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Review

Comprehensive Review on Solar Stills—Latest Developments and Overview

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Abstract: This up-to-date and comprehensive literature study provides a rich overview of recent developments in several solar still types. This review examines a large number of theoretical, experimental, and computational studies connected to the single-slope, double-slope, solar still with a condenser, hybrid, and other limited types of solar stills. To make the work more relevant to readers, the authors provide a panoramic view of solar still varieties as well as a complete overview of the most recently published review papers in the solar stills field. The most important conclusions drawn from prior research are carefully discussed and outlined in a useful table to give interested researchers a good road map of many various sorts of solar stills and encourage them to pursue new research avenues in this field. The foremost key results of the evaluated work are presented in a table for readers' convenience. The results indicated that the absorption in the basin was improved by adding charcoal, matt, sponge, jute and cotton clothes, dye, wick, porous or energy-storing material, black rubber, and floating absorber sheet. Moreover, the productivity of solar stills was significantly improved by using the inclined external flat-plate reflector, combined stills, condenser, sun tracking system, reflectors, greenhouse, hot water tank, solar collector, heat exchanger, and solar pond. Further, heat loss was minimized by re-utilizing the latent heat of condensation, cover cooling, and increasing the insulation thickness.

Keywords: solar still; water distillation; literature review; renewable energies

1. Introduction

The development of the world economy depends on water. It is the basic component of agriculture, industry, and infrastructure. Undoubtedly, water is one of the most needed components for life. While 70% of our planet is occupied by water, most of this water is saline. It is important to note that approximately 97% of water is found in the ocean, which is naturally salty; approximately 2% of the water is trapped in glaciers and icebergs in the arctic area; and Only 1% of water is fresh (accessible on the surface of the Earth or underground) for agricultural, animal, and human needs [1]. For instance, this very small amount of fresh water seems to be enough to maintain life and vegetation on our planet.

However, we need to keep in mind that this amount of fresh water is being reduced every day due to many reasons, such as water resources pollution due to industry growth and global warming. In the meantime, the need for fresh water is growing intensely due to the growth in population density. This has led to the well-known problem of water scarcity. A widely used solution for this problem is desalination. Desalination is considered one of the major key solutions and is a sustainable and effective solution to the problem of freshwater shortages [2,3]. Desalination is defined as a process in which fresh water is the end product of saline water. In this process, thermal energy is utilized to evaporate the saline water, resulting in clean water free of salts and inorganic and organic components. One of the greatest merits of this process is that requisite thermal energy may be easily obtained from solar energy. This is why solar desalination has great potential to help overcome the water shortage problem.

This literature study provides a comprehensive summary of current progress in solar stills. This study also includes a comprehensive evaluation of the most recent solar stills review papers. The reviewed papers include recent theoretical, numerical, and experimental works related to various types of solar stills. The most relevant conclusions derived from prior investigations are thoroughly analyzed and summarized.

2. Solar Still

Solar stills are considered an essential component of solar energy utilization for converting sea, brackish, or wastewater to fresh water. They consist of various components, such as the glass cover, water basin, absorber plate, insulation, and distillate trough channel. They can be defined as an efficient solar device for water distillation that directly uses the heat of the sun. Solar stills provide solar-powered desalination based on the concept that solar energy directly drives water evaporation. Solar stills can be used to distill, collect, and supply high-quality drinkable water essential for the daily survival of people who live in remote areas or small isolated communities [4]. Solar stills are simple, with no moving parts, are cheap to build using locally available materials, friendly to the environment with no pollution, have a low maintenance cost, and can be used in arid and salty areas, but their problem is their low water productivity and large area occupancy. Producing fresh water by utilizing a passive solar still would cost approximately $0.014 for each kilogram of water for a 30-year-lifetime system, as pointed out by Kumar and Tiwari [5]. The main idea of solar still operation and its thermodynamic model was introduced by Dunkle [6] and Lof [7], respectively. Solar stills are suitable for small-capacity and self-reliant water supply systems as they can only produce potable water by solar energy. Solar distilled water has a better taste than commercially distilled water; the main reason is that in solar distillation, the water is not subjected to a boiling process. Hence, its PH value is unaffected.

The most important solar still performance parameters are the efficiency and productivity as well as the internal heat and mass transfer coefficients. Their efficiency can be defined as the ratio of the latent heat energy of the condensed water to the total amount of solar energy incident on the still. Whereas productivity is defined as the amount of daily water output per unit area of the solar still. The temperature difference between the water in the basin and the inner surface glass cover governs the productivity rate of the stil [8]. Therefore, it mainly depends on the evaporation rate of the water from the basin and the vapor's condensation rate at the glass cover's lower surface. Generally, there are two main categories for solar stills classification, active and passive stills. For active solar stills, additional thermal energy is delivered to the basin by an external mode (such as collector/concentrator pane or waste thermal energy from chemical plants) so as to enhance the evaporation rate and hence the productivity. Moreover, the temperature differential between evaporation and condensation areas is increased in this type. While the solar still is called passive if this external mode is negligible. Therefore, the evaporation and condensation processes take place naturally. In this type, the basin water directly receives solar energy, and it is considered the sole source of energy that heats the water. So, the evaporation of the saline water leads to low productivity, which is considered the biggest disadvantage of the passive still. However, Tiwari et al. [9] concluded that passive solar stills are inexpensive sources of potable water, whereas the active ones are economical from a commercial point of view, such as in producing distilled water for retail purposes. Tiwari and Tiwari [10] classified the active solar distillation techniques as follows:

1. Active solar distillation of high temperature: In this method, the hot water is fed into the basin by adding more thermal energy using solar collectors. This technique raises the temperature from 20–50 °C to 70–80 °C to achieve better evaporation. The solar still is attached with a flat plate solar collector or a parabolic concentrator, heat pipe, solar pond, and photovoltaic-thermal energy (PV/T) modules. The efficiency of the solar still working by this technique decreases with increasing solar collector area [11]. Regenerative active solar and air bubble solar stills are other high-temperature active solar distillation examples.
2. Pre-heated water active solar distillation: the water basin's temperature is raised using pre-heated water. The waste hot water can be obtained from different sources such as chemical or food industries and thermal power plants. It is directly delivered to the basin or through heat exchangers. This technique can be used to increase the still productivity by about 3.2 times compared with the conventional still [12,13].
3. Nocturnal active solar distillation: In this technique, the hot water is fed into the basin only one time per day. Nocturnal distillation can be defined as the working of a solar still when sunlight is unavailable. This is normally achieved by using the daily stored solar energy through the night or by supplying waste heat which is available from different sources [14].

Solar stills employ the same processes encountered in nature for rainfall generation (i.e., evaporation and condensation). In this device, the impure water is placed in a container. The solar radiation crosses the glass cover and is then absorbed by the lower surface, which is coated with black paint. The absorbed radiation is converted directly into heat. This heat is absorbed by seawater, and partial evaporation of it takes place; the evaporated seawater is then condensed into distilled water on the internal side of the cover. After that, the drops of the distilled water begin to slide down due to gravity and are collected at the bottom of the inclined transparent cover [15]. Whereas the evaporated water leaves all the contaminants in the basin.

Solar stills consist of the following components [Ranjan and Kaushik [16]]:

1. Glass cover, where the water vapor condensation takes place.
2. Saline water (brine) body.
3. Collector plate or basin-liner, where saline water is reserved to absorb the solar radiation.
4. Base with insulation to reduce heat loss.
5. Sidewalls or edges.
6. Water container feed.
7. Distillate output.
8. Vapor leakage.
9. Connecting pipes.
10. Atmosphere, where the solar thermal energy interaction takes place.

The primary objective of solar stills is to maximize the distillate output. Distillate output depends on many different factors such as climate parameters (e.g., solar intensity, ambient air temperature, wind velocity, the humidity of the atmosphere, water-glass temperature difference, and sky conditions), design parameters (like the orientation of still, and tilt angle of cover.), and operating parameters (like water depth in the basin, and salinity of water) Garg and Mann [17].

3. Solar Still Types

Single-slope basin solar still: this is a popular passive still; two different processes occur within the same equipment, namely the distillation and heat collection process [18]. One of the main advantages of this equipment is that it feeds the water container at lower costs due to its simple design, as shown in Figure 1 (Yadav and Kumar [19] and Rahul and Tiwari [20]). It comprises a black-painted basin sealed in a fully airtight surface created from a transparent glass or plastic cover. The solar radiation passes through the cover and is absorbed by the black basin. As a result of solar radiation absorption, the basin water evaporates. The vapor rises until it impacts the inner cover surface and condenses into clean water. After that, it runs down alongside the cover bottom surface and is collected using the glass stopper [21]. This kind of still has the ability to supply large quantities of water, especially for arid remote areas. This kind of still has relatively low thermal efficiency, typically ranging from 20 to 46%, as well as low productivity of less than 6 L/m^2/day.

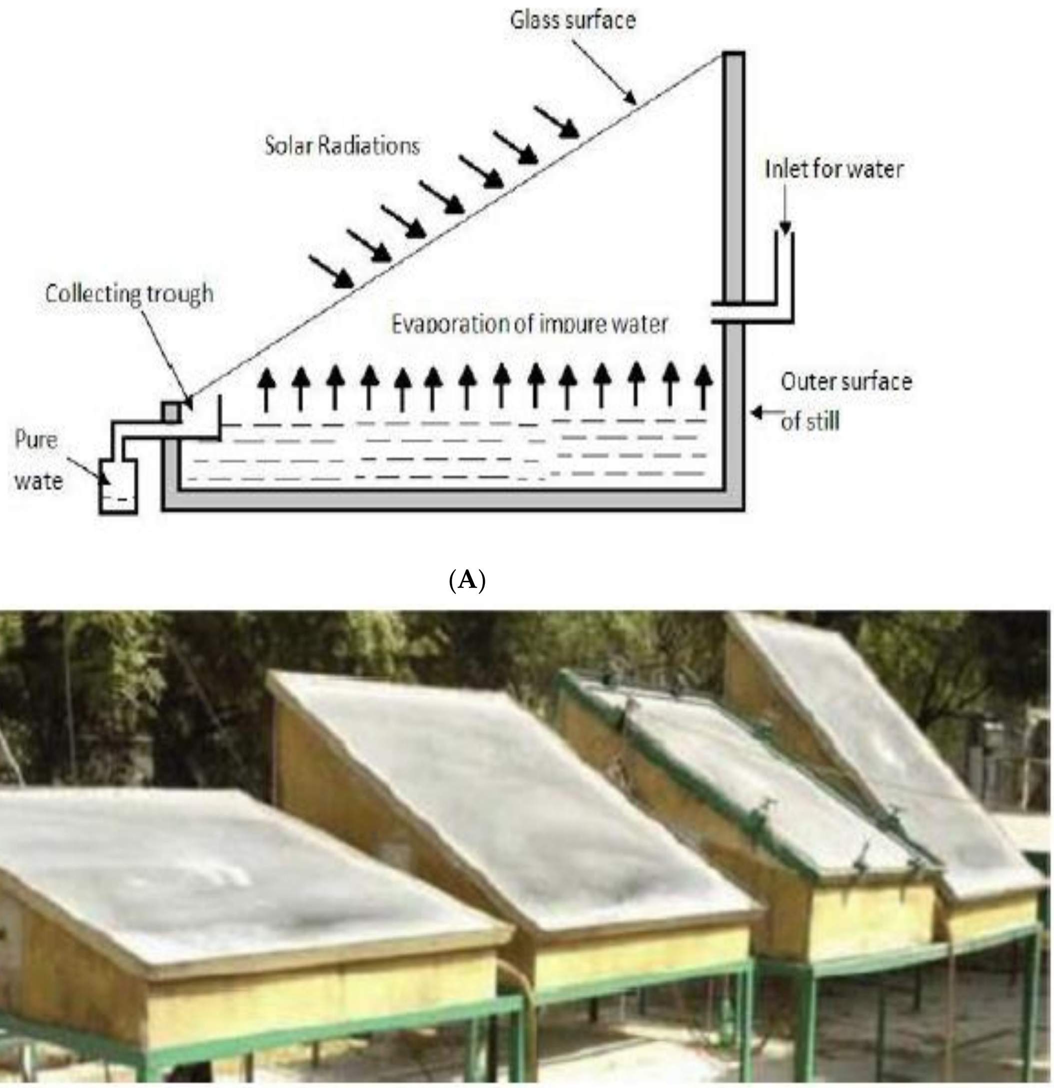

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Figure 1. Sketch and photo of the single-basin single-slope solar stills. (**A**). Yadav and Kumar [19] "Reprinted/adapted with permission from Ref. [19]. 2019, Elsevier", (**B**). Rahul and Tiwari [20] "Reprinted/adapted with permission from Ref. [20]. 2019, Elsevier".

According to these values, an area of one square meter as a minimum is needed to provide the essential needs of one person [22]. This poor efficiency is caused by the condensation heat losses to the surroundings throughout the glass cover; some useful heat is carried away by the warm condensate. At higher and lower latitude locations, a single-slope solar still collects a greater amount of radiation than a double-slope solar still. Figure 2 (Tayeb [23])) presents a sketch of the basin solar stills with different glass covers.

However, the productivity of this type can be improved by using sponge cubes [24], as presented in Figure 3 (Abu-Hijileh and Rababa'h [25]). Also, it can be improved by using an integrated natural circulation loop [26] or a phase-change material [27]. In any case, the single-slope basin solar still has some disadvantages, such as [28]:

1. Less solar radiation is intercepted as the water's surface is horizontally mounted.
2. Limited output because of the large thermal capacity of the water in the basin.
3. Low output of distilled water in comparison with other still types.
4. Low production capacity, typically 2–5 $L/m^2/day$.

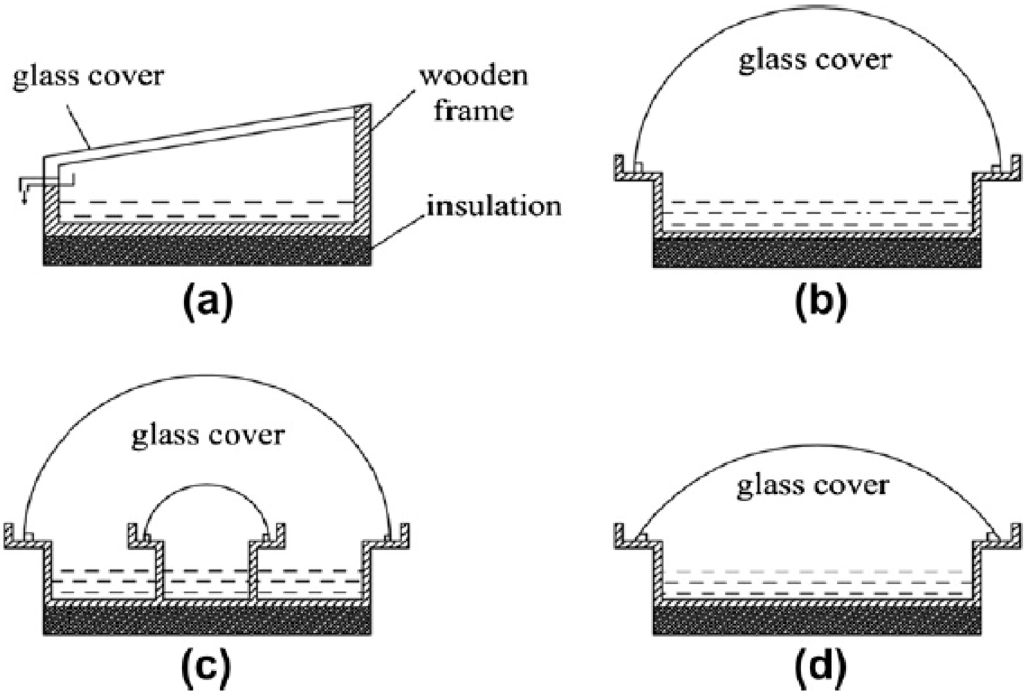

Figure 2. Sketch of the conventional basin solar stills with different glass covers (Tayeb [23], "Reprinted/adapted with permission from Ref. [23]. 1992, Elsevier"). (**a**) Sloped flat cover, (**b**) Half cylinder cover, (**c**) Two half cylinders cover, (**d**) Slightly curved cover.

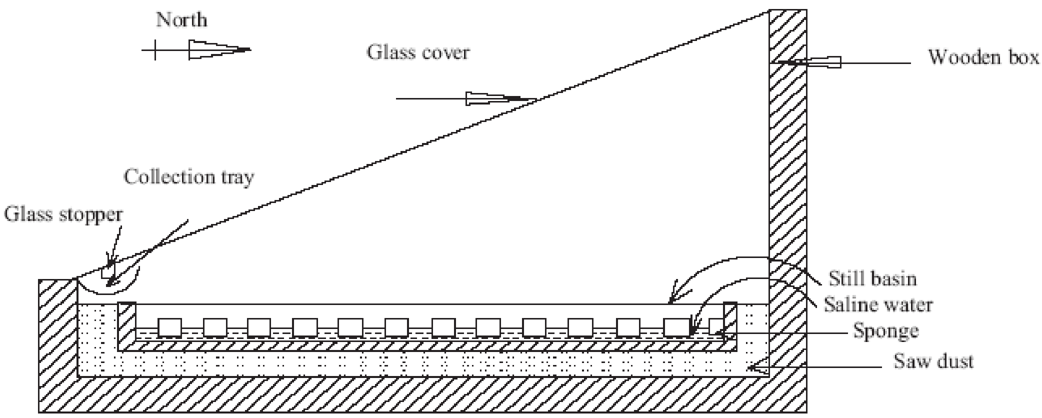

Figure 3. Sketch of the basin solar still with sponge cubes (Abu-Hijileh and Rababa'h [25], "Reprinted/adapted with permission from Ref. [25]. 2003, Elsevier").

Double-slope basin solar still (roof or greenhouse type): The basin in this type of still is airtight; it is normally constructed from concrete, galvanized iron sheet, or fiber reinforced plastic with a top transparent cover [29]. In order to be able to absorb maximum solar radiation, the base is painted in black. The distillate output is collected at the lower ends of the top cover. The saline is fed inside the basin for purification by using solar energy.

Figure 4 (El-Maghlany [30] and Hanane et al. [31]) presents a sketch and photo of the double-slope solar still, while Figure 5 (Ranjan and Kaushik [16]) shows the mechanism of energy transfer of the still. The key benefit of this type of distiller is the low production cost of clean water for household applications. This is due to the following reasons [32–35]:

1. Simple design.
2. Easy to handle.
3. Low cost of the water produced.
4. Its long operational life of at least ten years.
5. Its maintenance is cheap.
6. Able to capture the sunlight from different directions.

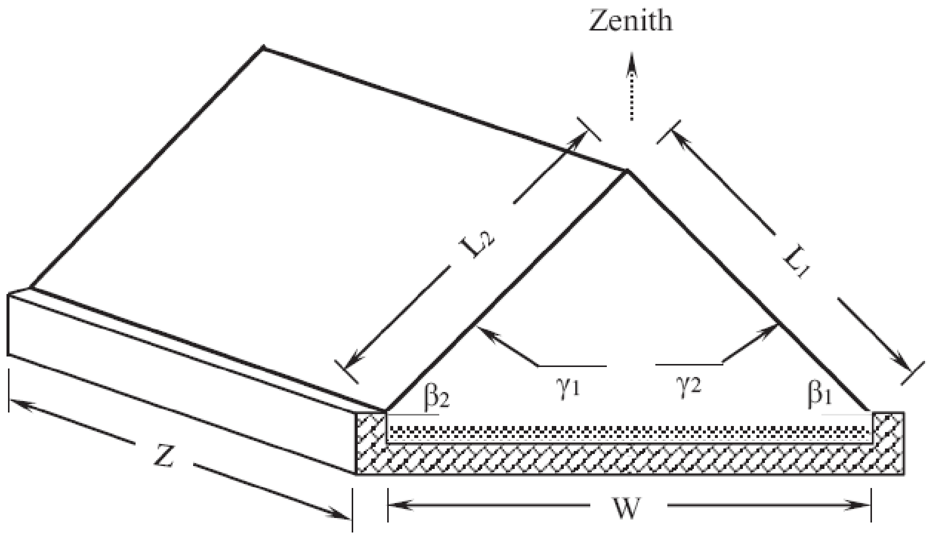

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Figure 4. Sketch and photo of the double slope basin solar still. (**A**). El-Maghlany [30], "Reprinted/adapted with permission from Ref. [30]. 2012, Elsevier". (**B**). Hanane et al. [31], "Reprinted/adapted with permission from Ref. [31]. 2002, Elsevier".

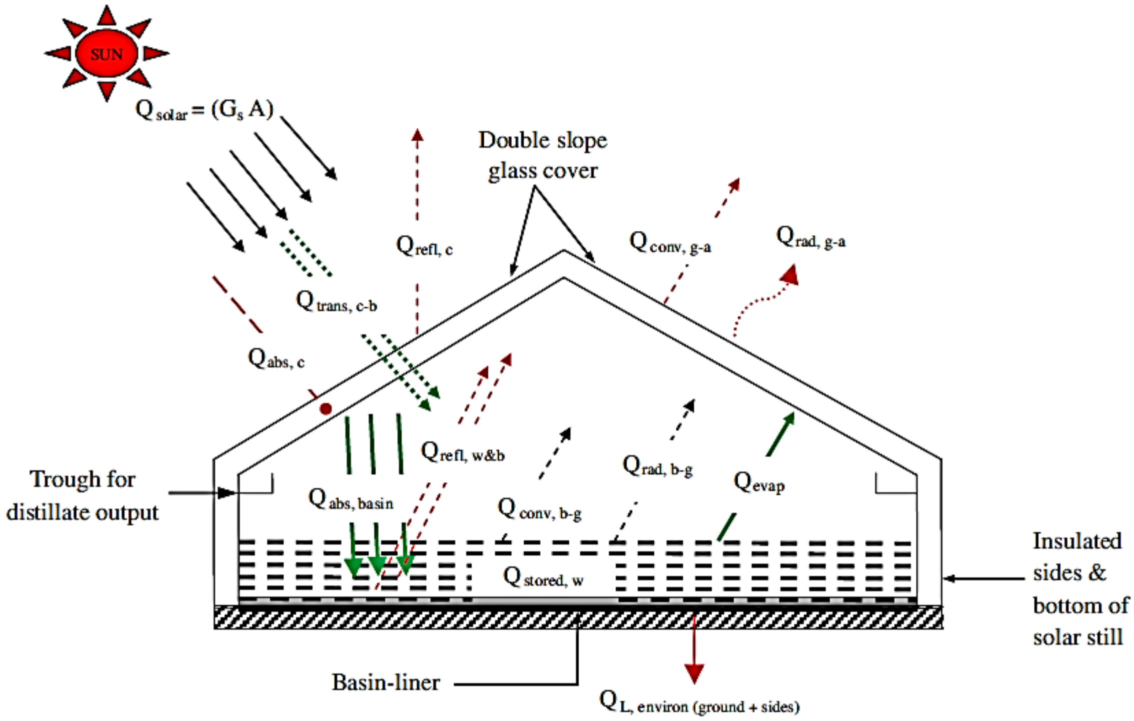

Figure 5. Heat transfer in a double-slope basin solar still (Ranjan and Kaushik [16], "Reprinted/adapted with permission from Ref. [16]. 2013, Elsevier").

