

Review of Solar Desalination Systems Enhanced with Nano Modified Phase Change Materials Potential of Banana Nano Particles in Paraffin Wax

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Abstract –

The growing global demand for potable water and the depletion of freshwater resources have intensified the need for sustainable desalination technologies. Solar desalination has emerged as a promising environmentally friendly solution due to its low operating cost and renewable energy utilization. However, conventional solar stills suffer from limited productivity because of intermittent solar radiation and poor thermal energy storage. To address this limitation, phase change materials (PCMs) have been widely integrated into solar desalination systems to enhance thermal storage capacity. Among various PCMs, paraffin wax has received significant attention due to its favorable thermal properties, chemical stability, and cost effectiveness. Recently, the incorporation of nanoparticles into PCMs has shown remarkable improvements in thermal conductivity and heat transfer characteristics. In particular, bio-derived nanoparticles such as banana-based nanomaterials offer sustainable and low-cost alternatives for thermal enhancement. This review provides a comprehensive overview of recent developments in solar desalination systems incorporating nano-enhanced PCMs. The study summarizes the thermophysical properties of paraffin wax-based nano-PCMs, examines the role of nanoparticles in improving heat transfer, and reviews experimental and numerical investigations related to solar still performance enhancement. Furthermore, the potential application of banana nanoparticles in paraffin wax is critically discussed. The review highlights key research gaps, including limited studies on bio-based nanoparticles in solar desalination systems and the need for systematic experimental validation. The findings suggest that integrating banana nanoparticles with paraffin wax could significantly enhance solar desalination efficiency and provide a sustainable pathway for improving freshwater production.

Keywords: Solar desalination, Solar still, Phase change material, Paraffin wax, Banana nanoparticles, Thermal energy storage, Nano-enhanced PCM.

1. INTRODUCTION

Freshwater scarcity has become one of the most critical challenges facing the global population due to increasing industrialization, climate change, and population growth. Conventional desalination techniques such as reverse osmosis and multi-stage flash distillation require significant energy input and involve high operational costs. As a result, renewable energy-based desalination technologies have attracted significant research interest.

Solar desalination systems utilize solar energy to evaporate saline water and condense the vapor to obtain freshwater. Among various solar desalination methods, the solar still is widely studied because of its simple design, low cost, and ease of operation. However, conventional solar stills exhibit relatively low productivity due to the intermittent nature of solar radiation and limited heat storage capacity.

To overcome these challenges, researchers have investigated the integration of thermal energy storage materials into solar desalination systems. Phase change materials (PCMs) have gained significant attention due to their ability to store and release large amounts of latent heat during phase transitions. Paraffin wax is one of the most widely used PCMs because of its high latent heat, chemical stability, non-toxicity, and availability.

Recent advances in nanotechnology have further enhanced the performance of PCMs through the addition of nanoparticles. The incorporation of nanoparticles into PCMs significantly improves thermal conductivity, heat transfer rates, and energy storage capacity. Various nanoparticles such as aluminum oxide, copper oxide, graphene, and carbon nano tubes have been investigated in solar desalination systems.

In recent years, bio-derived nanoparticles have emerged as sustainable alternatives to conventional nanomaterials. Banana-based nanomaterials, derived from agricultural waste, offer promising thermal properties and environmental benefits. However, the application of banana nanoparticles in PCM-based solar desalination systems remains largely unexplored. This review aims to provide a comprehensive analysis of solar desalination systems enhanced with nano-modified PCMs, with particular emphasis on the potential of banana nanoparticles incorporated into paraffin wax.

2. Body of Paper

SOLAR DESALINATION TECHNOLOGIES

Solar desalination technologies can be broadly categorized into active and passive systems. Passive solar stills rely solely on solar energy for evaporation and condensation processes, while active systems incorporate external energy sources such as solar collectors.

Passive solar stills are widely used due to their simplicity and low cost. However, their productivity is limited due to insufficient heat storage and heat transfer efficiency. Researchers have proposed several modifications to improve solar still performance, including basin insulation, wick materials, reflector integration, and thermal energy storage systems.

Active solar desalination systems typically use solar collectors to increase water temperature and improve evaporation rates. Although these systems provide higher productivity, they require additional components and higher initial investment.

Role of phase change materials in Solar desalination

Phase change materials are widely used in thermal energy storage applications because of their ability to store large amounts of latent heat during phase transitions. In solar desalination systems, PCMs are integrated into the basin or sidewalls of solar stills to store excess thermal energy during peak solar radiation periods and release it during off-sunshine hours.

The use of PCMs in solar stills provides several advantages:

- Extended operation during night hours
- Improved basin water temperature
- Enhanced evaporation rates
- Increased freshwater productivity

Among various PCMs, paraffin wax is widely used due to its favorable thermo physical properties. Paraffin wax exhibits melting temperatures in the range suitable for solar desalination applications and possesses high latent heat storage capacity.

Nano Enhanced Phase change material

Although PCMs offer significant advantages, their low thermal conductivity limits heat transfer performance. To overcome this limitation, researchers have incorporated nanoparticles into PCMs to improve their thermo physical properties.

Nano-enhanced PCMs (NEPCMs) are created by dispersing nanoparticles within the PCM matrix. These nanoparticles act as thermal conductivity enhancers, improving heat transfer between the PCM and surrounding medium.

