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Improving Solar Still Productivity with Phase Change Materials

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Abstract

Global population growth, industrialisation, and agricultural development are the main sources of the growing need for clean water. Soon, the shortage of fresh water will become a more pressing issue due to global population growth. Therefore, to produce drinkable water, individuals must work on developing innovative and effective methods all over the world. One of these devices that acts in this way is the solar still. This review article takes a look at solar stills and how they make use of efficient materials and experiments. A significant method entails the utilisation of paraffin wax alongside various Phase Change Materials (PCMs). The solar still is made more effective as a result of the increased productivity and thermal conductivity that comes from this combination. The integration of wicks in a modified solar still enhanced distillate yield and overall productivity. Another enhancing approach examined is the application of nanoparticles. Practical improvements in efficiency and heat conductivity were made possible by using these nanoparticles. Consequently, the solar still's thermal efficiency was improved, leading to an increase in the yield of potable water. Collaboration tactics utilising PCMs, reflectors, and nano-coating paint mixed with nanoparticles are highlighted in the article as highly effective. Thermal efficiency and freshwater generation were both greatly improved by combining these materials. The study reveals that among the many PCMs examined, paraffin wax demonstrates superior production and productivity relative to other alternatives. The innovation and improvement of solar desalination, the subject of this article, have relied heavily on solar stills. The solar desalination system operates better with paraffin-CuO than PCM, TiO_2, or GO.

Major Findings: *Using PCMs such as paraffin wax and nanoparticles improves solar still performance, yielding 28.13%-60% more freshwater per unit area than conventional solar stills. Adding wicks, fins, and reflectors boosts evaporation rates and production.*

Keywords: *Distilled Water, Phase Change Material, Renewable Energy, Solar Energy, Solar Still*

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1.0 Introduction

Chemical plants, commonly used in both agriculture and industry, contribute significantly to the contamination of subterranean water. Therefore, using hand pumps to obtain water for consumption or cooking is no longer safe. The shortage of fresh water will become an even more pressing issue in the not-too-distant future as a result of the escalating population around the globe. Therefore, to manufacture water that is safe to drink, individuals worldwide must collaborate to find innovative and efficient solutions. Among the many examples of devices that operate in this manner are solar stills. Numerous strategies can be employed to enhance the performance and production of solar desalination systems. Fins, sponges, and paraffin wax are some of the innovations that contribute to the enhanced efficiency and economic viability of the process. Solar desalination is an intriguing solution since it is more cost-effective than other methods[1-8].

One of the most common methods and the most potential is solar distillation, which uses solar energy to separate clean water from special saline water or contaminated water. Homemade Solar Stills in their simplest form have a glass cover that lets solar radiation enter, but it does not let out the evaporated water, therefore condensing and collecting it from the roof of the cover. Although traditional solar still is a low-cost, sustainable, and eco-friendly method, its efficiency and water productivity remain relatively low. This has led to extensive research in the field of solar stills to enhance their performance, among which one of the most promising concepts is the integration of PCMs in the solar still system.

The main limitations of solar stills are that solar radiation is intermittent and thermal efficiency is low, while also struggling to keep the water at a stable temperature. Therefore, the use of PCMs in solar stills is highlighted to overcome these main challenges. PCMs are capable of absorbing and releasing a large amount of latent heat during melting–solidification processes (i.e., solid–liquid–solid) and thus they offer the potential of improving the thermal energy storage performance of solar stills. The availability of PCMs enables the still to operate at times of cloudy weather or night (when the solar radiation does not fall directly on them). Consequently, this improves the regularity and increases the rate of water output, making solar distillation more practical for widespread deployment, especially in arid areas with low fresh water availability but high solar energy potential.

One of the main advantages of PCMs is that they increase the efficiency of solar stills, which brings us to our first point: the principle of solar distillation. Most solar stills work by utilising solar energy absorbed by the transparent cover, heating the water in the basin below. Once the water starts to boil, the steam rises into the air space below the cover, cools on the cold side of the cover surface, and is collected as fresh water. Both the solar radiation quantities and the thermal efficiency of the materials used in the still are crucial factors. Yet the strength of the sun changes over the day, or as weather patterns run through, and the efficiency of the still can suffer too substantially, resulting in low productivity. However, PCMs have effectively bypassed this criticism by increasing the thermal inertia of the solar still. A PCM is placed in the basin or any other part of a still, and once it absorbs heat in the time of high solar radiation, it stores the energy in latent heat form. The internal atmosphere of the solar still gets stabilised, and the solar still is more efficient due to long hours of operation with better distillation efficiency under non-ideal conditions.

The benefits of PCMs in solar stills are not only confined to temperature regulation. PCMs play a significant role in minimising thermal losses from conventional solar still during night as well as cloudy climate conditions. This is particularly important for regions where the weather can be erratic, for example, solar radiation can be down for days. Since the PCM create thermal storage, it functions after the sun shines as well. The readily-accessible water could also provide a more continuous, reliable supply of fresh water, an extremely important resource in communities that rely on solar stills for their water needs.

