids. Thermophysical properties of EG and PG considered from[21,23] at different temperatures. In-build subroutines have been used for the temperature dependent properties of water, EG (for nanofluid also) and PG.

Validation of the result

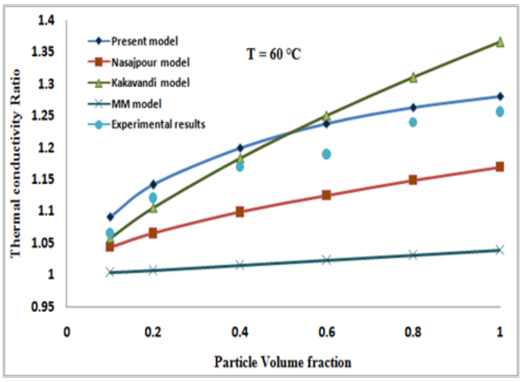

Figure 1: Validation of Predicted results with Experimental results

In order to verify the predicted results, the present model is validated with the experimental results[38] at a temperature 60°C with binary fluid as EG/DW in the ratio of 40:60. Other model predictions are not as accurate as the present model as shown in Figure1. For viscosity the predicted theoretically model results in good agreement[31] with 3-4% error. The numerical code has been verified with the theoretical data[26]. A similar trend has been observed and showed maximum deviation within 3% between the predicted and theoretical data, for vol. fraction range 0-1.5%.

Results and Discussion

Preparation, characterization and stability aspects of hybrid nanofluid: In the present work, Al_2O_3-CuO/(50/50) EG-W hybrid nanofluid was prepared using two- step method with dispersant span 80 by using an ultrasonic vibrator (Lark, India) generating ultrasonic pulses of 180 W at 40 kHz. To get a uniform dispersion and stable suspension, the Al_2O_3 the nanofluids were kept under ultrasonic vibration continuously for 6 h.

Characterization of the prepared powder sample and the XRD spectra and the SEM micrograph of the synthesized sample are shown in Figure 2. The reflections in the XRD pattern were identified as corresponding to the tetragonal phase of Al_2O_3 and cubical CuO nanoparticles. The average grain size of the hybrid particles was calculated to be 19 nm using the Scherrer formula. The microstructure of the powder sample shows that the as-prepared particles are in the form of tiny agglomerates and nearly spherical in shape.

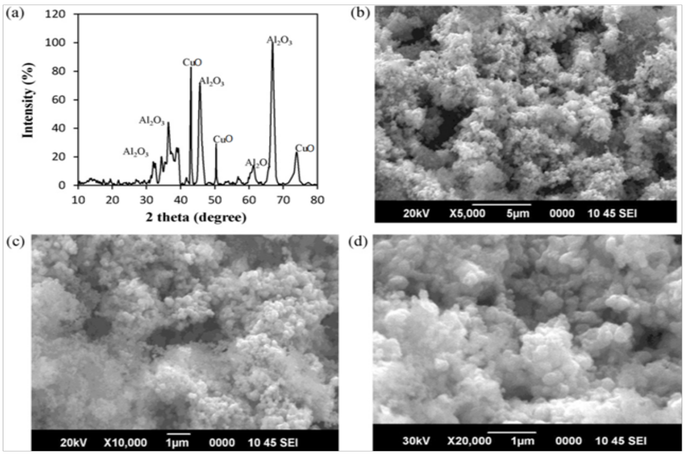

Figure 2: (a) XRD pattern, (b) SEM image at a magnification of 5000×, (c) SEM image at a magnification of 10,000×, (d) SEM image at a magnification of 20,000× of Al_2O_3–CuO hybrid particles.

The stability of hybrid nanofluid is dependent on volume concentration of the nanoparticles and the stability of the nanofluids at higher concentration is poor. Stability of the nanofluids was ensured by Zeta potential measurements. The colloidal solutions are least stable at the isoelectric point and eventually agglomerate affecting the stability of the suspensions. Generally, the stability of the suspension is poor when the absolute magnitude of the Zeta potential is smaller (around 10 mV) whereas large values of Zeta potential (>30 mV) are indicative of colloid stability. The measured values of Zeta potential of the prepared hybrid nanofluid in 50/50 EG-W base fluid are found to increase from +20.4 mV to +45 mV when the volume concentrations are decreased from 1.5% to 0.1%. The results are shown in Figure 3 a and b. confirm that the dilute nanofluids will be more stable.

