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Enhancing the solar still performance using different designs of absorber with heat storage materials and different wick materials: a review

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HIGHLIGHTS

- A summary of the many variables influencing the performance of different solar still designs is given
- Solar radiation is the aspect that most affects how well solar stills work
- A potential research agenda is presented for solar distillers

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ABSTRACT

Despite water covering more than two-thirds of the planet, improving potable water production technologies is a significant issue because of the increased demand for treated water. Solar desalination presents a simple, costless energy and friendly technology which utilizes solar energy and gives great incentive to decrease pollution effects produced by burning fossil fuels. In order to address the global drinking water shortage, particularly in rural and distant locations, this technique can be employed to give pure water to people using a solar still, which in many respects, is one of the most significant feasible uses of solar energy and perfect source of fresh water. However, due to the low productivity of conventional solar still, numerous experiments have been done to increase the daily output of solar stills by employing numerous active strategies to produce far more evaporation and condensation than a simple standard-type distiller. This work highlights the recent methods used for enhancing water productivity and their roles in augmentation productivity, performance, and thermal effectiveness of various solar distiller designs based on previous studies. Future suggestions based on identified research needs were made. This review is considered a reference guide to focus on the most efficient techniques.

1. Introduction

Fresh water is crucial for maintaining and supporting organisms and accomplishing industrial structures. Approximately 2.53% of the Earth's surface is covered by freshwater, whereas salt water makes up 96.5%. The earth receives much sunlight from the sun. The atmosphere reflects almost half of this. Sunlight is transmitted by the sun in vast amounts to the Earth. The atmosphere reflects almost half of this. The earth absorbs more solar energy in an hour than all of humanity does in a year. Saltwater from the oceans, seas, and saline groundwater makes up a large proportion, nearly 97% of the whole water on earth. Only 3% of the Earth's surface is covered by freshwater, which can be found in lakes, rivers, permafrost, glaciers, and ice caps. The remaining 0.007% is accessible surface freshwater. Humans require 4 to 5 liters of drinking water daily, which accounts for less than 1% of the total water on the planet. According to the Overall Population Outlook 2019, the world's population will exceed 7.7 billion. By 2030, it is anticipated to reach 8.5, 9.7 by 2050, and 11.2 billion by 2100. Unfortunately, the Earth's natural water cycle cannot make up for the annual deficit of about 4.2 trillion m^3 [1], as shown in Figure 1. A close relationship must be established between energy and water. As a result, it takes energy to gather, desalinate, and supply the water to users. Numerous plans and strategies have been used, including building dams and reservoirs, reusing wastewater, and desalinating seawater. However, there are several disadvantages to using dams and reservoirs, including the high initial cost and the fact that much land is used that could be used for industrial or residential activity. The absence of natural and conventional resources has led to a serious freshwater shortage that affects the entire world, especially in semi-arid and/or desert areas, demonstrating the significance of very well management systems, one widely used method is desalination technology used to meet the demands of freshwater production. Numerous problems with economic growth, population increase, and environmental degradation have been brought on by the demand for freshwater for various home, agricultural, and industrial uses [2].

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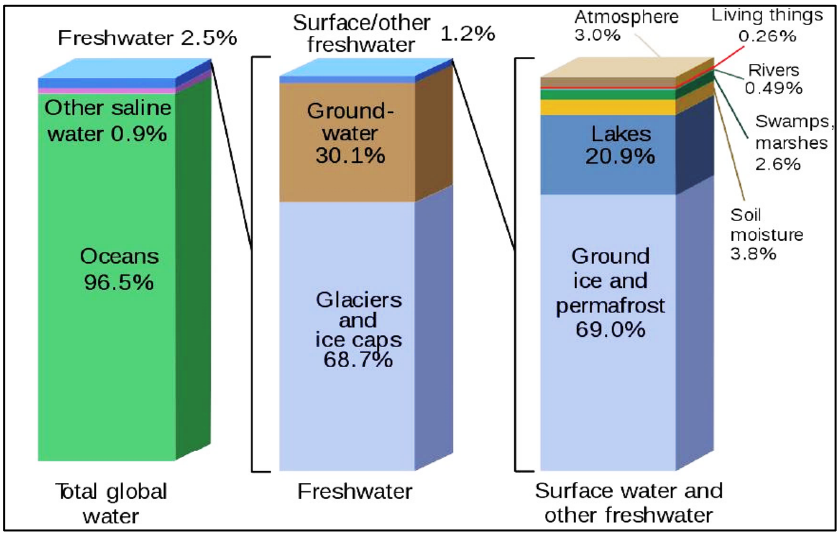


Figure 1: The distribution of water globally [1]

Because of the continuing loss of traditional fuel resources, there is fierce competition worldwide to acquire alternate energy sources. The sun is the most potential energy source. Solar thermal collectors can be used in various ways to invest in solar energy. They absorb solar radiation, convert it into thermal energy, and transport it to a working fluid [3]. Desalination is a practical method of producing drinkable water from salt water that uses solar energy to the main water supply network using three main methods: heat, electricity, and pressure. The operation is based on the characteristics of glass and other transparent materials (transmission, absorption, and reflection). There are two methods for achieving this: directly and indirectly. However, producing clean water for remote people's drinking and sanitary needs is difficult. The benefits of this approach are easy to design and construction, as well as cheap maintenance expenses. It is significant to note that solar thermal desalination procedures are economically feasible compared to other approaches [4,5], eco-friendly, and do not produce toxic byproducts. The present article was conducted to review the effect of several methods to enhance the freshwater yield, especially using phase change material (PCM), wick materials with different designs of the absorber and solar stills to increase evaporation area surface and other methods to increase the condensation rate, including external condenser which affects positively in increasing the amount of distilled water. The future study will address the combination of these techniques using an absorber surface floating on the surface of saline water with PCM and a wick material installed on it, as shown in Figure 2.

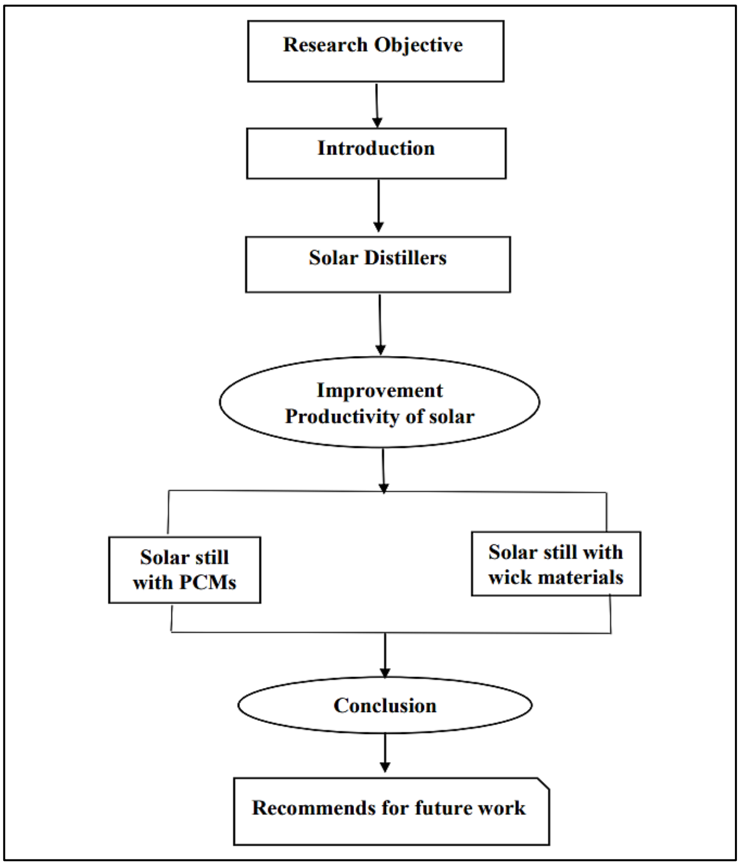


Figure 2: Flow chart for present work

2. Solar distiller

The most straightforward and easy-to-use desalination tool is the sun distiller, which consists of a seawater-filled black-painted basin surrounding a transparent cover that forms an airtight surface. Sunlight shines through the transparent cover, absorbed by the basin's black plate. As a result, the water inside the container becomes heated, which rises and evaporates inside the still because of its low density. Solar stills can be passive or active, depending on the heat source used to evaporate the water in the still:

- Passive Solar Still.
- Active Solar Still.