Additionally, the application of PCMs in solar stills concerning water production cost can also be decreased. While the use of PCM will require a larger initial investment in the form of PCM materials and their incorporation within the solar still, the payoffs in surface water productivity and energy efficiency should

ultimately provide a more cost-effective system. PCMs can enhance the efficiency of the still to harvest freshwater by reducing the time and energy needed to obtain a unit volume of freshwater, resulting in lower operating costs. In regions where the financial capabilities are limited, the cost-effective feature is of utmost relevance, providing a desirable solution for the low-cost production of water.

Besides thermal storage, the capability of PCMs may also make contributions to the environmental sustainability of the solar distillation system. As such, solar stills are already known to be a greener alternative to conventional desalination approaches that generally depend on fossil fuels and emit high levels of greenhouse gases. The application of PCMs increases the effectiveness of solar stills and decreases the solar energy consumption for generating fresh water. This may reduce the environmental cost of water production, thereby making solar stills an even more appealing solution for water-stressed and environmentally stressed regions in China and elsewhere.

Many experiments and analyses are being carried out on the usage of PCMs inside solar stills, which have previously indicated the potential of PCMs to increase productivity. Previous studies indicate solid PCMs, about paraffin wax, hydrated salts or fatty acids, by adding them to the solar still, effectiveness can be enhanced considerably. Such materials are chosen based on the melting point, how much latent heat they can store and how fast the latent heat can be released to the surroundings. PCMs incorporated in solar stills can be directly placed in the water basin, embedded in the top cover, or applied as a coating for PCM-based solar stills. There are advantages and challenges associated with each of the methods for PCMs, and various researchers are continuing to examine the best ways to incorporate PCMs into solar still designs.

An optimal PCM material in terms of cost, thermal performance and integration is one of the major issues while using PCMs in solar stills. To work with solar stills, PCMs need to be stable over a wide range of temperatures and have a melting point that fits that range. Nevertheless, to guarantee the effectiveness of heat transfer, the PCM must possess a high thermal conductivity not only during phase change absorption but also during phase change use. But such barriers will be overcome as technology progresses and other new materials and techniques allow further development of solar stills.

Overall, applying PCMs to enhance solar still performance is a possible solution to the worldwide water deficiency dilemma. PCMs are capable of improving the thermal efficiency and storage capacity and increasing the operational stability of solar stills, thereby increasing the yields of fresh water from solar stills, especially in the presence of fluctuating solar radiation or varying weather conditions. Therefore, integration of PCMs improves solar still performance and makes production systems more sustainable and cost-effective for water production. With ongoing research, PCM-enhanced solar still is expected to offer a more effective approach for sustainable fresh water production in resource-limited sites without access to traditional fresh water resources.

Even a low-cost, low-maintenance, user-friendly, easily assembled solar system requires non-conventional energy. Despite its numerous benefits, its poor efficiency and limited freshwater output make it less well-known. Many researchers have put out great effort to raise the cleanliness and efficiency of water generated by solar stills. A growing number of individuals are showing an interest in the latent heat method of thermal energy storage. Configurations for storing thermal energy, known as latent heat, are chosen by the PCM. PCMs' fundamental kinetics, chemical composition, and thermal physical characteristics are documented and studied by a variety of sources[9]. A configuration that is widely used to increase both production rates and efficiency is the single-slope solar still, which is seen in Figure 1.

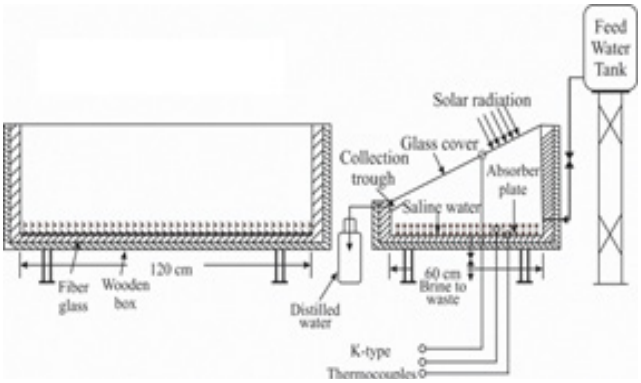


Figure 1. Solar still with a single slope without PCM.

Several operational aspects, ambient conditions, and design problems are among the critical factors that influence its performance. The effectiveness of the system is affected by many parameters, including modes of operation, water depth, and others. The integration of PCMs significantly improves the efficacy of solar stills. A wide range of challenges, such as active and passive operational modes at varying water depths, have been investigated by researchers to enhance the current procedure. The process of solar desalination, which makes use of the abundant energy provided by the sun, is making progress as a sustainable approach for producing fresh water through ongoing research and development. The primary characteristics of PCMs are outlined in Table 1.

Table 1. Important characteristics of PCMs

Different Characteristics	Properties
Material Characteristics	• A modest unit size is used. • The vapour pressure is relatively low. • The equilibrium of the phase is beneficial.
Kinetic Characteristics	• There is no undercooling. • It is sufficient to have a crystallisation rate.
Chemical Characteristics	• Absence of any chemical decomposition • Non-Toxic • Non-Corrosive • A high degree of chemical stability • Non-poisonous, non-explosive and non-flammable.
Thermodynamic Characteristics	• Phase change temperature fitted to use • High thermal conductivity • Density ought to be quite high. • The volume changes very little during the phase change. • A high level of latent heat must be maintained. • A large latent heat of fusion is expected. • The melting point must fall within the target range. • Enthalpy should be high.
Economical Characteristics	• Large availability • It should be cheap.

