Global NEST Journal, Vol 26, No 1, pp 05382
Copyright© 2024 Global NEST
Printed in Greece. All rights reserved

Solar still desalination techniques for the minimization of operational time and cost: a review

Vairavel Madeshwaren[a]*, Kathiresan Govindaraju[b], Suresh Thangavel[c] and Rajpradeesh Thangaraj[d]

[a]Department of Mechanical Engineering, Annapoorna Engineering College, Salem, Tamil Nadu, India

[b]Department of Mechanical Engineering College, Varuvan Vadivelan Institute of Technology, Krishnagiri, Tamil Nadu, India

[c]Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India

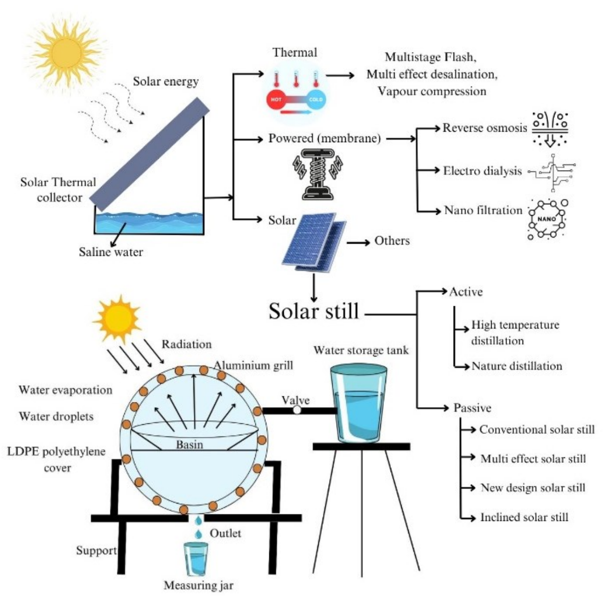
[d]Department of Mechanical Ensgineering, Kalasalingam Academy of Research and Education Krishnankoil, Tamil Nadu, India

Received: 11/09/2023, Accepted: 27/10/2023, Available online: 07/11/2023

*to whom all correspondence should be addressed: e-mail: phdannauniv2020@gmail.com

https://doi.org/10.30955/gnj.005382

Graphical abstract



Abstract

This current, comprehensive study of the literature provides a full review of recent developments in a variety of various kinds of solar stills. This review looks at studies on double-slope, hybrid solar stills, single-slope, with a condenser unit, and other particular types of solar stills. Along with a general review of the many types of solar stills, the writers also present a complete summary of the most recent research publications in the field to make the work more relevant to readers. This review study offers an overview of the various desalination techniques. The running expenses of desalination systems have not decreased over time, despite significant developments in the field. The cost of manufacturing desalinated water has been attempted to be lowered by the application of advanced technologies. The cost of producing desalinated water is significantly reduced when solar stills are used for desalination. In this review paper that follows, innovative designs and methods for solar still desalination are being used to increase daily productivity while lowering production costs. Numerous changes were tried to extend the residence time and surface area of water that could evaporate, but these changes did not cause the feed water to remain in the still's basin for an extended period.

Keywords: Solar still, desalination, active, passive, water surface, operational cost and time

1. Introduction

Water is a basic human requirement, and both industrialized and developing nations are struggling to maintain a year-round supply of high-quality drinking water. Industrial waste and sewage dumped into water bodies contaminate the water's cleanliness and cause fatal diseases in the underprivileged in developing nations. Therefore, it is imperative to take action to obtain pure water utilizing renewable energy. Only 1% of the water in natural sources is fresh and drinkable, 79% of it is salty, and 20% of it is brackish, according to a survey done on the issue. Many nations entrust the task of providing clean water to their residents to the rural areas. The brackish water is tried to distill. For this, many conventional techniques are popular. These include reverse osmosis, electroanalysis, thin-film distribution, multistage fresh evaporation, and multi-effect evaporation. However, these methods need a lot of energy and are not practical for collecting fresh water on a wide scale.

As part of the hydrologic cycle, the sun warms water from rivers, lakes, seas, and other big bodies of water, turning seawater into potable water. The solar energy is converted into short electromagnetic waves that move through transparent surfaces like glass during the solar distillation process. The basin still contains almost all toxins. The vapor cools and condenses into water droplets or a sheet of water on the underside of the colder glazing. The use of a thermocouple and a wooden box as insulation boosts freshwater output by reducing heat loss. There are both active and passive varieties of solar stills. The most popular kind of solar stills are passive solar stills, which only use sun energy to make distillate. Thermal energy collectors are one example of mechanical equipment used by an active solar system to supply hot water.

Photovoltaic (PV) technology is a fast-emerging field with rapidly falling costs. Furthermore, over the past few decades, a great deal more research has been done on combining this technology with desalination techniques. Additionally, using this method is a great way to supply small towns on isolated islands with access to the sea or brackish water with desalinated water. These communities are located in distant, dry areas. The solar system's extended lifespan, low noise level, simple maintenance, modular design, and lack of greenhouse gas emissions are among its many advantages. Typical electricity-dependent desalination techniques that might work well with this technology are reverse osmosis (RO) and electrodialysis (ED). In water-scarce areas, combining these techniques with solar PV systems shows a lot of promise for expanding water supplies.

2. Desalination process

The term "desalination" refers to the process of treating water that removes salts from brackish or seawater to create fresh drinkable water or water with a low total dissolved solids (TDS) content. Several methods can be used to desalinate water. Lee, Sangho, *et al.* (2019) the technologies for wastewater treatment that are most often used today are described in this section. Qasim, Muhammad *et al.* (2019) there are many different methods for purifying water, and both electric power and natural forces can be employed to accomplish the same thing. Thermal energy sources are used to heat the seawater during the phase shift or thermal process, which causes evaporation to produce condensed vapor and pure distilled water. Lin, Shihong (2019) the saline water is desalinated using the membrane method, which involves passing the water through a membrane with specific properties, such as porosity, selectivity, and electric charge, which allow the removal of ions from the saline water Darawsheh et al (2019). Figure 1 displays the various thermal and membrane-based desalination techniques.

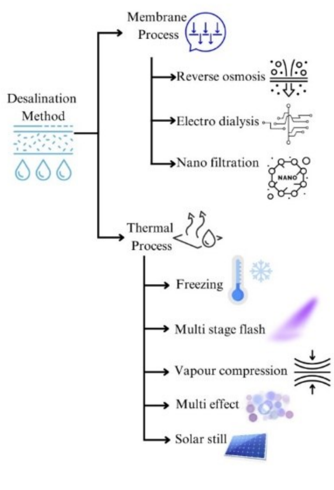


Figure 1. Methods of desalination process

An age-old technique for removing impurities and making saltwater potable is solar distillation. The procedure was described by Aristotle in the fourth century BC. In the 1960s, Dunkle *et al.* (1961) proposed and discussed the links between heat and mass transfer and showed how temperature and pressure affected the efficiency of a straightforward basin solar still. A summary of the theory underlying the many kinds of solar stills used in the 1970s was presented by Talbert *et al.* in 1970. Elsaid, Khaled, *et al.* (2020) the history of solar distillation in the 1980s was examined by Malik *et al.* (1982), who also discussed the improvements in the efficiency of several solar still types during that time. Desalination and renewable energy history have also been covered by Delyannis *et al.* (2003). Despite being utilized sparingly, solar still has been studied since the nineteenth century. When exploiting solar energy, two ways have traditionally been used. Koutsou, C. P., *et al.* (2020) one method involves directly absorbing energy from salt water, and the other involves heating water indirectly and letting it evaporate in a centralized facility.

The base water, which is seawater or brackish water, is heated to boiling during a phase transition or thermal process. When water is heated to a boil, salts, minerals, and contaminants are removed from and separated from the steam that results, and they are left with the base water. The condensed droplets of the steam's cooling and condensation melt to become drinkable water. Lower energy consumption is required for salt separation in membrane or single-phase processes because there is no phase transition (no heating to boiling). The three primary thermal desalination procedures are (i) MSF; (ii) MEF; and (iii) VCD, which may involve either MVC or TVC. The two primary membrane processes are ED and RO. Honarparvar, Soraya *et al.* (2020) for reverse osmosis to work, a pump that increases the saline solution's pressure to the required amount must be powered by electricity or shaft power. This water is desalinated by using the appropriate membranes at two electrodes with opposite charges, which is similar to electrodialysis, which also employs electricity to ionise water. All processes—thermal and membrane—require a chemical pre-treatment of raw seawater to avoid/prevent sealing, foaming, and fouling. They also requires a chemical post-treatment.

Apart from the thermal and membrane desalination procedures, there are two fundamental associative desalination techniques: freezing and ion exchange. In the 1950s and 1960s, these two desalination techniques piqued the curiosity of researchers. When ice crystals form during the freezing process, salts get separated, and cooling causes them to become desalinated. Cleanse the water once it has cooled but before the entire body of water freezes. Regenerative heat transfer, which has exceptional energy efficiency, occurs when something freezes then melts. Cations and anions are exchanged between organic and inorganic compounds during the ion exchange process. Demineralization is the result of this interaction. Since the year 2000, this procedure has been used in the industrial sector. Renewable and conventional energy sources are both compatible with the desalination plants.

3. Infrared technologies

As the name suggests, thermal technologies entail heating salt water and gathering condensed vapor to create clean water. Jadhav *et al.* (2021) due to the high expense, the thermal method is not used for brackish water desalination. Researchers assert that they have nevertheless been used to desalinate seawater. Feria-Daz, Jhon Jairo, *et al.* (2021) claim that they are frequently divided into the three groups of MSF, MED, and VCD. ZhiHong Zhang *et al.* (2019) the MSF, MED, and VCD distillation processes heat saline water to create water vapor, which is then condensed to create fresh water, starting the natural water cycle.

3.1. Multi-stage distillation (MSF)

The pressure at which each stage of the plant operates decreases over time. Ghazy, Mohamed, *et al.*(2022) the flashing of heated water into the pressure-reduced chamber produces a vapor that is known as the tubes run, which is cooled by the cooler feed water going in and falls into the trays as a hot freshwater product.

For more than a century, this technique has been used. This idea was discovered in the 1950s by Scottish inventor Weirs of Cathcart, who used it to create the MSF. Due to its economic scale and ability to run on low-grade steam, this had a significant impact on development and application during the 1960s. Rezk, Hegazy, *et al.*(2022) and Tayefeh, Mohammad (2022) currently, 64% of the world's desalinated water is produced by the MSF. The MSF is a reliable method, but the process is energy-intensive because it uses both heat and mechanical energy.

3.2. Multi-effect distillation (MED)

The multi-effect distillation process is the first type of desalination and, thermodynamically speaking, produces the most fresh water from seawater. The MED utilizes the notion of minimizing the ambient pressure with the effects ordered serially and operates in a sequence of evaporators referred to as effects. Assad, Mamdouh El Haj, *et al.* (2022) this enables seawater used as feed to boil multiple times without requiring additional heating after the initial effect. The saltwater is heated to the point of evaporation in the first effect after preheating.

Xu, Shiming, *et al.* (2022) the first effect's vapor is supplied into a network of tubes, where it condenses and warms the surface of the tubes. The heat from the condensation of the steam in the tube provides the energy needed to cause the saline water to evaporate. The next lower pressure stage (effect) receives the evaporated salty water with a smaller percentage of saline water, where it condenses to produce fresh water. Paixão, D. F. S., et al (2023) it uses some of the heat it produces in this process to evaporate some of the remaining seawater feed. This indicates that the seawater injected into the tubes in the first action is only partially evaporated. Hadavi, Hamed, *et al.* (2023) the residual feed water is fed to the second effect when it is applied to a tube bundle once more. Do Thi *et al.* (2023) the vapor is condensed to generate fresh water after heat is released to evaporate some of the remaining feed water. Shahzada, Aly, *et al.* (2023) this goes on for multiple effects up to 21 effects with a performance ratio of 10 to 18.

The top brine temperature (TBT) in a few plants has been designed to function at 70°C in the first effect, which decreases the risk of seawater scaling while increasing the additional heat transfer area in the form of tubes. Parsa, Seyed Masoud, *et al.* (2021) an MSF Plant uses more energy than a MED Plant, which uses less. Chen, Qian, *et al.* (2021) the MED plant has a greater performance ratio than the MSF plant. In terms of thermodynamics and heat transport, the MED is thought to be more effective than the MSF.