Using passive solar distillers, solar radiation is the only energy source to heat the water and create evaporation directly absorbed by the basin water. On the other hand, active solar still systems use the heat produced by external systems like solar ponds and collectors and waste heat from neighboring enterprises to boost water temperatures and increase production. Cooling this vapor to the dew point initiates condensation and produces clean water. This water flows down the cover by gravity and is collected in a graduated cylinder. As the basin water heats up and condenses on the underside of the glass, a significant quantity of heat from the still is lost through the glass. This heat loss reduces solar efficiency to 30–40% and water production to roughly 6 L/m^2day. Due to the low efficiency and productivity of distillers, much recent research has focused on improving the original design and developing new modifications or varieties of distillers [6-8]. The productivity of SS has been observed in numerous research and depends on several factors. First, uncontrollable variables like the intensity of solar radiation [9]. At atmospheric temperature, wind velocity cannot be tightly controlled [10]. Second, the design of still or design absorber surface, operating, and modification parameters such as insulation thickness, basin depth, glass cover material, tilt, and heat capacity [11], wick material [12], tracking [13], heat pipe [14,15], Nanofluids film cooling [16], photovoltaic panel and thermoelectric generator [17,18], phase change material [19], and external condenser [20], can be applied as a controlling factor to optimize SS performance. Solar stills are categorized according to their shapes as single slope [21], corrugated [22], tubular solar stills [23], convex [24], stepped [25], and pyramidal and triangular [26].

3. Different methods for improving the productivity of solar stills

Among various thermal energy materials (TESMs), phase change materials (PCMs) manage energy levels inside thermal systems by storing large amounts of energy when it is available and releasing it when needed by changing its physical state [27,28]. There are many types of PCM, among which paraffin wax is commonly used. PCM has a high latent heat of fusion that can store more energy, a high melting point of 40°C to 90°C, a high density, and a low price that reduces volume while still achieving excellent performance and pure water productivity [29]. According to previous studies, the distillation method has to be greatly improved to increase the system's output. In order to boost the solar still's output, it must increase the evaporation surface of the solar still by applying a new absorber design. The advantage of this review is to understand the role and impact of different methods and processes (plate in many different designs, PCM, wick material) on the productivity of fresh water to enable future researchers to find a pathway for the possibility of combination between many techniques.

3.1 Solar still with pcms as a thermal energy storage material (TESM)

One of the essential components in boosting the efficiency of solar stills is that all of the heat that the basin surface absorbs, such as sunlight, must be used without loss. For this purpose, using PCMs as thermal energy storage commonly stores energy for when the sun is bright and uses the stored energy at night to operate stills at lower ambient or inside basins temperatures.

Panchal and Shah [30], increased the efficiency of single-slope basin solar still and the yield of Solar still SS by increasing the still surface area; aluminum and galvanized iron floating plates are used in two solar stills, as shown in Figure 3. The accumulative productivity using the suspended aluminum plate in solar still, galvanized iron plate, and conventional SS is 3,212, 2,600, and 2,300, respectively. The suspended aluminum plate is obviously a useful material for improving solar still yield. Srivastava and Agrawal [31], improved the SS yield by floating multiple porous absorbers made of black jute fabric. The modified SS distillate output has an improvement in output by 68% on days with no clouds and 35% on days with some clouds. This is due to the absorber's great sensitivity to solar intensity; higher temperatures could not be maintained because of the rapid drop in surface temperature caused by cloud shading. The conventional still suffered less damage in comparison. After sunset, there is an appreciable amount of output in the modified still since the absorber is continuously supplied with warm basin water that is properly insulated (under THERMOCOL insulation). Dual Reflector Boosted Solar Radiation provides 79% gain over CSS because most radiation is reflected onto the still here. Compared to single-plane reflectors, where most of the sun's rays are reflected away from the still. Younes et al. [32], have improved the productivity of SS by using corrugated CWSS and half-barrel BWSS instead of flat absorbers. Also, a combination of copper oxide (CUO) nanoparticles with phase change material (PCM) was added in gaps beneath the wick SS. Comparison with the traditional solar still (CSS) measurements show 134% and 124% daily yield increases in CWSS and BWSS. It can be found that the CWSS shows better performance when compared with CSS, FWSS, and BWSS. The maximum PCM and water temperatures were reached at about 12:30, and they began to fall again due to the solar intensity. PCM first absorbs power from the still absorber. Nehar et al.[33], accelerated the pace of condensation and improved the performance of SS. Two separate triangular-channeled modified absorber plates and rectangular channel (RC) with external copper capacitors (ECC) were used. Without external copper capacitors (ECC), traditional solar still (SS), triangular-channeled, and rectangular channel absorber had average productivity of 1.04, 1.39, and 1.28 L/m^2, respectively. Adding ECC to the modified SS increased the average productivity of SS with triangular-channeled and rectangular channels by 23.6% and 19.3%, respectively. A cost analysis of the improved SS is introduced to examine the total economic viability of the solar distiller unit. Hence, the conventional SS had a CPL value of 0.028 0.019 $/L/m^2 compared to 0.019 $/L/m^2 when using a different pattern absorber.

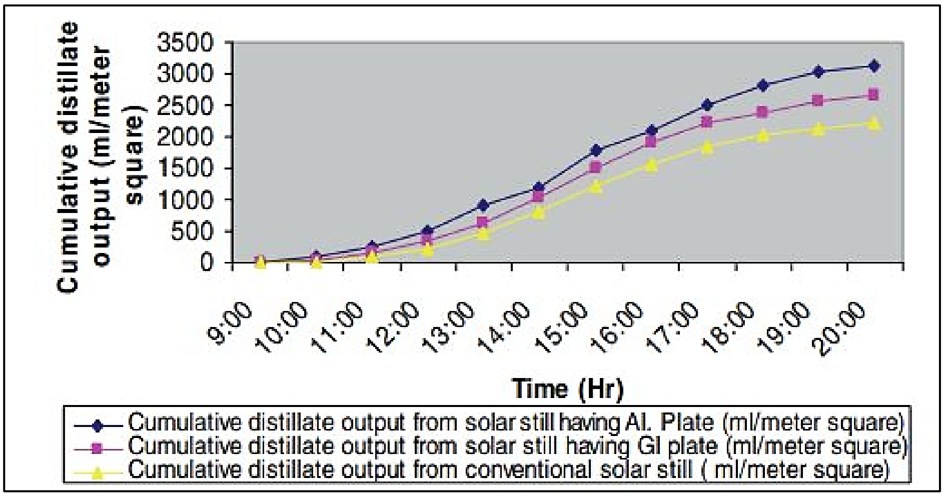


Figure 3: Development of the modified still [30]

Matrawy et al. [34] carried out a study to examine the performance of SS by forming a corrugated evaporation surface using a porous media (black coat) that absorbs and saturates by capillary action. The outcome is the proposed wick-type solar still achieves a productivity improvement of about 34% compared to a CSS due to the higher temperature of the corrugated wick-type surface at the same operating conditions. It was determined that the corrugated porous surface of the corrugated solar still provided almost 75% of the overall production. Kabeel and Abdelgaied [35], improved the efficiency of an adapted pyramidal solar still by using a 25 mm thick graphite absorber and a cooling glass cover to accelerate the pace at which water vapor condenses. The research found the initial cumulative yields of MPSS ranged from 105.9% to 107.7% versus traditional pyramid stills. This is due to the modified pyramid-shaped still MPSS having larger temperature difference between the basin and glass surface than the traditional still, and the efficiency of the modified pyramid-shaped still MPSS when using the graphite absorber plate with cooling the glass cover enhanced productivity by 97.2-98.9% as compared to a traditional pyramid-shaped still and the cost of distillate water produced is reduced by 13.6%.

