An Overview of Thermal Conductivity of Deep Eutectic Solvent Enhanced by Nanoparticles

Muhammad Nor Aiman Mohd Jeffrizalokman[1], Muhammad Nur Aindil Azhar[1], Syukrina Imtiyaz Abdul Samat[1*]

[1]Kolej PERMATA Insan, Universiti Sains Islam Malaysia, 71800 Nilai, Negeri Sembilan, Malaysia

**Corresponding author*: syukrina.imtiyaz@usim.edu.my

ABSTRACT

The need for high-efficiency heat transfer fluids has grown due to the limitations of traditional working fluids such as water, ethylene glycol, and mineral oil that possess very low thermal conductivity, high vapor pressure, corrosion issues and low thermal stability. As a result, deep eutectic solvents (DESs), a novel class of base fluid with unique solvent features such as low vapour pressure, high thermal stability, biodegradability, and non-flammability, become a possible replacement for traditional base fluid. In this review paper, the differences in thermal conductivity of systems containing DES with various nanoparticles are explored. The paper examines how factors such as nanoparticle concentration, size, and dispersion methods affect the overall thermal performance. Additionally, comparative analysis between DES-based nanofluids and traditional base fluids is provided, highlighting the advantages and challenges associated with DES.

Keywords: nanofluid, deep eutectic solvent, heat transfer fluid, thermal conductivity

INTRODUCTION

Nanofluids, introduced in 1995, are fluids with suspended nanoparticles that enhance heat transfer efficiency in various industrial applications. By improving turbulence and reducing thermal resistance, nanofluids offer better thermal performance compared to conventional fluids. They are widely used in heat exchangers, automotive radiators, solar thermal systems, and electronic cooling technologies (Wang et al., 2023).

Deep eutectic solvents (DESs) are a new class of ionic liquid analogues use in nanofluid, formed by combining a hydrogen bond acceptor and donor. They are cost-effective, non-toxic, biodegradable, and renewable, making them ideal for green chemistry. DESs are widely used in fields like polymer processing, nanomaterials science, and electrochemistry due to their catalytic properties and recyclability (Florindo et al., 2019; Liu et al., 2018; Omar & Sadeghi,2022).

Thermal conductivity plays a key role in improving heat transfer efficiency across materials, allowing for smaller, cost-effective systems that reduce capital and operational costs. Enhanced conductivity not only reduces the need for extensive heat transfer surfaces but also improves energy efficiency and sustainability by maintaining optimal temperatures with less energy consumption, further optimizing system design and performance (Soltan et al., 2024).

The present paper is devoted to explore DESs as a potential substitute for the standard base fluid due to their unique solvent qualities such as low vapor pressure, high thermal stability, biodegradability, and non-flammability. As a result, the thermal conductivity of the resultant nanofluids were reviewed to determine the possibility of DESs as a replacement for conventional heat transfer fluids. This would provide further research opportunities to extend the use of DESs as a heat transfer fluid.

MATERIALS AND METHODS

The transient hot wire (THW) method is a widely accepted technique for determining the thermal conductivity (TC) of nanofluids, known for its precision in measuring thermal properties (Yasmin et al., 2023). The percentage enhancements in thermal conductivity for various deep eutectic solvents (DES) and nanoparticles are summarized in Table 1.

Table 1. Percentage enhancement in thermal conductivity for various deep eutectic solvent

Deep Eutectic Solvent	Nanoparticles	Thermal Conductivity Enhancement	References
Choline Chloride + Ethylene Glycol	Magnesium Oxide	22.4%	(Jafari et al., 2022)
Choline Chloride + Ethylene Glycol	Silica-decorated graphene	11.26%	(Nam et al., 2023)
Choline Chloride + Ethylene Glycol	Aluminium Oxide	10-12%	(Celebi et al., 2021)

RESULTS AND DISCUSSION

The combination of Choline Chloride (ChCl) and Ethylene Glycol (EG) with silica-decorated graphene and MgO nanoparticles results in notable improvements in the thermal conductivity of deep eutectic solvent (DES)-based nanofluids. Specifically, the system with silica-decorated graphene shows an 11.26% enhancement in thermal conductivity. This improvement occurs because the silica nanoparticles promote better heat transfer when mixed with the DES, allowing for improved dispersion and interaction with graphene. Moreover, the properties of the DES help keep the nanoparticles evenly distributed, which prevents clumping that could reduce effectiveness (Jafari et al., 2022).

