



Effect of Surfactant Concentration on Thermal Conductivity and Viscosity of Al_2O_3 -ZnO- MWCNT-EG Ternary Nanofluid

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ABSTRACT

A significant amount of research in the field of nanofluids has shown that these fluids possess remarkable thermophysical properties, which are influenced by various parameters. The present study investigates the effect of surfactant concentration on nanofluids using three types of nanoparticles: Al_2O_3 , ZnO, and MWCNT, mixed in the ratio of 60:30:10. The surfactant mass concentration was taken as 0.5 times the total mass of the three nanoparticles. The volume concentration of nanoparticles was varied from 0.01% to 0.05%, while maintaining a constant ratio of 60:30:10. Thermal conductivity and viscosity of the nanofluid were measured over temperature ranges of 25°C to 35°C and 40°C to 70°C, respectively. These properties were compared with a reference nanofluid prepared using the same nanoparticle but with a surfactant concentration of 1/3 times the total nanoparticle mass. The experimental results showed an enhancement in thermal conductivity of 46.43% compared to the reference nanofluid for 0.01% volume concentration and 25°C. A maximum reduction in viscosity of 66.63% was observed at 70°C for a 0.05% volume concentration. The results showed that the thermal conductivity increased when the concentration of surfactant was increased from 1/3 times to 1/2 times the of total mass of nanoparticles. Also, the viscosity was reduced compared to the reference nanofluid.

Keywords: Surfactant; Thermal conductivity; Viscosity; Ternary nanofluid.

1. INTRODUCTION

A new class of fluid, known as nanofluid, is replacing the conventional fluids in many applications as heat transfer fluids due to its enhanced thermophysical properties. However, there are various parameters such as the shape, size, and type of nanoparticles used, volume concentration of the nanoparticles, and the type and concentration of surfactant used, which influence the thermophysical properties of synthesized nanofluids. The critical micelle concentration of the surfactant is one that provides the highest thermal conductivity and lowest viscosity of the new fluid.

The enhancement of thermal conductivity in Cu-H₂O nanofluid was examined in (Li *et al.* 2008) by varying the concentration of SDBS. It was observed that the addition of surfactant to the base fluid increased the thermal conductivity ratio, reaching a maximum at around 0.03 wt%, with further increase showing a decrease in the same. The presence of excess surfactant had a negative influence on thermal conductivity, which was attributed to the progressive accumulation of surfactant on the particle surface causing the reduction in heat transfer area. The viscosity of nanofluids is also influenced by the concentration and type of surfactant used in preparing the nanofluid. In (Alphonse *et al.* 2009), PEG 2000 in different concentrations was added

to titanium dioxide- water nanofluid. They observed that with increasing volumetric concentrations of titanium and PEG, the viscosity of the fluid decreased to a minimum value. However, higher concentrations of PEG 2000 affected the viscosity adversely, and hence it is important to optimize the concentration for better performance. TiO_2 -W nanofluid was tested for its thermal conductivity with three types of surfactants (Saleh *et al.* 2014). It was found that the presence of surfactant influences the thermal conductivity of nanofluids. Maximum enhancement was obtained with SDS; CTAB resulted in lower enhancement.

Viscosity and thermal conductivity analysis of TiO_2 -water nanofluids conducted in (Das *et al.* 2016) using four different surfactants showed that CTAB and acetic acid (AA) provided a stable nanofluid solution. In (Hormozi *et al.* 2016), the thermal performance of a hybrid of alumina-silver -water was examined. In (Khairul *et al.* 2016), the effect of surfactant on the thermal conductivity and viscosity of the Al_2O_3 -DIW and CuO-DIW using 0.05% to 0.2% SDBS was studied. They reported that the stability of the fluid was good, and thermal conductivity increased while viscosity decreased.

Using various surfactants in $\text{Mg}(\text{OH})_2$ -water nanofluids, the stability of the fluid was tested (Asadi *et*

al. 2017). They used CTAB, SDS, and oleic acid with different surfactant volume concentrations. The effect of surfactant on the thermophysical property of Al_2O_3 -water nanofluid was experimentally investigated in (Das *et al.* 2017). Among the various surfactants used, SDBS was found to be the best stabilizing agent. They observed that the clustering of particles and polydispersity index of the nanofluid decreased with the use of SDBS, and the thermophysical properties such as viscosity and thermal conductivity were enhanced.

