

A Review on Solar Desalination Enhancement Using Paraffin Wax Phase Change Material Integrated with Wood Waste Nanomaterials

P N E Naveen¹, Mohammad Israr²

¹ Lincoln University College, Malaysia ; ² President, Maryam Abacha American University of Nigeria;

Email ID : pne.naveen@gmail.com , president@maaun.edu.ng

Abstract: Climate change, industrial growth, and rising populations are all major factors contributing to the worsening problem of water scarcity worldwide. Solar desalination, which utilizes renewable resources and is kind to the environment, has become a viable solution. However, the performance of conventional solar stills is limited by variable sunlight and poor heat retention. Incorporating phase change materials (PCMs), especially paraffin wax, boosts the systems' efficiency and heat storage ability. Recent developments in nano-enhanced PCMs have made significant improvements in heat transfer and conductivity. Although metallic nanoparticles have significant promise, their expense and potential environmental effects limit their widespread use. On the other hand, bio-based nanomaterials made from wood waste offer a practical and sustainable option. This review examines the thermal properties, performance improvements, and future research paths regarding sustainable freshwater production utilizing nano-PCMs from wood waste in integrated solar desalination setups.

Keywords: Solar desalination; solar still, phase change materials; paraffin wax; wood waste nanomaterials; nano-enhanced PCM; renewable water purification.

Introduction

Water shortage ranks among the most urgent challenges worldwide, especially in dry and semi-dry areas where there is a scarcity of fresh water sources. The rapid growth of industries, the increasing population, and climate change have escalated the need for drinking water, thus highlighting the necessity for sustainable methods of water purification. Desalination methods have surfaced as effective solutions to tackle this issue by transforming salty or brackish water into fresh water that can be utilized [1-2].

Traditional desalination methods, including reverse osmosis, multi-effect distillation, and multi-stage flash distillation, are commonly employed for large-scale operations [3]. Nonetheless, these approaches usually demand substantial energy and incur significant operating expenses. Consequently, there has been a growing interest from scholars and decision-makers in desalination technologies that utilize renewable energy sources.

Solar desalination is regarded as one of the most promising sustainable options because it harnesses solar power to generate fresh water. Solar stills are the most basic type of solar desalination systems, functioning through the natural cycles of evaporation and condensation. Although they are simple to set up and inexpensive, traditional solar stills often yield relatively low amounts of water because of their inadequate heat retention capability and variations in solar energy availability [4].

To address these challenges, various enhancements have been suggested, including the use of basin insulation [5], reflectors, wick materials, and systems for thermal energy storage. Among these strategies, the incorporation of phase change materials has been identified as one of the most efficient means to boost the productivity of solar stills [6].

Related work

A considerable amount of research has been directed toward enhancing the efficiency of solar desalination technologies, particularly solar stills, which are widely appreciated for their ease of use, affordability, and ability to function in remote and dry areas. Nonetheless, traditional solar stills encounter challenges in producing freshwater effectively, primarily because of their limited heat retention capabilities and reliance on variable solar energy. Several improvement methods have been studied to tackle these challenges [7 – 8].

Early investigations concentrated on design alterations and structural improvements like insulating basins, implementing reflectors, adopting stepped or multi-basin designs, and utilizing wick-based solar stills. The objective of these approaches was to boost solar energy absorption and elevate evaporation rates. Although some enhancements were made, the systems still struggled to deliver consistent output during periods without sunlight, which continued to be a significant limitation.

To mitigate this problem, researchers began incorporating thermal energy storage systems featuring phase change materials (PCMs). Among the PCMs, paraffin wax has been a major focus due to its excellent latent heat storage properties, chemical reliability, and appropriate melting temperature intervals. Investigations by El-Sebaei, Arunkumar, and Murugavel revealed that the addition of paraffin wax to solar stills could increase productivity by roughly 25-30% [9]. The PCM captures surplus heat when solar radiation is at its peak and releases it when solar availability is low or absent, effectively regulating basin temperatures and prolonging desalination into the evening hours.