All three PCMs achieved the peak distillate at a depth of 1 cm, and the total distillate showed a linear decrease with increasing water depth. Examining the performance of the three PCMs in a copper cylinder revealed total distillate increases of 1200, 1010, and 930 ml/m-day for paraffin wax, stearic acid, and lauric acid, respectively[10]. PCMs are shown in Table 2 to have the thermo-physical properties that are described.

The solar still is simulated on a computer both with and without PCM, such as stearic acid, to investigate how the mass of stearic acid PCM influences the production of daylight, but how it increases productivity at night, because during the day, PCM accumulates more heat[11].

Saturating the area under the basin liner with 3.3 cm of stearic acid can raise the evaporative heat transfer coefficient by about 27%. As a consequence, the liner's convective heat transfer coefficient to the water will increase by double. During summer days, productivity was measured at 9.005 kg/m² with PCM and 4.998 kg/m² without PCM. Research indicates that PCM operates more effectively in basins with reduced water levels throughout winter. Solar stills that used PCM saw a 24% improvement in total productivity and a 30% increase in productivity when combined with pin fins, compared to Conventional Solar Stills (CSS)[12].

The utilisation of hollow square fins increased production by 3.33 per cent, reaching 5.50 litres per cubic metre per day. The use of hollow circular fins resulted in a productivity increase to 6.10 L/m²/day, representing a

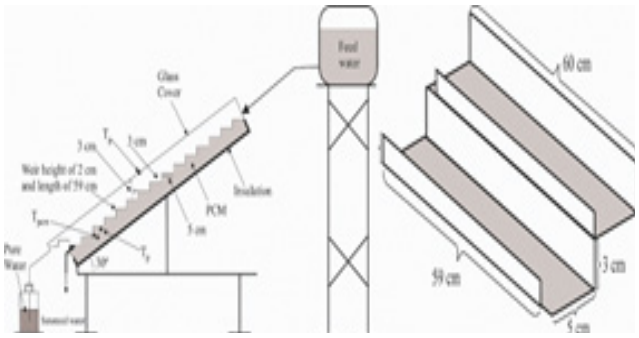


Figure 2. Schematic of weir-type cascade solar desalination system wax[14].

Table 2. Important characteristics of PCMs

S. No.	Properties of material	Lauric Acid	Paraffin Wax	Stearic Acid
1	Chemical composition	$CH_3(CH_2)_{10}COOH$	$C_{31}H_{64}$	$CH_3(CH_2)_{16}COOH$
2	Melting point temperature, °C	42- 46 °C	58- 60 °C	52- 56 °C
3	Thermal conductivity, W/m° C	0.16	0.24	0.29
4	Specific heat capacity, KJ/ kg °C	2.1	2.95	1.59
5	Latent heat of fusion, KJ/kg	178	226	199
6	Solid density, kg/m^3	862	818	847

47% improvement. A 90.1% increase, or 7.89 L/m^2/day, in accumulated productivity was achieved by using PCM with hollowed circular fins. The tubular solar still showed a daily efficiency that was 90.2% higher than that of the traditional solar still as a result of the implementation of PCM in conjunction with hollow circular fins[13].

Within the basin liner, an experiment was conducted on a solar desalination system of the weir type that utilised a cascade configuration and contained 18 kilogrammes of paraffin wax as PCMs. This experiment was carried out in addition to the development of theoretical models for solar desalination systems that included and did not include paraffin wax (Figure 2)[14].

The daily amounts of distilled water were 6.7 kg/m^2 with PCM and 5.1 kg/m^2 without PCM. Results show that adding paraffin wax PCM to solar stills during traditional daytime hours in Zahedan, Iran, improves their performance by 31%.

Using three-dimensional numerical research, this paper examines the impacts of natural double diffusive convection within the framework of a triangle solar still. To discretise the governing equations, the results of which are achieved through the formulation of the prospective vorticity vector in three dimensions, an application of the finite element method is brought into play. The thermal performance improved by 38% at both the evaporating and condensing surfaces, while the mass performance improved by 55% at both of those surfaces compared to the previous state[15].

The trial results on solar stills with and without PCMs each contained 7.54 litres per square metre of distilled water daily under Egyptian conditions. The solar still that did not contain PCM held 4.5 litres per square metre. As an additional point of interest, it was concluded that the cost of one litre of fresh water produced by a solar still with and without PCM was 0.032 dollars and 0.033 dollars, respectively, after the solar still was utilised[16]. Figure 3 depicts the apparatus used in the experiment.

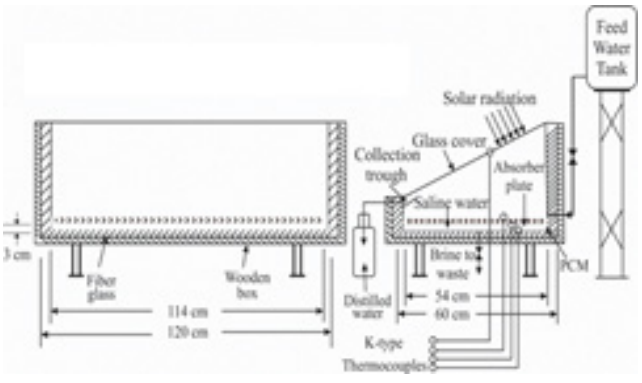


Figure 3. Arrangement of the experimental apparatus made up of PCM[16].