In (Choi *et al.* 2018), four different surfactants, namely SDBS, CTAB, SDS, and TX-100, were used to study the stability characteristics of MWCNT-water-based nanofluids. An enhancement in solar absorption and stability of the nanofluid was observed, which varied depending on the type of surfactant used. The study concluded that SDBS was the most effective surfactant, providing good suspension stability and enhanced solar absorption in the temperature range of 10-85°C.

In (Das *et al.* 2018), TiO_2 - water nanofluids were studied for their thermophysical properties using CTAB, SDBS, and acetic acid as surfactants. The maximum enhancement in thermal conductivity observed was 5.8% for SDBS-added nanofluids at the highest particle volume concentration at 60°C.

In the experimental investigation carried out in (Kim *et al.* 2018), various surfactants such as SDBS, SDS, and DB were used. A mono nanofluid of MWCNT-W and graphite-W was prepared. The study showed that the thermal conductivity was influenced by the surfactant concentration and decreased as surfactant concentration increased. It was also observed that carbon-based nanofluids exhibited better thermal conductivity when SDS was used as the surfactant.

The effectiveness of stabilizing agents on the thermal conductivity and viscosity of Al_2O_3 , CaO-water nanofluid was studied in (Ebrahimisareh *et al.* 2019). The effect of surfactants on the stability of alumina nanofluids was studied in (Cacua *et al.* 2019). In (Li *et al.* 2019), the stability of water-based gold and silver particle nanofluids was studied. Several surfactants were used in (Almitani *et al.* 2021) in silica-DIW nanofluid to study the thermal conductivity behavior of the fluid. The study reported an increase in thermal conductivity with the increase in volume concentration of surfactants. Among all the surfactants used, ionic surfactants provided the highest thermal conductivity, whereas nonionic surfactants resulted in low thermal conductivity.

Molecular dynamic simulation of Cu-W nanofluids with CTAB surfactant, carried out in (Abu-Hamdeh *et al.* 2021), showed that the addition of surfactant molecules to the nanofluid increased the thermal conductivity from $0.741 \text{ W m}^{-1} \text{ K}^{-1}$ to $0.783 \text{ W m}^{-1} \text{ K}^{-1}$. Surfactant concentrations of 1%, 2.5%, 5% and

7.5% were used, while the particle volume concentration of the fluid was maintained at 1%. The thermal conductivity increased with increasing surfactant concentration from 1% to 5%, with thermal conductivity values of $0.77 \text{ W m}^{-1} \text{ K}^{-1}$ and $0.785 \text{ W m}^{-1} \text{ K}^{-1}$. The intermolecular interactions between the molecules were found to decrease beyond 5% surfactant concentration.

Although nanoparticles are known to enhance the thermophysical properties of nanofluids, the effect of surfactant concentration on the stability and thermophysical behaviour of ternary nanofluids has not been sufficiently investigated. In the reference paper (Bindu and Joselin, 2022), the study considered a surfactant concentration equal to one-third of the nanoparticle mass. However, the effect of using a different surfactant concentration remains unclear. Therefore, the present study investigates the behaviour of an EG-based ternary nanofluid with surfactant concentration equal to half of the total nanoparticle mass. A detailed experimental study was conducted for thermal conductivity and viscosity for a temperature range of 25 °C to 35 °C and 40 °C to 70 °C, respectively.

2. MATERIALS AND CHARACTERIZATION

2.1 Materials

Three nanoparticles, namely aluminum oxide (Al_2O_3), zinc oxide (ZnO), and multi wall carbon nanotube (MWCNT) nanoparticles, were used in the study. Al_2O_3 and zinc oxide ZnO were bought online from Sigma - Aldrich Chemical Pvt Limited, Bangalore, India. MWCNT nanoparticle was bought from Biomall.in (techinstro), India. The base fluid was used as Ethylene Glycol (EG). The properties of the nanoparticle, surfactant, and EG are given in Tables 1, 2, and 3.

