NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Short communication

Socioeconomic Implications of a New Quaternary Molten Salt Heat Transfer Fluid for Concentrated Solar Power Plants

Collins C. Kwasi-Effah, Osarobo Ighodaro, Henry O. Egware, Albert I. Obanor

Department of Mechanical Engineering, University of Benin, Benin City, Edo State, Nigeria

Abstract

Concentrated solar power (CSP) represents a promising renewable energy technology with the potential to mitigate greenhouse gas emissions and enhance air quality. However, the limited adoption of current heat transfer fluids (HTFs) due to their high viscosity presents a challenge. In this short communication, we present a novel quaternary molten salt HTF for CSP plants which is comprised of KNO_3, $LiNO_3$, $Ca(NO_3)_2$, and $NaNO_2$. This salt mixture exhibits reduced viscosity, increased heat capacity, and improved thermal stability compared to existing HTFs. Our findings suggest that this quaternary molten salt holds promise as a more efficient and cost-effective HTF for CSP plants.

Keywords: Social impact, Quaternary salt, Heat transfer fluid, CSP plant

10.5281/zenodo.14043148

Social Impact

Concentrated solar power (CSP) offers clean and renewable energy solutions that can significantly reduce greenhouse gas emissions and enhance air quality. However, the limited utilization of current heat transfer fluids (HTFs) due to their high viscosity poses a challenge for wider adoption. The development of a novel quaternary molten salt HTF by [1] with reduced viscosity by 45% compared to solar salt can yield substantial social impact by enhancing the efficiency and cost-effectiveness of CSP plants.

The adoption of this innovative HTF would likely attract increased investments in CSP technology, facilitating the transition away from fossil fuel dependency and supporting global climate change mitigation efforts. Moreover, the application of the new salt mixture extends beyond CSP plants, finding potential use in thermal energy storage and solar desalination, further contributing to sustainable development.

Aligned with the Sustainable Development Goals (SDGs) of SDG 7 [2]: Affordable and Clean Energy and SDG 13: Climate Action, the development of this quaternary molten salt HTF holds promise in bolstering the share of renewable energy worldwide and curbing greenhouse gas emissions.

Methodology

This research employed a systematic approach encompassing the formulation and characterization of a quaternary nitrate-based molten salt HTF. The chemical composition of the HTF was meticulously determined, considering factors such as thermal stability, heat capacity, viscosity, and corrosion resistance. Table 1 shows the sample composition of the new quaternary heat transfer fluid. Furthermore, laboratory-scale experiments were conducted to evaluate the thermal performance and operational feasibility of the HTF within a simulated concentrated solar power system.

Table 1: Quaternary mixture [1].

	$Ca(NO_3)_2$	$LiNO_3$	KNO_3	$NaNO_2$
S1	40 wt%	5 wt%	25 wt%	30 wt%
S2	38 wt%	10 wt%	24 wt%	28 wt%
S3	36 wt%	15 wt%	23 wt%	26 wt%
S4	34 wt%	20 wt%	21 wt%	25 wt%
S5	32 wt%	25 wt%	20 wt%	23 wt%
S6	30 wt%	30 wt%	19 wt%	21 wt%
S7	28 wt%	35 wt%	18 wt%	19 wt%

Results and implications

The study yielded noteworthy findings regarding the properties of the quaternary molten salt HTF, highlighting its potential as a more efficient and cost-effective solution for CSP plants. The specific observations include:

a. Melting Temperature: The addition of $LiNO_3$ led to a decrease in the melting temperature of the quaternary mixture. Sample S7 exhibited the lowest melting temperature at 73.5°C, while S1 demonstrated the highest at 100.1°C.

b. Heat Capacity: The incorporation of $LiNO_3$ resulted in an increase in the heat capacity of the quaternary mixture. On average, the heat capacity of this novel HTF surpassed that of the commercial salt (Hitec) commonly employed in concentrated solar thermal power plants.

c. Viscosity: As the concentration of $LiNO_3$ increased, the viscosity of the salt mixture decreased. This characteristic indicates its suitability as an efficient heat transfer fluid, contributing to reduced pumping power requirements and improved overall efficiency of solar thermal power plants.

d. Thermal Stability: The quaternary salt mixture exhibited favorable thermal stability, with decomposition temperatures ranging from 590°C to 620°C. This represents an improvement over other novel mixtures and commercial salts.

e. Thermal Conductivity: The quaternary salt mixture demonstrated superior thermal conductivity compared to commercial organic oil and a commercial salt (Hitec XL). This heightened thermal conductivity facilitates enhanced heat transfer within the system.

The addition of $LiNO_3$ in the salt mixture induces modifications in its microstructure, resulting in reduced viscosity, improved heat transfer properties, enhanced thermal conductivity, and overall system performance.

Implication on cost effectiveness

The introduction of the new quaternary molten salt HTF has the potential to significantly enhance the cost effectiveness of concentrated solar power (CSP) plants compared to traditional salts like the solar salt. The lower viscosity of the quaternary molten salt HTF reduces the pumping power requirements, thereby reducing operational costs associated with fluid circulation within the system. This improvement in cost efficiency can make CSP technology more economically viable and attractive for widespread adoption.

While specific cost figures may depend on factors such as production scale and market conditions, the cost effectiveness of the new quaternary molten salt HTF can be inferred from its improved properties compared to traditional salts. Previous studies such as [3, 4,5,6] have reported viscosity reductions of up to 40% with the use of alternative HTFs. Considering the even lower viscosity, higher heat capacity, and improved thermal stability of the new quaternary molten salt HTF, it is plausible to expect a comparable or potentially greater percentage reduction in cost compared to conventional HTFs.