Water film solar still: This type is cheap, as shown in Figure 6 (Mousa and Bassam [36]). Its construction is simple and easy. It comprises a basin, 5 mm thick glass cover and a cooling film of a thickness of 1.3 mm. The continuous-feeding water film is passed over the glass cover surface to reduce the glass temperature [37]. The cooling film plays a vital role in glass cover cleaning, which results in increasing the efficiency by up to 20% (Kaushal [38]).

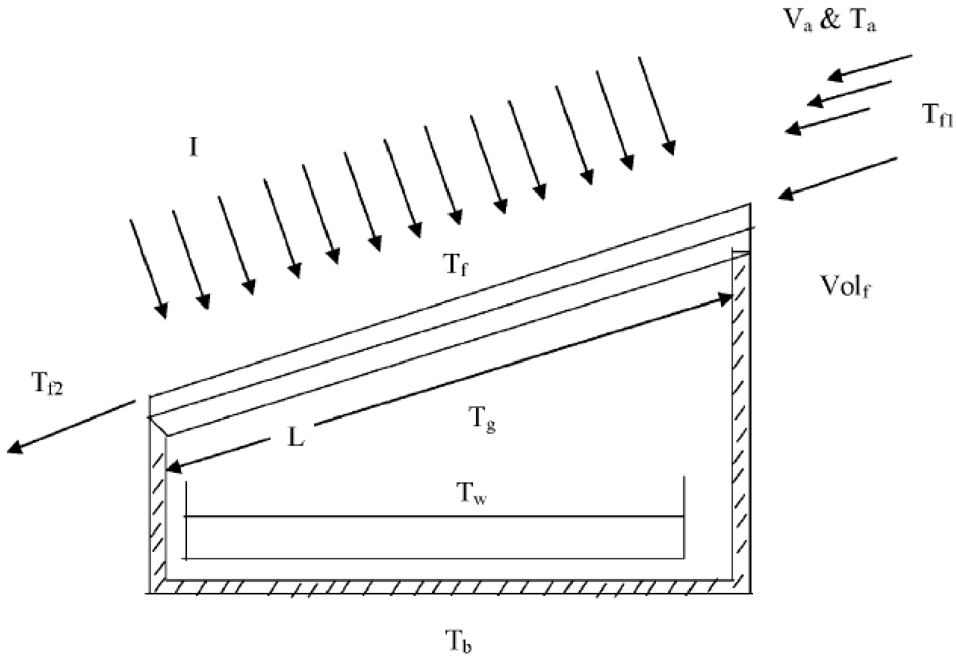

Figure 6. Schematic of water film solar still (Mousa and Bassam [36], "Reprinted/adapted with permission from Ref. [36]. 1997, Elsevier").

Multiple effect diffusion solar still: It comprises a glass cover, flat-plate reflector, casters for manual azimuth tracking, and a number of vertical and parallel partitions with narrow air gaps of a few millimeters between partitions, as shown in Figure 7 (Tanaka et al. [39]). This type has high productivity because of the use of latent heat with an added advantage of cost savings. For more details about the multiple effect diffusion solar still, the reader can refer to articles by Tanaka et al. [39] and [40,41]. This type can be improved by adding a vacuum-tube collector and heat pipe [42]. It has many advantages, such as [43]:

1. It occupies less ground space compared to conventional stills.
2. There is no chance of contamination of feeding water, even in cases of small gaps between the condenser and the evaporator, which makes it very suitable for rural, remote, arid, and urban applications.

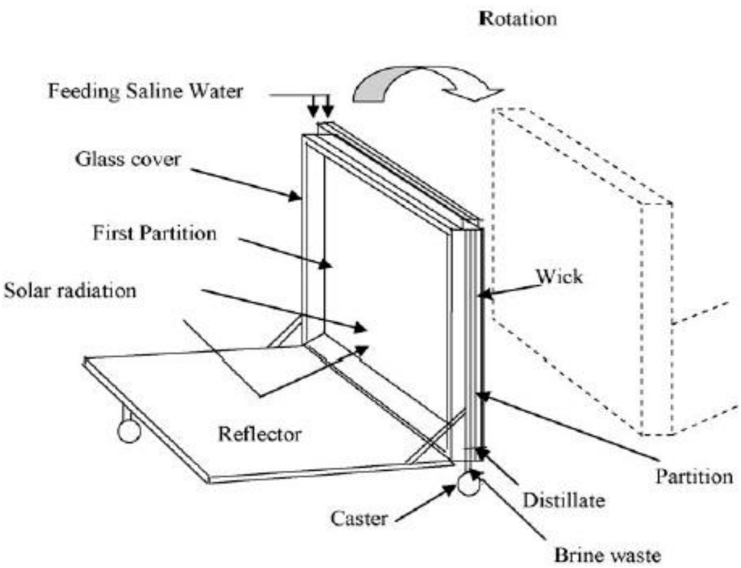

Figure 7. Multiple effect diffusion solar still (Tanaka et al. [39], "Reprinted/adapted with permission from Ref. [39]. 2000, Elsevier").

Basin type solar still with internal and external reflectors: This type consists of a basin liner with internal reflectors, a glass cover, and an external reflector, as depicted in Figure 8 (Tiwari and Tiwari [44]). The main advantage of using these reflectors is to permit additional radiation to be introduced to the solar still. Therefore, the daily productivity was enhanced by 70–100% in winter compared to standard basin solar still. Solar reflectors are known for their high solar radiation concentration; therefore, they are always recommended for use in areas with weak solar radiation or low temperatures [45]. The configuration flexibility of the absorber plate is improved by using external reflectors which redirect the solar beams [46,47]. The reflectors are normally constructed from extremely reflective materials (e.g., mirror-finished metal plates). The external reflectors tend to enhance both direct and diffuse radiation transmitted through the glass cover. Figure 8 shows also a photo of this type of the solar still (Tanaka [46]).

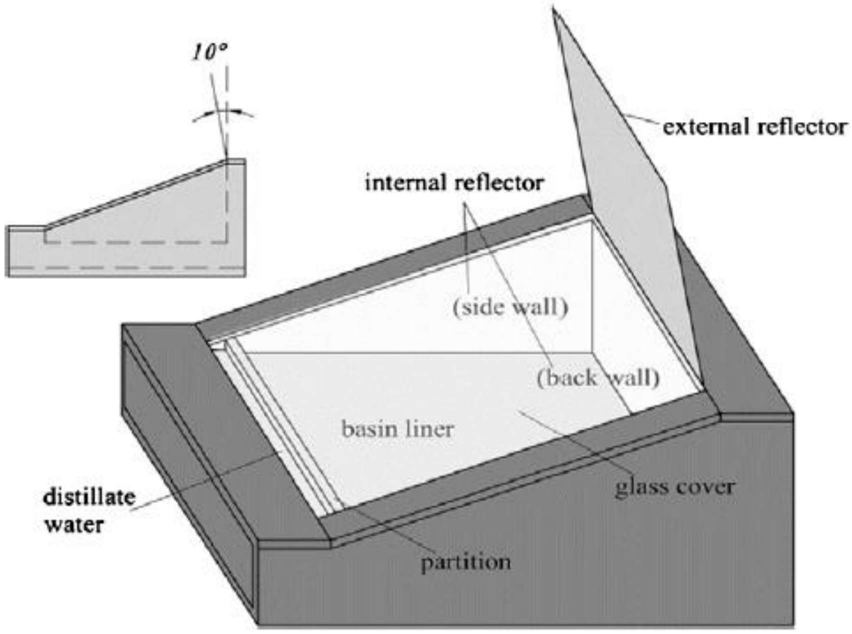

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Figure 8. Sketch and photo of the solar still with a vertical external reflector. (**A**) Tiwari and Tiwari [44], "Reprinted/adapted with permission from Ref. [44]. 2006, Elsevier". (**B**) Tanaka [46], "Reprinted/adapted with permission from Ref. [46]. 2009, Elsevier".

Regenerative solar still: The principle of this type depends on reducing the glass temperature as much as possible by passing the feeding water over the glass cover, as illustrated in Figure 9 (Zurigat and Abu-Arabi [48]). This design aims to maximize the water and glass cover temperature difference by transferring the heat from the glass to the flowing water. Therefore, the regeneration process recovers heat from the glass cover, leading to enhancing the condensation and preheating the feed water simultaneously [49]. This increases still productivity by about 20% compared to a conventional still [50,51].

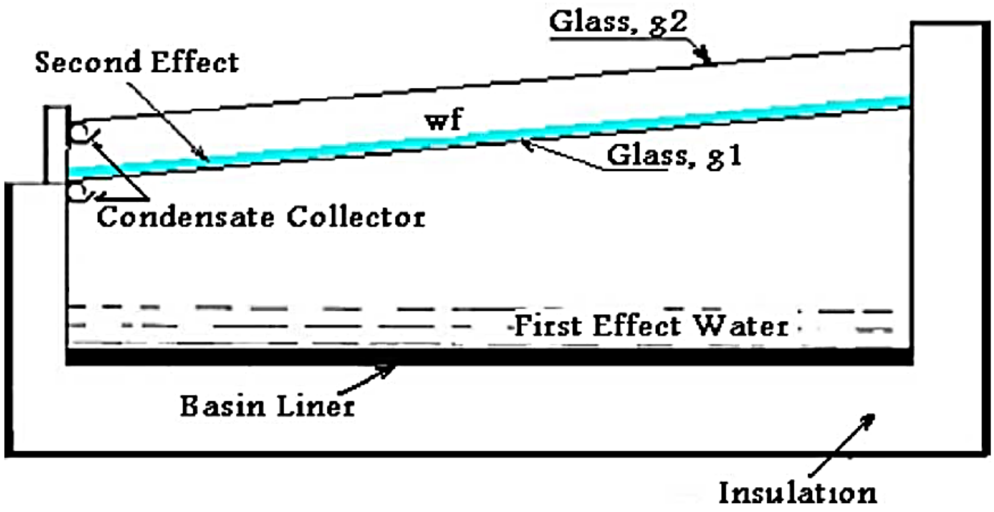

Figure 9. Sketch of the regenerative solar still (Zurigat and Abu-Arabi [48], "Reprinted/adapted with permission from Ref. [48]. 2004, Elsevier").

Double-basin solar still: In this type, an additional glass sheet is placed in-between the basin liner and the glass cover (Figure 10 (Al-Karaghouli and Al-Naser [52] and Elango and Murugavel [53])). The main purpose of this added glass sheet is to be used as an additional basin for the saline water. Therefore, the assembly of this still is considered as two simple basin solar stills, with one basin located on top of the other. The productivity of the still is enhanced by the proper employment of the latent heat of vaporization [54].

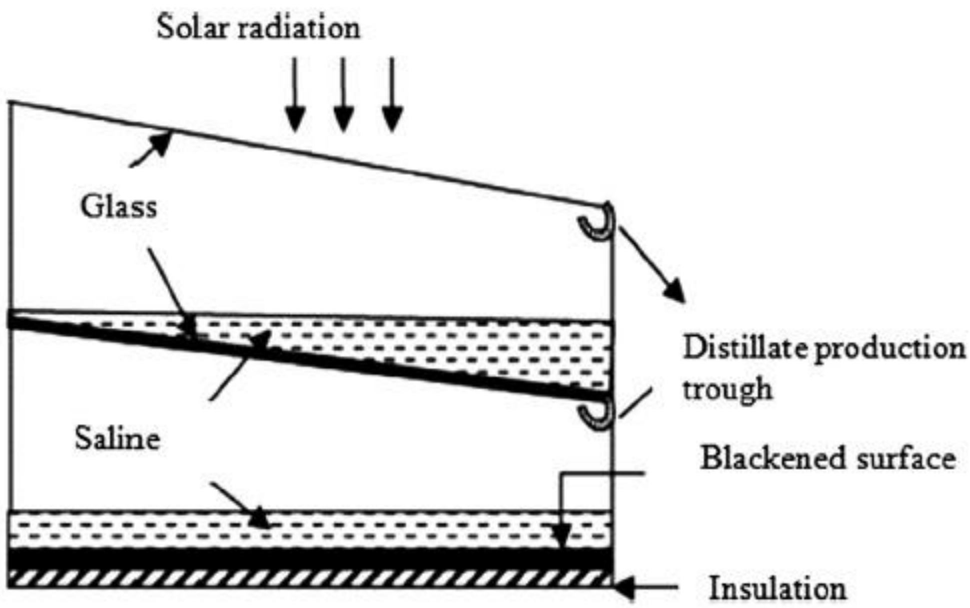

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Figure 10. *Cont.*

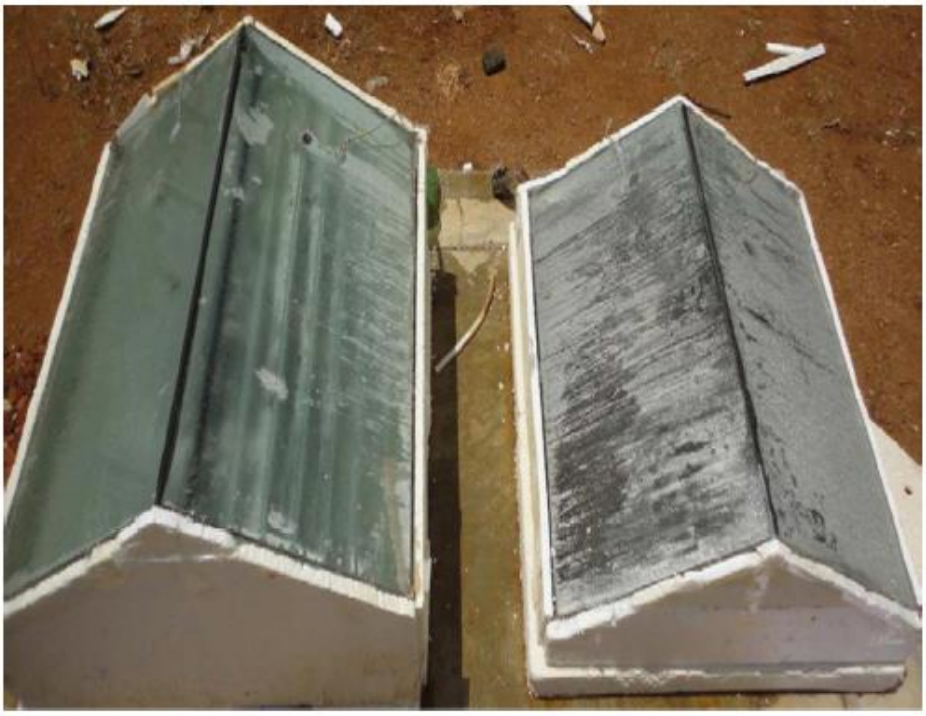

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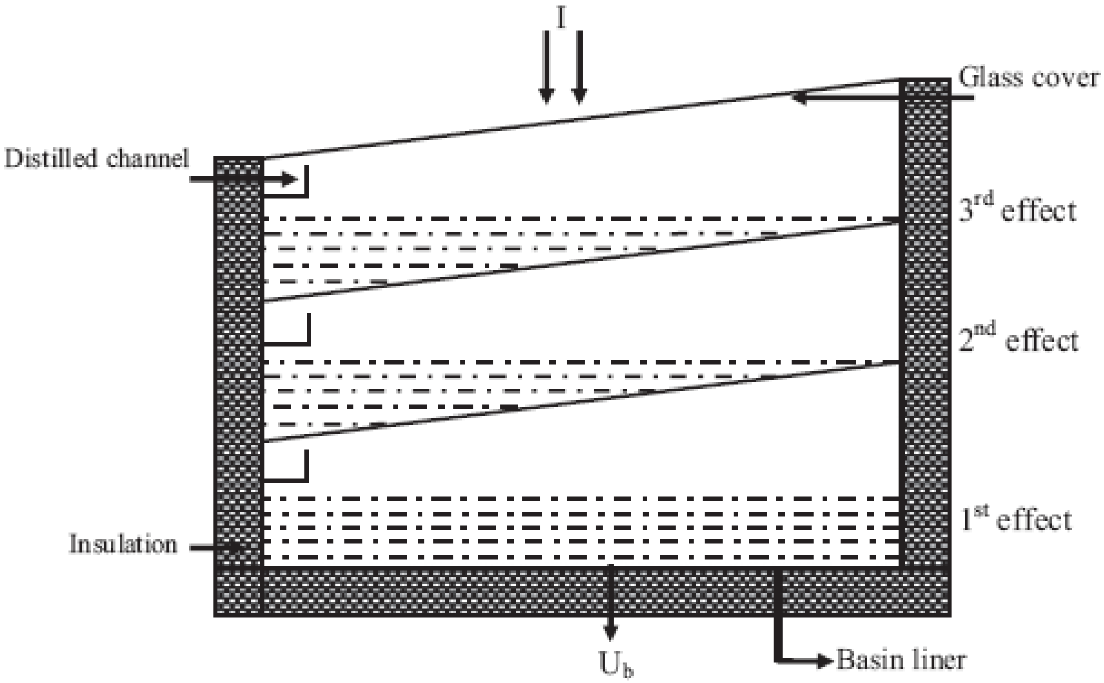
Figure 10. Sketch and photo of the double basin solar still. (**A**). Al-Karaghouli and Al-Naser [52], "Reprinted/adapted with permission from Ref. [52]. 2004, Elsevier". (**B**). Elango and Murugavel [53], "Reprinted/adapted with permission from Ref. [53]. 2015, Elsevier".

Triple-basin solar still: it comprises three water-filled basins, the lower, the middle and the upper basin (Figure 11 (El-Sebaii [55] and Srithar et al. [56])). This type of still produces maximum daily productivity for the least mass of water available in the middle and the lower basins [57]. The disadvantage of this type is the relatively high maintenance cost and the extra effort of using additional basins. For further details about this type, the reader can refer to El-Sebaii [55].

Fin type solar still: It consists of various fins located at the solar still base to expand the basin area, as shown in Figure 12 (El-Sebaii and El-Naggar [58]). This design improves the still performance by enhancing the heat transfer from the basin to the water [59,60]. It was experimentally proven that the average daily distilled water output of this type is increased by 30% compared to the conventional still [61,62].

Hybrid solar still: This active mode of the solar still consists of a still integrated, for example, with a flat plate solar collector (Figure 13 (Ranjan and Kaushik [16])) or a compound parabolic concentration (CPC) collector (Figure 14 (Tanaka [63])). These collectors introduce additional solar radiation into the still and increase its inlet water temperature [64]. Therefore, the still productivity is greatly improved. On the other hand, similar results can be obtained if the still is integrated with a hot water storage tank [65], a mini solar pond [66,67], a heat exchanger [68,69], a heat pipe [70], an evacuated tube collector [71,72], solar air heater [73], photovoltaic-thermal (PV/T) modules [5,74], solar chimneys [75], cooling tower [76,77], and solar water heater [78,79]. Figure 15 illustrates some photos related to various types of hybrid solar stills [Gajendra et al. [80], Omara et al. [81], Siddiqui et al. [82], and Panchal and Pravin [83].



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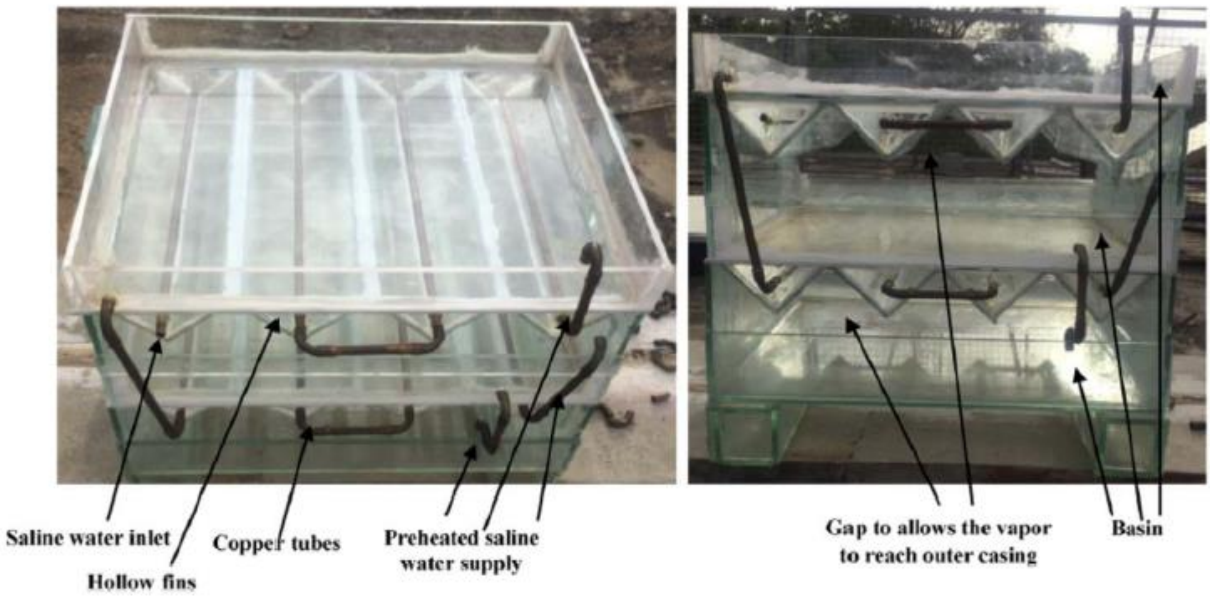

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Figure 11. Sketch and photo of the triple basin solar still. (**A**). El-Sebaii [55], "Reprinted/adapted with permission from Ref. [55]. 2005, Elsevier". (**B**). Srithar et al. [56], "Reprinted/adapted with permission from Ref. [56]. 2016, Elsevier".

