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Recent advances and potential applications for solar still-based direct solar desalination systems

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Abstract: Fresh water scarcity depletes available water resources continuously. According to the World Economic Forum, this issue represents the most significant worldwide peril that impacts the entire human race. According to the United Nations, climate change is projected to impact potable water supplies to around 40% of the population by 2030. Numerous endeavors have been undertaken to transform saltwater into potable water via osmosis, multi-effect thermal desalination, and energy-intensive technologies. In the inverse, renewable energy can be utilized to desalinate a portion of the ocean's water, and solar desalination systems serve as a comprehensive case study demonstrating the significance of energy and cost reductions. This study examines recent advancements in solar water desalination, emphasizing integrating solar energy with other disciplines to increase productivity, decrease costs, and enhance energy efficiency. The objectives of desalination are to enrich the thermal energy source, decrease the cost of potable water, and improve the distilled water. A comprehensive examination of emerging technologies about solar water desalination, including but not limited to concentrated solar energy, photovoltaic panels, humidification and dehumidification methods, and evaporation aides.

Keywords: wall, mounted, evacuated tube.

1. Overview

The achievement of sustainable development objectives depends on water, a finite resource. When water resources are exhausted and cannot provide the demand for freshwater, this is referred to as a water shortage [1]. Considering its potential to influence every region during the next ten years, the World Economic Forum named this problem as the most significant global risk in 2015. The UN World Review estimates that by 2030, freshwater scarcity may affect up to 40% of the world's population as a result of greenhouse gas emissions and climate change [2].

However, there aren't any thorough reviews of solar stills (SS) in the literature. A variety of new scientific, technological, and development approaches for increasing SS production are discussed in this article. Economic evaluations of energy and energy-related products are also given. The current article presents a thorough analysis of current initiatives to improve SS performance. It will aid engineers and scientists in understanding the myriad SS advancements that call for continuous improvement. The findings of this work may serve as a roadmap for further investigation. The format of this document is as follows:

1. **Overview**

2. Performance of Solar stills

The amount of water condensate by unit area of the basin in a single day, or cubic meters, kilograms, or liters of water per square meter of the basin area per day, is the standard way to quantify the performance of a solar still. The energy and mass balance equations can be solved and applied to the glass cover, basin, and salted water components of a solar still to forecast its performance.

2.1 Enhancement techniques in SS

Numerous studies have concentrated on enhancing the efficiency of solar stills, and numerous tactics have been employed to enhance SS thermal efficiency.

- Adjusting the basin area.
- Cover the glass's thickness.
- Heat storage materials.
- Evacuated tubes.
- Nano fluids.
- Fins, trays, and wick materials.
- Cooling the cover
- Tilt angle.

A number of prior reviews have covered the historical evolution of solar distiller technologies, including desalination technology in terms of enhanced heat gain, system design development, and evacuated tube utilization.

Any technology that uses a solar distiller has several financial and operational advantages, such as lower energy usage, better water quality, and possible cost savings over standalone systems due to the wall-mounted solar distiller's increased efficiency in producing fresh water and using less energy.

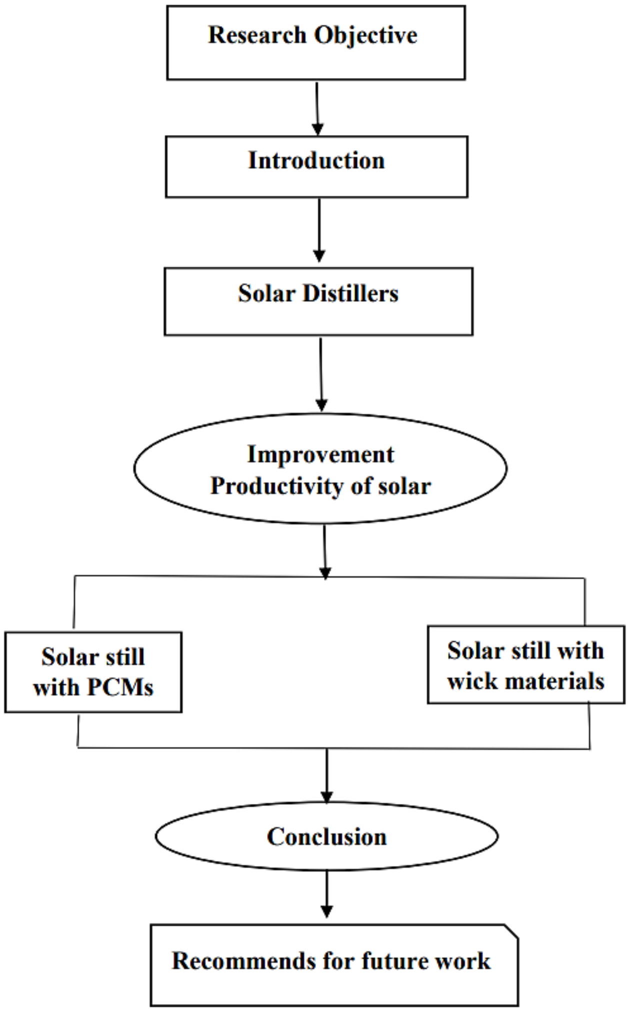

Figure 1. Enhancement Techniques of SS [3].

2.1.1 Heat storage materials.

Hyal et al. [3] revealed that researchers are continually searching for methods to improve solar performance using different absorber designs with different thermal storage and filament materials. Many experiments have been conducted to increase the daily production of solar stills using different effective strategies to achieve greater evaporation and condensation processes compared to simple standard stills, thus improving water productivity and its role and increasing thermal efficiency from the difference in the design of solar stills.

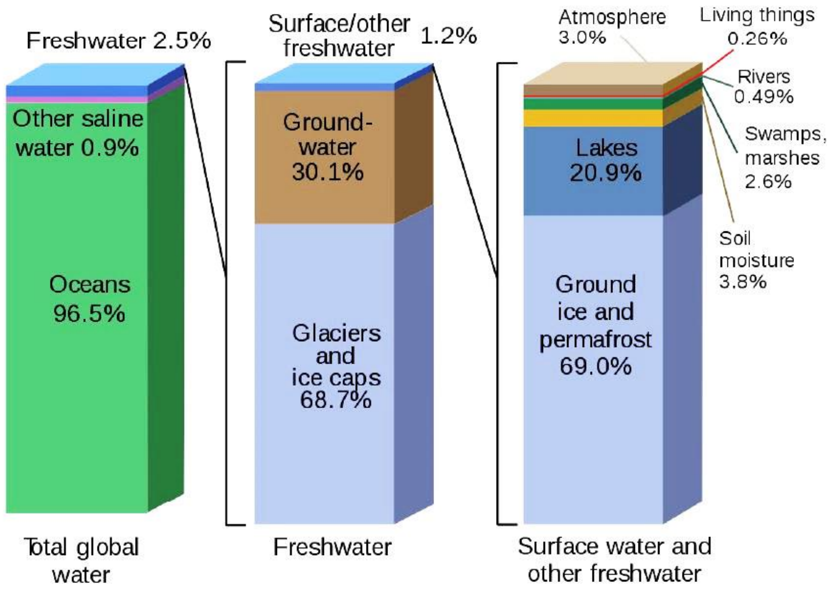

Figure 2. The distribution of water globally [3].

Alshqirate et al. [4] studied improvements to the Analytical study of utilizing natural fibers to increase SS's efficiency for distilling water. In that work, the surface area exposed to solar intensity was increased, thus increasing the evaporation rate and water productivity, and natural fibers were added to the basin. In addition, it benefits from its ability to act capillary and as a heat sink (thermal storage material). According to the results, using natural fibers led to a cumulative daily increase in freshwater productivity of 44.5% over traditional fibers, reaching 5160.8 g/m^2.

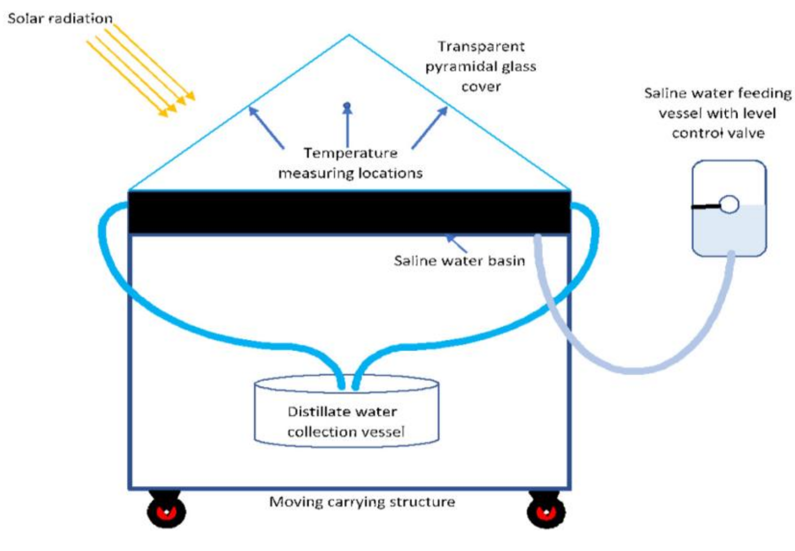

Figure 3. Schematic diagram of thermocouple locations [4].

Sambare et al. [5] present a review of technological, scientific, and development initiatives to enhancing the production of freshwater from a tubular solar still by utilizing appropriate materials for heat storage, To increase their output, jute cloth, iron fragments, and wire mesh have been explored as possible energy storage materials. Every experiment was conducted at Nagpur, India, at a constant trough depth of 2 cm [21.1458°N, 79.0882°E]. Thermal and energy efficiency were increased by 35.1% and 88.1%, respectively, with the usage of wire mesh. Wired networks are the most productive networks ever, according to experimental investigations. Comparing this to traditional solar stills, iron components, and jute fabric revealed improvements of 41.35%, 10.33%, and 29.78%, respectively. Utilizing wire mesh not only lowers expenses.

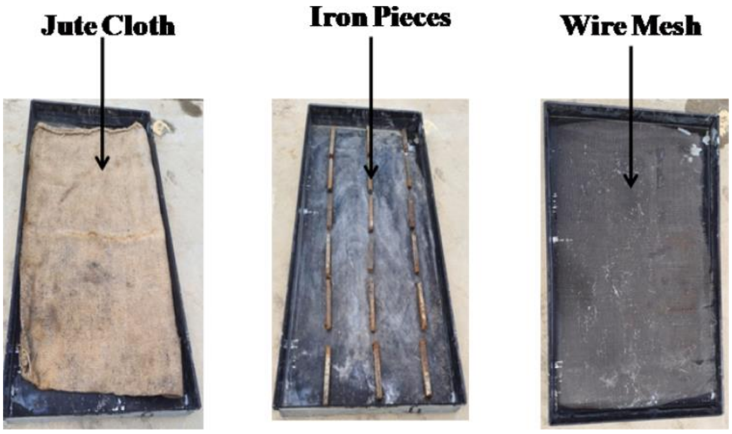

Figure 4. TSS with various energy-storing materials(a) Jute cloth, (b) Iron pieces, and (c) Wire mesh [5].

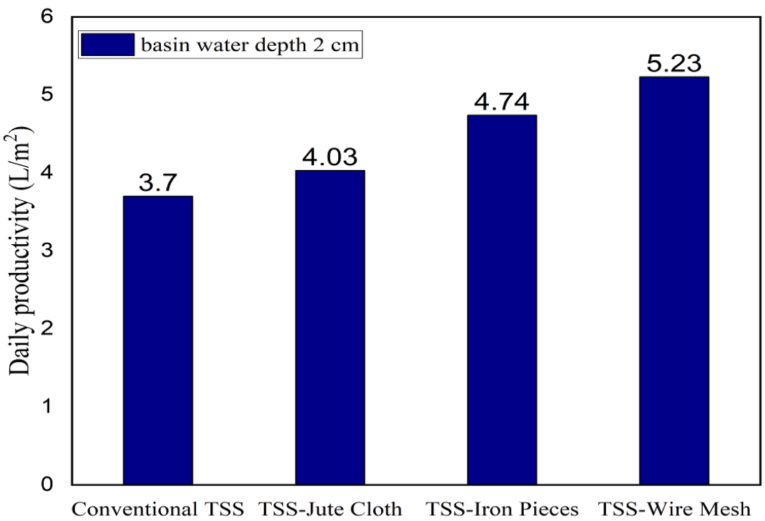

Figure 5. Daily productivity of Conventional-TSS, TSS-Jute cloth, TSS-Iron pieces, and TSS-Wire mesh [5].

