Applied Water Science (2024) 14:147
https://doi.org/10.1007/s13201-024-02188-1

REVIEW ARTICLE

Recent advances in solar still technology for solar water desalination

Maha A. Tony[1] · **Hossam A. Nabwey**[2,3]

Received: 17 August 2022 / Accepted: 22 April 2024 / Published online: 5 June 2024

Abstract

Water is signified as the gift of nature. However, modern societies are in tremendous need of fresh water due to the abundant industrial sector and factory growth that is leading to more and more such natural resource pollution. Also, there are global arid and desert areas where there are fewer regular rainfalls besides groundwater scarcity. Additionally, although there are abundant water bodies, most of them are not suitable for domestic irrigation, and especially for drinking purposes since they are brackish or saline water. Thus, water desalination is essential with no impact on the environment. Solar desalination is proven to be a sustainable and reasonable way for producing potable water. Numerous sorts of solar stills are introduced, and the most exhibited one is the conventional type of solar still, that is, so-called basin solar still. However, the low productivity of such solar still is signified as its major concern. Researchers have made their efforts to improve the productivity of solar stills through various designs and operating parameters. This detailed review is mainly focused on the various types of solar stills, their analyses and the status of several solar distillers. Throughout the entire work, it is confirmed and recommended to enhance the performance through advanced modifications that are also discussed. Such modifications are including advanced designs such as pyramid triangular solar stills, tubular, double basins and hemispherical and spherical solar stills. Also, integrated systems stills are recommended, such as connected solar stills with photo voltaic cells (PVC) or solar collectors to increase productivity.

Keywords Solar-thermal · Desalination · Solar stills · Review · Saline water · Modifications

List of symbols

ξ	Overall still efficiency
Q	Daily output from solar still (L/day)
A	The aperture area of the solar still (m^2)
G	The global solar irradiation (MJ/m^2)

Abbreviations

PVC	Photovoltaic cell
PCM	Phase change material
MED	Multiple effect distillation
MSF	Multi-stage flash desalination
TVC	Thermal vapor compression
MVC	Mechanical vapor compression
RO	Reverse osmosis
ED	Electro-dialysis
TDS	Total dissolved solids
ETC	Evacuated tube collector
FPC	Flat plate collector
PTC	Parabolic trough concentrator
PVT	Photovoltaic-thermal solar still
SC	Desalination chimney
SSD	Solar still desalination
HDH	Humidification–dehumidification

✉ Maha A. Tony
dr.maha.tony@gmail.com

[1] Advanced Materials/Solar Energy and Environmental Sustainability (AMSEES) Laboratory, Basic Engineering Science Department, Faculty of Engineering, Menoufia University, Shebin El-Kom, Egypt

[2] Department of Mathematics, College of Science and Humanities in Al-Kharj, Prince Sattam Bin Abdulaziz University, 11942 Al-Kharj, Saudi Arabia

[3] Basic Engineering Science Department, Faculty of Engineering, Menoufia University, Shebin El-Kom, Egypt

Introduction

Freshwater scarcity is a global ban in current society. Modern societies are signified with population explosion and industrial expansion; the result is tandem water consumption (Tony 2020a, b, c; Thabet et al. 2020). Hence, some countries are facing a shortage of fresh water, which is categorized as the core of human beings' daily life as well as the heart of the industrial sector. However, on the other side, the watercourse is more often than not, polluted through industrial effluents and human discharges into the environment (Thabet et al. 2021; Tahnoon et al., 2022; Tony et al. 2015). Thus, the result is a huge amount of polluted wastewater by chemicals and hazardous substances, which must be treated prior to final disposal. Furthermore, in arid zones, i.e., deserts and industrial areas, potable water feeding is signified as a complicated issue since wherewithal is costly. Brackish water represents 99% of available water on the planet, whereas only 1% is accessible as freshwater (Tony 2021a, b, c, d; Ashour et al., 2017; Damir et al., 2008).

