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RESEARCH ARTICLE

Enhancement of productivity of solar still with use of energy storage materials: A short review

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ABSTRACT

Solar still technology is a sustainable, low cost option for freshwater production in water scarce areas, but with limited productivity. The present short communication discusses some recent developments in improvement of the efficiency of solar stills by incorporating different thermal energy storage materials. Use of natural materials, agricultural wastes, and phase change materials (PCM) effectively store surplus thermal energy during the day to continue the distillation process at night. The technology that yielded the most fresh water (8.69 L/m^2/day) and reduced potable water costs by 50.52% was eggshell powder, and wick-covered cement conical fins yielded 7.90 L/m2/day. Moreover, the use of agricultural wastes such as carbonized custard apple seeds increased productivity by 115.5%. The results show that the hybrid designs and low-cost natural storage media configurations are consistently superior to the traditional designs. The optimization using AI, long-term durability tests under field conditions, and scaling of hybrid thermal storage systems to further enhance the commercial viability are highlighted as future research priorities.

Keywords: solar still; productivity; litre; process innovation

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1. Introduction

Solar energy is among the most abundant, renewable and environmentally friendly types of energy available on earth [14][17]. It is a sustainable solution to increasing energy and freshwater needs, and

is a less reliant on fossil fuels [12]. A solar still is a basic desalination system that uses solar energy to vaporize salt and/or dirty water, followed by condensation, to yield fresh drinking water [11]. Solar still technology is especially suited for remote and water scarce areas because of its low cost, ease of operation and minimal maintenance needs. But, boosting its productivity is still a major research area for achieving its practical application [13].

Solar stills filled with energy storage materials that store the surplus heat energy when solar radiation is high and dissipate it slowly when solar intensity drops or after sunset. This will help to keep water warm for a longer period and prolong the evaporation and condensation cycle. Consequently, the productivity of the freshwater is enhanced, especially in the evening and night. [15] Moreover, energy storage materials promote the thermal performance, heat retention and economic and operational effectiveness of solar desalination systems (SDSs). Sensible or latent heat storage materials have been used to enhance the productivity of solar still [16].

2. Enhancement of productivity of solar still with help of Energy storage materials

Mohamed Koraiem M. Handawy et al [3] discussed about the application of natural materials to enhance solar still performance. The study involves the analysis of the use of natural thermal storage materials, porous media and wick materials with economic and environmental impacts. The results indicated that the natural thermal storage materials yielded the greatest performance gain, ranging between 10.1–159.1% for the increase in freshwater productivity, whereas 2.6–145.1% and 9.4–62.1% improvements in freshwater productivity were obtained for porous and wick materials, respectively. The costs of the three materials, thermal storage, porous, and wick materials, respectively, were reduced by 13.2–83.1%, 7.2–45.8%, and 8.1–32.7%. In addition, the thermal efficiencies were improved by up to 60.9%, 51.1% and 70.8%. In general, the review pointed out the huge potential of natural materials in the realization of more efficient, sustainable and economically viable solar desalination systems.

S. Mohamed Illyas et al [4] tested the performance of an improved hemispherical solar still that used the thermal energy storage materials Sodium Sulfate Decahydrate and Sodium Carbonate Decahydrate along with graphite plates. There was a remarkable improvement in the production of fresh water both during the day and night operation in the experimental results. The modified systems generated the cumulative daily production of water by 31.4% and 26.8% over the conventional solar still. One noteworthy improvement was seen in productivity at night, with a rise of up to 154.4%.

The performance of an optimized conical solar still with the use of eggshell powder as a natural thermal energy storage material was assessed by Mohamed Benghanem et al [5]. The experimental results showed that the addition of eggshell powder was effective in improving the thermal performance of the still, which resulted in a large amount of freshwater production. The modified system was able to produce 8.69 l/m/day which is 102.1% more than the conventional solar still produced. Eggshell powder not only enhanced the productivity but also cut down the potable water cost by 50.52% and made the system more economically attractive.

M. Yuvaperiyasamy et al [6] studied the use of various energy storage materials and Taguchi optimization and machine learning techniques to enhance a single slope solar still. The results indicated that the paraffin wax was superior to the other stones used namely the blue metal stone, basalt stone and kanche marbles. The distillate yield was 3.76 L/m²/day with a solar intensity of 1000 W/m² and an inlet water temperature of 45 °C under optimal conditions of 2 cm water depth.Under optimal conditions (water depth 2 cm, inlet water temperature 45 °C, and solar intensity 1000 W/m2), a distillate yield of 3.76 L/m2/day and water temperature of 60.30 °C were obtained. Water depth was found to have the greatest effect on the analysis. The Random Forest model was found to be reliable and effective as the prediction error was less than 1%.