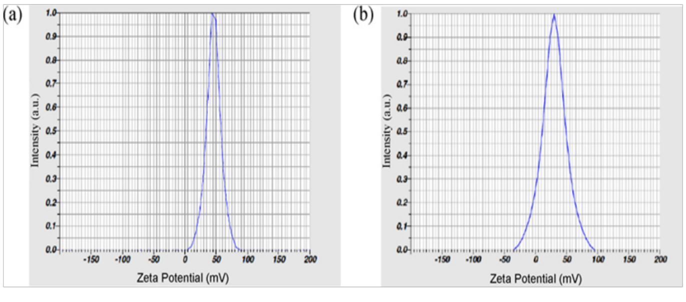

Figure 3: (a) Zeta potential of the 0.1% volume concentration hybrid nanofluids (b) Zeta potential of 1.5% vol. concentration Al_2O_3-CuO/(50/50) EG-W hybrid nanofluid.

Effect on thermal conductivity with EG and PG mass fractions: Variation of thermal conductivity for Al_2O_3-CuO(50/50)/EG-W and Al_2O_3-CuO(50/50)/PG-W hybrid nanofluid on various mass fractions of EG and PG as binary base fluids at different temperature and solid particle volume fraction has been shown in Figure 4,5. It is observed that as the EG concentration is increased the net thermal conductivity of the hybrid nanofluid decreases, due to the lower thermal conductivity of the EG. So increase in EG mass fraction, decreases the thermal conductivity. However, the addition of solid nanoparticle into the binary base fluid results in an increment in thermal conductivity due to an increment of net thermal conductivity of the high thermal conductivity of solid nanoparticles. The higher solid particle concentration leads to an increase in the number of particles and hence increase in surface to volume ratio and collision rates among them. Moreover, an increment in thermal conductivity is observed as there is an increment in temperature, the reason could be the Brownian motion of the nanoparticles and the interaction among the nanocomposites. Other previous author also encountered the similar results[26]. Since, the PG thermal conductivity is lower than water soon adding the PG concentration into the binary base fluid leads to a decrease in the net thermal conductivity of hybrid nanofluid. It is observed that on adding the solid nanoparticle into the mixture leads to improvement in thermal conductivity due to increase in the surface area to volume ratio. Also, higher temperature cause to enhance the thermal conductivity due to the improvement of Brownian motion of the nanoparticles within the mixture[26].

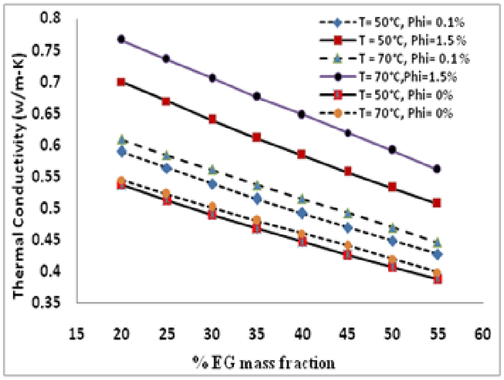

Figure 4: K-with EG mass fraction (T=50-70°C)

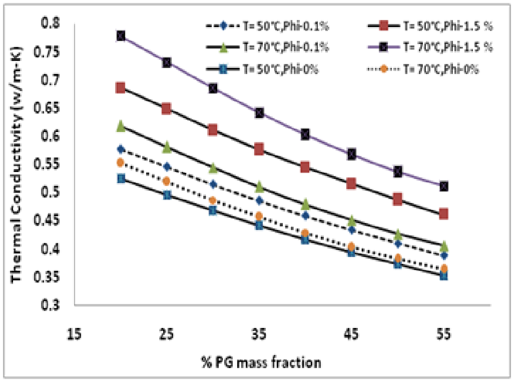

Figure 5: K with PG mass fraction(T=50-70°C)