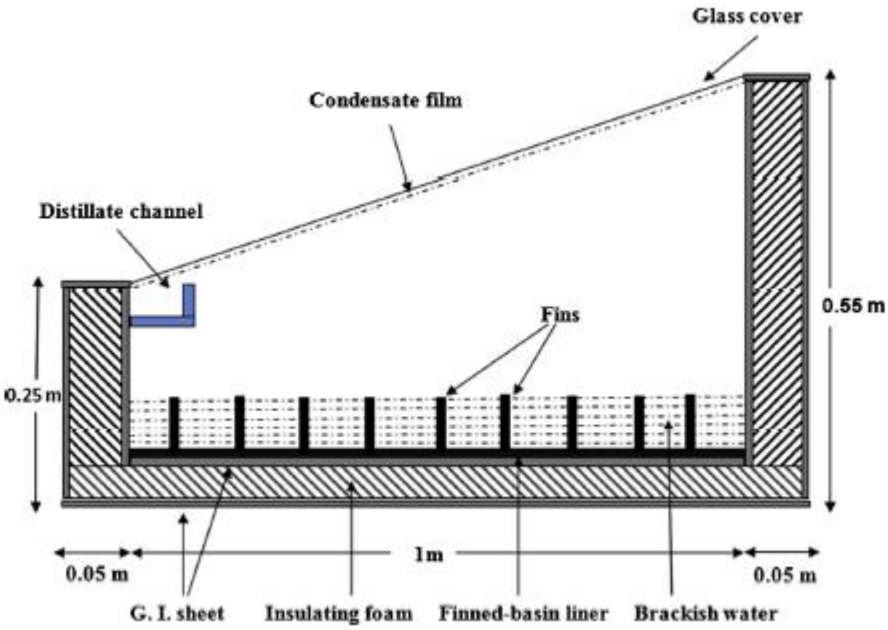

Figure 12. Sketch of the fin-type solar still (El-Sebaii and El-Naggar [58], "Reprinted/adapted with permission from Ref. [58]. 2017, Elsevier").

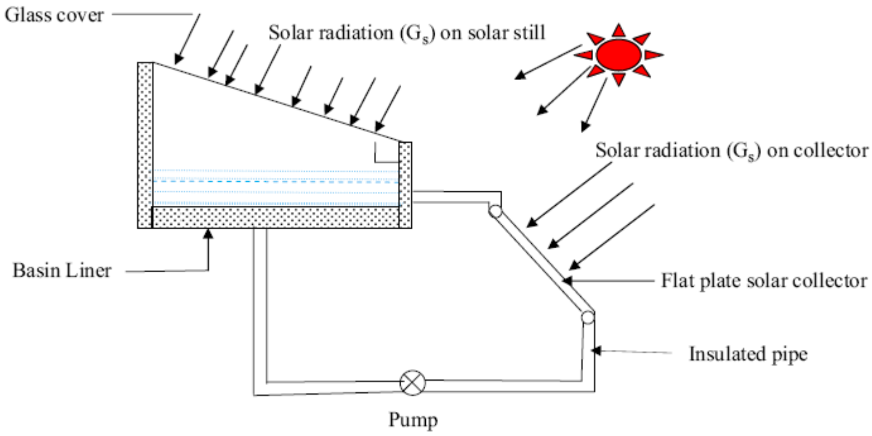

Figure 13. Sketch of the solar still integrated with a flat plate solar collector (Ranjan and Kaushik [16], "Reprinted/adapted with permission from Ref. [16]. 2013, Elsevier").

Multi-wick solar still: this is a passive solar still (Figure 16 (Tiwari et al. [9])); the brine flows slowly over a tilted surface covered with a thin layer of wicks. Since the flowing brine has a low heat capacity, it evaporates quickly. In this type, black wet jute cloth represents the liquid surface that could be easily oriented in order to obtain the maximum radiation, and thus a limited amount of water is heated to high temperatures leading to rapid evaporation. The multi-wick solar still has some merits, such as [84,85]:

1. Needs a short time to produce the fresh water compared with the conventional still.
2. Its productivity can be increased up to 50%.
3. Economical, since its cost is 50% less than the cost of a conventional basin still for the same area.

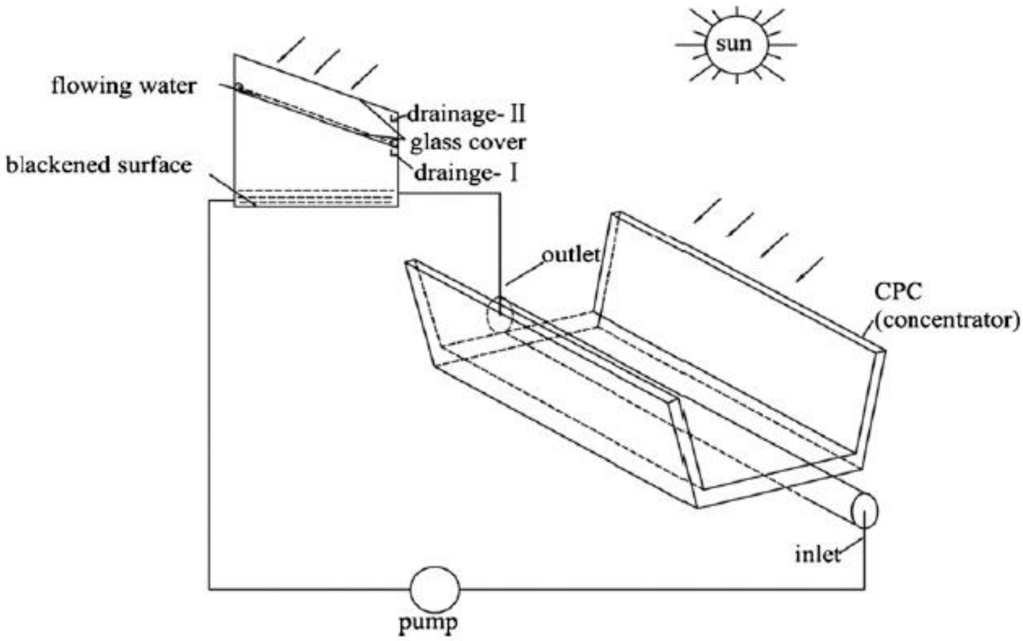

Figure 14. Sketch of the solar still integrated with a (CPC) collector (Tanaka [63], "Reprinted/adapted with permission from Ref. [63]. 2011, Elsevier").

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Figure 15. *Cont.*

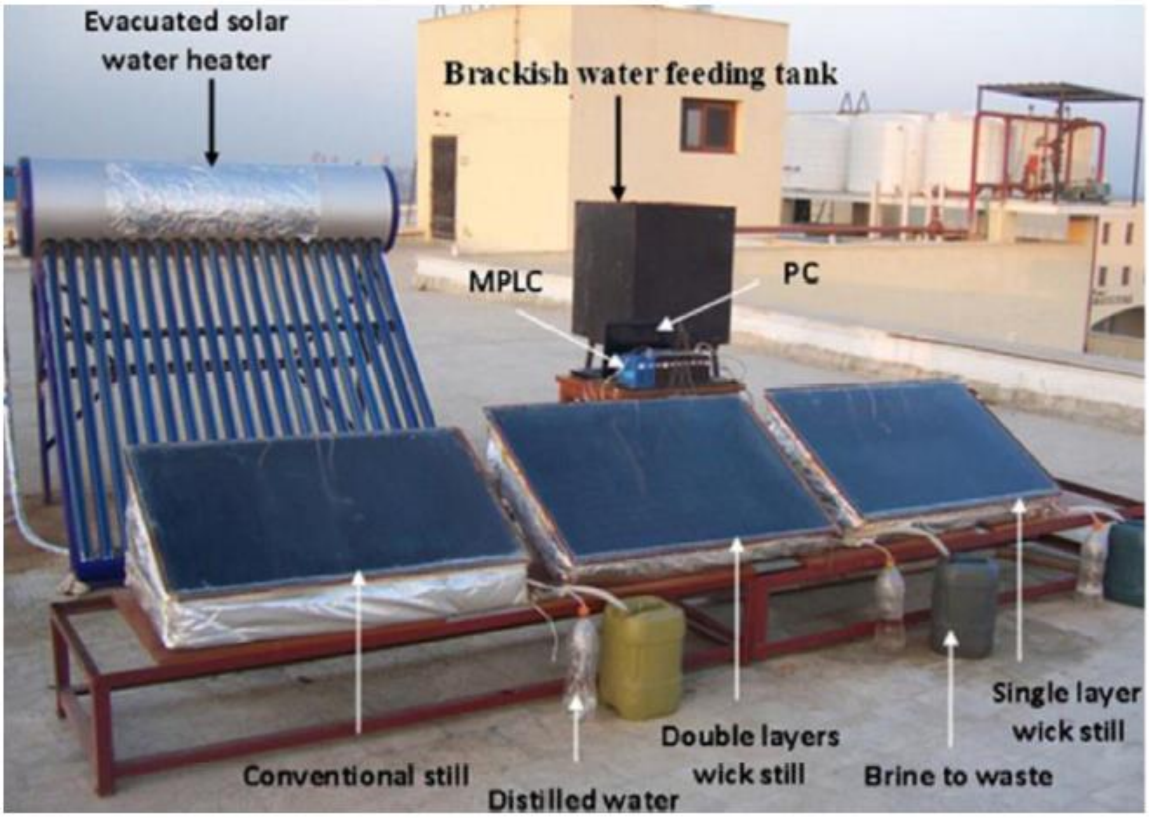

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Figure 15. *Cont*.

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Figure 15. Photos related to various types of hybrid solar still. (**A**). Solar still with Photovoltaic-Thermal (PV/T) modules (Gajendra et al. [80], "Reprinted/adapted with permission from Ref. [80]. 2011, Elsevier"). (**B**). Solar still with evacuated solar water heater (Omara et al. [81] "Reprinted/adapted with permission from Ref. [81]. 2013, Elsevier"). (**C**). Solar still with solar air heater (Siddiqui et al. [82], "Reprinted/adapted with permission from Ref. [82]. 2016, Elsevier"). (**D**). Solar still with evacuated tube collector (Panchal and Pravin [83], "Reprinted/adapted with permission from Ref. [83]. 2016, Elsevier").

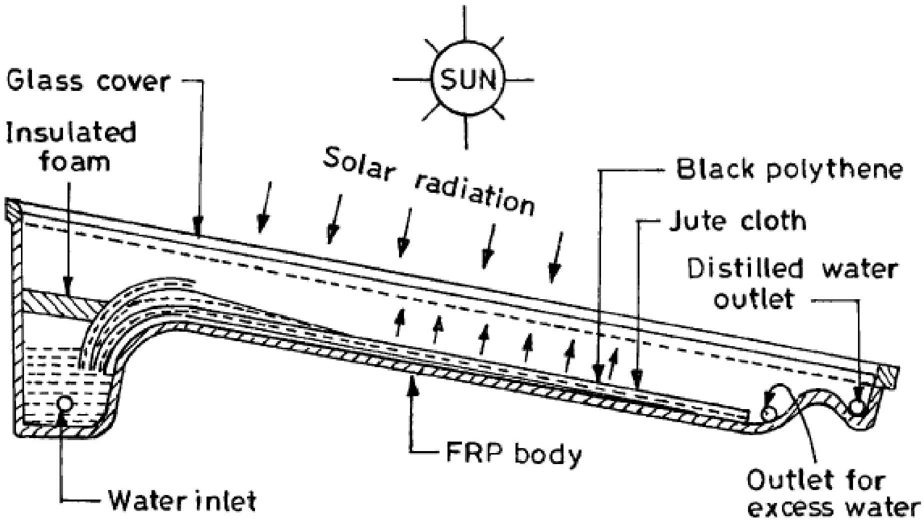


Figure 16. Cross-section of FRP multi-wick solar still (Tiwari et al. [9], "Reprinted/adapted with permission from Ref. [9]. 2003, Elsevier").

This type of still can be modified to be a so-called concave wick-surface solar still (Figure 17 (Kabeel [86])), where this surface is used for evaporation. This design increases the evaporation rate since the water surface level is lower than the upper limit of the wick surface. While the glass covers at the four sides of a pyramid-shaped still are employed for condensation and reducing the shading effect compared to that of a conventional solar still. The concave wick solar still efficiency reached about 45% [87].

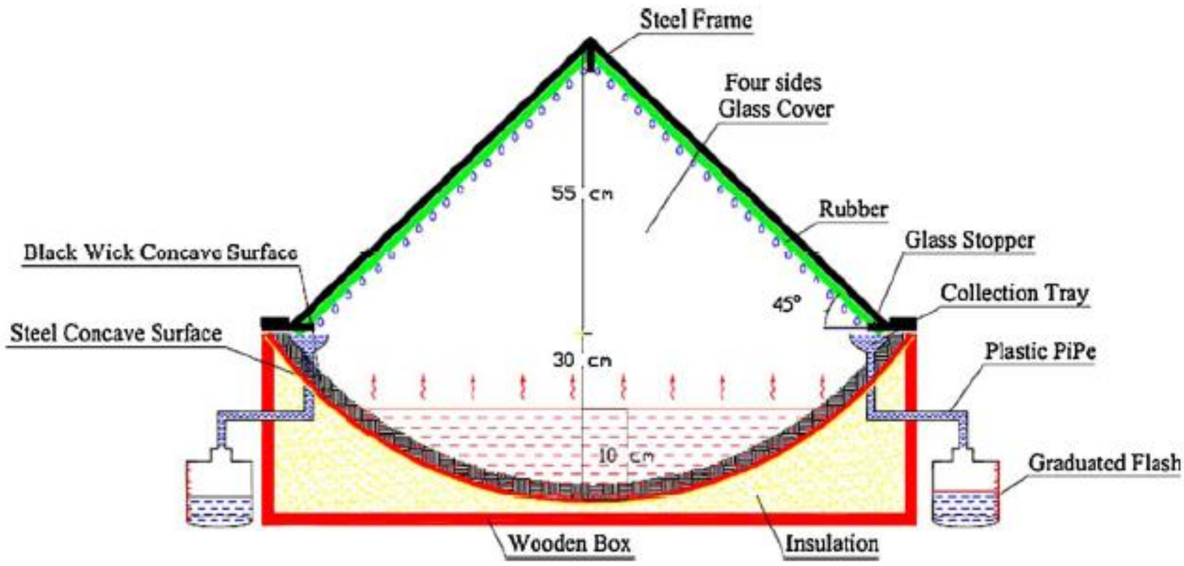


Figure 17. Schematic diagram of concave wick surface solar still (Kabeel [86], "Reprinted/adapted with permission from Ref. [86]. 2009, Elsevier").

Wick-basin solar still: This type of solar still (Figure 18 (Minasian and Al-Karaghouli [88])) is formed by connecting a small conventional basin solar still with a wick type. Therefore, the basin type is fed directly by the hot waste salt water that leaves the wick type. The wick-basin solar still produces 85% and 43% more distilled water annually than the basin and the wick solar stills, respectively.

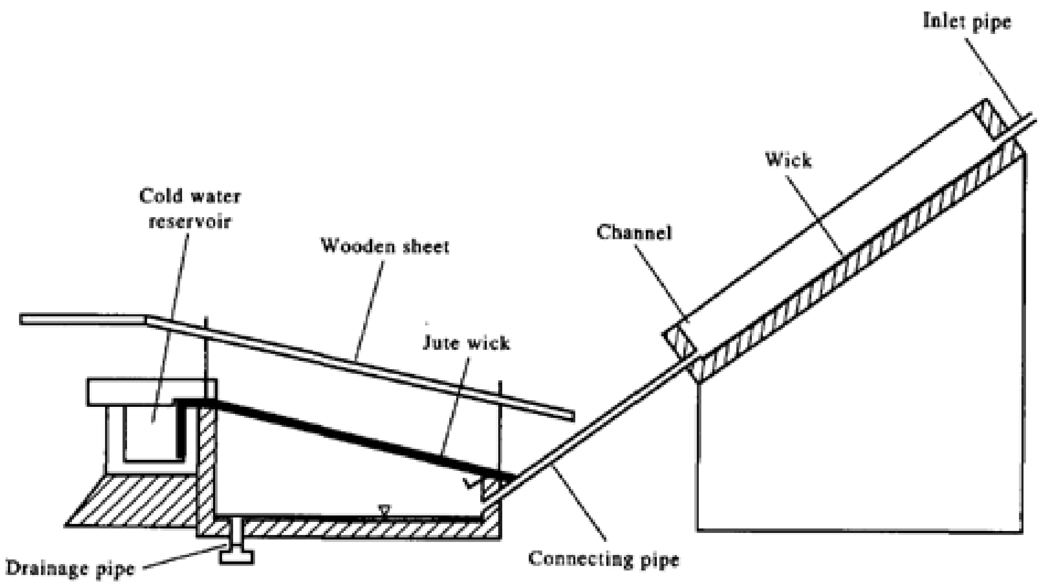


Figure 18. Schematic diagram of the wick-basin solar still (Minasian and Al-Karaghouli [88], "Reprinted/adapted with permission from Ref. [88]. 1994, Elsevier").

Stepped solar still: This type (Figure 19 (Velmurugan et al. [89])) was suggested to overcome the issue of maintaining a minimum depth in the solar still. So, the absorber plate of the still was re-structured as a stepped shape. This modification is useful to provide a larger surface area, increases the stay time of the water on each step and improves the evaporation rate. Since it helps retain and spread the evaporated water and enhances the still's productivity [90,91]. This type can be used to heat up and humidify agricultural greenhouses and recover clean water from waste water. The productivity of this type can also be improved by employing both internal and external reflectors, as illustrated in Figure 20 (Omara et al. [92]).

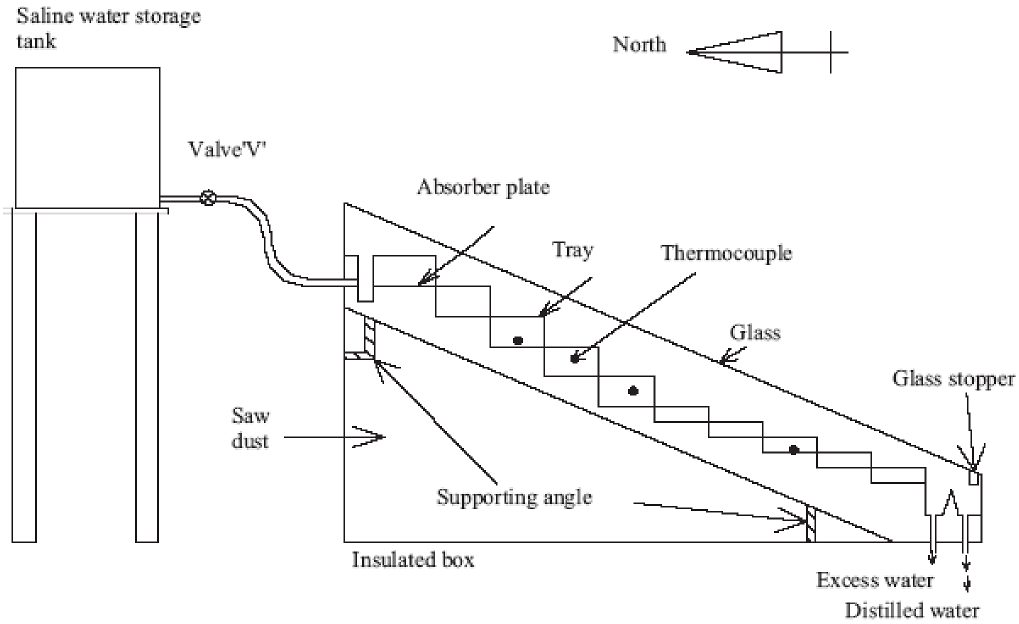


Figure 19. Schematic diagram of stepped solar still (Velmurugan et al. [89], "Reprinted/adapted with permission from Ref. [89]. 2009, Elsevier").

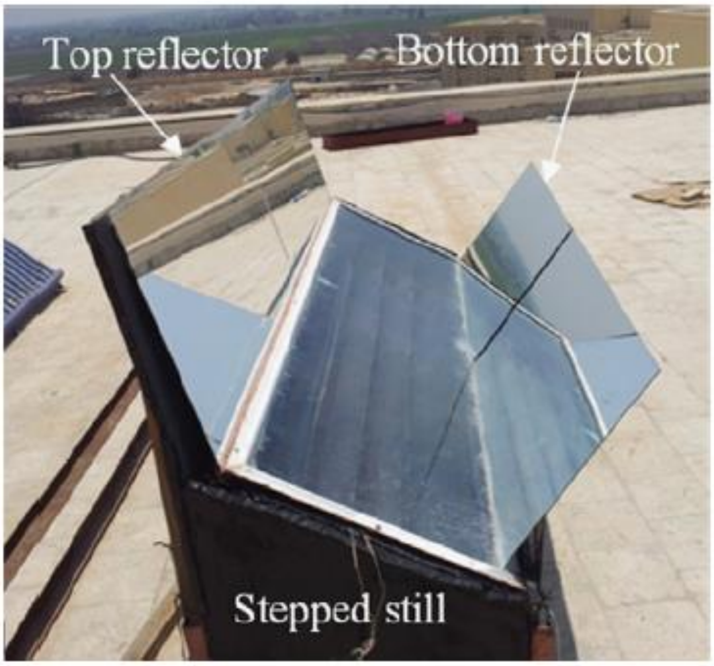
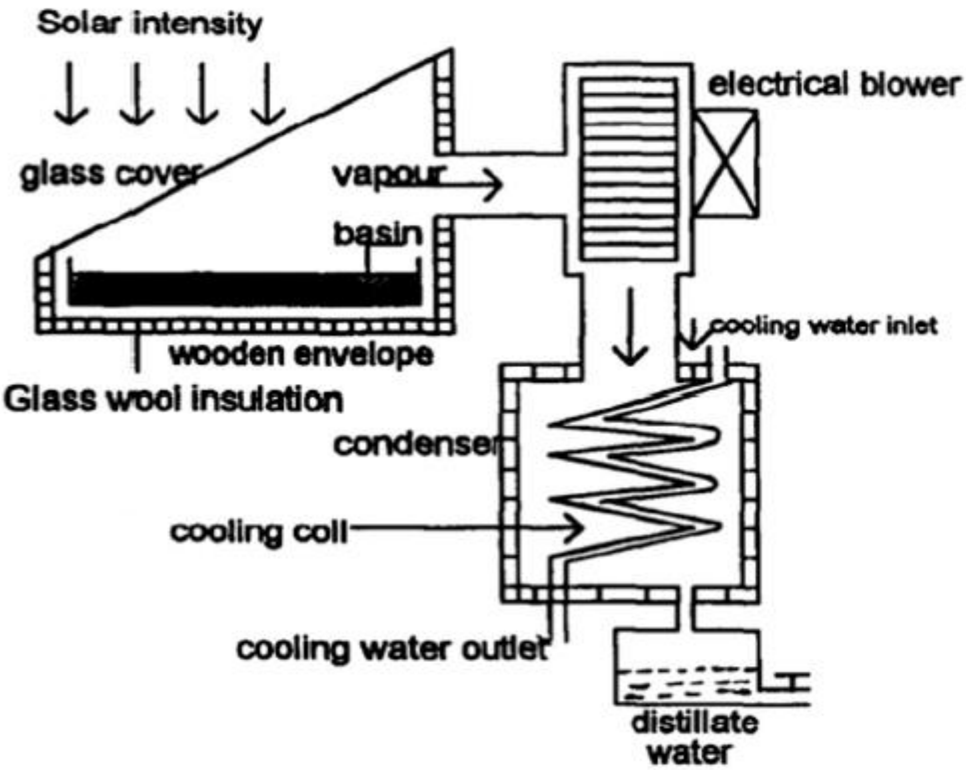


Figure 20. Stepped solar still with internal and external reflectors (Omara et al. [92], "Reprinted/adapted with permission from Ref. [92]. 2014, Elsevier").

