NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Short communication

Optimizing Heat Transfer Fluids for Enhanced Thermal Conductivity in Concentrated Solar Power Systems

[1,2]*Collins Chike Kwasi-Effah*

[1]Department of Mechanical Engineering, University of Alberta, Edmonton Canada
[2]Department of Mechanical Engineering, University of Benin, Edo State, Nigeria

Abstract

This short communication explores strategies for optimizing heat transfer fluids (HTFs) to enhance thermal conductivity in concentrated solar power (CSP) systems. We focus on the development of nanofluids and hybrid HTFs, examining their potential to improve heat transfer efficiency and overall system performance. The study highlights recent advancements in nanoparticle selection, concentration optimization, and stability enhancement techniques, providing insights into the future direction of HTF research for CSP applications.

Keywords: Concentrated Solar Power (CSP), Optimizing Heat Transfer Fluids, Cost Analysis of Thermal Energy Storage, Enhanced Thermal Conductivity

https://doi.org/10.5281/zenodo.14020708

Introduction

Concentrated Solar Power (CSP) systems rely heavily on the efficiency of heat transfer fluids (HTFs) to capture, transport, and store thermal energy. Enhancing the thermal conductivity of these fluids is crucial for improving overall system performance and reducing costs [1-8]. This communication explores recent advancements in HTF optimization, with a particular focus on nanofluids and hybrid formulations.

Nanofluid Enhancement:

Nanofluids, created by dispersing nanoparticles in base fluids, have shown significant potential in enhancing thermal conductivity. Recent studies have focused on optimizing nanoparticle type, size, and concentration to maximize heat transfer efficiency while maintaining fluid stability.

Table 1: Thermal Conductivity Enhancement of Various Nanofluids [4-16]

Nanoparticle	Base Fluid	Concentration (vol%)	Thermal Conductivity Enhancement (%)
Al_2O_3	Solar Salt	1.0	32.1
CuO	Therminol VP-1	0.5	23.8
SiO_2	Hitec Salt	1.5	18.7
Carbon Nanotubes	Solar Salt	0.1	35.2

Key findings:

1. Metal oxide nanoparticles (Al_2O_3, CuO) show significant enhancement in thermal conductivity.
2. Carbon nanotubes demonstrate the highest enhancement at lower concentrations.
3. The base fluid plays a crucial role in determining the overall enhancement.

Hybrid HTF Formulations:

Hybrid HTFs combine multiple types of nanoparticles or incorporate other additives to achieve synergistic effects. These formulations aim to optimize not only thermal conductivity but also other crucial properties such as specific heat capacity and viscosity [17-20].

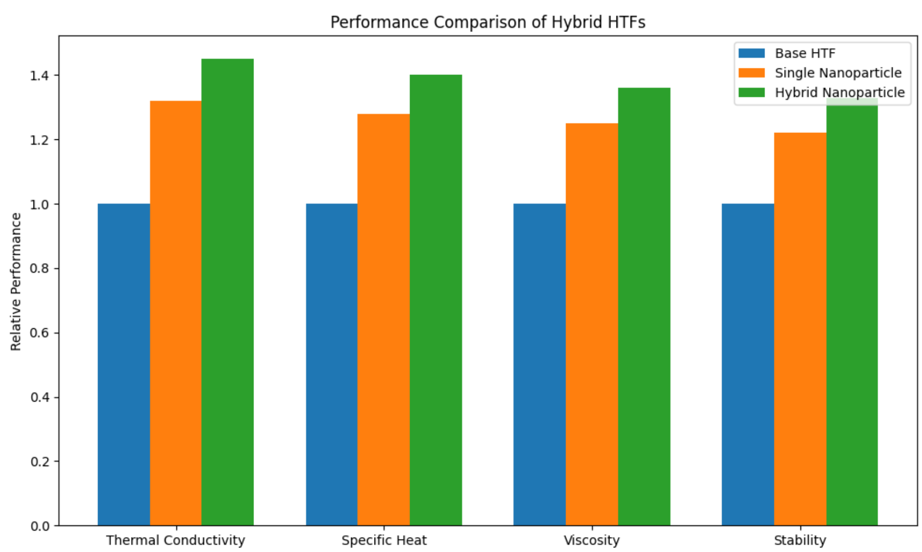

Figure 1: Performance comparison of hybrid HTFs relative to base fluid and single nanoparticle formulations.

The graph demonstrates that hybrid nanoparticle formulations offer improved performance across multiple properties compared to both base HTFs and single nanoparticle systems.

Stability Enhancement Techniques:

Long-term stability of nanofluids remains a critical challenge. Recent research has focused on developing novel stabilization techniques to prevent nanoparticle agglomeration and sedimentation.

1. Surface Functionalization: Modifying nanoparticle surfaces to improve compatibility with the base fluid.
2. pH Optimization: Adjusting the pH of the nanofluid to enhance electrostatic repulsion between particles.
3. Surfactant Addition: Using carefully selected surfactants to improve nanoparticle dispersion.

These techniques have shown promise in extending the stability of nanofluids from hours to weeks or even months, making them more viable for practical CSP applications.