Vishwanath Kumar et al [7] have studied the use of spherical cement balls and iron chips as thermal energy storage media for a solar still used for the treatment of municipal wastewater. The maximum freshwater yield was obtained from combined configuration (MSS-R), 4.2 L/m²/day, 49.7% higher than conventional configuration. It also had the greatest energy efficiency (43.5%) and exergy efficiency (3.72%). The production cost was lowered to $0.0165/L and the payback period was shortened to 158 days. Water quality was greatly enhanced, and standards for potable water were achieved, with evidence of sustainable wastewater treatment.

Arpit Nema et al [8] used black painted aggregate stones and silica sand as thermal energy storage materials to enhance the productivity of a passive solar still. The experimental results revealed that the aggregate stones solar still has the highest rate of freshwater production rate of 2.590 L/day, followed by the silica sand solar still of 2.095 L/day and the conventional solar still of 1.120 L/day. The productivity in the case of aggregate stones was found to be 131.25% and in the case of silica sand, it was 87.05%. The water production cost was economically evaluated and it came down to Rs. The stone for aggregate is sold at the rate of 1.62/L. The price of silica sand is Rs.1.98/L as compared to Rs. 3.65/L for the conventional still. Overall, the technical and economical performances of the aggregate stones were optimum.

Bady, attia and Kabeel [9] conducted a study on the performance of a conical solar still using wick covered cement conical fins which were used as thermal energy storage and capillary enhancement materials. Experimental results showed that the productivity of the solar still increased with fin spacing. The system in unwicked cement fins had a collector efficiency of 6.20, 6.65 and 7.15 L/m2/day for spacing of 0 cm, 1 cm and 2 cm respectively. The freshwater yield was further increased to 6.80, 7.30 and 7.90 L/m²/day when wick material was added. 2 cm spacing resulted in the highest productivity because there is less shading effect and a greater evaporation rate. The economic and environmental evaluations also revealed the advantages of the proposed design, making it an effective and environmentally friendly desalination method.

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Anburaj et al [10] studied the performance of an inclined solar still using energy storage materials with bamboo wicks. The performance of modified configurations were compared with a conventional inclined solar still to see which configuration is most efficient for increasing the production of clean water. The outcome revealed that the bamboo wick with copper as energy storage material provided the best performance out of all the tested configurations. The heat storage and evaporation properties were greatly improved, which significantly improved the distillation process. The maximum value of thermal efficiency obtained was 53.6 % with the bamboo-copper composite. Overall, the study proved that the use of bamboo wick material along with copper energy storage is a simple and effective way of improving the efficiency and productivity of inclined solar stills.

Attia et al [1] proposed a simple and practical approach to enhance the performance of conical solar stills by incorporating sand roses which are readily available materials. The experimental work was carried out well and the comparison between the conventional and the modified systems was well presented. Significant gains in freshwater productivity, thermal performance and profitability were observed. This was important because the work was based on a low cost material that was easily available in nature and was also found to have positive environmental effects: improved CO_2 mitigation.

Noman et al [2] studied the effect of carbonised custard apple seeds (CAS) as a low cost and environment friendly material used to improve the performance of a tubular solar still. The experiments were conducted systematically and the modified system was compared with a conventional tubular solar still, working under the same operating conditions. The outcome indicated that the productivity of the freshwater increased from 2.27 kg/m^2/day to 4.88kg/m2/day, an increase of 115.5%. Similarly, daily exergy and energy efficiency levels were improved from 1.34% to 3.95% and 18.8% to 41.2%, respectively. Economic, environmental and sustainability issues were also considered as part of the study and helped to enhance the practical value of the study findings. Overall, the work has proved an effective approach of using agricultural wastes to enhance the solar desalination performance. Table 1 shows the comparison of various researchers to enhance productivity of solar still with help of energy storage materials.