Solar still integrated with an external or internal condenser: In the first type, an external condenser (Figure 21 (Tiwari et al. [9] and Emad [93])) is coupled with the solar still so as to promote the evaporation of the saltwater in a still and increase its productivity [94,95]. The main purpose of adding the external condenser is to help in reducing heat loss by convection from water to glass since the condenser serves as an extra and efficient heat and mass sink. When an internal condenser is used (Figure 22 (Khalifa et al. [96])), the temperature difference on the glass surface, as well as the four sidewalls, causes the condensation process. In order to be able to increase the still efficiency, the four sidewalls may be cooled down by circulating the water through tubes attached to the wall surface [97].



(**A**)

(**B**)

Figure 21. Sketch and photo of the solar still coupled with an external condenser. (**A**). Tiwari et al. [9], "Reprinted/adapted with permission from Ref. [9]. 2003, Elsevier". (**B**). Emad [93], "Reprinted/adapted with permission from Ref. [93]. 2014, Elsevier".

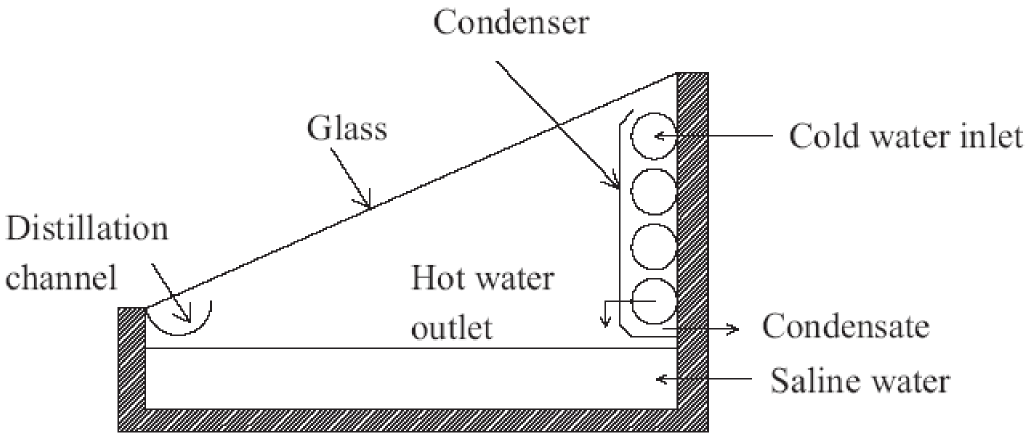


Figure 22. Solar still coupled with an internal condenser (Khalifa et al. [96], "Reprinted/adapted with permission from Ref. [96]. 1999, Elsevier").

Weir-type solar still: In this type, a weir-shaped plate is used to severe as an absorber (Figure 23 (Sadineni et al. [98])). It comprises of a tilted absorber plate reformed to make weirs and two basins. These weirs are utilized to transfer water from the upper basin to the lower collector; the unevaporated water is pumped back to the top tank using a small pump. The weir-type solar productivity is still 20% greater than the standard single basin solar type. Using the wastewater from the systems was suggested as a means of producing solar hydrogen.

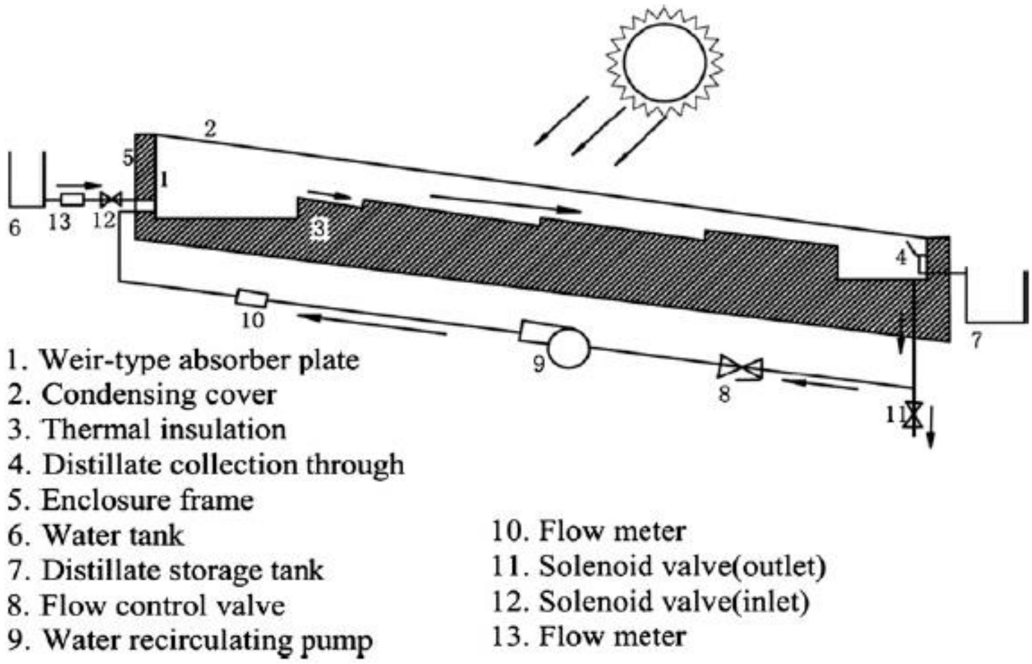
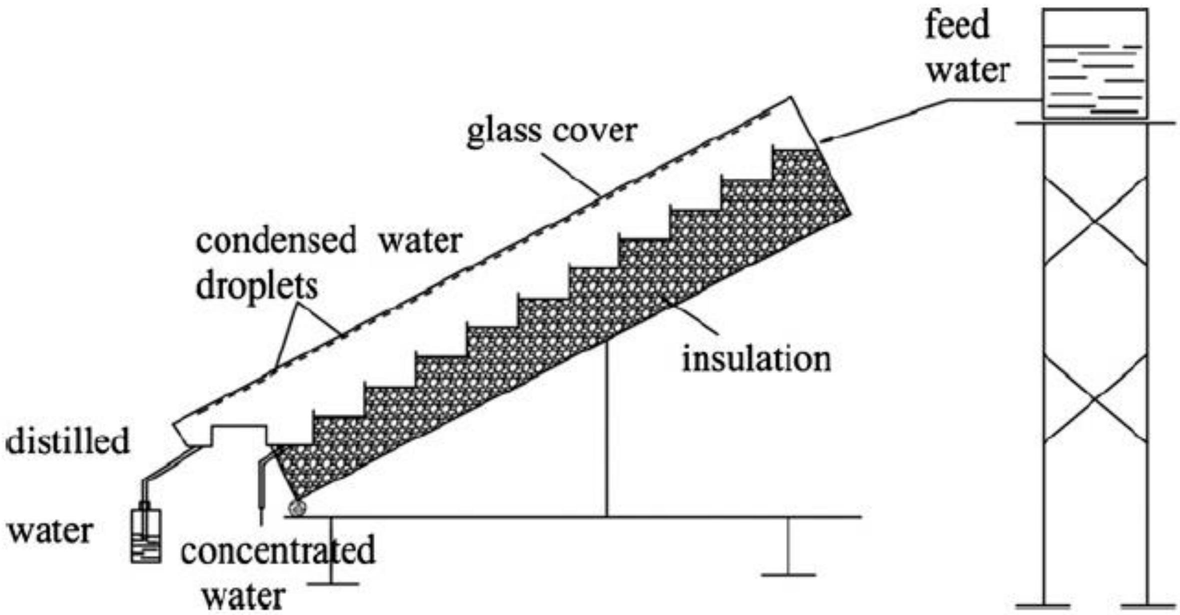
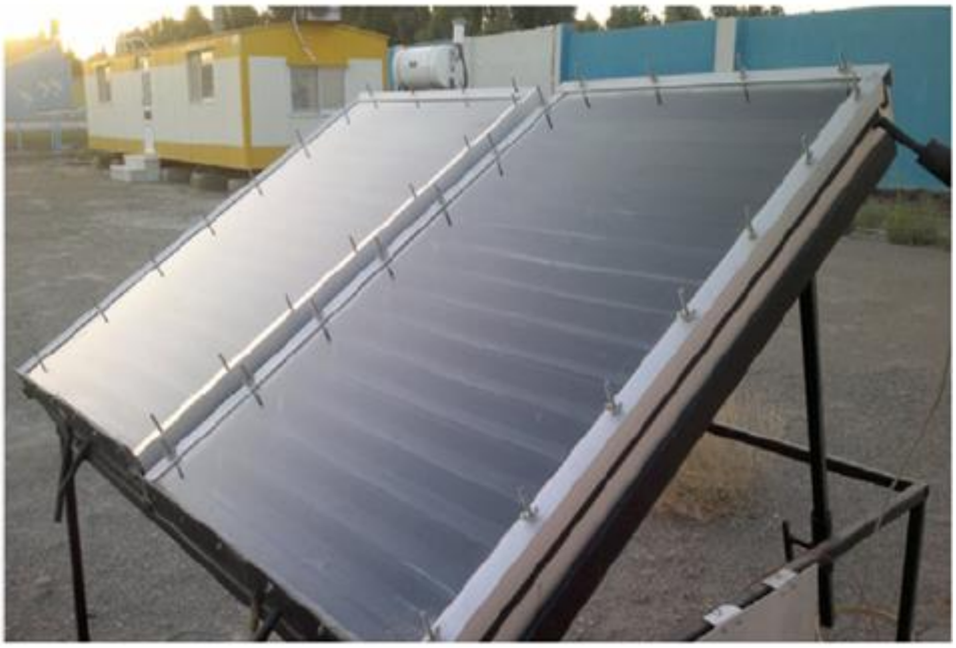


Figure 23. Schematic of a weir-type solar still (Sadineni et al. [98], "Reprinted/adapted with permission from Ref. [98]. 2008, Elsevier").

Weir-type cascade solar still: It comprises various absorber steps (Figure 24 (Tabrizi et al. [99,100])). All these steps are equipped with weirs; the main duty of the weir is to feed the water over the evaporation surface. The produced clean water is collected in the collection channel while the brine is drained from the outlet [101,102]. This results in enhanced water residence time.



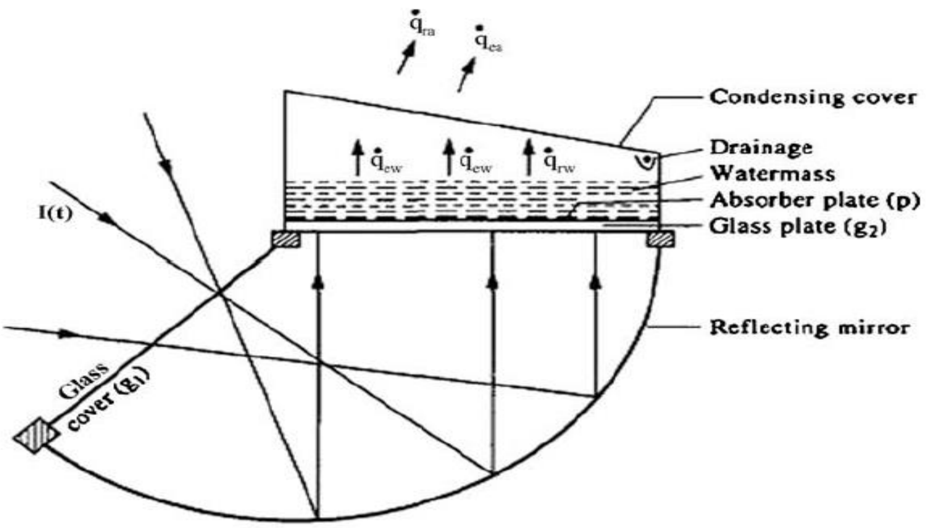
(**A**)



(**B**)

Figure 24. Sketch and photo of the weir-type cascade solar still. (**A**). Tabrizi et al. [99], "Reprinted/adapted with permission from Ref. [99]. 2010, Elsevier". (**B**). Tabrizi et al. [100], "Reprinted/adapted with permission from Ref. [100]. 2016, Elsevier".

Inverted absorber solar still: for this type, first, the solar radiation is transmitted throughout the glass cover and then reflected back to the inverted absorber. A curved reflector is placed under the basin; hence the lower surface of the basin is also heated. Due to heat loss, a portion of the collected solar energy is transported to the water mass above the inverted absorber via convection. When the evaporated water contacts the inner surface of the condensing cover, it releases the latent heat, and condensation takes place. Because of the gravity force, the condensed water flows down the condensation surface and is then collected through the lower-end drainage. Because of the significant reduction in bottom heat loss, this kind provides almost double the output of a regular solar still [103]. Figure 25 illustrates a sketch and photo of the inverted absorber solar still (Tiwari and Sangeeta [104] and Dev et al. [105]).



(**A**)

(**B**)

Figure 25. Sketch and photo of the inverted absorber solar still. (**A**). Tiwari and Sangeeta [104], "Reprinted/adapted with permission from Ref. [104]. 1998, Elsevier". (**B**). Dev et al. [105], "Reprinted/adapted with permission from Ref. [105]. 2011, Elsevier".

Tubular solar still: This passive type comprises a rectangular-shaped blackened metallic tray placed inside a cylindrical glass tube, as shown in Figure 26 (Amimul et al. [106]). The glass tube length and diameter are slightly bigger than the tray length and width. Saline fed through one end of the tube is partially evaporated, while the rest is discharged throughout the other end. The evaporated water is condensed on the inner surface of the glass cover and then flows down by gravitational force, and is finally collected at one end of the lower section of the glass tube. The purity of the water produced in this type is larger than in a standard one and can be used, for example, in chemical laboratories and desert irrigation [107]. Also, the tubular solar still has many advantages, such as [108]:

1. Ease of construction.
2. Easy removal of the basin-accumulated salts.
3. Placement of the basin inside the enclosure, preventing heat loss and increasing the still performance.

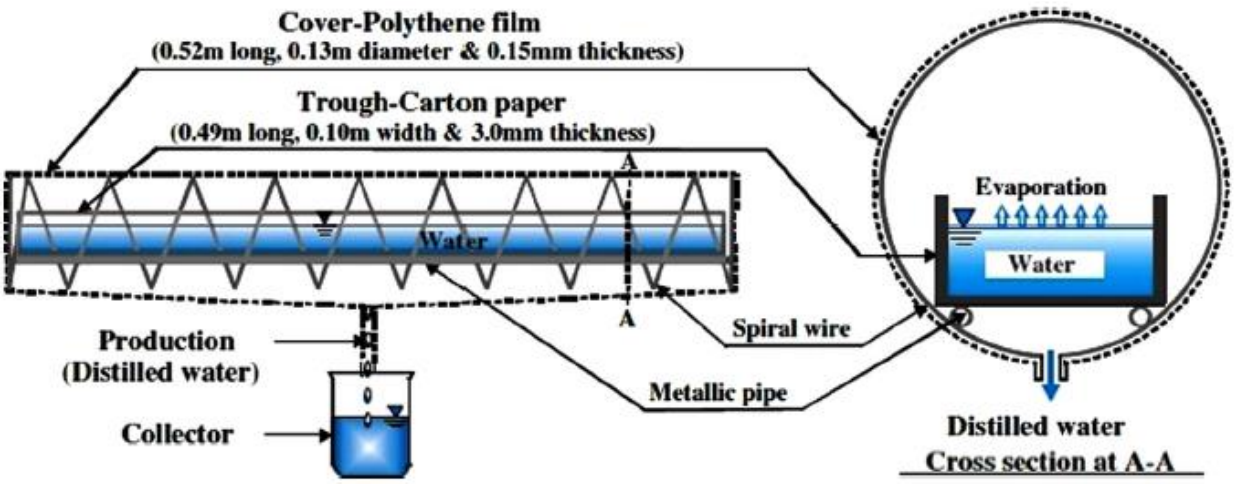


Figure 26. Schematic diagram of the tubular solar still (Amimul et al. [106], "Reprinted/adapted with permission from Ref. [106]. 2012, Elsevier").

Tubular multi-wick solar still: This passive type can be considered as a mixture of tubular and multi-wick solar stills, as presented in Figure 27 (Ashok and Anand [109]). The tray-type basin of the tubular solar still is substituted by the FRP tray; this tray includes a black jute cloth of the same size lying along the incline, with the upper edge immersed in the saline water. The condensation surface area increases by around 50% compared to a flat surface. This is due to the curvature of the upper half of the glass cover. Therefore, the temperature difference between the water and the glass cover increases and leads to increased still productivity.

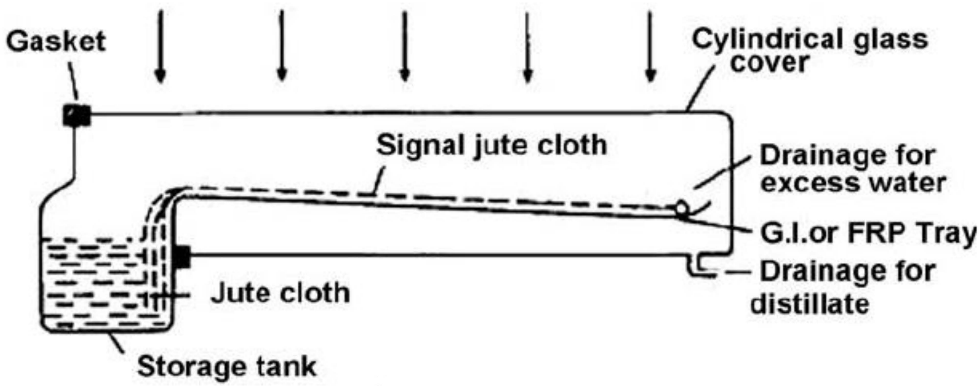


Figure 27. Diagrammatic representation of the tubular multi-wick solar still (Ashok and Anand [109], "Reprinted/adapted with permission from Ref. [109]. 1992, Elsevier").

Spherical solar still: The basin of this type has a spherical geometry to reduce the shadow of still walls, which is noticed in the conventional solar still. It comprises a horizontal black metal plate placed in the middle of a transparent spherical enclosure usually made from glass, as shown in Figure 28 (Dhiman [110]). One of the drawbacks of this type is that there is no change in its inclination angle. If the water is fed to the condenser part (upper part of the sphere), it flows downward due to gravity, collects in a channel, and flows inside the basin. The efficiency of this design is approximately 30% higher than the conventional basin solar still.

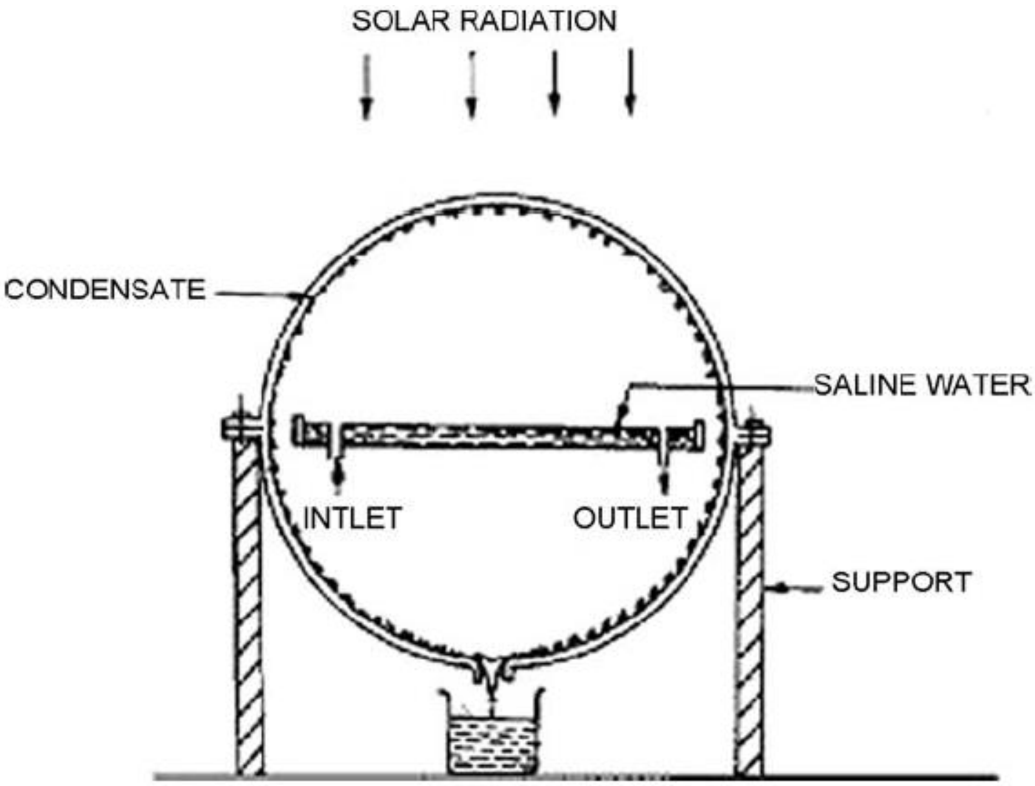


Figure 28. Schematic diagram of the spherical solar still (Dhiman [110], "Reprinted/adapted with permission from Ref. [110]. 1988, Elsevier").

Double or multi-effect solar still: the working principle of this type is based upon the double or multiple condensation–evaporation cycles (Figure 29 (Abdel Dayem [111])). While in a single effect still, the latent heat of condensation is emitted to the surrounding environment. So, this cycle is repeated such that the condensation heat is utilized for driving a subsequent evaporation process. This is a very efficient way of producing desalinated water at lower temperatures, up to 70 °C, but with an associated cost penalty. This type of still is more productive than conventional stills due to the recovery of the latent heat of condensation since the heat emitted from the condensed vapor is used for feed water vaporization.