On the contrary, there is an abundance of seawater that requires salinity removal, which requires additional energy costs. Places that are endowed with ample solar radiation and brackish water could be used as a supply in reasonable amounts of potable water at economical expenses (Aclan et al., 2022; Masnsour et al., 2019). Solar still is a promising desalination technology since it is cheap, easy to construct and a manageable tool to supply potable water to rural communities (Suresh and Shanmugan 2019; Tony 2020a). Solar stills use a cheap energy source, the sun, to offer a viable solution for water desalination that could be used for either irrigation or even drinking purposes. Water evaporation needs about 2.3 MJ/kg energy, which is considered more energetic than reverse osmosis; however, it only requires energy in the forms of heat rather than in terms of electrical power (Kabeel 2009; Tayeb et al. 2018). The simple solar still working principle is similar in all solar still distillation types, which depends on the solar radiation incidence on a transmittance glass cover. The radiation is then absorbed by the black inner surface in the solar basin specifically the bottom. Hence, the water in the basin becomes hot and therefore it evaporates (Alatawi et al. 2022; Zhao et al. 2009). Subsequently, condensation occurs on the inner side of the surface of the glass cover that covers the basin. Afterward, droplets of distilled water are collected on a specific tray along the slope of the glass cover. Solar still overall efficiency (ξ) could be found as a ratio of the amount of utilized solar radiation used in evaporation to the whole amount of incident solar radiation on the solar still. Thus, the approximate daily output in liters per day (L/day) from solar still can be expressed as (Q), which could be signified as the following:

$$Q = \frac{\xi GA}{2.3} \tag{1}$$

where A is the aperture area of the solar still (m^2) and G is the global solar irradiation (MJ/m^2). However, it is noteworthy to mention that although the solar still device is a reliable tool for water desalination, it possesses the drawback of low productivity. Thus, scientists are focusing on improving its productivity and limiting its drawbacks. Therefore, researchers' interest is focusing on improving both system design and process parameters performance (Taha 2010; Ashour and Tony 2017). Although numerous review papers have focused on the developments on the solar still, there is still a gap in the research cited that the scholars discussed the enhancement of the solar still on the competent designs and recent performances. Thus, the present article deals with reviewing and discussing specific aspects of solar desalination and solar still design, i.e., the design development and configurations, operating principles and factors influencing performance, and recent research efforts to improve their efficiency and throughput. Moreover, their summarized recent technologies and future scope suggestions are also presented.

Bibliometric analysis

Currently, with modernized search schemes, a helpful tool has emerged for analyzing and classifying a definite topic, which is signified by the term “bibliometric analyses.”. "Bibliometric analyses” could be mapping key aspects of the most cited items related to solar still and their related terms of desalination application. Google Scholar search platform is used to attain the cumulative search in the field of “Solar still” AND “Desalination", and the results are displayed in Fig. 1. A profile of the current status of the studies in the field is exhibited. Overall, research papers were obtained and presented as annual cumulative publications, reviews, research articles and editorial material and letter numbers jointly with the “Solar still” AND “Desalination" application profiles. The number of the research cited articles, as recorded in Fig, 1 is an increase, which gives the opportunity for the research and development of the solar still to its maximal level to reach a satisfied reasonable, sustainable option for water desalination opportunity. A brief outline of the investigated research conducted are research articles and review articles that popularly represent this technology, as referred in the sub-plotting in Fig. 1.

Hence, to signify the state-of-the-art figure of the solar still, the literature survey analysis was conducted on the Web of Science platform. The search items were "Solar still AND Desalination”. Subsequently, the data revealed from the "Web of Science Core Collection" database and the VOS viewer software (version 1.6.16.0) were extracted through the period of 2000 to January 2022. The design purpose is to analyze the keywords of the research articles. The designed mapping incorporates a network. Then, the overlay and density visualization mapping are designed through VOS viewer software. Presently, the current search is based on the co-occurrence associated with authors' keywords and is designated to be the minimum occurrence number.