3.3. Vapour compression distillation (VCD)

The vapor compression distillation technique works in conjunction with other procedures including single-effect vapor compression and evaporation and multi-effect distillation (MED). The idea of vapor compression facilities is to lower the pressure by lowering the boiling point temperature. In the process known as vapor compression distillation (VCD), Wen *et al.* (2020) the heat needed for evaporation is predominantly produced by compressing the vapor. The mechanical compressor is often electrically powered, and solely electricity is utilized to distill water. Mallinak et al (1987) To put it another way, the compressor draws a vacuum from the evaporator before compressing and condensing the vapor it has drawn. Kelsey, Laura, *et al.*(2021) the feed sea water is sprayed onto the heat bundle's exterior, where it practically produces more vapor as it boils and evaporates.

The thermo vapor compressor (TVC) is the name for the steam jet type. By lowering the ambient pressure inside the main vessel, a venture hole at the steam jet generates and extracts water from the main vessel. Razmi, Amirreza, *et al.* (2019) while MVC units have a size range of up to 3000 m3/day, TV units have a size range of up to 20,000 m3/day. The biggest unit's energy usage is 8 kWm3. Sharan, Prashant, *et al.* (2019) both the MVC and the TVC units are used in drilling sites, businesses, and resorts. VCD is a straightforward and power-efficient method because of its low operating temperature. Scale formation and tube corrosion are reduced by the low working temperature (below 70°C).

3.4. Alternative/Associative processes

In the process of desalinating water, many procedures have been modified. However, no other approach has been as successful in commercializing as the MSF, ED, and RO. Alternative/associative approaches may be useful in terms of performance, cost-effectiveness, commercialization, and utilization in specific situations. Ion exchange solvent process and freezing are these processes.

3.5. Freezing

In the 1950s and 1960s, research on freezing was limited to finding ways to enhance the performance of products. The idea is that by cooling the water until crystals form under the predetermined circumstances, feed water or seawater can be desalinated. The dissolved salt in the feed water is excluded from the freezing process. The combination is washed and rinsed to get rid of the salts in the remaining water at the point of ice crystal formation (before the entire bulk of feed water turns frozen). After that, the ice crystals are melted to create fresh water. High energy efficiency is made possible by the regenerative nature of the freezing and melting heat transfer processes. In the latter half of the 20th century and the first half of the 21st century, several plants were constructed, although they were not financially viable. However, in Saudi Arabia, solar-powered desalting facilities using freezing technology were developed in the late 1980s. The freezing technique has a better use in the treatment of industrial waste in the second decade of the new century. The freezing method of desalination uses the least amount of energy and has less corrosion and scaling. Desalinated water created by the freezing technique can be utilized as drinking water and for irrigation. It does, however, require managing ice and water combinations.

3.6. Ion exchange: solvent process

Industrial effluent, seawater, and brackish water have all been effectively treated using ion exchange membranes. They are effective in treating pharmaceuticals that contain ionic species as well as in the production of simple chemical compounds. Aroussy, Youssef, *et al.* (2020) Ion exchangers are solids that can transform cations into anion in solution and vice versa. However, it cannot be used to treat and desalinate brackish or seawater due to the high initial investment expenses.

3.7. Reverse osmosis (RO)

RO is a membrane separation method for desalinating water that was originally commercialized in the early 1970s. In this procedure, feed water is filtered and pressurized before passing through a semi-permeable membrane, which allows water to pass through while keeping salt from clogging the passage. By passing over a membrane, this separation from the solutes (dissolved material) occurs without heating or phase change. Only pressurizing the supply of water through the membrane is what uses the energy. During this procedure, water crosses the membrane against its usual flow direction, leaving behind concentrated dissolved salts. Aly, Shahzada, *et al.* (2021) saline water delivery system: To filter out material, raw seawater is pushed via garbage bins and provided (traveling) screens.

3.7.1. Pre-treatment

It prevents fouling of the membrane surfaces, high-pressure pumps, and RO section, pre-treatment is crucial to the RO process. Using a multi-media gravity filter with the ability to remove particles larger than 0 m, the seawater is treated in this stage to remove debris, particles, and suspended solids. Through biological disinfection, chemicals like sodium hypochlorite are injected into the water to kill bacteria and algae and stop the proliferation of microorganisms. Sulphuric acid is also added to control the production of scale and to modify the PH, along with ferric chloride as a flocculant.

3.7.2. High-pressure pumping

To allow the water to travel through the membrane, a high-pressure pump must be used to supply the necessary pressure. The semi-permeable barrier allows water to pass through but blocks the passage of discharged salts. The concentrated brine water is dissolved by it. The pressure range of brackish water is 15 to 25 bars, while the pressure range of seawater is 54 to 80 bars.

3.7.3. The RO membrane separation modules

Only a limited quantity of salts pass through a RO membrane, despite the fact that in theory it should be semi-permeable and have a high water permeability, providing an impenetrable barrier to salts. A membrane has a large surface area for the greatest flow. Some membranes have discharge pressures of up to 84 kg/cm2 and can function as pumps. The pressure for seawater varies from 54 to 80 bars.

3.7.4. Post-treatment

The water is stabilized by the post-treatment. To meet the requirements for drinkable water and to remove dissolved gases such as hydrogen sulfide and carbon dioxide, the line is added. When opposed to MSF and MED procedures, material corrosion issues in RO processes are less common. Instead of metal alloys, polymeric materials are used. running membranes and the use of energy recovery devices lower the running costs of RO plants. In the 1990s, two improvements happened that helped lower the operational costs of RO plants.

1) The employment of energy recovery devices and the creation of more effective membranes. 2) The most recent membranes have higher water flux rates per unit area, better salt rejection, lower costs, and longer useful lives. However, some of the drawbacks that need to be fixed/remediated include the need for a significant amount of raw water, the membrane scaling brought on by salt precipitation, and the susceptibility of membranes to fouling.

3.8. Electro dialysis (ED) and electro dialysis reversal

By using electrical currents to move salt ions through a membrane during the electrochemical separation process known as electrodialysis (ED), drinkable water is produced in the process's byproduct. The original purpose of ED was to desalinate seawater. However, it has traditionally been used with brackish water. The membrane stack, pre-treatment system, post-treatment system, power supply for the direct current rectifier, PV system, and low-pressure circulation pump are the essential parts of an ED unit. These theories serve as the foundation for how electrodialysis functions. These ions go in the direction of the electrodes with the opposite electric charge because like poles repel one another and unlike poles attract one another. The concentrated water (brine) is left behind as the feed water passes through the membranes and produces a steady stream of desalinated water. In other words, the positively charged electrode rejects cations while allowing anions to flow through the anion-permissible membranes. The negatively charged electrode rejects anions while allowing cations to pass through the cation-acceptable membranes. The membranes desalinate the input water as it passes through them, producing the product water while discarding the brine.

Although the productive channel and brine channel in electrodialysis reversal (EDR) are the same as those in an ED plant, it is a variation of the basic ED process. Doctorate polarity fluctuates throughout time, which reverses the flow through the membranes. It is avoided to build channels to the feed water. This increases the viability of the self-cleaning process. In reality, because the EDR is self-cleaning, it only needs a minimal amount of feed water pre-treatment and chemical addition for membrane cleaning. With a salinity of up to 12000 ppm TDS, brackish water is better suited for the ED process.

3.9. Photovoltaic modules in solar still

Materials and technology used in photovoltaic (PV) systems directly convert solar radiation into electrical energy. The core component of the SPV system is the solar cell. Alexander Becquerel's 1839 discovery of the photoelectric effect served as the foundation for the convergence approach. The photoelectric effect illustrates how positive and negative charge carriers are released when light touches a substance. It is only a P-N junction diode, nothing more. Typically, a single SPV cell has a power output of only one or two Watts. These fragile, thin cells are made of a variety of semiconductor materials. For long-term weather resistance, SPV cells are sandwiched between glass and/or polymer-based protective coatings. The interconnections are determined by the desired voltage and current levels. The electrical grid is then connected to one or more arrays as part of a complete SPV power production system. Because SPV systems are modular, they may be designed to meet almost any size of electric power requirement.

Solar cells may create power in two ways. The first technique absorbs input light photons to produce electron-hole pairs. Since the incoming photon has greater energy than the band gap of the SPV cell material, electron-hole pairs permeate into the solar cell. However, electrons and holes are metastatic and, on average, only persist for the duration of the minority carriers' lifespan before recombination. If the carriers recombine, the electron-hole pairs generated by light will be lost, and no current will flow and no power will be generated by SPV cell. The second method is for the *P-N* junction to gather these carriers. This recombination is prevented by spatially isolating the electron and hole through a *P-N* junction where the action of the electric field alienates the carriers. If the minority carrier produced by light reaches the junction, it is floated over it by the electric field and becomes a majority carrier. The light-generated carriers flow via the external circuit if the solar cell's emitter and base are shorted.

There are two ways solar cells can produce power. In the first method, electron-hole pairs are created by absorbing photons of incoming light. Electron-hole pairs enter the solar cell because the energy of the incoming photon is higher than the band gap of the material used in the SPV cell. On the other hand, holes and electrons are metastatic and usually only survive as long as the minority carriers do before recombining. The electron-hole pairs produced by light will be lost if the carriers recombine, and the SPV cell will stop producing power and current. The P-N junction can collect these carriers as the second technique. By spatially separating the electron and hole through a P-N junction, where the action of the electric field alienates them, this recombination is avoided.

4. SOLAR stills and their types

Salty or brackish water is desalinated using solar radiation. Simple desalination technology without any moving parts. A gloomy basin with feed saline water at the bottom is encircled by a transparent glass cover at the top of a solar still. The complete system has airtight insulation at the bottom and sides, as shown in Figure 2. Solar energy is gathered by the glass cover's outside surface and then sent into the solar still, where it is absorbed by the basin's blackened surface. Warming up, evaporating from the basin, and condensing on the inside surface of the glass, the salty water in the basin separates the microbes and salts from the pure distillate. The efficiency of solar still will increase if there is a sustained large temperature differential between the evaporating and condensing surfaces and there is little vapor loss.

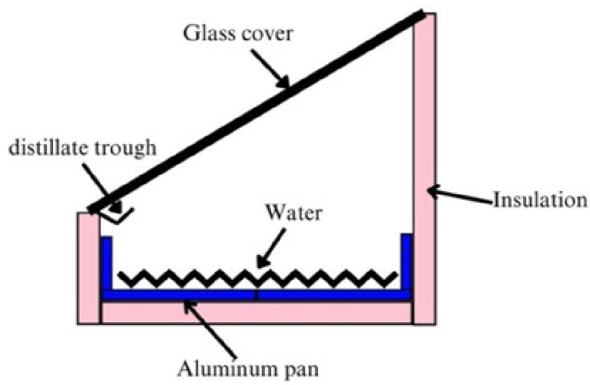


Figure 2. Solar still

According to the table below (Figure 3), solar distillation is divided into different categories based on the processes involved, the experimental setting employed, and the shape and design of the solar still. However, with active solar still, the rate of evaporation and condensation is further increased by including additional sources into the already-existing desalination system, such as reflectors, solar collectors, and condensers.

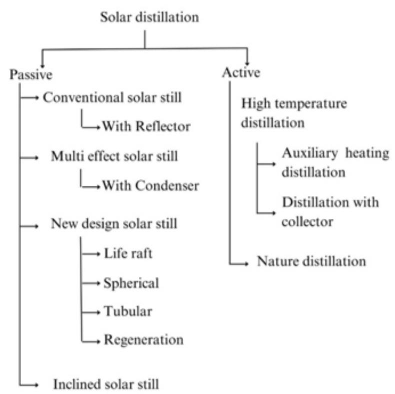


Figure 3. Classification of solar stills

The various kinds of solar stills that are used have already been covered in these. This section examines in detail the many designs of single-basin, newly developed, and stepped solar stills that are presented in the literature.

4.1. Basin solar stills

Several researchers changed the design of the single-basin solar still to improve productivity. Additional subcategories of basin sun stills include double slope basin solar stills, triple basin solar stills, and inverted multi-basin solar stills.

4.2. Double slope basin solar still

Murugavel *et al.* (2008) as seen in Figure 4, a single basin, double slope simulation solar still was created. In this instance, the two slopes of the glass were used to collect the distillate. Fathy *et al.* (2018) the trials are carried out for three systems—a solar still with fixed PTC, a solar still with tracked PTC, and a conventional solar still—as well as for two scenarios of saline levels in the basin of 20 and 30 mm during the summer and winter seasons. The findings show that PTC-equipped solar stills outperform conventional solar stills in terms of productivity and sill temperatures. Gnanaraj *et al.* (2018) to modify the façade, an exterior mirror was placed. Productivity was slightly increased by internal modifications. Productivity significantly increased when both internal and external improvements were achieved. In comparison to a solar still with no alterations, the efficiency of the double-slope single-basin solar still with both external and internal adjustments was 53.89% greater. Jani *et al.* (2019) in 35°N and 89°E, the double slope single basin solar still was tried. For the circular fin and square fin solar stills, the production was assessed for differences in water depth in the basin.

