

Performance evaluation of Al_2O_3 and CuO Nanoparticles dispersed in Silicone Oil to Enhance Thermo-Physical Properties

Katumuri Dasu¹, Mrs. B. Usha Rani²

¹ M.Tech Scholar, ² Senior Assistant Professor

Department of Mechanical Engineering, Nadimpalli Satyanarayanaraju Institute of Technology, Sontyam, A.P., India

Abstract— Nanofluids are widely studied for their ability to improve heat transfer performance by enhancing the thermo-physical properties of conventional base fluids. This study focuses on the performance of Al_2O_3 (Aluminum Oxide) and CuO (Copper Oxide) nanoparticles dispersed in silicone oil at different mixing proportions to enhance its thermo-physical properties. Silicone oil is selected as the base fluid due to its excellent thermal stability, high boiling point, and insulating characteristics, though its low thermal conductivity limits its efficiency in advanced cooling applications. In this investigation, Al_2O_3 and CuO nanoparticles are mixed with silicone oil at varying proportions of 0.25%, 0.5%, 0.75%, and 1.0% by volume concentration to prepare stable nanofluid samples. The prepared nanofluids are experimentally analyzed to evaluate changes in thermal conductivity, viscosity, density, and specific heat capacity under different temperature conditions. Results show that increasing nanoparticle concentration improves thermal conductivity significantly, with CuO -based nanofluids exhibiting greater enhancement compared to Al_2O_3 due to its inherently higher thermal conductivity matrix. However, higher mixing proportions also increase viscosity, which may affect fluid flow and pumping efficiency. The study concludes that the addition of Al_2O_3 and CuO nanoparticles in optimized mixing proportions can effectively enhance the thermophysical properties of silicone oil. Among the tested samples, an intermediate concentration provides the best balance between thermal performance improvement and acceptable flow behavior, making these nanofluids promising for transformer cooling, electronic thermal management, and industrial heat transfer systems.

Keywords: Nanofluids; Al_2O_3 ; CuO ; Silicone Oil; Thermal Conductivity; Viscosity; Thermophysical Properties.

1. Introduction

Renewable energies are gaining an increasing role in the world economy because they are sustainable and safe. The overall over-exploration of fossil fuel leads to environmental degradation and global warming; thus, eco-friendly energy technology needs to be developed continuously. Nowadays, solar energy stands as one of the key sources for sustainable development for the conversion of thermal and electrical energy using solar collectors and solar panels. However, the higher operational cost and lower efficiency involved in conventional solar energy conversion loops often limit its maximum utility.

The absorbed solar radiation is converted into heat, which is transferred directly to the working fluid. This configuration relies entirely on specialized heat exchanging fluids (absorbing fluids or thermic fluids). Common industrial thermic fluids include ethylene glycol, ethylene glycol-water mixtures, silicone-based fluids, and hydrocarbon oils. Heat transfer fluids dispersed with nanoparticles can drastically improve the thermal and optical properties of the conventional fluids, thus augmenting their performance profiles.

Silicone oil is an attractive base medium for high-temperature and insulation intensive applications. It comprises any liquid polymerized siloxane with organic side chains, with polydimethylsiloxane being the most commercially prominent member. These polymers are of deep commercial interest because of their relatively high thermal stability, electrical insulation, weather resistance, hydrophobicity, physiological inertness, small surface tension, and low viscosity-temperature coefficients. However, its low native thermal conductivity limits its heat absorption throughput.

Suspending solid metallic oxides like Al_2O_3 and CuO at nanoscale levels (under 100 nm) offers a passive engineering solution to dramatically elevate the underlying fluid layer thermal mechanics.

2. Experimental Methodology

2.1 Material Selection and Properties

In this investigation, high-purity spherical nanoparticles of Al_2O_3 and CuO were acquired as the active solid dispersed phase. Industrial-grade silicone oil was utilized as the continuous base fluid domain due to its unique high flash point and structural chemical stability. The volume concentration fractions chosen for individual validation were 0.25%, 0.5%, 0.75%, and 1.0% respectively.

2.2 Formulation and Ultrasonic Dispersion

A rigorous two-step synthesis method was carried out to manufacture highly stable nanofluid suspensions. The structural weight of nanoparticles required to achieve precise volumetric concentration batches was computed via standard density-volume fraction relations. Initial mechanical dispersion was established using high-speed magnetic stirring for 45 minutes to homogenize the primary mixture and minimize dry surface cluster formations.

To suppress localized nanoparticle agglomeration driven by inter-particle Van der Waals forces, the liquid solutions were systematically processed using an ultrasonic probe sonicator for 4 continuous hours. Probe sonication provides deep micro-convective shear stress fields that break up micro-scale particle clusters into their original standalone grain distributions, generating a stable, uniform suspension matrix without relying heavily on chemically reactive surfactants.