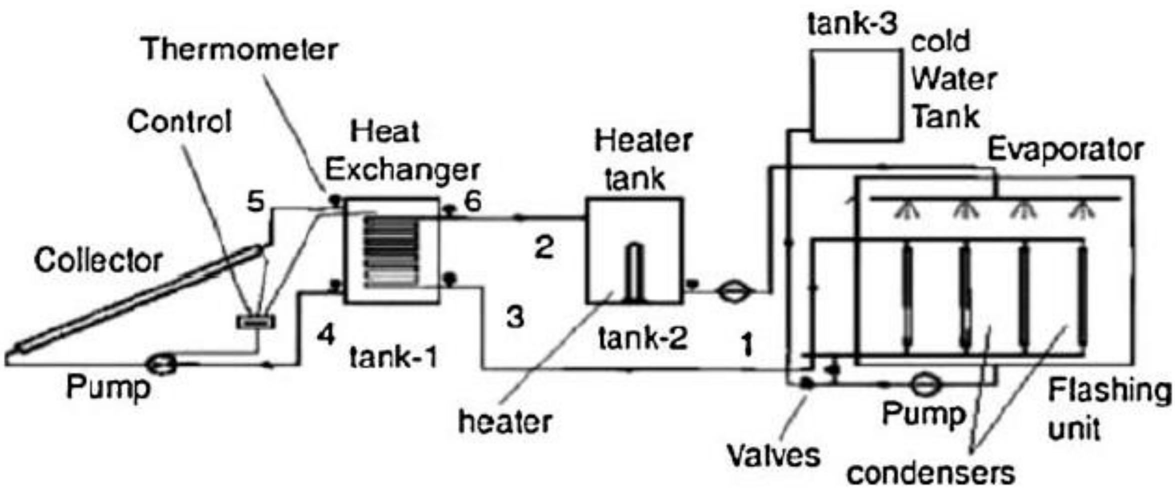
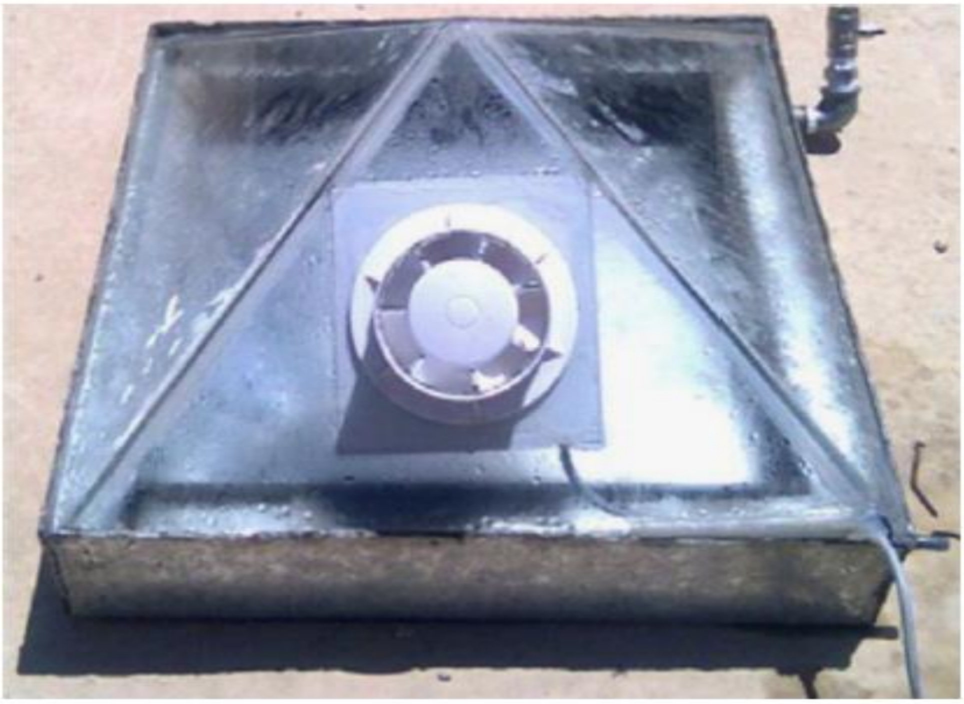


Figure 29. Diagrammatic representation of the multi-effect solar still (Abdel Dayem [111], "Reprinted/adapted with permission from Ref. [111]. 2006, Elsevier").

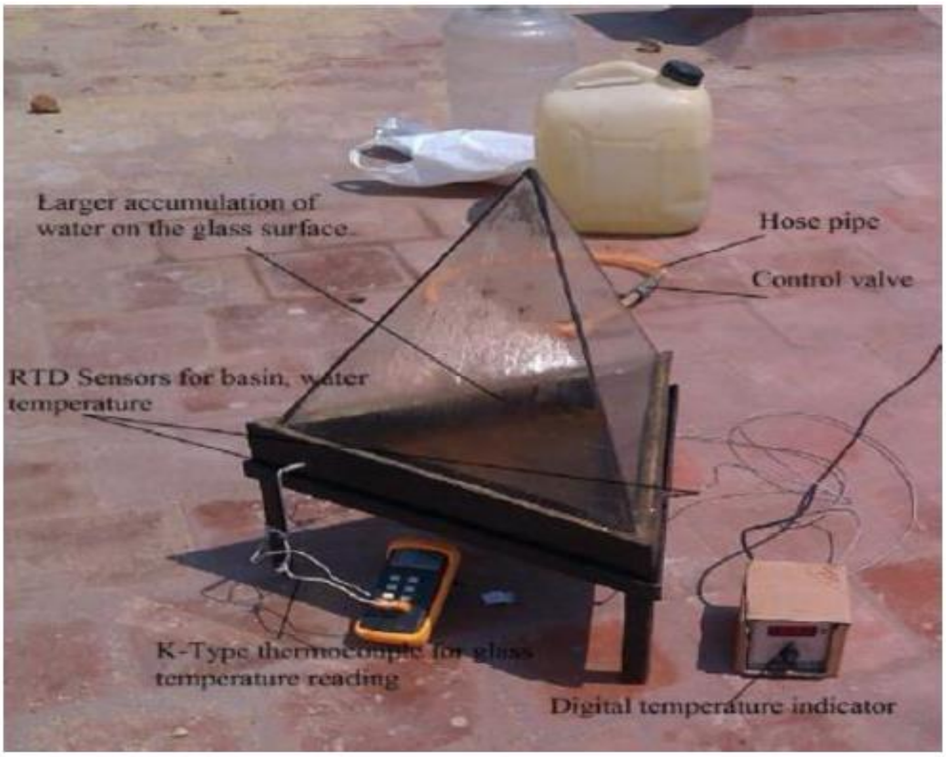
Hemispherical solar still: It comprises a circular basin and an absorber plate. The condensed water is collected frequently in the conical-distillate port, which is located at the lower section of the circular basin (Figure 30 (Ismail [112])). In this type, the hemispherical cover is employed to enhance the solar energy collected by the solar still. Researchers have found that the water depth is in inverse proportion to both the productivity and the efficiency of the hemispherical solar still [113].

Figure 30. Photo of the hemispherical solar still (Ismail [112], "Reprinted/adapted with permission from Ref. [112]. 2009, Elsevier").

Triangular or pyramidal solar still: In this type, the glass cover has a form of a pyramid or a triangular shape (Figure 31 (Kianifar et al. [114] and Sathyamurthy et al. [115])). In this design, the effects of shadow from the sidewalls and the orientation of the solar still are minimized. This increases the distillate output and maintains the water temperature by distributing the heat input inside the still [116,117].



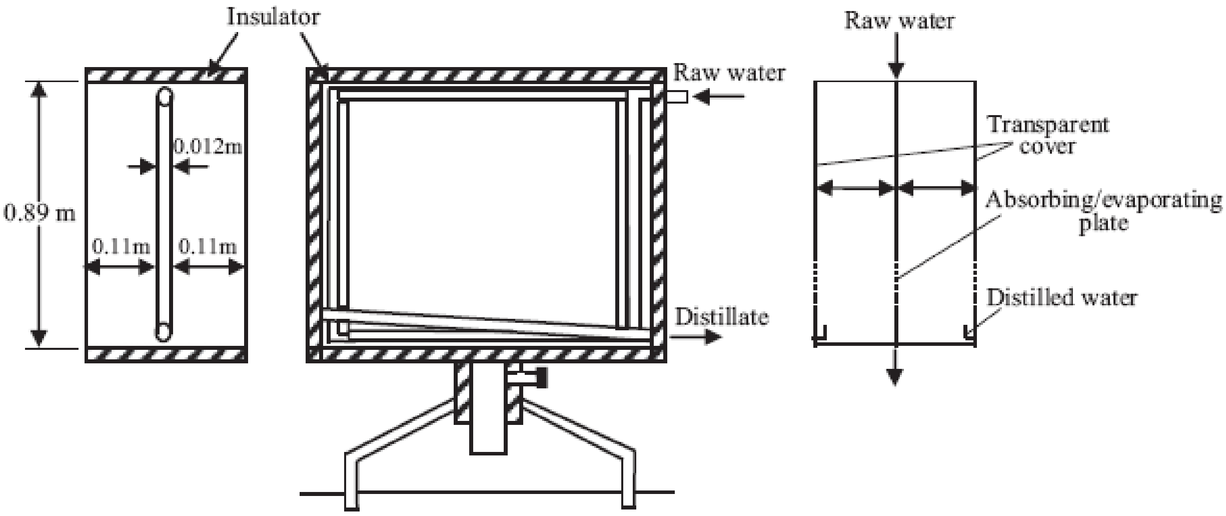
(**A**)



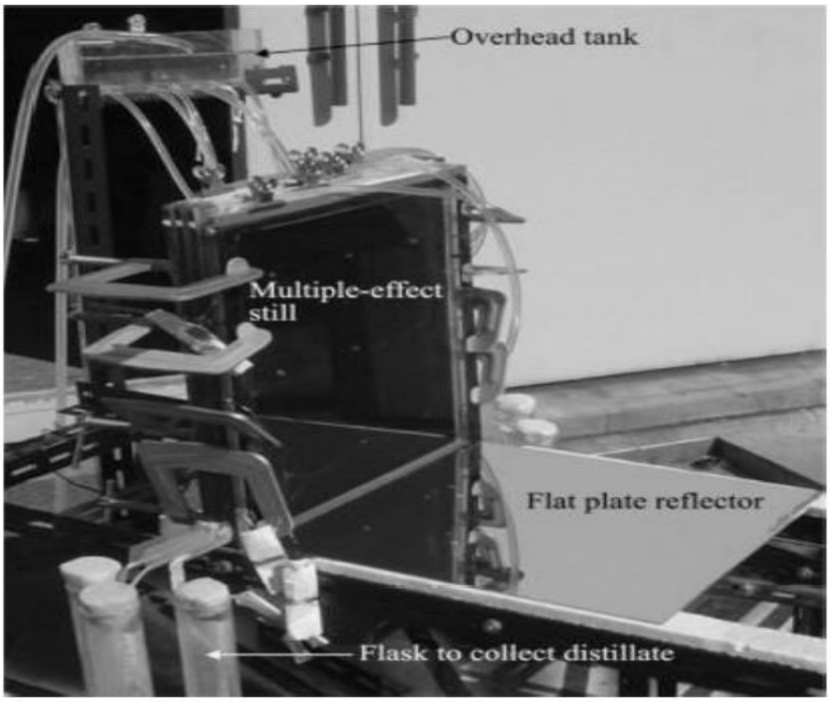
(**B**)

Figure 31. Photos of the triangular solar still. (**A**). Kianifar et al. [114], "Reprinted/adapted with permission from Ref. [114]. 2012, Elsevier". (**B**). Sathyamurthy et al. [115], "Reprinted/adapted with permission from Ref. [115]. 2014, Elsevier".

Vertical solar still: In this type, the width and breadth are much less than the height. Therefore, vertical solar stills are tall in shape, as shown in (Figure 32 (Kiatsiriroat et al. [118] and Tanaka [119])). The vertical solar still comprises a vertical black absorption/evaporation plate where a transparent material covers both sides. The saline is fed at the top and flows along both sides of the plate. It is suitable for use in cities where land cost is extremely high or in places where there are not enough horizontal spaces to install other types of stills. Unfortunately, this type is characterized by low productivity (1.31 L/(m^2.day)) and low efficiency (21.1%). This indicates that this type is unsuitable for obtaining an effective distillate output [120–122].



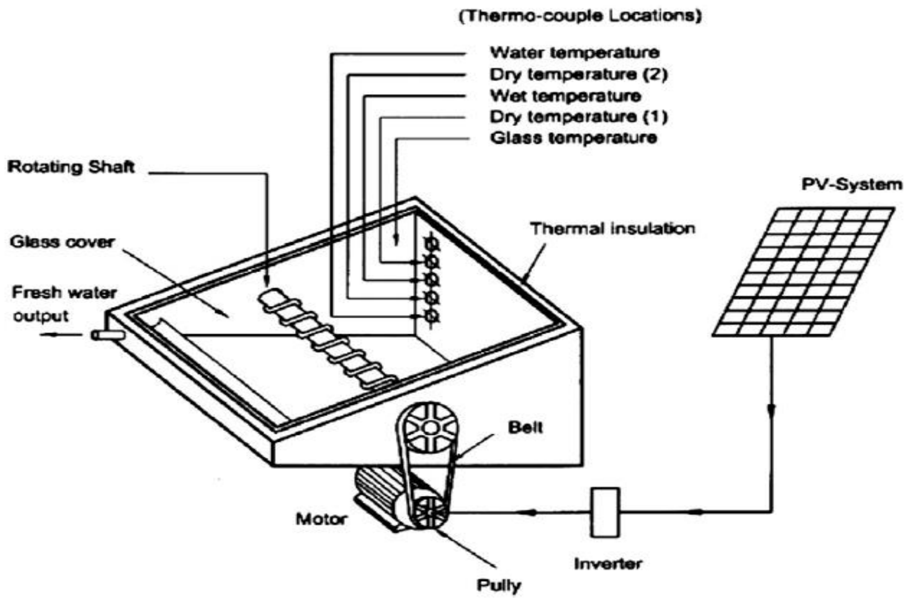
(**A**)



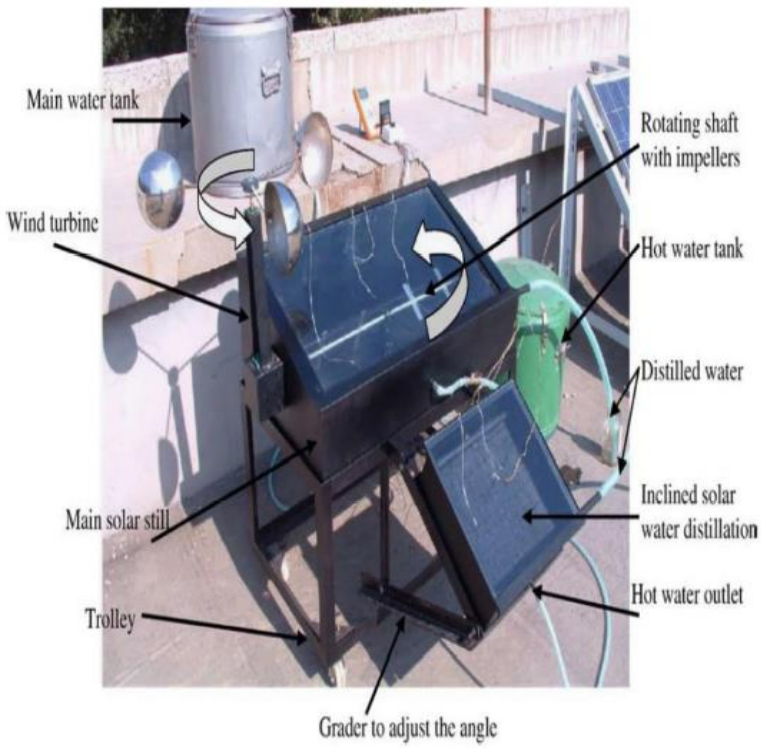
(**B**)

Figure 32. Sketch and photo of the vertical type solar still. (**A**). Kiatsiriroat et al. [118], "Reprinted/adapted with permission from Ref. [118]. 1987, Elsevier". (**B**). Tanaka [119], "Reprinted/adapted with permission from Ref. [119]. 2009, Elsevier".

Rotating shaft solar still: In this type (Figure 33 (Abdel-Rehim and Lasheen [123] and Eltawil and Zhengming [124])), a rotating shaft is added next to the basin water surface, the main purpose of this shaft is to break up the thermal boundary layer of water. This increases both the vaporization and condensation rates. Moreover, it increases vibrations, encouraging water droplets to leave the cover and enter the collection channel. Wind turbines can also be used in a solar still to drive the rotating shaft and increase the distillate output.



(A)



(B)

Figure 33. Schematic diagram and photo of the rotating shaft solar still. (**A**). Abdel-Rehim and Lasheen [123], "Reprinted/adapted with permission from Ref. [123]. 2005, Elsevier". (**B**). Eltawil and Zhengming [124], "Reprinted/adapted with permission from Ref. [124]. 2009, Elsevier".

Inverted tickle solar still: This type is composed of a tilted absorber plate with a blackened upper surface. The saline water flows to the back side of the plate. This type is characterized by a low water flow rate; hence, the water temperature is increased in order to produce the vapor. The condensation occurs in another section in which a heat exchanger is used for heat recovery [125,126].

Conical solar still: This type is basically composed of a galvanized iron circular base (Figure 34 (Gad et al. [127])). Both the sides and the base are painted in black to enhance the absorption of solar energy. A tilted circular collection channel is utilized for condensed water collection. The design of this type has a significant role in increasing the distillate output. This is because of the reduction in the shadow effect and the maximum utilization of solar radiation.

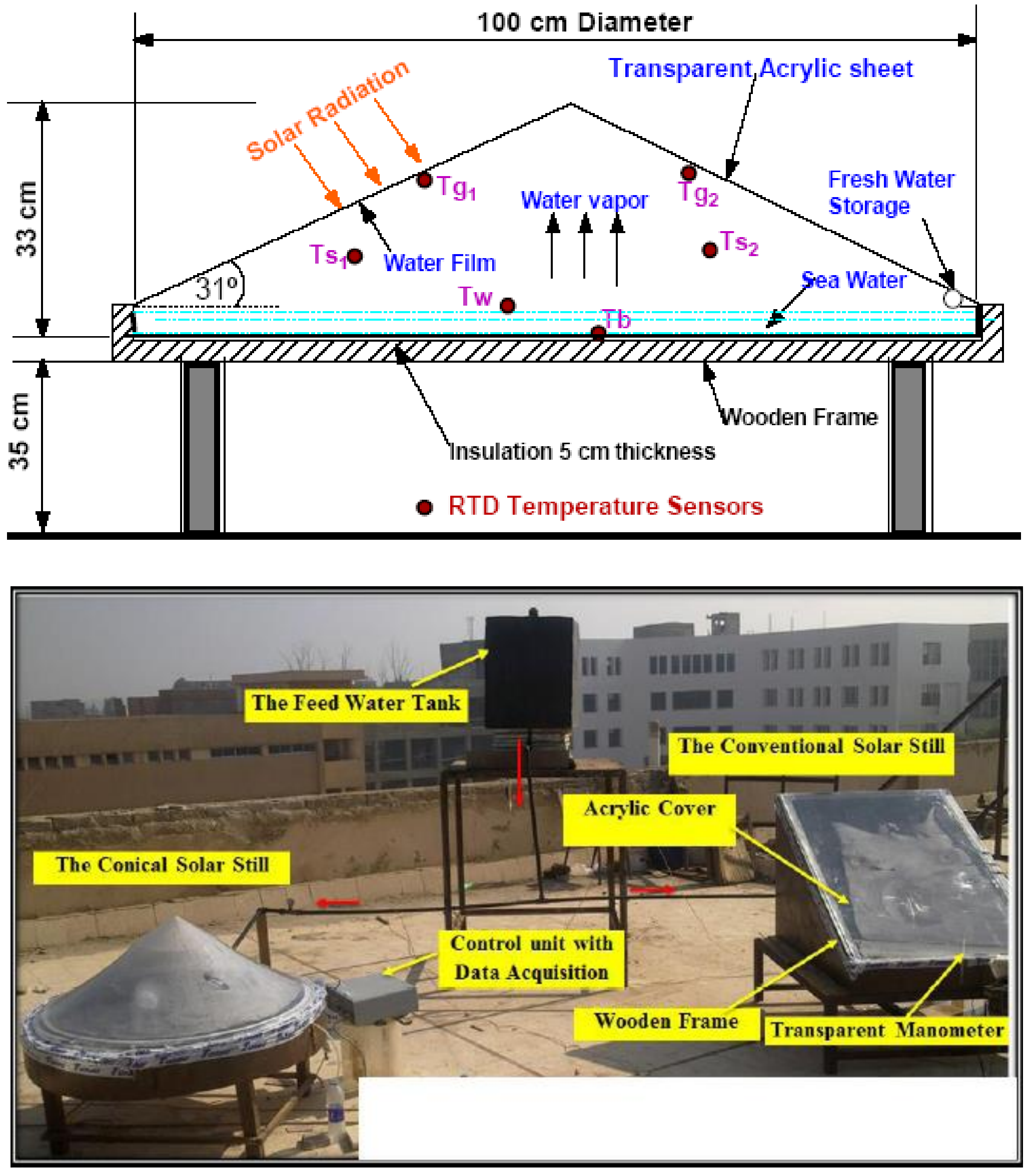


Figure 34. Schematic diagram and photo of the conical solar still (Gad et al. [127], "Reprinted/adapted with permission from Ref. [127]. 2015, Elsevier").

Vapor adsorption type solar still: This type comprises a plywood box and is integrated with a vapor adsorbing bed at the basin (Figure 35 (Kannan et al. [128])). Such a design aims to enhance the saline water temperature by employing an adsorbing bed pipe network with an activated carbon-methanol pair included in the still basin. Holes are provided for the distilled water output and the brackish water input. The external parts of the wooden box are covered with a metal sheet to protect the box from rain and solar radiation. The basin is made of a galvanized iron sheet which is precisely chosen to offer good conductivity at an economical cost. The sensible heat absorbed by activated carbon and the latent heat of the menthol's vaporization helped reduce heat loss from the bottom of the still.

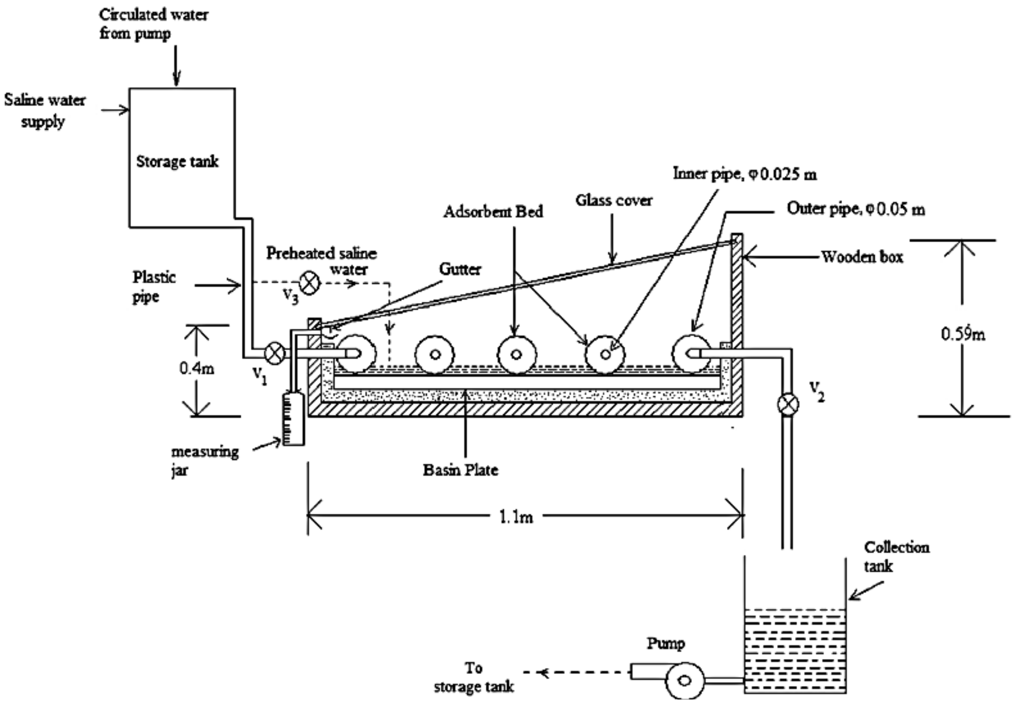


Figure 35. Schematic diagram of the vapor adsorption solar still (Kannan et al. [128], "Reprinted/adapted with permission from Ref. [128]. 2014, Elsevier").

