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# Review of Phase Change Materials Technique Used to Enhance the Performance of Single Slope Solar Stills for a Solar Water Desalination

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***Abstract:*** *Clean water is becoming increasingly difficult to come by, particularly for those who live in rural and coastal locations. The water must be treated before use, even for individuals who discover subterranean water. The most effective method for desalinating and purifying muddy water is to use solar thermal energy, which is freely available. The lack of sufficient clean freshwater sources and the abundance of contaminated water that could potentially be turned into drinkable water are the main motivators for this endeavor. Among the many designs on the market, solar stills using phase-change materials seem appealing for thermal applications in secluded and wet environments. One possible method to capture heat and lower losses in solar stills is to employ phase change material (PCM). The review paper's main objective is to investigate the use of PCMs in single slope solar stills to boost distillate yield. We also go over the best PCMs depending on the kind of solar still.*

***Keywords:*** *Single Slope Solar Stills, Solar Desalination, Productivity, Review Phase Change Materials.*

## I. Introduction

The world's growing water shortage is becoming a major issue, and it's getting harder than we think for individuals who live in distant locations to get access to clean, freshwater. The oceans contain about 97% of the world's water, with the remaining 3% coming from freshwater found in lakes, rivers, ice, and groundwater, which meets most of the needs of humans and other animals. As a result, many people have contributed to the solution by offering methods for purifying water, but the issue persists globally. Utilizing solar distillation is one of the best gifts because solar energy is a promising energy source[1,2].

In order to generate fresh water, impure (salty or brackish) water has been desalinated using solar energy, a plentiful and free energy source [3,4]. A component of the solar desalination process used to produce freshwater is the solar still. This gadget uses the sun's

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trapped heat to evaporate brackish water that is held in an enclosed basin. Water that has evaporated condenses on the inner surface solar still cover, causing freshwater to accumulate [5]. Solar stills can be inexpensive, easy to create, and effective since they offer multiple development options. Additionally, they are more widely beneficial and require less upkeep. They are made out of a black paint-colored basin that is heated by the sun and holds salty water in it. A clear material, such as glass, covers the basin [6].

Passive solar stills and active solar stills are the two primary categories of solar desalination systems. Active solar stills employ additional energy sources to speed up the evaporation and condensation processes, whereas passive solar stills only use solar radiation to evaporate the water. Active solar stills can produce fresh water more quickly and are usually more efficient than passive solar stills. This is because the water is heated by external energy sources, which speeds up its evaporation [7]. The main drawback of solar stills is their low daily water yield, which leaves room for numerous improvements to boost output. Both active and passive solar system yields are influenced by operational, design, and meteorological factors. Nevertheless, human control over meteorological parameters is unattainable. In order to increase the productivity of the still, the researchers conducted empirical research. They discovered that the still's productivity is dependent on a number of factors, including the heat capacity, glass cover material, wind velocity, basin water depth, intensity of solar radiation, and temperature of ambient [8].

Many researchers have used a variety of techniques to increase the productivity of passive solar stills, including double slope solar stills [2][9], hemispherical solar stills [3][10], varied thickness glass cover solar stills [4][11], solar stills with external and internal reflectors [5][12], solar stills with a condenser [5][12], solar stills with sensible reservoir materials [6][13], latent heat reservoir materials [7][14], corrugated and fins solar stills [8][15], solar stills with inclination of glass covers flat and convex [9][16], solar stills with wick material [10][17], weir type solar stills [11][18], spherical solar stills [12][19], sensible materials [13][20], solar stills with internal mirrors and sun tracking systems [14][21], etc.

In recent times, numerous researchers have employed phase change materials to enhance the performance of solar stills and increase the rate of evaporation. The primary goal of using PCM was to improve the solar still's heat transfer [2]. As the sun rises in the morning, the PCM charging process starts, raising the water's temperature. Additionally, the sensible heat produced by the heat transferred to the PCMs produces a slow increase in temperature. In the end, the PCMs melt and release latent heat of fusion, which is extra heat without a temperature increase. At sunset, the discharge procedure takes place. As a result of the heat being rejected by the water in the basin, the water temperature at the base starts to drop, and the latent heat is lost first, then the sensible heat, causing the PCM to go from a liquid to a solid state. Consequently, phase change materials can be utilized to store excess energy during sunrise period and release it during sunset time, thereby increasing the productivity of solar stills [22].