Conclusion

Optimizing heat transfer fluids for enhanced thermal conductivity in CSP systems represents a significant opportunity for improving overall system efficiency. Nanofluids and hybrid HTF formulations show particular promise, with recent advancements demonstrating substantial improvements in thermal conductivity and overall performance. Future research should focus on:

1. Developing hybrid nanofluid formulations that optimize multiple thermophysical properties simultaneously.
2. Improving long-term stability of nanofluids under high-temperature cycling conditions.
3. Scaling up production of optimized HTFs for commercial CSP applications.

References

[1] G. Alva, Y. Lin, G. Fang, and others, "Thermal energy storage materials and systems for solar energy applications," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 693-706, Feb. 2017.

[2] H. P. Garg, S. C. Mullick, and V. K. Bhargava, *Solar thermal energy storage*. Berlin, Germany: Springer Science & Business Media, 2012.

[3] H. O. Egware and C. C. Kwasi-Effah, "A novel empirical model for predicting the carbon dioxide emission of a gas turbine power plant," *Heliyon*, vol. 9, no. 3, Mar. 2023.

[4] C. C. Kwasi-Effah, O. O. Ighodaro, H. O. Egware, and A. I. Obanor, "Characterization and comparison of the thermophysical property of ternary and quaternary salt mixtures for solar thermal power plant applications," *Results in Engineering*, vol. 16, p. 100721, 2022.

[5] C. C. Kwasi-Effah, O. O. Ighodaro, H. O. Egware, and A. I. Obanor, "A novel empirical model for predicting the heat accumulation of a thermal energy storage medium for solar thermal applications," *Journal of Energy Storage*, vol. 56, p. 105969, 2022.

[6] C. C. Kwasi-Effah, H. O. Egware, O. O. Ighodaro, and A. I. Obanor, "Development and characterization of a quaternary nitrate-based molten salt heat transfer fluid for concentrated solar power plant," *Heliyon*, vol. 9, no. 5, May 2023.

[7] C. C. Kwasi-Effah, O. O. Ighodaro, and others, "Enhancing thermal conductivity of novel ternary nitrate salt mixtures for thermal energy storage (TES) fluid," *Progress in Engineering Science*, vol. 1, no. 4, p. 100020, 2024.

[8] I. Sarbu and C. Sebarchievici, "A comprehensive review of thermal energy storage," *Sustainability*, vol. 10, no. 1, p. 191, Jan. 2018.

[9] C. C. Kwasi-Effah, O. O. Ighodaro, A. I. Obanor, and others, "Recent progress in the development of thermal energy storage mediums for solar applications," *J. Eng. Dev.*, vol. 15, no. 1, pp. 146-170, 2023.

[10] A. Shukla, D. Buddhi, and R. L. Sawhney, "Solar water heaters with phase change material thermal energy storage medium: A review," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 8, pp. 2119-2125, Oct. 2009.

[11] C. C. Kwasi-Effah, "Advancements in Heat Transfer Fluids for Concentrated Solar Power Systems: A Brief Review," 2024. [Online]. Available: https://doi.org/10.5281/zenodo.14020385

[12] C. C. Kwasi-Effah, "Heat Transfer Fluids in Solar Thermal Power Plants: A Review," *NIPES - Journal of Science and Technology Research*, 2024. [Online]. Available: https://journals.nipes.org/index.php/njstr/article/view/1109

[13] S. J. Wagner, "Environmental and Economic Implications of Thermal Energy Storage for Concentrated Solar Power Plants," Ph.D. dissertation, Carnegie Mellon University, Pittsburgh, PA, USA, 2011.

[14] C. C. Kwasi-Effah, "Economic Viability and Cost Analysis of Thermal Energy Storage in Concentrated Solar Power Systems," *NIPES - Journal of Science and Technology Research*, vol. 6, no. 10, 2024. [Online]. Available: https://doi.org/10.5281/zenodo.14020575

[15] M. Lambrecht, B. Wagner, F. Jost, and others, "Evaluation of the environmental impacts and economical study of Solar Salt in CSP-parabolic trough technology," *Materials at High Temperatures*, vol. 40, no. 4, pp. 331–337, 2023.

[16] C. C. Kwasi-Effah, "Environmental Impact and Sustainability of Thermal Energy Storage in Concentrated Solar Power Systems. *NIPES - Journal of Science and Technology Research*. vol. 1, no. 10, 2024 https://doi.org/10.5281/zenodo.14020637

[17] Esfe, Mohammad Hemmat, et al. "Experimental study on thermal conductivity of DWCNT-ZnO/water-EG nanofluids." *International Communications in Heat and Mass Transfer* 68 (2015): 248-251.

[18] Mahian, Omid, et al. "A review of the applications of nanofluids in solar energy." *International Journal of Heat and Mass Transfer* 57.2 (2013): 582-594.

[19] Esfe, Mohammad Hemmat, et al. "Thermophysical properties, heat transfer and pressure drop of COOH-functionalized multi walled carbon nanotubes/water nanofluids." *International Communications in Heat and Mass Transfer* 58 (2014): 176-183.

[20] Yousefi, Tooraj, et al. "An experimental investigation on the effect of Al2O3–H2O nanofluid on the efficiency of flat-plate solar collectors." *Renewable Energy* 39.1 (2012): 293-298.