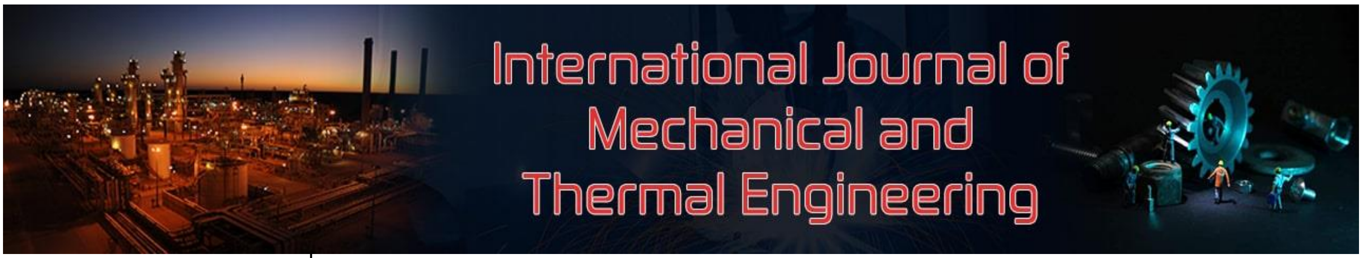

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A review on progresses in solar still technology with phase change material

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Abstract
The utilization of solar desalination processes using solar stills to maintain the purity of water. The purpose of this process is to remove impurities and salt from water to make it suitable for consumption. The study involves analyzing various factors that influence the conditions of the solar desalination process at different stages. The article reviews the application of highly efficient materials and experimental endeavors in the realm of solar stills. One notable technique involves using Paraffin wax in combination with different Phase Change Materials (PCMs). This combination leads to increased productivity and thermal conductivity, ultimately enhancing the output of the solar still. In a modified solar still, the incorporation of wicks resulted in amplified distillate output and an overall improvement in productivity. Another enhancement strategy discussed is the utilization of nano-particles. The incorporation of these nano-particles led to improved daily efficiency and thermal conductivity. This, in turn, raised the thermal efficiency of the solar still and augmented the yield of fresh water. The article also underscores the efficacy of collective approaches involving Phase Change Materials, reflectors, and nano-coating paint mixed with nano-particles. These combined materials resulted in a notable increase in thermal efficiency and fresh-water yield. Among the various Phase Change Materials explored, the study concludes that paraffin wax exhibits the highest output and productivity compared to other options. In essence, the article highlights the advancements and innovations in solar desalination using solar stills.

Keywords: Solar still, solar desalination, phase change material (PCM), nano particles

1. Introduction

Solar desalination is a water purification process that utilizes solar energy to remove salt and impurities from water sources, making it suitable for consumption. Fresh water resources like underground water, rivers, lakes, and dams play a crucial role in providing water for various needs. The Sun, being a primary source of energy, produces a substantial amount of energy annually compared to other sources. In the solar desalination process, solar energy is harnessed to address water purification challenges. This method targets the removal of salt content, resulting in the production of fresh water. As the demand for fresh water grows, solar radiation is increasingly employed to power this process. Solar desalination effectively treats seawater, transforming it into potable water by leveraging the Sun's energy. Various techniques are employed to enhance the efficiency and output of solar desalination systems. Innovations such as fins, sponges, and the use of substances like paraffin wax contribute to making the process more efficient and economically viable. Compared to alternative methods, solar desalination is cost-effective, making it an attractive solution.

One commonly used configuration is the single slope solar still (as shown in Fig. 1.), which is designed to improve efficiency and production rates. Key parameters influencing its performance include operational aspects, environmental conditions, and design considerations. The operational mode, water depth, and other factors impact the efficiency of the system. Incorporating Phase Change Materials (PCMs) further enhances the performance of solar stills. Researchers have explored various factors to optimize the process, including active and passive modes of operation at different water depths. Through ongoing research and development, solar desalination continues to evolve as an effective means of producing fresh water sustainably, utilizing the Sun's abundant energy.