According to Gnanaraj *et al.* (2019), the traditional still produced 1880 ml/m2•d of distillate each day. The distillate output of the stills with finned corrugated basins, black granite stills, wick stills, reflector stills, and stills with all external and internal alterations. These numbers exceeded the conventional still's production by respective margins of 58.47, 69.84, 42.33, 93.3, and 171.43 percent.

Modi et al (2021) glass covers with East- West and North-South orinetations were used during the trials. Al2O3 nanoparticles improved the distilled output of the still by 19.67%, 32.21% and 39.21%, respectively for the water depths of 10 mm, 30mm, and 20 mm for the North-South orientation.

Elmaadawy and Khaled (2021) a thermal and economic analysis of the system was performed by computing energy and exergy efficiencies as well as production costs. The results showed the intended improvements in each circumstance, and the MDSSS-III produced the best outcomes. The yield, typical energy efficiency, and typical exergy efficiency in this case all improved by 68, 50.6, and 146.3% in comparison to CSS. Essa (2020) the basin liner and fins of the solar still were covered with a 2.3 cm coating of silica gel.

4.3. Triple basin solar still

Two glass sheets are placed between a single-basin still's glass lid and basin liner in Sebaii *et al.*'s produced triple basin still (Figure 5). Kabeel *et al.* (2018) according to the experimental findings, a graphite-based single-basin still generates greater daily output than a typical single-basin. A single-basin still that used graphite produced about 8.76 l/m2 per day as opposed to the average 5.90 l/m2 per day. Compared to a typical single-basin still, daily manufacturing of the single-basin still using carbon as a useful storage material is higher.

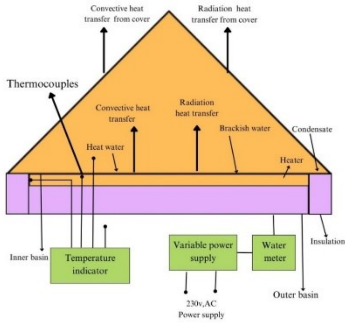


Figure 4. Single basin double slope simulation still

Manokar and A. Muthu (2018) the performance of the Inclined Solar Panel Basin (ISPB) in active and passive modes with and without the Flat Plat Collector (FPC) is compared in the current study. The active and passive modes, with daily yields of 6.3 and 8.2 kg, respectively, produce the highest yields. The daily efficacy of the active mode is 46.87% and 6.6% whereas the daily efficacy of the passive mode is 39.82% and 2.9%, respectively.

Srithar and Rajaseenivasan (2018) this article discusses recent developments in the solar still with dehumidification and humidification desalination systems employing renewable energy sources to increase the rate at which fresh water is produced.

Al-harahsheh and Mohammad (2018) in this study, water was desalinated experimentally using a solar still outfitted with PCM and connected to a solar collector. The amount of desalinated water produced rose directly as the temperature and hot water flow rate increased. Additionally, the maximum unit output was achieved at a cooling water flowrate optimum of roughly 10 ml/s.

Ghandourah and Emad (2022) in the current study paper, it is show how using corrugated plates could expand the evaporation area and boost PSS production. Because the absorber plate is made of a corrugated sheet, it is referred to as a pyramid solar still with a corrugated absorber plate (PSSCAP). Mevada and Dinesh (2022) in this experimental work, an effort was made to increase the distillate production and efficiency of SS by utilizing the excellent absorption and heat transfer ability of ESM. For SSWESM and CSS, the daily distillate yields were 2.3 kg/m2 and 3.2 kg/m2, respectively. Because it boosts water evaporation during the day and releases heat at night, the ESM generates more distillate than the CSS.

Sharshir and Swellam (2022) the MTSS and conventional TSS (CTSS) were evaluated about several factors, including thermal energy efficiency, freshwater output, energy efficiency, and total heat transfer coefficient. According to the findings, the productivity of freshwater was increased by 28, 59.2, and 82.5% depending on the order of the cases.

Gnanaraj *et al.* (2022) examined how quickly production values and temperature parameter values changed as the number of sunshine hours increased and decreased as the main objective. The heat-storing substance in the still increased production by 23.08% over the standard still. But the still with the reflector had a 62.97% increase in production.

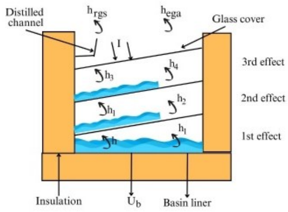


Figure 5. Triple Basin Solar still. (Source Sebaii *et al.* 20051)

4.4. Multi-basin inverted solar still

To raise the water temperature and decrease bottom heat loss, Suneja and Tiwari (1999) created the inverted absorber multi-basin solar still depicted in Figure 6.

Patel *et al.* (2020) in the ongoing study, a CTBSS that uses EVHPP, CS as an absorber, and SHSM is experimentally tested.

Modi *et al.* (2020) the performance of the spherical basin solar still has been examined for a variety of water masses, including 5 L, 4 L, 3 L, 2 L, and 1 L in the basin. For 5 L, 4 L, 3 L, 2 L, and 1 L water masses, the daily yields in the basin were 9.9034 L/m2, 8.7832 L/m2, 7.7678 L/m2, 5.8937 L/m2, and 3.8974 L/m2, respectively.

Kumar and Vishwanath (2015) the current study aims to describe the design requirements and emphasize the benefits and drawbacks of several solar stills that have been the subject of research in the recent past. Additionally, a discussion of potential future developments is provided, along with some suggestions for enhancing solar stills to more efficiently generate potable water.

Sharshir and Swellam (2022) experimental data were collected and examined to determine the impacts of adding nanoparticles and ultrasonic foggers to a modified pyramid solar still (MPSS) with evacuated tubes and an external condenser in comparison to a conventional pyramid solar still (CPSS). The statistics show that the levels of freshwater produced by MPSS, which employs six evacuated tubes and an external condenser, are 91.09%, 18.48%, and 45.26% greater than those of CPSS.

Chauhan and Vikash Kumar (2021) extensively studied how to improve solar desalination technology by using new nanocrystals and phase change materials (PCM) to increase the output and efficacy of solar stills. Chaurasiya and Prem Kumar (2022) in this study, the impact of different altered designs is examined. It is clear that among all the design modifications, the Fresnel lens merged with single-slope single-basin passive solar still enhances output by 732.89%. When hybrid solar and a PV/T collector are used together, production is increased by 370 percent.

Arunkumar (2019) a simple device called a solar still uses solar energy to evaporate and condense water to purify it. Between 2 and 5 l/m2/day are commonly produced by the common solar still (CSS). Somwanshi et al (2023) the performance of CLIWSS has been calculated for November and June in Gujarat, India. The storage tank enhances the distillation of water during the night. The maximum hourly distillate production of the planned still is 2.345 L/m2/h for May and 3.213 L/m2/h for December.

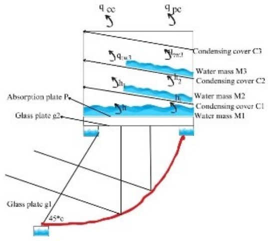


Figure 6. Inverted absorber multi-basin solar still. (Source: Suneja and Tiwari 1999)

4.5. Innovative solar stills

To increase productivity, several researchers adjusted the geometry of solar stills in their design. The following subcategories of newly designed solar stills can be made based on their design: Spherical, Pyramid, and Tubular solar stills.

4.6. Spherical solar still

A straightforward spherical and pyramid solar still with low thermal capacity, small weight, low cost, and simple operation was created by Jayaprakash *et al.* (2009) and is depicted in Figures 7 and 8.

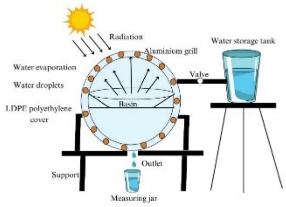


Figure 7. Spherical solar still. (Source: Jayaprakash *et al.*2009)

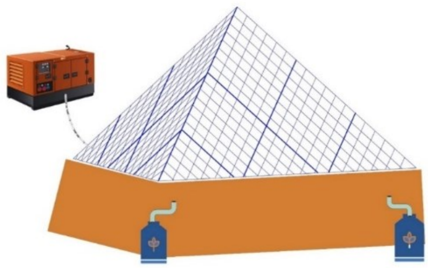


Figure 8. Pyramid-shaped solar still. (Source : Kabeel *et al.* 2009)

4.7. Tubular Solar still

According to Figure 9, Tiwari and Kumar (1988) created a tubular solar still with a rectangular black iron tray resting on a glass tube.

4.8. Stepped solar stills

To increase productivity, several researchers updated the Stepped solar stills' architecture. Stepped solar stills can be further divided into the following categories according to design:

- Cascade solar still

- Tilted wick type solar still
- Steeped solar still
- Improved wick type-basin solar still

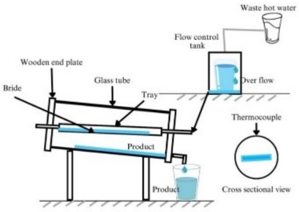


Figure 9. Tubular solar still. (Source: Tiwari and Kumar 1988)

4.9. Cascade solar still

According to Figure 10, Ziabari *et al.* (2013) created a cascade-style solar still with negative stairs to lengthen the duration of the waterfalls.

4.10. Wick-type solar still

According to Figure 10, Mahdi *et al.* (2011) created a tilted wick-type solar still using charcoal cloth as a wet wick material to wet the entire Stepped absorber surface.

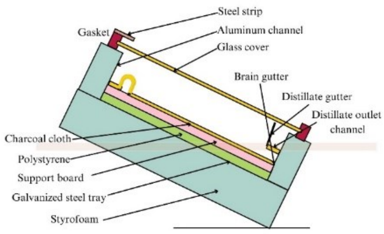


Figure 10. Tilted wick type solar still. (Source: Mahdi *et al.* 2011)

4.11. Steeped sunlight still

In experiments, Omara *et al.* (2013) used the immersed solar still with internal reflectors seen in Figure 11. Here, two stills of identical size have been created, one of which has a flat absorber plate and the other a steep absorber plate.

4.12. Improved wick type-basin solar still

Figure 12 depicts the improved wick-basin solar still created by Minasian *et al.* (1994). In order to increase the total distillate productivity of the integrated solar desalination system, a basin-type sun still and a stepped wick-type solar still were combined in this study. This system was created to recover the waste heat that was lost from the Stepped solar still and was used to power the basin sun still, which was kept in cover and shade.

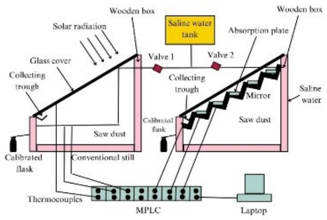


Figure 11. Schematic diagram of the conventional and stepped solar still with internal reflectors. (Source: Omara *et al.* 2013)

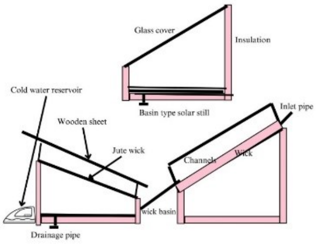


Figure 12. Improved wick-basin type solar still. Source: Minasian *et al.* 1994)

5. Advantages of stepped solar stills over basin stills

Water will be still on a level absorber plate in a basin, but it will flow down an inclined absorber plate in an inclination still. In an inclined still, as opposed to a basin still, the longer flow of feed water enhances the evaporation rate and distillate production. The ability to concurrently create hot water and freshwater distillate gives the inclined still an edge over basin stills. Comparing inclined stills to basin stills, there are two key advantages. To raise the distillate output in basin stills from 2.5 liters/m2/day to 3.5 liters/m2/day—which is insufficient for the average person's daily consumption—several adjustments were performed. According to Prakash *et al.* (2015), Table 1 compares the distillate productivity of basin and stepped-type solar stills in the literature. Stepped stills have some advantages over basin stills that result in higher productivity for the same collector area. For this reason, the performance of Stepped type solar stills was thoroughly reviewed in the next section.

