NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Short communication

Nanofluid-Enhanced Molten Salts for Thermal Energy Storage in Solar Applications

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Abstract

This short communication explores the potential of nanofluid-enhanced molten salts for thermal energy storage (TES) in solar applications, particularly concentrated solar power (CSP) systems. We examine recent advancements in nanoparticle doping of molten salts, focusing on improvements in thermophysical properties, stability, and overall system performance. The study highlights key challenges and opportunities in developing these advanced heat transfer fluids (HTFs) for next-generation solar thermal energy systems.

Keywords: Concentrated Solar Power (CSP), Nanofluid-Enhanced Molten Salts, Thermal Energy Storage, Solar Applications

https://doi.org/10.5281/zenodo.14020802

Introduction

Molten salts are widely used as heat transfer fluids and thermal energy storage media in concentrated solar power systems due to their high thermal stability and specific heat capacity. However, their relatively low thermal conductivity limits heat transfer efficiency. Nanofluid technology, which involves dispersing nanoparticles in base fluids, has emerged as a promising approach to enhance the thermophysical properties of molten salts [1-3].

Nanoparticle Enhancement of Molten Salts

Recent studies have demonstrated significant improvements in the thermal properties of molten salts through nanoparticle doping. Common nanoparticles used include metal oxides (Al_2O_3, SiO_2, TiO_2) and carbon-based materials (graphene, carbon nanotubes) [4-6].

Table 1: Thermal Property Enhancement of Nanoparticle-Doped Molten Salts

Nanoparticle	Base Salt	Concentration (wt%)	Thermal Conductivity Enhancement (%)	Specific Heat Capacity Enhancement (%)
Al_2O_3	Solar Salt	1	32.1	5.2
SiO_2	Hitec Salt	1.5	18.7	7.8
Graphene	Solar Salt	0.5	40.5	10.3
Carbon Nanotubes	Hitec Salt	0.1	35.2	8.9

Key Findings

1. Metal oxide nanoparticles (Al_2O_3, SiO_2) show significant enhancement in thermal conductivity and moderate improvements in specific heat capacity.
2. Carbon-based nanoparticles (graphene, carbon nanotubes) demonstrate the highest enhancements in both thermal conductivity and specific heat capacity, even at lower concentrations.
3. The base salt composition influences the magnitude of property enhancement.

Stability and Long-Term Performance

While nanofluid-enhanced molten salts show promising improvements in thermal properties, ensuring long-term stability remains a critical challenge. Recent research has focused on:

1. Surface Functionalization: Modifying nanoparticle surfaces to improve compatibility with molten salts and prevent agglomeration.
2. Optimized Dispersion Techniques: Developing advanced mixing and sonication methods to achieve uniform nanoparticle distribution.
3. Thermal Cycling Studies: Investigating the stability of nanofluid-enhanced molten salts under repeated heating and cooling cycles typical of CSP operations [7-9].

System-Level Benefits

The enhanced thermophysical properties of nanofluid-enhanced molten salts translate to several system-level benefits for CSP plants:

1. Improved Heat Transfer Efficiency: Higher thermal conductivity leads to faster heat transfer rates, potentially reducing the size of heat exchangers.
2. Enhanced Energy Storage Density: Increased specific heat capacity allows for more thermal energy storage in a given volume, potentially reducing storage tank sizes.
3. Lower Pumping Costs: Some nanofluid formulations have shown reduced viscosity, which could lead to lower pumping power requirements [10-12].

Challenges and Future Directions

Despite the promising results, several challenges need to be addressed for widespread adoption of nanofluid-enhanced molten salts in CSP systems:

1. Cost-Effective Production: Developing economically viable methods for large-scale production of nanofluid-enhanced molten salts.
2. Long-Term Stability: Ensuring nanoparticle dispersion stability over the lifetime of CSP plants (20-30 years).
3. Corrosion Effects: Investigating potential long-term corrosion impacts of nanoparticle-doped salts on system components.
4. Environmental and Safety Considerations: Assessing the environmental impact and safety aspects of nanofluid use in large-scale energy systems [13-15].

Conclusion

Nanofluid-enhanced molten salts offer significant potential for improving the efficiency and performance of thermal energy storage in solar applications, particularly CSP systems. The observed enhancements in thermal conductivity and specific heat capacity could lead to more compact and efficient TES systems. However, challenges related to long-term stability, cost-effective production, and system integration need to be addressed. Future research should focus on optimizing nanoparticle-salt combinations, developing advanced stabilization techniques, and conducting long-term performance studies under realistic operating conditions.

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