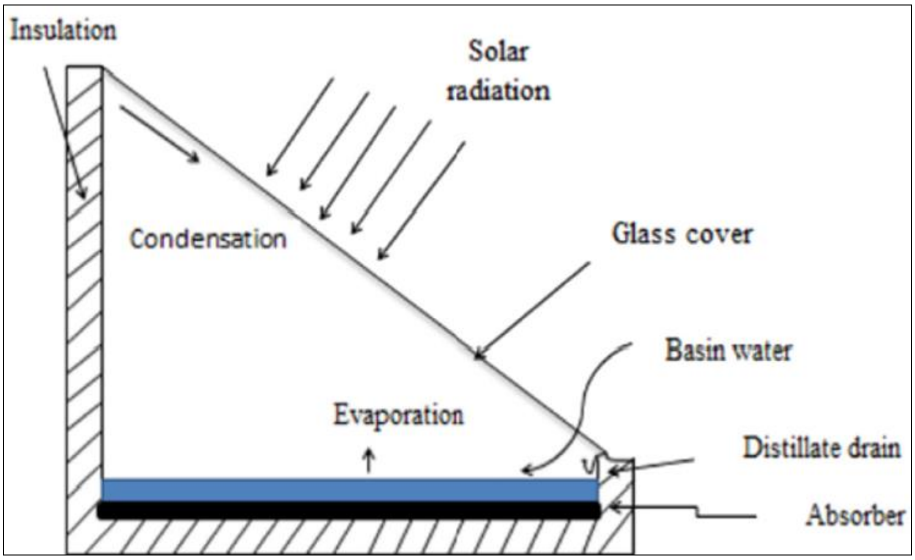

Fig 1: Single slope solar still

The maximum distillate was obtained at a 1 cm depth for all three PCMs, and total distillate decreased linearly with water depth for all three PCMs. They compared the performance of the three PCMs and found that the total distillate was increased by 1202, 1015, and 930 ml/m^2-day for paraffin wax, stearic acid, and lauric acid, respectively, when stored in a copper cylinder [1]. Table 1 show the thermo-physical properties of phase change materials.

Table 1: Thermo-physical properties of PCM **[1]**

Material properties	Lauric acid	Stearic acid	Paraffin wax
Chemical formula	$(CH_3(CH_2)_{10}COOH)$	$(CH_3(CH_2)_{16}COOH)$	$(C_{31}H_{64})$
Melting temperature, °C	42-46 °C	52-56 °C	58-60 °C
Latent heat of fusion KJ/kg	178	199	226
Solid density, kg/m^3	862	847	818
Thermal conductivity, W/m-°C	0.16	0.290	0.24
Specific heat capacity, KJ/kg °C	2.1	1.590	2.95

The palmitic acid as the PCM, varied the mass of PCM and water as study parameters. It is found that the total accumulated productivity in solar still with PCM and PCM with pin fins improved by 24% and 30%, respectively, compared to conventional solar still (CSS) [2]. The fitting an array of copper hollow fins on the absorber surface and installing a PCM reservoir below the absorber surface. The results of the study showed that the traditional tubular still had an accumulated productivity of 4.15 L/m^2/day. The utilization of hollow square fins improved the productivity to 5.52 L/m^2/day with a 33% improvement. The utilization of hollow circular fins improved the productivity to 6.11 L/m^2/day with a 47.2% enhancement. The utilization of PCM with hollow circular fins increased the accumulated productivity to 7.89 L/m^2/day, representing a 90.1% improvement. The daily efficiency of the tubular solar still was increased by 33.1% and 47.4% when using the hollow square fins and hollow circular fins, respectively, as compared to the conventional case. The use of PCM with hollow circular fins increased the daily efficiency of the tubular solar still by 90.2% as compared to the conventional case [3]. By three-dimensional numerical investigation of the effects of natural double diffusive convection in a triangular solar still. The governing equations are formulated on the basis of the three-dimensional formulation of the potential-vorticity vector and discretized using the finite element method. The thermal performance improved by 38% and the mass performance by 55% at the evaporating surface and condensing surface [4]. The computational fluid dynamics (CFD) modeling approach for solar stills that eliminates the need to specify glass and water temperatures as boundary conditions. The model accounts for the absorption of solar radiation and radiative heat transfer within the solar still by solving the DO radiative transfer equation. This method considers the latent heat of evaporation/condensation as a sink/source term in the energy equation, and the required evaporation and condensation rates are calculated by integrating Fick's law on the water and glass surfaces. This method accurately predicts transient temperature and concentration distributions and productivity in passive and active solar stills throughout a day with moderate computational cost [5]. The Organic PCMs are most appropriate for thermal storage with SAHS due to their desirable properties, such as acceptable melting temperature range, high latent heat of fusion, non-toxicity, chemical stability, and inexpensiveness. However, their thermal conductivity is generally lower than that of inorganic PCMs such as salt hydrates [6].