Elgendi et al. [6] examined SS desalination technology advancements. A review of employing thermoelectric materials to increase solar still productivity; Electrical energy may be produced from thermal energy and vice versa using thermoelectric materials. Applications for thermoelectric materials in solar still-water desalination systems are numerous. Additionally, they can be utilized in solar stills to produce electricity using thermal energy. The most important change to sun stills for using thermoelectric materials to produce potable water from brackish or saline water are contrasted and explained. Conclusion: Thermoelectric materials enhance solar energy performance. They do this by raising yield and producing electricity in hybrid systems using thermoelectric generators or heaters.

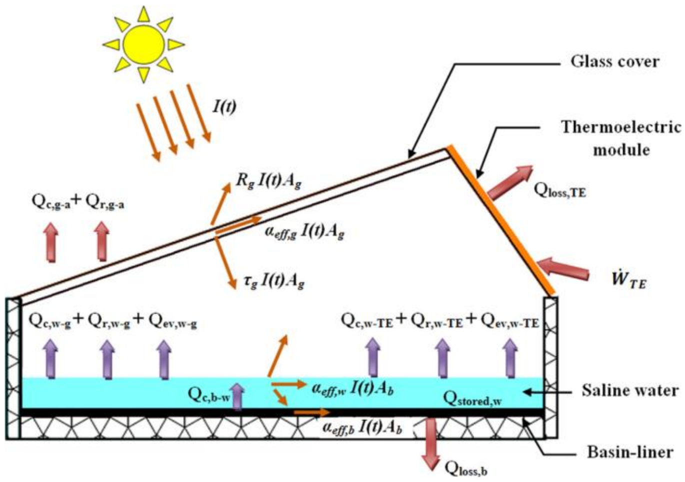

Figure 6. Energy balance for the solar still with TEC module [6].

Aly et al. [7] showed that experts are always looking for ways to enhance and assess an oval tubular solar still's performance using phase change material (PCM), tubular solar stills (TSS) with the integration of phase change material (PCM) and cover cooling in an innovative oval form (OTSS). The oval tubular solar still (OTSS) is constructed from a transparent oval tube that allows light to pass through it in all directions to maximize solar irradiation.

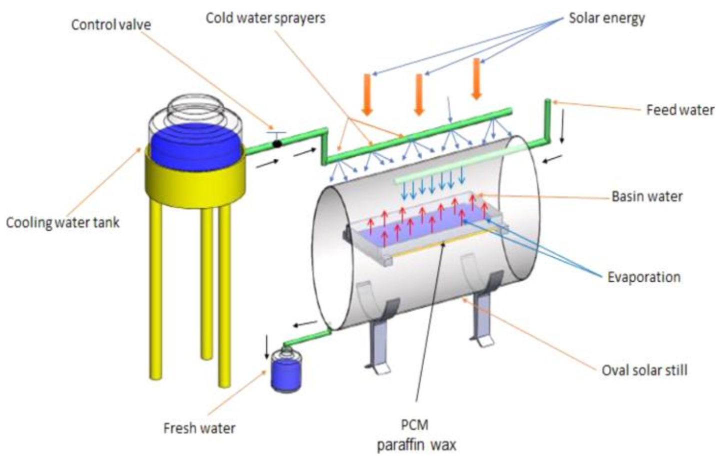

Figure 7. Schematic diagram of the OTSS experimental setup [7].

A black basin is integrated into the tube to enhance water evaporation and absorption. The production rate in the absence of cooling is shown to decline as the basin's water depth increases; at the ideal water level of 0.5 cm, the maximum production rate was 5.21 L/m²/day. On the other hand, at the ideal water-cooling flow rate of 2 L/h, the maximum production rate of 6.34 L/m²/day was attained with cooling.

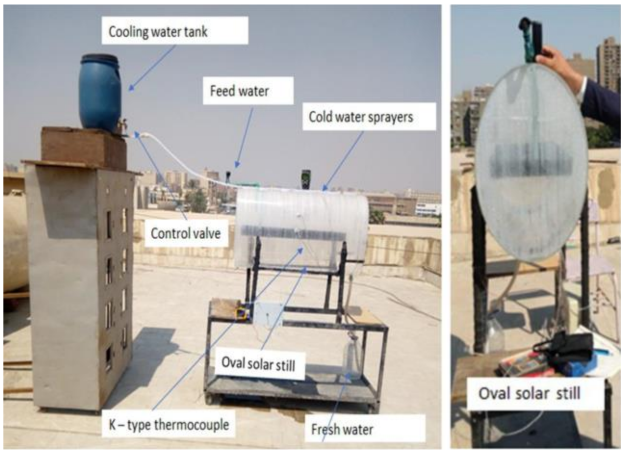

Figure 8. Photograph of the experimental setup from different views [7].

Shah et al. [8] provide an overview of research, development, and technology projects aimed at performing a performance analysis of black gravel solar stills. Black gravel will heat up more quickly than air or water because of its lower heat capacity. Heat is transferred from the pebbles to the water through convection. The midday sun has a significant thermal energy content, which is stored in the black gravel and used to maintain the vaporization of saltwater throughout the evening and night. Because black gravel is so inexpensive, it was discovered that production could still be boosted by 10–17% at almost no expense. Additionally, the efficiency of the solar still was improved by 12–16%.

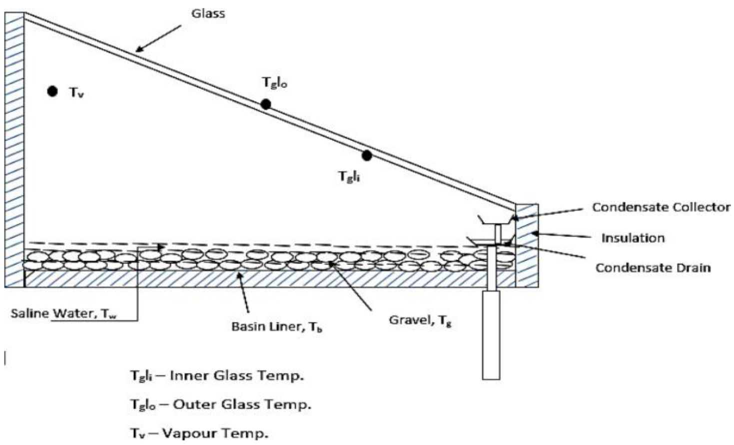

Figure 9. Experimental setup of Solar still with gravels [8].

Kumaravel et al. [9] highlighted that scientists are always looking for ways to enhance pebble and blue metal stones' capabilities as thermal energy storage materials in single-slope solar stills, and three one-meter-square solar stills are identical. Every SS has a cover cooling and dripping device to prevent water from evaporating and keep the water level constant. By utilizing blue metal stones in a cooling and dripping arrangement, the yield of distillate from a solar still can be greatly boosted. It aims to boost the amount of distillate produced each day. Results illustrated that the integration of the two stones increased output by 18% compared to a solitary still; however, the blue metal stone produced 1.5 times more potable water than the pebble stone in the solar still. The cooling mechanism of the glass cover facilitated a reduction in temperature to a range of 4 to 5 degrees Celsius.

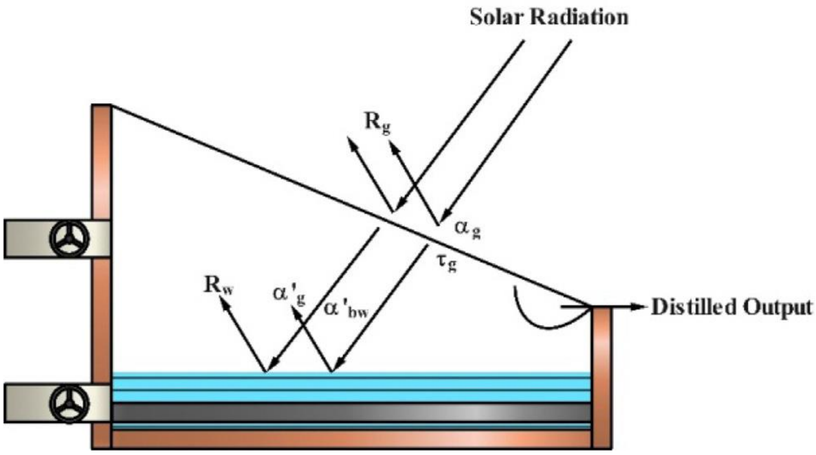

Figure 10. Solar radiation transmission [9].

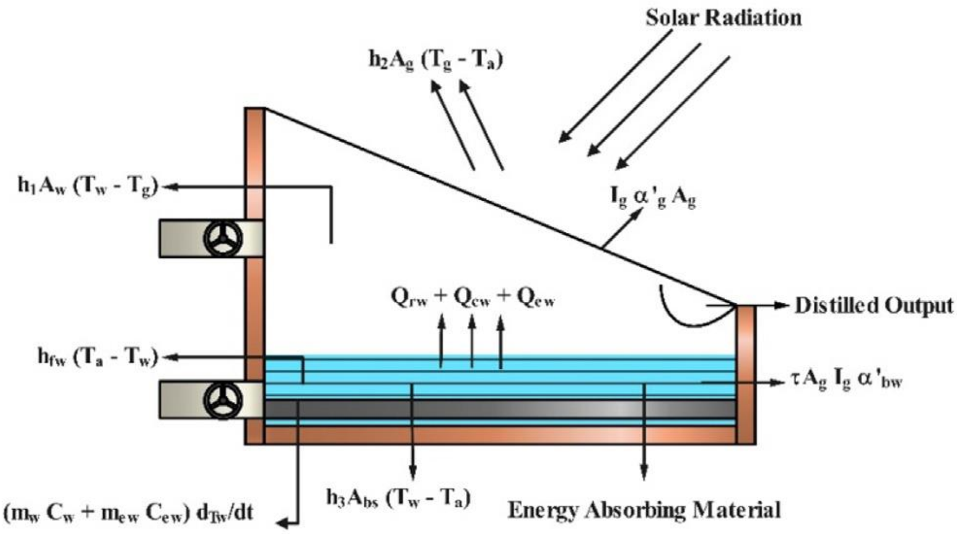

Figure 11. Energy balance in solar still [9].

2.1.2. Nano Fluid

Sahu and Tiwari [10] investigated the performance improvement of SS using nanoparticles (NP) at different water heights. The system performance was examined with and without NP. Results indicated that the use of nanomaterials improved water properties and thus increased water productivity and reduced the cost of producing desalinated water.

