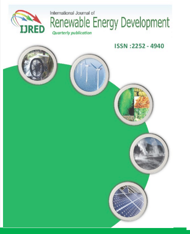
Contents list available at IJRED website

Int. Journal of Renewable Energy Development (IJRED)

Journal homepage: https://ijred.undip.ac.id



Review Article

Influence of Various Basin Types on Performance of Passive Solar Still: A Review

Tri Hieu Le[a*], Minh Tuan Pham[b], H Hadiyanto[c,d], Van Viet Pham[a], Anh Tuan Hoang[e,*]

[a] *Institute of Maritime, Ho Chi Minh city University of Transport, Ho Chi Minh city, Vietnam*

[b] *School of Transportation Engineering, Hanoi University of Science and Technology, Hanoi, Vietnam*

[c] *Center of Biomass and Renewable Energy (CBIORE), Diponegoro University, Indonesia*

[d] *School of Postgraduate Studies, Diponegoro University, Indonesia*

[e] *Institute of Engineering, Ho Chi Minh city University of Technology (HUTECH), Ho Chi Minh city, Vietnam*

ABSTRACT. Passive solar still is the simplest design for distilling seawater by harnessing solar energy. Although it is undeniable that solar still is a promising device to provide an additional freshwater source for global increasing water demand, low thermal efficiency along with daily distillate yield are its major disadvantages. A conventional solar still can produced 2 to 5 L/m^{2}day. Various studies have been carried out to improve passive solar stills in terms of daily productivity, thermal efficiency, and economic effectiveness. Most of the researches that relate to the daily output improvement of passive solar still concentrates on enhancing evaporation or/and condensation processes. While the condensation process is influenced by wind velocity and characteristics of the condensed surface, the evaporation process is mainly affected by the temperature of basin water. Different parameters affect the brackish water temperature such as solar radiation, design parameters (for example water depth, insulators, basin liner absorptivity, reflectors, sun tracking system, etc). The inclined angle of the top cover is suggested to equal the latitude of the experimental place. Moreover, the decrease of water depth was obtained as a good operational parameter, however, the shallow water depth is required additional feed water for ensuring no dry spot existence. Reflectors and sun-tracking systems help solar still absorb as much solar intensity as possible. The internal reflector can enhance daily yield and efficiency of stepped solar still up to 75% and 56% respectively, whereas, passive solar still with the support of a sun-tracking system improved daily yield up to 22%. Despite large efforts to investigate the impact of the different parameters on passive solar distillation, the effect of the basin liner (including appropriate shapes and type of material), needs to be analyzed for improvement in practical utilization. The present work has reviewed the investigation of the solar still performance with various types of basin liner. The review of solar stills has been conducted critically with rectangular basin, fins basin, corrugated basin, wick type, steps shape, and cylindrical shape basin with variety of top cover shapes. The findings from this work conclude that the basin liner with a cylindrical shape had better performance in comparison with other metal types and provides higher freshwater output. Stepped type, inclined, fin absorber, and corrugated shapes had the efficient performance. Further exploration revealed that copper is the best-used material for the productivity of passive solar still.

Keywords: renewable energy; water production; passive solar still; distillate yield; absorber basin

Article History: Received: 3rd May 2021; Revised: 6th June 2021 ; Accepted: 10th June 2021; Available online: 15th June 2021

How to Cite This Article: Le, T.H.,Pham, M.T., Hadiyanto, H., Pham, V.V., Hoang, A.T. (2021). Influence of various basin types on performance of passive solar still: A review. *International Journal of Renewable Energy Development*, 10(2), 789-802

https://doi.org/10.14710/ijred.2021.38394

1. Introduction

Energy-relevant problems and global shortages of water are escalating over the years. The environmental issues related to fossil fuel are so hazardous that increasingly solutions for preserve our mother earth were paid serious attention by both developed and developing countries (Hoang *et al.* 2021d)(Hoang & Pham 2019). The basic way to solve pollution from fossil fuel is to move away from them by replacing with clean fuels like biodiesel and renewable diesel, alternative resources such as wind, solar or wave energy, and geothermal (Hoang *et al.* 2021b). Thereby, efficiency enhancement and emissions reductants are key standards for developing advanced and new energy technologies (Hoang & Le 2019) (Hoang *et al.* 2021e). Another worldwide trouble is the lack of potable water resources (Arun Kumar & Suresh Mohan Kumar 2021). The majority of water on the Earth is not drinkable due to the high concentration of saline components (Ardeshiri *et al.* 2018). Meanwhile, usable water in rivers, lakes, and ground even the sea is polluted due to the development of industry and freight transport which discharge toxic pollutants and may cause oil spills (Ravishankar *et al.* 2013). Contaminate water source has negative effects not only on human health and animals but on agricultural products also (Hoang *et al.* 2021c)(Hoang

---

[*] Corresponding author: Tri Hieu Le (lehieumttvimaru@gmail.com); Anh Tuan Hoang (hatuan@hutech.edu.vn)

et al. 2021a). Drinking unsafe water unknowingly can cause acute, chronic diseases in people, and transmits diseases such as diarrhea, cholera, dysentery, typhoid, and polio (Tiwari & Sahota 2017). The main objects are afflicted by waterborne diseases are children. Therefore, many nations have to build desalination plants to meet the drinking water demand of the populace, which takes an additional burden for using fossil fuel (Abdelmaksoud *et al.* 2020) (Buabbas *et al.* 2020).

Using wind or sun, well-known as renewable energy for distillation is a promising technique (Handayani & Ariyanti 2012) (Hosseini 2019). The solar energy source is an environmentally friendly and economical resource and appropriate for purifying drinkable water. Devices utilizing the sun's energy (Liu *et al.* 2019), to distill sea or brackish water named solar distillation of water or solar stills (El-Sebaii & El-Bialy 2015). It is able to remove hazardous heavy metals, inorganic and organic substances, and bacteria from the water by solar still (Hanson et al. 2004). Even, Total Dissolve Solid can be reduced up to 30 PPM by the solar distiller, which meets the requirement for drinking water (Pawar & Gaikawad 2020). Furthermore, solar still is one of the low-carbon technologies because there is no greenhouse gas exhausted from them (Anwar & Deshmukh 2020). Regions acceptable to use sunlight power can build solar still on a large scale to supply drinkable water for the community (Anwar & Deshmukh 2018).

A conventional solar still is a simples design that generally consists of a basin with a single glass cover on its top (Maddah 2019). Impure water will be filled inside the basin which can be insulated on all its own sides. When the sun appears, the rays will transmit through the cover and the basin will absorb this energy to evaporate the brackish water. The water vapor touches the cover with lower temperature and then gets condensed into droplets on the cover surface. As these droplets grow heavier, they will flow down to a collector due to gravity effects (top cover usually inclines a specific angle). However, the area of 1 m^2 conventional solar still only satisfy the water needs of a person (2 to 5 L/m^2day) (Dsilva Winfred Rufuss *et al.* 2016). The experiment of Mousavi et al. showed the daily productivity of 4.24 kg/m^2 day (Taheri Mousavi *et al.* 2020) Moreover, Alawan *et al.* (Alwan *et al.* 2020) investigated the heat transfer coefficient and cumulative yield in a conventional solar distiller. The highest total coefficient of heat transfer was 33.37 W/m^2·k. They obtained 4.8 L/m^2day at water depth of 1 cm. This indicates the poor energy efficiency and low distilled freshwater in comparison with other methods of distillation. Numerous researchers endeavor to enhance the daily output as well as efficiency of a conventional solar still by improving evaporation rate and/or condensation rate. The improvement of the condensation process can be done by cooling the condensed surface with water or forced air. (Arunkumar *et al.* 2016) experimented with tubular solar still and investigated the effect of cooling water and air over cover on the distillate yield. According to their report, the daily yield of using air cooling increased 49% compared to without cooling and that of cooling water flow raised 64% compared to airflow. (Sharshir *et al.* 2016) also, confirm based on their results that employing the water-cooled condenser cover enhanced the output yield by approximately 47.80%. Meanwhile, the rise in basin water temperature can enhance the evaporation rate. The increment of water temperature depends on the amount of solar radiation absorbed by the system. (Abdallah & Badran 2008) used a sun-tracking system to support a solar still. The obtained results showed an increment of 22% in daily productivity and 2% in thermal efficiency. Abed *et al.* (Abed *et al.* 2017) developed a three-stage metallic still under the help of a satellite solar collector. Their system had the daily yield of 4.94 L/m^2day and the efficiency of 84% is higher than other solar stills. Some researchers designed refletors to raise solar irradiation for solar still, which was reviewed by (Omara *et a*l. 2017b). According to their work, the use of both internal and external reflectors improved the productivity of simple solar still to 75% (Tanaka 2009) and that of stepped solar still up to 125% (Omara *et al.* 2014). Johnson *et al.* (Johnson *et al.* 2019) applied the Fresnel lens to improve the performance of passive solar still. The productivity of solar still with Fresnel lens was 5 times higher than that without the lens. Furthermore, a basin known as an absorber is an important part of a solar still, which affects to the temperature of brackish water, evaporation process as well as daily yield. The absorber can be fabricated from plastic, metal sheets, copper, aluminum, steel, or some material with a high thermal capacity. As a result, various works endeavored to alter basin design with the purpose of improving efficiency and daily yield.