Kaviti et al. [36], conducted experimental trials on a twin SS with aluminum 18 truncated-conical fins carried out at water depths of 10 mm, 20 mm, and 30 mm. The overall yield of the solar still with truncated-conical fins is 830 ml at 10 mm, 640 ml at 20 mm, and 555 ml at 30 mm depth which is maximum because the truncated conic fins absorb more solar radiation and provide water more heat. The conventional still is 795 ml at 10 mm, 505 ml at 20 mm, and 30 mm is 430 ml. The maximum energy efficiencies are 54.11%, 45.52%, and 33.12% at three water levels, respectively. Exergy efficiencies are increased over the traditional still by 6.20%,10.52%, and 14.51% at 1,2,3 cm. Kabeel et al. [37], conducted experimental studies in a pyramid SS with hollow circular fins with and without paraffin wax melting at 56°C beneath the absorber. Less energy is lost from the basin's bottom side, increasing energy storage. Outcomes show an efficiency of 32.2% for CPSS, 45.9% for modified Pyramid Solar Still without PCM (MPSS), and solar Still 64.3% with PCM under Egyptian weather conditions. The absorber temperature when using hollow circular fins is higher than the conventional absorber surface due to the presence of fins. Its effects on the water temperature. The cost of producing pure water using traditional solar pyramid stills and solar pyramid stills with hollow circular was about 0.0227 and 0.025 dollars per liter, respectively. However, using the PCM with hollow circular fins dropped the cost to 0.019 $/liter. Alaian et al. [38], performed experimental investigations of solar still with wick pin fins supported vertically at the still basin using steel wires to increase the still productivity and efficiency. The outcomes observed that the still efficiency reached about 55% due to the effect of the pin-fin absorbent. Productivity improved by approximately 23%. Sonker et al. [39], performed experimental and numerical simulations of solar still. PCMs kept in copper cylinders, including paraffin wax, stearic acid, and lauric acid at different levels of water depth (1–5 cm) as shown in Figure 4. It can also be observed that maximum output has been obtained at 1 cm for all three PCMs. This was because as the water depth increases, the water in the basin increases, leading to lower water temperature; the overall distillate increased by 1202, 1015, and 930 ml/m^2. Kabeel et al. [40], conducted experimental research on two changes to increase solar still production. These changes are:

1) effect of using PCM (paraffin wax) in tabular solar still (TSS) with nanoparticles.
2) TSS with Nano-PCM (graphite nanoparticles).

Paraffin wax productivity is 2.59 kg/m^2, 3.35 kg/m^2, and 5.62 kg/m^2 for the conventional still, still with PCM, and still with Nano-enhanced with PCM. Because the conductivity of NPCM is improved by 52% compared to PCM with no nanoparticles, the NPCM's better capacity to transmit heat, the hourly yield increases both in the sun's light and at sunset so that the productivity of the third change was raised around 20% compared to TSS with PCM. Hedayati et al. [41] investigated double-slope solar stills' exergy performance (DSSS) improved with PCM and photovoltaic heat collectors. They reported an increase in the module's exergy efficiency by adding PCM. On July 6^{th,} the exergy efficiency increased by 45% than December 23rd due to higher solar radiation intensity and ambient temperature in July.

The increase in mass flow rate improved the exergy efficiency when more than one collector was used. The improvement rate was 27% and 2%, respectively. Abu-Arabi et al. [42], used three types of PCM (sodium acetate trihydrate, sodium thiosulfate pentahydrate, and paraffin wax) with solar collectors to enhance its performance over a conventional one. Two sources heated the PCM; the first was fed straight from the SS basin, while the second utilized hot water from a solar collector circulating through a heat exchanger submerged in a PCM. Humidity control is a common issue in constructed settings in subtropical climates because it is critical to maintaining pleasant and healthy conditions within restricted airspace. Eidan et al. [43], concluded that when PCM mass is high, the yields are high production and efficiency until the PCM mass reaches 20 kg, the efficiencies achieved were 52, 54.6 and 52.6% for STP, SAT, and PWAX PCM materials, respectively, and the productivities were 12.8, 15.5 and 13.4 ml/min. When SAT is used as PCM, the highest production and efficiency are achieved because it has a high latent heat value (265 kJ/kg) with a melting point of 58°C. Aboud et al. [44] examined how temperature and humidity affect the quantity of water created by humid air. Findings show that when evaporation increases, the amount of moisture in the air rises, the relative humidity reaches 100%, the humidity coefficient rises between 25% and 65%, and the water vapor condenses and produces dew. Bhargva et al. [45], improved the productivity of conventional solar still by adding rectangular aluminium fins and a bamboo cotton wick to the still basin as shown in Figure 5. The daily productivity of the solar still improved by about 19% when bamboo cotton wick was spread over the rectangular fins in the still basin. When compared to CSS, MSS has an overall productivity and thermal efficiency that are greater by 19% and 3.5%, respectively. Karthikeyan and Natarajan [46], conducted an experiment to examine the effectiveness of solar water distillation at various basin water thicknesses with a spinning hollow cylinder and flat plate solar collector. Results showed that modified solar water distillation yielded an increase of 188% compared to conventional solar water distillation at the same basin water thickness. The maximum production rate increase for a modified solar water distiller connected to a solar water heater automatically varies in speed according to the intensity of solar radiation (310%).

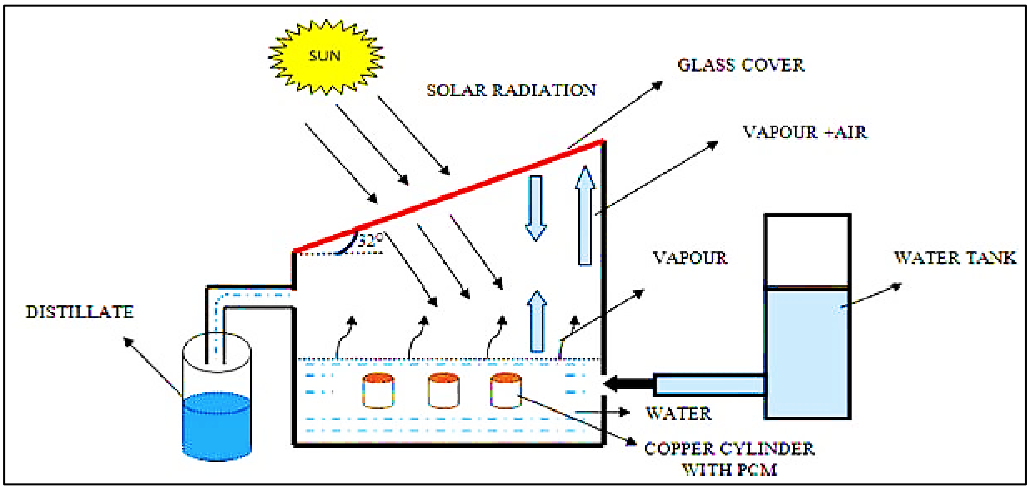


Figure 4: Modified solar still [39]

Figure 5: Photograph of modified still and conventional still [45]

Jalil et al. [47], conducted an experimental to cool a heat sink using Nano particle addition. When phase change material (paraffin wax) of a thickness of 30 and 60 mm under different power in (11 W, 13 W, and 15 W) and air velocities (3.4 m/s, 2.5 m/s, and 1.5 m/s). The heat sink with PCM can lower temperatures by up to 18°C. Abbas et. al [48] conducted an experiment to insulate a hollow brick wall using PCM capsules inserted into it as insulation materials. This study conducted the true impact of PCM capsules with melting point 43°C embedded in the gaps between hollow bricks constituting the Iraqi wall. Compared to the wall without PCM, using the PCM capsules causes the south wall's inner surface (TW) of the PCM room to drop by roughly 4.7°C. Salih et al. [49], an experimental conducted on double-pass solar air heater using multiple types of PCM. Using rectangular capsules filled with paraffin wax for thermal process in solar air heater at (0.6, 0.9, 1.2, 1.5, and 1.8) kg/min of variable airflow rates. When airflow rate increases, the melting phase takes longer and lowers the paraffin's melting temperature. For different sun intensities of 825, 725, and 625 W/m^2 at the 0.6 kg/min air flow, the period of heater's discharging was three hours with the air temperature between 17.95-3℃, at two hours 14-3℃, and 1.25 hours with 11-2.5℃. Abbas et al. [50] used PCM as a thermal insulation material of Hollow Brick Walls. When PCM is used in a south wall will result in a1-hour time lag increase, a 2.7℃ drop in room temperature, and an hour rise in the time lag when compared to not treating a wall (NTW).