6. Advances in research in stepper-type solar stills

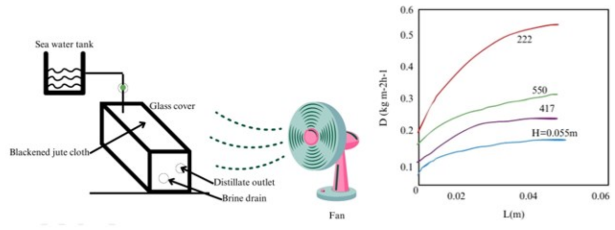
The output of Stepped-type solar stills has also been the subject of numerous investigations. The important research initiatives made to improve the functionality of Stepped-type solar stills are summarised in this section.

Table 1. Comparison in productivity for basin and Stepped type stills

The type of step still	Researcher and testing place	Specifications of Stepped still	% increase in productivity from the basin still
Steeped type still	Omara *et al.* (2013), Egypt	Basin area =0.3x0.4 m^2	47%
Wick-type solar still	Aybar *et al.* (2004), Cyprus	Glass cover = 4 mm. Still inclination =40°	60%
Cascade-type solar still	Ziabari *et al.* 2013, Africa	Glass cover = 4 mm. Basin area =2.36 m^2	34%
Improved wick-basin type still	Minasian *et al.* (1992), Iraq	Glass cover = 5 mm. Cover inclination =20°. Wick = Jute cloth. Basin area =2.5x1.69 m^2	75%
Weir-type solar still	Sadeini *et al.* (2006), Las Vegas	Still inclination =25.6°. Basin area =2.7x1.45 m^2	30%

6.1. Design, operational and climatic parameters

In a thorough examination and analysis using artificial simulation on solar stills of the wick type, Yeh Ho-Ming Yeh *et al.* (1986) documented the impacts of metrological and operational parameters on the distillate productivity of the system. The system was tested with various insulation thicknesses and a cover plate inclination of 10° to further increase output. According to experimental findings, solar stills without insulation produced less distillate per unit time than solar stills with insulation. The experiment's wick-type Stepped solar distiller is depicted in Figure 13 a and b shows how the productivity of the distillate is affected by the thickness of the insulation.



(a) (b)

Figure 13. (a) Schematic diagram of a Stepped wick-type solar distiller with artificial simulation. (Source: Ho-Ming Yeh *et al.* 1986). (b) Effect of insulation thickness on distillate productivity. (Source: Yeh Ho-Ming Yeh *et al.* 1986)

Phillips Agboola *et al.* (2012) conducted experiments that discovered that the daily distilled water obtained during the summer season was 6.41 kg/m2, which was extremely high and about twice as much as the daily distilled water collected during the winter season (3.327 kg/m2). The daily efficiency was determined to be 52.4% during the summer season and 43.6% during the winter. The experiment's Stepped water desalination system is depicted in Figure 14.

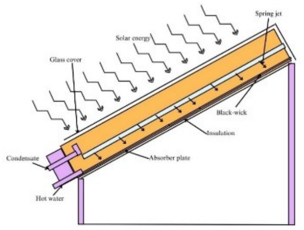


Figure 14. Schematic diagram of Stepped solar water desalination system (ISWD). (Source: Agboola *et al.* 2012)

6.2. Water mass flow rate and incline angle

Aybar et al (2005) . produced and tested stepped solar water distillation system performance. The investigations were tested and conducted using various mass flow rates of saline feed water. On the Stepped absorber plate, different kinds of wick materials were used to increase the distillate production. This Stepped solar still produces hot and fresh water simultaneously, in contrast to traditional sun stills. According to the experimental findings, the productivity of distilled water increases with lower mass flow rates and by up to three times when wick material is utilized on a stepped absorber plate. The experiment's Stepped water desalination system is depicted in Figure 15.

Two-stepped solar stills were the subject of tests by Sheeba *et al.* in 2012. In one Stepped still, wick material was utilized, but not in the other Stepped still. Different inflow water mass flow rates and inclination angles were used to test how well the Stepped solar stills performed. Based on the investigation, it was discovered that for low mass flow rates of water and an inclination angle of 26°, the distillate productivity was high. When compared to non-wick-stepped solar stills, the production of the distillate increases by twofold in wick-stepped sun stills.

6.3. Use of wick material

Sodha et al (1981). did an experimental and theoretical analysis of the performance of a multiple-wicks-stepped type solar still distiller. The feed water's surface area was increased by the capillary action of the blackened wet jute cloth material used in this solar still. Murugan and Saravanan (2020) the current study's objective is to conduct an experimental analysis of the SPSS's (square pyramid solar still) performance using various vertical wick materials. According to the findings, productivity levels in a basin with a water depth of 2 cm were accordingly 14.4%, 23.1%, 31.3%, and 39.6% greater than those in a basin with a water depth of 3 cm, 4 cm, 5 cm, and 6 cm.

Ramalingam and Vignesh Kumar (2021) a 1-year-old dried coconut coir disc's heat transfer coefficient, porosity, absorbency, and capillary rise were found to be 73.25%, 2 seconds, 10 millimeters per hour, and 37.21 W/m2K, respectively. Compared to other discs composed of coconut coir, these figures are higher. Essa *et al.* (2020) researchers looked examined how well the modified solar still performed while the revolving discs rotated at different speeds. The freshwater distillate produced by the disc distiller outperformed that of the traditional distiller, according to the results.

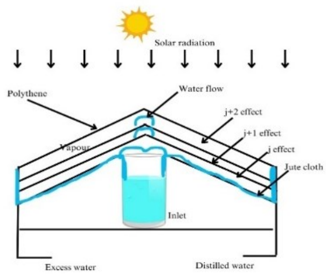


Figure 15. Sectional view of double slope triple effect wick type still. (Source: Singh and Tiwari 1989)

Abdullah (2023) the primary goal of the current investigation is to determine how different hessian wicks made of jute, cotton, plush, and silk fabric affect the operation of cables pyramidal solar stills (CPSS). According to the results, CPSS had an overall yield of 8000 mL/m2/day as opposed to 3550 mL/m2/day for PSS. In comparison to the PSS, the CPSS yield incremental improvement was 125%. Tuly (2021) numerous research projects have been launched and are continuously being worked on to improve an SS's FWY. This is achieved by introducing numerous changes to the layout and design of SS and by enhancing the functional and design criteria, such as active SS with solar photovoltaic.

A simple thermal study was performed by Singh and Tiwari (1989) on the triple effect multi-wick solar still depicted in Figure 2.18. The findings indicate that three effects at a flow rate of 10-2 kg/sec in the second and third effects are the ideal number.

6.4. Specially designed wick-type solar stills

Researchers have proposed a variety of wick-type solar still systems to boost distillate output. The several wick-type solar still designs include the following:

- Wick-basin type (Minasian and Al-Karaghouli 1995)
- (Yeh Ho-Ming *et al.*, 1986) Basisn wick type
- Multi-effect type (Ohshiro *et al.*, 1996)
- Stepped-wick construction (Aybar *et al.*, 2005)
- Tilted-wick floating cum type (Janarthanan *et al.* 2006)
- Flat plate reflectors with a tilted wick design (Tanaka Hiroshi and Yashuhito 2007)
- V-type solar still uses wick as an absorbent material Wick type with fin for a single basin (Velmurugan *et al.* 2009)
- Wick type with a double slope (Murugavel *et al.* 2008)
- Concave wick-type (Kabeel *et al.*, 2009)
- Wick-type clothing movement (Helmy *et al.* 2011)

A DC motor was used to drive the cloth wick's rotation. When the motor was turned off, the cloth wick was left out in the sun, and when it was turned on, the wet fabric was submerged in water. By linking it to a microcontroller chip for high-speed data storage, a computer is created. The studies were carried out under various motor ON and OFF period circumstances. The distillate yield and thermal efficiency of the still were found to be at their highest with an ON period of 30 seconds and an OFF time of 25 minutes, according to the data. The concept for a stepped solar still with a cloth-moving-wick construction is shown in Figure 16.

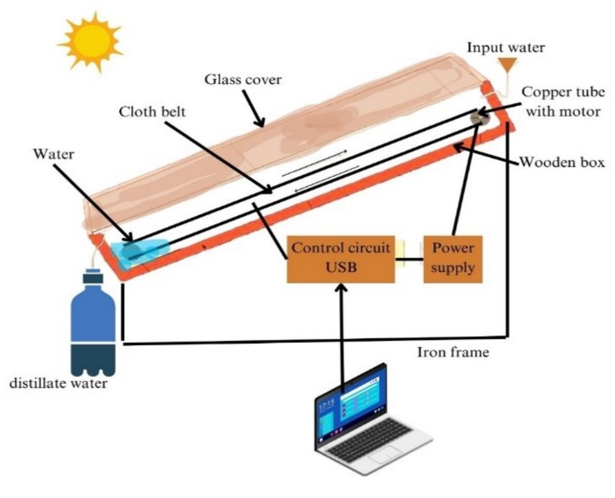


Figure 16. Cloth moving wick type Stepped solar still

6.5. Impact of water spraying against glass cover

Dhiman and Tiwari (1990) looked at the effects of water flowing over the glass cover of a multi-wick solar still. In this case, the water is made to flow over the inside surface of the glass cover to increase the temperature difference between it and the water in the still. This water-cooling effect led to an approximate 10% improvement in distillate production in the multi-wick solar still. The multi-wick schematic diagram is shown in Figure 17. Water was running over the glass lid of the stepped solar still.

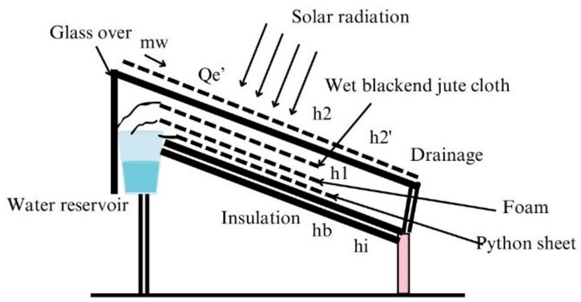


Figure 17. A multi-wick still shown in schematic form with water pouring over the glass cover. (Source: Dhiman and Tiwari 1990)

In an experiment on the performance of tilting solar still by Janarthanan *et al.* (2006), the wick material was produced to flow over the water surface as depicted in Figure 18a. The research revealed that for both slanted and floating wick surfaces, there was little variation between the theoretical and experimesntal values. Maridurai (2022) in the current study, paraffin wax is combined with solar stills and flat plate collectors (FPC). Heat energy is provided during periods of low solar radiation using phase change material (PCM)-based heat storage and FPC imitation as a preheater. Higher productivity of water is shown at shallower depths. With FPC and heat storage, productivity still rises to 22%, while the peak yield rises by 15%.

Abd Elbar *et al.* (2020) utilising solar power, the salt water is heated even more. The system's efficiency is also evaluated in relation to the black steel wool fibres present in the still basin. According to the findings, preheating 40, 50, and 60% of the salty water boosts a solar desalination system's freshwater yield by 10.4%, 15.5%, and 20.9%, respectively. Additionally, it increases energy efficiency by 8.2%, 13%, and 20% while increasing productivity by 26.86%, 33.51%, and 60.64%. Kamlesh and Pansal (2020) a review study illustrates research on the single-slope and double-slope active solar stills with solar photovoltaic.

Hassan and Hamdy (2020) the annual increase in energy and exergy output over CSS is enhanced to a maximum of 216.6% and 325%, respectively, with CSS + SD + PTC. Manokar and Muthu (2020) the AISPBSS was the subject of research using a varied mass flow rate of water (mf). The greatest freshwater yield at mf at 1.8, 3.2, and 4.7 kg/h is, respectively, 7.5, 6.5, and 5.4 kg. Hashemi *et al.* (2022) a comprehensive analysis of the integrated solar still's energy, efficiency, economics, and environmental (4E) impacts is used to experimentally characterize the device in its normal functioning. Figure 18b shows the theoretical and present experimental efficiency.

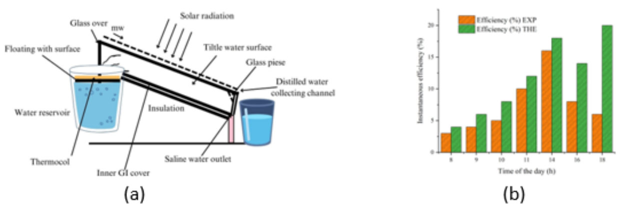


Figure 18. (a) image of the still cut in half, displaying the water's flow over the windows. (Source: Janarthanan *et al.* 2006). (b) A cutaway view of the still reveals water pouring over the glass coverings. (Source: Janarthanan *et al.* 2006)

El-Samdony *et al.* (2014) conducted a theoretical investigation of an immersed solar still with a cooling water film over the glass cover. The performance of an immersed solar still with a water cooling layer and a typical basin solar was compared in this study. Figure 19a depicts the schematic for the basin solar still and immersed solar still with water film cooling. Figure 19b shows the variation in distillate productivity for the basin and immersed solar stills.