Widespread reviews of solar stills have been undertaken to compare their thermal performance and to introduce promised technique as well as advanced material for them, such as performance of the integration between solar still with various solar collectors was carried out in the study (Sathyamurthy *et al.* 2017), optimum values of a passive solar still parameter and good design for southern Bangladesh was done by (Sarkar *et al.* 2017), (Omara *et al.* 2017a) undertook the cooling techniques review for solar stills, Performance of solar still with reflectors was investigated in (Omara *et al.* 2017b), (Shukla *et al.* 2017) reviewed latent heat energy storage using in solar still, (Sharshir *et al.* 2017) reviewed energy and exergy analysis for solar stills, Application of nano particle in solar distillation of water was reviewed in (Parikh 2018), a review of nano fluids usage in solar stills for improvement of heat and mass transfer was conducted by (Bait & Si-Ameur 2018), (Arunkumar *et al.* 2013a) summarized solar stills had efficient high productivity, how fin configuration parameters influence on solar still performance was answered in review of (Mevada *et al.* 2020). Furthermore, parameter influences on the daily productivity including climatic, design, and operational parameters were presented by Muftah *et al.* (Muftah *et al.* 2014). However, they limited types of solar stills, including single basin stills, multiple-effect stills, wick solar stills, and hybrid designs which generally were designed with flat plate basin liner. Meanwhile, the effect of other basin liner designs on the temperature of brackish water as well as the daily yield was not analyzed in their study. An additional study was carried out by Nguyen *et al.* (Nguyen *et al.* 2018) efforted to review influenced parameters and measures enhancing the productivity of both passive and active solar distillation of water. According to their investigation, the temperature of brackish water is one of the parameters that has a great effect on the output of the distillation process. Nevertheless, parameters that affect basin water temperature were not sufficient and there was a shortage of basin liner's effects. An extensive review of advancements in solar still's design and their performance was summarized by (Awasthi *et al.* 2018). Although some special shapes of basin liner were introduced in this paper, their effect was not investigated. Obviously, there are few reviews that assess the performance of solar still base on the basins and how their designs affect the temperature of brackish water along with the evaporation process (one of two major processes in the distillation of seawater). As a result, this present review is carried out. This paper investigated comprehensively different basins of passive solar stills fabricated and studied in the last decade with the sole aim to investigate the most suitable design for basin and to provide the suggestion for future work.

2. Materials and Methods

This work concentrates on published studies on the control of passive solar stills with different basins to investigate the best performance design for basin type. A number of peer-reviewed articles of repute related to passive solar still have been chosen for this review.

The collected journals are subsequently classified into four groups based on the shape of the basin, namely: Single rectangular absorber, fin, and corrugated absorber, weir type absorber, and cylindrical absorber. The single rectangular absorber is further categorized on the basis of the top cover into subcategories such as single slope cover, double slopes cover, pyramid top cover, tubular top cover, special design of the top cover. All articles were considered carefully, and their considerable results were taken note of comprehensively below. To explore the most energy-efficient absorber, every design is compared. The step-by-step of carrying out the present review is illustrated in Figure 1.

3. Single rectangular basin with various top covers.

3.1 Single rectangular basin single cover.

Figure 2 described the construction of a basic conventional solar distillation of water. (Phadatare & Verma 2007) estimated experimentally the influence of water height on the performance of single basin solar still with a Plexiglas cover. The results achieved from the experiment showed the highest yield of 2.1 L/m^{2}day at 2 cm of the water height, following by 4, 6, 8 10, and 12 cm of water height. Water depth of 12 cm got the lowest productivity, however, its efficiency was the highest of 34%. (Agrawal & Rana 2018) also investigated the effect of water level on a conventional solar still, and they reported that efficiency and productivity are 34.4% and 4.26 kg/m^{2}day, at low water depth.

In addition, the improvement of residence time for brackish basin water can be done by the wick usage that helps the basin water to reach higher temperature quickly and enhance the evaporation process. Thanks to the wick, the brine is kept shallow and prevented dry spot's existence. Capillarity, thermal conductivity, as well as solar absorption ability are factors that affect the performance of the wick. Various materials of wick such as jute, cotton, stones were investigated on solar still and researchers indicated that this is the most efficient and effective technique to increase the daily yield. Indeed, a solar distiller using a wick is normally designed in form of an inclined model.

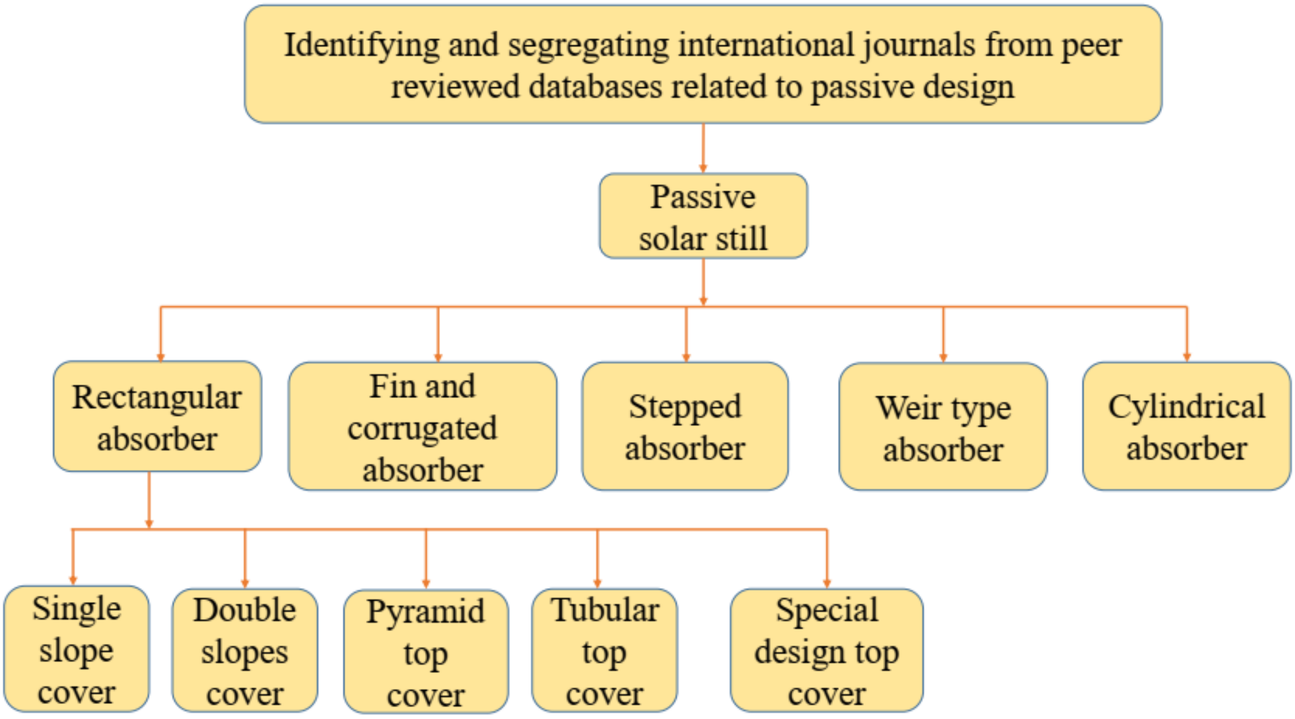


Fig. 1 Footsteps to conduct the present review

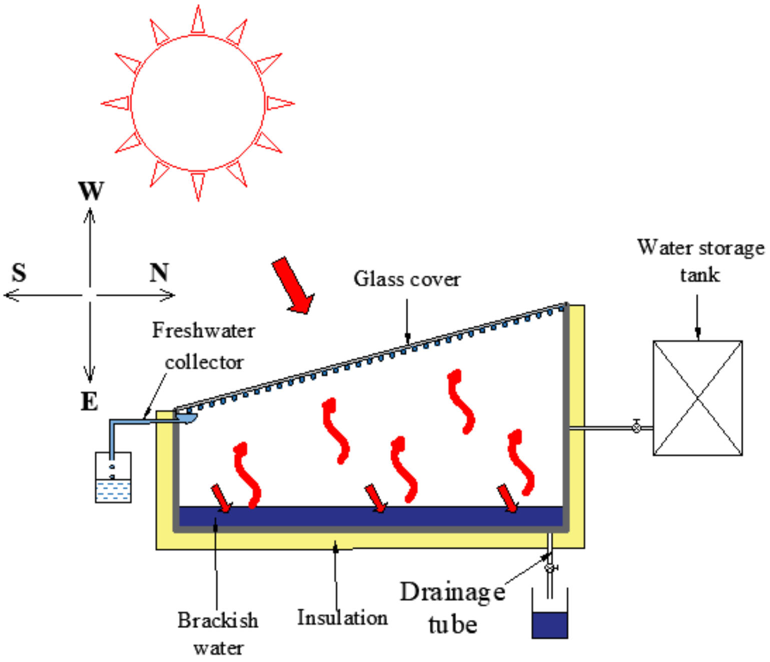


Fig. 2 Schematic diagram of conventional solar still.