Abbas et al. [51] studied a numerical investigation by using PCM with and without addition of Nano which was used to fill the cylinder cavities as insulation material. The finding revealed that the surface temperature reduced to 4.7°C with pure PCM and 4.7°C without Nano. Jalil and Salih [52] investigated the optimum thickness of paraffin wax insulator filling a double-glazed window. The maximum thickness of wax must be filled in the window to maintain the temperature at specified range was 2 cm in May, 3 cm in June, 3.5 cm in July, 3.5 cm in August, September 3 cm, and 1.5 cm in October. Elashmawy et al. [53] developed a new design of 12 aluminum tubes filled with PCM (paraffin wax) with copper rods to increase the properties installed inside a tubular solar still with a parabolic solar concentrator PTC. Results demonstrate a significant improvement in device performance and output in freshwater at an approximately low production cost. The productivity and effectiveness of the manufactured device were increased by using PCM tubes by 40.51% and 38.25%, respectively, and decreased the cost of producing fresh water by 21.8%. Srinivas and Avssks [54] analyzed the performance of SS using pyramids solar still. The system is operated at different water depths, 5 cm, and 10 cm, along with paraffin wax material and preheated water. The hourly productivity is higher in the case of solar still with PCM during sunny days. Results observed the still efficiency, with PCM at a 10 cm depth of water PCM is 45.99% and 54.76% for a 5cm depth. There is a 75% increase in the efficiency of the still when operated with PCM at a 5 cm depth of water. The distillate yield of the still with PCM is 2.56 liters/m^2 /day means that the temperature gradient between the basin and the glass cover is high as shown in Figure 6. Alawee et al. [55] studied a comprehensive study to analyze the performance of a double-slope solar still with an elevated basin. Solar still with an elevated basin was performed and achieved excellent results. The average increase in freshwater production from EBSS (Elevated Basin Solar Still) was 36.7% compared to CSS. Kabeel et al. [56], developed an experimental study to improve the Performance of double Slope Solar Still. Used double slope solar still with collector solar water heater and gravel as a storage medium. When the solar still with an internal reflector was integrated, the findings revealed an 18.5% increase in distillate water. Furthermore, productivity increases by 48% when gravel and a collector solar water heater are used.

Kabeel et al. [57], studied an experimental comparison study about the solar still with internal reflectors, solar still with different thermal heat storage (THS), and solar still with composite black gravel CM. The solar still water yield improved by 37.55% when using the composite black gravel-phase change material (CM) rather than phase change material. This is due to CM's high heat storage capacity compared to PCM, and CM has a larger heat discharge to the water, so it can heat the salty water more than PCM, increments the water evaporation rate after sunset, which leads to an increment in producing water. The energy and exergy efficiency improvement was about 38% and 37%, respectively. Compared to solar still without PCM, the water cost needed to produce 1 L with PCM was about 0.0014 US$/m^2, with a reduction of about 27%. Sharshir et al. [58] Improved the solar still performance by using a V-corrugated basin instead of a flat basin, wick material, and comparing the effect of two different PCM as latent and compared with traditional one in the same weather conditions. Results showed increased productivity of four cases by ratios of 11%, 25.7%, 34.1 %, and 39.6%, respectively. It may be noted that the fourth case showed the best water productivity and thermal performance. It had daily productivity of 4737.5 mL/m^2 and 45 % thermal efficiency. Furthermore, the thermal performance in terms of thermal and exergy efficiencies improved by 39.75% and 44.04%, whereas the average total heat transfer coefficient increased by 5.5%. Moreover, the freshwater price was 0.0137 $/L, likewise a 17.5% cost reduction. Dhivagar et al. [59] used conch shell biomaterial as an energy storage material that stores energy during the daytime and releases it at nighttime. Also, the porous surface of the conch shells acts like a porous absorber and absorbs a large amount of solar radiation, which leads to increasing the water temperature. The findings demonstrated that solar stills using conch shells as an energy storage biomaterial and porous media were 10.8% more productive overall than conventional solar stills (CSS). The energy and exergy efficiency of CSSS exceeded CSS by 10.3%. Additionally, modified solar stills reduced CO_2 emissions and CPL by around 11.1% and 10.9% less than traditional ones.

Jahanpanah et al. [60] studied the effect of using low-temperature PCM on the productivity of SS by using a commercial salt hydrate low-temperature PCM with a melting point of 28°C and latent heat of fusion of 225 kJ/kg. Results showed that PCM addition could significantly enhance the device’s overall performance by storing the solar heat during sunshine hours and releasing it during hours with lower and zero solar radiation. Adding 3 kg and 6 kg of PCM still enhanced productivity by 8% and 30.3%. The conclusion showed that enchantment by the addition of PCM was nonlinear. Therefore, doubling the PCM amount increased the overall productivity more than twice while increasing the desalination efficiency from 28.13% to 36.42%. The results show that low-temperature PCMs could efficiently improve the solar stills’ performance. Gholizadeha and Farzi [61] investigated the effect of placing sand within the basin of a simple basin-type solar still on its performance.

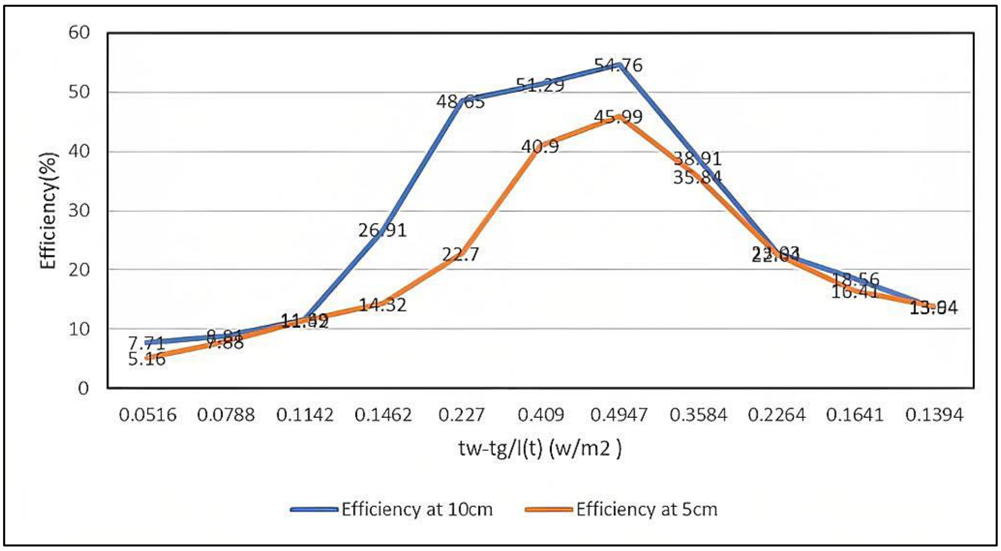


Figure 6: Comparison of Efficiency at 10cm and 5cm water depth [54]

