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Short communication

Comparative Analysis of Ternary and Quaternary Salt Mixtures for Solar Thermal Power Plants

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Abstract

This short communication presents a comparative analysis of ternary and quaternary salt mixtures for use in solar thermal power plants, particularly in concentrated solar power (CSP) systems. We examine the thermophysical properties, thermal stability, and overall performance of these advanced heat transfer fluids (HTFs) and thermal energy storage (TES) materials. The study highlights recent developments in salt mixture formulations, focusing on their potential to enhance CSP system efficiency and reduce operational costs.

Keywords: Concentrated Solar Power (CSP), Comparative Analysis of Ternary and Quaternary Salt Mixtures, Solar Thermal Power Plants

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Introduction

As concentrated solar power (CSP) technology advances, the development of more efficient heat transfer fluids (HTFs) and thermal energy storage (TES) materials becomes crucial. Ternary and quaternary salt mixtures have emerged as promising alternatives to traditional binary salt mixtures, offering potential improvements in thermophysical properties and operational temperature ranges [1-8].

Comparison of Salt Mixtures:

Table 1: Comparison of Key Properties for Binary, Ternary, and Quaternary Salt Mixtures

Property	Binary (Solar Salt)	Ternary Mixture	Quaternary Mixture
Composition	60% $NaNO_3$, 40% KNO_3	$NaNO_3$-KNO_3-Na_2SO_4	$NaNO_3$-KNO_3-$Ca(NO_3)_2$-$LiNO_3$
Melting Point (°C)	220-230	213.5	95-120
Decomposition Temperature (°C)	565-600	600-640	550-600
Specific Heat Capacity (J/g·K)	1.5-1.6	1.6-1.7	1.5-1.7
Thermal Conductivity (W/m·K)	0.5-0.6	0.5-0.7	0.5-0.8
Cost	Moderate	Low-Moderate	Moderate-High

Key Findings:

1. Melting Point: Quaternary mixtures show significantly lower melting points, potentially reducing freezing risks and startup energy requirements [5-11]
2. Thermal Stability: Ternary mixtures, particularly those containing sulfates, demonstrate higher decomposition temperatures, allowing for higher operating temperatures [7-10]. Specific Heat Capacity: Both ternary and quaternary mixtures show slight improvements in specific heat capacity, enhancing energy storage density
3. Thermal Conductivity: Quaternary mixtures tend to have marginally higher thermal conductivity, potentially improving heat transfer efficiency [11-22].
4. Cost Considerations: Ternary mixtures, especially those incorporating cheaper components like sulfates, may offer cost advantages over binary and some quaternary mixtures .

Performance in CSP Systems:

Ternary salt mixtures, such as the $NaNO_3$-KNO_3-Na_2SO_4 system, have shown promising results in experimental studies. For instance, a novel ternary molten salt (TMS) formulation demonstrated a 13.17% wider use temperature range compared to solar salt, with a 9.03% higher average specific heat capacity. This expansion of the operational temperature range can significantly enhance the overall efficiency of CSP plants.

Quaternary mixtures, particularly those incorporating calcium and lithium nitrates, have shown remarkable reductions in melting point while maintaining good thermal stability. This characteristic allows for reduced parasitic heating requirements during plant startup and non-operational periods, potentially improving the overall plant efficiency and reducing operational costs .

Challenges and Future Directions:

Despite the promising properties of ternary and quaternary salt mixtures, several challenges remain:

1. Long-term Stability: Further research is needed to assess the long-term stability of these mixtures under repeated thermal cycling conditions typical in CSP operations .
2. Corrosion Behavior: The impact of more complex salt compositions on material corrosion rates needs thorough investigation to ensure system longevity .
3. Scale-up and Economic Viability: While some ternary mixtures offer cost advantages, the economic feasibility of large-scale production and implementation of more complex salt mixtures requires further study.

Conclusion:

Ternary and quaternary salt mixtures show significant potential for improving the performance of CSP systems. Their enhanced thermophysical properties, particularly the wider operational temperature ranges and improved specific heat capacities, offer promising avenues for increasing plant efficiency and reducing costs. However, further research is needed to address challenges related to long-term stability, corrosion behavior, and economic viability at commercial scales. As the field progresses, these advanced salt mixtures may play a crucial role in the next generation of high-efficiency, cost-effective CSP plants.

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, 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.

[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, 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.

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

[17] 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.

[18] 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.

[19] 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.

[20] 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

[21] 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.

[22] 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