Short communication

Innovative Thermal Energy Storage Solutions for CSP: Current Progress and Future Outlook

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Abstract: The advancement of thermal energy storage (TES) systems is key to the operational success and sustainability of Concentrated Solar Power (CSP) plants. This short communication delves into recent innovations in TES fluids, including quaternary nitrate mixtures enhanced with nanoparticles, while discussing the economic and environmental implications of these advancements.

1. Introduction

CSP technology has emerged as a critical part of the renewable energy landscape, offering stable power supply capabilities. The development of high-performance TES systems is vital for maximizing CSP efficiency and reducing reliance on fossil fuels [1-31]. TES fluids play a pivotal role in storing and transferring thermal energy effectively.

2. Cutting-Edge TES Fluid Technologies

Quaternary nitrate-based molten salts have been developed to improve the thermal performance of TES systems. These advanced mixtures exhibit superior thermophysical properties such as higher thermal stability and enhanced heat transfer efficiency, surpassing traditional binary salt compositions [12-16].

3. Nanoparticle Doping: Enhancing Performance

Research has demonstrated that the addition of nanoparticles like Al_2O_3 to TES fluids results in significantly improved thermal conductivity and overall energy storage efficiency (Ayinla et al., 2024). This approach not only raises the operating temperature limits but also boosts the heat retention capacity of the fluids [29-30].

4. Balancing Economic and Environmental Goals

While innovative TES fluids offer marked performance benefits, their widespread adoption hinges on economic feasibility and environmental sustainability. The UN Sustainable Development Goals (SDGs) underscore the importance of integrating economic and ecological considerations into technological development. Economic analyses and lifecycle assessments help guide decision-making in CSP technology deployment.

5. Challenges and Future Perspectives

Despite these advancements, challenges remain. The high costs associated with developing and maintaining advanced TES fluids, as well as the need for improved long-term stability, are notable

hurdles. Future research must focus on reducing production expenses and exploring more sustainable fluid formulations to ensure broader adoption.

Conclusion

Advancements in TES fluids, particularly through the use of quaternary nitrate mixtures and nanoparticle doping, represent significant strides in CSP technology. Continued interdisciplinary efforts are crucial to address the remaining challenges, optimize performance, and align with global sustainability objectives.

References

[1] Kwasi-Effah, C. C., Egware, H. O., Obanor, A. I., & Ighodaro, O. O. (2023). Development and characterization of a quaternary nitrate based molten salt heat transfer fluid for concentrated solar power plant. *Heliyon, 9*(5).

[2] Pedersen, C. S. (2018). The UN sustainable development goals (SDGs) are a great gift to business!. *Procedia Cirp, 69*, 21-24.

[3] IRENA. (2020). Renewable Power Generation Costs in 2019.

[4] Mehos, M., et al. (2017). Concentrating Solar Power Gen3 Demonstration Roadmap. NREL/TP-5500-67464.

[5] Palacios, A., et al. (2020). Thermal energy storage in concrete tanks: Design and testing. *Solar Energy, 206*, 1-8.

[6] Fernández, A. G., et al. (2019). Thermal energy storage for CSP plants through the use of molten salt binary mixtures. *Solar Energy Materials and Solar Cells, 201*, 110082.

[7] U.S. Department of Energy. (2023). Generation 3 Concentrating Solar Power Systems.

[8] Prieto, C., et al. (2016). Review of technology: Thermochemical energy storage for concentrated solar power plants. *Renewable and Sustainable Energy Reviews, 60*, 909-929.

[9] González-Roubaud, E., et al. (2017). Review of commercial thermal energy storage in concentrated solar power plants: Steam vs. molten salts. *Renewable and Sustainable Energy Reviews*.

[10] Alva, G., Lin, Y., Fang, G., et al. (2017). Thermal energy storage materials and systems for solar energy applications. *Renewable and Sustainable Energy Reviews, 68*, 693-706.

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

[12] Vignarooban, K., et al. (2015). Heat transfer fluids for concentrating solar power systems – A review. *Applied Energy, 146*, 383-396.

[13] Benoit, H., et al. (2016). 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*, 298-315.

[14] Egware, H. O., & Kwasi-Effah, C. C. (2023). A novel empirical model for predicting the carbon dioxide emission of a gas turbine power plant. *Heliyon, 9*(3).

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

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

[17] Sarbu, I., & Sebarchievici, C. (2018). A comprehensive review of thermal energy storage. *Sustainability, 10*(1), 191.

[18] Shukla, A., Buddhi, D., & Sawhney, R. L. (2009). Solar water heaters with phase change material thermal energy storage medium: A review. *Renewable and Sustainable Energy Reviews, 13*(8), 2119-2125.

[19] Kwasi-Effah, C. C., Ighodaro, O., & Obanor, A. I. (2023). Recent progress in the development of thermal energy storage mediums for solar applications. *J. Eng. Dev., 15*(1), 146-170.

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

[21] Kwasi-Effah, C. C. (2024). Economic Viability and Cost Analysis of Thermal Energy Storage in Concentrated Solar Power Systems. *NIPES - Journal of Science and Technology Research, 6*(10).

[22] Lambrecht, M., Wagner, B., Jost, F., & others. (2023). Evaluation of the environmental impacts and economical study of Solar Salt in CSP-parabolic trough technology. *Materials at High Temperatures, 40*(4), 331–337.

[23] Kwasi-Effah, C. C. (2024). Environmental Impact and Sustainability of Thermal Energy Storage in Concentrated Solar Power Systems. *NIPES - Journal of Science and Technology Research, 1*(10).

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

[25] Mahian, O., et al. (2013). A review of the applications of nanofluids in solar energy. *International Journal of Heat and Mass Transfer, 57*(2), 582-594.

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

[27] Kwasi-Effah, C. C. (2024). Optimizing Heat Transfer Fluids for Enhanced Thermal Conductivity in Concentrated Solar Power Systems. *NIPES - Journal of Science and Technology Research*.

[28] Yousefi, T., et al. (2012). An experimental investigation on the effect of Al_2O_3–H_2O nanofluid on the efficiency of flat-plate solar collectors. *Renewable Energy, 39*(1), 293-298.

[29] Ayinla, R. D., Kwasi-Effah, C. C., & Egware, H. O. (2024). 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, 6*(3).

[30] Kwasi-Effah, C. C., & Rabczuk, T. (2018). Dimensional analysis and modelling of energy density of lithium-ion battery. *Journal of Energy Storage, 18*, 308-315.

[31] Kwasi-Effah, C. C., & Unuareokpa, O. (2024). Enhancing thermal conductivity of novel ternary nitrate salt mixtures for thermal energy storage (TES) fluid. *Progress in Engineering Science, 1*(4), 100020.

[32] Lambrecht, M., et al. (2023). Evaluation of the environmental impacts and economical study of Solar Salt in CSP-parabolic trough technology. *Materials at High Temperatures, 40*(4), 331-337.

[33] Kwasi-Effah, C. C., & Osikhuemhe, M. (2024). Environmental and Economic Trade-offs in Heat Transfer Fluids for Concentrated Solar Power: A Brief Review. *NIPES - Journal of Science and Technology Research*.

[34] Tamilarasan, S. K., et al. (2024). Recent Developments in Supercritical CO2-Based Sustainable Power Generation Technologies. *Energies, 17*, 4019.