The results showed that the presence of sand within the basin of the still increased its water productivity and thermal efficiency by 21.16% as shown in Figure 7. Rasheed [62], aimed to improve the performance of SS and calculate the productivity of the solar still in Babylon-Iraqi weathers by using the principle of the thermal and low-pressure vessels leading to a change in latent heat and sensible heat. A possible outcome is to provide a suitable combination to get a better yield of drinking water from saline water. A maximum distilled yield is 1.5 to 2.2 L/day is obtained with a 0.54 m^2 area. So, implementing PCM reduces the water temperature compared to desalination without PCM. The overall output will be more compared to desalination without PCM. Jaber et al. [63], improved the performance of double slope solar still by increasing the evaporation rate of the system using a parabolic trough collector integrated into a heat exchanger tube submerged in a wax basin coupled with a solar still. So, the temperatures and productivity of sun stills with parabolic trough collectors are higher than those without solar stills. The productivity output of solar still without PTC was (3620 to 3380) ml/day, and the solar still tracks PTC (4970 and 4800) ml/day, respectively. This means that the total output of potable water from the solar still with tracked PTC is higher than that of potable water from the solar still without PTC. PCM is the faster method to induce condensation within the solar still. It kept hot despite the ambient temperature falling; PCM began to release latent heat into the still basin water as sunset approached, which increased productivity.

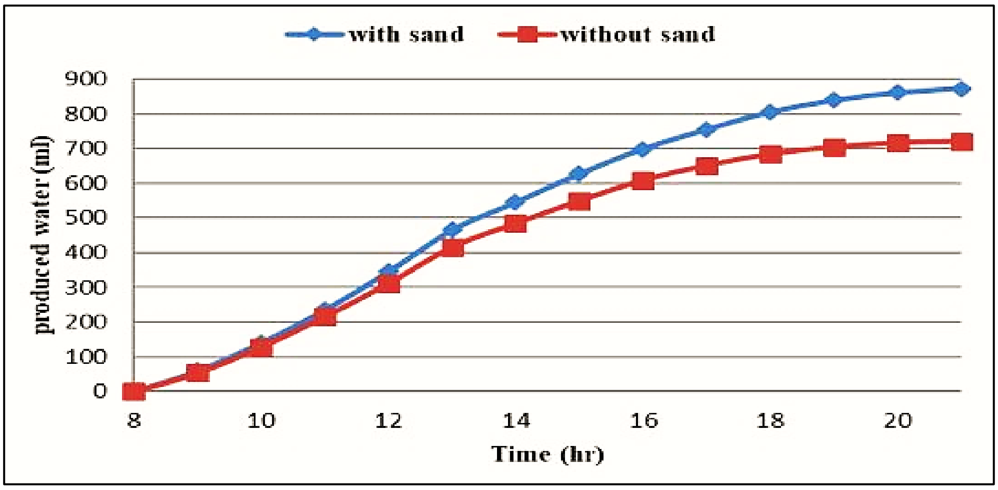


Figure 7: Cumulative water production of the stills [61]

Toosi et al. [64], improved the stepped solar still to increase productivity by adding PCM chambers fixed to the stepped solar still. Also, constructed external condenser has been made to see how it affects the operation of the stepped solar still. The outcomes from four cases—Case I, a single stepped solar still (SSSS); Case II, a stepped solar still with an external condenser; Case III, a stepped solar still with PCM; and Case IV, a stepped solar still with an external condenser and PCM. Single-stepped solar had a 28.21% efficiency. According to the findings, Case II, III, and IV all had higher productivity rates than Case I, increasing by 26%, 43%, and 104%, respectively. The comparison of four different experimental instances shows how well a PCM and external condenser work together in stepped solar stills.

Saeed et al. [65], improved the thermal conductivity of paraffin wax. Most people use paraffin wax (PCM) using Nanoparticles (Al_2O_3). According to the results, a kilogram of PCM was the appropriate amount of augmentation. So, using 3% of Al_2O_3 nanoparticles dispersed in 1 kg of paraffin wax offers the chance to roughly double the daily productivity of a single slope solar panel already in use. When solar radiation diminishes, the PCM or NPCM layer acts as a heat storage layer, extending the solar still's working period. Namshad et al. [66], presented an experimental investigation and mathematical modeling of inverted V-type solar still integrated with drip system as shown in Figure 8 (a,b). The mean standard deviations between theoretical and experimental values are less than 7% (temperature of rippled wick), 8% (temperature of glass in rippled system), 11% (temperature of flat wick), and 7% (temperature of glass in flat system), an average for the working hours of the day. The output from flat system and rippled system was found to be around 7.5 kg/day and 7.11 kg/day, respectively. Sebastian and Thomas [67], experimentally investigated a new floating absorber of three layers. The absorber was made of three layers of CuGECFC. The first layer was a plasmatic copper-coated spectral selective sheet. The last layer was carbon foam. The middle layer was cotton fabric wrapped around the Carbon foam. The efficiency of the three-layer floating absorber still was 88.6% as compared with an aluminum floating absorber. to evaluate relative diurnal performance. Although the three-layer floating absorber-based still's improved evaporation potential, its productivity and daily still efficiency was negatively impacted by a large increase in vapor space temperature of up to three times. High vapor space temperature resulted in a 14.7% increase in water production costs. Yousef et al. [68], improved solar still performance using hollow cylindrical pin fins embedded in PCM. The test was carried out on three cases: conventional solar still, solar still with PCM, and solar still with pin fins heat sink embedded in the PCM. The results revealed that PCM negatively affects daytime productivity by 3%, with an increment in overall productivity by 46% compared to the solar still with PCM. The third case achieved the best performance compared to CSS. Solar still with pin fins heat sink is higher than CSS and SS with PCM by 17% and 7%. Using PCM approximately extends productivity by 5-15 h after sunset.

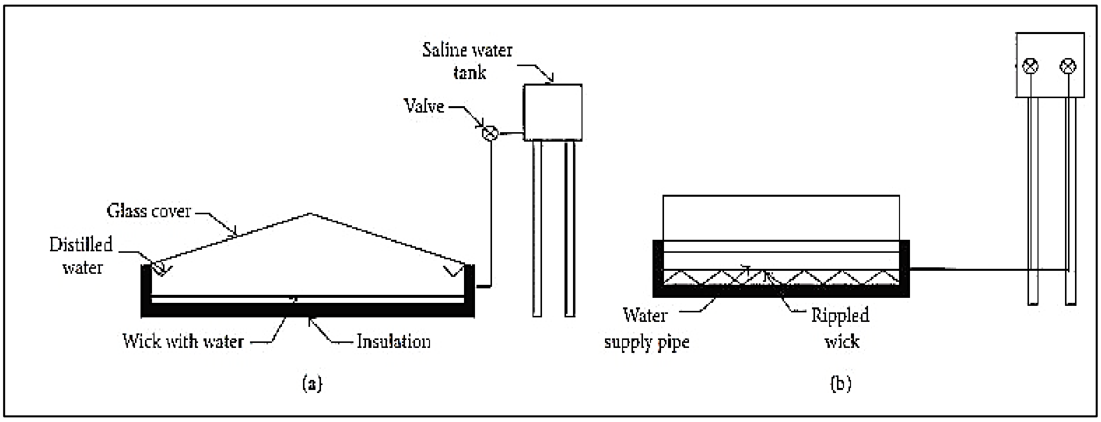


Figure 8: a) Cross-sectional view of the still (front view), b) Cross-sectional view of still (side view) [66]