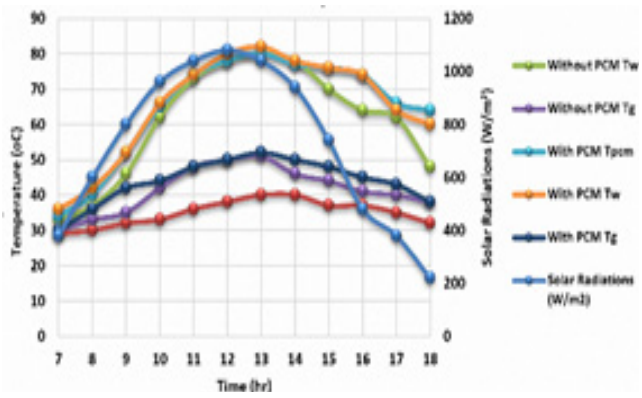


Figure 4. PCM-treated and untreated solar hourly temperature and radiation.

Both graphs and a description of the findings were provided. The highest temperatures that the water in the basin may reach in solar stills with PCM are 82 degrees Celsius and 78 degrees Celsius, respectively. However, in solar stills without PCM, the temperatures range from 25 to 51°C and 28 to 50°C, respectively. This is illustrated in Figure 4.

Figure 5 illustrates the increase in the hourly pure water enhancement. This represents how the growth in the rates of water evaporation and condensation has led to the observed increase. Figure 5 also indicates how the increase has occurred. PCM solar stills can generate a larger quantity of pure water each hour in comparison to conventional solar stills. This is on account of the elevated water temperature that is created within the basin compared to conventional solar stills.

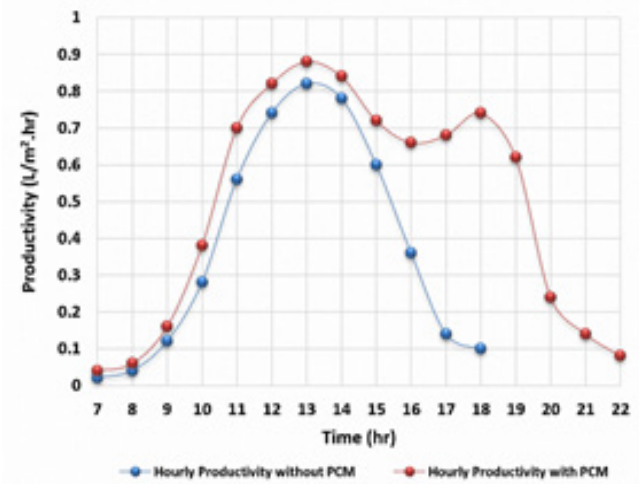


Figure 5. Hourly productivity difference between solar with and without PCM.

Because of their advantageous properties, organic PCMs are considered to be particularly well-suited for thermal storage in Solar Air Heating Systems (SAHS)[17]. Because brackish water salinity significantly affects solar still distillate output, factoring it into thermal modelling is critical for improved outcomes[18]. It is much simpler to determine the thermophysical parameters of brackish water when the salinity of the water is included in the equations as a significant and helpful variable.

Multiple-tray solar distillation produces premium distilled water at a reasonable price by desalinating brackish or seawater. The research findings reveal that the solar heating system achieved the highest evaporator temperature of 77 °C. From an economic standpoint, it was anticipated that 16 DA per litre may be obtained by distilling water using solar equipment. When compared to the 45 DA per litre price of a commercial product of the same grade, this is a huge savings[19]. Through the examination of the impact that PCM (tricosane) has on the alteration of water temperature and the increase in the quantity of freshwater that is generated. During the experiment, the mass ratio of PCM to water was varied at values of 0 weight, 0.17 weight, 0.35 weight, and 0.51 weight, all while keeping the water mass at a constant 3 kilograms. The freshwater output exhibits an inverse relationship with the ratio value during the day, while it directly correlates with the ratio value at night[20]. The addition of 6 kilogrammes of low-temperature Polycyclic Aromatic Hydrocarbons (PCM) resulted in a 33 per cent increase in total productivity and a 34.3 per cent increase in desalination efficiency[21].

Researchers have inserted a cylindrical parabolic concentrator that makes use of a focal pipe into a solar desalination system to enhance the amount of water that can be generated by the device. PCM and an oil heat exchanger together make up this system.

To increase the temperature of the PCM/water mixture, two external heat sources are used: an oil heat exchanger and a cylindrical parabolic concentrator. After experimentation, the data were analysed for comparison. The freshwater productivity in novel and conventional solar stills has been quantified at 10.77 and 4.48 litres/m², respectively. It was observed that the price of a container of pure water containing one litre of water for a modern

solar still is $0.0174, whereas the price for an older solar still is $0.0177[22]. The system operates better with paraffin-CuO than PCM, TiO_2, or GO.