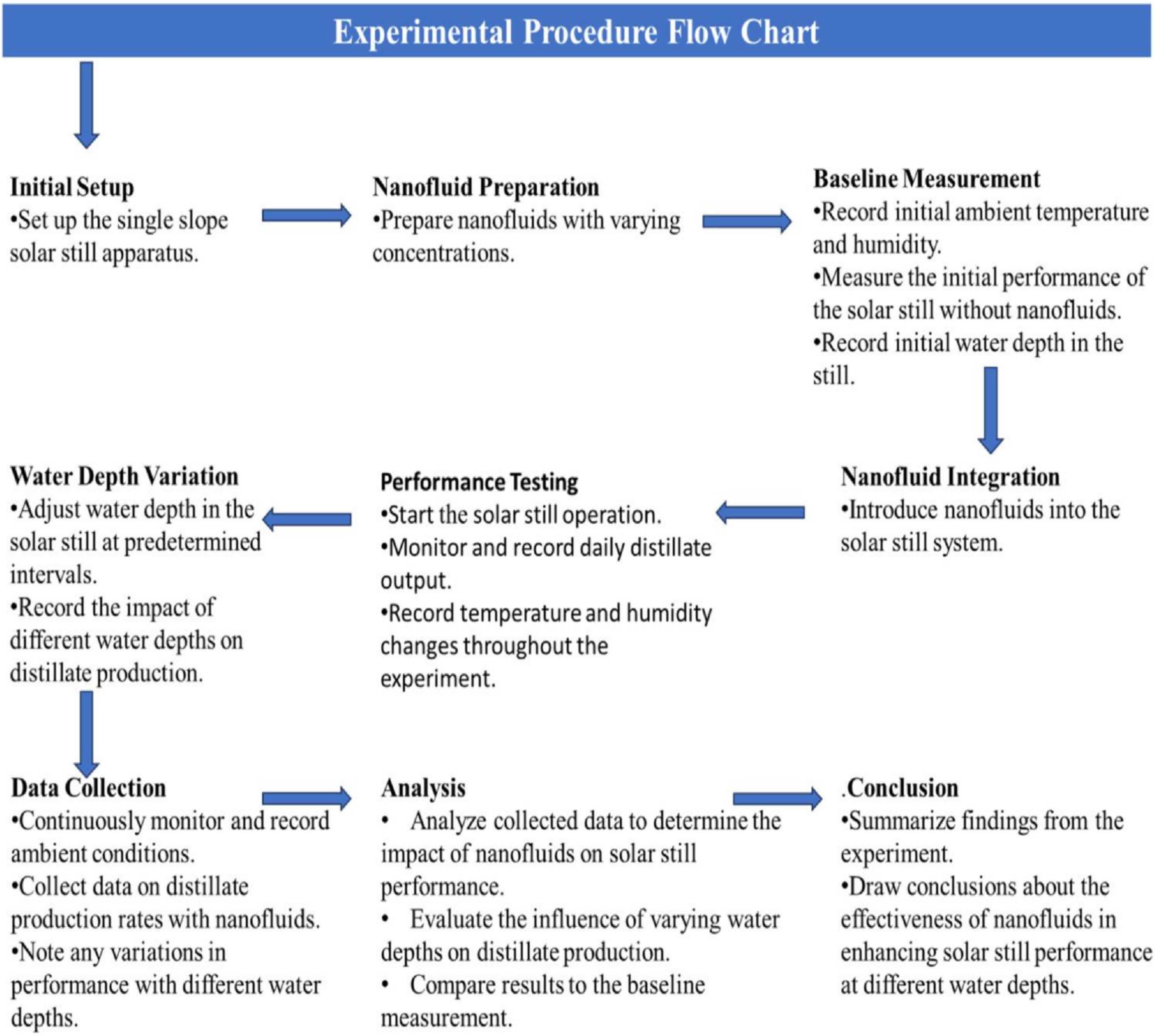

Figure 12. Experimental flow chart [10].

Toosi et al. [11] analyzed approaches for the experimental testing of the newly designed gradient solar involving a constant magnetic field and employed the following materials: Fe_3O_4 + graphene oxide + paraffin as nanofluid. The modified SS utilizes a combination of 3 absorbent sections and an evaporating section to increase the production rate and avoid full saturation of the device space. The SSS system was subjected to trials where different materials were utilized to increase the daily production rate. The continuous magnetic field was found to improve the distillate yield and thermal conductivity when using the hybrid NPCM, as well as making it a cost-effective option.

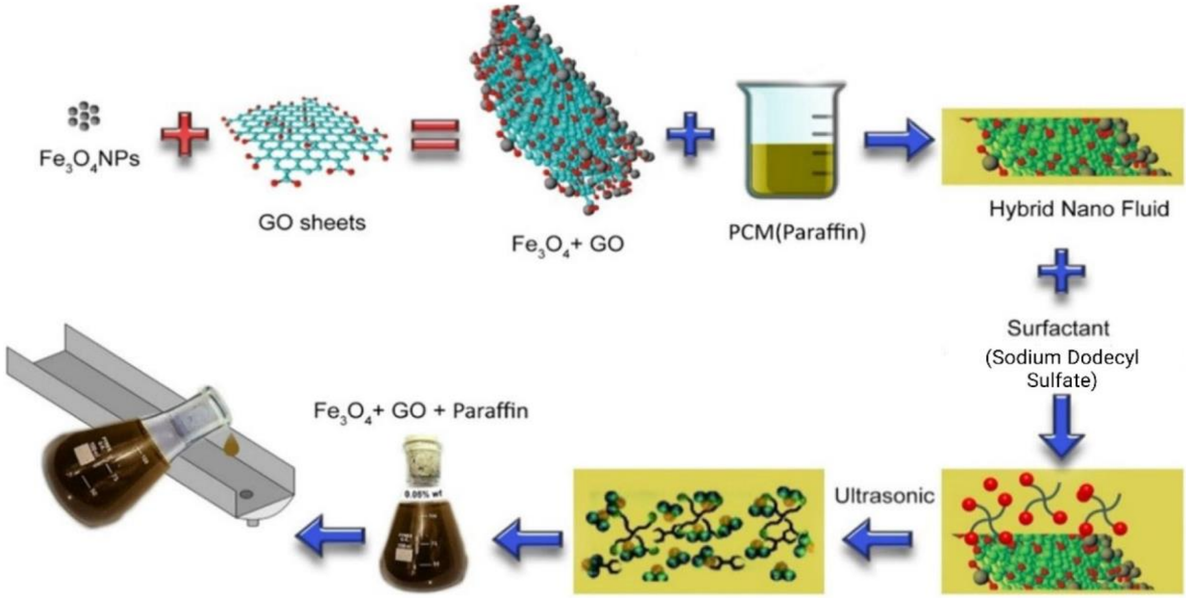

Figure 13. The steps followed in preparing the Fe3O4 + GO and Paraffin mixture [11].

Afolabi et al. [12] comprehensively analyzed the solar still desalination system improvements. Investigation of double-slope solar still through experimentation using micro-encapsulated thermal energy storage and PCM nano-additions. It is demonstrated how a double-slope solar still (DSSS) is integrated with PCM-TES. The PCM was micro-encapsulated in an epoxy resin composite using vacuum mole techniques. The effect of TES on productivity was ascertained by comparing data gathered from classic DSSS-TES and DSSS-TES.

According to the results, the DSSS-TES system produced 7.5 liters of drinkable water per day. Even better results were obtained by extending the operation duration by three hours. Moreover, greater rates of condensation and evaporation coincided with the 105% rise in output.

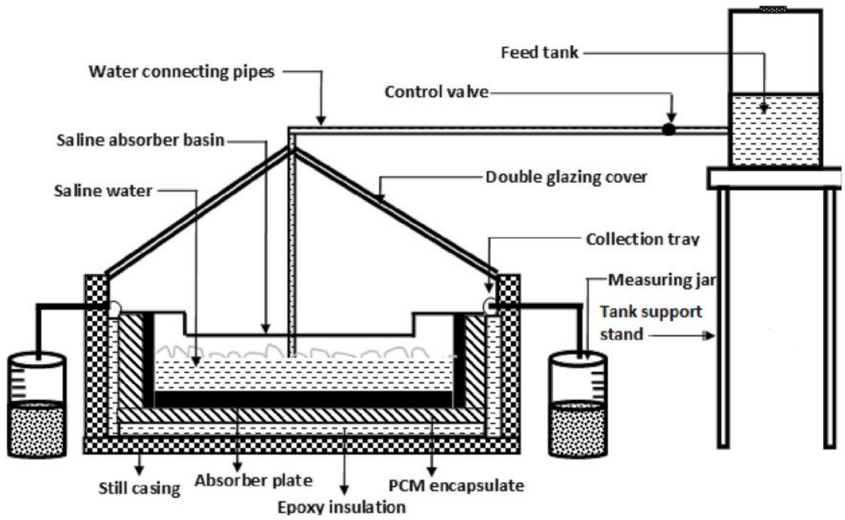

Figure 14. Cross-sectional view of double slope solar still with PCM encapsulate [12].

Mohamed et al. [13] revealed that improving the performance of conventional solar systems by applying Nano-doped coatings (NDPs). In the described experiments, a layer of Nano-doped black paint (NDBP) was applied to the absorbing surface of a standard solar still to improve the performance of the device. The results showed that the Nano-coating changed the condensation mechanism of all materials from a film-like to a drop-like state. It was also concluded that droplet condensation at larger surface inclination angles resulted in an increase in condensation yield. For example, at a surface inclination angle of 50°, the 23rd Nano-coating increased condensation formation on the glass surface. In addition, additional collectors were used to estimate the droplet volume before and after the coating process. The results also showed that the productivity of a conventional solar still system could be increased by approximately 25-32% by using a thermal Nano-coating. The design change resulted in an average increase of 18% in freshwater productivity.

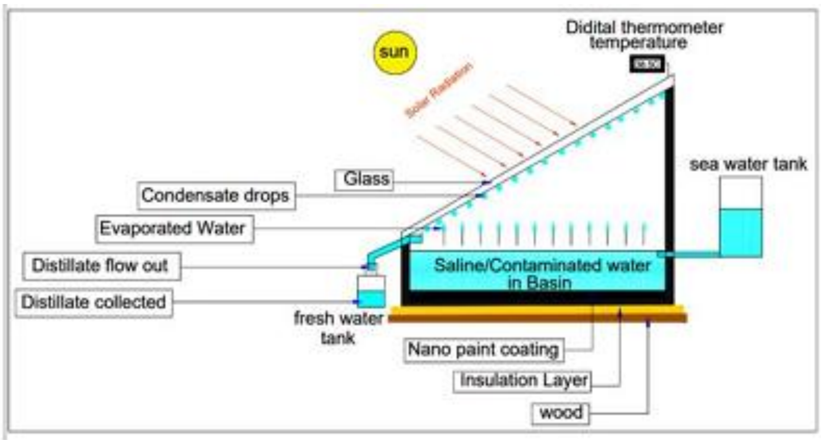

Figure 15. Sketch diagram of the experimental [13].

Murali et al. [14] presents a review of Enhanced solar still efficiency through the incorporation of phase change materials (PCMs) and Nano-PCMs for integrated energy storage, the research focuses on analyzing how the use of Phase Change Material (PCM) and Nano Phase Change Materials (NPCM) can impact the efficiency of solar stills. In order to improve productivity, PCM and a combination of NPCM are placed inside 12 copper tubes that are submerged in 1 mm of water. The study evaluates the thermal performance in four different scenarios, all of which maintain a constant water level of 1 mm in the basin. These scenarios include a traditional still with 12 empty copper rods and 142 g of PCM in each tube, as well as two other stills with NPCM Samples 1 and 2. Sample 1 consists of 0.75% nanoparticle concentration and 142 g of PCM in the first 6 tubes, while Sample 2 contains 2% nanoparticle concentration and 142 g of PCM in the remaining 6 tubes. The nanoparticles used are aluminum oxide (Al2O3) with sizes ranging from 20 to 30 nm, and paraffin wax (PW) is chosen as the latent heat storage (LHS) medium due to its melting temperature of 62° C. The thermal properties of the NPCM compositions, including melting point and latent heat fusion, are analyzed using a differential scanning calorimeter (DSC). The results show that adding nanoparticles increases the specific heat capacity and latent heat of fusion in phase change materials (PCM). This is due to several mechanisms, including aiding nucleation, enhancing energy absorption during phase change, and altering crystallization behavior within the PCM. Productivity and efficiency measurements demonstrate significant improvements: Case 1 achieves 2.66 units of daily production and 46.23% efficiency, while Cases 2, 3, and 4 yields 3.17, 3.58, and 4.27 units of daily production, respectively. Importantly, the use of nanoparticle-enhanced PCM results in a 60.37% increase in overall productivity and a 68.29% improvement in overall efficiency.