3.2 Solar still with wick materials to increase evaporation rate

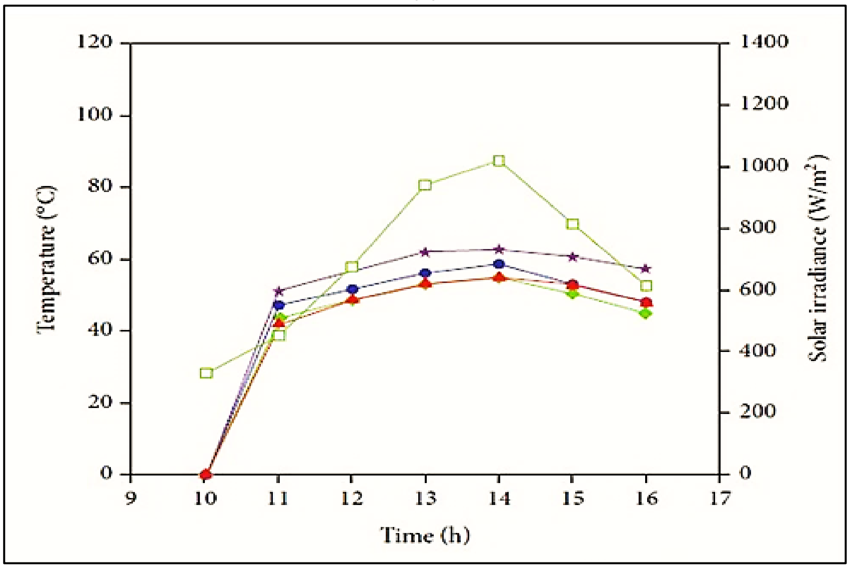
One of the effective modifications to improve the evaporation process by increase the area exposed to solar radiation [69]. So, the use of black porous wicks made of rubber, jute, cotton, metal strips, pin fin wicks, stone, and sponges has an important effect on enlarging the surface area of free water and decreasing the volumetric heat capacity of still and the probability of vapor molecules colliding because of the random motion of vapor particles increased as the rate of evaporation increased. At the inner side of the glass cover, vapor particles were accumulated. The distillation yield is increased because of the temperature difference between the vapor and the glass. Thermal conductivity, capillary rise, porosity, water repellency, wick heat transfer coefficient, and water absorption determine the wick's effectiveness. Feed water steadily runs through the wick, absorbs solar energy, evaporates, and collects on the glass's interior surface [70]. Wick Solar Still has some obstacles as well. The first major issue is core material degradation and pore blockage due to salt buildup. It is challenging to precisely regulate the brine flow to prevent dry areas on the wick's surface [71]. Numerous research studies were developed to select the optimum option for ensuring the still's high performance [72]. Jute cloth was the most popular natural material since it's affordable and wide accessibility and used to achieve the system's high evaporation surface area with a cumulative distillation yield 62% higher than that of solar stills [73 -75], in numerous research projects, charcoal carbon fabric has been used as a heat-absorbing material. Therefore, Wick-type solar distillers can be more efficient by choosing appropriate wick materials and studying other distiller design modifications. The following research was carried out to ascertain the effect of using various wick materials on the performance of all types of solar stills:

Increasing heat transfer surface area and the turbulence inside tubes or channels using corrugated or finned surface is one of the more efficient ways to increase the convection heat transfer rate [76], 7-moveable absorber plates [77], and wavy absorbent [78]. For example, Abdullah et al. [79], investigated the effect of a new configuration absorber (corrugated) in tray solar still with or without PCM (PCM+ copper dioxide to increase evaporative surface), adding a wick to expose a small amount of water at the evaporative surface to solar radiation. Phase Change materials (PCMs) can be utilized to lower heat loss rates since they can store energy during solar radiation peaks and release it at night when the sun isn't shining. Conventional solar still produced freshwater yields that were 57% and 87% higher than CSS, respectively. When using an electric stove, productivity also increased by 150%. The corrugated trays still (CTSS) employs electric heaters to increase the temperature of the water inside, which favorably influences the evaporation of the trays' solar still. These electric heaters were powered by a photovoltaic (PV) panel system's energy. Moreover, the overall water yield of corrugated tray solar stills CTSS was improved by 180%, PCM combined with copper oxide, and electric heaters compared to CSS. Suneesh et al. [80], carried an experiments for inclined wick solar still (IWSS) receiving warm water, is utilized to spread the water on the glass cover using a thin layer of cotton gauze for cooling reasons. After that, the water is gathered and returned to the hot water tank. In modified stills with and without a cotton gauze layer, the production of purified water was measured at 5.6 and 6.3 l/m^2. Under the ideal environmental circumstances, thermal efficiency was recorded at 60% and reached 68%. Kabeel [81] studied a concave wick still. Concave designs have less shadowing than traditional ones because all sides are glass. The still's center had a saltwater basin with a depth of 10 cm, while the outside had a depth of 30 cm. Results revealed an increase in surface areas for evaporation and absorption. Each day, the average yield of the concave wick solar system was still 4.1 l/m^2. Calculations showed that the greatest immediate efficiency was 45%, and the average thermal efficiency was 30%. Additionally, afternoon tests showed that the maximum pure water per hour was 0.5 L/h^2. The anticipated price of 1 l of distillate for this solar still was 0.065 $. Modi and Modi [82], conducted experiments to boost single-slope dual-basin solar stills' production at various saline levels. The studies were conducted under the environment of Valsad, Gujarat (20.61°N, 72.91°E), India, at the two water depths of 0.01 m and 0.02 m. various wick materials were used, including jute fabric and black cotton fabric in the shape of small piles. The yield from the still with the small pile of jute cloth increased by 18.03% and 21.46%. It is concluded when compared to a still with a small pile of black cotton cloth at depths of 0.01 and 0.02 m, respectively. When compared to the still with the black cotton cloth small pile, it was found that the still with the small jute cloth pile produced more material overall. Saravanan and Murugan [83], conducted experiments in a square pyramid still (SPSS), various vertical wick materials (including woolen fabric, terry cotton, polyester, and jute cloth) are used (SPSS). Results showed that productivity was higher in basins with water depths of 2 cm than in those with 3, 4, 5, and 6 cm, respectively, by 23.1%, 14.4%, 31.3%, and 39.6%. The capillary action of the wick material increases the rate of evaporation. Experimental results also demonstrated that SPSS productivity with woolen fabrics was 9.4%, 20.9%, and 33.1% higher than jute, terry, cotton, and polyester.

Sharshir et al. [84] proposed a linen wick (LW) containing carbon black nanoparticles (CBN) to improve double-stepped solar still's thermal and financial analysis (SDSSS). As a result, conventional solar still (CSS) was found to be about 2.4, 0.25 l/m^2, and SDSSS delivered 2.92, 0.38 l/m^2 throughout the day and at night, but adding LW to SDSSS increases productivity to 3.26, 0.55l/m^2 for day and night. The daytime and nighttime productivity in the freshwater of SDSSS containing carbon black nanoparticles (CB) was about 3.55 and 0.6 l/m^2, respectively. In other words, the cumulative freshwater productivity was 45.4% higher for the SDSSS than for the TSS. In contrast, the daytime and nighttime productivity of SDSSS combined with LW and CBN yielded the highest yields of about 4.46 l/m^2 and 0.9 l/m^2 throughout the day and at night. Economic analysis showed that conventional SDSSS, SDSSS with LWs, SDSSS with CBNs, and SDSSS with LWs and CBNs all had total costs per liter of produced freshwater that were cheaper than TSS by 13.73, 19.91, 23.83, and 47.22%, respectively. Sharshir et al. [85] improved the efficiency of the inclined wick solar still using new wick metal chip pads with various basin metals (aluminum, copper, and steel. The results show that employing aluminum and copper basin stills increases yield by 34.23% and 54.26%, respectively, versus traditional inclined solar stills. Using steel, aluminum, and copper, respectively, with wick metal chip pads between two layers of wicks, boosted daily production by 27.76%, 41.54%, and 65.3%. With a copper basin and a novel wick-copper chips pad, a modified IWSS achieved the highest efficiency of 60.98%. While the conventional inclined wick solar still CIWSS with steel basin has a thermal efficiency of 37%. COMSOL Multiphysics, a finite element program, was used to do a numerical simulation with actual weather conditions. Sharshir et al. [86] carried experiments to increase surface area, sensible heat storage capacity, and enhance the efficiency of traditional solar stills, 100 cotton bags filled with sand are uniformly arranged vertically across the basin area. Modified solar still (MSS) cumulative distillation yields for weights of 30 kg and 40 kg of basin water were greater than 28.56% and 30.99%, respectively. Compared to conventional solar still (CSS), overall efficiency is up 31.31% at 40 kg of basin water and 28.96% at 30 kg. It is possible to deduce that supplementing the sandbags with conventional stills significantly enhances the distillate yield, efficiency, and productivity. Singh et al. [87] presented the performance of a solar still having novel octagonal-pyramid shape with a single slope solar still. The experiments also evaluated by varying the depth of saline water inside the basin and angle of inclination of glass cover. It is observed that the optimum condition for high distillation is obtained when depth of water inside the basin is 5 cm with angle of inclination of glass cover which is 30°. Results showed that underground borewell water provides high distillation due to low density. Furthermore, the performance of the octagonal-pyramid solar still is enhanced by adding different latent heat and sensible heat materials in the octagonal-pyramid solar still. Hence, the addition of brick to the octagonal-pyramid still yields the highest productivity compared to incorporation of paraffin wax. Hence, it can be concluded that the octagonal design of the solar still has shown an increased productivity when compared to a single slope solar still (conventional still) under all the conditions as shown in Figure 9 (a,b).