3. Physical and Mathematical Formulations

The stability and internal transport interactions of nanofluids are strongly influenced by the balancing of micro-forces. As defined by the classical DLVO theory, the net stability of a colloidal suspension is determined by the summation of attractive Van der Waals forces and repulsive electrical double layer (EDL) interactions:

$$V_{\text{total}} = V_{\text{Van der Waals}} + V_{\text{Electrostatic}} + V_{\text{Steric}}$$

Mechanical stabilization pathways like probe sonication actively minimize cluster diameter, while chemical stabilization pathways can introduce steric hindrances (via polymers or non-ionic surfactants) or electrostatic repulsions (via pH manipulation or ionic surfactant loading). Additionally, the classical Einstein suspension model suggests that the effective dynamic viscosity increases strictly with the volumetric packing factor of the solid cores, while the effective thermal conductivity escapes classical Maxwell models due to intense Brownian motion and localized micro-convective fluid layer clustering surrounding the solid nanoparticle interfaces.

4. Results and Discussion

4.1 Thermal Conductivity Enhancement

Experimental testing reveals a definitive correlation between solid nanoparticle concentration, operating temperature, and resultant thermal conductivity values. Baseline silicone oil exhibits a thermal conductivity of $0.138 \text{ W/m}\cdot\text{K}$ at room temperature. Upon introducing Al_2O_3 nanoparticles, thermal conductivity increases monotonically with volume concentration, reaching a maximum value of approximately $0.158 \text{ W/m}\cdot\text{K}$ at 1.0% volume loading.

Comparatively, CuO nanoparticles demonstrate an even more aggressive performance transformation profile. At the maximum 1.0% concentration threshold, the CuO /silicone oil mixture reaches a thermal conductivity peak of $0.166 \text{ W/m}\cdot\text{K}$. This superior improvement is heavily driven by the higher inherent thermal conductivity matrix of copper oxide structures compared to aluminum oxide compounds, combined with enhanced micro-convective energy transportation via particle-to-particle chaotic collision tracks.

4.2 Viscosity Analysis and Flow Behavior

While thermal properties experience clear benefits, the addition of solid nanoparticulates induces a continuous increase in the internal shear resistance (viscosity) of the base fluid. For both Al_2O_3 and CuO configurations, increasing the

volumetric fraction from 0.25% to 1.0% raises fluid viscosity across all measured operating temperatures. The higher solid packing concentration restricts the layer-by-layer molecular motion of the silicone oil chains, thereby escalating the overall internal shear stress.

Furthermore, the viscosity profiles remain temperature-sensitive; as operating temperatures increase, the absolute viscosity drops noticeably for all samples due to thermal expansion and accelerated kinetic separation of the fluid molecules. Experimental data indicates that an intermediate volume fraction (between 0.5% and 0.75%) delivers the most practical design compromise, ensuring substantial thermal conductivity benefits while keeping the absolute viscosity and pumping penalties within structurally manageable levels.

Table 1: Measured Thermo-Physical Properties of Silicone Oil Nanofluids at 30°C

Concentration (%)	(Vol Base Silicone Oil	Al_2O_3 (W/m·K)	Nanofluid CuO (W/m·K)	Nanofluid
0.25 %	0.138	0.142	0.145	
0.50 %	0.138	0.147	0.152	
0.75 %	0.138	0.153	0.159	
1.00 %	0.138	0.158	0.166	

5. Conclusion

This investigation experimentally analyzed the thermal conductivity and viscosity profiles of Al_2O_3 and CuO nanoparticles stably dispersed within an insulating silicone oil base fluid. The core conclusions are summarized below:

- Stable silicone oil-based nanofluids were successfully synthesized up to a 1.0% volume fraction via a refined two-step technique utilizing 4 hours of continuous high-power probe ultrasonication.
- Thermal conductivity increased monotonically with higher particle loading. CuO nanofluids demonstrated a superior enhancement profile over Al_2O_3 , reaching a maximum thermal conductivity of 0.166 W/m·K at 1.0% volume concentration.
- An unavoidable growth in dynamic viscosity was observed at elevated concentrations due to standard fluid layer shear resistance and increased solid phase friction.
- Optimizing the particle loading at an intermediate concentration range (0.5% to 0.75% vol) provides the most balanced thermodynamic design, rendering these fluids highly viable for advanced transformer core cooling, industrial heat exchangers, and high-temperature solar thermic collection applications.

References

- [1] Chen L, Xie H. Silicon oil based multiwalled carbon nanotubes nanofluid with optimized thermal conductivity enhancement. *Colloids Surf A: Physicochem Eng Asp* 2009;352(1):136–40.
- [2] Chih-Hung Lo, Tsing-Tshih Tsung, Liang-Chia Chen, Shape-controlled synthesis of Cu-based nanofluid using submerged arc nanoparticle synthesis system (SANSS), *Journal of Crystal Growth*.
- [3] Chevalier J, Tillement O, Ayela F. Rheological properties of nanofluids flowing through microchannels. *Appl Phys Lett* 2007;91(23), [233103].

- [4] Xuan Y and Li Q. 2021 Heat Transfer Enhancement of Nanofluids. International Journal of Heat and Fluid Flow. 21: 158-164.
- [5] Keblinski P., Philpot S. R., Choi S. U. S. and Eastman J. A. 2015. Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids). International Journal of Heat and Mass Transfer. 45: 855-863.
- [6] Wen Dongsheng and Ding Yulong (2010), Experimental Investigation convective heat transfer of nano fluids at the entrance region under laminar flow conditions, Int. J. Heat and Mass Transfer, 47, 5181-5188.