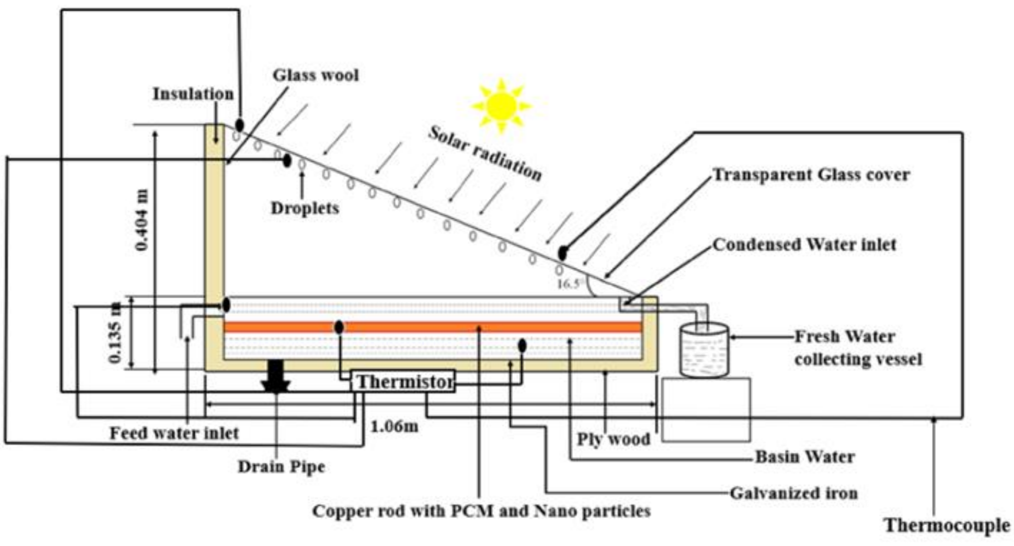

Figure 16. Schematic diagram of experimental setup. [14].

Abu-Zeid et al. [15] revealed that improving the efficiency of solar still unit through the use of v-corrugated basin, internal reflecting mirror, flat-plate Solar collector, and Nano fluids, This research study focuses on improving the conventional solar still (CSS) unit by incorporating a v-corrugated-type basin, internal reflecting mirror, flat-plate solar collector (FPSC) still, and FPSC Nano fluids. The use of these enhancements resulted in a significant increase in distillate productivity (Pd) by up to approximately 22.39%, 41.72%, 70.10%, and 104.13% compared to the CSS unit. This improvement in Pd can be mainly attributed to a significant increase in the temperature difference between the basin water and the cold interior glass cover surfaces (ΔTw-gi), with increments of around 34.33%, 52.32%, 77.37%, and 112.87% compared to the CSS unit.

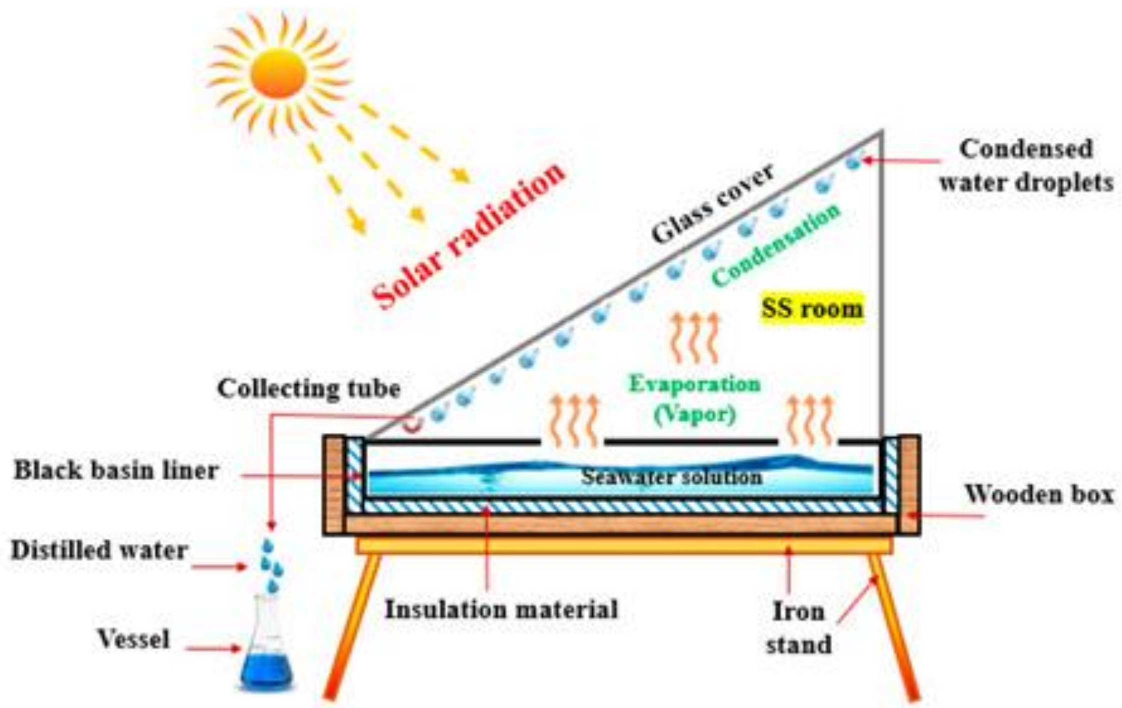

Figure 17. Solar still. [15].

Furthermore, the integration of a v-corrugated basin, internal reflecting mirror, FPSC still, and FPSC Nano fluids also led to a substantial increase in the average daily thermal efficiency (ηth) by approximately 22.01%, 26.71%, 39.57%, and 56.21%, respectively. These results demonstrate that incorporating these enhancements in a combined seawater distillation system can greatly enhance the performance of the CSS unit. By increasing the basin water temperature (Tw) and the temperature difference between the basin water and the cold interior glass cover surfaces (ΔTw-gi), the overall performance of the solar still unit is significantly improved.

2.1.3. Trays

Shanmugan et al. [16] comprehensively analyzed the technical evaluation of solar PV integrated with a tank and ramp to produce electricity and water simultaneously. This work focused on integrating solar PV system collectors with solar stills. This integration resulted in a reduction in external energy sources, an improvement in heat transfer processes through evaporation and condensation inside the solar still, an increase in the total distillate production, a decrease in the cost of producing desalinated water and, thus, improving the efficiency of the system.

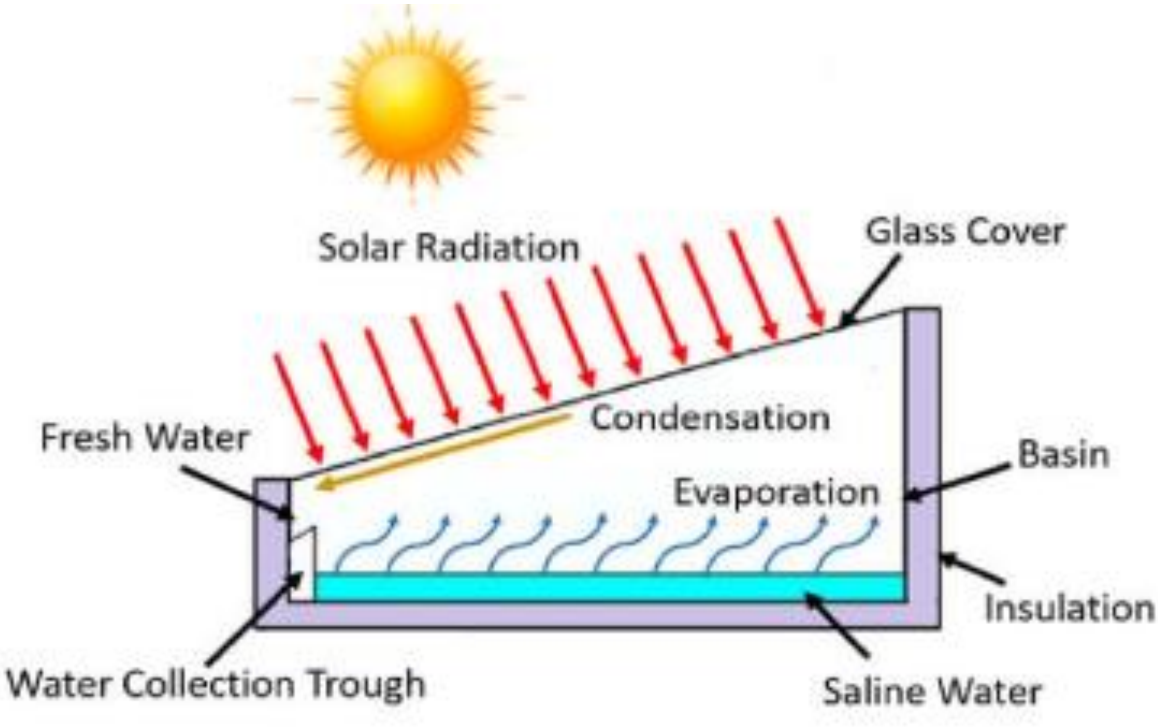

Figure 18. Holistic view of simple solar still [16].

Singh [17] presents a review of the optimization analysis of basic requirements for adjusting S.S. The work was done on a dual-slope solar system with a parabolic solar receiver and annual evacuated tubes with a (30°) tilted glass cover and fully evacuated tubes.

The results with the use of vacuum tubes and a glass cover showed an improvement in production, an increase in desalinated water 16.94 L/m²/day, and also a decrease in energy 8.4%.

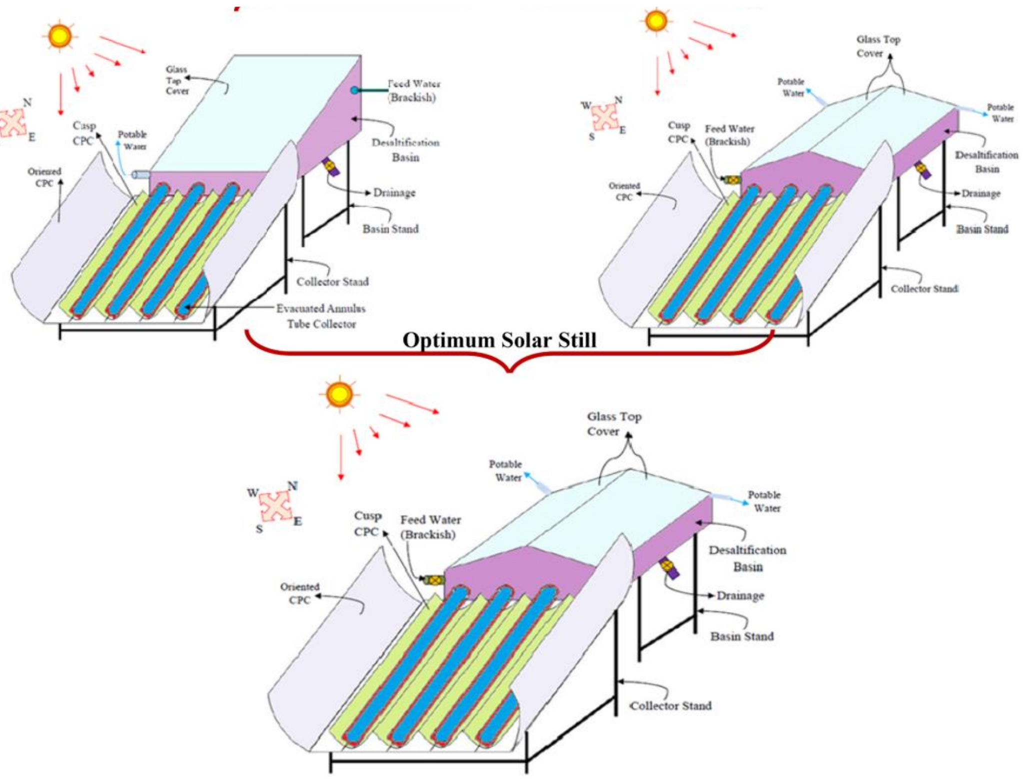

Figure 19. Schematic flow diagram for the optimized and modified solar still [17].

Abdullah et al. [18] revealed that researchers are continually searching for methods to improve the employ of an SSS with an external condenser, a phase-change material, a copper heating coil, and both internal and external reflectors. Using a copper water heating coil, internal and external reflectors, Nano scale phase change materials (PCM-Ag), and an external condenser, a modified solar still (MSS) and a conventional solar still (CSS) were operated. Five sets of experiments were performed to compare the performance of MSS and CSS in the same climate.

Incorporating external reflectors—top and bottom—into the modified solar still increased thermal throughput/efficiency, and using an external condenser improved the yield of desalinated water.