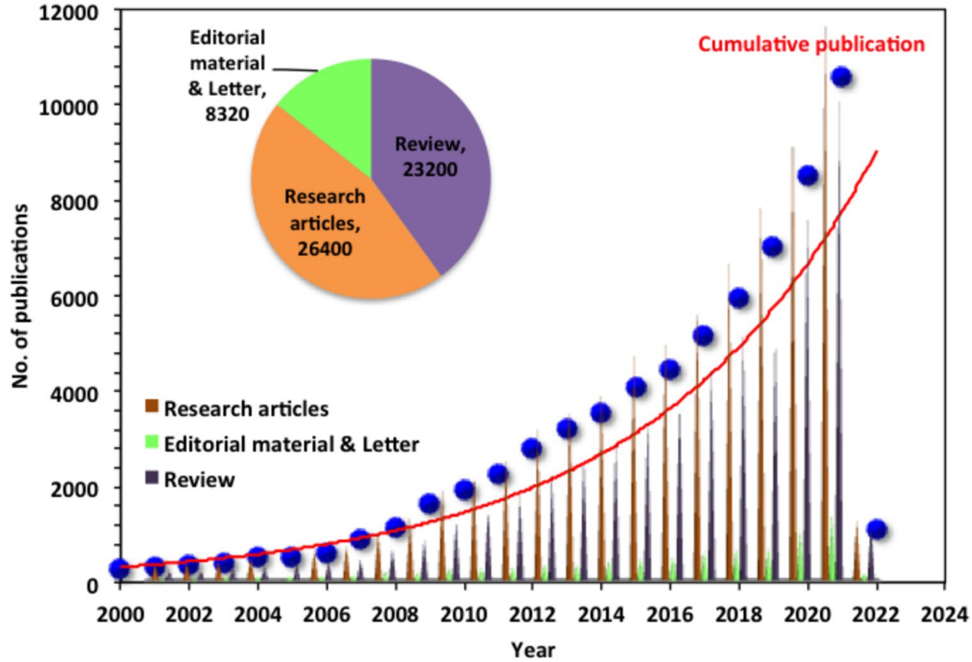

Fig. 1 Compared publications on the solar still publication related to desalination from 2000 to 2022. Source for "Solar still AND Desalination" cases data: www.googlescolar.com (Accessed on 15 January 2022)

Consequently, the parameters are adjusted in the software, and the mapping is designed. The most common feature of the VOS viewer is overlay visualizations, which are used to categorize density visualization over periods. Solar still research showed that obtained from the cited research articles, the bibliometric mapping of clusters could be identified as seen in Fig. 2. The hotspots clusters can demonstrate the intensive research studies based on the analyzed results attained via the data from "Web of Science" core

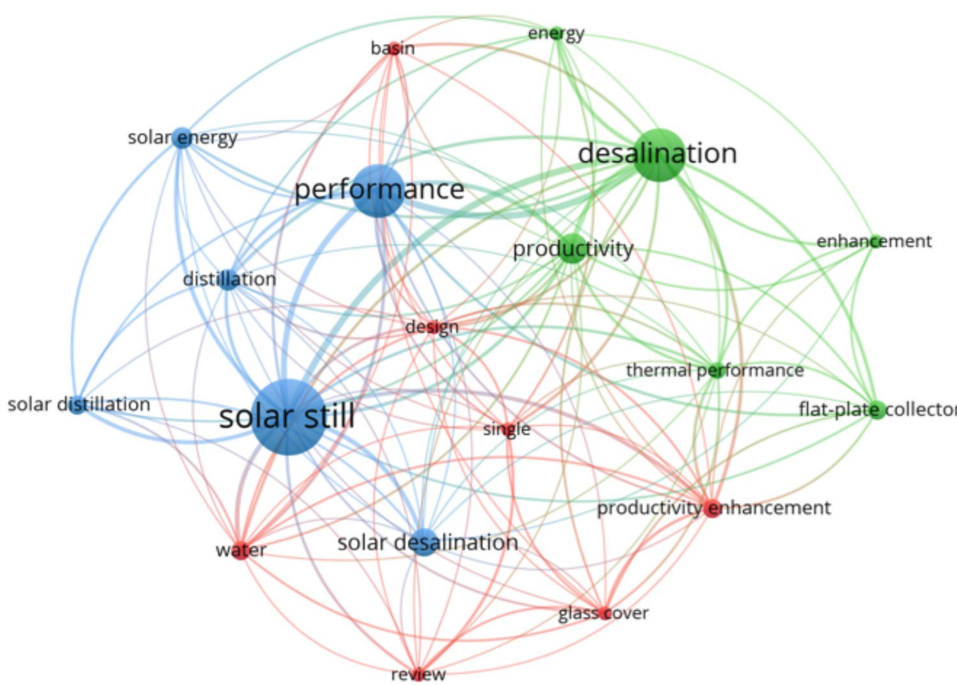

Fig. 2 Key terms occurrences network visualization map in solar still publication related to desalination technology

collection from the search terms “TI is (Solar Still AND Desalination)”.

