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Short communication

Environmental and Economic Trade-offs in Heat Transfer Fluids for Concentrated Solar Power: A Brief Review

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Abstract

This short communication examines the environmental and economic trade-offs associated with heat transfer fluids (HTFs) used in concentrated solar power (CSP) systems. We review recent literature on the life cycle impacts, cost considerations, and performance characteristics of common HTFs, including synthetic oils, molten salts, and emerging nanofluids. Our analysis reveals complex interactions between environmental benefits, economic viability, and technical performance, highlighting the need for a holistic approach in HTF selection for CSP applications.

Keywords: Concentrated Solar Power (CSP), Environmental and Economic Trade-offs in Heat Transfer Fluids, Review

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Introduction

Concentrated Solar Power (CSP) systems have emerged as a promising renewable energy technology, capable of providing dispatchable power through thermal energy storage. The choice of heat transfer fluid (HTF) is crucial for CSP performance, influencing both environmental impact and economic viability [1-25] This review synthesizes recent findings on the environmental and economic aspects of HTFs in CSP systems.

Environmental Considerations

Life Cycle Assessment (LCA) studies have shown that the choice of HTF can significantly affect the overall environmental footprint of CSP plants. Lambrecht et al. (2023) conducted an LCA of Solar Salt (60% $NaNO_3$–40% KNO_3) in parabolic trough CSP systems, finding that it offers lower environmental impacts compared to synthetic oil-based HTFs [26]. The study reported that Solar Salt allows for higher operating temperatures and improved plant efficiency, potentially reducing lifecycle greenhouse gas emissions. However, the production and disposal of molten salts present environmental challenges. The mining and processing of nitrate salts can lead to water pollution and soil degradation. Synthetic oils, while less environmentally impactful in production, pose risks of toxicity and potential spills during operation.

Nanofluids, an emerging class of HTFs, show promise in enhancing thermal properties but raise concerns about nanoparticle toxicity and end-of-life disposal.

Economic Trade-offs

The economic viability of HTFs in CSP systems is primarily assessed through their impact on the Levelized Cost of Electricity (LCOE). Lambrecht et al. (2023) estimated that replacing synthetic oil with Solar Salt in a 50 MW parabolic trough plant with 6 hours of thermal storage could reduce the LCOE of the thermal energy storage system by approximately 31% [26].

However, the initial investment costs for molten salt systems can be higher due to the need for specialized materials to withstand corrosion and high temperatures. Synthetic oils, while more expensive per unit volume, often require less costly infrastructure and have lower freezing points, reducing operational complexities in certain climates.

Nanofluids present a complex economic picture. While they offer potential efficiency gains, the cost of nanoparticle production and the need for stabilization additives can increase overall HTF costs. Long-term stability and potential for nanoparticle agglomeration also raise concerns about maintenance costs and system longevity.

Performance and Efficiency:

The trade-offs between environmental impact and economic viability are closely tied to HTF performance. Molten salts typically allow for higher operating temperatures (up to 565°C for Solar Salt), enabling higher power cycle efficiencies [26]. However, their high freezing points (around 220°C for Solar Salt) necessitate trace heating systems, increasing parasitic energy consumption.

Synthetic oils offer lower freezing points and viscosities, reducing pumping costs, but their thermal stability limits (typically around 400°C) constrain overall system efficiency. Nanofluids have demonstrated significant enhancements in thermal conductivity – up to 45.6% for MoS_2 nanowires at 90°C – potentially improving heat transfer efficiency and reducing required HTF volume.

Conclusion

The selection of HTFs for CSP systems involves complex trade-offs between environmental impact, economic viability, and technical performance. While molten salts offer environmental and efficiency benefits, they present challenges in terms of corrosion and freezing. Synthetic oils provide operational flexibility but with environmental concerns and efficiency limitations. Nanofluids show promise in enhancing performance but face hurdles in long-term stability and cost-effectiveness.

Future research should focus on developing HTFs that balance these competing factors, potentially through hybrid systems or novel formulations. Additionally, comprehensive techno-economic and environmental assessments of emerging HTFs in real-world CSP applications are needed to guide future developments in this field.

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