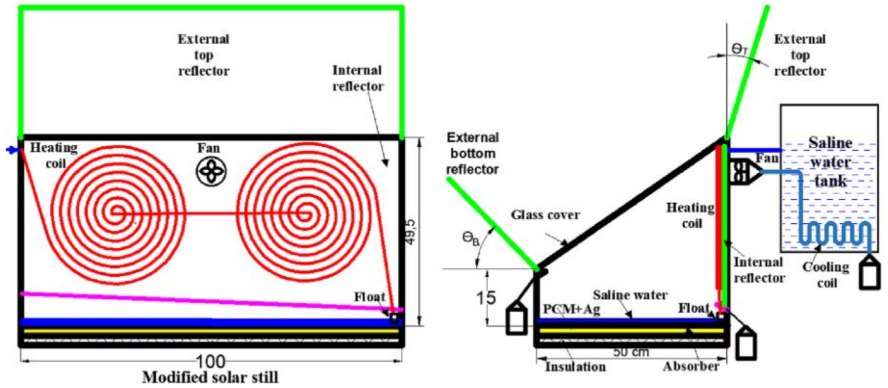

Figure 20. Schematic representation of the experimental setup [18].

2.1.4. Wick Materials

Ramzy et al. [19] revealed that researchers are continually searching for methods to improve the execution of an S.S.S.S Use of various porous adsorbents. An assortment of absorbable materials, including loofah, black loofah, soft steel wool, and steel wool padding, have been employed in the design and fabrication of comparable SS. The performance of each skill is measured under the same ambient climate conditions, and a variety of variables are measured. The results showed that the desalinated water production rate using steel wool pads is higher than the other materials mentioned above.

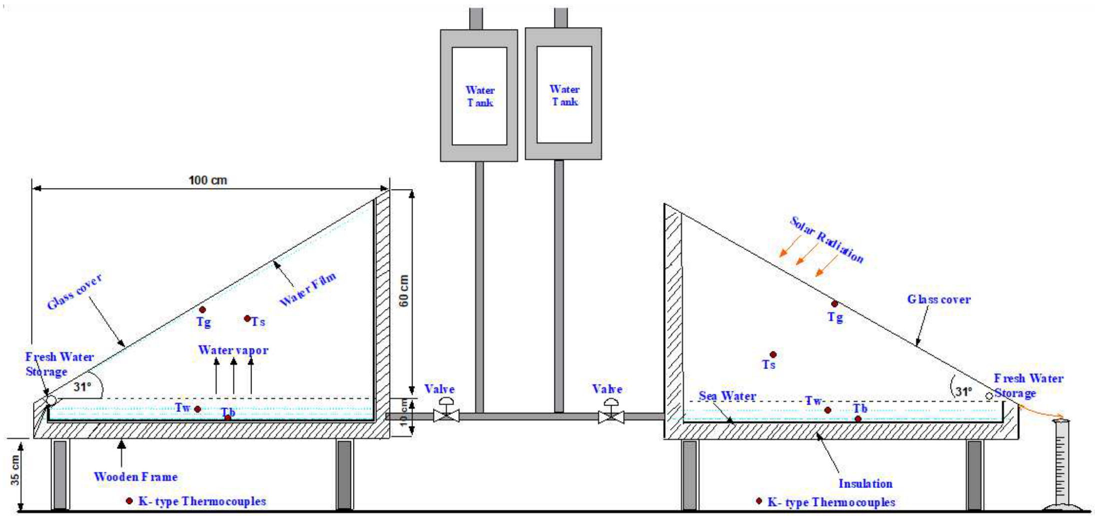

Figure 21. Schematic drawing for the experimental setup [19].

El-Said et al. [20] studied improvements to solar still productivity using absorptive mesh pulse flow systems. A metal wire mesh was used to act as an absorber, with varying pulsating flow of water and changing the number of layers of the wire mesh to improve the solar still, as it led to an increase in the absorption surface area. It was verified that the use of two layers of wire mesh worked to increase the production of desalinated water.

Figure 22. SS-WM desalination system [20].

Wiener et al. [21] revealed that improving the performance of solar distillation systems using textiles and polyurethane rollers, this study proposes a solar distillation system that is cost-effective and energy-efficient while ensuring sustainability. Fabric-coated polyurethane rollers with capillary action increase the evaporation surface, thereby significantly improving the performance. Water vapor condenses on the inclined aluminum plates of the cooling chamber and is collected in the distillation chamber inside the solar still. The thermodynamic, energy and economic performances of the proposed model as well as the productivity are evaluated. The maximum instantaneous system efficiency and exergy efficiency of the produced solar distillation system are approximately 62.16% and 7.67%, respectively. Of particular note are the cost-effectiveness and performance improvements of the system. The average daily distillate productivity of the proposed distillery is estimated to be 1.14 L/m^2, with an annual production of 416.54 L/year. The estimated cost of producing 1 liter of distillate is $0.023.

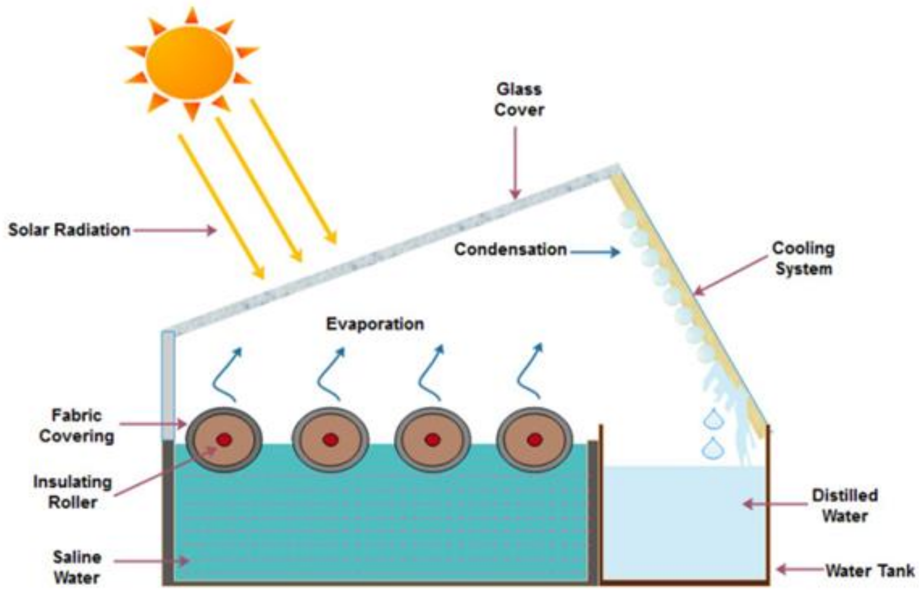

Figure 23. Schematic diagram of solar still experimental setup [21].

Dumka et al. [22] analyzed improving the efficiency of solar stills using Plexiglas and jute cloth: an experimental investigation, in this study, the performance of a modified solar still (MSS) utilizing Plexiglas and jute fabric was compared to that of a conventional solar still (CSS). The aim was to enhance heat localization and thin-film evaporation. Two solar stills with the same 1 m^2 basin area were built using fiberglass-reinforced plastic for testing purposes. A heat transfer model based on linear regression was employed in the theoretical analysis. Performance evaluation was conducted through exergy analysis, with a cost per liter also factored into the study.

Results showed that the MSS produced 35% more distillate compared to the CSS. Additionally, the MSS resulted in a 45% decrease in the cost of distillate production compared to the CSS.

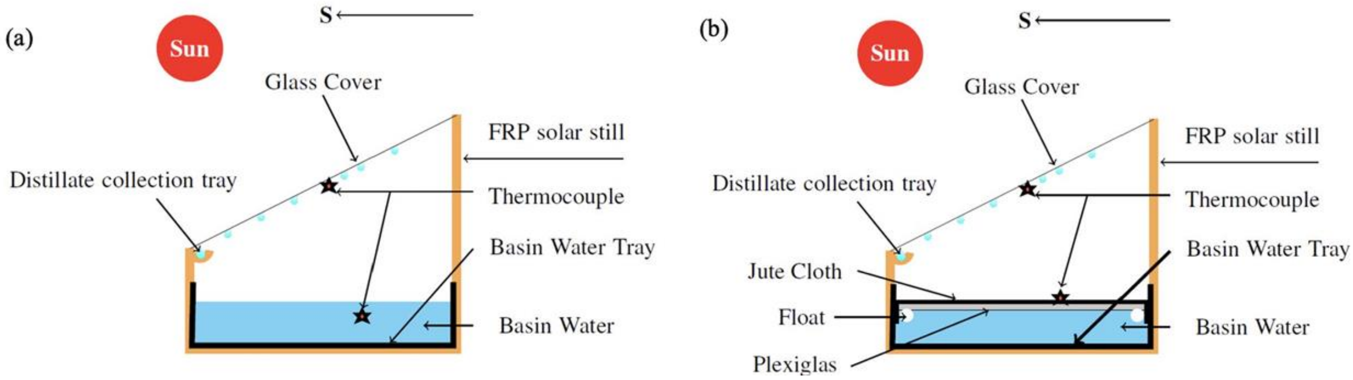

Figure 24. Schematic diagram of solar still cell. a CSS (b) MSS [22].

2.1.5. Fins

Somwanshi and Shrivastav [23] studied improvements to make closed solar still at an angle of inclination with an external lower reflector. A closed-loop tilted solar wick was created with an external ground reflector placed at an angle, which increases the amount of solar radiation that reaches the solar wick, increasing the amount of the total distillation product.

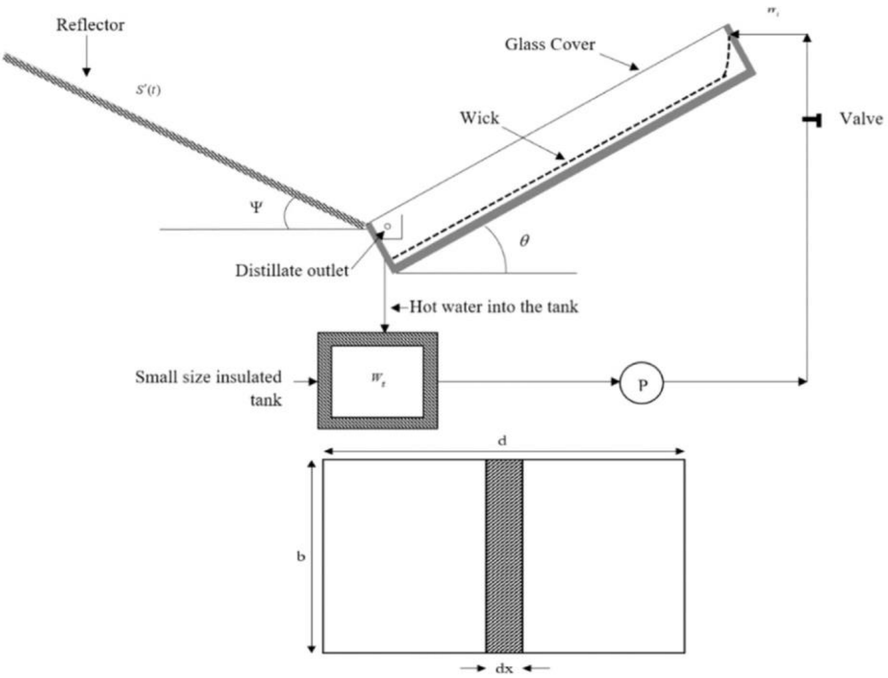

Figure 25. Schematic of CLIWSSR [23].

Arifin et al. [24] studied application of thermal energy storage in single-sided solar stills. The single slope solar still (S4) is a conventional still that uses solar energy as the primary energy source, this study aims to test the S4 with the addition of thermal energy storage (TES) in the basin. This additional absorber heat can maintain heat absorption throughout the production day. The additional TES was used with hollow discs formed with modified soy wax as the phase change material. The study conducted experiments between 07:00 and 21:00 GMT +7 and compared the performance of the conventional S4 with the additional TEM. The results show that the addition of the TES device affects the performance of the S4. The results show that the additional TES increases the gain power of the S4 by 220ml over the conventional S4, an improvement of 8.22%.