Effect on dynamic viscosity with EG and PG mass fractions: Figsure 6,7. illustrated the variation in dynamic viscosity of hybrid nanofluid with various on varying EG and PG mass fractions of binary base fluids at different temperature and volume fraction. It is observed that at T= 50°C, with an increase in EG concentration the dynamic viscosity increases continuously vol. fractions but at a higher temperature, say T= 70°C the dynamic viscosity of hybrid nanofluid increases on increase in % EG mass fraction. Optimum viscosity is observed for 50% of EG mass fraction binary base fluid. Figure.10 illustrated the variation of dynamic viscosity of hybrid nanofluid with PG mass fraction as binary base fluid at various vol. fractions. It is observed that on increasing the % PG concentration into the base fluid results in first remains constant value of dynamic viscosity then minimum around at 30% of PG mass fraction as the binary base fluid. Optimum dynamic viscosity observed for the Al_2O_3-CuO hybrid nanofluid with 30% PG binary base fluid at a temperature of 70°C. However, binary base fluid with PG mass fractions has no such optimum value at a temperature of 50°C. Addition of nanoparticles into the binary base fluid results in an increase in viscosity, due to increase in a number of nanoparticles and hence there will be number of the collision which leads to increase in the value of dynamic viscosity.

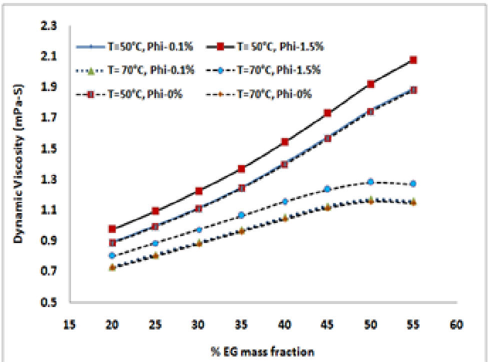

Figure 6: µ with EG mass fraction (%)

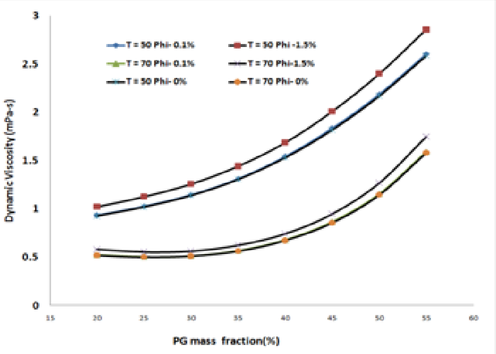

Figure 7: µ with PG mass fraction (%)

Variation in dynamic viscosity of hybridnanofluid on EG and PG mass fractions as binary base fluid at a higher temperature of 70°C has been shown in Figure 8, 9. at different particle vol. fractions. It is observed that on adding the solid particle with EG as a binary base fluid leads to an increase in the dynamic viscosity of hybrid nanofluid. The dynamic viscosity is maximum at vol. the fraction of 1.5% and optimum viscosity occurred at 50% EG as binary base fluid at a higher temperature of 70°C. Hybrid nanofluid with 1.5% vol. fraction in 50% EG as binary base fluid results from 13% increase in dynamic viscosity compared to pure 50% EG binary base fluid. Hybrid nanofluid with beyond 50% EG of binary base fluid, the dynamic viscosity starts decreasing for all vol. fractions at a higher temperature. However, optimum dynamic viscosity observed for the Al_2O_3-CuO hybrid nanofluid with 30% PG binary base fluid at a temperature of 70°C. Hybrid nanofluid with vol. fraction 1.5% in 30% of PG as binary base fluid results 16.2% higher dynamic viscosity compared to pure PG binary base fluid. The hybrid nanofluid in optimum 30% PG binary base fluid may be considered as a potential candidate as heat transfer fluid due to minimum viscosity at higher temperatures.