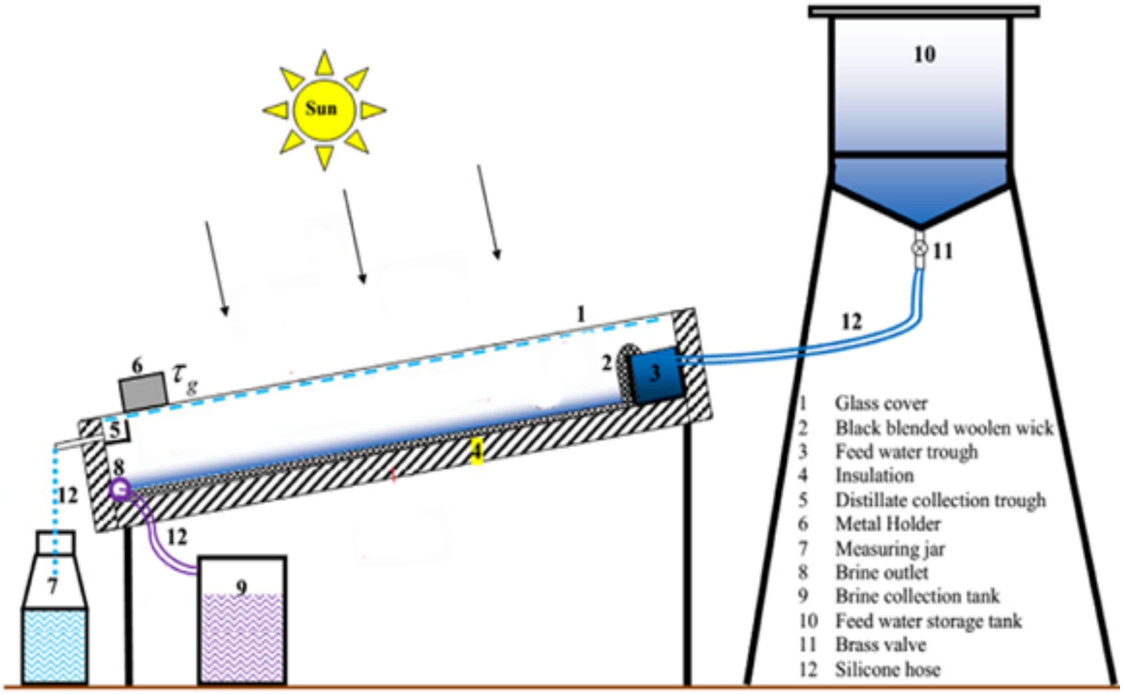


Fig. 3 Tilted solar still with wick material usage (Sharon *et al.* 2017)

Agboola *et al.* (Agboola *et al.* 2014), investigated inclined wick solar still and 3.25 kg/m^2/day of potable water was produced 40.1% of energy efficiency. In the study of (Srivastava & Agrawal 2014), floating blackened jute cloth was employed in solar still, which showed an increase of up to 57.4% of productivity compared to a passive one. Meanwhile, in Agrawal *et al.* work (Agrawal *et al.* 2017), multiple cloth absorbers with a spherical shape were arranged in a single-basin solar still. Its productivity and efficiency are 46.33% and 55.73% higher than that of a single basin single slope solar still, respectively. Sharon *et al.* (Sharon *et al.* 2017) compare the performance of title solar still with basin and title solar still with blackened wick, shown in Figure 3. They concluded that the highest yield of tilted solar still with basin and wick was 4.99 L/d and 4.54 L/d obtained in April.

3.2 Single rectangular basin double slope

Omara *et al.* (Omara *et al.* 2017a) indicated that the rate of condensation can be increased by cooling the condenser with the flow of water or air, which enlarging the temperature gradient between the top cover and water in the basin. A solar still with a separate glass condenser was studied experimentally by El-Bahi and Inan (El-Bahi & Inan 1999). Their results show the increment of the solar still efficiency up to 45.83% because the condenser is cooled and their model got 7 L/m^2 day of the freshwater production. An experiment with double glass covers was conducted by Abu-Arabi *et al.* (Abu-Arabi *et al.* 2002). The saline water flowed on a glass that separated another glass and basin, which kept the middle glass cool, and a 34% rise in productivity was achieved compared to a conventional one.

Whereas, a different design of double-slope solar still includes two glass covers oriented in different directions in order to collect solar radiation better. Numerous works related to double slope solar still were investigated with respect to heat storage, parametric variation, heat loss coefficient, and orientation The tilt angle of glass covers is optimized depending on the orientation of surfaces (El-Maghlany 2015). A double-slope solar still used wick material was assessed in Pal *et al.* work (Pal *et al.* 2018), as shown in Figure 4. Their findings showed 35% and 3.83% of thermal and exergy efficiency. Gnanaraj and Velmurugan (Gnanaraj & Velmurugan 2019) built a single rectangular basin double glass solar still as a reference case to assess modified stills, which have a distillate output of 1.88 L/m^2.day.

3.3. Single rectangular basin pyramid cover

The purpose of a pyramid shape on the top of solar stills is to capture solar energy from all directions. Parameters influencing a triangular-pyramid solar distiller such as wind velocity and water depth were studied in the study (Sathyamurthy *et al.* 2014). They found that water depth of 2 cm obtained the highest daily yield of 4.3 kg/m^2day. Fath *et al.* (Fath H. E. S., El-Samanoudy M., Fahmy K. 2003) compared two solar stills: a pyramidal still (4 slopes) and a conventional solar still. They reported that the average daily productivity of pyramid solar still is equal to that of single slope stills. An analysis of pyramid wick-type solar still performance was carried out experimentally by Prakash *et al.* *(Prakash et al.* 2016). They confirmed that pyramid wick solar still has better efficiency in comparison with a pyramid basin one and a conventional one, which is 50.25% with 5.25 L/m^2 day of productivity. A four slopes pyramidal still and two slopes triangular prism still was tested by (Wassouf *et al.* 2011), which has 2.5 L/m^2day and 1.5 L/m^2day, respectively. Kabeel *et al.* (Kabeel *et al.* 2016) conducted experiment of three square pyramid solar still which has different inclined angle of the top cover (30.47^o, 40^o, and 50^o) as illustrated in Figure 5. Maximum accumulated distillate water productivity of 4.13 L/m^2day belonged to the model has an inclined angle of condensation surface of 30.47^o. Prakash and Jayaprakash (Prakash & Jayaprakash 2020) evaluated performance of a stepped multiple basin pyramid solar still. The average efficiency of their system was obtained to be 50.85% and the daily average yield was 3.25 L/m^2day.

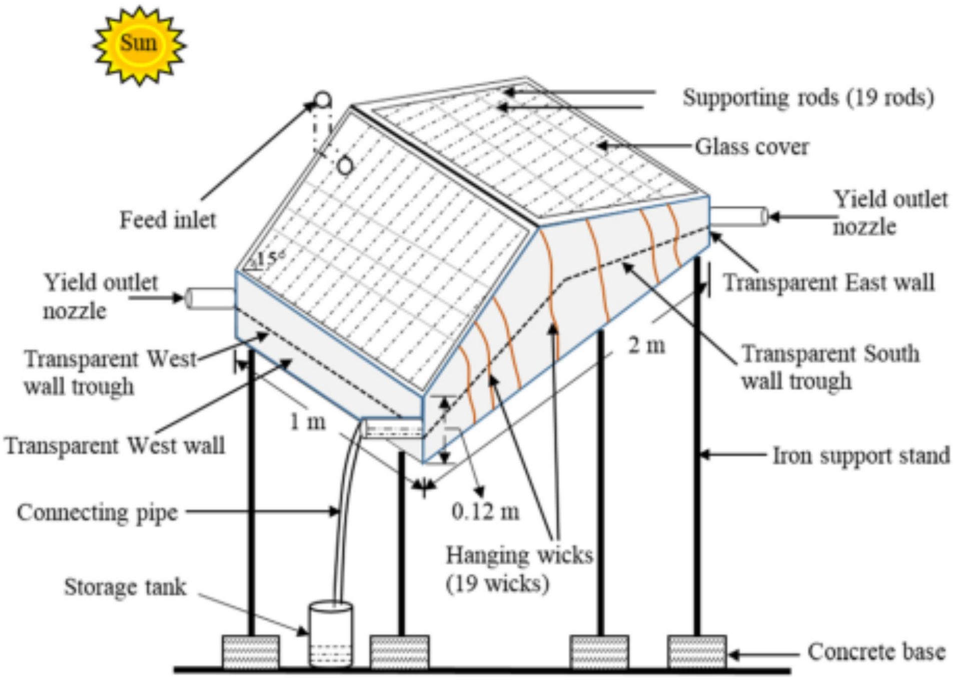


Fig. 4 Multi-wick double-slope solar still (Pal *et al.*, 2018)

3.4 Single rectangular basin tubular cover

An experiment was performed by Arunkumar *et al.* (Arunkumar *et al.* 2013b) to investigate the effect of cooling techniques on the performance of tubular solar still (TSS) with a compound parabolic concentrator (CPC). air and water are used to cool the outside cover of tubular solar still. They reported that that the output of TSS-CPC was 2.050 kg/m²day, which can increase by 2 and 2.95 kg/m²day with air and water cooling, respectively. The behavior of triangular and TSS was tested under similar real environmental conditions (Rahbar *et al.* 2018). The efficiency and distilled water yield of the former were 35% and 1.336 L/m²day while that of the latter obtained 41% and 1.6 L/m²day. It is noted that TSS has better performance as compared to triangular still. Experimental investigation of absorber plate shapes influences the behavior of TSS was done by (Elshamy & El-Said 2018). Collected basin shapes included semi-circular corrugated (TSS-SCC) and the flat plate basin (TSS-FPB) were studied at the weather of Giza in Egypt. According to their findings, TSS-SCC distilled 4.3 L/m²day of freshwater, which improved by 26.47% in comparison with TSS-FPB. Further results reported that TSS -SCC had An exergy of 23.7% and efficiency of 25.9%. In addition to TSS studied, Sathyamurthy et al. (Sathyamurthy *et al.* 2020) compared the performance of TSS using fin absorber and flat absorber, which is shown in Figure 6. TSS with fin absorber had a daily distillate yield of 3.04 kg/m²day, which is 1.5 times higher than that of TSS with the flat absorber.