Table 1. Properties of nanoparticles

Molecular Formula	Density (g/cm ³)	Shape	Size	Appearance
Al_2O_3	3.8	Spherical	< 50nm	White color powder
ZnO	6.5	Spherical	<100nm	White color powder
MWCNT	1.2	Cylindrical	Avg. inner/outer diameter 10-30nm/ 5-10nm	Black color powder

Table 2. Properties of ethylene glycole

Base Fluid	Boiling Point(°C)	Density (g/cm ³)	Chemical Formula
EG	197	1.11	(CH_2OH) ₂

Table 3. Prosperities of SDBS

Surfactant	Type (-)	Molecular Weight (g/mol)	Density (g/cm ³)	Chemical Formula
SDBS	Anionic	348.48	1.06	C ₁₈ H ₂₉ NaO ₃ S

2.2 SEM Characterization of Al₂O₃, ZnO and MWCNT nanoparticles

SEM analysis of Al₂O₃, ZnO, and MWCNT nanoparticles was conducted to study the characteristics of the particles.

3. EXPERIMENTAL METHODS

3.1 Preparation of Nanofluid Sample

The samples were prepared using a two-step method. First, the mass of nanoparticles was calculated using the fundamental equation for 50 mL of base fluid. The volume concentration of ternary nanofluid was taken as 0.01, 0.02, 0.03, 0.04 and 0.05%. The mixture ratio was maintained at 60:30:10 for Al₂O₃, ZnO, and MWCNT, respectively.

The nanoparticle ratio of 60:30:10 was selected based on the reference study, which reported improved thermal performance and stability for this composition. The volume concentration and mixture ratio were selected based on values reported in the reference paper. In the reference paper, the mass of the surfactant was taken as one-third of the total mass of the nanoparticles. However, in the present study, the mass of the surfactant was taken as 1/2 times the total mass of the nanoparticles.

3.2 Measurement of Thermal Conductivity

The KD₂ Pro thermal property analyzer (Decagon Devices, Inc., USA) was used to measure the thermal conductivity of ternary nanofluids of Al₂O₃, ZnO and MWCNT nanoparticles at different volume concentrations. The device could measure thermal conductivity in the range of 0.02 W to 2.00 W·K⁻¹ with an accuracy of ±0.001. It was calibrated at 25°C using Glycerine. CAS 56-81-5 at atmospheric pressure.

Each measurement was repeated three times, and the average value was reported to ensure repeatability and accuracy. The uncertainty in thermal conductivity measurement was within ±5.0% based on instrument specifications and repeated measurements.

3.3 Measurement of Viscosity

The viscosity of the nanofluid and base fluid was measured using a Brookfield LVDV-III Pro plate-and-cone rheometer with a measurement range of 1.0 to 2000 cP, together with a constant temperature circulator

(JULABO F-25, Germany). The viscometer possessed an accuracy of ±1.0%, and repeatability ±0.2% in the full-scale range.

4. RESULT AND DISCUSSION

4.1 Thermal Conductivity of Nanofluid in the Present Study

Fig. 1 shows the effect of varying volume concentrations of ternary nanofluid of Al₂O₃/ZnO/MWCNT-EG nanofluid. The thermal conductivity of the Al₂O₃/ZnO/MWCNT-EG ternary nanofluid generally increased with volume concentration and temperature due to enhanced Brownian motion and intensified particle interaction. The maximum thermal conductivity of 0.287 W/m·K was observed at 25°C for $\phi = 0.1\%$. However, slight reductions in thermal conductivity at intermediate temperatures were also observed for certain concentrations. These anomalous variations may be attributed to nanoparticle agglomeration, interfacial resistance, or temporary instability in the suspension. Overall, the ternary nanofluid exhibited improved thermal transport characteristics compared to the base fluid.

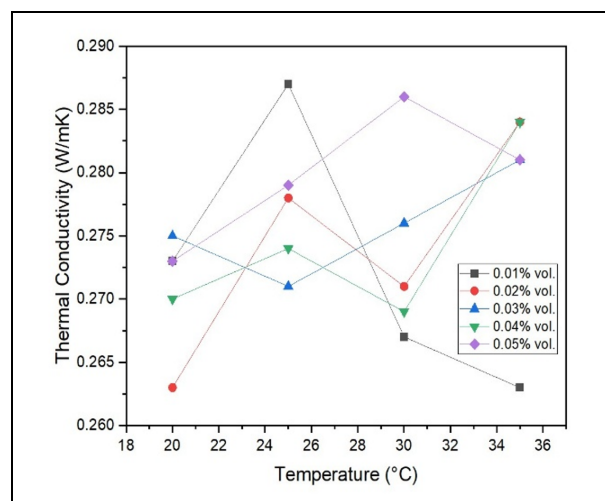


Fig. 1: Thermal conductivity variation of the present nanofluid at volume concentration ranging from 0.01% to 0.05%