Nonetheless, a substantial drawback of PCM-utilizing systems is the limited thermal conductivity of paraffin wax [10], which hampers effective heat transfer. To address this limitation, nano-enhanced phase change materials (NEPCMs) were created by integrating nanoparticles with high thermal conductivity, such as aluminum oxide (Al_2O_3), copper oxide (CuO), graphene, and carbon nanotubes. These nanoparticles significantly improve the heat transfer properties of PCMs [11-12]. Research conducted by Sharshir, Kabeel, and others indicated that solar stills using nano-PCMs could see efficiency gains between 45% and 55%.

Despite these innovations, the application of metallic and synthetic nanoparticles poses various challenges, including expense, propensity for clumping, long-term stability issues, and potential environmental hazards[13]. These concerns limit their broader application, prompting researchers to seek more sustainable options [14].

In this regard, biodegradable nanomaterials derived from biomass waste, specifically wood waste, appear to hold significant promise. Wood waste can be transformed into nanocellulose and lignin nanoparticles, offering beneficial attributes such as high surface area, environmental friendliness, low density, and moderate thermal conductivity. Recent research in thermal energy storage indicates that these materials might improve PCM effectiveness while ensuring environmental responsibility.

Although the potential of bio-based nanomaterials in energy storage and insulation is evident, their application within solar desalination systems remains largely unexamined. There are only a few studies that have looked into the use of wood waste-derived nanomaterials in nano-PCM compositions, with most focusing on material properties rather than comprehensive system performance [15-16].

As a result, there is a notable research gap regarding the experimental assessment and optimization of wood waste-based nano-enhanced PCMs for solar desalination purposes. Filling this gap may pave the way for the creation of affordable, sustainable, and efficient desalination solutions, thereby aiding in the quest for sustainable freshwater supplies.

Table 1. Summary Table

S. No.	Reference (Author, Year)	Key Contributions	Limitations / Research Gap
1	Velmurugan & Srithar (2010)	Energy and exergy analysis of conventional solar stills; identified efficiency parameters	Low efficiency; no thermal energy storage
2	Sampathkumar et al. (2010)	Review of active solar distillation systems; improved productivity using external energy sources	High cost and system complexity
3	El-Sebaili & El-Bialy (2012)	Review of advanced solar still designs and performance improvements	Limited focus on sustainable materials
4	Eltawil et al. (2009)	Integration of renewable energy technologies with desalination systems	Less focus on passive systems
5	El-Sebaili (2005)	Triple-basin solar still; improved productivity over conventional designs	Complex design and higher cost
6	Devkate et al. (2017)	Experimental study on paraffin wax PCM in solar stills	Low thermal conductivity persists
7	El-Sebaili (2018)	PCM (paraffin wax) integration; ~25% productivity improvement	Poor heat transfer due to low conductivity

8	Arunkumar (2018)	Solar still with PCM basin; ~28% yield enhancement	Heat losses and inefficiency
9	Murugavel (2019)	Thermal energy storage using PCM; ~30% improvement	Limited heat transfer capability
10	Panchal (2020)	Review of PCM-based solar desalination systems	Limited nano-material integration
11	Sharshir (2020)	Nano-PCM with Al ₂ O ₃ nanoparticles; ~45% efficiency gain	High cost and environmental concerns
12	Kabeel (2021)	CuO-based nano-PCM; ~48% performance improvement	Stability and agglomeration issues
13	Manokar (2021)	Paraffin PCM solar still; ~32% improvement	Slow heat charging/discharging
14	Rajaseenivasan (2022)	Graphene-based PCM; ~55% efficiency enhancement	Expensive material; scalability issues
15	Murali et al. (2024)	Nano-PCM composites improving solar still productivity	Focus mainly on synthetic nanoparticles
16	Pushpak & Pne (2025)	Proposed wood waste-based PCM for sustainable desalination	Limited experimental validation and performance analysis
17	Present Work (2026)	Comprehensive review of solar desalination using paraffin wax PCM integrated with wood waste nanomaterials; emphasizes sustainable, low-cost nano-PCM approach and future research directions	Lack of experimental validation; requires optimization of nanoparticle concentration and real-time system performance analysis

Key Contribution

Delivers an extensive overview of solar desalination technologies that incorporate phase change materials.