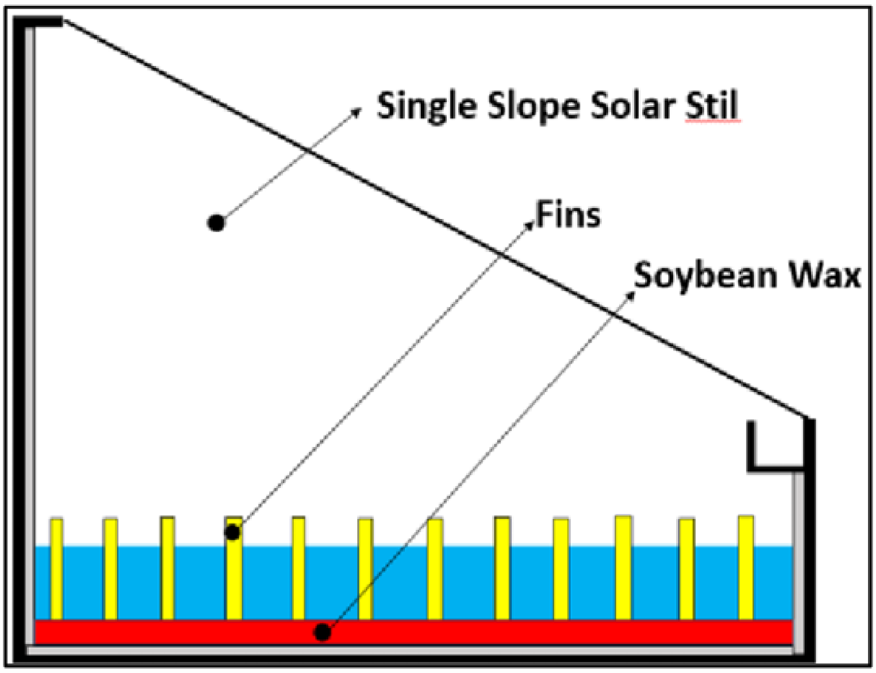

Figure 26. Conventional single slope solar still with additional TES [24].

Shareef et al. [25] analyzed approaches for improving the work of the solar still by adding absorption chips and creating a different shape for the transparent cover. Two surfaces of absorbent materials were used, one of which was solid and the other distributed in the form of flakes. Two glass covers were also made, one in the shape of a pyramid and the other in the shape of the letter W. The results showed that cutting the foil and changing the shape of the cover increased the distillation yield and thus efficiency for the Production of desalinated water.

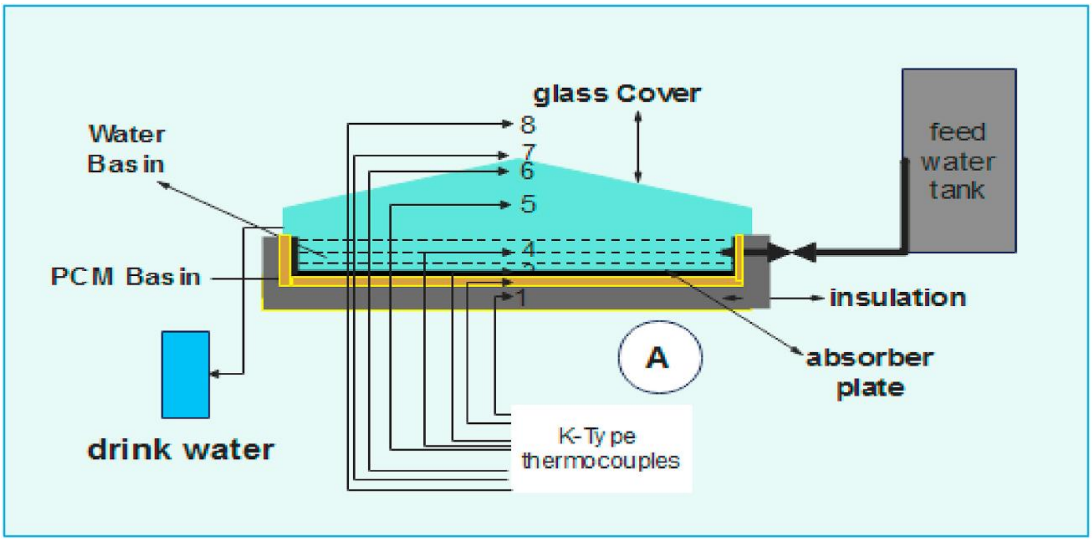

Figure 27. Schematic diagram of traditional solar still with thermocouples [25].

Atteya and Abbas [26] presented a review of technological, scientific, and development initiatives to improve the sampling of an ambulated solar still with diverse strand racks and mirrors. The development composition of different SS sand layers was carried out to improve their performance, and the sand was used as a thermal buffer the effect of internal mirrors and the cooling coil on the performance of SS layered on sand was also studied. Experimental results showed that the flax sub layer improves the graded SS products. The maximum increase in the accumulated product of graded flax was achieved with internal glasses and cooling coil at 1 cm sand layer height and black sand.

Figure 28. Photo of the experimental test rig [26].

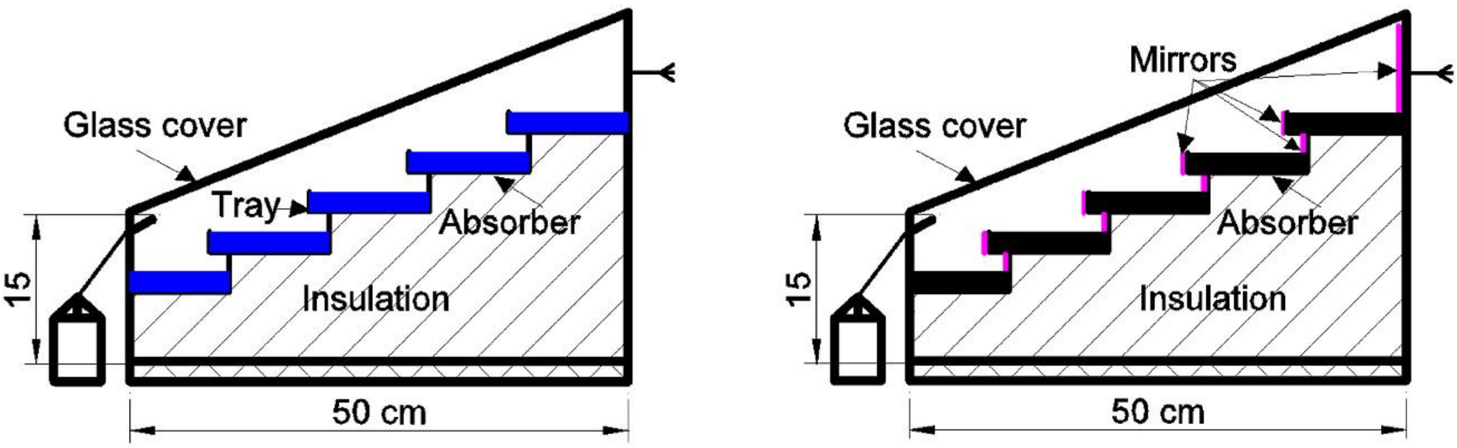

Figure 29. Schematic drawing of setup [26].

Soltanian et al. [27] demonstrated that Proposal for an Enhanced Solar Still Concept Using Reflectors and Comparison with Traditional Solar Stills, this study introduces a mirror-enhanced solar still and conducts a mathematical analysis to compare its water output with traditional solar stills. The mirror-enhanced solar still offers various advantages over conventional designs, such as lower glass temperatures, higher water basin temperatures, and greater solar irradiation absorption. As a result, the proposed system can boost water production from 7.5 L/day to 24 L/day. These findings demonstrate the effectiveness of the new approach, suggesting its potential application in large-scale projects in arid and semi-arid regions.

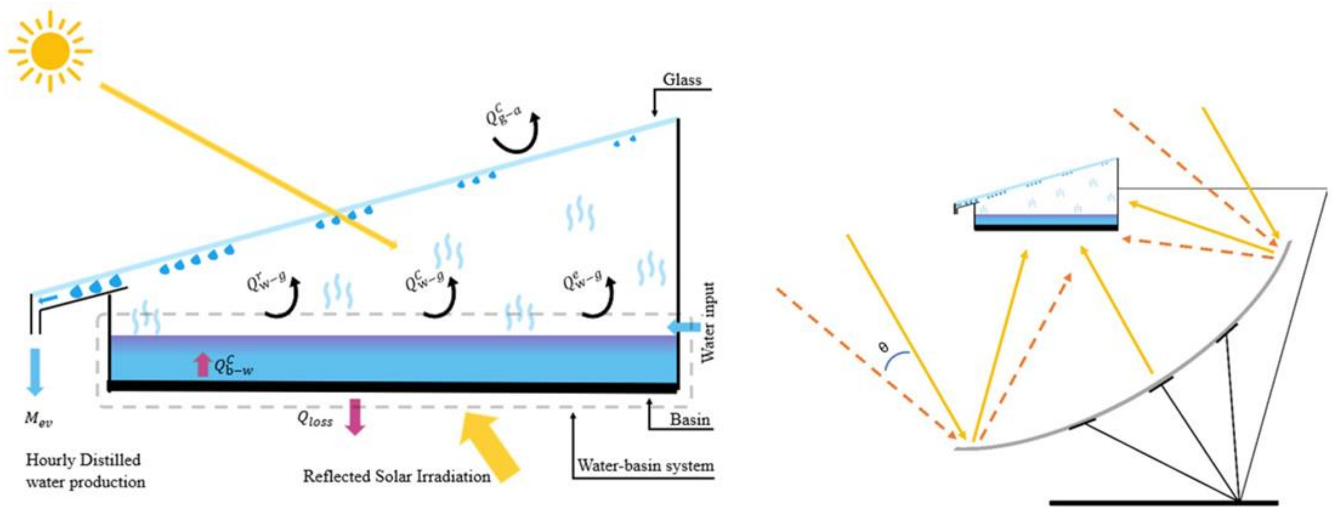

Figure 30. Schematic diagram of the energy balance of a single solar still slope

and structure of the proposed system [27].

2.1.6. Cover Cooling

Shatar et al. [28] investigated methods to improve the passive solar stills' efficiency. An evaluation of a solar still with thermoelectric cover cooling and a partially coated condensing cover in terms of energy, energy efficiency, economy, and environment. This study improved the passive solar still by adding a thermoelectric cooling system and a partly covered condensation cover. In Malaysia's tropical climate, the impact of different thermoelectric cooling powers (12 W and 36 W) was examined and contrasted with a reference solar still. A detailed analysis of the solar still's performance was conducted, considering freshwater yield, energy, exergy, environmental, and economic factors. The findings demonstrated that a 36 W thermoelectric cooling capacity might boost freshwater production by 126%. Compared to the reference solar still, the energy efficiency increased by 44% while the energy efficiency declined by 25%.