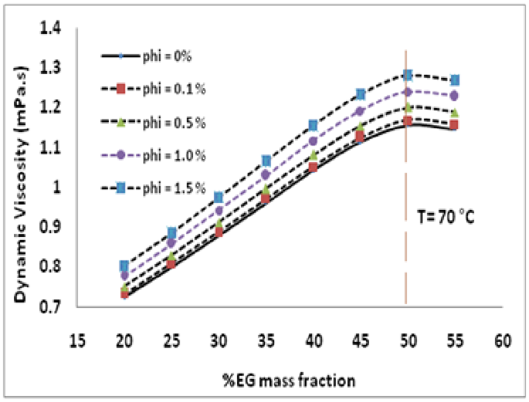

Figure 8: µ with EG mass fraction (%)

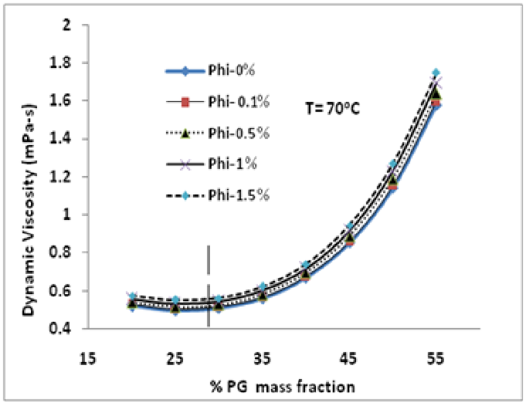

Figure 9: µ with PG mass fraction (%)

Effect on thermal conductivity and dynamic viscosity with various model: Comparison thermal conductivity of hybrid nanofluid for a different model has been studied at a temperature of 60°C and at 1% volume fraction which is depicted in the Figsure.10, 11. Among all the models the thermal conductivity increases with particle volume fractions. But it can also be observed that thermal conductivity of hybrid nanofluid with binary base fluid is lower in modified Maxwell model at any solid particle volume fraction, as the predicted model is the function of particle solid fraction only. The other two modelshave an average value of thermal conductivity due to temperature dependent parameters. Hybrid nanofluid simulated with the present model having 27.17% higher thermal conductivity than the Maxwell model for EG binary base fluids. However, hybrid nanofluid simulated with present model having 29% higher thermal conductivity than Maxwell model for PG binary base fluids.

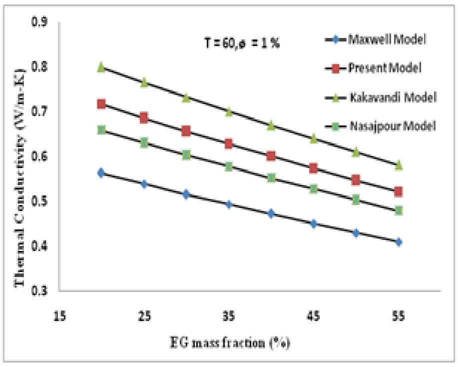

Figure 10: K-models with EG mass fraction

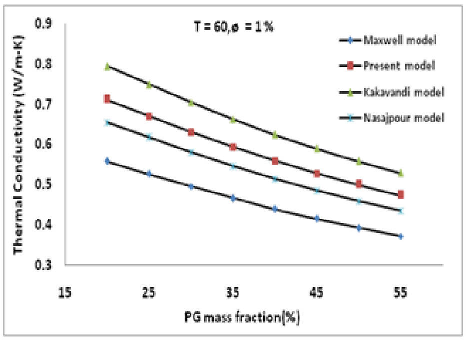

Figure 11: K-models with PG mass fraction

Comparison dynamic viscosity of hybrid nanofluid for a different model has been studied at a temperature of 60°C and at 1% volume fraction which is depicted in the Figure.12,13. Among all the models, the dynamic viscosity increases with particle volume fractions. But it can also be observed that dynamic viscosity of hybrid nanofluid in EG as binary base fluid is higher in Pak and Cho model at any solid particle volume fraction, as the predicted model is a function of particle solid fraction only. The other two model has an average value of dynamic viscosity due to temperature dependent parameters. Hybrid nanofluid simulated with the present model having 53.84% lower dynamic viscosity than Pak and Cho for EG binary base fluids. However, hybrid nanofluid simulated with the present model having 83.3% lower dynamic viscosity than Pak and Cho model for 30% PG binary base fluids.