## II. Working of solar still

A solar still is a low-tech solar desalination apparatus that is used to transform brackish water and salty into freshwater. The components of the still are as follows Fig. 1[23]:

1. The glass cover, which causes condensation of water vapor.
2. Body of salty water (brine).
3. A collector plate, also known as a basin liner, that stores salt water to absorb solar energy.
4. Insulate the base to stop heat loss.
5. Sides or borders.
6. Water supply via container feed.
7. Distillation outcome.
8. Vapor infiltration.
9. Joining pipes.
10. The atmosphere, which is the site of the interaction between solar thermal energy.

As seen in Figure 1, solar radiation enters the closed distillation system through the upper glass cover. The bulk of water both partially absorbs and reflects this solar light. Water absorptivity and depth are sequentially dependent on solar radiation absorption by the water mass. When solar radiation eventually reaches the linear plate of the basin, it can be stored in water mass due to its greater thermal power, with the remaining end being squandered into space. The temperature differential between the glass cover and the water mass rises after the water layer has heated. We discovered that the brackish solution layer and upper cover experience three different types of heat transfer: convection, evaporation, and radiation. On the inner surface of the upper glass panel, vapor condenses, releasing latent heat. Ultimately, gravity causes condensed water to naturally gather in the tilt direction of the glass cover. This water is then attached to the assembly tube that is pushed out for use. Convection and radiation lose thermal energy that reaches the top cover and wastes it to the surroundings [24].

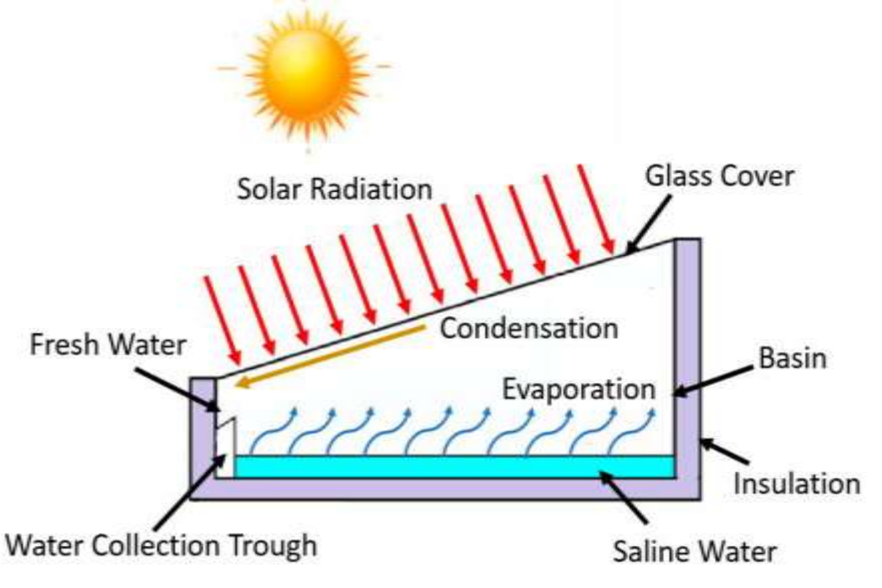


Figure1 Mechanism of potable water output in a single slope solar still.