2.0 Impact of Incorporating Diverse Nanoparticles with PCMS in Solar Stills

Adding three changes, PCM, film cooling, and flake graphite nanoparticles, improved the production of fresh water by about 74%. According to the findings of the study, the addition of flake graphite nanoparticles to fresh water can improve the water's quality by lowering its depth from two centimetres to half a centimetre, while elevating both the temperature and the vapour pressure of the water[23]. The performance of the Corrugated Tray Solar Still (CTSS) was significantly improved when PCM was coupled with CuO nanoparticles. The total distillates that were produced by the CTSS and the Flat Tray Solar Still (FTSS) were 87 per cent and 57 per cent higher than those that were produced by the Conventional Sun Still (CSS)[24]. According to the results of an experiment conducted on paraffin containing 0.5% mass of silica nanoparticles, the addition of PCM and n-PCM resulted in an increase in the generation of freshwater by 51.22% and 67.07%, respectively[25]. The most important physical and thermal characteristics are outlined in Table 3.

Table 3. Physical and thermal characteristics of paraffin wax and paraffin wax with nanoparticles of CuO[24].

Properties	Paraffin Wax	Paraffin wax with nanoparticles of CuO
Density	876 kg/m^3	941kg/m^3
Latent heat of fusion	190 kJ/kg	187 kJ/kg
Melting point	54^{0}C	53^{0}C
Specific heat	2.1 kJ/kg^{0}C	2.05 kJ/kg^{0}C
Thermal conductivity	0.21 W/m^{0}C	0.28 W/m^{0}C

A comparison of the thermal characteristics of PCM and n-PCM is presented in Table 4. After comparing theoretical models with experimental results, we found that using large masses of PCM reduces productivity, while reducing total heat transmission from 10.4 W/m^{2}K to 2.6 W/m^{2}K increases productivity[26]. This pertains to sodium thiosulfate pentahydrate PCM and an external solar collector. Adding cooling water to the glass cover at a stream rate of 0.1 kg/s can help boost output by injecting three types of nano-particles: TiO_2, CuO, and GO into paraffin wax PCM. Four solar stills, each measuring 0.5m^2, were tested experimentally. Their analysis included comparing the four solar stills' production rates and costs per litre. Compared to solar stills using paraffin PCM, paraffin TiO_2, or paraffin GO, those using paraffin CuO exhibit superior performance[27]. It gives clean water at a 50% lower cost than bottled water in India.

Table 4. Thermal properties of PCM and n-PCM[25].

Properties	PCM	n-PCM
Latent heat of fusion (kJ/kg)	140	136
Melting point	55 ^{0}C	54.3 ^{0}C
Specific heat (kJ/kg. K)	2.10	2.08

To enhance the thermal characteristics of nano-enhanced PCM and, consequently, increase the amount of solar energy that is absorbed, nanoparticles of CuO and Al_2O_3 were added to paraffin wax (Table 5). An additional layer of black paint, which contained CuO nanoparticles, was sprayed over copper pipes to enhance their heat conductivity and their ability to absorb solar beams. When CuO and Al_2O_3 nano-enhanced PCM were utilised at a concentration of 0.3 weight per cent and CuO nano-coated, respectively, the productivity of solar stills increased by 55.8% and 49.5%, respectively[28].

Over time, the solar still that makes use of nano-composite PCMs (Al_2O_3 that is mixed with paraffin wax) generates a greater quantity of distillate than the solar still that operates solely with paraffin wax or that does not possess any thermal storage. The

Table 5. Thermo-physical properties of paraffin wax, CuO and Al_2O_3 nanoparticles

Properties	Paraffin Wax	Nanoparticles of CuO	Nanoparticles of Al_2O_3
Density (kg/m^3)	780	6310	3890
Latent heat of fusion (kJ/kg)	226	-	-
Melting point (^{0}C)	52	-	-
Specific heat (kJ/kg. K)	2.17	0.55	0.88
Thermal conductivity (W/m. K)	0.228	17.7	40

solar still has a daily efficiency of 45% when nano-composite PCMs are used, 40% when paraffin wax is used alone, and 38% when thermal storage is not present[29].

3.0 Modifications in Solar Still

Experimental work on a weir-type cascade solar desalination system was conducted concurrently with the development of theoretical models for systems that use and do not use paraffin wax. The trial utilised 18 kilogrammes of paraffin wax as a PCM beneath the basin liner. The result was a 31% improvement in productivity[14]. Experiments on solar stills in Egypt showed that output increased by 68% under these conditions, regardless of whether phase transition materials were used or not[16]. The study showed that the integration of flake graphite nanoparticles into freshwater can improve productivity quality. Flake graphite nanoparticles enhance freshwater output by around 74%[23]. Adding 3.3cm of stearic acid under the basin liner doubles the convective heat transfer coefficient between the water and the solar still liner. Therefore, the production is around 80 per cent higher[12]. To further enhance the quantity of water generated, an additional experiment was carried out using a solar desalination system that included a focus pipe and a cylindrical parabolic concentrator; the outcomes showed a productivity increase of 140%[22]. In contrast to the CSS, the CTSS generated 180% more water when a corrugated absorber, PCMs combined with CuO nanoparticles, and electric heaters were utilised rather than the CSS. Productivity at the CTSS increased by a factor of 150 per cent as a direct result of the installation of electric heaters[29].