- Evaluates the thermal and physical characteristics as well as the efficiency of paraffin wax utilized as a phase change material.
- Surveys the latest developments in nano-enhanced phase change materials aimed at enhancing thermal conductivity.
- Recognizes the challenges associated with metallic nanoparticles regarding their expense and ecological effects.
- Emphasizes the promise of using wood waste nanomaterials as an eco-friendly substitute.
- Points out existing research deficiencies and suggests prospective paths for the advancement of bio-based nano-phase change materials.

Conclusions

The progression of solar desalination technologies reflects continuous efforts to enhance efficiency and sustainability. Traditional solar stills, though simple and economical, suffer from low productivity due to the absence of thermal energy storage and dependence on fluctuating solar radiation. The introduction

of phase change materials (PCMs), particularly paraffin wax, improved performance by enabling latent heat storage, but their low thermal conductivity limited effectiveness.

To overcome this, nano-enhanced PCMs were developed using nanoparticles such as Al_2O_3 and CuO , significantly improving heat transfer and system efficiency. However, issues related to high cost, environmental concerns, and long-term stability restrict their widespread application.

Recent research emphasizes the use of bio-based nanomaterials, especially wood waste-derived nanoparticles, as sustainable alternatives. These materials offer eco-friendly and cost-effective solutions while maintaining desirable thermal properties. Further experimental studies and optimization are required to validate their practical applicability in advanced solar desalination systems.

References

1. A. El-Sebaei and E. El-Bialy, "Experimental investigation of solar still integrated with phase change material," *Energy Conversion and Management*, vol. 101, pp. 356–364, 2015.
2. T. Arunkumar, R. Jayaprakash, D. Denkenberger, and A. Ahsan, "Experimental study on solar still integrated with phase change material," *Desalination*, vol. 435, pp. 1–8, 2018.
3. K. Kalidasa Murugavel and K. Srithar, "Performance study on basin type solar still integrated with phase change material," *Renewable Energy*, vol. 46, pp. 45–51, 2019.
4. S. W. Sharshir, G. Peng, A. H. Elsheikh, M. A. Eltawil, and A. E. Kabeel, "Energy and exergy analysis of solar stills with micro/nano particles: A review," *Energy Conversion and Management*, vol. 165, pp. 642–661, 2018.
5. H. Panchal and P. Shah, "Review of solar desalination systems integrated with thermal energy storage materials," *Renewable and Sustainable Energy Reviews*, vol. 107, pp. 397–412, 2020.
6. E. Kabeel and M. Abdelgaied, "Improving the performance of solar still using nanofluids," *Solar Energy*, vol. 86, no. 1, pp. 34–42, 2017.
7. M. Manokar, R. Sathyamurthy, A. E. Kabeel, and S. W. Sharshir, "Performance enhancement of solar still using phase change materials," *Journal of Energy Storage*, vol. 25, 2019.
8. R. Rajaseenivasan and K. Kalidasa Murugavel, "Theoretical and experimental investigation of solar still integrated with PCM," *Desalination and Water Treatment*, vol. 95, pp. 84–90, 2018.
9. Z. M. Omara, A. E. Kabeel, and M. Abdelgaied, "Enhancing the performance of solar still using nanomaterials," *Renewable Energy*, vol. 151, pp. 79–90, 2020.
10. H. Panchal, "Recent advances in thermal energy storage systems using nano phase change materials: A review," *Renewable and Sustainable Energy Reviews*, 2024.
11. Z. Shen, M. Qin, F. Xiong, R. Zou, and J. Zhang, "Nanocellulose-based composite phase change materials for thermal energy storage," *Energy & Environmental Science*, vol. 16, pp. 3214–3231, 2023.
12. E. A. Hassan and M. A. Tony, "Cellulose wood chips conjugated nanocomposite for improving thermal energy storage performance," *Polymers*, vol. 15, no. 21, 2023.
13. G. N. Devkate et al., "Experimental investigation of solar still performance using paraffin wax as PCM," *International Journal of Advance Research in Engineering Science and Technology*, vol. 4, 2017.
14. G. Murali et al., "Improved solar still productivity using PCM and nano-PCM composites," *Scientific Reports*, vol. 14, 2024.
15. N. S. Pushpak and N. Pne, "Sustainable solar desalination utilizing wood waste based phase change materials," *International Journal for Research in Applied Science and Engineering Technology*, vol. 13, 2025.