4.2 Comparison of Thermal Conductivity of Nanofluid in the Present Study with the Reference

The thermal conductivity of the present Al₂O₃/ZnO/MWCNT-EG ternary nanofluid was compared with the reference nanofluid and base fluid for volume concentrations ranging from 0.01% to 0.05%, as shown in Fig. 2. The results indicate that the present nanofluid exhibited higher thermal conductivity than both the reference nanofluid and the base fluid at all temperatures considered. This enhancement can be

attributed to the synergistic effect of hybrid nanoparticles and the improved dispersion stability provided by SDBS surfactant. For the volume concentration of 0.01%, the thermal conductivity of the present nanofluid was a maximum of 0.287 W/m-K at 25°C, followed by a slight reduction at higher temperatures. The enhancement in thermal conductivity with temperature is mainly due to intensified Brownian motion and improved energy transport between nanoparticles. However, the observed decrease at higher temperature may be associated with nanoparticle agglomeration, increased interfacial resistance, or temporary instability in the suspension. Similarly, for 0.02% volume concentration, the present nanofluid showed significantly higher thermal conductivity than the reference nanofluid and the base fluid. Although minor fluctuations in thermal conductivity were observed at intermediate temperatures, the overall enhancement trend remained consistent.

These anomalous variations may be due to experimental uncertainty or changes in nanoparticle interaction and dispersion behavior at elevated temperatures. Overall, the present ternary nanofluid demonstrated superior thermal transport characteristics compared to the reference nanofluid and base fluid, confirming the effectiveness of nanoparticle hybridization and surfactant-assisted stabilization in enhancing thermal conductivity.