Analysis of authors and research collaborations

To get a superior signification of the frontiers in the subject of solar still and desalination, a bibliometric analysis for the leading researchers and authors or team works for the most creative scientists in the field is conducted using VOS viewer. The most active and productive countries in conducting solar still studies based on desalination are Egypt, India and Saudi Arabia, as displayed in Fig. 4A. The size of the cluster and label is signified by the weight of the item. Hence, the superior the weight of the country, the greater the item's label and circle, as shown in Fig. 4A.

The information in Fig. 3B follows the research papers by the main authors. The mapping signifies the most strength authors are Kabeel, Omara, Kumar, El-agouz, Youneg, and their co-workers, who are mainly attentive to solar still for investigating such technology, i.e., desalination. It is notable to mention that there is a shortage in the cooperation of researchers from different organizations and countries that require prospective work. Additionally, still, there is a leak in the work done in the field.

Bibliometric analysis is a promising technique that could reveal the internal links of published documents (as displayed in Fig. 4A). It is found the most occupied articles are cited in Desalination journal, Solar Energy, Energy Conversion and Management, Applied Energy and Renewable and Sustainable Energy Review. It is noteworthy to mention that researchers appear to categorize published articles in high-quality journals. Furthermore,

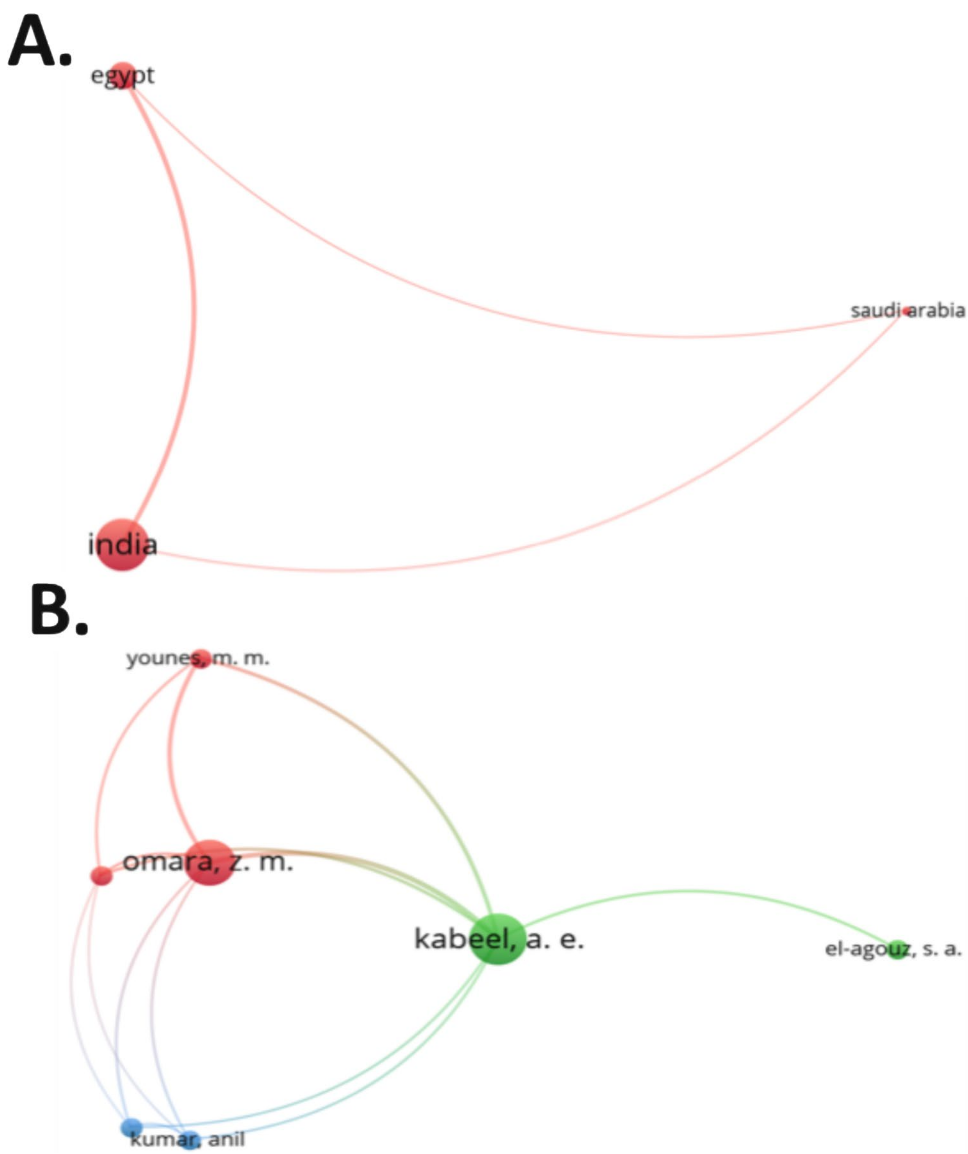

Fig. 3 Bibliometric network mapping generated via VOS viewer. **A**. Network map showing the collaborations between various countries in Fenton's reagent for treating Emerging Pollutants; **B**. Co-authorship overlap visualization map for solar still desalination technology

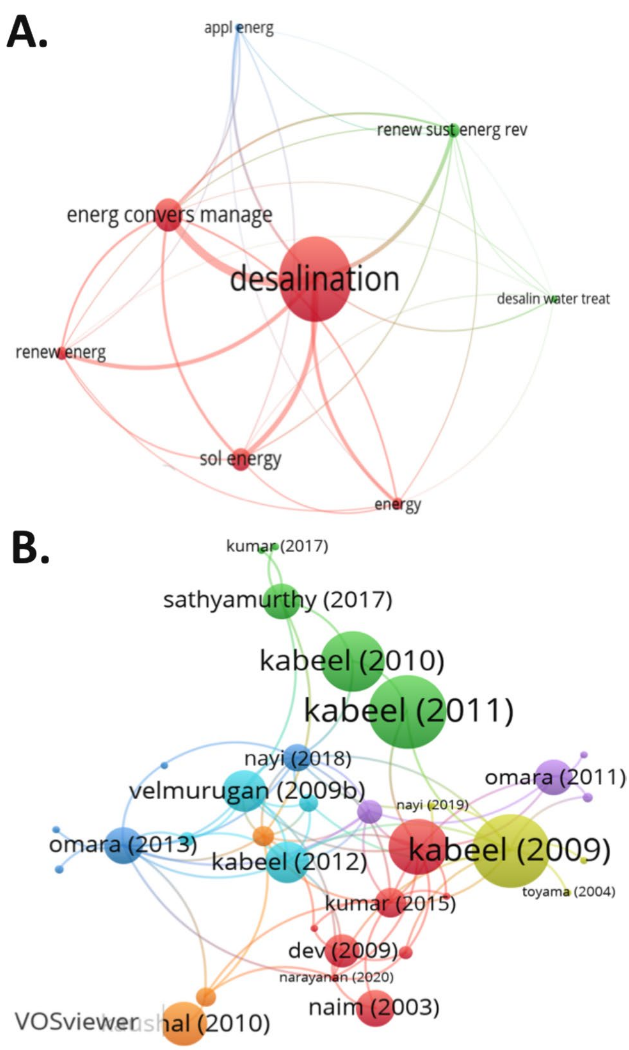

Fig. 4 Article sources **A** and citation authors **B** network visualization map in solar still based on desalination technology

the visualization citation articles report is considered and displayed in Fig. 4B. As can be seen from the mapping, Kabeel (2009), (2010), (2011), and (2012) are the greatest clusters, which signifies such authors possess the most cited articles in the field. Moreover, Velmurgan (2009) and Devi (2009) are also signified as most cited articles. Thus, the author's collaboration analysis indicates that the groups led by Prof. Kabeel, Prof. Omra and Prof. Kumar are the typically continuous research group. Those groups initiated the earliest study on solar still and desalination field. They cited a continued direction of investigation till now, while the number of publications is also considerable compared to other research groups. However, it is noteworthy to mention that the cooperation of scientists between various institutions and countries is required to be further enhanced.