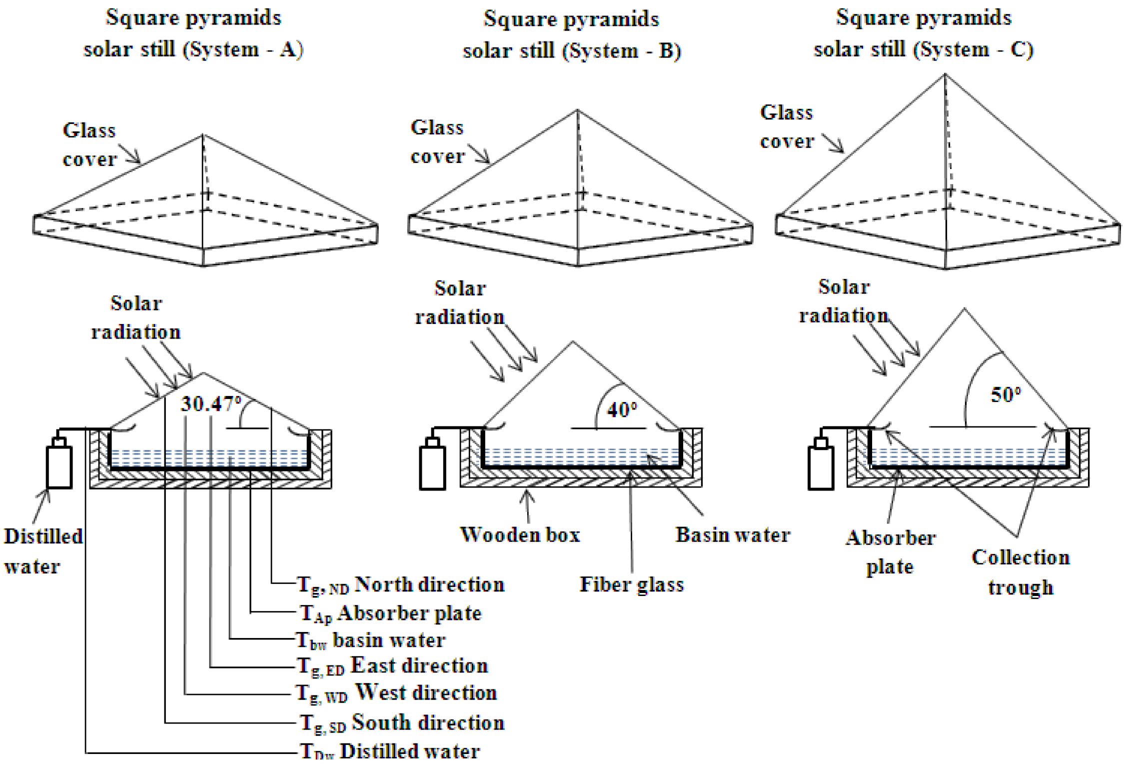


Fig. 5 Square pyramid solar still (Kabeel *et al.* 2016).

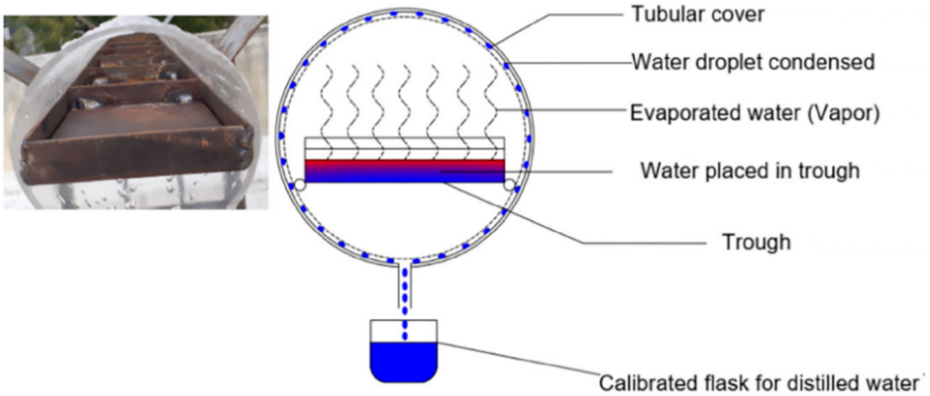


Fig. 6 Tubular solar still (Sathyamurthy *et al.* 2020)

3.5 Single basin with special covers

Arun Kumar *et al.* (Arunkumar *et al.* 2012) covered the top of solar still with an acrylic hemispherical sheet and experimented with and without water cooling. The distilled yield of their model ranged between 3.58 and 3.68 L/m^2day without cooling and from 4.18 to 4.2 L/m^2day with the water cooling technique. An experimental report of four basin solar stills with different shape curves of hemispherical covers was obtained in Tayeb's work (Tayeb 1992). His work revealed that an inclined flat glass cover obtained the highest daily yield and efficiency of 1.25 L/m2day and 21.8%, 2 half-cylinders covers, a half-cylinder cover, and a slight curve cover respectively. Khan *et al.* (Khan *et al.* 2021) also researched hemispherical solar still and the impact of water cooling on its behavior, as shown in Figure 7. They got 3.6 L/m^2day without cooling and 4.2 L/m^2day with the cooling technique. In the study (Attia *et al.* 2021), tray basins made of iron, zinc, and copper with a hemispherical cover were investigated to compare to a traditional hemispherical solar still, which is shown in Figure 8. The copper tray displayed the best performance with 7.35 kg/m^2day of distillate yield and 57.2% of energy efficiency, following by zinc tray basin (6.3 kg/m^2day-49%), iron tray basin (5.5 kg/m^2day-42.8%), and conventional hemispherical solar still (4.8 kg/m^2day-37.4%).

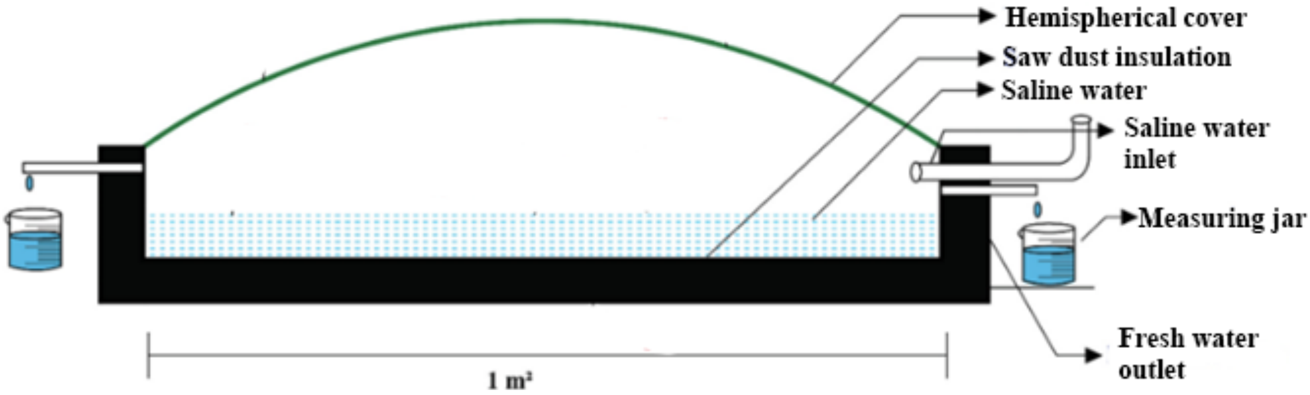


Fig. 7 Spherical solar still (Khan *et al.* 2021)

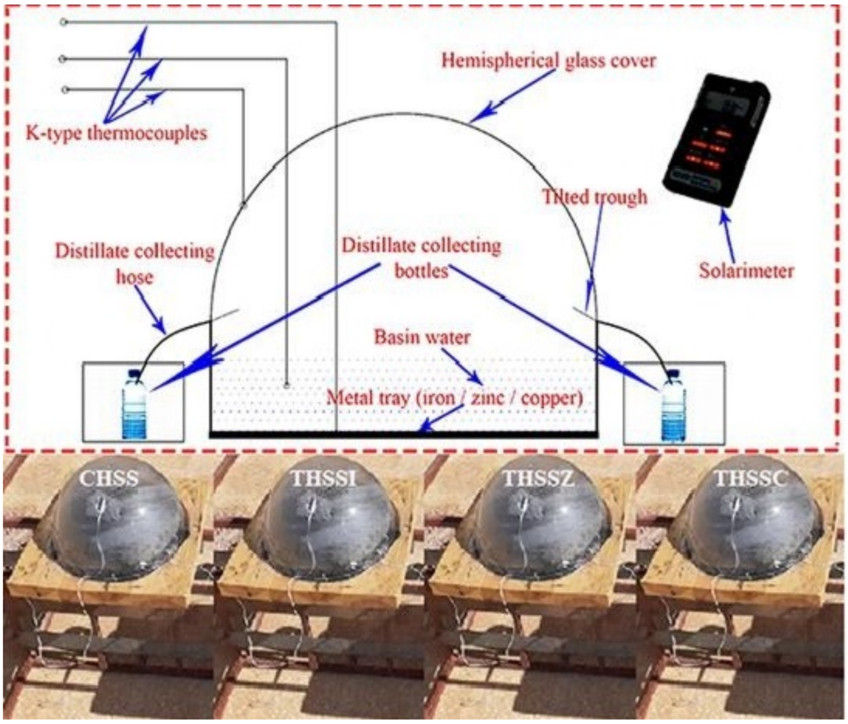


Fig. 8 Schematic and photo of conventional spherical solar still (CHSS) and spherical solar still with iron basin (THSSI), zinc basin (THSSZ), and copper basin (THSSC) (Attia *et al.* 2021).