Capillary film solar still: This type can re-use the vapor condensation heat to evaporate another quantity of water. It uses both solar energy and the capillary effect. Because of the surface tension, a very thin layer of water-saturated tissue is kept in contact with the metal plane. The efficiency of this type is in direct proportion to the inlet temperature of the brackish water and the solar radiation intensity [129].

Masonic solar still: This type is characterized by low maintenance cost due to its rigid construction. It also can resist severe weather conditions. It is made up of bricks, sand, and cement (Figure 36 (Navale et al. [130])). The inner surface of the still is coated with tiles. Covering the inner area with black resin helps to avoid leakages, heat loss, and captures more solar radiation. The condensate is gathered through a conduit provided at the tilted glass end.

Humidifier-dehumidifier solar still: This type consists of a rectangular box with a glass cover and a condensing cover at the bottom. The still is divided into upper and lower evaporation chambers (Figure 37 (Fath et al. [131])). Both of them are divided by a central insulated stepped sheet carrying a group of basins. Air circulates between the upper heated and humidified chamber and the lower cooled and dehumidified chamber in order to produce the water.

Figure 36. Photo of the masonic solar still (Navale et al. [130], "Reprinted/adapted with permission from Ref. [130]. 2016, Elsevier").

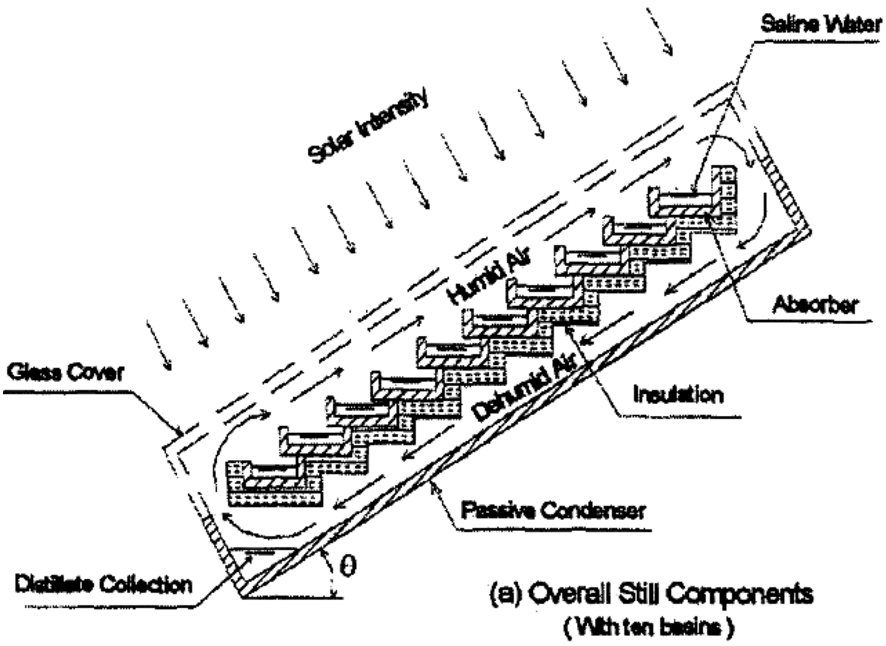


Figure 37. Schematic diagram of the humidifier-dehumidifier solar still (Fath et al. [131], "Reprinted/adapted with permission from Ref. [131]. 2003, Elsevier").

Thermoelectric solar still: This type is provided with a thermoelectric module to enhance the temperature difference between the evaporation and condensation sectors (Figure 38 (Rahbar and Esfahani [132])). A heat pipe cooling device is utilized to cool the thermoelectric cooler's hot side. The maximum efficiency of this still is about 7%.

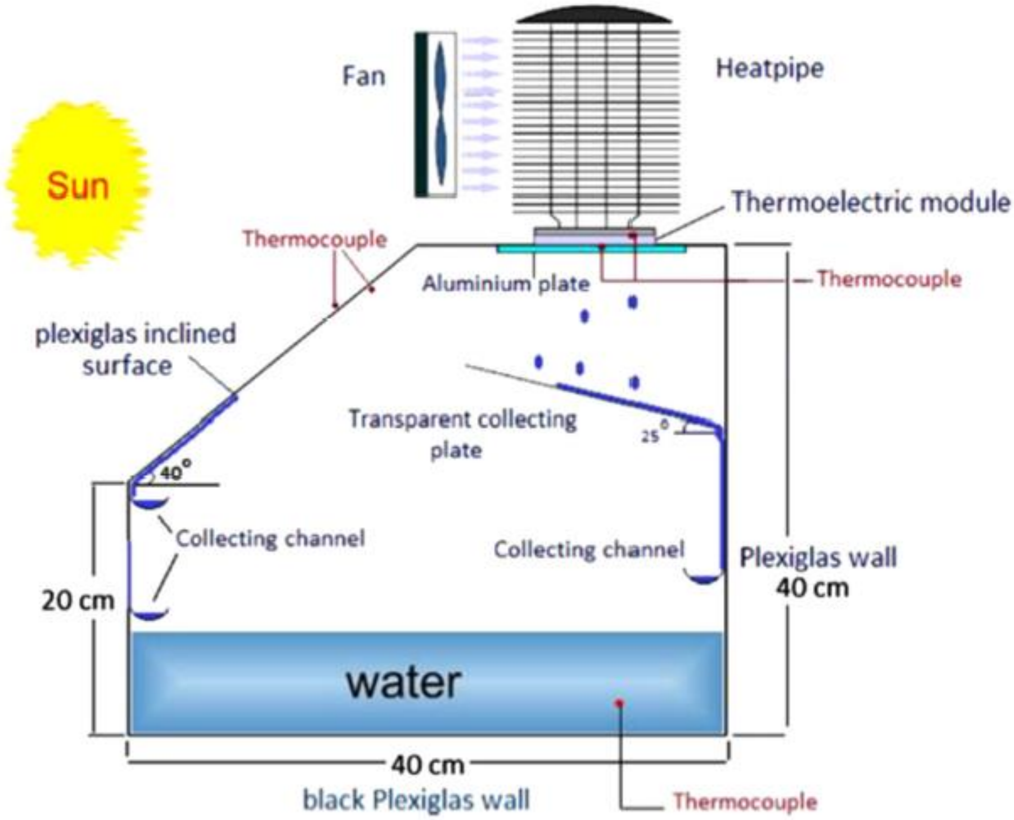


Figure 38. Diagrammatic representation of the thermoelectric solar still (Rahbar and Esfahani [132], "Reprinted/adapted with permission from Ref. [132]. 2012, Elsevier").

V-type solar still: The main advantage of this type is that the distilled water is directed into the center water collecting tube, as shown in (Figure 39 (Suneesh et al. [133])). The productivity of this type can be increased if a boosting mirror is used [134].

Multi-stage evacuated solar still: This type comprises three insulated levels stacked on top of one another (Figure 40 (Ahmed et al. [135])). The different stages of the still are perfectly sealed, such that the water vapor that evaporated during the boiling process is only allowed to pass through a small orifice connecting between two stages. In order to decrease the heat loss to the environment, a thick insulation layer is utilized. The heat is introduced to the system through the lower stage using a solar collector. A solar-operated vacuum pump is also employed to remove the non-condensable gases. This kind of still produces around (9 kg/(m^2/day)) and has an 87 percent distillation efficiency.

Basin multiple-effect diffusion-coupled solar still: For this type, the basin is integrated with a multiple-effect diffusion still to enhance its productivity. It has a triangular cross-section basin comprising an inclined double glass cover facing the sun, a horizontal basin liner, and a number of vertical partitions in contact with saline-soaked wicks (Figure 41 (Tanaka et al. [136])). This type's productivity was four times higher than the conventional basin type still and about 40% higher than the conventional multiple-effect stills.

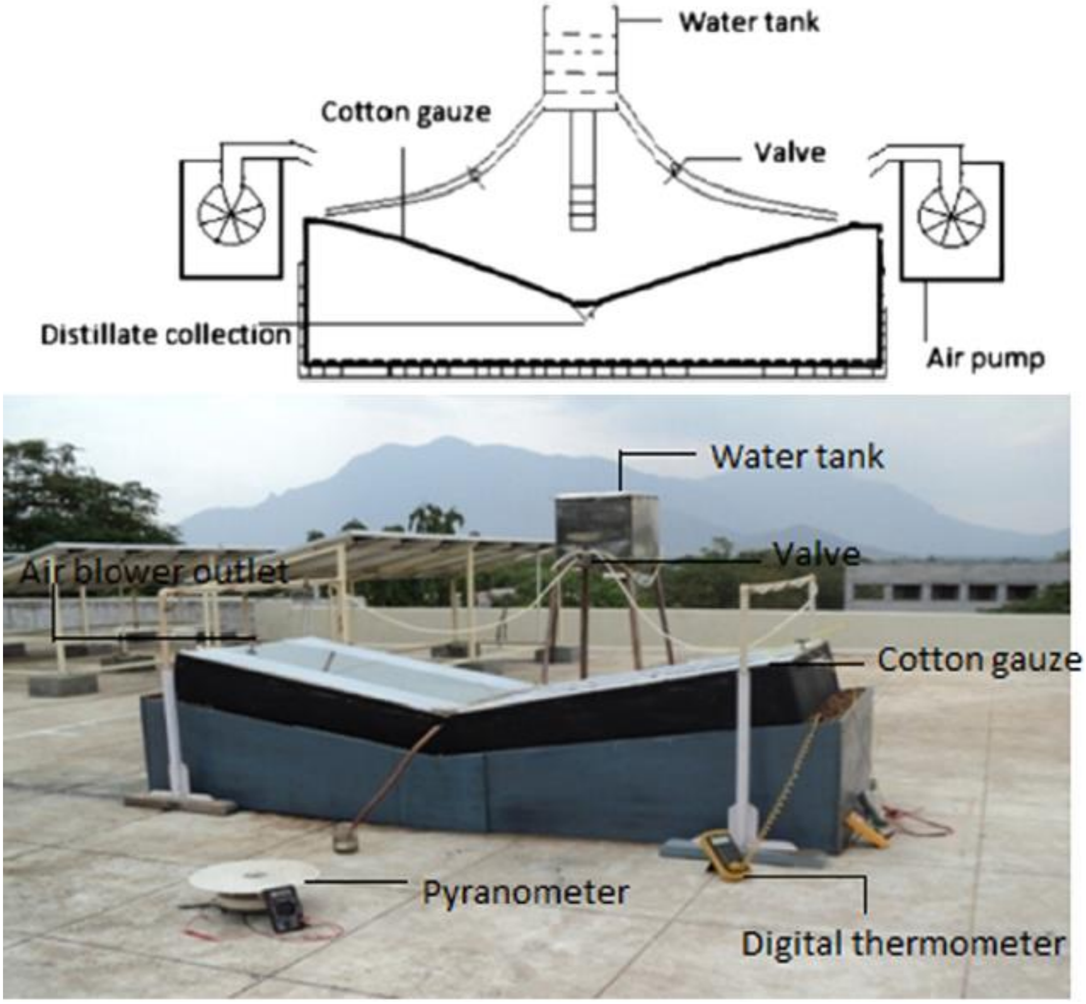


Figure 39. Schematic diagram and photo of V-type solar still (Suneesh et al. [133], "Reprinted/adapted with permission from Ref. [133]. 2014, Elsevier").

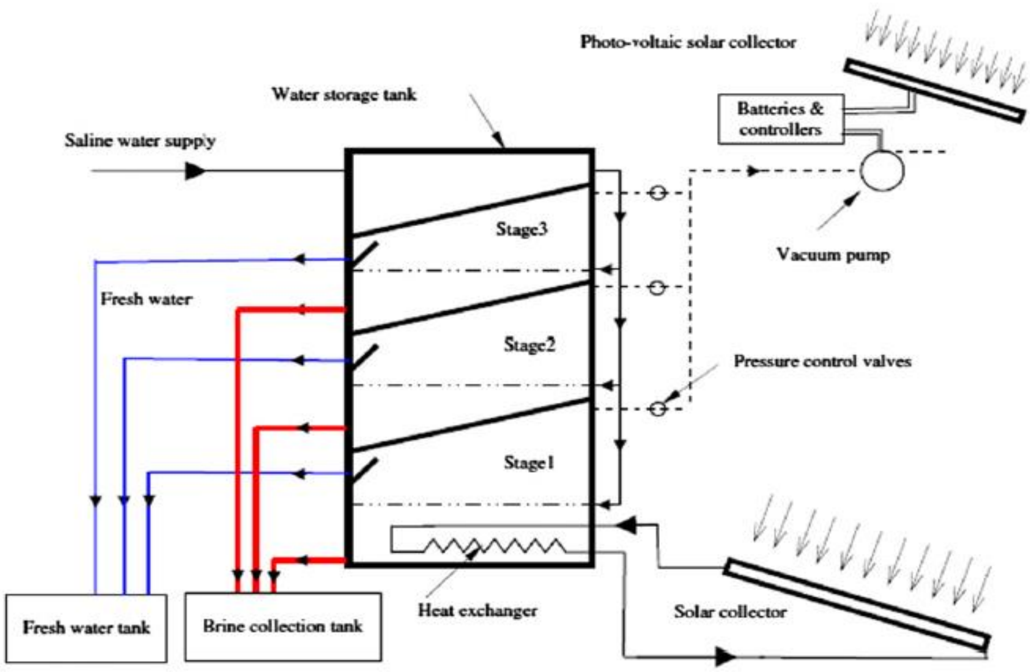


Figure 40. *Cont*.

Figure 40. Schematic diagram and photo of multistage evacuated solar still (Ahmed et al. [135], "Reprinted/adapted with permission from Ref. [135]. 2009, Elsevier").

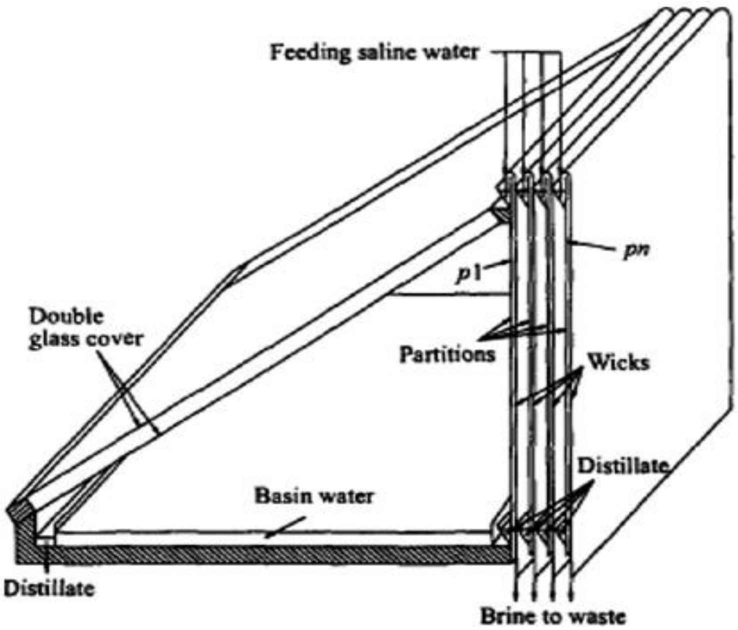


Figure 41. Schematic diagram of basin-multiple-effect diffusion coupled solar still (Tanaka et al. [136], "Reprinted/adapted with permission from Ref. [136]. 2002, Elsevier").

Shallow basin solar still: In this type, the volumetric heat capacity of water is less, and its temperature is high; this leads to a significant enhancement in the evaporation rate and productivity. However, this productivity is still highly sensitive to any small changes in solar radiation intensity. The nocturnal production for this is still very low, and it is preferable for lower solar radiation intensity [137].

Point focus elliptical shape solar still: This type includes concave mirrors for reflecting and concentrating the sun rays on a solar still located at the focus (Figure 42

(Nassar et al. [138])). A vacuum of 562.5 torr is established in the solar still to decrease the boiling temperature of the feed water. The outlet vapor is condensed in the condenser and behaves as a water trap before entering the vacuum pump.

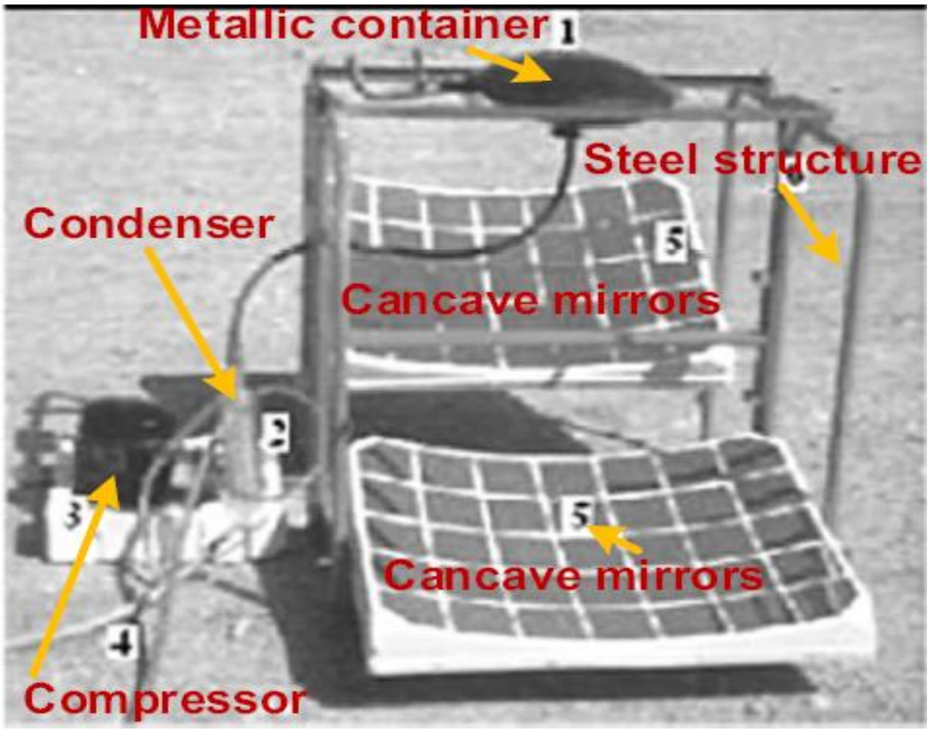


Figure 42. Photo of the point focus elliptical shape solar still (Nassar et al. [138], "Reprinted/adapted with permission from Ref. [138]. 1984, Elsevier"). (1) container, (2) condenser, (3) compressor, (4) flexible tube, (5) concave mirrors.

Air bubbled solar still: This type depends on the simultaneous impact of forcing the dry air bubbles together with the glass cover cooling effect (Figure 43 (Pandey [139])). A blower and control valves are used to force the air to bubble over the basin water. This modification enhances both the evaporation and condensation phenomena and leads to an increase in distillate production.

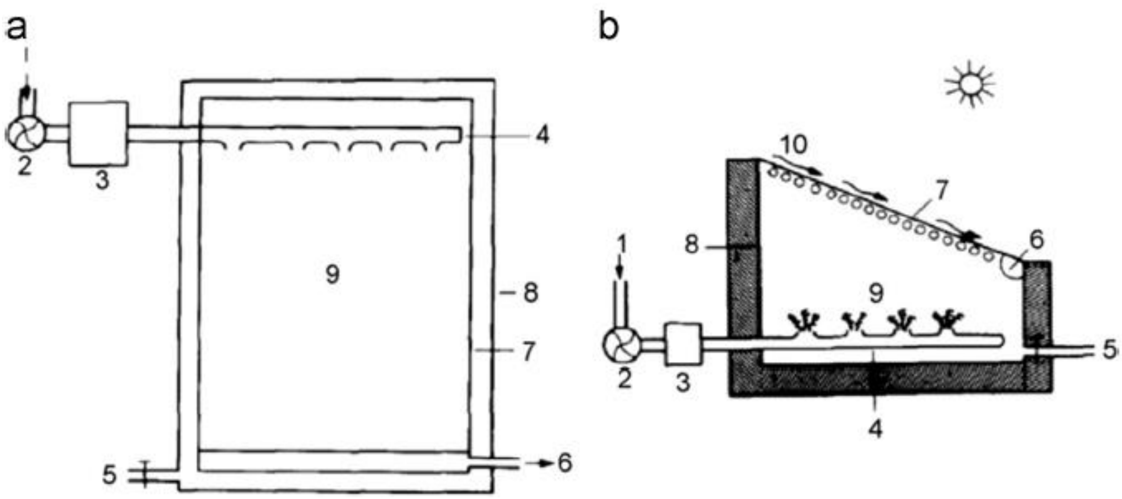


Figure 43. Diagrammatic representation of air-bubbled solar still (**a**) top view, (**b**) side view (Pandey [139], "Reprinted/adapted with permission from Ref. [139]. 1984, Elsevier").

Semi-circular trough solar still: This type has a trough with a semi-circular shape (Figure 44 (Sathyamurthyet al. [140])). In order to increase its efficiency, baffles were suspended in this trough, increasing its efficiency to approximately 38%.

Figure 44. Photo of the semi-circular trough solar still (Sathyamurthy et al. [140], "Reprinted/adapted with permission from Ref. [140]. 2015, Elsevier").

There are also other types of solar stills such as active vibratory solar still, corrugated basin liner solar still, double condensing chamber solar still, solar film covered stills, and the vertical micro-porous evaporator still.