Solar distillation

In order to generate fresh water from the salty resources, the same basic principle occurs in nature that is incorporated in the production of rainfall through the hydrological cycle which could be a man-made desalination system to produce potable water from the salty supplies. By energy-aided sources, salts could be separated from water through desalination technology. Generally, desalination tools for saline water treatment are broadly categorized into two classifications, namely evaporative or thermal desalination and membrane desalination technologies. Thermal desalination technologies are based on phase change to attain potable water from saline water through external heat addition to the saline water. Fundamentally, it is based on a cyclic evaporation and condensation occurrence. Thermal desalination could be of various types, such as multiple effect distillation (MED), multi-stage flash (MSF) desalination, thermal vapor compression (TVC), and mechanical vapor compression (MVC) (Ashour and Tony, 2014; Tony 2022). However, in membrane desalination tools, salts could be separated from the saline aqueous media with the aid of selective membranes. In this pressure-driven membrane process, potable water is obtained without phase change, which is so-called reverse osmosis (RO) or electro-dialysis (ED). Figure 5 represents the most common desalination technologies. Such conventional techniques are extremely energy-consuming techniques that require heat and another kind of mechanical or electrical energy to separate salts from water for thermal or membrane technology, respectively (Kabeel 2009).

On the other hand, solar desalination proved to be the most reliable and cost-efficient methodology for water desalination to access potable water from saline solution. In such techniques, the naturally abundant solar energy is used to simply evaporate the water in a zero-energy-cost technique. Solar still is composed of a container that is filled with brackish water, whose inner surfaces are coated with black paint and is fitted with a glass cover. The solar radiation penetrates the transparent glass cover and is absorbed by the basin liner, which in turn heats the water. The hot water is then evaporated; after that it is condensed underneath the glass surface. Finally, the condensed water is collected in a trough that is fitted along the length side. The worldwide installed desalination capacity is analyzed as RO 53%, MSF 25%, MED 8%, ED 3%, and 11% for other processes (Omara et al. 2016).

Membrane desalination is based on membrane and uses high pressure from motor pumps to discrete permeate water from saline water, i.e., brackish or seawater. However, on the other hand, thermal desalination applies heat to vaporize permeate water. The considerable amount of