The invention of spherical cover for solar still was presented in 1988 by Dhiman (Dhiman 1988). He concluded that its efficiency is 30% is higher than that of basic solar still and the daily yield could reach approximately 2.75 kg/m^{2}day if absorbtivity of the basin was 0.8. As designing most of the solar thermal application, one of the critical parameters need to consider is heat transfer. The heat transfer in solar applications can enhance by enlarging the surface area. The absorber plate is the essential component of solar still. An energy absorption rate of the basin affects how much freshwater distilled by the solar still; hence, (Mevada *et al.* 2020) reported that the absorber with the bigger area is desirable. Nevertheless, making the basin area larger directly means the increase of size and space which influences the economic efficiency of a solar still. In this case, Zhang *et al.* (Zhang *et al.* 2019) and Maradiya *et al.* (Maradiya *et al.* 2018) revealed that solar stills are designed with corrugated as well as fins basins are better. A Finned and corrugated basin were designed in the study of (Omara *et al.* 2011), and their behavior was compared to a similar area conventional solar still. The maximum distillate yield of the finned and corrugated basin was 4.1 and 4.4 L/m^{2}day, while that of the passive solar still was 3.4 L/m^{2}day. 41%, 45%, and 34% of energy efficiency were obtained with finned, corrugated, and rectangular basins. Exposure of basin by corrugated absorber improved conventional solar still up to 20,35% in the study of (Selvendiran *et al.* 2014)

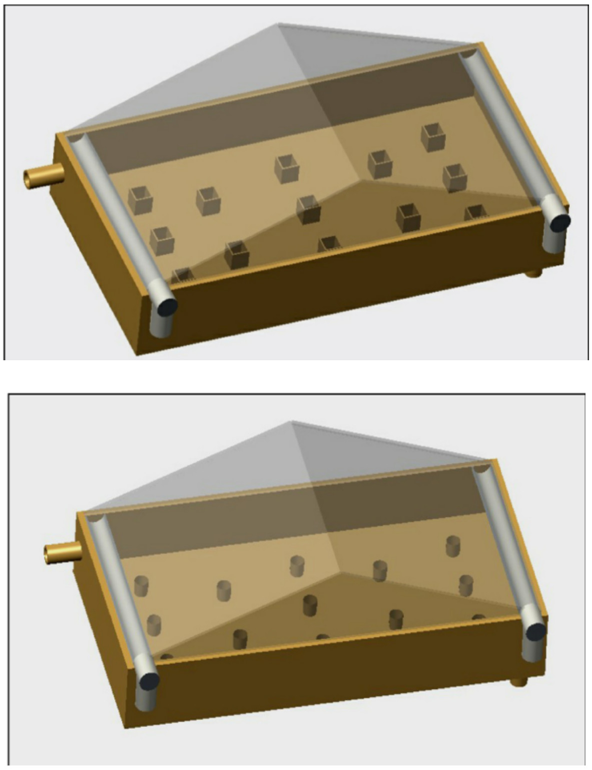


Fig. 9 Single basin double slope solar still with rectangular and cylindrical fins (Jani & Modi 2019)

4. Fin and corrugated absorber

Nagarani *et al.* (Nagarani *et al.* 2014) remarkable that a good design of fins may improve heat transfer with reduction of volume and price. Jani and Modi (Jani & Modi 2019) compared performance of two double-slope solar stills with different shapes of fins welded on the basin: hollow circular and square (Figure 9). It is observed that the performance of circular fined still was better than that of square finned still. Furthermore, the conventional double slope solar still was studied with six cases: without any modification, using a finned corrugated basin, employing black granite, still with wick, using external reflector, still with all external and internal modifications were tested in (Gnanaraj & Velmurugan 2019). The productivity of still with finned corrugated basin was approximately 3 L/m^{2}day, increased 58.47% as compared to conventional still which observed 1.88 L/m^{2}day.

5. Stepped basin and Weir type basin

The characteristic of stepped basin solar still is to have higher thermal efficiency because of less volume of air inside solar still and the larger total basin area for similar overall size compared to a conventional solar still (Abdul & Khan, Bhuibhar 2018). Supplying water stagnant maintains each step at a sufficient level. The number of steps is collected and design based on still dimension. Concept design of stepped basin solar still assembled a mirror reflector on every steps basin was proposed by Omara *et al.* (Omara *et al.* 2013) as shown in Figure 10. The stepped solar still without reflectors displayed a yield of 5.84 L/m^{2}day and daily efficiency of 53% while using reflectors showed a yield of 6.35 L/m^{2}day and daily efficiency of 56%. Abujazar *et al.* (Abujazar *et al.* 2018) proposed an inclined solar still with a stepped basin made from copper for higher efficacy. Its daily output was 4.35 L/m^{2}day. (Saadi *et al.* 2018) modified a conventional solar still by integrating a stepped evaporator on a higher vertical side and compared it to a conventional solar still under desert weather. The productivity obtained the highest of 5.82 L/m^{2}day in the summer season when the solar intensity is the highest in a year, following spring, autumn, and winter, which proved that daily yield is directly proportional to solar irradiation.

Weir type solar still looked like a combination of stepped basin and inclined basin solar still. The weir-type design makes the gap from absorber plate to top cover smaller, which supports the still to saturate rapidly with water and improve the efficiency of solar stills. Additionally, the time spent on the evaporation surface increases due to the weir shape. Sadineni et al. presented a new weir shape absorber using for solar still (Sadineni *et al.* 2008). The weirs have a small step height of 1.6 mm to minimize the water depth on the basin. The brine was circulated in the system by a recirculated pump to raise the evaporation rate. Their model produced 5.5 kg/m^{2}day which improve that of the conventional still by 20%.

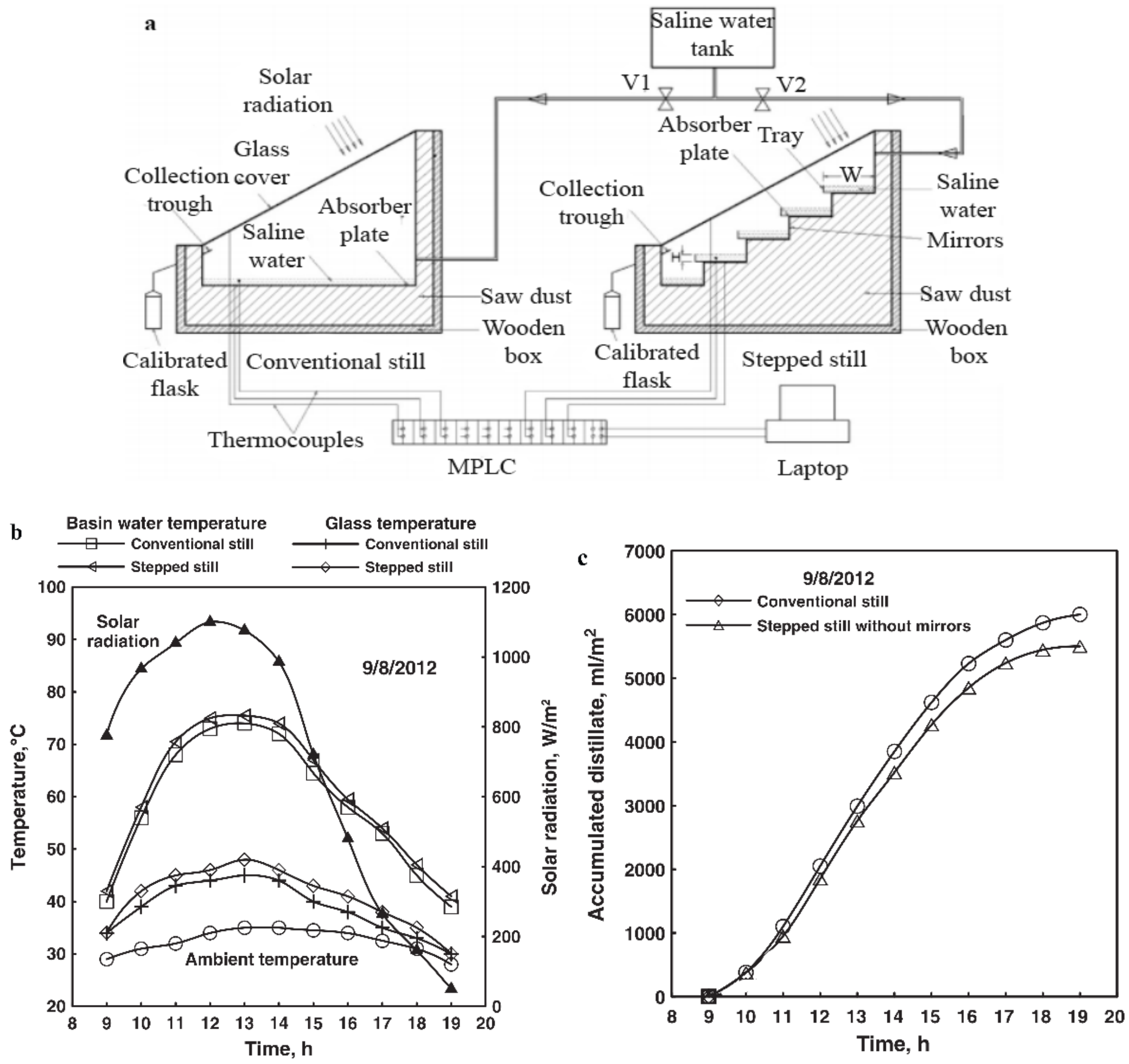


Fig. 10 Stepped basin solar still (a): schematic diagram; (b): Solar diation and temperature of basin water and glasscover; (c): accumulated distillate yield (Omara *et al.* 2013)