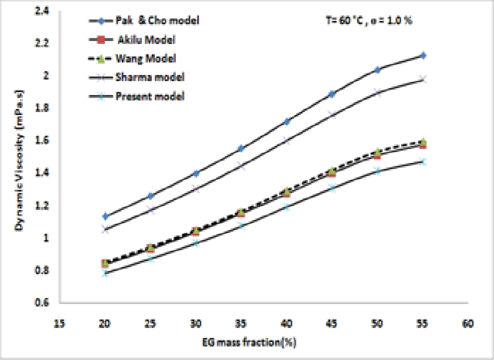

Figure 12: µ with EG mass fraction (%)

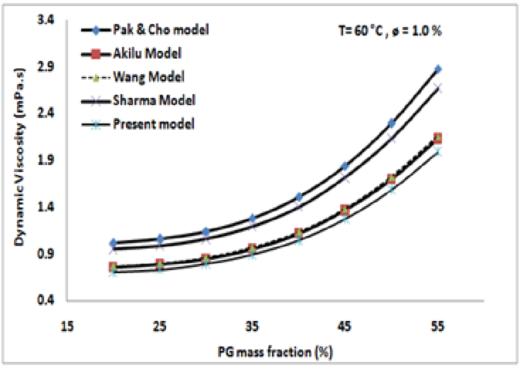

Figure 13: µ with PG mass fraction (%)

Effect on thermal conductivity and dynamic viscosity with particle shape: Figure14, 15 demonstrated the variation of thermal conductivity for hybrid nanofluid of different shape with various EG and PG mass fraction binary base fluids. Among all shapes of nanoparticle the thermal conductivity is observed to be decreasing on increase in the % EG concentration, the reason is the lower value of EG conductivity than water. The thermal conductivity is observed to be higher in spherical and cylindrical nanoparticle shape and then followed by bricks, blades and platelets shape nanoparticles. The similar results were encountered by[28,29], improving the heat transfer efficiency of synthetic oil with silica nanoparticles. Hybrid nanofluid with a spherical shape having 1.8% higher thermal conductivity than platelet shape hybrid nanofluid with EG binary base fluids.

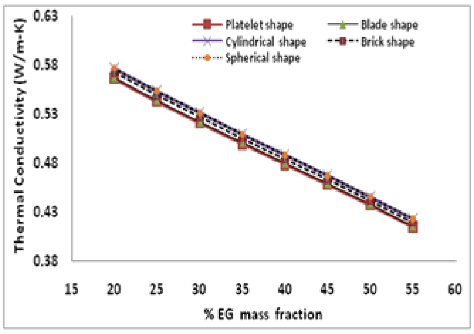

Figure 14: k-shape with EG mass fraction (%)

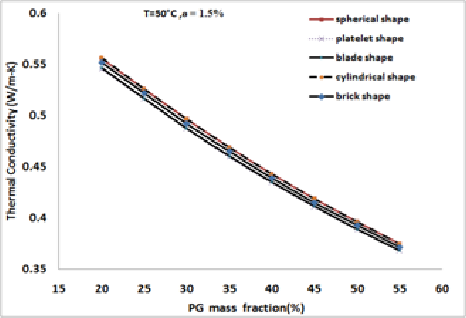

Figure15: k-shape with PG mass fraction (%)

At a constant temperature of 70°C and particle vol. fraction of 1.5%, the variation of dynamic viscosity of Al_2O_3-CuO hybrid nanofluid in EG and PG mass fraction as binary base fluids for different shape are depicted in Figure16, 17. It is observed that an increase in EG mass fraction into the base fluid results in an increase in dynamic viscosity for all the shapes of nanoparticles. Optimum viscosity observed at 50% EG binary base fluid for spherical, cylindrical, platelets, blade and brick shape nanoparticles for hybrid nanofluids. Dynamic viscosity of platelets shapes hybrid nanofluid in 50% EG binary base fluid found to be maximum and followed by cylindrical, blades, bricks and then spherical shape hybrid nanofluids.