Agrawal and Rana [88], carried out theoretical as well as experimental research to enhance distillate performance by using several floating wicks in the shape of V (black jute cloth) wrapped with pieces of THERMOCOL (insulation material). The modified solar still (MSS) increases distillate production by approximately 26% over conventional solar stills, with daily efficiencies of 56.62% in the summer and 47.75% in the winter, the maximum daily productivity for sunny days is around 6.20 kg/m^2 as shown in Figure 10. Essa and Abdullah [89], used tubular solar stills with rotating drums as a modified technique for examining how the performance of tubular stills is affected by the usage of closed and open drums with and without a wick at various drum rotation speeds. As a result, the yield of the tubular drum at 0.1 rpm was 121% for the closed drum and 136% for the open drum, and at 0.05 rpm with wick, the productivity was 140% for the closed drum and 175% for the open drum. On the other hand, Tubular drums' thermal and exergy efficiency was 56.4% and 3.45% for closed drums and 61% and 3.6% for open drums.

(a)



(b)

Figure 9: (a) Photograph of experimental setup of the octagonalpyramid solar still, (b) Variation of basin water temperature, glass temperature, and solar radiation of the conventional and octagonal-pyramid solar still [87]

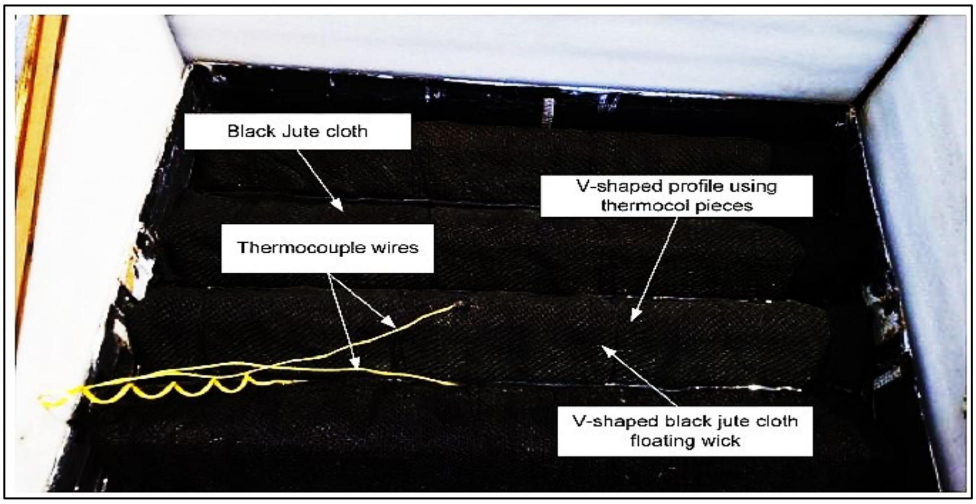


Figure 10: Diagram of a rotating wick solar still solar still [88]

Ahmed and Ibrahim [90], developed an experimental study of single-slop solar stills with different wick materials (black velvet fabric, thick sponge, jute fabric, black cotton fabric, and black sheet). The test apparatus includes three conventional SS units, the first for comparison with the conventional type. The second was also traditional, but in addition to spreading a wick material sheet and completely submerging it in the basin. The last still was an improved design based on a suspended wire mesh (12 mesh wire mesh) to be immersed slightly in saline basin water mesh wires to increase the area of absorption and evaporation. Superior performance achieved by lightweight black cotton fabric improves daily distilled. The following two solar stills outperform conventional stills by approximately 26.9% and 20.8%, respectively. Rajan et al. [91], proposed a novel design of low cost maintenance free hemispherical solar still for desalination in remote areas with low literacy rate. Low Density Polyethylene (LDPE) sheet of 400 micron thickness replaces expensive and difficult to maintain glass and acrylic top cover to produce distilled water. A separate arrangement is included for analyzing the wick effect in still. Distillate yield was typically found to be 2.2 liters/m^2, much less than 3.5 liters/m^2 but robustness of design and the low cost makes it more appropriate for remote areas. 22.85% efficiency is achieved from this still. Seralathan et al. [92], presented the performance and exergy investigations on an inclined solar still with baffle arrangements as shown in Figure 11 (a,b) to improve freshwater yield for two different mass flow rates (mf1 = 0.0833 kg/min and mf 2 = 0.166 kg/min). Highest accumulated freshwater yield is achieved as 2.908 kg/m^2 day during the month of May for mf1 = 0.0833 kg/min. The accumulated freshwater yield improved by 4.23% in comparison with inclined solar still designs. Moreover, the yield is better by 3.49%–61.56% in comparison with various solar still design. The exergy analysis for mf1 = 0.0833 kg/min shows a maximum hourly exergy efficiency of 6.82%.

Sharshir et al. [93], used nanotechnology (nanoparticles Fe_3O_4 and copper dioxide CUO) near the surface's top, and cotton-hung pads with thread ends were immersed in seawater to increase the effectiveness of the solar still. Results showed that the modified solar still (MSS) also improved productivity by about 17.55% compared to traditional solar still (TSS). Comparing the modified solar still to the traditional still, the distillate productivity increased by approximately 42.3% with Fe_3O_4 and 56.6% with CUO. The efficiency was about 45% for MSS with Fe_3O_4, 30% for cotton pads, and 51% for MSS with CUO, with an exergy of 103% improvement. Sharshir et al. [94], used a v-corrugated absorber with copper oxide Nanofluids and wick materials to raise the productivity of a pyramid distiller (PD) and improve its performance. According to the findings, water production was increased by 28.38%, 45%, and 72.95%, respectively, compared to the classic pyramid distiller, using a developed pyramid distiller (DPD), developed pyramid distiller with wick (DPDW), and developed pyramid distiller with CUO with thermal efficiencies of 43.2%, 49.8%, and 60.5%. Abdullah et al. [95], used convex solar still at various heights and utilized wick materials (jute, cotton) with PCM and Nanoparticles (Ag). As a result, productivity was 54% higher than it would have been with a classic solar still (CSS) with a 15 cm convex height.