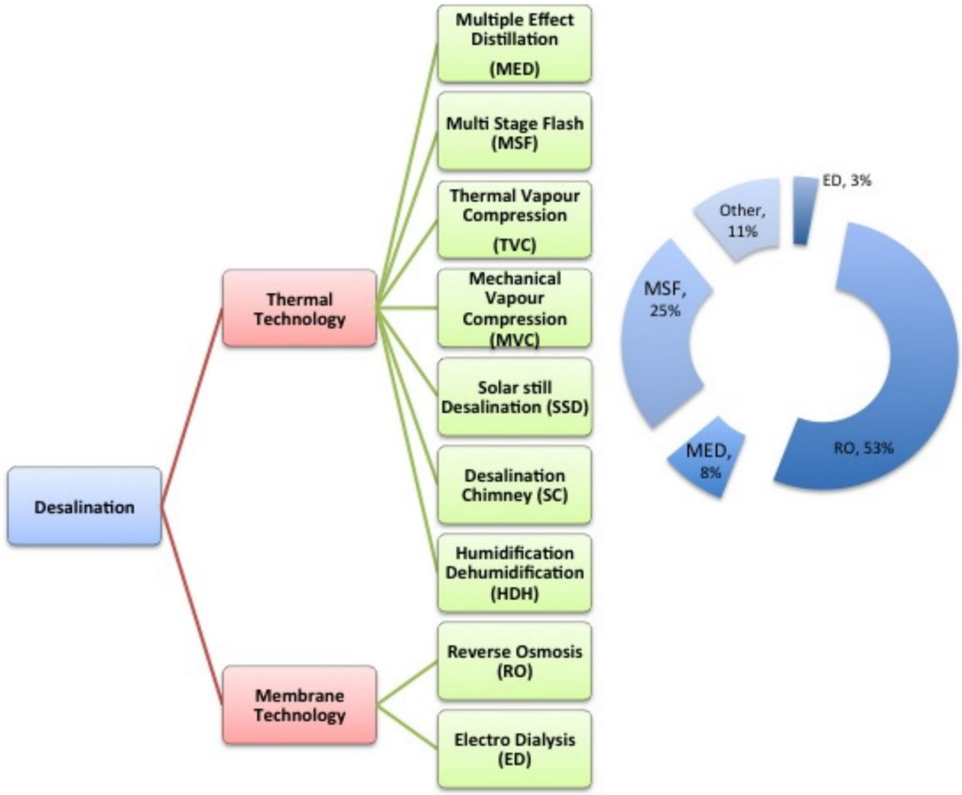

Fig. 5 Categorization of water desalination technologies and processes installation capacity

Table 1 Mechanistic assessment of desalination performance

Desalination process	Type of saline water	Energy Required / kWh/m^3	Thermal Energy/ kWh/m^3	Operating Temperature/ °C
MED	Seawater, Brackish water	1.5–2.5	6	70
MSF	Seawater, Brackish water	2.5–3.5	12	90–110
TVC	Seawater, Brackish water	1.6–1.8	14.6	63–70
MVC	Seawater, Brackish water	7–12	–	–
RO	Seawater, Brackish water	3.5–5	–	Ambient
ED	Brackish water	1.5–4	–	Ambient

MED: Multiple effect distillation, MSF: multi-stage flash, TVC: thermal vapor compression, MVC: mechanical vapor compression, RO: reverse osmosis, and ED: electro-dialysis

energy required for both thermal and membrane desalination technology is exhibited in Table 1. As displayed in the table, thermal desalination requires both thermal and electrical energy, but membrane desalination requires only electrical energy. Energy consumption for RO technology tends to consume energy in the range of between (3.5 and 5 kWh/m^3). Recently, due to the recent advancements in membrane technology, membrane techniques have managed to substitute thermal techniques in desalination plants (Tiwari 2004).

Brack water, most commonly known as brackish water, is a mixture of salt water and fresh water. Although brackish water is saltier than fresh water, it is not salty as seawater. Seawater comprises high quantities of dissolved salts/solids ranging from total dissolved solids (TDS) 15,000 mg/L to over 40,000 mg/L of total dissolved solids. However, lower amounts of salts are contained in the brackish water, which has only TDS 1000–15,000 mg/L-dissolved salts/solids. Thus, each desalination technology is based on treating specific types of saline water, namely brackish, saline, or maybe could treat both types (as seen in Table 1). It is noteworthy to mention that brine is very salty water, typically as seawater, predominantly a highly concentrated water solution of mainly salt of sodium chloride. Natural brines present underground, such as in salty lakes or as seawater, and they are the sources of common salts, such as chlorides and sulfates