## III. Factors affecting the productivity of still

### 3.1. Metrological parameters

#### 3.1.1. Intensity of Solar radiation

The primary climatic factor influencing the freshwater production of solar stills is the intensity of solar radiation. A number of theoretical and practical investigations have been conducted to investigate how solar insolation affects solar still productivity. Morse and Read [25] conducted an analytical investigation to determine how different sun insolation parameters affected the solar still's production. Their findings shown that variations in solar intensity levels have a substantial impact on the production of solar stills. Velmurugan et al. [26] investigated how solar radiation affected stepped solar still productivity. Productivity was observed to rise with sun intensity. Elmi Idil Mouhoumed et al. [27] investigate how the daily production of fresh water from seawater in the Djiboutian environment is affected by a number of factors, including solar radiation, the amount of water in the basin, the thickness of the glass cover, the salinity of the water, and wind speed. They discovered that differences in temperature rise in proportion to sun radiation. As a result, the hourly distillate output rises and peaks during midday, when the sun continues to receive its highest amount of solar radiation. Kamal [28] effectively shown that the yield of a solar still is highly reliant on the input of solar energy. Additionally, it was established by Rahbar and Esfahani [29] in the review still that air temperature and sun intensity had a direct impact on solar still performance.

#### 3.1.2. Air temperature

Numerous studies have also looked closely at how ambient temperature affects solar still performance [30,31]. It should be noted that different scholars have differing opinions regarding how ambient temperature affects solar still productivity. A low temperature of ambient or a high speed of wind was found to be beneficial in increasing productivity by Garg et al. [32], Copper [33], Malik and Tran [34], and Voropoulos et al. [35]. A different conclusion was reported by [36], Hollands [37], Yeh and Chen [38], Hinai et al. [39], and Nafey et al. [40]. These contradictions could be caused by a larger temperature differential between the glass cover and the brine as well as a bigger loss of heat to the surrounding area due to a lower temperature of ambient or a higher wind velocity. Productivity is positively impacted by the former and negatively by the latter. According to research by Hinai et al. [41], it was found that a 10–12°C rise in ambient air temperature led to an 8.2% increase in productivity.

#### 3.1.3. Air velocity

Numerous writers investigated how wind speed affected the solar still's ability to produce fresh water. They came to the conclusion that productivity improves in proportion to wind speed [42]. According to Sathyamurthy et al. [43], solar productivity continues to rise by 8% and 15.5% as wind speed increases from 1.5 m/s to 3.5 m/s and 4.5 m/s. A study by Dimri et al. [44] examined how wind velocity affects both active and passive solar still yields. In both situations, they have found that the yield rises as wind velocity does. According to Zurigat and Abu-Arabi [45], increasing velocity of wind from 0 m/s to 10 m/s improves the output. El-Sebaii [42] examined the impact of wind speed on the solar still. Following theoretical analysis, experimental values were analyzed and good resemblance between them was discovered. El-Sebaii [46] demonstrated how wind speed affected the output of both passive and active type stills and came to the conclusion that wind velocity enhanced output.

**3.1.4. Relative humidity**

Although it is an uncontrollable weather feature, relative humidity affects the solar still output. According to research by Koffiet et al. [47], humidity changes were observed ranging from 40% to 65%. Mohsenzadeh et al. [48] Examine how a solar still's aspect ratio and humidity affect its water productivity. They come to the conclusion that a solar still with reduced humidity will operate better. In Melbourne's summer, the modified solar still producing a water yield of 18.8% more produced 3.49 kg $m^{-2}$ $d^{-1}$ for a relative humidity of 62%. It is possible to see that the distilled water reduced as the relative humidity increased for a given ambient temperature because of the low convection coefficient between the still and its surroundings as well as the lower saturation temperatures of the steam inside the still [49,50].

**3.1.5. Cloud and dust of cover**

Without any cleaning procedure, the layer of dust that has formed on the glass surface reduces the transparency of the cover, which lowers the productivity of the distillate. According to El-Nashar [51], dust buildup on the glass surface can cause a 70% reduction in the amount of yearly solar radiation that enters the solar still. In actuality, transmittance diminishes with increasing dust collection [52]. Conversely, Zamfir et al. [53] carried out an experiment to ascertain how clouds affected the monthly average performance of a still. The outcomes showed that the performance is below monthly general days' average cloudy days. Hegazy [54] used various tilt angles to examine how the buildup of dust on the glass surface affected the transmittance of solar radiation. It was discovered that the formation of dust and the transmission of solar radiation are highly correlated. At a 30° tilt angle, dust on the condensing cover reduces the transmission of solar energy by an average of 1%, according to another study [55]. According to similar studies, glass transmittance decreases by 6% in the winter and 10% in the summer [56].