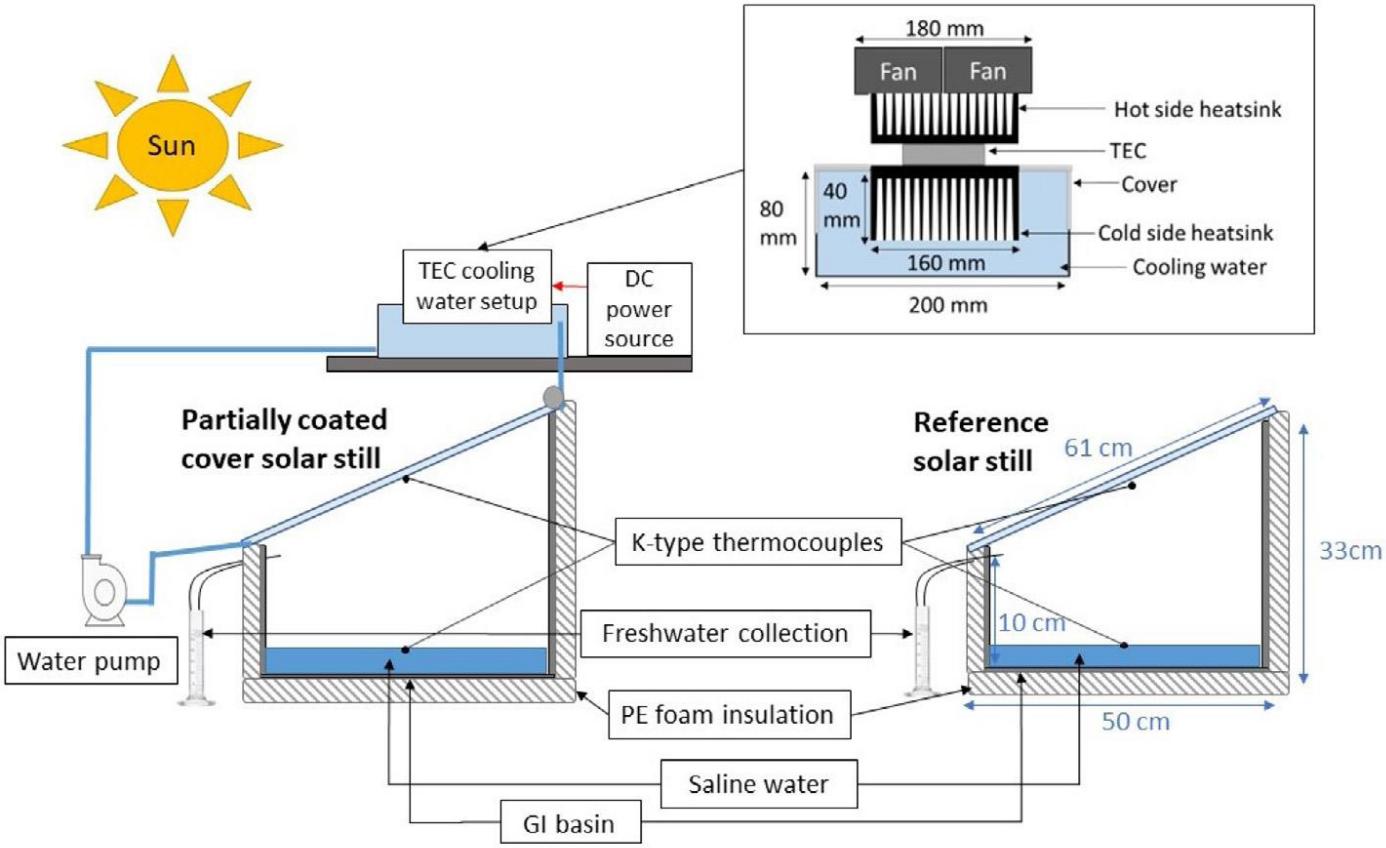

Figure 31. Solar still outdoor experimental setup [28].

Shatar et al. [29] demonstrated that scientists are always looking for ways to further their research on the effectiveness of SS with thermoelectric cooling systems for different types of cover materials; using various cover materials, an experimental inquiry was conducted to ascertain the impact of altering thermoelectric (TEC) cooling power on the solar still. Three different kinds of cover materials glass, polycarbonate (PC), and acrylic (PMMA) were investigated for the (TEC) cooled solar still. By adjusting the applied TEC current from 2A to 4A, the (TEC) cooling power was changed from 12 W to 36 W. The study was conducted in Kuala Lumpur, Malaysia, at the University of Malaya. When using a current of 4A for (TEC) cooling, the productivity of the solar still with glass cover was boosted by as much as 76%. The maximum energy efficiency for glass can be achieved with a solar still with (TEC) cooling.

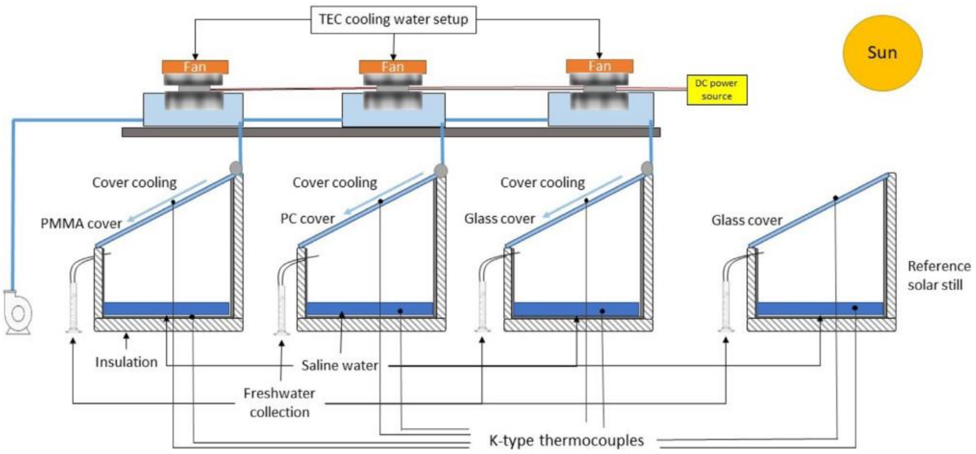

Figure 32. Solar still outdoor experimental setup [29].

Mohammed et al. [30] demonstrated that Implementation of a novel stepped square pyramid solar still for seawater desalination under Upper Egyptian climatic conditions, improved pyramid solar still (MPSS) with multi-level water pool surface. Improving the performance of pyramid solar still is the main focus of the proposed strategy. To achieve this goal, four water tanks were built and integrated into the pyramid solar still, with their sizes increasing in proportion to the surface area of the condensing glass. The water pool area per square meter of solar still can be increased by 25% compared to the conventional pyramid solar still (CPSS) with the same condensing coverage area. The results show the consistency between the theoretical results and the experimental results. The maximum yield of CPSS is 2524 mL/m^2 and the maximum yield of MPSS is 3415 mL/m^2. The stratified area yield is increased by 35.3% compared to CPSS. In addition, the efficiencies of CPSS and MPSS are 23.5% and 31.7%, respectively. Furthermore, the northern condensation cap obtained the highest fresh water yield with a recorded value of 1174 mL/m^2. The cost of distilled water under the proposed system is $0.0179 per liter.

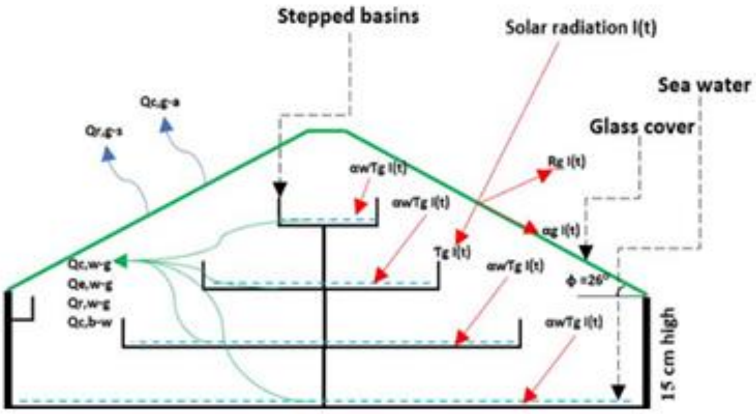

Figure 33. Schematic of the heat flow through the parts of MPSS. [30].

3. Performance Assessment

3.1. **Analysis of Energy Efficiency**

Angappan et al. [31] revealed that researchers are continually searching for methods to Examine solar stills with integrated solar cookers to increase output: an experimental, energy-related, and financial study; the absorption area and water productivity of the system are enhanced by the combination of a box solar cooker and a solar still. The solar distiller and the solar cooker were divided to bring up the temperature of the salt water. A mirror is incorporated within the solar cooking box to increase the absorber panel's solar energy intensity. The output from the active solar still (ASS) and passive solar still (PSS) was 5.5 L/m^2 and 3.9 L/m^2 per day, respectively, according to the data. In addition, the improvement increased freshwater production by almost 41% compared to the PSS system while lowering costs.

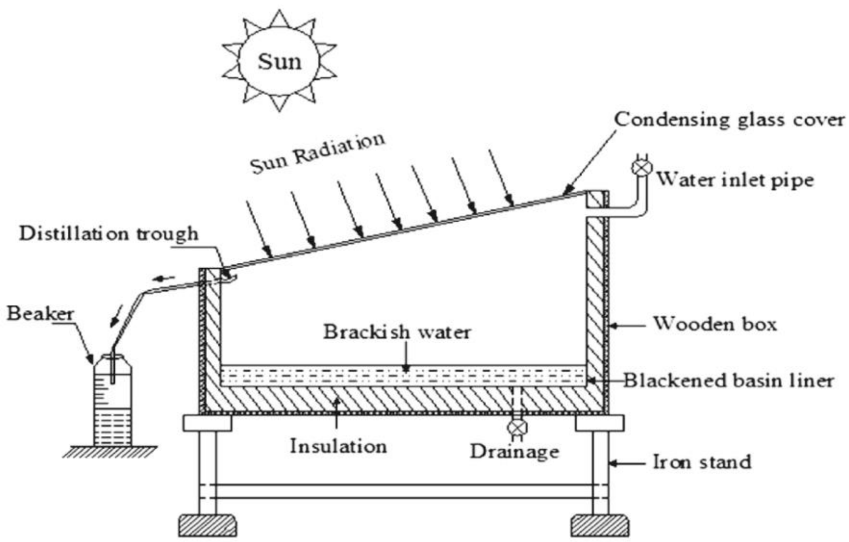

Figure 34. Schematic diagram of PSS used in experimental work [31].

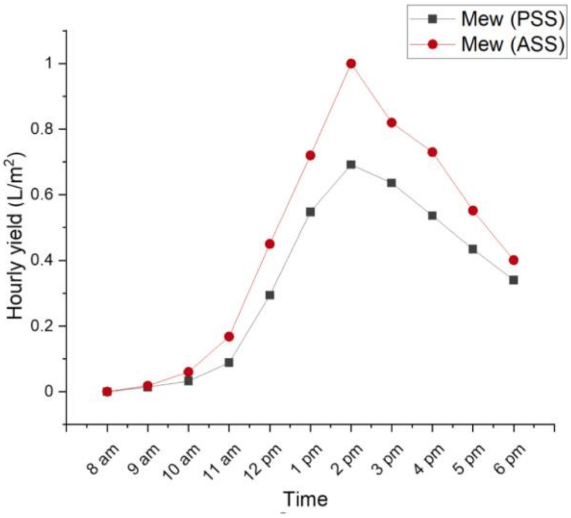

Figure 35. Hourly variations of freshwater generation in both PSS and ASS [31].

Hammoodi et al. [32] demonstrated that researchers are always looking for ways to get better at the variables affecting the performance of solar stills of the pyramid type, the specific variables influencing pyramid solar stills' performance. These include operating, design, and meteorological parameters. Even if the design, The number of basins and slopes, the forms of SS, the cover's angle, the thermal energy storage, the rates at which the basin absorbs energy, the reflectors and mirrors, the sun tracking system, the thickness of the insulation, the additional materials, and the level of the water in the basin are all included. This review aims to investigate the current state of several pyramid solar still designs from this standpoint. Numerous studies have shown that by adding absorber plates with greater heat storage capacity, pyramid still production may be raised by up to 35% and 88%, respectively. On the other hand, the production of distillate is increased by reflectors and mirrors by 48% and 53%, respectively.

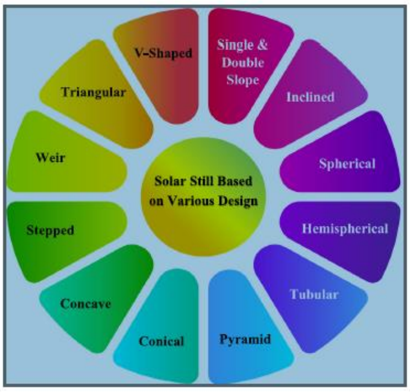

Figure 36. Classification of solar still based on geometry [32].