The solar stills, the improved basin-type, single-slope, multi-wick and the improved basin-type, double-slope, multi-wick employing black cotton wick performed better than the standard modified basin-type, single-slope and modified basin-type, double-slope systems (Figure 6). Several measures, such as exergoeconomic, enviroeconomic, yield, energy, and exergy matrices, confirmed this. The results demonstrated that solar stills equipped with dangling wicks were more efficient in terms of energy and exergy, and they generated a greater quantity of distillate in total[30]. Within the scorching New Borg El-Arab, Egypt, climate, the efficiency of solar desalination was tested and compared under five distinct conditions. The examples covered here range from the traditional solar still to one that incorporates PCM, from solar stills with hollow cylindrical pin fins to solar desalination systems that use PCM, from solar still basins that combine PCM and steel wool fibres to those that use only steel wool fibres. Results showed that whereas PCM increases overall production, it decreases freshwater productivity during the day. Solar photovoltaic modules (PCMs) with hollow cylindrical pin fins have far better thermal performance than those with other designs. Adding PCM and steel wool fibres to a basin increased freshwater flow by 14% during the day and decreased it during the night[31].

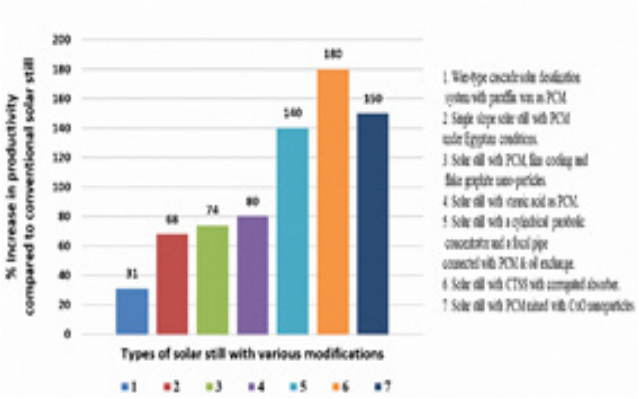


Figure 6. Increase in the productivity of solar stills with different modifications.

Using cold and hot temperatures, this study examines the exergy effectiveness of a dual-slope solar desalination system in Zahedan, Iran, that uses PCM and a Photovoltaic Thermal (PV/T) collector. The findings indicated that elevating the mass flow rate from 0.001 kg/s to 0.01 kg/s might enhance the output of pure water. Exergy effectiveness exhibited a decline on colder days compared to warmer days. According to the study, increasing the amount of salt water by up to 10 kg decreases production during the day and increases it at night[32].

4.0 Conclusion

This paper addresses the efforts of the research community to raise solar still performance. In particular, research in the literature emphasises the use of PCMs to increase the output of solar stills. The compilation of this work involves the use of paraffin wax, nanoparticles, solar stills, and various other PCMs with modifications. We have drawn the following conclusions from this study.

- Solar stills use paraffin wax, a highly effective PCM. From 28.13% to 36.42%, the efficiency of desalination can be improved by using paraffin wax. The maximum productivity with paraffin wax is 1200 ml/m²/day, while stearic acid and lauric acid yield 1010 ml/m²/day and 930 ml/m²/day, respectively.
- The wicks that were placed in the basin helped to increase the pace of evaporation. A 53.0% increase in overall productivity is achieved by using wicks in modified stills, which also results in the highest distillate output. It is also possible to increase the amount of freshwater produced by using black-covered paint, reflectors, glass balls, and photovoltaic heaters.
- The use of hollow circular fins resulted in a 33% increase in productivity to 5.50 L/m²/day; on the other hand, the use of square fins led to 6.10 L/m²/day, an increase of 47.0%.
- The solar still was equipped with a variety of nanoparticles to boost its productivity. When paraffin wax was combined with a variety of nanoparticles, the result was a productivity improvement that ranged from 40 per cent to 60 per cent, based on the percentage of weight. Within solar stills, the addition of nanoparticles resulted in improvements to thermal conductivity, absorption rate, daily efficiency, and the amount of freshwater produced.

The efficiency of solar stills is inadequate, hindering their extensive utilisation. PCMs are substances that are capable of absorbing or releasing considerable quantities of heat during the processes of melting or solidification, respectively. To figure out how to overcome this problem, researchers have examined the possibility of using PCMs. According to the findings of this investigation, the use of PCM in solar stills resulted in a significant increase in the amount of freshwater that was produced by the stills, while at the same time resulting in a reduction in the overall annual cost of distillate production. The fact that this is the case suggests that the utilisation of PCM could potentially improve the practicability of solar stills for the generation of freshwater. It is required to conduct additional research to improve the architecture of solar stills and increase the amount of freshwater that they produce. Our recommendation also includes the pursuit of future research activities to enhance the efficiency of passive solar stills. The purpose of this study is to highlight the necessity of increasing the efficiency of solar stills and the potential benefits that may be gained by utilising phase transition materials to accomplish this objective.