4. Review of Papers Related to Solar Stills

Fath [141] reported a comprehensive review and technical assessment of the different kinds of solar stills. The development in still configurations, the unit problems encountered during the operation, and the environmental impact were also highlighted. Murugavel et al. [22] presented a review of the various methods used for improving single-basin passive solar still efficiency. The following conclusions were given:

1. For low latitude locations, double slope stills are preferable and should be south–north oriented.
2. The cover tiling angle was optimized for a better water condensation rate.
3. Using a black painted aluminum and water level at (2 cm) increasing still efficiency by (28%).
4. Daytime and nighttime productivity was proportional to water depth and heat capacity of basin.
5. Using a Mica sheet to serve the absorber results in better surface heating.
6. Mirrors are necessary to reflect sun rays falling on the still sidewalls into its basin.

Arjunan et al. [142] presented a comprehensive overview and technical evaluation of India's several passive and active solar distillation systems. The classification of these systems was summarized. They noted that water desalination is very important in India due to the rapid increase in its population, changing lifestyles, and the huge need for fresh water. An economic evaluation of solar stills was also briefly described. The following summarizes their findings:

1. Solar still performance was enhanced by decreasing basin water capacity, addition of different dyes to the water, absorptivity increment, collecting reflection radiation and heat loss reduction.
2. Still performance was enhanced by using different active methods such as flat-plate collector, heat exchanger, solar pond, solar heater, or other heating devices.
3. Still productivity was increased at a lower glass cover angle; high temperature difference between water and cover, increased mass flow rate for higher inlet water temperature and when the water flowed over a glass cover with a constant velocity.
4. Water absorptivity was increased by adding dyes and preheating the feeding water.
5. Black rubber, black granite gravel and aluminum sheet were considered good materials for enhancing the basin heat capacity and absorptivity.
6. Dry ambient air bubbling and glass cover cooling magnified the still efficiency.

Sampathkumar et al. [143] presented a comprehensive review of the technological advancement as well as thermal modeling of various active solar distillation systems. According to their discussions, the following conclusions were given:

1. Active solar still performance was affected by controlling water depth in the basin, basin material, wind velocity, inlet water temperature, length of a solar still, solar radiation intensity, local climatic conditions, insulation thickness, ambient temperature, and glass cover inclination angle.
2. Copper was an ideal material for making the still cover.
3. Glass temperature reduction increased the water evaporation rate.
4. Still productivity was increased by (57.8%) when coupled with a solar pond, and a sponge cube was used in the still.
5. The most important factors for the proper solar still selection are solar radiation intensity, total water output requirement, salt/saline water available, cost of the still, ease of operation, maintenance cost, better employment of available waste hot water, and the useful lifetime of the solar still.
6. Composite materials were recommended for basin liners as they tend to enhance thermal conductivity and still productivity.

Kaushal [38] presented a detailed review and comparison of various kinds of solar stills. He observed that still productivity was decreased by (2%) when the wind speed increased from 0 to 3.6 mph. Five different headings were considered in his comparison (such as geometry, properties, results, merits, and drawbacks). All the reviewed types produced clean water from brackish or salt water. The development of the mathematical models for these devices was also described. The following points were concluded:

1. Fully insulated solar still achieved the maximum efficiency by 50%. While for partially insulated ones, the efficiency was 14.5%.
2. Continuously cleaning of the glass cover was essential to increase the still efficiency.
3. Produced amount of distilled water per day of the still integrated with a reflector was about 14% greater than that of the still without it.
4. The suitable solar still was selected according to the local and operating conditions.

Velmurugan and Srithar [144] reviewed modifications employed on solar stills for enhancing their productivity. They concluded the following points, based on the reviewed papers:

1. Productivity of solar stills was improved by varying the free surface area of water, temperature difference between water and glass cover, absorber plate area, inlet water temperature, saturation pressure of the water, glass angle, and water depth.

2. Free surface area of water was increased by using sponges in the basin.
3. Floating perforated aluminum plate usage increased productivity by 40% for a brine depth of 6 cm.
4. Maximum annual yield of the still was achieved when tilting angle of glass was equivalent to the place latitude.
5. Concave shape of the wick surface increases the evaporation area of the still due to its capillary effect.
6. Still productivity was enhanced by 100% when vacuum technology was applied.
7. Reflectors, condenser, hot water tank, combined stills, asphalt basin liner, cooling film, and sun-tracking systems were utilized to maximize the still yield.

Kabeel and El-Agouz [145] performed a detailed review of several solar still improvements which different researchers suggested to enhance its productivity. Some of these improvements include the use of sponge cubes, greenhouse, external and internal condenser, sun tracking system, reflectors, flat plate solar collector, and PCM. Also, they highlighted the cost analysis of the still and its vibratory harmonic effect. They concluded the following points:

1. Still productivity was directly proportional to thermal conductivity, solar radiation intensity, and wind velocity; and is in inverse proportion to cover thickness, cover temperature, and water depth.
2. Material selection was a key factor in the design of a solar still.
3. A considerable reduction in glass cover temperature was achieved by a continuous flow of a cooling film of water over the glass.
4. Still efficiency was increased by using a packed layer at the bottom of the basin or by adding a rotating shaft near the basin water surface.
5. Average daily water production of fin- and sponge-stepped solar still was 80% higher than a standard single-basin solar still.
6. If a condenser was coupled with a solar still, its efficiency was increased more than twice compared with the conventional still efficiency.
7. Using a sun-tracking system increasing the productivity by 22%. Productivity was enhanced by 36% when using a flat plate solar collector.
8. Weir-type still productivity was almost 20% greater than the standard single basin still.
9. PCM was more effective in cases of lower mass of basin water in winter.

In their review, Xiao et al. [146] attempted to categorize the solar stills into six types according to the still design guidelines. They also provided a summary of the most commonly used heat and mass transfer correlations reported in the literature. They made some suggestions, which can be listed as follows:

1. If stills were coupled with solar collectors, extra electricity was needed by the solar still for brine circulation. Also, both the operating and installation costs were increased.
2. Still efficiency was enhanced by circulation of cooling water over the glass cover.
3. Still productivity was augmented by increasing areas of both the absorber plate and free surface of water by adding sponge cubes in the basin.
4. Both the productivity and thermal efficiency were improved by recovering the latent heat of the vapor.
5. Still performance was improved by utilizing heat storage systems such as heat reservoir, PCM storage, solar pond, and energy storing materials such as quartzite rock.
6. The distillation process of the still was highly affected by climate and operating conditions.
7. When solar radiation was weak, it was recommended to use reflectors and solar collectors. When it was relatively strong, it was suggested to increase free surface area, vapor latent heat recovery, heat storage system installation, and condensation enhancement.

Sivakumar and Sundaram [147] reviewed different methods and practices to enhance the efficiency of active and passive solar stills. The results of different performance improvement techniques applied to solar stills were compared, summarized, and tabulated.

The impact of designing and meteorological parameters on the solar still performance was also reviewed. They concluded some essential points, which were highlighted as follows:

1. Distillate output was increased by 18% by adding sponge cubes over the water surface, and was increased by 21% if an inclined reflector was coupled with the still.
2. Still efficiency was improved by using energy storage materials which such as a baffle-suspended absorber plate, charcoal particles, packed layers, utilizing a hot water storage tank, PCM, black rubber, black ink, black dye, gravel, jute cloth, sensible storage medium, and absorbing materials.
3. Still productivity was enhanced by using vacuum technique, wick materials, sun-tracking system, coupling the still with an external reflector, solar collector, cooling tower, using asphalt as a basin liner material, and controlling the glass cover tilt angle.
4. Stepped solar still efficiency was enhanced by 112% when integrated with a solar air heater and a cooling glass cover.
5. Still productivity was increased by approximately 50% when the wind speed was increased.

Murugavel et al. [148] presented a review of various methods for improving the productivity of different kinds of inclined solar still. They mentioned that the main advantages of this type are the high surface area and thin water surface while preserving continuous wetness along the tilted surface, and the loss of heat through the raw water drain is considered the main drawback. They introduced the following conclusions:

1. No significant improvement in still productivity was noticed when the number of basins was more than three.
2. Still productivity was increased by 27.6% when coupled with a solar pond.
3. Inclined wick solar still production was 20–50% higher than the traditional one.
4. Wick solar still efficiency was in an inverse proportion to the feedwater mass flow rate.
5. For the still with a cover inclination angle of 20° and external reflector inclination angle of 20°, the productivity was greater by approximately 2.45 times compared to that of a conventional still with no reflector.

Manikandan et al. [149] reviewed various designs of wick-type solar stills. They described the working principles of various kinds of this still in detail and compared their thermal performance. It was found that the jute wick, charcoal wick, cotton cloth, and floating perforated black aluminum plate as absorber material in the basin significantly impacted still productivity. Rajaseenivasan et al. [150] presented various methods applied to improve the multi-effect solar still productivity. They indicated that the wick type solar still was considered a preferred and economical option for freshwater production. The following conclusions were inferred:

1. Using multi-effect solar still rather than single-effect still led to an increase in production as a result of the optimized usage of the latent heat and the reduced cost.
2. Using energy-storing materials in the lower basin of the double basin still increased productivity by 169.2%.
3. Distillate output of the multi-effect solar still coupled with a condenser was 62% higher than the conventional one.
4. Evaporation rate was increased due to the increment of the basin water temperature, which results from supplying the waste hot water in the basin.
5. Multi-effect diffusion still coupled with a flat plate collector and reflector results in a better yield than the conventional one.

Muftah et al. [151] introduced a comprehensive review of factors influencing the performance of active/passive basin-type solar still. They deduced that the production of the solar still was significantly affected by ambient conditions (temperature, solar radiation, wind speed, dust, and cloud cover), operational parameters (depth of water, various dyes, water flow over a glass cover, surfactant additives, salt concentration, and still orientation) and design conditions (such as various passive/active designs of solar stills, cover slope, materials selection, storing materials, reflectors, and insulation). They presented the following conclusions:

1. Productivity was improved by increasing the total solar radiation, ambient air temperature, wind speed, and water absorptivity and decreasing the water depth, thickness of the cover, dust accumulation, salt concentration, glass cover inclination, and the gap between the water surface and condensing cover.
2. It was recommended to use a distillate channel manufactured from aluminum. Silicon rubber was also very efficient in sealing the transparent cover to avoid vapor leakage since it remains elastic for a long time.
3. Mixing of dye with water enhanced the absorption of the incident solar radiation by increasing its absorptivity.
4. Productivity was increased by 70% if the still was integrated with a passive condenser, while it was increased by 36% if it was coupled with a solar collector.
5. Productivity was increased by 70–100% if both internal and external reflectors were used. While it was increased by 63% by tilting the glass cover alone.
6. The basin type solar still produces water that costs between \$0.035 and \$0.074 per liter.

Manokar et al. [152] presented a detailed review of various parameters influencing the rates of evaporation and condensation of passive solar stills. They concluded that:

1. Evaporation rate of still was greatly affected by the basin construction materials, water depth, absorption rates of basin water and still basin, the volumetric heat capacity of the basin, water inlet temperature, and the top surface water temperature.
2. Water absorptivity for solar radiation can be improved by using dissolved salts, violet dye, and charcoal.
3. Condensation rate of still was affected by the glass cover temperature and the wind speed.
4. The distillate output marginally decreased when the water flow over the glass was increased; this is mainly due to the drop in basin water temperature.

Yadav and Sudhakar [153] provided a rich review of different domestically used solar still designs. The performance parameters like thermal efficiency, energy, exergy, heat transfer, and economic analysis were also discussed for these designs of solar stills. They illustrated a simple comparison between these types based on location, results obtained, and special features of the system. They referred that there are two types of heat losses in the passive solar still. The first one was called the external heat loss, which covered the heat losses from the glass cover, bottom (basin), and sidewalls of the still. While the second was called the internal heat loss, which covered the convection, evaporation, and radiation heat losses. They also mentioned that the productivity and efficiency of domestic solar stills were greatly improved by introducing a heat reservoir under the basin liner. They submitted the following conclusions:

1. Thermal performance of the single-basin single-slope solar still increased by about 380% when a step-wise water basin was used rather than a flat one coupled with a sun-tracking system.
2. The distillate water productivity of the hybrid solar still was increased by 215% when the hot brackish water was fed during the night.
3. The payback period of the solar still is in direct proportion to the overall fabrication cost in addition to maintenance, operating, and feed water costs.
4. Hybridization of the domestic solar still at the small scale was considered among the best methods to enhance its yield.
5. Maximum thermal efficiency obtained from the solar still ranged between 17.4–45%.

Prakash and Velmurugan [154] presented a review about parameters still influencing the productivity of solar stills. The parameters covered are the absorption area, minimum water depth, water-glass cover temperature difference, inlet water temperature, heat storage, PCM, vacuum technology, humidification and dehumidification, thermoelectric cooling, and other methods such as using reflectors, condensers, and multi-effect distillation. Based on their survey, the following conclusions are provided:

1. Productivity was increased when absorption area and water-glass cover temperature difference increased.
2. Preheating the inlet water to the still basin improved its productivity.
3. Heat storage medium and PCM are able to produce distillate during off-shine hours, enhancing productivity.
4. Maintaining vacuum technology and using reflectors, condensers, exhaust fans, and other design modifications enhanced the performance of solar stills.
5. The optimal number of collectors is directly proportional to the basin's water mass for the hybrid solar.
6. Still efficiency and productivity were improved by employing different semiconducting oxides such as CuO, PbO_2, and MnO_2.

Durkaieswaran and Murugavel [155] reviewed the progress made in various designs of solar stills. The authors noted that the solar still productivity depended on the collector surface area, which was responsible for maximizing the absorption of direct and diffused radiation. Based on the reviewed papers, they concluded that no specific design of the still was optimized, and further work was needed in this field. Kabeel et al. [156] reviewed the various techniques applied to enhance the stepped solar still performance. They highlighted the following significant points:

1. The stepped still productivity was increased by 125% when coupled with internal and external reflectors. While it was boosted by around 66% when an external condenser was used.
2. The productivity was 56.60% and 29.24% higher than that of the flat stepped solar still when the shape of its absorber was considered convex and concave, respectively.
3. Stepped solar still productivity was increased by 75% compared to the conventional one if a reflector was used. On the other hand, it was improved by about 380% if coupled with a sun-tracking system.
4. When both fins and sponges were used, the productivity was improved by about 96% when compared to the classical stepped one.
5. The usage of PCM in a weir-type cascade solar still improved productivity by 31%.

El-Sebaii and El-Bialy [157] presented a review of different designs and cost analyses of solar stills. They also discussed various parameters that influence the performance of the considered designs of solar stills. They deduced that:

1. The double-effect solar still was more effective than the single one, since it uses the available energy more than once.
2. The efficiency of the still paired with a heat exchanger was directly proportional to the heat exchanger length and the working fluid mass flow rate.
3. The productivity of the double basin solar still was strongly a function of water depth in the lower basin.
4. It was recommended to disconnect the solar collector from the still during off-sunshine hours to reduce heat losses and obtain a high daily yield.
5. The daily production of the vertical solar still was in inverse proportion to the gap spacing between the absorber and the glass cover.
6. Metallic or porous fins improved the still productivity by about 15–45%.
7. The productivity of the stepped solar still was strongly a function of tray depth and width.

Elango et al. [158] presented a comprehensive review of the different thermal models produced for various kinds of passive and active solar stills in addition to the modifications efforts conducted to enhance the stills' performance. They concluded that further research was required on solar/hybrid systems, especially waste heat recovery from other water and power cogeneration resources. Kumar et al. [159] reviewed various types of single and multi-effect passive and active solar stills in detail with more description of the design specifications. They highlighted the advantages and disadvantages of different types of solar stills. They presented the following conclusions:

1. Using reflectors on winter days increased productivity by about (70–100%).
2. Productivity of a still with a tilted flat glass cover was higher than with semi-sphere, bilayer semi-sphere, and arch covers.
3. For single effect passive basin stills, productivity increased from 34% to 42% by using cover cooling.
4. Use of a solar operated fan was a cost-effective way to enhance the evaporation rate.
5. Still productivity was increased by about 93% and 43.80% when integrated with a heat pipe collector and a shallow solar pond, respectively.

Manchanda and Kumar [160] introduced inclusive review and analyses of different models and performance factors of the passive solar still. They mentioned some parameters that need to be improved to enhance the efficiency of this technique; these parameters include bulkiness, high initial cost, thermophysical characteristics of the basin material, flow rate, and insulation material and its thickness. They determined that the angled solar still with wick and weir, reduced water depth, still orientation, condensing cover cooling, and energy storage materials substantially improved distillate production. Furthermore, they determined that an exterior reflector should be slightly shifted forward in the winter and somewhat backward in the summer for optimal usage of solar rays. Its length should be equal to the still length. Rufuss et al. [161] presented a comprehensive review of the different types of solar stills, including passive and active designs, single-and multi-effect types, and the different existing and emerging modifications for improving productivity, including reflectors, heat storage, fins, collectors, condensers, and mechanisms for enhancing heat and mass transfer. Photovoltaic-thermal and greenhouse-type solar stills were also discussed. They also investigated the vibratory harmonic effect and the economic analysis of solar stills. Based on their review and discussions, the following conclusions were given:

1. Both the efficiency and productivity of the still depended on different operating and design parameters such as climatic conditions and the water depth.
2. Using asphalt in the single-slop basin liner still increased productivity by about 29%, while wicks and stepped evaporators resulted in productivity increases of 20–53%.
3. The fin solar still productivity increased with fin height while it decreased with fin thickness. Also, it was noted that using too many fins decreased the still output.
4. The best location for the heat storage material was below the basin, while the best materials were paraffin and acetamide.
5. Still productivity was increased by about 70% if coupled with an air heater. While it was increased by 80% if it was coupled with a solar pond.
6. Adding a separate condenser increased the condensation rate inside the solar still and increased its freshwater productivity.
7. It was recommended to integrate the solar still with a cooling tower. This decreased the condensate temperature by increasing the temperature difference between the glass cover and the water, increasing the distillate output.

Yadav and Kumar [19] reviewed the recent advances, various designs, performance, and relevant parameters for stepped and weir type solar stills. They mentioned that these stills were designed to increase the surface area within the same volume of still. Thermo-economic analysis of different solar stills was also discussed. They listed the following conclusions:

1. The distance between the glass cover and the water surface should be minimal and have a constant value. The cover thickness was also considered a minimum.
2. The productivity of the stepped still was improved by about 380% if an internal reflecting mirror was used on its insulated wall.
3. Stepped and weir-type solar stills had high productivity compared to the conventional still.

4. The weir-type still productivity was higher than the stepped type. Since the surface area and stay time of water on its absorber plate was larger than the stepped still with similar dimensions.

Sharma and Modi [162] described the various techniques used for enhancing the spherical solar still productivity. They introduced the following conclusions:

1. The spherical solar still productivity was improved by using the reflector since the energy incident was increased for the same basin size. Also, it was improved by cooling the condenser part of it.
2. Preheating the inlet water and using a vacuum increased the still productivity.
3. Using a suitable glass cover thickness and wick material in the basin enhanced the still productivity.
4. A tracking system was not required in the spherical solar still, but if the reflector was used, efficiency was improved by using the tracking system.

Panchal [163] presented a comprehensive review of using various thermal energy storage materials for improving solar still performance. They highlighted the following essential points:

1. Thermal energy storage materials can store energy during the sunshine period and release it during the off-sunshine period, which increases the distillate output.
2. The dust accumulated on the glass cover resulted in reduced distillate output of a solar still integrated with thermal energy storage materials.
3. Sponge cubes were an efficient thermal energy storage material due to their porous property to store the energy during the sunshine period and its capillary action for the effective area increment.
4. Light black cotton cloth was the most effective wick material in the basin.
5. Charcoal particles were good heat storage materials and increased the distillate output by 15%.
6. Black dye with rocks enhanced distilled water production by 65%.
7. When black rubber matt, black ink, and black dye were used, the productivity was enhanced by about 38%, 45%, and 60%, respectively.
8. The distillate output was increased by 28%, 43%, and 60% when coated wiry metallic sponges, uncoated metallic wiry sponges, and volcanic rocks were used.
9. Annual yield of solar still was increased when the glass cover inclination angle was equal to the place latitude.

Abujazar et al. [164] reviewed the various parameters influencing solar still productivity. These parameters include environmental (e.g., solar intensity, ambient temperature, relative humidity, wind speed, and dust cover), design (evaporation area, water depth, cover condensing angle, thermal storage materials, additives, solar tracking, reflectors, and insulation) and operational parameters (dust accumulation, still maintenance, water feeding, and the solar still position). Their results showed that environmental parameters significantly influenced productivity due to the unpredictability of meteorological factors. But, when design and operational parameters were varied, an increase in productivity was observed. Also, the mathematical model and the cost analysis of the solar still were well described. Based on their detailed review, the following points were summarized:

1. The stepped solar still has higher productivity than the conventional one.
2. The insulation material helped in reducing heat losses from the basin bottom and sidewalls.
3. At nighttime, the distillate output increased with increasing water depth.
4. Insulation of condensing cover is recommended to prevent excessive thermal radiation from escaping from the basin liner to the external environment.
5. Solar still was influenced by the evaporation area, water depth, and the solar still cover angle.

6. The main parameters of desalination units' cost analysis included the capital recovery factor, fixed annual cost, sinking fund factor, annual salvage value, average annual productivity, annual cost, annual maintenance operational cost, and cost per liter.
7. In southern regions of the earth, a solar still should be oriented such that its input end faces the south direction. While, in northern regions, it should be oriented towards the north.

Sharshir et al. [165] reviewed the factors influencing solar still production (climatic, operational, and design parameters) together with enhancement techniques up to the end of 2014 (such as wicks, vacuum technique by using internal and external condensers, internal and external reflectors, stepped solar still, phase change materials and nanoparticles). Based on their review, they came to the following conclusions:

1. Still productivity is in direct proportion to the glass–water temperature difference. This technique was used in the regenerative still, still with double glasses and triple-basin still.
2. Still productivity is in direct proportion to the free surface area of the water in the basin. This was achieved by putting sponge cubes in the basin or using baffle-suspended absorber plates.
3. Increasing the temperature difference between the glass cover and the brine increased the still productivity.
4. Using glass of low thickness and relatively high thermal conductivity enhanced heat transfer through the glass cover.
5. The distillate production was increased by 100% if the vacuum technique was utilized. While it was increased by about 114% if wicks were used in the still basin.
6. Water and air solar collectors have increased daily productivity by 175%. While the still efficiency was improved by about 50% if a vibratory harmonic effect was used.

Kabeel et al. [166] introduced a comprehensive review of studies and developments of different solar stills integrated with different external, internal, or built-in condensers. They mentioned that the condenser was used to enhance the distillate yield by increasing the water–glass temperature difference. They introduced the following conclusions:

1. The condensation rate of the single-slope solar still was enhanced by positioning the condenser on the shaded side of the still.
2. The condensation process in the solar still was enhanced by increasing the cooling on the wall surface.
3. The power fan was necessary in order to exhaust both the water vapor and the non-condensable gases from the still to the condenser.
4. For large and economic water productivity, it was recommended to use the double condensing chamber solar still.
5. Distillate water yield was improved by 53.2% when the still was paired with an external condenser.
6. The still efficiency was increased by about 47% when an external condenser was used.