The brackish water salinity has a significant effect on the distillate yield of solar stills, making its inclusion in thermal modeling crucial for better results. The inclusion of brackish water salinity in the equations as a decisive and effective parameter also improves the determination of brackish water thermophysical properties [7]. The mathematical model to predict the productivity of a solar still involving PCM showed that fresh water production increased upon decreasing feed flow rate, using PCM with a higher melting point, and increasing solar irradiation intensity [8]. The multiple tray solar distillation to desalinate brackish or sea water and produce high-quality distilled water at a competitive cost. The results of the study indicate that the highest evaporator temperature achieved with the solar heating system was 77 °C. From an economic standpoint, the cost of producing distilled water with the solar equipment was estimated to be 16 DA per liter, which is significantly lower than the cost of a similar quality commercial product, which is 45 DA per liter. This makes multiple tray solar distillation an interesting alternative for small-scale desalination of brackish or sea water, especially in remote areas where access to fresh water is limited [9]. The addition of 6 kg of low-temperature PCM increased the overall productivity by 30.3% and increased the desalination efficiency from 28.13% to 36.42% [10]. By the investigation of the effect of PCM (tricosane), on the temperature change of water and the amount of fresh water produced. The experiment varied the ratio of mass of PCM to mass of water at values of 0, 0.17, 0.35, and 0.51, while the amount of water used was fixed at 3 kg of tap water. During the day, fresh water production is inversely proportional to the value of Ratio, while during the night, fresh water production is directly proportional to the value of Ratio [11]. The performance of pyramid solar still by adding hollow circular copper fins to the absorber plate and PCM tank below the absorber surface. It showed that the conventional pyramid solar still had a maximum productivity of 4.02 L/m^2/day. However, the utilization of hollow circular fins at the absorber enhanced the productivity to 5.75 L/m^2/day, representing a 43% enhancement in the daily productivity. The addition of PCM to the hollow circular fins increased the productivity to 8.1 L/m^2/day, representing a 101.5% enhancement in daily productivity. The daily efficiency of the conventional pyramid still reached 32.2%, while the hollow fins utilization enhanced the daily efficiency to 45.9%, representing a 42.4% improvement. The PCM addition further augmented the daily efficiency to 64.3%, representing a 99.5% improvement. It was found that the cost of distillate water production reached approximately 0.0227 and 0.025 $/liter for the conventional pyramid still and pyramid still with hollow circular fins, respectively. However, the utilization of PCM with hollow circular fins reduced the cost of distillate water production to 0.019 $/liter [12].

2. Effect of adding various nano-particles with pcm in solar still: The experimental result of paraffin with 0.5% mass of silica nanoparticles showed that the incorporation of PCM and n-PCM improved the fresh water production by 51.22% and 67.07%, respectively [13]. Table 2 shows the thermal properties of PCM and n-PCM.

Table 2: Thermal properties of PCM and n-PCM [13]

Properties	PCM	n-PCM
Melting Temperature	55 ^{0}C	54.3 °C
Latent Heat of fusion (kJ/kg)	140	136
Specific Heat (kJ/kgK)	2.10	2.086

The performance of the corrugated tray solar still (CTSS), phase change material (PCM) mixed with CuO nanoparticles, the total distillates of the CTSS and flat tray solar still (FTSS) were higher than that of the conventional solar still (CSS) by 87% and 57%, respectively [14]. Table 3 shows the thermo-physical properties of PCM and PCM with nanoparticles.

Table 3: Thermo-physical properties of paraffin wax and paraffin wax with nano-particles [14]

Property	Paraffin wax	Paraffin wax with CuO nano-particles
Density	876 kg/m^3	941 kg/m^3
Melting point	54 ^{0}C	53 ^{0}C
Latent heat of fusion	190 kJ/kg^{0}C	187 kJ/kg^{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

By the anthracite media to increase solar energy absorption, CuO and Al_2O_3 nanoparticles were added to paraffin wax to improve the thermal properties of nano-enhanced PCM. CuO nanoparticles were also added to black paint and sprayed on copper pipes to enhance thermal conductivity and solar intensity absorption. The results showed that the productivity of solar stills improved by 55.8% and 49.5% using CuO and Al_2O_3 nano-enhanced PCM at a concentration of 0.3 wt% and CuO nano-coated, respectively [15]. Table 4 shows the thermophysical properties of CuO and Al_2O_3 nanoparticles and paraffin wax.

Table 4: Thermo-physical properties of CuO and Al_2O_3 nano-particles and paraffin wax [15]

Properties	Paraffin wax	CuO nano-particles	Al_2O_3 nano-particles
Melting point (°C)	52	-	-
Latent heat of fusion (kJ/kg)	226	-	-
Thermal conductivity (W/m.k)	0.228	17.6	40
The specific heat (kJ/kg.k)	2.17	0.55	0.88
Density (kg/m^3)	780	6310	3890
Purity	-	99%	99%
Color	White	Black	White

The solar still with FGN (flake graphite nanoparticles), FGN and PCM, FGN and film cooling, and FGN, PCM with film cooling and the productivity enhanced by 50.28%, 65%, 56.15%, and 73.8%, respectively. These modifications have been shown to increase productivity by as much as 73.8% compared to the conventional still. The effect of water depth on productivity enhancement was also investigated, and it was found that productivity increases by around 13% when the water depth decreases from 2 cm to 0.5 cm. It was also observed that the performance of solar stills decreases as the water depth increases for both modification of still with FGN and FGN with PCM [16]. The solar still integrated with nano-composite phase change materials (Al_2O_3 dispersed in paraffin wax) has a higher cumulative yield of distillate than the solar still with paraffin wax alone or without any thermal storage. The daily efficiency of the solar still is found to be 45% with nano-composite phase change materials, 40% with paraffin wax alone, and 38% without any thermal storage [17].