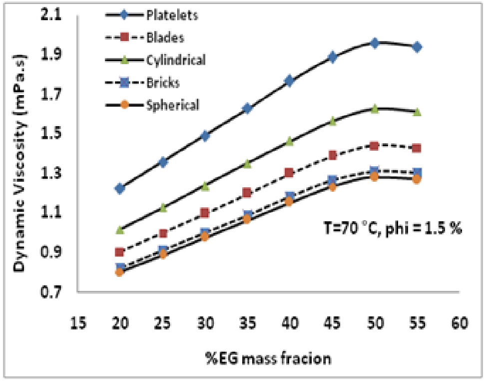

Figure 16: µ-shape with EG mass fraction

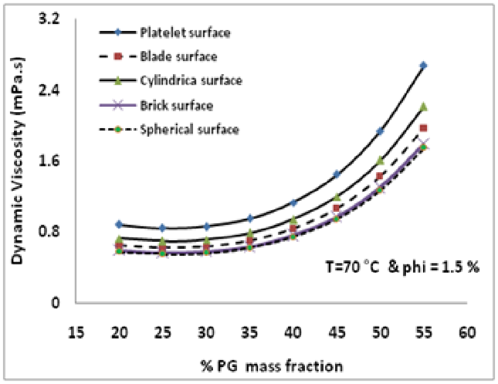

Figure 17: µ-shape with PG mass fraction

Various other authors also observed the same result[34-36]. Property of the hybrid nanofluid depends upon the base fluid and also on the shape of the nanoparticle considered. However, optimum dynamic viscosity observed for the Al_2O_3-CuO hybrid nanofluid with 30% PG binary base fluid at a temperature of 70°C. Similarly, the dynamic viscosity of platelets shapes hybrid nanofluid in 30% PG binary base fluid found to be maximum and followed by cylindrical, blades, bricks and then spherical shape hybrid nanofluids.

Conclusions

The following conclusions have been drawn from the theoretical analysis of thermal conductivity and viscosity evaluation of Al_2O_3-CuO/hybrid nanofluid in EG and PG binary base fluids with a temperature range of 50°C-70°C.

- The Zeta potential measurement concluded that the prepared Al_2O_3-CuO/ (50/50) EG/W hybrid nanofluid is in stable condition with a temperature range of 60°C.
- The thermal conductivity of Al_2O_3-CuO hybrid nanofluid in PG binary base fluid is higher compared to EG base fluid. Increase in temperature and vol. fraction both results in increasing the thermal conductivity of hybrid nanofluid in EG and PG binary base fluids.
- The optimum range of dynamic viscosity observed for hybrid nanofluid in 50% EG and 30% PG binary base fluids. Beyond 50% EG, the viscosity gradually decreases and a 13% increase in dynamic viscosity observed compared to pure 50% EG binary base fluid.
- Dynamic viscosity of platelets shapes hybrid nanofluid in 50% EG binary base fluid found to be maximum and followed by cylindrical, blades, bricks and then spherical shape hybrid nanofluids. Due to lower viscosity of Al_2O_3-CuO/ hybrid nanofluid in 30% PG binary base fluid and higher thermal conductivity, it is considered as the potential candidate for heat transfer fluids at a higher temperature range
- Hybrid nanofluid with a spherical shape having 1.8% and 2% higher thermal conductivity than platelet shape hybrid nanofluid with EG and PG binary base fluids respectively. It has also been observed that the thermal conductivity of nanofluids increases remarkably with on increasing volume fraction of nanoparticles.

Nomenclature

EG	Ethylene glycol
PG	Propylene glycol
CuO	Copper Oxide
Al_2O_3	Aluminium oxide
CK	conductivity enhancement coefficient
μeff	effective dynamic Viscosity
keff	effective thermal conductivity, W/m-K
μ_{hnf}	dynamic viscosity of hybrid nanofluid
k_{hnf}	Thermal conductivity of hybrid nanofluid, W/m-K
μ	Dynamicviscosity [cP]
k	thermal conductivity [W/m-K]
Ø	Nanoparticles vol. fraction (%)
T	temperature [°C]
ρ	Density [kg/m3]
p	particle
bf	base fluid
hnf	hybrid nanofluid
eff	effective

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