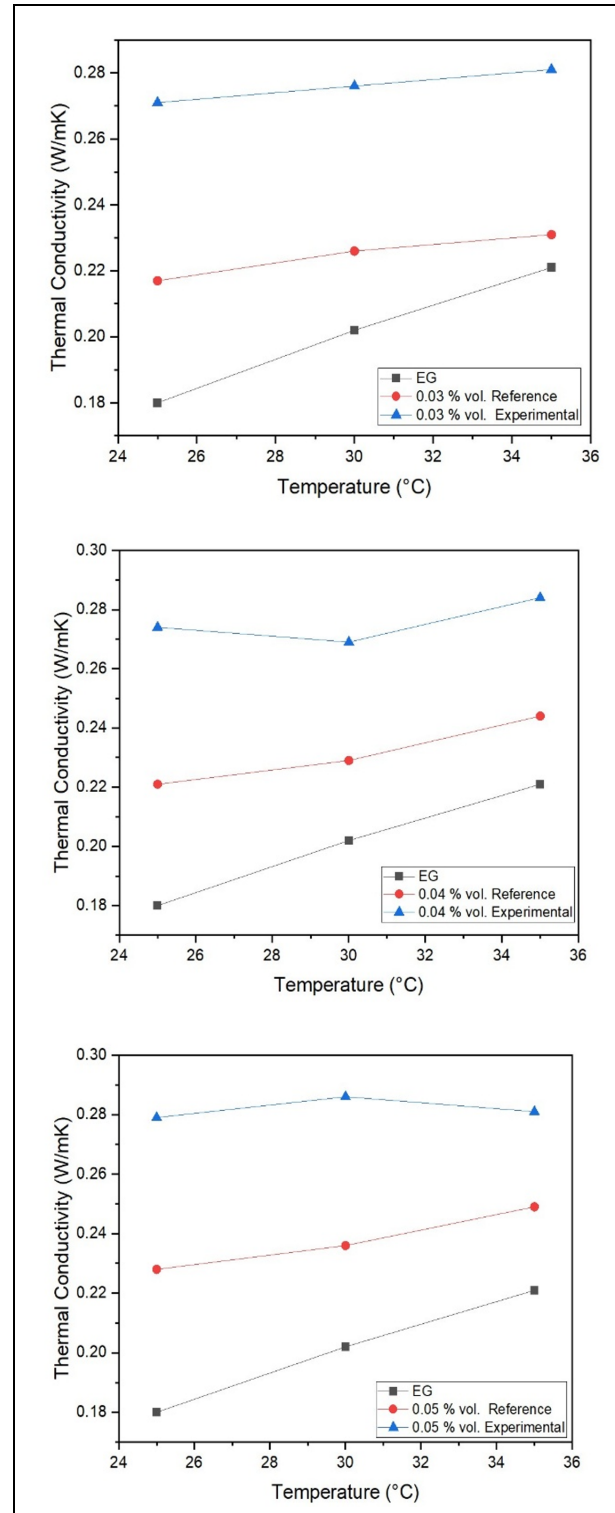
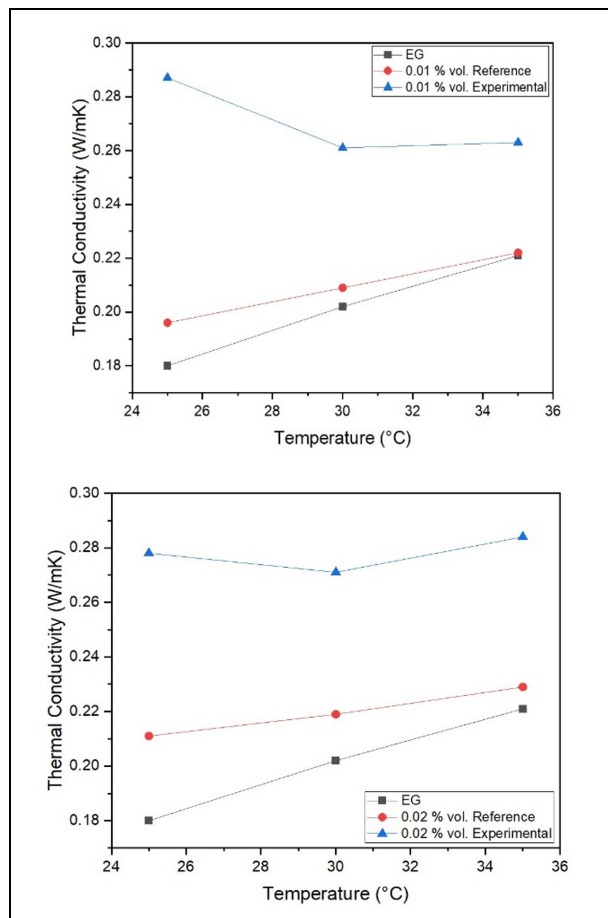


Fig. 2: Comparison of thermal conductivity of the present nanofluid, reference nanofluid and base fluid at at volume concentration of (a) 0.01%, (b) 0.02%, (c) 0.03%, (d) 0.04% and (e) 0.05%

In general, the thermal conductivity increased with increasing temperature and nanoparticle concentration due to intensified Brownian motion, enhanced particle collision, and improved heat transport

mechanisms within the nanofluid. The maximum thermal conductivity obtained in the present study was 0.287 W/m-K at 30°C for 0.01% concentration, while higher concentrations also demonstrated significant enhancement compared to the reference nanofluid.

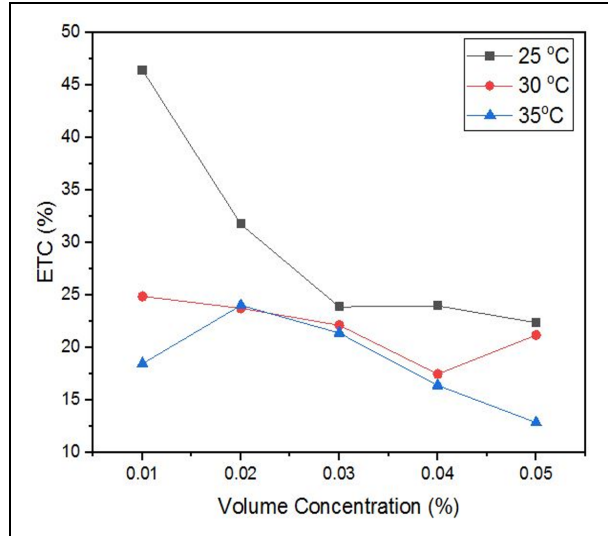


Fig. 3: Percentage enhancement in thermal conductivity of the present nanofluid compared with the reference nanofluid for volume concentrations from 0.01% to 0.05% at different temperatures

