NIPES-Journal of Science and Technology Research 6(10) 2024 pp 57-60. ISSN-2682-5821

NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Short communication

Recent Advances in Molten Salt-Based Nanofluids for Thermal Energy Storage in Concentrated Solar Power: A Brief Overview

[1,2]Collins Chike Kwasi-Effah, Martin Osikhuemhe[2]

[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 summarizes recent advancements in molten salt-based nanofluids for thermal energy storage (TES) in concentrated solar power (CSP) systems. We highlight key developments in nanoparticle-enhanced molten salts, focusing on improvements in specific heat capacity (SHC) and thermal conductivity. The study discusses synthesis methods, characterization techniques, and the underlying mechanisms of property enhancement, providing insights into the future direction of nanofluid research for CSP applications.

Keywords: Concentrated Solar Power (CSP), Recent Advances in Molten Salt-Based Nanofluids, Review

https://doi.org/10.5281/10.5281/zenodo.14029078

Introduction

Concentrated solar power (CSP) with thermal energy storage (TES) offers a promising solution for sustainable electricity generation. Molten salt-based nanofluids have emerged as potential candidates for enhancing the efficiency of CSP systems by improving the thermophysical properties of heat transfer fluids (HTFs) and TES materials [1-27].

Nanofluid Synthesis and Optimization

Recent studies have explored various combinations of base salts and nanoparticles to optimize TES performance. Table 1 summarizes some notable achievements in SHC enhancement:

Table 1: SHC enhancements for various molten salt-nanoparticle combinations [28]

Base Salt System	Nanoparticle	NP Size (nm)	NP%	Max. Cp Enhancement (%)
$NaNO_3$-KNO_3 (60:40 wt.)	SiO_2	15.2	1.0	15.00
KNO_3	SiO_2	20-25	4.0	15.70
$NaNO_3$-KNO_3 (60:40 wt.)	Al_2O_3	20	2.0	8.30
K_2CO_3-Li_2CO_3-Na_2CO_3 (4:4:2 wt.)	SiO_2	20	1.0	113.70

Two primary synthesis methods have been developed:

1. Two-step method: Nanoparticles are prepared separately and then dispersed in the molten salt.
2. One-step method: Nanoparticles are formed in-situ within the molten salt matrix.

Characterization Techniques

Advanced characterization methods have been crucial in understanding nanofluid properties:

1. Differential Scanning Calorimetry (DSC) for SHC measurements
2. Thermogravimetric Analysis (TGA) for thermal stability assessment
3. Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) for morphological analysis
4. X-ray Diffraction (XRD) for crystallographic structure determination

Enhancement Mechanisms

Several theories have been proposed to explain the observed enhancements in thermophysical properties:

1. Formation of a semi-solid layer at the nanoparticle-salt interface
2. Development of nanostructures within the salt matrix
3. Increased phonon transport due to nanoparticle addition

Challenges and Future Directions

Despite significant progress, challenges remain in nanofluid development for CSP applications:

1. Long-term stability of nanoparticle dispersions at high temperatures

2. Scale-up of synthesis methods for industrial production
3. Understanding and optimizing nanoparticle-salt interactions for maximum property enhancement

Future research should focus on:

1. Developing novel nanoparticle-salt combinations for further property improvements
2. Investigating the long-term performance of nanofluids under realistic CSP operating conditions
3. Exploring hybrid nanofluid systems that combine multiple types of nanoparticles

Conclusion

Molten salt-based nanofluids show great promise for enhancing the efficiency of CSP systems through improved thermal energy storage. Recent advancements in synthesis methods and characterization techniques have provided valuable insights into the behavior of these complex systems. As research progresses, nanofluid-enhanced molten salts could play a crucial role in the widespread adoption of CSP technology, contributing to a more sustainable energy future.

References

[1] G. Alva, Y. Lin, G. Fang, et al, "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] Vignarooban, K., et al. "Heat transfer fluids for concentrating solar power systems – A review. Applied Energy", 146, 2015, 383-396.

[4] Benoit, H., et al. "Review of heat transfer fluids in tube-receivers used in concentrating solar thermal systems: Properties and heat transfer coefficients". Renewable and Sustainable Energy Reviews, 55, 2016, 298-315.

[5] 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.

[6] 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.

[7] 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.

[8] 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.

[9] C. C. Kwasi-Effah, O. O. Ighodaro, et al., "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.

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

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

[12] 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.

[13] 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

[14] 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

[15] 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.

[16] 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

[17] 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.

[18] 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. [Online]. Available: https://doi.org/10.5281/zenodo.14020637

[19] M. H. Esfe, et al., "Experimental study on thermal conductivity of DWCNT-ZnO/water-EG nanofluids," *International Communications in Heat and Mass Transfer*, vol. 68, pp. 248-251, 2015.

[20] O. Mahian, et al., "A review of the applications of nanofluids in solar energy," *International Journal of Heat and Mass Transfer*, vol. 57, no. 2, pp. 582-594, 2013.

[21] M. H. Esfe, 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*, vol. 58, pp. 176-183, 2014.

[22] C. C. Kwasi-Effah, "Optimizing Heat Transfer Fluids for Enhanced Thermal Conductivity in Concentrated Solar Power Systems," *NIPES - Journal of Science and Technology Research*, 2024. [Online]. Available: https://doi.org/10.5281/zenodo.14020708

[23] T. Yousefi, et al., "An experimental investigation on the effect of Al_2O_3–H_2O nanofluid on the efficiency of flat-plate solar collectors," *Renewable Energy*, vol. 39, no. 1, pp. 293-298, 2012.

[24] R. D. Ayinla, C. C. Kwasi-Effah, and H. O. Egware, "Thermal Conductivity Enhancement of Quaternary Nitrate Salt Mixtures for Thermal Energy Storage with Al_2O_3 Nanoparticle Doping," *NIPES - Journal of Science and Technology Research*, vol. 6, no. 3, 2024. [Online]. Available: https://doi.org/10.5281/zenodo.14020924

[25] C. C. Kwasi-Effah. "Advancements in Hybrid Heat Transfer Fluids: Potential for Reduced Melting Points in CSP Applications". *NIPES - Journal of Science and Technology Research* vol 6, no. 10, 2024 https://doi.org/10.5281/zenodo.14026856

[26] M. Lambrecht, et al. "Evaluation of the environmental impacts and economical study of Solar Salt in CSP-parabolic trough technology. *Materials at High Temperatures*, *40*(4), 2023. https://doi.org/10.1080/09603409.2023.2182588

[27] C. C. Kwasi-Effah, M. Osikhuemhe. "Environmental and Economic Trade-offs in Heat Transfer Fluids for Concentrated Solar Power: A Brief Review." *NIPES - Journal of Science and Technology Research*. 2024 https://doi.org/10.5281/zenodo.14027127

[28] S.K.Tamilarasan, et al. "Recent Developments in Supercritical CO_2-Based Sustainable Power Generation Technologies" *Energies* **2024**, *17*, 4019. https://doi.org/10.3390/en17164019