3. Modification in solar still

The flat trays solar still (FTSS), corrugated trays solar still (CTSS), and conventional solar still (CSS). Additionally, three electric heaters were used to heat the basin water, and the heaters derived their energy directly from a PV module installed beside the backside of the solar still, utilizing the same space as the solar still. The total freshwater yield of the CTSS was improved by 150% and 122% when using electric heaters and PCM with CuO nanoparticles, respectively, compared to the CSS. Furthermore, the total water production of the CTSS was enhanced by 180% when using a corrugated absorber, PCM mixed with CuO nanoparticles, and electric heaters compared to the CSS. Using electric heaters, the productivity of the CTSS was enhanced by 150% [14]. By the comparision of a conventional solar still (CSS) with a solar still with energy storage materials (SSWESM) that included black color glass balls, black granite, and white marble stone. The study found that the SSWESM produced a higher distillate yield than the CSS, with a daily distillate yield that was 76% higher. The SSWESM also had higher basin water and inner glass cover temperatures than the CSS, with the maximum value of basin water temperature reached during peak hours. The ESM increased the evaporative heat transfer coefficient of water, resulting in faster charging and slower discharging in the release of heat [18]. The modification of a double slope solar still with internal sidewall reflector (ISR), hollow circular fin (HCF), phase change material (PCM), and nanoparticle mixed PCM (nano-PCM) to enhance its performance. The results showed that the modified still with ISR, HCF, and PCM had a 51.8% increase in productivity compared to the conventional still. Moreover, adding nanoparticles to PCM resulted in a further 21.5% increase in productivity compared to PCM [19]. The modified basin type single slope multi-wick solar still and modified basin type double slope multi-wick solar still with black cotton wick performed better than modified basin type single slope solar still and modified basin type double slope solar still in terms of yield, energy, exergy, energy matrices, exergoeconomic, and enviroeconomic methodologies. The results showed that the modified solar stills with hanging wicks produced more distillate and had higher energy and exergy efficiency [20].

4. Conclusion

This reviews discussing the research community's efforts to improve the performance of solar stills. Specifically, studies in the literature that focused on using phase change materials (PCM) to enhance the productivity of solar stills. This study is summarized by using Paraffin wax, nano-particles and modifications in solar still and some other PCMs. The following conclusions have been made based on this study.

- Paraffin wax is the highly efficient PCM used in solar still. It gives the maximum productivity of 1202 ml/m^2-day whereas stearic acid and lauric acid gives 1015 and 930 ml/m^2-day. The paraffin wax can increase the desalination efficiency from 28.13% to 36.42%.
- The square fins improved the productivity to 5.52 L/m^2/day with a 33% improvement and the utilization of hollow circular fins improved the productivity to 6.11 L/m^2/day with a 47.2% enhancement.
- Evaporation rate enhanced when wicks were used in the basin. By using wicks in modified still, it gives the maximum distillate output and the gain in overall productivity was 53.5%. The black coated paint, reflectors, glass balls and PV heater can also used to enhance the productivity of fresh water.
- Different types of nano-particles were added in the solar still to further enhance the productivity. Paraffin wax was also added with different types of nano-particles and there was an increase the productivity from 40% to 60% with respect to weight percentage. Thermal conductivity, absorption rate, daily efficiency, freshwater yield increased when nano-particles were used in solar still.

5. Summary and future prospects

The productivity of solar stills is often low, which limits their widespread adoption. To address this issue, researchers have explored the use of PCM, which are materials that can absorb or release large amounts of heat during the process of melting or solidifying, respectively. This review found that integrating PCM into solar stills significantly improved the fresh water productivity of the stills, and also reduced the total annual cost of distillate yield. This suggests that the use of PCM has the potential to make solar stills a more viable option for producing fresh water. However, further investigations are needed to improve the design of solar stills and increase their fresh water output. Also suggest that future research ideas should be employed to achieve improved performance of passive solar stills. In summary, this review highlights the importance of improving the performance of solar stills, and the potential benefits of using phase change materials to achieve this goal.

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