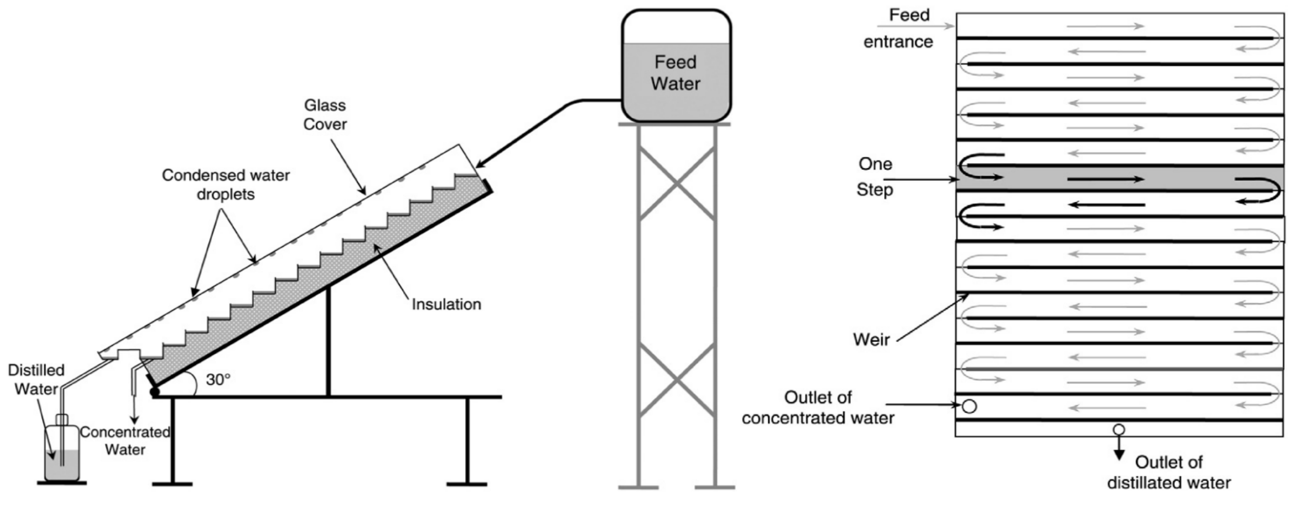


Fig. 11 Weir-type cascade solar still (Tabrizi *et al.* 2010).

Figure 11 describes a weir-type cascade solar still which was introduced by Tabrizi *et al.* (Tabrizi *et al.* 2010). 15 steps absorber plate was fabricated and equipped with a weir of 5 mm in height responsible for extending the residence time of water and remaining water depth to be shallow. Their obtained results showed that the daily distillate yield is decreased with a growth in the mass flow rate. The highest productivity reached 7.4 kg/m^2day at 0.065 kg/min of flow rate. Energy and exergy analysis of weir type cascade solar still with and without phase change material storage was conducted by Sarhaddi *et al.* (Sarhaddi *et al.* 2017). The solar still without PCM reached the highest energy and exergy efficiencies of 76.69% and 6.53%.

6. Cylindrical and half-cylindrical shape basin

Elashmawy (Elashmawy 2020) fabricated tubular solar still consists of a half-cylinder aluminum trough covered by a transparent tube and compare to rectangular basin type and . reported a 67,6% increase in productivity using tubular solar still with a semicircular trough filled with a black cloth. The concentration of solar irradiation on the tube was increased using the parabolic concentrator. Kabeel *et al.* (Kabeel *et al.* 2020) proposed modification of tubular solarstill with basin was designed by half two half-cylinders was arranged concentrically. They integrated this still with cylindrical parabolic concentrators (CPC). Saltwater was filled in the gap between two half-cylinders. 7.48 L/m^2day of daily output and 61.4 % of daily efficiency were recorded with 2 cm of water layer thickness, following by 1 cm, 3 cm, and 4 cm. Kabeel and Abdelgaied (Kabeel & Abdelgaied 2017) replaced the basin of conventional solar still with a group of two coaxial pipes which comprised a copper outer pipe and a copper inner pipe with a smaller diameter. Brackish water will fill in the gap between them. Four cases with different diameters of the inner tube were investigated and they found that a bigger diameter of the inner tube means the smaller gap between the outer and inner tubes had higher productivity and efficiency. 5 mm of this gap obtained the maximum daily yield of 8.15 L/m^2day, improved 97.8% in comparison with a conventional solar still. Figure 12 describes the schematic diagram of a multi-group of two coaxial pipes solar still and temperature of different parts in the coaxial still. The highest temperature of brackish water reach a peak of 92°C at 13 o'clock. Table 1 compares the performance of different solar stills with various shapes of basin liner.

7. Conclusion

Utilizing solar to distillate seawater namely solar still is one of the favorable approaches to meet the globally increasing demand for potable water, due to its advantages of available abundance and low carbon energy. Various designs of basin or absorber have been invented and investigated for productive innovations of solar still. From the briefly detailed investigation on the different type of basin, the conclusions have been drawn following:

According to this present review, multi-groups of two coaxial pipes basin has the highest productivity due to its cylindrical shape which can absorb solar energy more effectively than a flat plate.

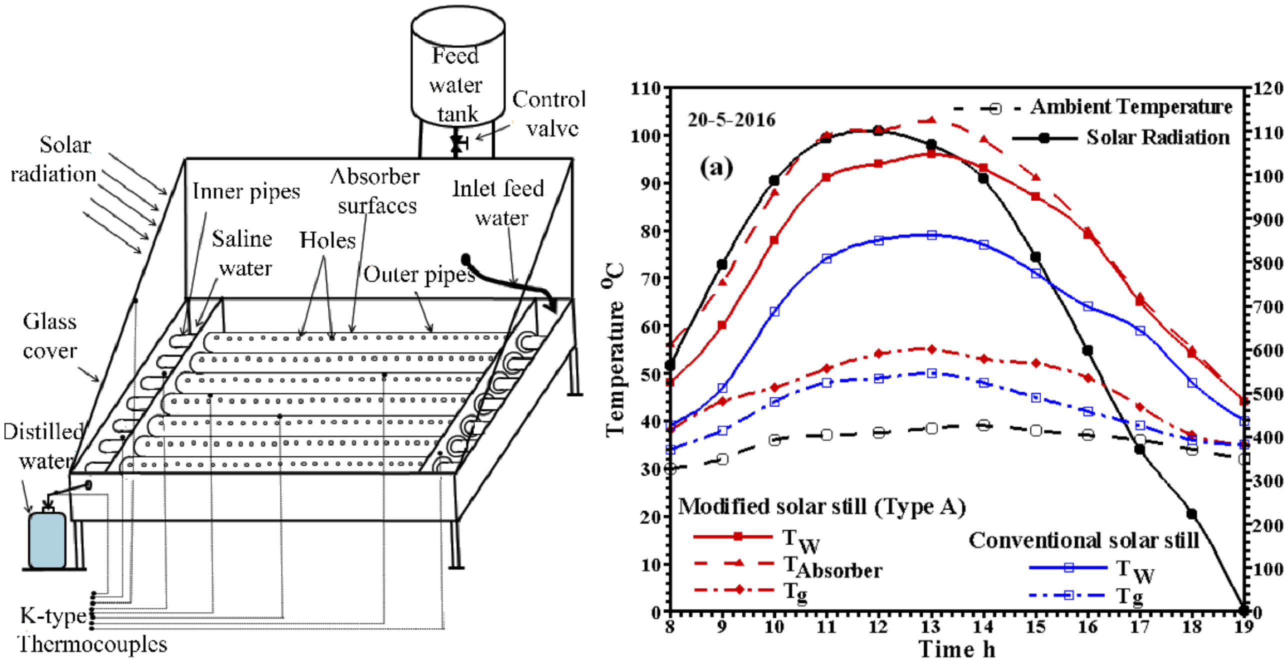


Fig. 12 Schematic diagram of multi-group of two coaxial pipes solar still (Kabeel & Abdelgaied 2017).

Table 1
Performance comparison of all basin type in solar stills

No.	Basin types	Basin material	Top cover	Igm (W/m^2)	t_e (hour)	T_w (°C)	Me (L/m^{2}day)	η (%)	Ref.
1	Horizontal rectangular basin	Galvanized iron	Single slope	911	24	65	4.26	34%	(Agrawal & Rana 2018)
2		iron	Single slope	850	11	61	3.25	34%	(Omara *et al.* 2011)
3		Iron plate	Double slopes	N/A	23	55	1.88	N/A	(Gnanaraj & Velmurugan 2019)
4		Black painted	Triangular slope	800	11	74	4.3	N/A	(Sathyamurthy *et al.* 2014)
5		Wick	Four sides glass pyramid cover	1035	9	75	4.82	50.3	(Prakash *et al.* 2016)
6		Galvanized iron	Four sides glass pyramid cover	954	9	79	4.13	N/A	(Kabeel *et al.* 2016)
7		Galvanized iron	Tubular cover	1100	7	59	3.4	27.1	(Elshamy & El-Said 2018)
8		Mild steel	Hemispherical cover	732	8	63	3.68	34	(Khan *et al.* 2021)
9		Copper	Hemispherical cover	1000	12	75	7.35	57.2	(Attia *et al.* 2021)
10		Metallic plate	Spherical cover	730	10	-	2.8	30	(Dhiman 1988)
11	Inclined rectangular basin	Stainless	Single slope	932	12	74	4.99	41.6	(Sharon *et al.* 2017)
12		Wick	Single slope	932	12	74	4.54	33.83	(Sharon *et al.* 2017)
13	Corrugated basin	Iron sheet	Single slope	850	11	64	3.95	41	(Omara *et al.* 2011)
14	Semi-circular corrugated basin	steel	Tubular	1100	7	60	4.3	34.1	(Elshamy & El-Said 2018)
15	Fin basin	Iron sheet	Single slope	850	11	66	4.55	47.5	(Omara *et al.* 2011)
16		iron	Double slope	N/A	23	54	2.99	43	(Gnanaraj & Velmurugan 2019)
17		Mild steel	Tubular cover	950	10	59	3.04	N/A	(Sathyamurthy *et al.* 2020)
18	Stepped basin	Copper	Single slope	1000	11	72.5	4.35	29.8	(Abujazar *et al.* 2018)
19		Mild steel	Four sides pyramid cover	993	9	58	3.25	50.85	(Prakash & Jayaprakash 2020)
20	Weir type basin	Galvanized steel	Single slope	1000	12	90	5.5	N/A	(Sadineni *et al.* 2008)
21	Weir-type cascade	Aluminum	Single slope	800	11	58	4.84	76.69	(Sarhaddi *et al.* 2017)
22	Multi-groups of two coaxial pipes	Copper	Single slope	1115	11	96	8.15	67.6	(Kabeel & Abdelgaied 2017)
23	Half cylinder basin	Aluminum	Tubular cover	1050	24	70	3.6	30.2	(Elashmawy 2020)

Note: I_{gm}: maximum solar radiation; t_e: experimental time; T_w: Highest temperature of brackish water; M_e: daily yield; η: thermal efficiency

The rectangular basin was attached fins or fabricated corrugated shape can expose the area of water in solar still, which leads to the higher rate of the evaporation process. As a result, the thermal efficiency of the system is enhanced. The productivity of all basin types is directly proportional to solar radiation and inverse proportional with water depth. Stepped and weir-type cascade solar stills provided good improvements.