The incorporation of high-temperature nanoparticles into phase change materials can enhance their thermal conductivity. Magnetic nanoparticles make it easier to get rid of impurities in water-based systems and improve the properties of PCMs. However, one drawback of these magnetic nanoparticles is their potential to pose risks to aquatic environments. Due to their exceptional thermal

conductivity, nanoparticles such as graphene, TiO_2, and Al_2O_3 are employed in several applications. Additional properties of Phase Change Material (PCM) are improved by the presence of nanoparticles with thermal conductivity. These qualities include phase transition temperature, viscosity, and latent heat capacity. The amount of research conducted on materials based on graphene has been low. Accordingly, Carbon Nanotubes (CNT) have the potential to become a key contender in the field of solar desalination if researchers can properly overcome the economic, environmental, and technological issues associated with materials such as graphene.

- By incorporating a double slope solar still with a reflector that functions as an external source and high thermal conductivity nanoparticles, and PCM that function as inside sources, it will be possible to enhance the performance of a solar still in the future without compromising its efficiency.
- To enhance the solar still's capacity for storing heat, the wick material may be thicker.
- Researchers can additionally investigate the stability of nanoparticles when they are disseminated in PCM. This is because the stabilisation of nanoparticles is an essential component during the mixing process of nanomaterials and PCM.
- To enhance the thermophysical properties of nanoparticles, it is possible to undertake research on various nanoparticle sizes and their stability throughout the sonication process.
- In addition to paraffin wax, alternative PCMs must be used, and the quantities of these PCMs must be altered to increase storage capacity.

5.0 Acknowledgements

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6.0 References

1. Kumar R, Dhapekar NK, Tiwari R, Rao YA, Narain RS, Yadav AS, *et al*. Prospects of renewable energy scenario in India. In: Goyal R, Patel S, Sharma A, editors. Renewable energy: Accelerating the energy transition. Singapore: Springer Nature Singapore; 2024:15-31. https://doi.org/10.1007/978-981-99-6116-0_2
2. Yadav AS, Gattani A. Solar thermal air heater for sustainable development. Mater Today: Proc. 2022; 60:80-86. https://doi.org/10.1016/j.matpr.2021.11.630
3. Agrawal Y, Bhagoria JL, Gautam A, Sharma A, Yadav AS, Alam T, *et al*. Investigation of thermal performance of a ribbed solar air heater for sustainable built environment. Sustain Energy Technol Assess. 2023; 57:103288. https://doi.org/10.1016/j.seta.2023.103288
4. Yadav AS, Agrawal A, Jain A, Saxena R, Kumar M, Sharma A, *et al*. Revisiting the recent advancements in the design and performance of solar greenhouse dryers. In: Kumar A, Zunaid M, Subramanian KA, Lim H, editors. Recent advances in manufacturing and thermal engineering. Singapore: Springer Nature Singapore; 2023. p. 275-292. https://doi.org/10.1007/978-981-19-8517-1_20 PMCid:PMC10581321.
5. Yadav AS, Agrawal A, Sharma A, Sharma S, Maithani R, Kumar A. Augmented artificially roughened solar air heaters. Mater Today: Proc. 2022; 63:226-239. https://doi.org/10.1016/j.matpr.2022.02.548
6. Yadav AS, Alam T, Gupta G, Saxena R, Gupta NK, Allamraju KV, *et al*. A Numerical investigation of an artificially roughened solar air heater. Energies. 2022; 15(21). https://doi.org/10.3390/en15218045
7. Yadav AS, Gattani A. Revisiting the influence of artificial roughness shapes on heat transfer enhancement. Mater Today: Proc. 2022; 62:1383-1391. https://doi.org/10.1016/j.matpr.2021.12.254
8. Yadav AS, Shrivastava V, Yadav R, Sachan K, Kumar V, Sudarshan, *et al*., editors. Revisiting the energy-efficient modified solar still. Proceedings of the 10th international symposium on hydrogen energy, renewable energy and materials; 2025; Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-3272-5_6
9. Asbik M, Ansari O, Bah A, Zari N, Mimet A, El-Ghetany H. Exergy analysis of solar desalination still combined with heat storage system using Phase Change Material (PCM). Desalination. 2016; 381:26-37. https://doi.org/10.1016/j.desal.2015.11.031
10. Sonker VK, Chakraborty JP, Sarkar A, Singh RK. Solar distillation using three different phase change materials stored in a copper cylinder. Energy Reports. 2019; 5:1532-1542. https://doi.org/10.1016/j.egyr.2019.10.023
11. El-Sebaii AA, Al-Ghamdi AA, Al-Hazmi FS, Faidah AS. Thermal performance of a single basin solar still with PCM as a storage medium. Appl Energy. 2009; 86(7-8):1187-1195. https://doi.org/10.1016/j.apenergy.2008.10.014