Quantifying the exact percentage reduction in cost would require comprehensive economic analyses and comparative studies involving different HTFs currently used in CSP plants. These studies could assess factors such as material costs, operational expenses, and maintenance requirements. Nonetheless, the improved characteristics of the quaternary molten salt HTF, coupled with its potential for lower pumping power requirements, suggest a significant potential for cost savings in CSP plant operations.

It is important to note that the actual cost effectiveness and percentage reduction compared to other traditional salts will depend on various factors, including the specific application, local conditions, and market dynamics. Therefore, comprehensive economic evaluations and cost-benefit analyses would be necessary to provide precise estimates of the cost advantages and percentage reductions associated with the adoption of the new quaternary molten salt HTF in CSP plants.

Thermal Conductivity and Implications on Plant Size and Cost

The enhanced thermal conductivity of the new quaternary molten salt HTF compared to traditional salts can have significant implications for the size and cost of concentrated solar power (CSP) plants. Thermal conductivity refers to the ability of a material to conduct heat, and a higher thermal conductivity can facilitate more efficient heat transfer within the system.

The improved thermal conductivity of the quaternary molten salt HTF enables improved heat transfer from the solar collector to the power generation system. This means that a smaller heat exchanger or heat transfer surface area may be required to achieve the desired heat transfer efficiency. Consequently, the overall size of the CSP plant can be reduced, resulting in potential cost savings in terms of material requirements, construction, and land usage [7-12].

Moreover, the reduced size of the plant can have additional cost implications beyond the initial construction phase. Smaller CSP plants generally require less maintenance, have lower operating costs, and may require a smaller workforce for operation and maintenance activities. These factors can contribute to improved cost effectiveness and potentially shorter payback periods for investors.

However, it is important to note that the exact implications on plant size and cost will depend on several factors, including the specific design of the CSP plant, the heat transfer requirements, and the local conditions. Detailed engineering and economic analyses are necessary to precisely quantify the cost implications and determine the optimal plant size based on the specific characteristics of the quaternary molten salt HTF.

Nonetheless, the higher thermal conductivity of the new quaternary molten salt HTF offers the potential for more compact and cost-effective CSP plant designs. By enabling efficient heat transfer, this can contribute to overall cost reduction and improved economic viability of CSP technology.

The improved melting point temperature, heat capacity, and thermal stability of the new quaternary molten salt HTF have significant implications for the size, cost, and operating efficiency of concentrated solar power (CSP) plants.

Implications on melting point, heat capacity and thermal stability

The lower melting point temperature of the quaternary molten salt HTF allows for operation at lower temperatures, which can have several advantages. Firstly, it reduces the energy required for heating the HTF to its operating temperature, resulting in lower energy consumption and potentially reducing operating costs. Secondly, it can enable the use of less expensive construction materials and components that are designed to operate at lower temperatures, leading to potential cost savings in plant construction.

The higher heat capacity of the quaternary molten salt HTF allows it to absorb and store more heat energy. This can contribute to improved thermal energy storage capabilities in CSP plants. By storing excess heat during peak solar radiation periods, the plant can continue to generate electricity during periods of low solar radiation or at night, enhancing its overall operational efficiency. The increased heat capacity also enables a more stable and consistent supply of thermal energy, resulting in a more reliable power generation system.

The improved thermal stability of the quaternary molten salt HTF, as indicated by its higher decomposition temperature, offers several benefits. It enhances the longevity and durability of the HTF, reducing the need for frequent replacements and maintenance. This can result in cost savings and increased plant availability, improving the overall operating efficiency of the CSP plant. Additionally, the enhanced thermal stability reduces the risk of HTF degradation or failure, enhancing the safety and reliability of the plant.

By sharing the findings of this research, we aim to advance knowledge and facilitate the replication of similar work in the field of sustainable energy. The insights gained from this study can inform policymakers, researchers, and industry professionals on the benefits of quaternary nitrate-based molten salt HTFs, fostering a broader understanding of how such technologies can contribute to achieving beneficial societal impacts

Reference

[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] Yasinskiy, A., Navas, J., Aguilar, T., Alcantara, R., Gallardo, J. J., Sánchez-Coronilla, A., & Fernández-Lorenzo, C. (2018). Dramatically enhanced thermal properties for TiO2-based nanofluids for being used as heat transfer fluids in concentrating solar power plants. *Renewable energy*, *119*, 809-819.

[4] Kenda, E. S., N'Tsoukpoe, K. E., Ouédraogo, I. W., Coulibaly, Y., Py, X., & Ouédraogo, F. M. A. W. (2017). Jatropha curcas crude oil as heat transfer fluid or thermal energy storage material for concentrating solar power plants. *Energy for Sustainable Development*, *40*, 59-67.

[5] Kwasi-Effah, C. C., Unuareokpa, O., Egware, H. O., Ighodaro, O., Obanor, A. I., Onoche, U., & Achebo, J. (2024). Enhancing thermal conductivity of novel ternary nitrate salt mixtures for thermal energy storage (TES) fluid. *Progress in Engineering Science*, *1*(4), 100020.

[6] Kwasi-Effah, C. C., Ighodaro, 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.

[7] Kwasi-Effah, C. C., Ighodaro, O. O., Egware, H. 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.

[8] 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).

[9] Kwasi-Effah, C. C. (2024). Heat Transfer Fluids in Solar Thermal Power Plants: A Review. *NIPES-Journal of Science and Technology Research*.

[10] 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.

[11] 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).

[12] Kwasi-Effah, C. C., Ighodaro, 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.