(a) **(b)**

Figure 11: (a) ISSB experimental arrangement (b) close view of baffles arrangement [92]

The thermal efficiency is 41.2% for jute and about 40.8% for the cotton wick; adding Ag Nanoparticle increases the productivity by 72% compared with CSS. Hansen et al. [96], studied the effectiveness of modified solar stills employing multiple types of absorbers (rectangular stepped absorber, wire mesh absorber, and flat absorber) and various wick materials (water coral fleece, wood pulp paper, and polystyrene sponge) to boost the evaporating surface area. Coral fleece wick type produces the largest amount of pure water and considers to be the most efficient wicking material, according to the findings of the experiments. Using the coral fleece wick over wire mesh stepped, flat plate absorbers increased the freshwater output by 71.2%, 57.2%, and 45.4%, respectively. Hammoodi et al. [97], carried a review on the effects of Magnetic Field on the Performance of Solar Distillers. It focuses on how magnetic fields affect the production, performance, and efficiency of various solar stills. Due to changes in the saltwater's hydration shell, magnet sizes, positions, and densities substantially impact pure water's productivity by accelerating the evaporation rate. AL-Zaedy [98] experimentally Studied the enhancement of Single-Basin Solar Still Using Dye Solutions" constructed single slope solar still with various dyes to boost water productivity. The outcomes showed that distilled water's productivity using Methylene Blue and Methyl Orange solutions was enhanced by 18% and 28 %, respectively. The efficiency using the Methyl Orange and Methylene Blue solutions was enhanced by 74.3% and 62.53%, while 58.89% is superior to simple water in still.

Farag et al. [99], experimentally studied the performance water Distillation Device by Using Solar Energy". Evaluated the efficiency of the still experimentally at different weather conditions. The findings demonstrated that freshwater production rose as sun radiation did. On rainy and wet days, efficiency was 11.4%, whereas, on sunny days, it was 5.155%. Sharshir et al. [100] used three types of wick solar stills with evaporation area dimensions with different types of wick materials, cooling of the glass cover, and external reflectors. The still 2 has the higher performance using Cotton cloth wicks as it has the best capillary action out of all these wicks, which led to the distillate obtained from using a black cotton towel and black jute cloth by 19.17% and 24.14%, respectively. And the cost of 1 liter of freshwater distillate was decreased by 1.82%. With application glass cover cooling on still 2, solar still with cotton cloth wicks increased the freshwater productivity and energy efficiency by 30.59 and 33.13%, with a decrement in the cost of 1 L of freshwater distillate by 7.69%, respectively. Adding a top and bottom reflector to type (B) solar still with cotton cloth wicks increased the freshwater productivity and energy efficiency by 37.99 and 39.96%, respectively. Adding reflectors and cover cooling to wick solar increase freshwater productivity and energy efficiency by 52.36 and 58.5%, respectively. On the other hand, the cost per liter of freshwater was reduced by 9.8%.

Abdelaziz et al. [101], enhanced the performance of tubular solar still TSS by using five attempts using a v-corrugated aluminum basin, v-corrugated aluminum basin with wick materials, adding carbon black (CB) 1.5 wt. % nanofluid on wick material on the v-corrugated aluminum basin (heat localization), using pure paraffin wax under the v-corrugated basin integrated with wicks and carbon black nanofluid (1.5 wt.%). Finally, the best case consists of the v-corrugated basin combined with a wick, 1.5 wt. % CB nanofluid and CB nanoparticles with 3 wt. % was added to paraffin wax under the basin. The results showed that the productivity was enhanced by 21.4, 42.77, 58.48, 73.56, and 88.84% compared with the conventional one. For the best case (fifth case), the thermal energy and exergy efficiencies were enhanced by 82.16 and 221.8%, respectively, whereas the cost could be saved by 22.47%, compared to the conventional tubular solar still. Essa et al. [102], investigated two designs of SS where the wick belt made from black jute material is designed to be rotated inside the solar still in the shape of L-RWSS and LC-RWSS. Also, I studied the effect of using quantum dots Nanofluid. Outcomes show that the total yield of LC-RWSS is higher than that of L-RWSS by 19% with nano and 17% without Nanofluid. The yield of L-RWSS and LC-RWSS reached 8200 and 9600 mL/m^2 .day, respectively. Distilled water from LC-RWSS costs 0.019 $/L, and L-RWSS is 0.022. El-Said et al. [103], enhanced the productivity of SS by using metal wire mesh (WM) which increases the absorber area with pulsed water flow. Evaluation of system performance variables (sprayer feed water flow rate, pulsed water flow operation frequency, size, and the number of wire mesh layers) depends upon evaluations of water production, economics, and .thermodynamics. The packed absorber enhances thermal energy absorption and storage. The productivity was enhanced by about 102% for medium and large sizes and.41 % using the small wire mesh size, and 30 %. Compared to traditional design, the enhancement in the water yield, thermal efficiency, and cost by about 102 % and 44 %, respectively.

Shoeibi al. [104] studied a review of using porous materials, nanoparticles, and phase change materials to enhance water productivity by enhancing the evaporation of solar water desalination systems. A detailed overview was supplied to help academics and engineers choose the better design. The energy efficiency was enhanced by 94.14% using activated carbon as a porous media. The productivity of the solar still desalination by aluminum fins was 42.3%, and black steel wool fiber by about 20.9%. Dhivagar et al. [105], evaluated the performance of SS using the effect of magnetic powders, which perform dual roles as a heat storage media and a porous absorber medium to enhance the absorption of solar radiation and increase freshwater productivity. Thermal energy is stored throughout the day, and when solar radiation is low, it is released. When compared to CSS, the MPSS was a 39.8% greater evaporative and a 14.5% greater convective heat transfer rate. Modified still had a total water productivity of 31.2% higher than CSS's. Additionally, MPSS's energy was enhanced by 18.9% compared to CSS and exergy efficiencies by 19.04%. The reduction of CO_2 improved by almost 45.53%. The MPSS and CSS's respective energy economic parameters with energy bases were 33.1 and 24.56 kWh/$ as shown in Figure 12.

Figure 12: Experiment view of MPSS. MPSS, modified solar still [105]

4. Conclusion

Water scarcity has become a major issue of national and international concern. Desalination technology is rapidly developing to desalinate seawater, brackish water, industrial wastewater, etc., using the most common instrument for solar distillation, the solar distiller; solar stills are simple, have no fuel consumed and are easy to understand. Many studies have been conducted to increase the daily output of solar distillers by employing a variety of active ways to generate significant amounts of evaporation and condensation compared with traditional distillers. This study aims to review the productivity of several types of solar distillers with different geometries, construction, wick material, construction, and external integration to improve distillate production and thermal efficiency. Based on previous studies, the conclusions that can be drawn are:

1) Using PCMs as thermal energy storage significantly increases SSs' efficiency and performance. PCM stores energy during the day (the sun's brightness) and uses the stored energy at night, so it works even when the outside temperature is low. PCM increases yield by 30-40%.
2) The wick material significantly impacts expanding water surface area and diminishing volumetric heat capacity in the still, improving evaporation rate and increasing the yield. The distillate output of modified still is an output gain of 68% on a clear day, and 35% on a partially clear day is obtained.
3) Using different absorber plates (triangular, rectangular, channels) increased the average productivity between 23.6-19.3%.
4) Using wick still improve productivity by 34%, pyramid still 40%, double slope 46%, single slope 26%.
5) Using a floating absorber improve productivity by 15-20%

5. Future recommendation

We recommend focusing on using a floating absorption surface with phase change material, and floatable wicks were used to increase the evaporation surface area and cause a Localization of absorbed insolation on the evaporation surface of saline water, which, in turn, is expected to reap good results in increasing the productivity of distilled water.
Declaration of competing interest we confirm that we do not belong to or participate in any group or entity with a financial or non-financial stake in the topics or materials discussed in this work.

Author contributions

Conceptualization L. Hyal. J. Jalil and A. Hanfesh ; methodology, J. Jalil; formal analysis, J. Jalil; investigation, L. Hyal; writing—original draft preparation, L. Hyal; writing—review and editing, L. Hyal; visualization, A. Hanfesh ;supervision, J. Jalil and A. Hanfesh.; project administration, J. Jalil and A. Hanfesh. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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