However, slight fluctuations in thermal conductivity were observed at certain intermediate temperatures, particularly for concentrations of 0.02%, 0.04%, and 0.05%. These anomalous variations may be associated with temporary nanoparticle agglomeration, increased interfacial thermal resistance, or minor instability in nanoparticle dispersion at elevated temperatures. Despite these fluctuations, the overall thermal conductivity trend remained higher than that of the reference nanofluid and base fluid. The results confirm that the addition of SDBS surfactant at 1/2 times the total nanoparticle mass improved nanoparticle dispersion and contributed significantly to the enhancement of thermal transport properties in the present ternary nanofluid.

4.4 Viscosity of Nanofluid in the Present Study

The viscosity of the ternary nanofluid generally decreased with increasing temperature, which agrees with the conventional behavior of fluids due to the reduction in intermolecular cohesive forces at elevated temperatures. It is shown in Fig. 4. A maximum viscosity of 8.755 cP was observed at $\phi = 0.03\%$ and 40°C, whereas the minimum viscosity of 2.57 cP was obtained at $\phi = 0.01\%$ and 70°C. For volume concentrations of 0.01%, 0.02%, and 0.03%, viscosity continuously decreased with increasing temperature from 40°C to 70°C, confirming the expected thermal thinning behavior of nanofluids. However, for concentrations of 0.04% and

0.05%, a slight increase in viscosity was observed when the temperature increased from 60°C to 70°C. This behavior deviates from the conventional trend and may be associated with nanoparticle agglomeration, instability of particle dispersion at elevated temperatures, or enhanced particle-particle interactions at higher concentrations.

4.5 Percentage Enhancement in Viscosity of Present Nanofluid with Reference Nanofluid

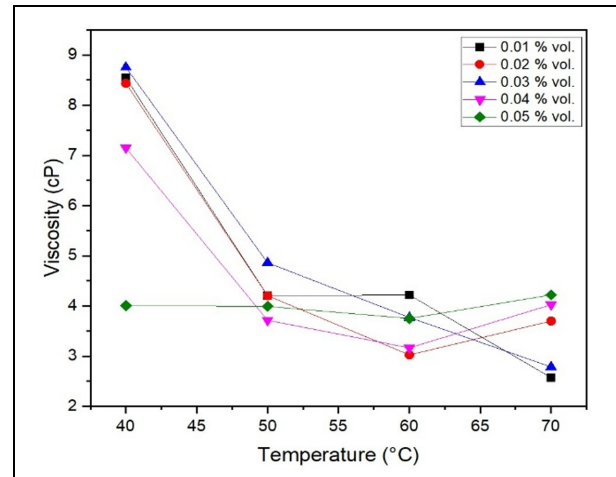


Fig. 4: Viscosity variation of the present nanofluid at volume concentration ranging from 0.01% to 0.05%

Reduction in viscosity of the present nanofluid with respect to the base fluid and reference nanofluid was calculated. These values were plotted with the volume concentration along the x-axis and percentage reduction in viscosity along the y-axis for the four different experimental temperature of 40°C, 50°C, 60°C and 70°C. The viscosity reduction of experimental nanofluid with the reference nanofluid is shown in Fig.5.

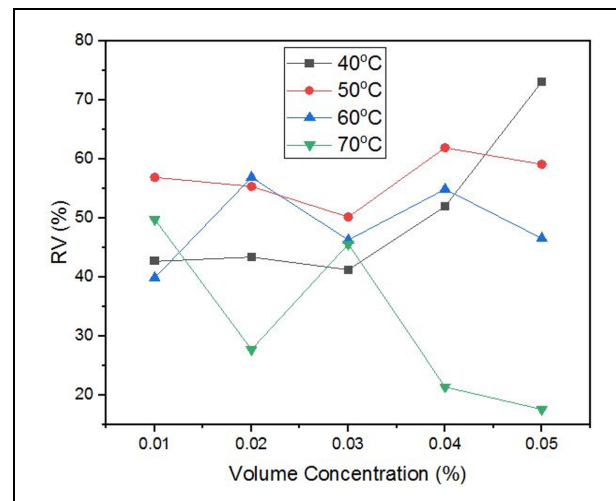


Fig. 5: Percentage reduction in the viscosity of the present nanofluid compared with the reference nanofluid for volume concentrations from 0.01% to 0.05% at temperatures