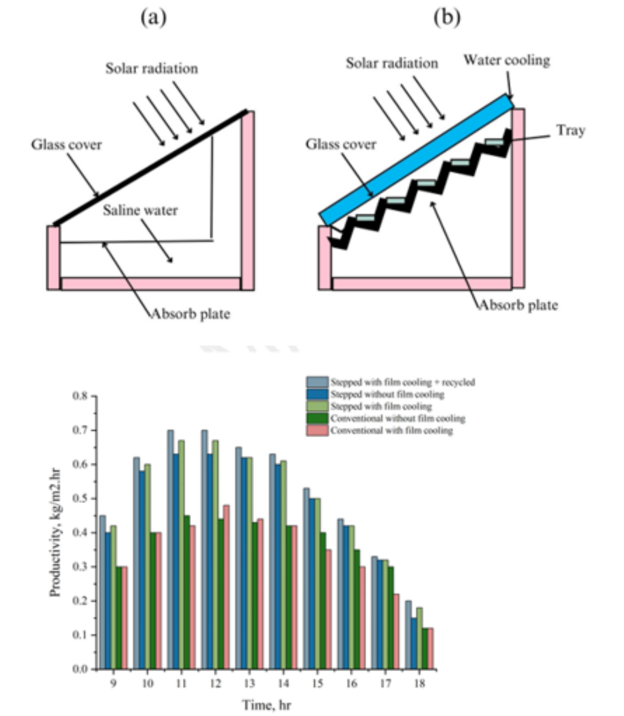


Figure 19. (a) Schematic of the basin and steeped solar still with water film cooling. (Source: El Samdony *et al.* 2014). (b) Distillate productivity varies for basin-style and immersed solar stills. (Source: El-Samdony *et al.* 2014)

6.6. Absorber plate design

A weir-type Stepped solar still, like the one in Figure 20, was the subject of a 2008 study by Sadineni *et al.* The Stepped absorber plate in this system, which is made up of several weirs, regulates the flow characteristics of the saline water input. This unique configuration of weirs in the absorber plate boosts production by 20% compared to a straightforward basin solar still.

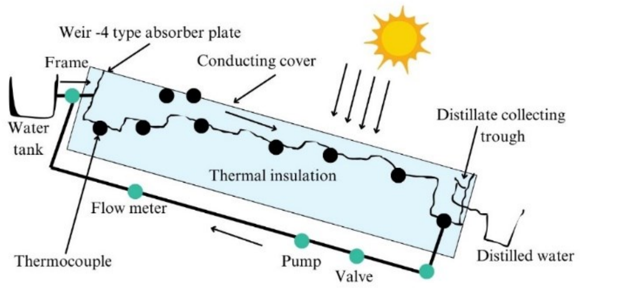


Figure 20. Schematic diagram of the weir-type Stepped solar still. (Source: Sadineni *et al.* 2008)

A corrugated immersed solar still's effectiveness was investigated by El-Zahaby *et al.* in 2011. In this arrangement, a reciprocating feeding mechanism shot saline water droplets into the corrugated immersed solar still. With its unique set-up and absorber plate design, the still can produce 6.355 liters of distillate per square meter every day.

6.7. Sun tracking technique and tilt angle

Tanaka *et al.* (2009) investigated a vertical flat plate reflector-mounted tilted-wick solar still for one-step azimuth tracking, as shown in Figure 21. In this study, the solar still was set up to rotate once throughout the day while facing the sun's position in the south. The performance of the still was theoretically examined by assessing its mass and heat transfer parameters. The still was configured with an ideal tilt angle and was coupled with a vertical reflector to receive the maximum solar energy. On the summer solstice, the daily distillate productivity was at its highest and was 57% higher than that of the traditional tilted-wick solar still.

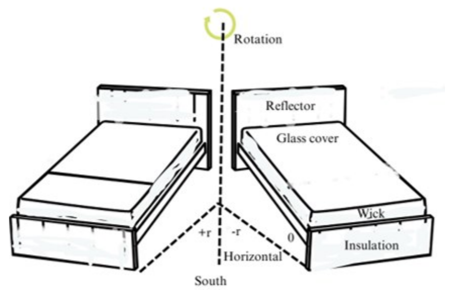


Figure 21. Schematic diagram of tilted-wick solar still. (Source: Tanaka *et al.* 2009)

6.8. Impact of materials for energy storage

Figure 22 shows that Velmurugan *et al.* (2009) investigated the effectiveness of a stepped solar still for the desalination of wastewater. The larger and finer effluent particles were settled down in this tank's three layers of pebble, coal, and sand. The settled effluents were then kept in a storage tank and fed into a steeped solar still from there. Sponge and pebbles were utilized as sensible energy-storing materials in the fin-type stepped still to increase productivity. The production of the distillate was twice as high for this configuration as compared to a typical stepped solar still, according to the results.

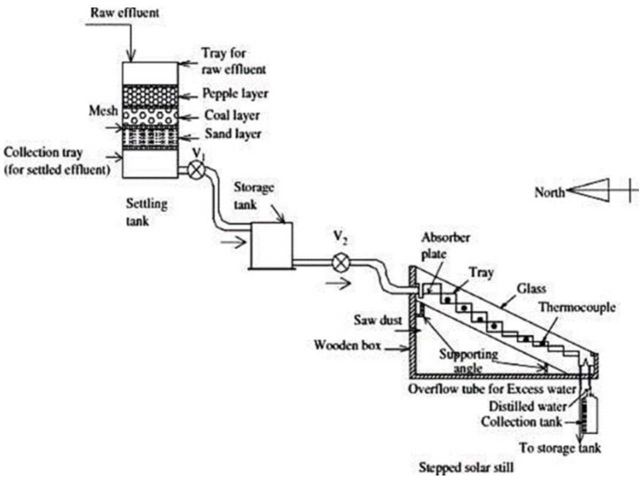


Figure 22. Schematic diagram of the experimental setup for effluent desalination. (Source: Velmurugan *et al.* 2009)

6.9. The relationship between phase-change materials and mass flow rate

Radhwan et al (2004) according to Figure 23a, this steeped solar still was specifically created with five steeped basins and a greenhouse. To provide the heated and humidification conditions in agricultural greenhouses (GH), a specific arrangement was devised. The still performance in two scenarios—still with LHTESS and still without LHTESS—was compared.

Thalib and Mohamed (2020) when compared to other stills, the tests showed that TSS-NPCM demonstrated the best performance and the largest yield. The daily energy efficiency of the stills was additionally determined to be 46%,59%, and 31%, respectively, while their daily energy efficiency was reported to be 2.20%, 3.75%,and 1.67%, respectively. The reported distillate yields for TSS-PCM, TSS-NPCM, and CTSS were 4.3, 6.0, and 7.9 kg, respectively. Toosi *et al.* (2021) the experiments were conducted in the same climate-controlled environment as Iran.

Kateshia *et al.* (2022) compared the energy, efficiency, and cost data for standard solar stills and solar stills that store PCM in various kinds of fatty acids and use pin fins to improve heat transfer. Dawood *et al.*(2020) showed that the hollow square fins enhanced productivity to 5.52 L/m2/day, an increase of 33%, from the traditional tubular's overall productivity of 4.15 L/m2/day. In addition, the utilization of hollow circular fins resulted in a 47.2% increase in production, reaching 6.11 L/m2/day.

Essa (2022) the revolving cylinder of the tubular sun still (TSS), in comparison to the conventional solar still (CSS), increased distiller production, according to the test results. According to the findings, a modest drop in air mass flow rate lowers the heat load for the greenhouse and the productivity of the distillate. The impact of mass flow rate on the distillate yield of a steeped solar still is depicted in Figure 23b.

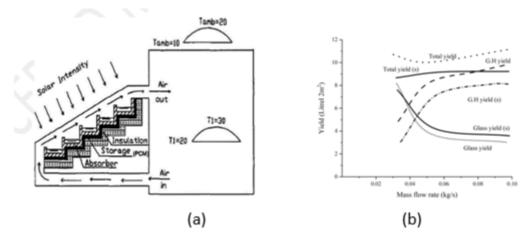


Figure 23. (a) Steeped solar still with built-in LHTESS and greenhouse. (Source: Radhawan *et al.* 2004). (b) Effect of mass flow rate on distillate yield of steeped solar still. (Source: Radhawan *et al.* 2004)

Experimental research by Farshchi Tabrizi *et al.* (2010) deals with a thin layer of water which was also present on the evaporation surface, which reduced channelization. For the experiment, two distinct kinds of solar stills—one with LHTESS and the other without—were employed. On partially cloudy days, conventional stills without LHTESS were found to produce more distillate, but stills with LHTESS were found to produce more in the summer. Both kinds of solar stills were capable of producing the greatest amount of distillate at a minimum mass flow rate of water of 0.055 kg/min. Figure 24b depicts the variation in overall productivity in the cascade solar still with phase-change material as a function of various mass flow rates.

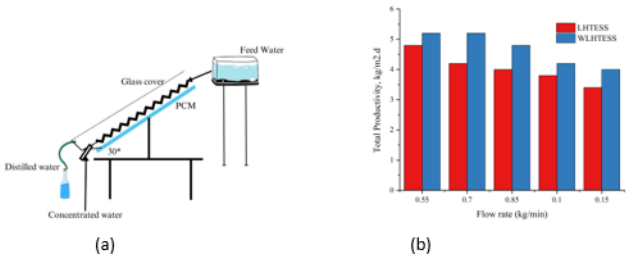


Figure 24. (a) View of the cascading solar still. (Source: Farshchi Tabrizi *et al.* 2010). (b). Total productivity varies with different mass flow rates.

6.10. Still Integration with reflectors

Tanaka *et al.* (2007) explored whether a flat plate reflector, as depicted in Figure 25, may boost a slanted wick solar still's performance. A theoretical analysis that evaluated the heat and mass transfer variables was used to evaluate the effectiveness and distillate productivity of the slanted wick solar still. They found that over four typical days, adding external reflectors to the still boosted the amount of distillate produced daily by almost 9% on average.

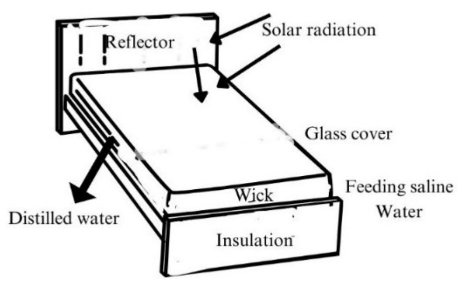


Figure 25. Diagrammatic representation of a tilting wick still with an exterior reflector

6.11. Condenser integration with a still

For the inverted tickling solar still depicted in Figure 26, Badran *et al.* (2004) conducted modeling and experimental. The flow of feed saline water was channeled around the back side of the Stepped absorber plate in this inverted trickle solar desalination system. To boost the volume of water vapor created during the evaporation process, the water flow rate in this case was limited to a minimum. To recuperate the heat lost during the condensation process, this system additionally had a heat exchanger. The still distillate output was increased to 2.8 liters per day, an 18% increase over the prior work, with an optimal tilt angle of 47° and a minimum mass flow rate of 0.7 g/s.

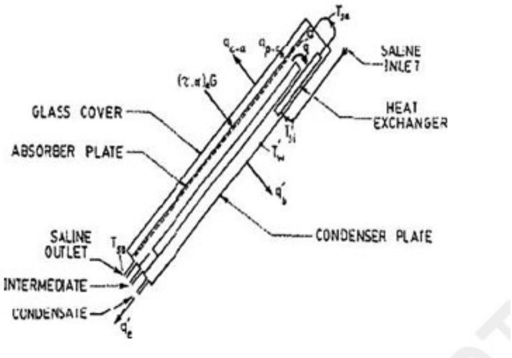


Figure 26. Schematic diagram of the inverted trickle still with external condenser. (Source: Badran *et al.* 2004)

6.12. Integration of still and solar collectors

By utilizing a vacuum tube solar collector to raise the feed water temperature of the solar still, Kabeel *et al.* (2012) improved the performance of the stepped solar still. By changing the trays' size (length and depth), saline water was taken, and the performance was further enhanced. To compare the productivity and efficiency of immersed-type sun stills to standard basin solar stills, experiments were undertaken. According to the findings, the immersed solar still produced 53% more distillate than the basin solar. Additionally, it was discovered that the distillate yield was higher in the steeped solar still for a tray dimension of 50 mm depth and 120 mm length. The schematic for the immersed solar still with the vacuum tube solar collector is shown in Figure 27.