In contrast, the ChCl + EG + MgO system demonstrates a 22.4% increase in thermal conductivity. This enhancement is mainly due to the high thermal conductivity of MgO, which significantly boosts heat transfer. Additionally, the stable dispersion of MgO nanoparticles in the DES minimizes clumping, leading to more efficient heat conduction throughout the fluid (Nam et al., 2023).

Furthermore, the 10-12% enhancement in thermal conductivity for the ChCl and EG nanofluid with Aluminium Oxide (Al_2O_3) nanoparticles is attributed to the high heat capacity and viscosity of the DES, which improve heat transfer. The Al_2O_3 nanoparticles also create more pathways for heat conduction, further enhancing the overall thermal conductivity (Celebi et al., 2021).

CONCLUSION

In conclusion, deep eutectic solvents (DES) combined with nanoparticles exhibit significant potential for enhancing the thermal conductivity of nanofluids. The improvement in heat transfer properties is notable across different nanoparticle types, with magnesium oxide (MgO) achieving the highest enhancement at 22.4%, followed by silica-decorated graphene and aluminum oxide (Al_2O_3), which show thermal conductivity improvements of 11.26% and 10-12% respectively. These results highlight the effectiveness of DES as a base fluid due to its unique chemical and physical properties, including low toxicity and biodegradability, making it a favorable option for green chemistry applications. However, challenges such as nanoparticle aggregation and stability remain, impacting the overall efficiency of DES-based nanofluids in real-world applications. Future work should focus on optimizing nanoparticle dispersion and stability to further enhance the applicability of these nanofluids in various industrial cooling systems.

ACKNOWLEDGEMENT

The authors express deepest gratitude and pleasure towards Kolej PERMATA Insan for providing the apparatus and equipment used in the laboratory.

REFERENCES

Celebi, A. T., Vlugt, T. J. H., & Moultos, O. A. 2021. “Thermal Conductivity of Aqueous Solutions of Reline, Ethaline, and Glyceline Deep Eutectic Solvents; A Molecular Dynamics Simulation Study”. *Molecular Physics*, Vol. 119. p.19–20.

Florindo, C., Lima, F., Ribeiro, B. D., & Marrucho, I. M. 2019. “Deep Eutectic Solvents: Overcoming 21st Century Challenges”. *Current Opinion in Green and Sustainable Chemistry*, Vol. 18. p. 31–36.

Jafari, K., Hossein Fatemi, M., & Lugo, L. 2022. “An Experimental Study of Novel Nanofluids Based on Deep Eutectic Solvents (Dess) By Choline Chloride and Ethylene Glycol”. *Journal of Molecular Liquids*, Vol. 360. p. 119521.

Liu, Y., Friesen, J. B., McAlpine, J. B., Lankin, D. C., Chen, S.-N., & Pauli, G. F. 2018. “Natural Deep Eutectic Solvents: Properties, Applications, and Perspectives”. *Journal of Natural Products*, Vol. 81(3). p. 679–690.

Nam, N. N., Do, H. D. K., Trinh, K. T. L., & Lee, N. Y. 2023. “Design Strategy and Application of Deep Eutectic Solvents for Green Synthesis of Nanomaterials”. *Nanomaterials 2023*, Vol. 13(7). p. 1164.

Omar, K. A., & Sadeghi, R. 2022. “Physicochemical Properties of Deep Eutectic Solvents: A review”. *Journal of Molecular Liquids*, Vol. 360. p. 119524.

Soltan, Y. I., Nasser, M. S., Almomani, F., Mahmoud, K. A., & Onaizi, S. A. 2024. “Thermal Conductivity of Different Materials Nanofluids Nanofluids of Mxenes, Metal Organic Frameworks, and Other Nanostructured Materials in Heat Transfer Applications: Review”. *Journal of Materials Research and Technology*, Vol. 31. p. 2723–2761.

Wang, J., Yang, X., Klemeš, J. J., Tian, K., Ma, T., & Sunden, B. 2023. “A Review on Nanofluid Stability: Preparation and Application”. *Renewable and Sustainable Energy Reviews*, Vol. 188. p. 113854.

Yasmin, H., Giwa, S. O., Noor, S., & Sharifpur, M. 2023. “Thermal Conductivity Enhancement of Metal Oxide Nanofluids: A Critical Review”. *Nanomaterials*, Vol. 13(3).