## IV. Improve the productivity of the solar still

**4.1 Use of PCMs in solar stills**

A crucial consideration in the design of any solar thermal application is heat transport. The use of thermal energy storage media other than water to boost the distillation unit's performance has been a significant advancement in the field of solar distillation in recent years. The thermal energy storage medium aids in the storage of thermal energy so that it can be used later on for industrial, building heating and cooling applications, and solar distillation. The thermal energy can be stored as sensible heat, latent heat, or both [57]. When using a sensible heat storage system, energy is retrieved or stored by heating or cooling a liquid or solid without causing the material to change phases. Liquids such as water, sodium, heat transfer oil (Caloria HT43, Therminol T66, Servotherm), certain inorganic molten salt (Hitec), and solids such as rocks, pebbles, refractories (Magnesium oxide, Aluminum oxide, Silicon 7 oxide), and metal strips are examples of sensible energy storage materials. Additionally, a combination of solid and liquid heat storage media is employed. In this instance, the liquid fills the hollow spaces in the porous or granular material. Heat is removed from a material when it freezes and stored in the material during melting in a latent heat storage system. For example, organic materials (paraffin wax, capric acid), inorganic materials ($CaCl_2.6H_2O$,

$Na_2SO_4.10H_2O$, $Mg(NO_3)_2.6H2O$), and other compounds (ice, $NaNO_3$, NaOH, $LiCO_3/K_2CO_3$) can all be used as phase change materials (PCM). A PCM classification is provided in Fig. 2 [58].

The primary benefits of thermal energy storage are higher reliability, reduced operating costs, improved economics, and an increase in overall efficiency. But, wind energy and solar energy (during the wet season) aren't always accessible when you need them. Phase transition materials can be employed for energy storage as a solution to this issue. When executing the solar distillation experiment beneath the water basin, phase change materials are used to achieve latent heat. We discovered that both distillate and efficiency increase [59]. Thus, it is worthwhile to look into the potential application of phase change materials (PCMs) as a thermal energy storage medium in solar system applications.

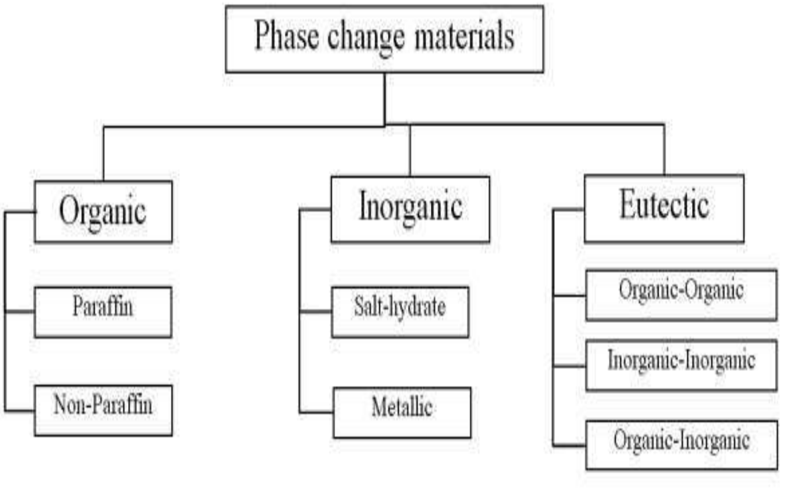


Fig.2: Classifications of PCMs [58]

**4.2 Reviews of SS with PCM**

Many solar stills have been categorized according to their design and level of modification. Numerous researchers used phase-change materials to study on various solar stills. The following is a recent overview of several phase change materials that are used in solar desalination systems from 2018 to 2023.