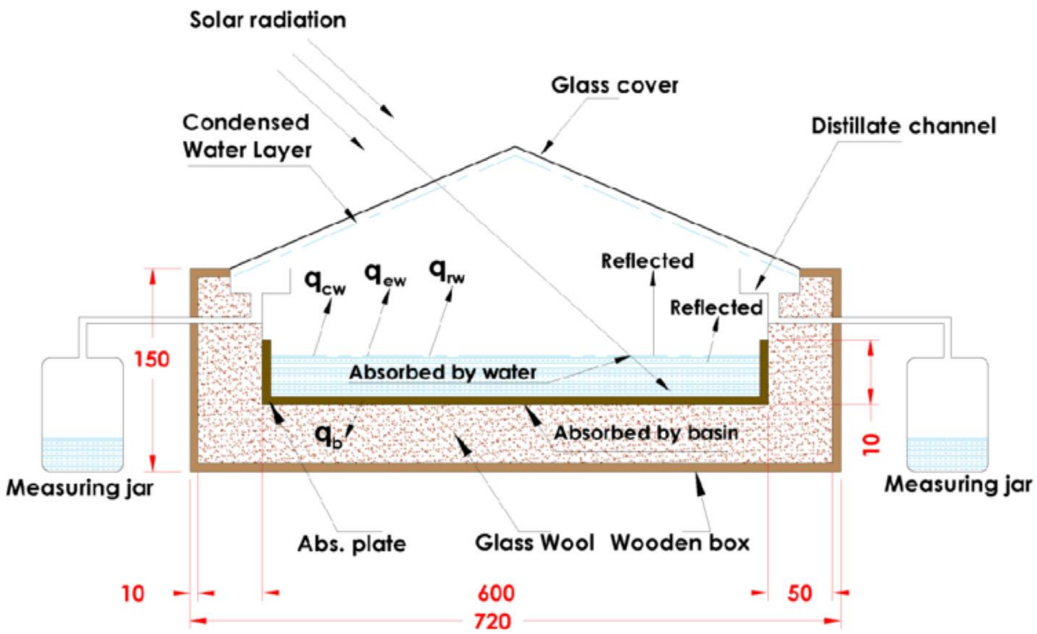

Figure 37. Schematic view of a conventional solar still [32].

Tiwari and Rathore [33] investigated ways to connect thermal energy storage with solar still improvements for water desalination using a comparison study of three types of SSS: CSS, CSS with PCM composite under basin liner separated by copper sheet, and CSS with PCM composite connected to copper pipes. PCM (OM 37) was mixed with powdered graphite to improve the final composite's thermal conductivity. A 6 cm water depth was used to record the temperature of the basin, the water, and the glass. Experimental methods were used to record the hourly and daily distillates.

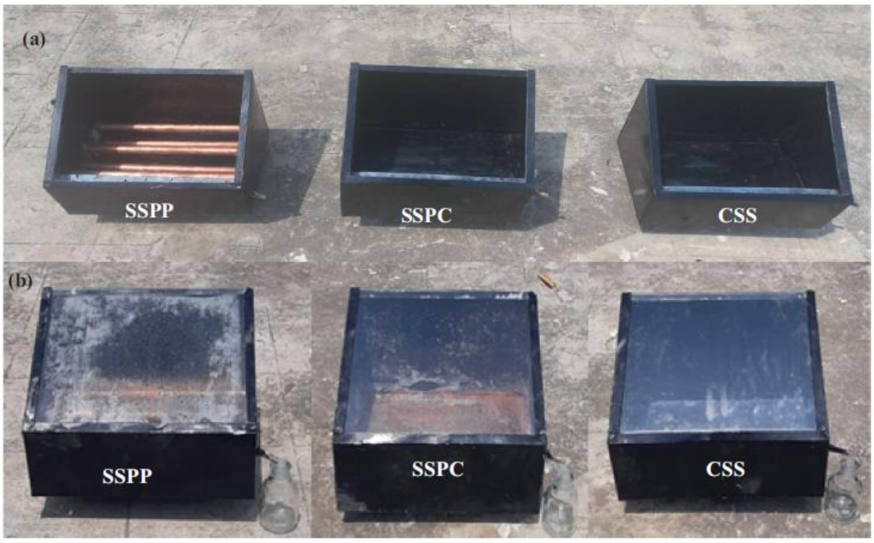

Figure 38. All three fabricated solar stills (a) Without glass cover and (b) With Glass cover [33].

The solar still with the PCM composite under the basin demonstrated the best performance, with the results indicating higher performance in solar stills equipped with the material.

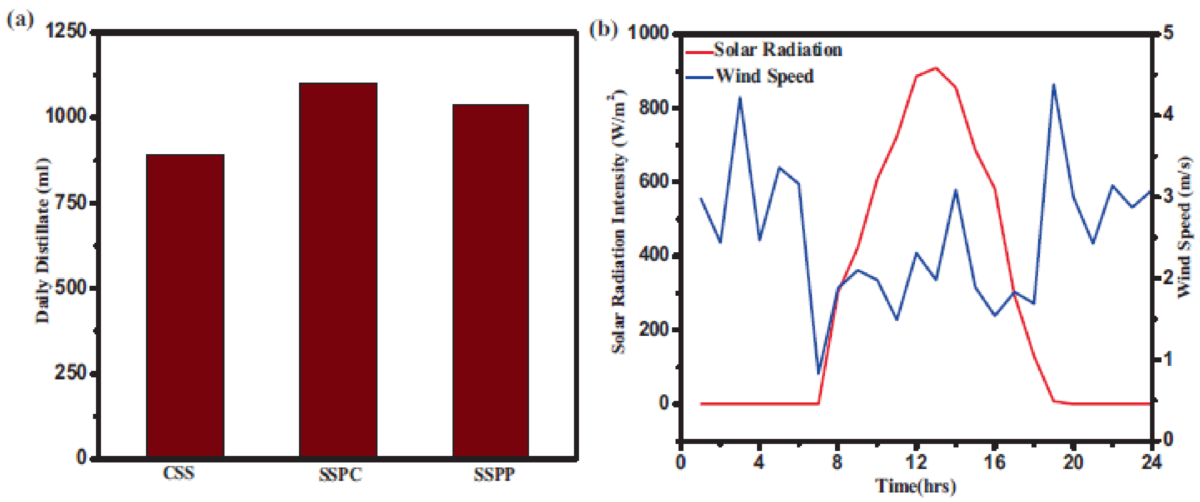

Figure 39. (a) Histogram showing daily distillate values of CSS, SSPC, and SSPP and (b) Measured Solar radiation and Wind Velocity at the location [33].

Evaluation of various adjustments in comparison

After the assessment of performance variables, which include cost, energy and energy efficiency, productivity growth, and distillate output, the comparison revealed that the changes (heat storage and trays) increased productivity and improvements. The nodes' energy efficiency increased using cap and nanofluidic cooling techniques. The tactics that demonstrated the lowest estimated cost were trays and nanofluids.

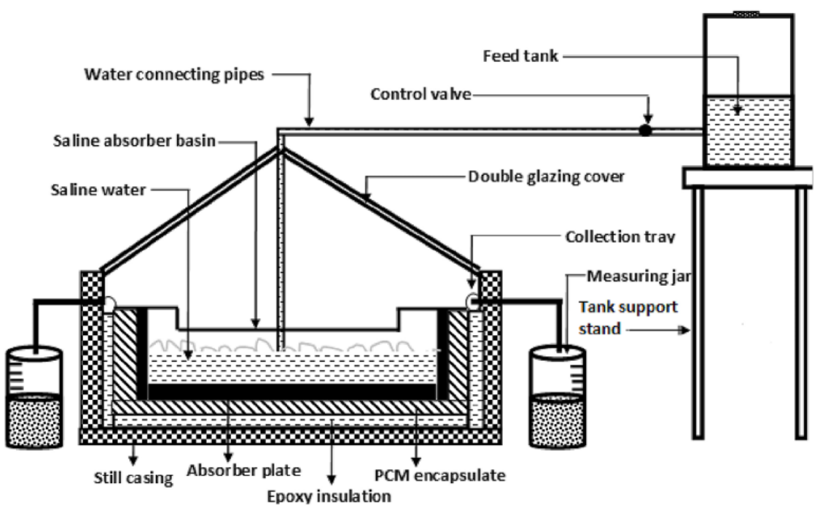

Figure 40. Cross-sectional view of double slope solar still with PCM encapsulate [12].

Table 1. Experimental works on the thermal performance of solar still.

Ref. No.	System Category	Maximum productivity L/m2/day	(ηth) %	(ηex) %	Percentage of improvement	Estimat ed cost USD/L
Hyal et al. [3]	23.6	68%	______	15-20	________	________
Alshqirate et al. [4]	5.1608	44.9	3.4	44.5	0.081	0.081
Sambare et al. [5]	5.23	35.1 %	8.1	41.35	0.00499	0.00499
Aly et al. [7]	6.78	61.59	4.14	41.26	0.017	0.017
Shah et al. [8]	2.1	26–30	9	10–12	_______	_______
Sahu and Tiwari [10]	3.480	24.49	______	11	.04	0.04
Toosi et al. [11]	Absorbing Materials witt SS	1.795	75	13.6	98	0.0162
Afolabi et al. [12]	Thermal energy storage	7.5	65	_____	14	______
Murali et al. [14]	SS using Nano fluids	3.176	68.29	4.27	22.06	0.087
Abu-Zeid et al. [15]	SS using Nano fluids	4.5	56.21	4.88	104.13	0.04
Singh [17]	optimized prerequisites	16.94	_____	8.4	4.6	0.07
Abdullah et al. [18]	SS with phase change material	3.130	62	____	17	0.018
Ramzy et al. [19]	Absorbing Materials witt SS	4.384	32.74	____	15	0.0034
El-Said et al. [20]	SS with wire mesh absorber	3.007	45	_____	30	0.008

Ref. No.	System Category	Maximum productivity L/m2/day	(ηth) %	(ηex) %	Percentage of improvement	Estimat ed cost USD/L
Wiener et al. [21]	SS using textiles and polyurethane rollers	1.14	62.16	7.67	21.46	0.023
Dumka et al. [22]	wick materials with SS	2.448	23.331	2.652	19	0.0146
Arifin et al. [24]	Thermal energy storage	1.275	25.76	17.54	8.22	0.04
Shareef et al. [25]	using slices absorber plate with SS	4.4	73	55	20	________
Atteya and Abbas [26]	SS with with different sand beds and reflectors	5.750	54.4	_____	92%	0.016
Soltanian et al. [27]	Fins	7.5-24	78.2	7.3	19.7	0.05
Shatar et al. [28]	SS with thermoelectric cover cooling	1.1	44	25	25	0.036
Shatar et al. [29]	various cover material	1.6544	23.6	7.04	76.3	0.042
Mohammed et al. [30]	pyramid type SS	3.415	31.7	________	35.3	0.0179
Angappan et al. [31]	solar collectors	5.5	75	1.2	41	0.0091

4. Conclusions and Recommendations

This review study presents the latest developments in solar stills and solar desalination systems with a focus on energy, exergy, and economic analysis. The main disciplines presented include the combination of multiple technologies in desalination to optimize heat sources, minimize costs, or maximize efficiency and the economic analysis, labor and energy consumption, and employment demonstrate the recent performance improvements of solar stills. Performance improvement strategies are compared based on the findings of previously published articles on solar stills. Advances include nanomaterial's, fins, shells and steps, filament materials, latent and sensitive heat storage materials, and cap cooling. The most important results can be drawn from the following overview and comparison:

- Using geothermal energy to condense fresh water allows increasing distillate production. As a result, the solar distillation system has a 104% increase in production compared to a conventional SS system. The maximum production is 24 L/m^2/day.
- stage solar still supplemented with a corrugated plate absorber and curved liner, PCM nanoparticles, and wicking materials can increase the distillate yield and thermal efficiency of the solar still to 16.94 L/m^2/day or 98% at an estimated cost of $0.008/L.
- The performance of SS is further improved by using covering and filament cooling materials with opposite effects, such as: B. Housing and heat storage materials (phase change materials).
- The use of PCM's square and circular hollow fins and the use of Nano fluids on the wicking material, complemented by a V-shaped corrugated basin, increased productivity by 19% and energy efficiency by 22% compared to conventional TSS.
- Productivity has been significantly improved by using heat storage systems in solar energy systems, with the increase exceeding about 15% compared to conventional systems.
- The maximum energy efficiency of 78.2% was achieved by using an integrated flat solar distillation device equipped with a super-hydrophilic glass cover, in addition to reflective mirrors containing nanomaterial's and ultrasonic sprays that function efficiently as humidifiers.
- The minimum cost to produce one liter of fresh water using solar desalination technology through wire mesh absorption, nanofluid, and phase change materials was $0.008 per liter.

It is recommended to expand research in the field of renewable energy with other desalination systems to reduce the cost of one liter of fresh water to meet the increasing needs of the population. This can be achieved by using phase change materials to store additional solar heat throughout the day, or by using nanoparticles to enhance heat transfer.

It is also advisable to use graded or corrugated absorbers to increase absorption efficiency. Additionally, the use of wick materials and mirrors is preferred as they enhance the evaporation process and absorb thermal energy more effectively.

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