Galvanized iron, iron, mild steel, galvanized steel, stainless steel, wick, aluminum, and copper are popular materials applying in solar stills. Among them, copper usage has the highest daily distillate yield and thermal efficiency. While wick is also a good choice since it is cheaper than metal material but its productivity and efficiency are significant. In the tubular stills, the rectangular basin has a better performance compared to the semi-cylindrical shape.

References

Abdallah S, Badran OO. 2008. Sun tracking system for productivity enhancement of solar still. *Desalination.* 220(1–3):669–76

Abdelmaksoud W, Almaghrabi M, Alruwaili M, Alruwaili A. 2020. Improving water productivity in active solar still. *Energy Sources, Part A Recover. Util. Environ. Eff.* 0(0):1–14

Abdul MAK, Khan, AG., Bhuibhar PPS. 2018. Performance & analysis and optimization of stepped type solar still. *Int. J. Eng. Sci. Res. Technol.* 7(3):69-74.

Abed FM, Kassim MS, Rahi MR. 2017. Performance improvement of a passive solar still in a water desalination. *Int. J. Environ. Sci. Technol.* 14(6):1277–84

Abu-Arabi M, Zurigat Y, Al-Hinai H, Al-Hiddabi S. 2002. Modeling and performance analysis of a solar desalination unit with double-glass cover cooling. *Desalination.* 143(2):173–82

Abujazar MSS, Fatihah S, Lotfy ER, Kabeel AE, Sharil S. 2018. Performance evaluation of inclined copper-stepped solar still in a wet tropical climate. *Desalination*. 425:94–103

Agboola OP, Al-Mutaz IS, Orfi J, Egelioglu F. 2014. Economic investigation of different configurations of inclined solar water desalination systems. *Adv. Mech. Eng.* 2014:

Agrawal A, Rana RS. 2018. Energy and exergy analysis of single slope single basin solar still in Indian condition: An experimental analysis. *Mater. Today Proc.* 5(9):19656–66

Agrawal A, Rana RS, Srivastava PK. 2017. Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison. *Resour. Technol.* 3(4):466–82

Alwan NT, Shcheklein S, Ali O. 2020. Investigation of the coefficient of heat transfer and daily cumulative production in a single-slope solar distiller at different water depths. *Energy Sources, Part A Recover. Util. Environ. Eff.* 0(0):1–18

Anwar K, Deshmukh S. 2018. Assessment and mapping of solar energy potential using artificial neural network and GIS technology in the southern part of India. *Int. J. Renew. Energy Res.* 8(2):974–85

Anwar K, Deshmukh S. 2020. Parametric study for the prediction of wind energy potential over the southern part of India using neural network and geographic information system approach. *Proc. Inst. Mech. Eng. Part A J. Power Energy*. 234(1):96–109

Ardeshiri F, Salehi S, Peyravi M, Jahanshahi M, Amiri A, Rad AS. 2018. PVDF membrane assisted by modified hydrophobic ZnO nanoparticle for membrane distillation. *Asia-Pacific J. Chem. Eng.* 13(3):1–12

Arun Kumar S, Suresh Mohan Kumar P. 2021. Improving the operating time of the multi slope shape solar still. *Energy Sources, Part A Recover. Util. Environ. Eff.* 1–13

Arunkumar T, Denkenberger D, Ahsan A, Jayaprakash R. 2013a. The augmentation of distillate yield by using concentrator coupled solar still with phase change material. *Desalination*. 314:189–92

Arunkumar T, Jayaprakash R, Ahsan A, Denkenberger D, Okundamiya MS. 2013b. Effect of water and air flow on concentric tubular solar water desalting system. *Appl. Energy*. 103:109–15

Arunkumar T, Jayaprakash R, Denkenberger D, Ahsan A, Okundamiya MS, et al. 2012. An experimental study on a hemispherical solar still. *Desalination*. 286:342–48

Arunkumar T, Velraj R, Denkenberger D, Sathyamurthy R, Vinothkumar K, et al. 2016. Effect of heat removal on tubular solar desalting system. *Desalination*. 379:24–33

Attia MEH, Kabeel AE, Abdelgaied M, Essa FA, Omara ZM. 2021. Enhancement of hemispherical solar still productivity using iron, zinc and copper trays. *Sol. Energy*. 216:295–302

Awasthi A, Kumari K, Panchal H, Sathyamurthy R. 2018. Passive solar still: recent advancements in design and related performance. *Environ. Technol. Rev.* 7(1):235–61

Bait O, Si-Ameur M. 2018. Enhanced heat and mass transfer in solar stills using nanofluids: A review. *Sol. Energy*. 170(June):694–722

Buabbas SK, Al-Obaidi MA, Mujtaba IM. 2020. A parametric simulation on the effect of the rejected brine temperature on the performance of multieffect distillation with thermal vapour compression desalination process and its environmental impacts. *Asia-Pacific J. Chem. Eng.* 15(6):1–14

Dhiman NK. 1988. Transient analysis of a spherical solar still. *Desalination*. 69(1):47–55

Dsilva Winfred Rufuss D, Iniyan S, Suganthi L, Davies PA. 2016. Solar stills: A comprehensive review of designs, performance and material advances. *Renew. Sustain. Energy Rev.* 63:464–96

El-Bahi A, Inan D. 1999. A solar still with minimum inclination, coupled to an outside condenser. *Desalination*. 123(1):79–83

El-Maghlany WM. 2015. An approach to optimization of double slope solar still geometry for maximum collected solar energy. *Alexandria Eng. J.* 54(4):823–28

El-Sebaii AA, El-Bialy E. 2015. Advanced designs of solar desalination systems: A review. *Renew. Sustain. Energy Rev.* 49:1198–1212

Elashmawy M. 2020. An experimental investigation of a parabolic concentrator solar tracking system integrated with a tubular solar still. *Desalination*. 411(2017):1–8

Elshamy SM, El-Said EMS. 2018. Comparative study based on thermal, exergetic and economic analyses of a tubular solar still with semi-circular corrugated absorber. *J. Clean. Prod.* 195:328–39

Fath H. E. S., El-Samanoudy M., Fahmy K. HA. 2003. Thermal - Economical Analysis and Comparison Between Pyramid Configuration and Signal Slope Solar Stills. *Seventh Int. Water Technol. Conf. Egypt 1-3 April 2003*. (April):565–90

Gnanaraj SJP, Velmurugan V. 2019. An experimental study on the efficacy of modifications in enhancing the performance of single basin double slope solar still. *Desalination*. 467(September 2018):12–28

Handayani NA, Ariyanti D. 2012. Potency of solar energy applications in Indonesia. *Int. J. Renew. Energy Dev.* 1(2):33–38

Hanson A, Zachritz W, Stevens K, Mimbela L, Polka R, Cisneros L. 2004. Distillate water quality of a single-basin solar still: Laboratory and field studies. *Sol. Energy*. 76(5):635–45

Hoang AT, Le AT. 2019. A review on deposit formation in the injector of diesel engines running on biodiesel. *Energy Sources, Part A Recover. Util. Environ. Eff.* 41(5):584–99

Hoang AT, Nguyen XP, Duong XQ, Huynh TT. 2021a. Sorbents-based devices for the removal of spilled oil from water: A review. *Environ. Sci. Pollut. Res. https://doi.org/10.1007/s11356-021-13775-z.*

Hoang AT, Nguyen XP, Le AT, Pham MT, Hoang TH, Al-Tawaha ARMS, Yondri S. 2021b. Power generation characteristics of a thermoelectric modules-based power generator assisted by fishbone-shaped fins: Part II–Effects of cooling water parameters. *Energy Sources, Part A Recover. Util. Environ. Eff.* 43(3):381–93

Hoang AT, Nižetić S, Duong XQ, Rowinski L, Nguyen XP. 2021c. Advanced super-hydrophobic polymer-based porous absorbents for the treatment of oil-polluted water. *Chemosphere*. 130274. https://doi.org/10.1016/j.chemosphere.2021.130274.

Hoang AT, Pham VV. 2019. A study of emission characteristic, deposits, and lubrication oil degradation of a diesel engine running on preheated vegetable oil and diesel oil. *Energy Sources, Part A Recover. Util. Environ. Eff.* 41(5):611–25

Hoang AT, Pham VV, Nguyen XP. 2021d. Integrating renewable sources into energy system for smart city as a sagacious strategy towards clean and sustainable process. *J. Clean. Prod.* 305(10 July 2021):127161. https://doi.org/10.1016/j.jclepro.2021.127161.