It clearly shows that the highest viscosity reduction happens for nanofluid having highest volume concentration of 0.05%. This occurs at the lowest temperature of 40°C with a percentage reduction of 66.63%. At 50°C, the percentage reduction in viscosity for all volume concentrations of 0.01% to 0.05% was 61.06%, 58.92%, 60.66%, 61.94%, and 52.56%, respectively. Almost keeping the value fallen 50 and 60. All 60°, the highest reduction was 61.17 for 0.02% volume concentration. At 70°C, the highest reduction of 55.69 occurs for 0.01%, and the lowest percentage reduction occurs for 0.05% with 4.31%. At higher temperature and higher volume concentration, the reduction in viscosity drastically decreased from 55.69% compared to the lower concentration of 0.01%. The viscosity of the present nanofluid showed a decrease when it was compared with the viscosity of the reference nanofluid. The study conducted in (Alphonse *et al.* 2009) using Poly Ethylene Glycol (PEG) 2000 showed that the viscosity can be reduced up to 50-60% compared to the nanofluid without PEG. The study in (Wang *et al.* 2013) showed a decrease in viscosity with an increase in dispersant. In (Hong *et al.* 2007), a lower viscosity of almost 60% was also achieved compared to the nanofluid without dispersant.

Such anomalous behavior can also arise from experimental uncertainties, including non-uniform temperature control, sedimentation effects, or limitations in viscosity measurements at higher temperatures. Since the percentage variation is significant, repeated experimental measurements and stability analyses are necessary to validate the observed trend. Overall, although the nanofluid predominantly exhibited temperature-dependent viscosity reduction, the abnormal increase at higher concentrations suggests that concentration-dependent stability effects may influence rheological behavior at elevated temperatures.

The thermal conductivity of the prepared nanofluid increased with both temperature and nanoparticle volume concentration compared to the base fluid and reference nanofluid. The enhancement can mainly be attributed to improved nanoparticle dispersion and reduced agglomeration due to the increased concentration of SDBS surfactant. The higher surfactant content enhanced electrostatic stabilization, thereby increasing the repulsive forces between nanoparticles and minimizing particle clustering and sedimentation.

In addition, the rise in temperature intensified Brownian motion of nanoparticles, which promoted micro-convection and improved heat transport within the base fluid. The combined effect of stable nanoparticle suspension and enhanced particle movement contributed to the observed increase in thermal conductivity. The improved stability of the present nanofluid compared to the reference nanofluid indicates that surfactant

concentration plays a significant role in enhancing thermophysical properties. Similar trends have been reported in previous studies, where appropriate dispersant addition improved nanoparticle stability and heat transfer performance while reducing viscosity variations.

5. CONCLUSION

The present study experimentally investigated the thermal conductivity and viscosity characteristics of a ternary hybrid nanofluid containing Al₂O₃, ZnO, and MWCNT nanoparticles dispersed in ethylene glycol with SDBS surfactant. The results confirmed that the prepared nanofluid exhibited enhanced thermal conductivity compared to the reference nanofluid, while maintaining comparatively lower viscosity under several operating conditions. The study demonstrated that surfactant concentration plays a significant role in determining the thermophysical behavior of the nanofluid. Increasing nanoparticle concentration improved thermal conductivity, whereas viscosity showed an overall decreasing trend with increasing temperature.

The optimized SDBS concentration used in the present work contributed to improved dispersion stability and better thermal performance. These findings indicate that the prepared ternary nanofluid has potential for advanced heat transfer applications such as electronic cooling systems, automotive radiators, heat exchangers, refrigeration systems, and solar thermal systems where enhanced thermal transport with manageable flow resistance is required. Future work can focus on long-term stability analysis, heat transfer coefficient evaluation under real flow conditions, pressure drop analysis, and system-level testing in practical thermal management applications.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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