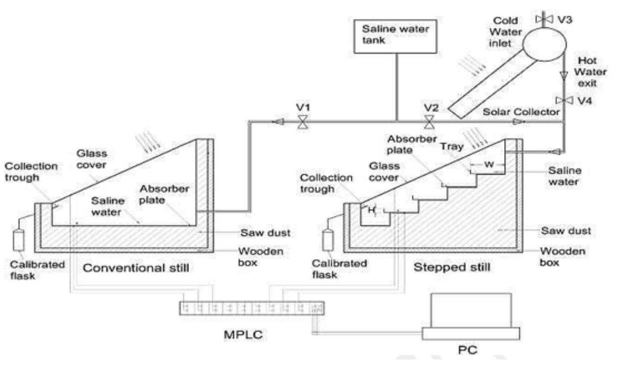


Figure 27. Diagram of the vacuum tube solar collector with a basin and immersed solar still. (Source: Kabeel *et al.* 2012)

6.13. Including stills in solar power systems

Figure 28 shows the combined performance of single-basin and stepped solar stills with the micro solar pond as studied by Velmurugan *et al.* (2009). In this particular operation, a combination of four parts—a settling tank, a tiny solar pond, a tiered solar still, and a basin-style sun still—was set up. The desalination of the wastewater is the purpose of the entire integrated system. Here, raw wastewater was transformed into settling effluent, which was then put into the little solar pond to heat up. Both types of solar stills received the preheated effluent in succession. Energy-storing components like stones, baffle plates, and fins can increase the productivity of the distillate during the day and at night. The analysis revealed that this integrated solar desalination system with energy-storing materials improved distillate productivity by 78% overall.

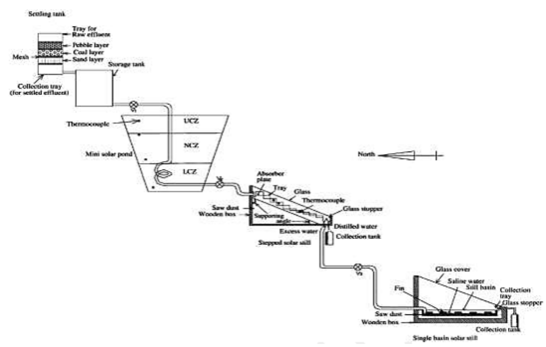


Figure 28. Stepped solar still and basin-style solar still combined with a solar pond. (Source: Velmurugan *et al.* 2009)

Abdulla *et al.* (2013) researched to assess the performance of an immersed solar still and solar air heater, as shown in Figure 29a. In this experiment, a solar air heater warmed the saline feed water inside the basin. In addition, aluminum filler was placed in the basin of the steeped solar still to act as a heat storage medium and enable distillate production at night. A higher temperature at the basin side promotes enhanced evaporation, but on the other hand, a lower temperature difference at the glass cover results in very little condensation. Glass cover cooling was added to the immersed solar still to solve this issue. When both hot air and glass cover cooling were used in the steeped solar still, the results revealed that the distillate production was 112% higher than that of a standard basin sun still. The hourly fluctuation of freshwater productivity for conventional and immersed stills is shown in Figure 2.32b.

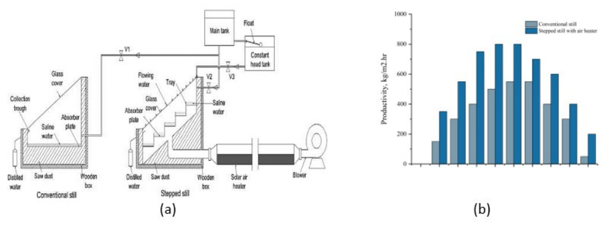


Figure 29. (a) Schematic of steeped solar still with solar air heater and glass cover cooling. (Source: Abdulla *et al.* 2013). (b) Hourly variation of productivity for conventional and steeped stills. (Source: Abdulla *et al.* 2013)

Omara *et al.* (2013) continuous water distillation was achieved by combining solar stills and evacuated solar water heaters. In this integrated solar desalination system, 3 types of solar stills (a basin solar still and two comparable wick-type solar stills) were used. Here, investigations involving single and double-wick layers of solar stills were carried out and their performance was contrasted with that of traditional solar stills. The results showed that when linked to the conventional wick solar still, the two-layer wick solar still generated 114% more distillate. Figure 30 shows the schematic for evacuated solar water heaters with double and single layers of wick-type solar stills.

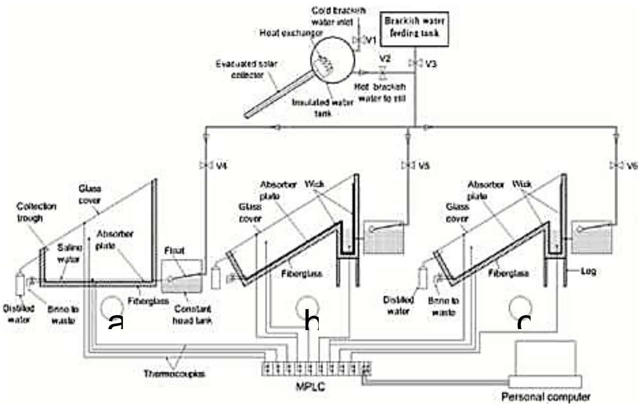


Figure 30. Schematics for evacuated solar water heaters and single- and double-layer wick solar stills. (Source: Omara *et al.* 2013)

6.14. Still Integration with other energy systems

It consists of three components, as indicated in Figure 31: a wind turbine, a stepped water desalination system, and the primary solar still. The spinning shaft with impellers in this system, which breaks up the boundary layer of the water surface in the basin of the main solar still, is operated by a wind turbine. Mohamed *et al.* (2009) the Stepped water desalination system was connected to the primary solar still's outflow in this instance. This device is capable of simultaneously producing hot and distilled water. Different mass flow rates and water depths were the subjects of the experiments. The system works best when the wind speed stays within the range of 1.0 to 2.0 m/s because it has little impact on the insolation and temperature.

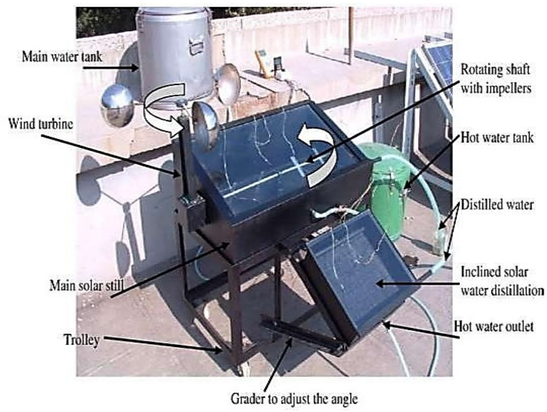


Figure 31. Schematic drawing of the hybrid solar still. (Source: Mohamed *et al.* 2009)

A concept by Sabah and Yousuf (2012) included a cooling cycle and an inverted solar still (ISS). In their experiment, they looked into the relationship between productive feed water and water depth temperature. The cooling cycle's condenser in this instance contributed thermal energy, boosting the distillate output of the inverted solar still. Figure 32 depicts the idea for the ISS with a cooling cycle.

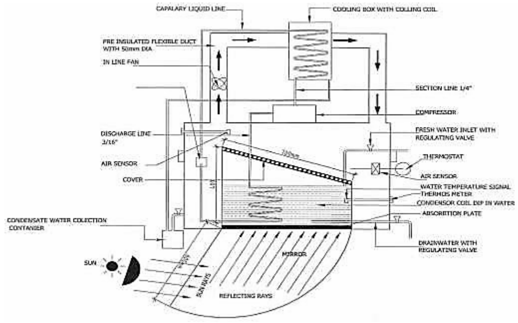


Figure 32. Schematic drawing of the inverted solar still with the refrigeration cycle. (Source: Sabah and Yousuf 2012)

Rahbar and Esfahani (2012) performed an experimental investigation using a heat pipe and a TEM on the portable solar still. A portable solar still with a thermoelectric unit and a heat pipe is shown schematically in Figure 2.36a. By connecting a thermoelectric module and an aluminium plate at the end of the cold side, a novel technique was used to hasten the condensation process. According to the investigations, the water temperature on the chilly side of the TEM was an average of 55 C. A greater variation in temperature between glass and water is possible with the TEM. The direction of heat transfer from various solar still components is depicted in Figure 33b.

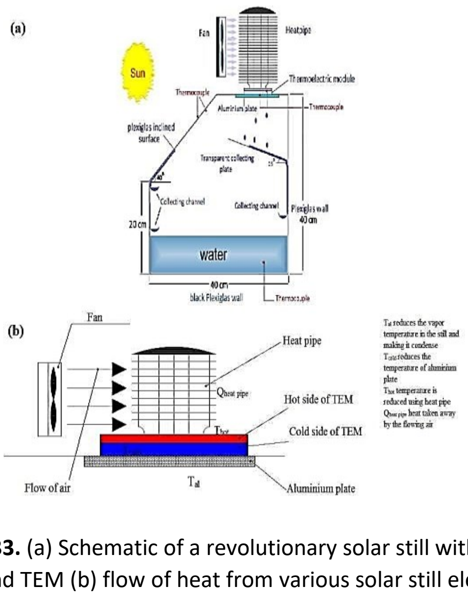


Figure 33. (a) Schematic of a revolutionary solar still with a heat pipe and TEM (b) flow of heat from various solar still elements for condensation. (Source: Rahbar and Esfahani 2012)

7. Parameters affecting the productivity of solar still

The performance of the solar still is indicated by the volume of distilled water generated in the basin each day (measured in liters per square meter per day). In summary, the performance of the solar panel is still directly influenced by its operational, design, and environmental factors. Among the design factors are the evaporation area, insulation, water depth, cover type, thickness, and tilt. The operational parameters are the salinity of the water and feed water preheating.

7.1. Environmental factors

The main environmental factors include wind speed, temperature, relative humidity, and sun radiation intensity.

7.1.1. Solar radiation

The sun's intensity and its atmospheric effects have a significant impact on solar still productivity. The regions with a high distribution of greater temperate will often produce more freshwater during the solar still. The pace of productivity and the amount of output are both influenced by the pattern of variation in solar radiation strength on the still during the day. To create a large amount of fresh water, the distillation process practically needs a high saline water temperature and excellent thermal lag.

7.1.2. Ambient air temperature

The atmospheric air temperature has a small positive impact on the solar yield. For every 10°F increase in air temperature, the reported increment on average is around 5 percent larger.

7.1.3. Velocity of wind

As the wind speed upsurges over a solar still, the temperature of the cover decreases, which causes condensation inside the still to occur more quickly. The temperature in the still is normally lower due to a shift in the thermal balance caused by a decrease in the temperature of the brine water. The increased wind speed only marginally reduces the yield since the evaporation rate causes the temperature of the salty water to drop by an exponential amount. According to various academic researches, there is no impact on production with increasing wind velocity when a seal is correctly sealed to prevent vapor leakage in the solar still. Nevertheless, the presence of poor tight joints in the still cover can significantly reduce productivity through increased wind velocity, depending on the aerodynamic coefficient as well as the position and size of the cracks. Strong winds can also lift glass sheets or rip plastic film. A proper design can deal with this issue.

Design Factors:

The productivity of solar stills is primarily influenced by four design factors: vapor tightness, brine depth, basin insulation, and condensate leakage.

Brine Depth:

Freshwater productivity will increase as water depth decreases. There is evidence for this phenomenon. To speed up evaporation, a still should reach a lofty brackish water temperature with the least amount of thermal lag. The huge thermal capacity of the earth's water beneath still causes a decrease in the normal uninsulated construction due to the influence of the shallow salinity water depth on aggregated heat capacity. Despite a vast range in water depth, it should be highlighted that 11 stills have been reported, defying theory or assumptions. The productivity variations are hardly noticeable.

7.1.4. Vapor tightness

Solar stills require the preservation of vapor and air spills to reserve at a functional minimum. The essential requirement for preventing vapor and glass from leaking from the solar still is sealants. Vapor leaking in the still has caused a significant drop in solar still productivity. As a result, the sealant issue has not yet been entirely resolved by the designers; however, an Australian still employed silicon rubber cement as the sealer with success. Some examiners have been successful in estimating the amount of vapor leakage that takes place in larger stills. The amount of water spillage can be estimated using either the wind-velocity coefficients or a natural thermal head, according to recent theoretical studies. To achieve this, though, you must either be aware of the location and size of the fractures or at the very least have some guesses.