Khandagre et al. [60] used magnesium sulfate heptahydrate ($Mg_2SO_4.7H_2O$) as a phase change material (PCM) to experimentally improve the performance of solar stills. With the addition of 0.5, 0.75, and 1 kg of $Mg_2SO_4.7H_2O$, respectively, the daily productivity of 1400, 1420, and 1400 ml/m$^2$/day for the sun still (without PCM) and 1800, 1900, & 1960 ml/m$^2$/day for the still (with PCM) were reported. Overall thermal efficiency was measured to be 64% for the still with PCM and was 47% without PCM.

Cheng et al. [61] used shape-stabilized phase transition materials to simulate and experimentally assess the solar still's performance. The modified solar still's daily productivity was found to be 43.3% higher than of the traditional solar still without PCM.

Kabeel et al. [62] employed a theoretical investigation of the performance of several PCMs on solar stills. They discovered that the most cost-effective and productive PCMs for solar still applications are inorganic PCM capric-palmatic and organic PCM A48.They advise using PCMs with lower thicknesses because their thickness doesn't significantly affect production. Erfan Hedayati-Mehdiabadi et al. [63] examined the energy efficiency of a dual slope solar desalination system in Zahedan, Iran, during cold and hot weather by employing phase change material and PV/T collector. The production of pure water can be increased by raising the mass flow rate from.001 to.01 kg/s, according to their data. Days with colder temperatures have poorer energy effectiveness than days with warmer weather. Additionally, it was shown that adding up to 10 kg of saline water during the day increased production at night and decreased it during the day. In the hot temperature of Egypt's New Borg El-Arab, Mohamed S. Yousef and Hamdy Hassan [64] conducted an experimental analysis and comparison of the sun desalination performances for the following five situations. The examples include: standard solar still, still with PCM, fins in the shape of hollow cylindrical pin used in the desalination system with PCM, solar still basin with steel wool fibers and PCM, and still basin with just steel wool fibers. According to their findings, while overall output has grown well, the usage of PCM has a detrimental impact on fresh water productivity throughout the day. Additionally, compared to other scenarios, the cylindrical fins utilized in the PCM in still achieve very superior thermal performance. In the case of steel wool fibers and PCM in the basin of still, daytime freshwater production is increased by 14%, whereas nighttime output is actually decreased. A conjectural form for analyzing a still using an external solar collector and PCM of sodium thiosulfate pentahydrate was published by Mousa Abu-Arabi et al. [65] and was compared with experimental work. They discovered that employing large masses of PCM lowers productivity, whereas lowering total heat transmission from 10.4 $W/m^2.K$ to 2.6 $W/m^2.K$ increases productivity. Adding cooling water to the glass cover at a stream rate of 0.1 kg/s can help boost output.

An integrated construction was suggested by Ghorbani et al. [66] to provide hot and fresh water for Yazd residential complexes. The thermal energy storage system (TES) with PCM, flat plate solar collectors, and the unit of multi-stage desalination make up the construction. The productivity of fresh water and the production of hot water have improved, according to the data

PCM (tricosane) was employed by Mousa et al. [67] as an absorbent material in a solar still. During the day, they saw that fresh water productivity was inversely correlated with PCM mass. On the other hand, productivity at night was directly correlated with PCM mass. The solar still of glass-cooled with PCM of (sodium acetate trihydrate, sodium thiosulfate pentahydrate, and paraffin wax) connected to collector of flat plate was theoretically examined by Mousa Abu-Arabi et al. [68] investigations were conducted into the effects of uncontrolled factors like sun irradiation, temperature of ambient, and speed of wind, as well as controllable factors like circulation rate of hot water, mass of phase change material, and cooling water flow rate. Comparing a solar still with PCM to a traditional solar still, it was found that the productivity of fresh water was 2.3 times higher.

Essentially, as Fig. 6 illustrates, Abed et al. [69] built an experimental setup consisting of a standard still, a solar water heater, PCM power storage caps, a high-frequency ultrasonic vaporizer, PVs, a feeding water tank, a water reservoir, a water pump, and a control system. In Baghdad, Iraq, a glass cover of 0.004 m was installed as a transparent still cover at 35° inclination angle. More space is required for installation the larger the arrangement.