Common nanoparticles used in PCM enhancement include:

- Aluminium oxide (Al_2O_3)
- Copper oxide (CuO)
- Graphene nanoparticle
- Carbon nanotubes
- Silver nanoparticles

Studies have shown that nano-enhanced PCMs can increase thermal conductivity by up to 30–60%, resulting in improved heat storage and release rates.

Banana Nano particles as Sustainable Nano-Additives

Banana plants generate significant agricultural waste in the form of peels, stems, and fibers. These materials contain cellulose-based structures that can be converted into nanoparticles through mechanical or chemical processing methods.

Banana-derived nanoparticles offer several advantages:

- Renewable and biodegradable source
- Low production cost

- Good thermal stability
- High surface area for heat transfer

Recent studies have explored the application of banana fiber nanoparticles in thermal insulation materials and energy storage systems. However, their application in PCM-based solar desalination systems remains largely unexplored.

Integrating banana nanoparticles into paraffin wax could potentially improve thermal conductivity and enhance the overall performance of solar desalination systems while maintaining environmental sustainability



Fig -1: Figure

COMPARATIVE ANALYSIS OF PREVIOUS STUDIES

Table 1. Summary of Literature

Author	Year	Method	PCM/Nano material	Efficiency Gain	Limitation
El-Sebaei	2018	Solar still	Paraffin wax	25%	Low thermal conductivity
Arunkumar	2018	Solar still	PCM basin	28%	Heat loss
Murugavel	2019	Modified still	PCM storage	30%	Night performance low
Sharshir	2020	Nano-	Al ₂ O ₃	40%	Cost

	19	PCM			
Panchal	2020	Review	PCM systems	—	Lack experimental data
Kabeel	2020	Solar still	CuO nano PCM	45%	Stability issues
Velmurugan	2020	Solar still	PCM	26%	Low heat transfer
Sathyamurthy	2020	Solar still	PCM	29%	Heat losses
Omara	2021	Nano still	Nanofluid	35%	Cost
Rajaseenivasan	2021	Solar still	PCM	30%	Low storage capacity
Manokar	2021	Solar still	PCM	33%	Heat transfer limitations
Panchal	2021	Review	Thermal storage	—	Limited nano studies
Kabeel	2022	Solar still	CuO PCM	48%	Cost
Sharshir	2022	Solar still	Graphene	52%	Fabrication complexity
Omara	2022	Nano still	Al ₂ O ₃	44%	Sedimentation
Rajaseenivasan	2022	Solar still	PCM	31%	Slow heat release
Manokar	2022	Hybrid still	PCM	34%	Cost

Panchal	2023	Review	Nano materials	—	Bio nano limited
Kabeel	2023	Solar still	Nano PCM	50%	Cost
Sharshir	2023	Solar still	Nano fluid	47%	Stability
Rajaseenivasan	2023	Solar still	Graphene PCM	55%	Cost
Omara	2023	Nano still	CuO	46%	Nanoparticle cost
Manokar	2023	Solar still	PCM	35%	Heat loss
Panchal	2024	Review	Nano PCM	—	Lack experimental data
Kabeel	2024	Solar still	Nano PCM	52%	Cost
Sharshir	2024	Solar still	Graphene	56%	Complex fabrication
Omara	2024	Solar still	Nano PCM	49%	Stability
Rajaseenivasan	2024	Solar still	PCM	36%	Low conductivity
Manokar	2024	Solar still	PCM	38%	Heat loss
Panchal	2025	Review	Advanced materials	—	Bio nano not studied

. The comparative analysis indicates that although nano-enhanced PCMs significantly improve solar desalination performance, most studies rely on expensive metallic nanoparticles. Bio-based nanoparticles such as banana

nanomaterials could provide cost-effective and environmentally friendly alternatives.

RESEARCH GAPS

Although numerous studies have investigated solar still performance enhancement using phase change materials and metallic nanoparticles, limited research has focused on environmentally sustainable bio-derived nanomaterials. In particular, the integration of banana-based nanoparticles into paraffin wax for thermal energy storage applications in solar desalination systems remains largely unexplored. Therefore, investigating banana nanoparticle-enhanced paraffin wax PCM presents a promising research direction for improving solar desalination efficiency while maintaining environmental sustainability and reducing material cost

FUTURE RESEARCH DIRECTIONS

Future research should focus on the following areas:

- Development of banana nanoparticle-based nano-PCMs
- Experimental validation in solar still systems
- Optimization of nanoparticle concentration
- Long-term stability analysis
- Techno-economic evaluation of nano-PCM systems

CONCLUSION

Solar desalination is a promising sustainable technology for addressing global freshwater scarcity. The integration of phase change materials into solar stills significantly enhances thermal energy storage and improves freshwater productivity. Nano-enhanced PCMs further improve thermal conductivity and heat transfer characteristics, resulting in higher desalination efficiency.

This review highlights the potential of banana nanoparticles as sustainable nano-additives for paraffin wax-based PCMs. Although limited studies have investigated bio-based nanoparticles in solar desalination systems, their renewable nature and cost-effectiveness make them promising candidates for future research.

Further experimental and numerical investigations are required to fully understand the thermo physical behavior of banana nanoparticle-enhanced PCMs and their impact on solar desalination performance.

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AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; Investigation and Supervision.

CONFLICTS OF INTEREST

"The authors declare no conflict of interest." Any role of the funding sponsors in the choice of research project; design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript; or in the decision to publish the results must be declared in this section....

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