7.1.5. Condensate leakage

If the tank is malfunctioning, the flow rate in one channel is so low that the whole flow can easily be lost (either externally or by changing to salt), and even the tiniest faults or cracks greatly reduce the distiller output. Only one piece of completely corrosion-resistant channels has been successfully identified. Thin steel tanks, polyethylene films, concrete, various coatings, and composite split plastic pipe have all failed in comparison to thin steel tanks, polyethylene films, and copper. Tanks must be deep enough to prevent leaks or overflows, random solutions or obstacles, and should be large enough to lessen brine's shadow. Condensate leaking from the tanks is the main factor contributing to the progressive decrease in distiller output.

7.1.6. Basin insulation

To increase the salt temperature and lessen heat loss, solar-still basins can include insulation on the bottom and sides. Shallow salt depths offer larger insulation benefits. Additionally, the insulation is more advantageous for tiny stills and individual bay-type stills than for continuous-basin stills because heat losses are related to the circumference. The annual production will rise by 15% for larger stills with continuous basins and brine depths of 2 inches under the 2-inch glass insulating layer.

7.1.7. Cover designs

An asymmetrical, double-sloped cover positioned at an angle of 10–20 degrees from the horizontal should be fairly helpful for large installations. While double-slope glass (0.125-inch Thickness) should be utilized at angles closer to 10 degrees when it surpasses 3 feet, single-slope glass (0.10-inch Thickness) can be used at angles near 20 degrees. The cover should be positioned more above the salt surface to lessen shade from the support. Compass direction does not affect productivity because there are stills with symmetrical, double-sloping covers that slope at a modest inclination. Single-sloping or asymmetrical glass coverings, which likewise have significant drawbacks, do not increase the filtration output or cost over the aforementioned design. They should be moistened to reduce downward compression, and additional care should be taken to avoid air damage and facilitate rain drainage. A number of blow-lift or mechanically supported stills use plastic covering. The 4-rail wet polyvinyl fluoride (often referred to as "Tedlar") plastic film is the most resilient plastic ever produced for solar stills. It costs more than glass right now and has a five-year anticipated lifespan.

8. Conclusion

This review paper's main contribution is to enhance the performance of a straightforward solar still. The straightforward solar distillation system employs energy storage materials, and experimental and theoretical parametric analyses are carried out to achieve the contributions. The existing literature has been used to analyse the energy analysis performance of PCM and sensible heat material as a fixed water depth in solar desalination, as well as for other applications like solar air heaters. This review work includes an energy analysis for solar desalination using sensible heat and latent heat storage materials, as well as for other applications such as solar air warmers under specific climatic circumstances. A water quality test was conducted on distilled water and salted water from a single slope passive solar still.

The accuracy of the readings obtained for the temperatures of the glass, water, and basin liner will also be determined using a novel thermal inquiry that has been designed. By raising the temperature difference between the glass and water (T), increasing the amount of heat that can be used by the distilled water (Qd), reducing heat loss by using energy storage materials inside the basin, and examining the effects of various energy storage material amounts, the study also aims to increase the efficiency of the solar still. This review paper additionally enhances the thermal efficiency of a solar air heater by using effective storage of energy materials.

Abbreviation

TDS - Total Dissolved Solids

MSF - Multi-Stage Flash Desalination

MEF - Multi-Effect Desalination

VCD - Vapor Compression Distillation

MVC - Mechanical Vapor Compression

TVC - Thermal Vapor Compression

ED - Electrodialysis

RO - Reverse Osmosis

MED - Multi-Effect Distillation

ISPB - Inclined Solar Panel Basin

FPC - Flat Plat Collector

PCM - Phase Change Material

PSSCAP-Pyramid Solar Still With Corrugated Absorber Plate

CTBSS - Conventional Triple Basin Solar Still

EVHPP - Evacuated Heat Pipes

CS - Corrugated Sheets

SHSM - Sensible Heat Storage Materials

CPSS - Conventional Pyramid Solar Still

CSS - Conventional Solar Still

IWSS - Inclined Wick Solar Still

SPSS - Square Pyramid Solar Still

PV - Photovoltaic

GH - Greenhouses

LHTESS-Latent Heat Thermal Energy Storage System

Reference

Abd Elbar, Ayman Refat, and Hamdy Hassan. (2020). "Energy, exergy and environmental assessment of solar still with solar panel enhanced by porous material and saline water preheating", *Journal of Cleaner Production,* **277**: 124175.

Abdelgaied, Mohamed, et al. (2021). "Improving the tubular solar still performance using square and circular hollow fins with phase change materials", *Journal of Energy Storage*, **38**: 102564.

Abdullah A. S., et al. (2023)"Increasing the productivity of modified cords pyramid solar still using electric heater and various wick materials", *Process Safety and Environmental Protection,* **169**: 169–176.

Abdullah A.S. (2013). “Improving the performance of steeped solar still”, *Desalination*, **391**, 60–65.

Al-harahsheh, Mohammad, et al. (2018). "Solar desalination using solar still enhanced by external solar collector and PCM", *Applied Thermal Engineering,* **128**: 1030–1040.

Aly, Shahzada, et al. (2021). "Pilot testing of a novel Multi Effect Distillation (MED) technology for seawater desalination", *Desalination* **519**: 115221.

Aly, Shahzada, et al. (2021). "Pilot testing of a novel Multi Effect Distillation (MED) technology for seawater desalination", *Desalination,* **519**: 115221.

Aroussy, Youssef, et al. (2020). "Thermo-economic simulation and analysis of a solar thermal cycle combined with two desalination processes by multi-effect distillation (MED)", *Materials Today: Proceedings* **30**: 1027–1032.

Arunkumar T., et al. (2019). "A review of efficient high productivity solar stills", *Renewable and Sustainable Energy Reviews,* **101**: 197–220.

Assad, Mamdouh El Haj, et al. (2022). "Desalination technologies: overview", 2022 Advances in Science and Engineering Technology International Conferences (ASET). *IEEE*

Aybar S. Egelioglu Fuat and Atikol U. (2005). “An experimental study on an inclined solar water distillation system”, *Desalination*, **180**, 285–289.

Badran A., Assaf L, Kayed S, Ghaith A. and Hammash I. (2004). “Simulation and experimental study for an inverted trickle solar still”, *Desalination*, **164**, 77–85.

Chauhan, Vikash Kumar, et al. (2021). "A comprehensive review of direct solar desalination techniques and its advancements", *Journal of Cleaner Production,* **284**: 124719.

Chaurasiya, Prem Kumar, et al. (2022). "A review of techniques for increasing the productivity of passive solar stills", *Sustainable Energy Technologies and Assessments,* **52**: 102033.

Chen, Fengying, et al. (2022). "Non-thermal technology and heating technology for fresh food cooking in the central kitchen processing: a review", *Food Reviews International* **38(4)**: 608–627.

Chen, Qian, et al. (2021). "A spray-assisted multi-effect distillation system driven by ocean thermocline energy", *Energy Conversion and Management,* **245**: 114570.

Darawsheh I., Islam M.D. and Banat F. (2019). "Experimental characterization of a solar powered MSF desalination process performance", *Thermal Science and Engineering Progress,* **10**: 154–162.

Dawood, Mohamed M. Khairat, et al. (2020). "Experimental study of productivity progress for a solar still integrated with parabolic trough collectors with a phase change material in the receiver evacuated tubes and in the still", *Journal of Energy Storage,* **32**: 102007.

Delyannis E. (2003). “Historic Background of desalination and renewable energies”, *Solarsss Energy*, 75, 357–366.

Dhiman N.K. and Tiwari G.N. (1990). “Effect of water flowing over the glass cover of a multi-wick solar still”, *Energy Conversion and Management*, **30**, 245–50.

Do Thi, Huyen Trang, and András József Tóth. (2023). "Investigation of Carbon Footprints of Three Desalination Technologies: Reverse Osmosis (RO), Multi-Stage Flash Distillation (MSF) and Multi-Effect Distillation (MED)", *Periodica Polytechnica Chemical Engineering* **67(1)**: 41–48.

Dunkle R.V. (1961). “Solar water distillation; the roof type still and multiple effect diffusion still, International Developments in Heat Transfer ASME”, In: Proceedings of International Heat Transfer Part V, University of Colorado, **895**. El-Sayed, M.M., 1983. Comparison of transient performance.

Elmaadawy, Khaled, et al. (2021). "Performance improvement of double slope solar still via combinations of low cost materials integrated with glass cooling", *Desalination*, **500**: 114856.

Elsaid, Khaled, et al. (2020). "Environmental impact of desalination processes: Mitigation and control strategies", *Science of the Total Environment*, **740**: 140125.

El-Samadony Y.E.F. and Kabeel A.E. (2004). “Theoretical estimation of optimum glass cover water film cooling parameter combinations of steeped solar still”, *Energy*, **68**, 744–750.

El-Zahaby A.M., Kabeel A.E., Bakry A.I., El-Agouz S.A. and Hawam, O.M. ((2011). “Enhancement of solar still performance using a reciprocating spray feeding system”, *Desalination*, **267**, 209–16.

Essa F. A., et al. (2022). "Experimental enhancement of tubular solar still performance using rotating cylinder, nanoparticles' coating, parabolic solar concentrator, and phase change material", *Case Studies in Thermal Engineering,* **29**: 101705.

Essa F.A., Abdullah A.S. and Omara Z.M. (2020). "Rotating discs solar still: New mechanism of desalination", *Journal of Cleaner Production,* **275**: 123200.

Essa F.A., et al. (2020). "Extracting water content from the ambient air in a double-slope half-cylindrical basin solar still using silica gel under Egyptian conditions", *Sustainable Energy Technologies and Assessments,* **39**: 100712.

Farshchi Tabrizi Farshad, Dashtban Mohammad and Moghaddam Hamid. (2010). “Experi-mental investigation of a weir-type cascade solarstill with built-inlatent heat thermal energy storage system”, *Desalination*, **260**, 248–53.

Fathy, Mohamed, Hamdy Hassan and Salem Ahmed M. (2018). "Experimental study on the effect of coupling parabolic trough collector with double slope solar still on its performance", *Solar Energy,* **163**: 54–61.

Feria-Díaz, Jhon Jairo, et al. (2021). "Commercial thermal technologies for desalination of water from renewable energies: a state of the art review", *Processes* **9(2)**: 262.

Ghandourah, Emad, et al. (2022). "Performance enhancement and economic analysis of pyramid solar still with corrugated absorber plate and conventional solar still: A case study", *Case Studies in Thermal Engineering,* **35**: 101966.

Ghazy, Mohamed, et al. (2022). "Cooling technologies for enhancing photovoltaic–thermal (PVT) performance: a state of the art", *International Journal of Energy and Environmental Engineering*, **13(4)**: 1205–1235.

Gnanaraj S. Joe Patrick and V. Velmurugan. (2019). "An experimental study on the efficacy of modifications in enhancing the performance of single basin double slope solar still". *Desalination,* **467**: 12–28.

Gnanaraj S. Joe Patrick S. Ramachandran and David Santosh Christopher. (2018). "Enhancing the productivity of double-slope single-basin solar still with internal and external modifications", *International Journal of Ambient Energy,* **39(8)**: 777–782.

Gnanaraj, Joe Patrick S. and Velmurugan V. (2022). "Experimental investigation on the performance of modified single basin double slope solar stills", *International Journal of Ambient Energy,* **43**(**1)**: 206–215.

Hadavi, Hamed, et al. (2023). "Hybrid multi-objective optimization and thermo-economic analysis of a multi-effect desalination unit integrated with a fuel cell-based trigeneration system". *Journal of Cleaner Production,* **407**: 137156.

Hashemi, Sina Abaszadeh, Mohsen Kazemi, and Mohammad Passandideh-Fard. (2022). "Experimental characterization of a solar still integrated with a spiral collector using energy, exergy, economic, and environmental (4E) analyses", *Sustainable Energy Technologies and Assessments,* **53**: 102521.

Hassan, Hamdy, et al. (2020). "Assessment of parabolic trough solar collector assisted solar still at various saline water mediums via energy, exergy, exergoeconomic, and enviroeconomic approaches", *Renewable Energy,* **155**: 604–616.

Honarparvar, Soraya, et al. (2021). "Frontiers of membrane desalination processes for brackish water treatment: A review", *Membranes,* **11(4)**: 246.

Jadhav, Harsh Bhaskar, Uday S. Annapure, and Rajendra R. Deshmukh. (2021). "Non-thermal technologies for food processing", *Frontiers in Nutrition,* **8**: 657090.