12. Kateshia J, Lakhera VJ. Analysis of solar still integrated with phase change material and pin fins as absorbing material. J Energy Storage. 2021; 35:102292. https://doi.org/10.1016/j.est.2021.102292
13. Abdelgaied M, Zakaria Y, Kabeel AE, Essa FA. Improving the tubular solar still performance using square and circular hollow fins with phase change materials. J Energy Storage. 2021; 38:102564. https://doi.org/10.1016/j.est.2021.102564
14. Dashtban M, Tabrizi FF. Thermal analysis of a weir-type cascade solar still integrated with PCM storage. Desalination. 2011; 279(1-3):415-422. https://doi.org/10.1016/j.desal.2011.06.044
15. Maatki C. Heat transfer enhancement using CNT-water nanofluids and two stages of seawater supply in the triangular solar still. Case Stud Therm Eng. 2022;30:101753. https://doi.org/10.1016/j.csite.2021.101753
16. Kabeel AE, Abdelgaied M. Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions. Desalination. 2016; 383:22-28. https://doi.org/10.1016/j.desal.2016.01.006
17. Sharma A, Chauhan R, Kallioğlu MA, Chinnasamy V, Singh T. A review of phase change materials (PCMs) for thermal storage in solar air heating systems. Mater Today: Proc. 2021; 44:4357-4363. https://doi.org/10.1016/j.matpr.2020.10.560
18. Hedayatizadeh M, Sarhaddi F, Pugsley A. A detailed thermal modelling of a passive single-slope solar still with improved accuracy. Groundw Sustain Dev. 2020; 11:100384. https://doi.org/10.1016/j.gsd.2020.100384
19. Diaf A, Cherfa A, Karadaniz L, Tigrine Z. A technical-economical study of solar desalination. Desalination. 2016; 377:123-127. https://doi.org/10.1016/j.desal.2015.09.017
20. Mousa H, Naser J, Gujarathi AM, Al-Sawafi S. Experimental study and analysis of solar still desalination using phase change materials. J Energy Storage. 2019; 26:100959. https://doi.org/10.1016/j.est.2019.100959
21. Jahanpanah M, Sadatinejad SJ, Kasaeian A, Jahangir MH, Sarrafha H. Experimental investigation of the effects of low-temperature phase change material on single-slope solar still. Desalination. 2021; 499:114799. https://doi.org/10.1016/j.desal.2020.114799
22. Kabeel AE, Abdelgaied M. Observational study of modified solar still coupled with oil serpentine loop from cylindrical parabolic concentrator and phase changing material under basin. Sol Energy. 2017; 144:71-78. https://doi.org/10.1016/j.solener.2017.01.007
23. Sharshir SW, Peng G, Wu L, Essa FA, Kabeel AE, Yang N. The effects of flake graphite nanoparticles, phase change material, and film cooling on the solar still performance. Appl Energy. 2017; 191:358-366. https://doi.org/10.1016/j.apenergy.2017.01.067
24. Abdullah AS, Omara ZM, Essa FA, Younes MM, Shanmugan S, Abdelgaied M, *et al*. Improving the performance of trays solar still using wick corrugated absorber, nano-enhanced phase change material and photovoltaics-powered heaters. J Energy Storage. 2021; 40:102782. https://doi.org/10.1016/j.est.2021.102782
25. Kumar PM, Sudarvizhi D, Prakash KB, Anupradeepa AM, Raj SB, Shanmathi S, *et al*. Investigating a single slope solar still with a nano-phase change material. Mater Today: Proc. 2021; 45:7922-7925. https://doi.org/10.1016/j.matpr.2020.12.804
26. Abu-Arabi M, Al-harahsheh M, Mousa H, Alzghoul Z. Theoretical investigation of solar desalination with solar still having phase change material and connected to a solar collector. Desalination. 2018; 448:60-68. https://doi.org/10.1016/j.desal.2018.09.020
27. Rufuss DDW, Suganthi L, Iniyan S, Davies PA. Effects of nanoparticle-enhanced phase change material (NPCM) on solar still productivity. J Clean Prod. 2018; 192:9-29. https://doi.org/10.1016/j.jclepro.2018.04.201
28. Shoeibi S, Kargarsharifabad H, Rahbar N. Effects of nano-enhanced phase change material and nano-coated on the performance of solar stills. J Energy Storage. 2021; 42:103061. https://doi.org/10.1016/j.est.2021.103061
29. Rajasekhar G, Eswaramoorthy M. Performance evaluation on solar still integrated with nano-composite phase change materials. Appl Sol Energy. 2015; 51(1):15-21. https://doi.org/10.3103/S0003701X15010119
30. Tuly SS, Islam MS, Hassan R, Das BK, Sarker MRI. Investigation of a modified double slope solar still integrated with nanoparticle-mixed phase change materials: Energy, exergy, exergo-economic, environmental, and sustainability analyses. Case Stud Therm Eng. 2022; 37:102256. https://doi.org/10.1016/j.csite.2022.102256
31. Yousef MS, Hassan H. An experimental work on the performance of single slope solar still incorporated with latent heat storage system in hot climate conditions. J Clean Prod. 2019; 209:1396-410. https://doi.org/10.1016/j.jclepro.2018.11.120
32. Hedayati-Mehdiabadi E, Sarhaddi F, Sobhnamayan F. Exergy performance evaluation of a basin-type double-slope solar still equipped with phase-change material and PV/T collector. Renew Energy. 2020; 145:2409-2425. https://doi.org/10.1016/j.renene.2019.07.160