Table 1. comparison of various researchers to enhance productivity of solar still with help of energy storage materials

Sr. No.	Author(s) & Year	Energy Storage Material Used	Distillate Output Received	Significant Remarks
1	Mohamed Koraiem M. Handawy et al. (2025)	Natural thermal storage materials	159.1% enhancement	Review study concluded that natural thermal storage materials provided the highest productivity improvement among all natural materials.
2	S. Mohamed Illyas et al. (2025)	SSD, SCD and graphite plates	31.4% enhancement	Thermal storage materials substantially improved daytime and nighttime productivity, especially nocturnal water production.
3	Mohamed Benghanem et al. (2025)	Eggshell powder	8.69 L/m²/day	Eggshell powder acted as a free and eco-friendly thermal storage material, increasing productivity by 102.1%.
4	M. Yuvaperiyasamy et al. (2025)	Paraffin wax	3.76 L/m²/day	Paraffin wax showed the best performance among all tested storage materials and was successfully optimized using machine learning.
5	Vishwanath Kumar et al. (2025)	Spherical cement balls and iron chips	4.20 L/m²/day	Combined use of cement balls and iron chips achieved the highest productivity and lowest water production cost.
6	Arpit Nema et al. (2025)	Black-painted aggregate stones	2.59 L/day	Aggregate stones outperformed silica sand due to superior solar absorption and heat storage characteristics.
7	Bady, Attia & Kabeel (2025)	Wick-covered cement conical fins	7.90 L/m²/day	Integration of wick material with cement fins enhanced evaporation and extended operating hours.
8	Anburaj et al. (2025)	Copper with bamboo wick	Not reported	Copper provided superior heat storage characteristics, resulting in the highest thermal efficiency of 53.6%.
9	Attia et al. (2026)	Natural sand roses	67.77% enhancement	Smaller sand rose diameters improved heat and mass transfer, resulting in higher productivity and lower water cost.
10	Noman et al. (2026)	Carbonised custard apple seeds (CAS)	4.88 kg/m²/day	Agricultural waste-derived carbonized material increased productivity by 115.5% and significantly improved energy and exergy efficiencies.

As seen in Table 1, the reported studies show that thermal energy storage materials can significantly enhance the productivity, efficiency, and economic feasibility of solar stills. The investigated materials yielded

the highest freshwater yields of 8.69 L/m2/day (eggshell powder) and 7.90 L/m2/day (wicked cement conical fins) respectively, showing that some naturally available and low cost materials can be superior to many regular storage materials. Materials that were derived from agricultural wastes, like carbonised custard apple seeds and eggshell powder showed exceptional productivity improvement and were also solving the waste management problem. The use of porous and wick-assisted structures further improved the evaporation process by increasing the effective surface area and the evaporation hours. The studies using PCMs (mainly paraffin wax) revealed that they have a steady thermal performance, and they have been effective in heat recovery, but their high material costs could prevent their use on a large scale. Multiple enhancement systems used on a single system tended to provide better results than single enhancement systems. Although very good productivity results have been achieved, the data from various studies is not comparable, as this is influenced by climatic conditions, still geometries, basin areas, and operating parameters. To optimize freshwater productivity and economic and environmental sustainability, further work is needed on standardized testing protocols, durability testing over time, and hybrid natural-material configurations.

3. Conclusion

From the present short communication, following points are concluded:

1. Natural thermal energy storage materials demonstrated productivity enhancements ranging from 10.1% to 159.1%.
2. Eggshell powder achieved the highest reported freshwater yield of 8.69 L/m²/day and reduced potable water cost by 50.52%.
3. Wick-assisted and fin-based thermal storage configurations produced yields of up to 7.90 L/m²/day, highlighting the benefits of hybrid enhancement techniques.
4. Agricultural waste-derived materials such as carbonised custard apple seeds increased freshwater productivity by 115.5%, supporting sustainable waste utilization.
5. Future research should focus on hybrid storage materials, long-term durability studies, and large-scale field implementation to further improve the commercial viability of solar desalination technologies.

Future work

1. Explore hybrid combinations of natural and phase change thermal storage materials.
2. Assess long-term durability and thermal stability under field conditions.
3. Investigate large-scale applications and techno-economic feasibility.
4. Utilize AI-based optimization techniques for enhanced solar still performance.

Declaration

During the preparation of this manuscript, the authors used ChatGPT and Paperpal solely for language refinement. AI-generated contents have been thoroughly reviewed and revised by the authors, who bear full responsibility for the integrity and factual accuracy of this work.

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