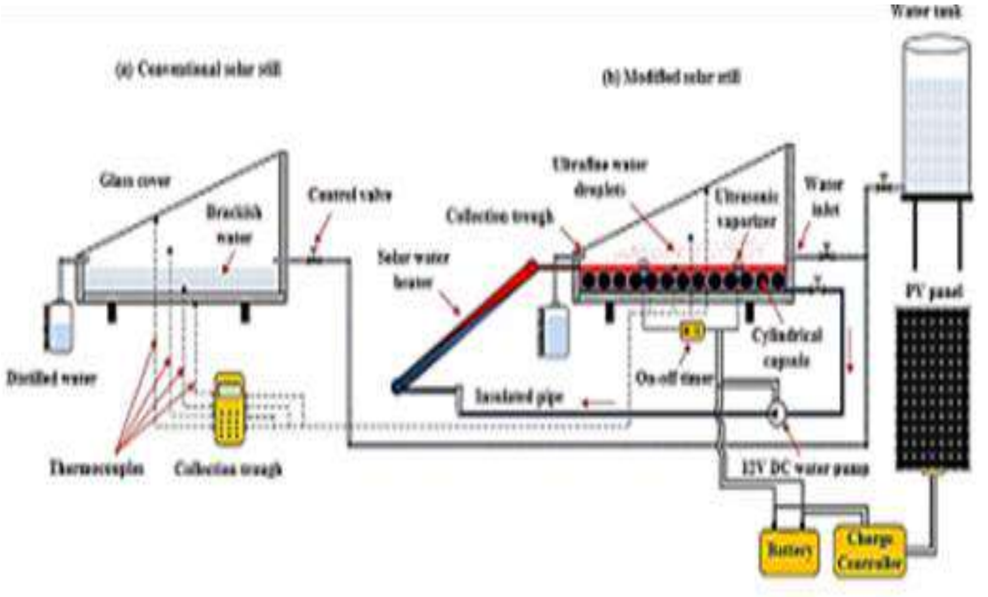


Fig. 6. Experimental Setup Layout (a): Conventional SS (b) Modified SS [17]

The effects of using three distinct absorber liners—a convex plate absorber, a stepped absorber, and an absorber covered in a corrugated sheet—have been investigated by Felemban et al. [7 in review] [70] Their output was examined and contrasted with that of a standard solar distiller. The dish distiller with the corrugated absorber, wicks, and energy storage material yielded higher results, increasing production by around 183% and improving thermal efficiency by 69.5 %.

Three still solar designs were modeled and their performances were compared by Abu-Arabi et al. [71]: the still of conventional type, the still with a flat plate collector, and still with PCM and collector. In their modeling, they used three different types of PCM. They examined a range of operational factors, including those that could be controlled, like the mass of PCM and the pace at which hot water circulates, and those that couldn't be controlled, including wind direction and solar radiation.

Mehdiabadi et al. [72] investigated the exergy performance of a photovoltaic-thermal collector and a double-slope solar still that was improved with PCM using numerical analysis. They stated that the addition of PCM increased the exergy efficiency of the module. The increases for July and December were 27% and 2%, respectively, indicating a greater summertime augmentation of energy.

Stepped double slope solar still experiments were conducted by Kulkarni et al. [73] and compared with conventional ones. After adding PCM, they observed improved productivity of water nearly 5 liters per day. Additionally, they stated the pH of distilled water is 6.95, which is closer to 7, while the pH of brackish water is 7.80.

## V. Conclusions

A few key details and observations of single slope solar stills, from theory to production model, have been presented in this article. Giving an overview of single slope solar stills, their operation, and potential improvements to boost their output constitute this paper's major contribution. PCM technique in stills were reviewed in this paper in order to increase its productivity. The review's conclusions can be used to develop workable policies and suggestions that will maximize the functionality, upkeep, and viability from an economic standpoint of solar stills. Anybody interested in installing solar still systems, including researchers, engineers, legislators, and individuals, can benefit from these instructions. This review helps to promote sustainable water purification technologies by using PCM and their implementation in areas facing water scarcity issues by deepening our understanding of single solar stills.

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