Hoang TH, Hoang AT, Vladimirovich VS. 2021e. Power generation characteristics of a thermoelectric modules-based power generator assisted by fishbone-shaped fins: Part I – effects of hot inlet gas parameters. *Energy Sources, Part A Recover. Util. Environ. Eff.* 43(5):588–99

Hosseini SE. 2019. Development of solar energy towards solar city Utopia. *Energy Sources, Part A Recover. Util. Environ. Eff.* 41(23):2868–81

Jani HK, Modi K V. 2019. Experimental performance evaluation of single basin dual slope solar still with circular and square cross-sectional hollow fins. *Sol. Energy*. 179(November 2018):186–94

Johnson A, Mu L, Park YH, Valles DJ, Wang H, Xu P, Kota K, Kuravi S. 2019. A thermal model for predicting the performance of a solar still with fresnel lens. *Water (Switzerland)*. 11(9):

Kabeel AE, Abdelgaied M. 2017. Performance enhancement of modified solar still using multi-groups of two coaxial pipes in basin. *Appl. Therm. Eng.* 118:23–32

Kabeel AE, Abdelgaied M, Almulla N. 2016. Performances of pyramid-shaped solar still with different glass cover angles: Experimental study. *IREC 2016 - 7th Int. Renew. Energy Congr.*

Kabeel AE, Harby K, Abdelgaied M, Eisa A. 2020. Performance of the modified tubular solar still integrated with cylindrical parabolic concentrators. *Sol. Energy*. 204(April):181–89

Khan MZ, Nawaz I, Tiwari GN, Meraj M. 2021. Effect of top cover cooling on the performance of hemispherical solar still. *Mater. Today Proc.* 38(8):384–90

Liu J, Song R, Nasreen S, Hoang AT. 2019. Analysis of the Complementary Property of Solar Energy and Thermal Power Based on Coupling Model. *Nat. Environ. Pollut. Technol.* 18(5):

Maddah HA. 2019. Modeling and designing of a novel lab-scale passive solar still. *J. Eng. Technol. Sci.* 51(3):303–22

Maradiya C, Vadher J, Agarwal R. 2018. The heat transfer enhancement techniques and their Thermal Performance Factor. *Beni-Suef Univ. J. Basic Appl. Sci.* 7(1):1–21

Mevada D, Panchal H, Sadasivuni K kumar, Israr M, Suresh M, Dharaskar S, Thakkar H. 2020. Effect of fin configuration parameters on performance of solar still: A review. *Groundw. Sustain. Dev.* 10:100289

Muftah AF, Alghoul MA, Fudholi A, Abdul-Majeed MM, Sopian K. 2014. Factors affecting basin type solar still productivity: A detailed review. *Renew. Sustain. Energy Rev.* 32:430–47

Nagarani N, Mayilsamy K, Murugesan A, Kumar GS. 2014. Review of utilization of extended surfaces in heat transfer problems. *Renew. Sustain. Energy Rev.* 29:604–13

Nguyen BT. 2018. Factors Affecting the Yield of Solar Distillation Systems and Measures to Improve Productivities. *Desalin. Water Treat.*

Omara ZM, Abdullah AS, Kabeel AE, Essa FA. 2017a. The cooling techniques of the solar stills' glass covers – A review. *Renew. Sustain. Energy Rev.* 78(April):176–93

Omara ZM, Hamed MH, Kabeel AE. 2011. Performance of finned and corrugated absorbers solar stills under Egyptian conditions. *Desalination*. 277(1–3):281–87

Omara ZM, Kabeel AE, Abdullah AS. 2017b. A review of solar still performance with reflectors. *Renew. Sustain. Energy Rev.* 68(September 2016):638–49

Omara ZM, Kabeel AE, Younes MM. 2013. Enhancing the stepped solar still performance using internal reflectors. *Desalination*. 314:67–72

Omara ZM, Kabeel AE, Younes MM. 2014. Enhancing the stepped solar still performance using internal and external reflectors. *Energy Convers. Manag.* 78:876–81

Pal P, Dev R, Singh D, Ahsan A. 2018. Energy matrices, exergoeconomic and enviroeconomic analysis of modified multi–wick basin type double slope solar still. *Desalination*. 447(September):55–73

Parikh R. 2018. Solar distillation system with nano particle: a review. *J. Energy Manag.* 3:29–34

Pawar PS, Gaikwad K. 2020. Recent Trends in Solar Cells. *SSRN Electronic Journal.* 8(7):3302-3304.

Phadatare MK, Verma SK. 2007. Influence of water depth on internal heat and mass transfer in a plastic solar still. *Desalination*. 217(1–3):267–75

Prakash A, Jayaprakash R. 2020. Performance evaluation of stepped multiple basin pyramid solar still. *Mater. Today Proc.* 45:1950-1956

Prakash A, Jayaprakash R, Kumar S. 2016. Experimental Analysis of Pyramid Wick-Type Solar Still. *Int. J. Sci. Eng. Res.* 7(4):1797–1804

Rahbar N, Asadi A, Fotouhi-Bafghi E. 2018. Performance evaluation of two solar stills of different geometries: Tubular versus triangular: Experimental study, numerical simulation, and second law analysis. *Desalination*. 443(April):44–55

Ravishankar S, Nagarajan PK, Vijayakumar D, Jawahar MK. 2013. Phase change material on augmentation of fresh water production using pyramid solar still. *Int. J. Renew. Energy Dev.* 2(3):115–20

Saadi Z, Rahmani A, Lachtar S, Soualmi H. 2018. Performance evaluation of a new stepped solar still under the desert climatic conditions. *Energy Convers. Manag.* 171(June):1749–60

Sadineni SB, Hurt R, Halford CK, Boehm RF. 2008. Theory and experimental investigation of a weir-type inclined solar still. *Energy*. 33(1):71–80

Sarhaddi F, Farshchi Tabrizi F, Aghaei Zoori H, Mousavi SAHS. 2017. Comparative study of two weir type cascade solar stills with and without PCM storage using energy and exergy analysis. *Energy Convers. Manag.* 133:97–109

Sarkar MNI, Sifat AI, Reza SMS, Sadique MS. 2017. A review of optimum parameter values of a passive solar still and a design for southern Bangladesh. *Renewables Wind. Water, Sol.* 4(1):1–13

Sathyamurthy R, El-Agouz SA, Nagarajan PK, Subramani J, Arunkumar T, Mageshhabu D, Madhu B, Bharathwaaj R, Prakash N. 2017. A Review of integrating solar collectors to solar still. *Renew. Sustain. Energy Rev.* 77(October 2015):1069–97

Sathyamurthy R, Kennady HJ, Nagarajan PK, Ahsan A. 2014. Factors affecting the performance of triangular pyramid solar still. *Desalination*. 344:383–90

Sathyamurthy R, Mageshbabu D, Madhu B, Muthu Manokar A, Rajendra Prasad A, Sudhakar M. 2020. Influence of fins on the absorber plate of tubular solar still- An experimental study. *Mater. Today Proc.* (In press):

Selvendiran R, Manikandan D, Babu RS. 2014. Experimental and performance analysisi of single slope single corrugated basin solar still. *Natl. Conf. Green Eng. Technol. Sustain. Futur. J.* 45(4):141–43

Sharon H, Reddy KS, Krithika D, Philip L. 2017. Experimental performance investigation of tilted solar still with basin and wick for distillate quality and enviro-economic aspects. *Desalination*. 410:30–54

Sharshir SW, El-Samadony MOA, Peng G, Yang N, Essa FA, Hamed MF, Kabeel AE. 2016. Performance enhancement of wick solar still using rejected water from humidification-dehumidification unit and film cooling. *Appl. Therm. Eng.* 108:1268–78

Sharshir SW, Elsheikh AH, Peng G, Yang N, El-Samadony MOA, Kabeel AE. 2017. Thermal performance and exergy analysis of solar stills – A review. *Renew. Sustain. Energy Rev.* 73(January):521–44

Shukla A, Kant K, Sharma A. 2017. Solar still with latent heat energy storage: A review. *Innov. Food Sci. Emerg. Technol.* 41:34–46

Srivastava PK, Agrawal A. 2014. Economics of a high performance solar distilled water plant. *Int J Res Eng Technol.* 3:283–85

Tabrizi FF, Dashtban M, Moghaddam H, Razzaghi K. 2010. Effect of water flow rate on internal heat and mass transfer and daily productivity of a weir-type cascade solar still. *Desalination*. 260(1–3):239–47

Taheri Mousavi SM, Egelioglu F, Ilkan M. 2020. Experimental and numerical study of the effect of various design configurations on the thermal performance of solar still desalination. *Energy Sources, Part A Recover. Util. Environ. Eff.* 0(0):1–15

Tanaka H. 2009. Experimental study of a basin type solar still with internal and external reflectors in winter. *Desalination*. 249(1):130–34

Tayeb AM. 1992. Performance study of some designs of solar stills. *Energy Convers. Manag.* 33(9):889–98

Tiwari GN, Sahota L. 2017. Review on the energy and economic efficiencies of passive and active solar distillation systems. *Desalination*. 401:151–79

Wassouf P, Peska T, Singh R, Akbarzadeh A. 2011. Novel and low cost designs of portable solar stills. *Desalination*. 276(1–3):294–302

Zhang J, Zhu X, Mondejar ME, Haglind F. 2019. A review of heat transfer enhancement techniques in plate heat exchangers. *Renew. Sustain. Energy Rev.* 101:305–28