Kabeel et al. [167] examined different adjustments made to solar stills to increase distillate water production. It was found that PCM, thermal energy storage materials, and glass-cover cooling increased the stills distillate output. The percentage enhancement in the productivity of these types was summarized in clear tables. Omara et al. [168] presented a survey about numerous sorts of solar stills coupled with an external or internal reflector. They mentioned that reflectors were a good and cheap modification for increasing the solar radiation directed to the basin liner or to its water and resulted in enhanced daily amount of distillate. They concluded the following points:

1. It was recommended to install reflectors in cold places where the solar radiation was weak.
2. To improve productivity throughout the whole year, the external reflector installation angle must be adjusted each season.

3. For stills with a large glass cover angle, the influence of the external top reflector was negligible.

Panchal and Patel [169] reviewed the different design and climatic parameters used to increase the distillate output of the solar still. The design parameters included the brine depth, condensing cover material, thickness, and inclination. The climatic parameters covered wind velocity, ambient temperature, and solar radiation. It was reported that the still productivity was directly proportional to the total solar radiation, ambient temperature and wind velocity. The following key points were presented:

1. South-facing stills were recommended for northern latitudes, while north-facing ones were provided for southern latitudes.
2. Reduction of glass cover temperature by using a continuous film or an intermittent flow of the cooling water flowing over it.
3. The still productivity was decreased with increasing water depth during the daytime, while the reverse occurred in the overnight production.
4. Lower thickness of the condensing glass cover provided increased productivity.
5. Large cover tilt angles were preferred in the winter, while smaller ones were better in the summer.
6. Because of its higher absorptivity than black paint, the use of asphalt basin liners increased distillate output.

Manokar et al. [170] presented a mini-review on solar stills integrated with a PV/T solar collector. They noted that, at high ambient temperature, the daily energy efficiency of a PV/T solar still was decreased. Furthermore, they inferred that PV cells could be placed at sidewalls of the solar still to improve the efficiency of PV cells and reduce the fixed cost of the solar panel. Very recently, Sathyamurthy et al. [171] performed a detailed review of solar stills integrated into various kinds of solar collectors in order to improve their productivity. The yield, economic aspects, and payback period of different types of solar still were also reviewed. It was found that the efficiency of the solar still with collector depended on the water flow rate inside the tube surface of the collector, minimum heat loss with the outside atmosphere, type of tube and absorber material, and convective heat transfer coefficient between water-tube-basin water. Furthermore, they noted that the use of concentrating collectors enhanced still efficiency by 137% with PCM balls and with the cover cooling technique. They also suggested manufacturing solar collectors from plastic materials to decrease their initial costs.

Table 1 summarizes the studies used to review investigations of solar stills.

Table 1. Summary of review investigations about the solar stills.

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
Fath [141]	21	1998	1. Single and double slope basin. 2. Multiple-effect diffusion. 3. Weir cascade. 4. Double basin. 5. Solar still with a condenser. 6. Hybrid. 7. Wick 8. Single and multi-effect.	Solar still productivity was improved by utilizing shaded areas, minimizing heat losses, re-utilizing latent heat of condensation, and cover cooling.
Murugavel et al. [22]	40	2008	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Solar still with a condenser. 4. Wick and tilted wick. 5. Regenerative. 6. Shallow basin.	1. Rubber was the best basin material for enhancing absorption, storage, and evaporation effects. 2. Lowering cover temperature increased productivity. 3. Black dye was the best absorbing material to increase still productivity.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
Arjunan et al. [142]	59	2009	1. Single slope basin. 2. Double slope basin. 3. Multi-basin. 4. Double condenser chamber. 5. Hybrid. 6. Wick and multi-wick. 7. Tubular. 8. Tubular multi-wick. 9. FRP single slope. 10. Inverted absorber solar. 11. Spherical. 12. Solar still integrated with greenhouse.	1. Single-slope-basin solar still received more radiation than a double one at low and high-altitude stations. 2. Floating absorber sheet improved still productivity. 3. Among stills evaluated, the multi-wick solar still was the most cost-effective and efficient. 4. Still performance was increased by different active methods such as flat-plate collector, heat exchanger, solar pond, and solar heater. 5. Still efficiency was enhanced by dry air bubbling and glass cover cooling.
Sampathkumar et al. [143]	93	2010	1. Double slope active solar still. 2. Single, double, and multi-effect active solar still. 3. Double basin active solar still. 4. Regenerative active solar still.5. Hybrid. 6. Multiple effect diffusion. 7. Tubular. 8. Stepped. 9. Fin-type single basin. 10. Multistage active solar still. 11. Air-bubbled. 12. Pre-heated water active solar still. 13. Nocturnal, active solar still.	1. Natural circulation model was recommended in active solar still to avoid electricity consumption by the pump in forced circulation mode. 2. Higher productivity of active solar stills during the nighttime was achieved by using energy-storing materials. 3. Solar still fed with hot water at a constant rate gave a higher yield than a still with hot water filled only once a day. 4. Copper was a very good material from which to manufacture the still cover.5. Composite materials were recommended as basin liners.
Kaushal [38]	48	2010	1. Single slope basin. 2. Roof solar still. 3. Tilted wick. 4. Water film. 5. Multi-effect diffusion. 6. Solar still made up of tubes for seawater desalting.	1. Maximum efficiency of solar still was 50%. 2. Continuous cleaning of glass cover was necessary. 3. Productivity of still with a reflector was increased by 14%. 4. Solar still was selected according to local and operating conditions.
Velmurugan and Srithar [144]	52	2011	1. Solar still with sponge cubes. 2. Regenerative. 3. Triple-basin. 4. Fin type. 5. Hybrid. 6. Wick and multi-wick type 7. Stepped. 8. Concave wick surface. 9. Solar still with an external or internal condenser.	Reflectors, condenser, combined stills, asphalt basin liner, cooling film, and sun-tracking systems were used to maximize the yield of the solar still.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
Kabeel and El-Agouz [145]	87	2011	1. Single slope basin. 2. Double-basin. 3. Multi-basin. 4. Rotating shaft. 5. Hybrid. 6. Wick and multi-wick type 7. Stepped. 8. Solar still with a packed layer. 9. Weir-type. 10. Fin type. 11. Solar still with sponge cubes. 12. Solar still with a condenser. 13. Multi-effect diffusion. 14. Basin solar still with reflectors.	1. The still performance was significantly influenced by basin water depth. 2. Rubber was the best basin for improving absorption, storage, and evaporation effects. 3. A flowing film of cooling water over the glass reduced the glass's glass cover temperature. 4. Condenser, sun tracking system, reflectors, a greenhouse, hot water tank, sponge cubes, solar collector, solar pond, and phase change material were used to improve the still performance.
Xiao et al. [146]	73	2013	1. Conventional basin. 2. Basin solar still with internal and external reflectors. 3. Wick. 4. Solar still with an external condenser. 5. Weir-type. 6. Weir-type cascade. 7. Hybrid. 8. Fin type. 9. Multiple-effect diffusion.	Performance of solar still was improved by: 1. Installing reflectors. 2. Coupling with solar collectors. 3. Condensation improvement. 4. Using a bigger free surface area. 5. Vapor latent heat recovery. 6. Coupling with heat storage systems.
Sivakumar and Sundaram [147]	83	2013	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Basin solar still with internal and external reflectors. 4. Tilted and multi-wick. 5. Stepped. 6. Hybrid. 7. Regenerative solar still. 8. Pyramidal. 9. Single or double effect. 10. Tubular. 11. Inverted absorber. 12. Hemispherical. 13. Weir-type cascade. 14. Vertical.	1. The still yield was significantly improved by using energy storage materials. 2. PCM increased still efficiency on summer days by 84.3%. 3. The usage of the sun tracking system resulted in increasing still productivity by 22%. 4. Still productivity was increased by 77% when coupled with a solar heater.
Murugavel et al. [148]	42	2013	1. Single and double slope basin. 2. Hybrid. 3. Solar still with a condenser. 4. Double or triple basin. 5. Wick and multi-wick. 6. Wick-basin. 7. Stepped solar still. 8. Inverted tickle. 9. Weir 10. Weir cascade. 11. Basin solar still with internal and external reflectors.	1. Still efficiency was increased by tilting the basin, referred to as sun angle. 2. Still productivity was improved by reducing feed water salinity. 3. The active solar yield was 51% higher than the passive.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
Manikandan et al. [149]	24	2013	Wick type solar still	1. Productivity increased by placing a reflector or a flat mirror over the still. 2. The bottom reflector directs sunlight to the evaporating wick, increasing distillate output by 25% and 10% in the summer and winter, respectively. 3. Charcoal absorber increased the evaporation rate. 4. Floating wick solar still provided maximum yield compared with other types.
Rajaseenivasan et al. [150]	75	2013	1. Single and double slope basin. 2. Double or multi-basin. 3. Basin-multiple-effect diffusion coupled. 4. Single and multiple-effect diffusion. 5. Pyramidal. 6. Hybrid. 7. Regenerative solar still. 8. Wick and tilted wick. 9. Multistage evacuated. 10. Solar still with a condenser. 11. Triple and quadruple -basin. 12. Inverted absorber.	1. The usage of film-cooling increased the efficiency to 20%. 2. High distillate output was obtained when forced circulation mode was utilized. 3. Employing parabolic collectors resulted in a higher yield than flat plate collectors.
Muftah et al. [151]	135	2014	1. Single and double slope basins. 2. Inverted absorber. 3. Basin solar still with reflectors. 4. Inverted tickle. 5. Stepped solar still. 6. Hybrid solar still. 7. Solar still with a condenser. 8. Triangular and pyramidal. 9. Double and multi-effect. 10. Weir cascade. 11. Wick and tilted wick 12. Solar still with a condenser. 13. Double basin.	1. When ambient air temperature increased by 10 °C, distillate output was enhanced by 8.2%. 2. If the still was integrated with a sun tracking system, its output improved by 50%. 3. Surfactant additives enhanced still productivity.
Manokar et al. [152]	73	2014	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Inverted absorber. 4. Solar still with a condenser. 5. Stepped. 6. Hybrid. 7. Regenerative. 8. Finned. 9. Hemispherical. 10. Wick.	1. Adding dye to the basin enhanced the water absorption coefficient. 2. Basin absorption rate improved by using charcoal, matt, sponge, jute, and cotton clothes. 3. Black rocks gave the highest productivity at night time. 4. Productivity increased by feeding waste hot water into the basin during the night.
Yadav and Sudhakar [153]	53	2015	1. Single basin single and double slope. 2. Hybrid 3. Hemispherical. 4. Triangular and pyramidal type. 5. Miscellaneous.	1. Productivity of hybrid still was enhanced by 215% when hot brackish water was fed during night time. 2. Productivity and efficiency of domestic stills were greatly improved by adding a heat reservoir under the basin liner. 3. The maximum thermal efficiency of solar still ranged between 17.4 and 45%.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
Prakash and Velmurugan [154]	70	2015	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Basin solar still with reflectors. 4. Wick-basin 5. Stepped. 6. Hybrid. 7. Regenerative. 8. Triangular and pyramidal. 9. Double and multi-effect. 10. Tubular. 11. Wick and tilted wick 12. Hemispherical. 13. Weir-type solar still. 14. Weir cascade. 15. Rotating shaft solar still. 16. Vertical. 17. Finned. 18. Double or multi-basin. 19. Corrugated solar still. 20. V-type 21. Solar still with a condenser. 22. Humidifier-dehumidifier. 23. Thermoelectric.	1. Minimum basin water depth increased the still productivity. 2. Additional basin increased the still cost but highly increased its distillate. 3. Use of dye, wick, porous or energy-storing material in the basin increased the productivity. 4. Increasing the insulation material thickness increased the still productivity up to 80%. 5. The use of finned or corrugated plates in the basin increased the still productivity.
Durkaieswaran and Murugavel [155]	21	2015	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Inverted absorber. 4. Concave wick. 5. Spherical. 6. Tubular multi-wick 7. Finned. 8. Pyramidal. 9. V-type. 10. Tubular. 11. Wick 12. Hemispherical.	1. The use of internal mirrors improved the thermal performance of single-slope basin solar still by 30%. 2. Quartzite rock with a size of 3/4 inch was the effective basin material of double slope basin solar still. 3. Distillate production of pyramidal solar still was improved by about 25% if forced convection was used compared with free convection.
Kabeel et al. [156]	32	2015	1. Stepped. 2. Weir-type cascade.	1. Stepped solar still had a high heat and mass transfer surface area. 2. Stepped solar still was efficient in recovering freshwater from wastewater. 3. The productivity of the stepped still was enhanced by 112% when incorporated with a solar air heater and glass cover cooling.
El-Sebaii and El-Bialy [157]	108	2015	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Inverted absorber. 4. Basin-multiple-effect diffusion coupled. 5. Stepped. 6. Hybrid. 7. Multi-stage evacuated. 8. Multiple-effect diffusion solar still. 9. Double and multi-effect solar still. 10. Tubular. 11. Wick and tilted wick 12. Inverted absorber multi-effect solar still.	1. Productivity increased significantly by using an additional basin. 2. Daily yield increased with increasing solar collector area. 3. Optimum area of vertical solar still absorber was 3.5 m^2. 4. Stepped solar still with internal reflectors and triple-basin solar still gave the lowest distillate production cost.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
			13. Vapor adsorption type. 14. Weir cascade. 15. Solar still with a condenser. 16. Vertical. 17. Finned. 18. Double or multi-basin. 19. Corrugated.	
Planet et al. [158]	86	2015	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Basin solar still with reflectors. 4. Vapor adsorption 5. Stepped. 6. Hybrid. 7. Regenerative. 8. Triangular and pyramidal. 9. Double and multi-effect solar still. 10. Tubular. 11. Wick and tilted wick 12. Multi-stage evacuated. 13. Weir-type. 14. Weir cascade. 15. Rotating shaft solar still. 16. Inverted absorber 17. Finned. 18. Double or multi-basin. 19. Inverted tickle 20. Solar still with a condenser.	Thermal models had the great advantage of predicting solar still performance at a reasonable cost.
Kumar et al. [159]	104	2015	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Basin solar still with reflectors. 4. Multiple-effect diffusion solar still 5. Spherical. 6. Hybrid. 7. Regenerative. 8. Triangular and pyramidal. 9. Double and multi-effect. 10. Tubular. 11. Wick and tilted wick 12. Hemispherical. 13. Weir-type. 14. Weir cascade. 15. Rotating shaft. 16. Inverted absorber solar still 17. Finned. 18. Double or multi-basin. 19. Corrugated 20. Basin-multiple-effect diffusion coupled solar still 21. Solar still with a condenser. 22. Multistage evacuated. 23. Air-bubbled.	1. Productivity was increased by 15% by employing a tilted external flat-plate reflector Compared with a vertical one. 2. The productivity of still with forced circulation was higher than still with thermosiphon effect.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
Manchanda and Kumar [160]	108	2015	1. Single and double slope basin. 2. Inverted absorber. 3. Basin solar still with reflectors. 4. V-type. 5. Stepped. 6. Double basin. 7. Finned. 8. Triangular and pyramidal. 9. Double effect solar still. 10. Tubular. 11. Wick and tilted wick. 12. Hemispherical. 13. Weir cascade.	1. Hollow rotating cylinder/drum inside solar still improved the productivity.2. Lower water depth (0.04 m) was the optimum operational parameter. 3. The price of distilled water was 2.8 times cheaper for passive stills than for hybrid PV/T active stills.
Rufuss et al. [161]	210	2016	1. Double or multiple-effect. 2. Double or triple basin. 3. Single-slope basin. 4. Single-basin double-slope. 5. Multiple slope. 6. Tubular. 7. Vertical. 8. Solar still with internal and external reflectors. 9. Stepped. 10. Wick type. 11. Weir-type cascade. 12. Finned. 13. Corrugated. 14. Hemispherical. 15. Triangular. 16. Hybrid. 17. Solar still with an external or internal condenser. 18. Regenerative. 19. Rotating shaft.	1. Latent heat was stored by using phase change materials. 2. The still shape had a great impact on the still performance. 3. Hybrid solar still productivity was 3.5 times more than that of the passive one. 4. The regenerative solar productivity was still 70% higher than the conventional still. 5. The addition of a wick increased the incident radiation inside the still.
Yadav and Kumar [19]	43	2016	1. Stepped solar still. 2. Weir-type solar still.	1. Distillate output of stepped and weir stills were 60–80% higher than conventional still. 2. Maximum productivity still occurs when the inclination angle of glass equals to latitude angle of its location. 3. Productivity of weir-type still was higher than stepped type.
Sharma and Modi [162]	13	2016	Spherical solar still.	1. Parabolic reflector was the best option for spherical solar still. 2. Jute is the best absorber of water in India. 3. Preheating inlet water and using a vacuum increased productivity.
Panchal [163]	56	2016	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Regenerative. 4. Wick. 5. Finned.	1. Blacknapthylamine dye increased distillate output by 29%. 2. Aluminum plate inside the solar still increased its productivity by 30%. 3. Productivity was increased in the range from 18–273% if sponge cubes were used. 4. Bricks gave less productivity during the morning time and high productivity during the evening.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
Abujazar et al. [164]	113	2016	1. Single slope basin. 2. Solar still with sponge cubes. 3. Basin solar still with reflectors. 4. Solar still with a condenser. 5. Stepped. 6. Hybrid. 7. Shallow basin. 8. Pyramidal. 9. Multi-effect. 10. Finned. 11. Wick and tilted wick 12. Hemispherical. 13. Weir-type. 14. Double basin.	1. Productivity was increased with an increase in relative humidity and evaporation area. 2. Copper and aluminum were recommended to manufacture the bottom frame of solar still. 3. It was recommended to use a condensing cover angle of 30° or 45° for optimum output. 4. Non-toxic, diluted acid solutions, such as citric acid or oxalic acid, were suggested to clean solar still. 5. Feed and freshwater qualities, unit size, and site location influenced capital and operating costs.
Sharshir et al. [165]	92	2016	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Basin solar still with reflectors. 4. Shallow. 5. Stepped. 6. Hybrid. 7. Regenerative. 8. Pyramidal. 9. Double effect. 10. Tubular. 11. Wick and tilted wick. 12. Multiple-effet diffusion. 13. Active vibratory. 14. Weir cascade. 15. Thermoelectric. 16. Solar still with a condenser. 17. Finned. 18. Multi-basin. 19. Corrugated.	1. Wick and stepped stills were used to solve the problem of minimum water depth. 2. Solar collectors and mini solar ponds efficiently increased the inlet water temperature. 3. Yield increased by increasing environmental air temperature, wind speed and solar intensity. 4. The addition of sand (10 kg) enhanced daily efficiency by 37.8%. 5. Productivity increased up to 273% if sponge cubes were used.
Kabeel et al. [166]	46	2016	Different solar stills are integrated with an external, internal or built-in condenser.	1. The usage of the condenser resulted in increasing the still yield by 70%. 2. Condenser increased productivity by increasing the condensation area. 3. Still productivity improved if coupled with a condenser and a solar chimney.
Kabeel et al. [167]	108	2017	1. Single and double slope basin. 2. Solar still with sponge cubes. 3. Inverted absorber. 4. Wick-basin 5. Stepped. 6. Hybrid. 7. Regenerative. 8. Triangular and pyramidal. 9. Vapor adsorption. 10. Tubular. 11. Wick. 12. Hemispherical 13. Semi-circular trough. 14. Solar still with a condenser. 15. V-type.	Distillate output was augmented by using additives to enhance solar absorption and increase mass flow rate over glass cover.

Table 1. *Cont.*

Reference	Number of Reviewed Papers	Year	Solar Still Types	Results and Remarks
			16. Corrugated. 17. Finned. 18. Double or multi-basin.	
Omara et al. [168]	51	2017	Different solar stills are integrated with an external or internal reflector.	Daily productivity increased by adjusting the still and reflector mirror inclination in any season.
Panchal and Patel [169]	44	2017	1. Single and double slope basin. 2. Double or multi-basin. 3. Hybrid.	1. Glass cover orientation depended on place latitude. 2. Still productivity was increased by decreasing cover temperature and increasing initial water temperature. 3. Still productivity was decreased at high wind velocity.
Manokar et al. [170]	28	2017	PV/T solar stills.	1. The high temperature of the panel had a detrimental impact on power generation. 2. The availability of solar radiation determined the productivity of solar stills and the electrical energy provided by PV panels.
Sathyamurthy et al. [171]	68	2017	Hybrid solar stills.	1. Freshwater yield increased by about 36% if stills integrated with solar collectors. 2. Black rubber could be added to the basin to increase its absorption rate. 3. The basin's sensitive heat storage materials improved its saline water evaporation rate.

5. Conclusions

This paper presents a widespread overview of the latest improvements related to solar stills. The presented and discussed results provide a fruitful reference source for improving the solar still design and performance. Below is a summary of the most important conclusions:

1. Thermal models have great advantages and the potential to predict solar still performance at reasonable cost and time.
2. Feed and freshwater qualities, unit size, and site location influenced capital and operating costs.
3. The productivity of solar stills can be significantly improved by:
    - 3.1. Providing a shaded area.
    - 3.2. Minimizing the heat loss by re-utilizing latent heat of condensation, cover cooling, and increasing insulation thickness.
    - 3.3. Lowering glass cover temperature.
    - 3.4. Using inclined external flat-plate reflector, combined stills, condenser, sun tracking system, reflectors, greenhouse, hot water tank, solar collector, heat exchanger, and solar pond.
    - 3.5. Increasing the free surface area of the solar still, environmental air temperature, wind speed, and solar intensity.
    - 3.6. Reducing feed water salinity.
    - 3.7. Feeding a waste of hot water into the basin during nighttime.
    - 3.8. Forced convection.
    - 3.9. Using an additional basin.
    - 3.10. Dry air bubbling
    - 3.11. Use of finned or corrugated plates in the basin.

4. Improving the absorption in the basin by adding charcoal, matt, sponge, jute, and cotton clothes, dye, wick, porous or energy-storing material, black rubber, and floating absorber sheet.
5. Use of rubber, composite material, or asphalt as basin liner.
6. Minimizing water depth in the basin.
7. Manufacturing the bottom frame of the solar still from copper or aluminum.

6. Recommendations for Future Work

Solar stills can be modified by using the traditional nanofluid or hybrid nanofluid. This line of research can be considered for future works.

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Abbreviations

CPC	Compound Parabolic Concentration
FRP	Fiber Reinforced Plastic
GI	Galvanized Iron
PC	Parabolic Concentration
PCM	Phase Change Material
PV/T	Photovoltaic-Thermal

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