Janarthan B, Chandrasekaran J and Kumar S. (2006). “Performance of floating cum tilted-wick type solar still with the effect of water flowing over the glass cover”, *Desalination*, **190**, 51–62.

Jani Hardik K. and Kalpesh V. Modi. (2019). "Experimental performance evaluation of single basin dual slope solar still with circular and square cross-sectional hollow fins", *Solar Energy*, **179**: 186–194.

Jayaprakash R, Perumal K, Arun kumar T, Kumar S and Selva kumar B. (2009). “Design and performance analysis of low cost solar still using transparent LDPE cover”, *Journal of Environmental Research and Development*, **4**, 465–475.

Kabeel A.E. (2009). “Performance of solar still with concave wick evaporation surface”, *Energy*, **34**, 1504–1509.

Kabeel A.E., Khalil A., Omara Z.M. and Younes M.M. (2012). “Theoretical and experimental parametric study of modified stepped solar still”, *Desalination,* **289**, 12–20.

Kabeel A.E., Mohamed Abdelgaied and Amr Eisa. (2018). "Enhancing the performance of single basin solar still using high thermal conductivity sensible storage materials", *Journal of cleaner production,* **183**: 20-25.

Kateshia, Jyotin and Vikas Lakhera. (2022). "A comparative study of various fatty acids as phase change material to enhance the freshwater productivity of solar still", *Journal of Energy Storage,* **48**: 103947.

Kelsey, Laura, et al. (2021). "Closing the water loop for exploration: 2020–2021 status of the brine processor assembly", 50th International Conference on Environmental Systems.

Koutsou C.P., et al. (2020). "Analysis of temperature effects on the specific energy consumption in reverse osmosis desalination processes", *Desalination,* **476**: 114213.

Kumar P. Vishwanath, et al. (2015). "Solar stills system design: A review", *Renewable and sustainable energy reviews,* **51**: 153–181.

Lee, Sangho, et al. (2019). "Hybrid desalination processes for beneficial use of reverse osmosis brine: Current status and future prospects". *Desalination,* **454**: 104–111.

Lin, Shihong. (2019). "Energy efficiency of desalination: fundamental insights from intuitive interpretation", *Environmental science* and *technology* 54, **1**: 76–84.

Mahdi J.T., Smith B.E. and Sharif A.O. (2011). "Experimental wick type solar still system: Design and construction", *Desalination*, **267**, 233–238.

Malik M.A.S., Tiwari G.N., Kumar A. and Sodha M.S. (1982). "Solar Distillation", Pergamon Press, Oxford, UK.

Mallinak E.S. (1987). Vapor Compression Distillation Subsystem (VCDS) Component Enhancement, Testing and Expert Fault Diagnostics Development, **2,** No. NAS 1.26: 172076.

Manokar A. Muthu, et al. (2018). "Comparative study of an inclined solar panel basin solar still in passive and active mode", *Solar Energy,* **169**: 206–216.

Manokar A. Muthu, et al. (2020). "Enhancement of potable water production from an inclined photovoltaic panel absorber solar still by integrating with flat-plate collector", *Environment, Development and Sustainability,* **22**: 4145–4167.

Maridurai T., et al. (2022). "Performance study on phase change material integrated solar still coupled with solar collector", *Materials Today: Proceedings,* **59**: 1319–1323.

Mevada, Dinesh et al. (2020). "Effect of fin configuration parameters on performance of solar still: a review", *Groundwater for Sustainable Development,* **10**: 100289.

Mevada, Dinesh, et al. (2022). "Investigation and performance analysis of solar still with energy storage materials: An energy-exergy efficiency analysis", *Case Studies in Thermal Engineering,* **29**: 101687.

Minasian A.N. and Al-Karaghouli A.A. (1994). "An improved solar still: the wick- basin type", Energy Conversion and *Management*, **36**, 213–217.

Modi Kalpesh V., Hardik K. Jani, and Ilesh D. Gamit. (2021). "Impact of orientation and water depth on productivity of single-basin dual-slope solar still with Al2O3 and CuO nanoparticles", *Journal of Thermal Analysis and Calorimetry* **143**(**2)**: 899–913.

Modi Kalpesh V., Kuldeep H. Nayi and Sonu S. Sharma. (2020). "Influence of water mass on the performance of spherical basin solar still integrated with parabolic reflector", *Groundwater for Sustainable Development,* **10**: 100299.

Mohamed A Eltawil and Zhao Zhengming. (2009). "Wind turbine-inclined still collector integration with solar still for brackish water desalination", *Desalination*, **249**, 490–497.

Murugavel K.K., Chockalingam KnKSK and Srithar K. (2008b). "An experimental study on single basin double slope simulation solar still with thin layer of water in the basin", Desalination, 220, 687–693.

Omara Z.M., Eltawil M.A. and El Nashar E.A. (2013). "A new hybrid desalination system using wicks/solar still and evacuated solar water heater", *Desalination*, **325**, 56–64.

Omara Z.M., Kabeel, A.E. and Younes M.M. (2013). "Enhancing the stepped solar still performance using internal reflectors", *Desalination,* **314**, 67–72.

Paixão, D.F.S., et al. (2023). "A dynamic optimization approach for a multi-effect desalination (MED) integrated with thermosolar storage system", *Solar Energy,* **262**: 111837.

Pansal, Kamlesh, et al. (2020). "Use of solar photovoltaic with active solar still to improve distillate output: a review", *Groundwater for sustainable development,* **10**: 100341.

Parsa, Seyed Masoud, et al. (2021). "Thermodynamic, economic, and sensitivity analysis of salt gradient solar pond (SGSP) integrated with a low-temperature multi effect desalination (MED): Case study, Iran", *Sustainable Energy Technologies and Assessments* **47**: 101478.

Patel Mit, Chetankumar Patel, and Hitesh Panchal. (2020). "Performance analysis of conventional triple basin solar still with evacuated heat pipes, corrugated sheets and storage materials", *Groundwater for sustainable development,* **11**: 100387.

Phillips Agboola O and Egelioglu F. (2011). "An experimental investigation of an improved incline solar water desalination system in Famagusta", *Desalination*, **6**, 3298–3308.

Prakash P and Velmurugan V. (2015). "Parameters influencing the productivity of solar stills", *A review, Renewable and Sustainable Energy Reviews*, **49**, 585–609.

Qasim, Muhammad, et al. (2019). "Reverse osmosis desalination: A state-of-the-art review", *Desalination,* **459**: 59–104.

Radhwan M. (2004). "Transient performance of a stepped solar still for heating and humidifying green houses", *Desalination*, **161**, 89–97.

Rahbar N. and Esfahani J.A. (2005). "Experimental study of a novel portable solar still by utilizing the heat pipe and thermoelectric module", *Desalination*, **284**, 55–61.

Ramalingam, Vignesh Kumar, et al. (2021). "Enhancing the fresh water produced from inclined cover stepped absorber solar still using wick and energy storage materials", *Environmental Science and Pollution Research,* **28**: 18146–18162.

Razmi, Amirreza, et al. (2019). "Thermodynamic analysis of compressed air energy storage (CAES) hybridized with a multi-effect desalination (MED) system", *Energy Conversion and Management* **199**: 112047.

Rezk, Hegazy, et al. (2022). "Multi-criteria decision making for different concentrated solar thermal power technologies", *Sustainable Energy Technologies and Assessments,* **52**: 102118.

Sabah A Abdul-Wahab and Yousuf Y Al-Hatmi. (2012). "Study of the performance of the inverted solar still integrated with a refrigeration Cycle", *Procedia Engineering*, **33**, 424–434.

Sadineni, S.B., Hurt R., Halford C.K. and Boehm R.F. (2008). "Theory and experimental investigation of a weir -type inclined solar still", *Energy*, **33**, 71–80.

Saravanan A., and M. Murugan. (2020). "Performance evaluation of square pyramid solar still with various vertical wick materials–an experimental approach", *Thermal Science and Engineering Progress,* **19**: 100581.

Sebaii A.A.E. (2005). "Thermal performance of a triple-basin solar still", *Desalination*, **174**, 23–37.

Sharan, Prashant, et al. (2019). "Cogeneration using multi-effect distillation and a solar-powered supercritical carbon dioxide Brayton cycle", *Desalination* **459**: 20–33.

Sharshir, Swellam W., et al. (2022). "4-E analysis of pyramid solar still augmented with external condenser, evacuated tubes, nanofluid and ultrasonic foggers: A comprehensive study", *Process Safety and Environmental Protection,* **164**: 408–417.

Sharshir, Swellam W., et al. (2022). "Performance improvement of tubular solar still using nano-coated hanging wick thin film, ultrasonic atomizers, and cover cooling", *Sustainable Energy Technologies and Assessments,* **52**: 102127.

Sheeba Jaisankar S and Prakash P. (2012). "Performance study on an inclined solar water distillation system", *Desalination*, **3**.

Singh A.K. and Tiwari G.N. (1989). "Performance study of double effect distillation in a multi wick solar still", *Energy Conversion and Management*, **33(3)**, 207–214.

Sodha M.S., Kumar Ashvini, Tiwari A, and Tyagi G. (1986). "Progresses in simple multiple wick solar still: analysis and performance", *Solar Energy*, **26**, 127–131.

Somwanshi, Aneesh, and Rupesh Shrivastava. (2023). "Thermal analysis of a closed loop inclined wick solar still (CLIWSS) with an additional heat storage water reservoir", *Solar Energy,* **262**: 111902.

Srithar K. and T. Rajaseenivasan. (2018). "Recent fresh water augmentation techniques in solar still and HDH desalination–A review", *Renewable and Sustainable Energy Reviews,* **82**: 629–644.

Suneja S and Tiwari G.N. (1999). "Effect of water depth on the performance of an inverted absorber double basin solar still", *Energy Conversion and Management*, **40**, 1885–1897.

Talbert S.G., Eibling J.A. and Lof G.O.G. (1970). "Manual on solar distillation of saline water", R&D Progress Report No. 546, US Department of the Interior.

Tanaka Hiroshi and Nakatake Yasuhito. (2009). "One step azimuth tracking tilted-wick solar still with a vertical flat plate reflector", *Desalination*, **235**, 1–8.

Tanaka Hiroshi and Nakatake Yasuhito. (2009). "One step azimuth tracking tilted-wick solar still with a vertical flat plate reflector", *Desalination*, **235**, 1–8.

Tayefeh, Mohammad. (2022). "An innovative rearrangement and comprehensive comparison of the combination of compressed air energy storage (CAES) with multi stage flash (MSF) desalination and multi effect distillation (MED) systems", *Journal of Energy Storage,* **52**: 105025.

Thalib M. Mohamed, et al. (2020). "Comparative study of tubular solar stills with phase change material and nano-enhanced phase change material", *Energies*, **13(15)**: 3989.

Tiwari G.N. and Kumar A. (1988). "Nocturnal water production by tubular solar stills using waste heat to preheat brine", *Desalination*, **69**, 309–318.

Toosi, Seyed Sina Adibi, Hamid Reza Goshayeshi, and Saeed Zeinali Heris. (2021). "Experimental investigation of stepped solar still with phase change material and external condenser", *Journal of Energy Storage,* **40**: 102681.

Tuly, S. S., et al. (2021). "Combined influence of fin, phase change material, wick, and external condenser on the thermal performance of a double slope solar still", *Journal of Cleaner Production,* **287**: 125458.

Velmurugan V., Naveen kumar K.J., Noorul Haq T. and Srithar K. (2009). "Performance analysis in steeped solar still for effluent desalination", Energy, **34**, 1179–1186.

Wen, Chuang, Hongbing Ding, and Yan Yang. (2020). "Performance of steam ejector with nonequilibrium condensation for multi-effect distillation with thermal vapour compression (MED-TVC) seawater desalination system", *Desalination* **489**: 114531.

Xu, Shiming, et al. (2022). "Analysis of a multi-stage air gap diffusion distillation system powered by low-grade sensible heat", *Applied Thermal Engineering*, **200**: 117660.

Yeh Ho-Ming and Chen Lie-Chaing. (1986). "Effects of climatic, design and operational parameters on the performance of wick-type solar distillers", *Energy Conversion and Management*, **26**, 175–180.

Zhang, Zhi-Hong, et al. (2019). "Non-thermal technologies and its current and future application in the food industry: a review", *International Journal of Food Science* and *Technology,* **54(1)**: 1–13.

Ziabari F.B., Sharak A.Z., Moghadam H. and Tabrizi F.F. (2013). "Theoretical and experimental study of cascade solar stills", *Solar Energy*, **90**, 205–211.