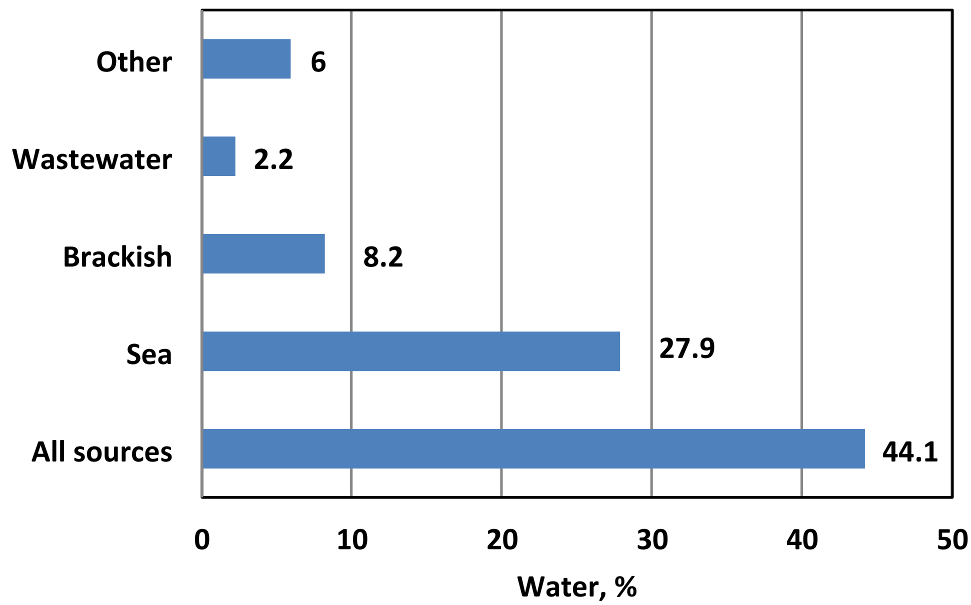

Fig. 6 Worldwide source water type

Table 2 Illustrative ion concentrations for seawater and brackish water and a municipal water supply authority (Wilf, 2007; Massachusetts Water Resources Authority, 2007; WHO, 2007)

Substance	Sea water (mg/kg)	Brackish water (mg/kg)	Municipal water authority value (mg/kg)
Na+	10,556	1837–90	30
Mg2+	1262	130–11.7	0.8
Ca2+	400	105–96	4.5
K+	380	8.5–6.5	0.9
Sr+	13	Na	Na
Cl-	18,980	2970–191	21
SO_4^{2-}	2,649	479–159	8
HCO_i	140	250–72.6	Na
Br-	65	Na	0.016
$B(OH)_3$	26	Na	Na
Fr-	1	1.4–0.2	1
SiO2	1	17–24	3.3
NO3	Na	5.0	0.11
TDS	34,483	5881–647	110

Na: not available

of magnesium and potassium. Brine comprises TDS higher than 35,000 mg/L. The percentage of each water resource is represented in Fig. 6. The corresponding ion comprising in the seawater and brackish water is represented in Table 2 (Dimri et al. 2008; Singh and Tiwari 2004).

Desalination is in need of energy; in contrast to fossil fuel, solar energy could drive desalination in a cost-free technology. Daily solar desalination is a viable water desalting option since there is an increase in water requirement with the critical energy and water situation. Thus, solar energy desalination could overcome the energy depletion crisis. The upsurge in the utilized energy per unit of water produced is reflected as intensification in the required area of solar collectors and hence increases the capital cost. Hence, commonly, it is usually evaluating the solar desalination system performance according to the number of liters that may be purified per day per unit area of collector (L/m^2-day). Moreover, the geographic location and the time of year play a significant role in solar performance. Thus, system designs need modifications to reach maximal performance (Suresh et al., 2010; Katekar et al., 2020).

Solar Still and its types

Back into the nineteenth century, the first large-scale man-made water desalination investigation was established and so–called solar still. It is a simple distiller tank that contains saline water. Such a tank is usually painted black to obligate high solar radiations where water is located beneath an inclined crystal cover, commonly glass. The solar radiation fleets through the transparent glass cover into the distiller tank, where saline water is heated up and thereafter evaporated into vapor via convection from the top of the distiller. Then, the vapors transfer to the space in the tank to touch the glass cover. Subsequently, heat is absorbed into the cover material, so, the vapors are transferred into a liquid state as drops of condensate on the tilt cover. The drops of condensate are collected in the distilling channel on the lower wall of the still basin, leaving all salts and impurities in the tank, which could be drained later through drainage (Tiwari and Sahota 2017; Tony and Lin 2021). While a traditional solar still can covert saline water into potable water, its low efficacy performance and poor distillation capacity are still obstacles of such system that needs to be improved.

Solar stills could be categorized as passive or active solar still types. Passive stills refer to the still type that use only solar energy that declines into the still unit. In such types, the systems work similarly to the hydrological cycle of nature. Since it uses the heat accumulated in saline water, evaporation and condensation processes occur within the still basin. However, in active solar stills, an external thermal energy source should be applied to the still unit that aids the saline water to be heated. Such energy could use thermal collectors, photovoltaic panels and concentrators conjugated by the distillation unit. A conventional boiler could supply via a concentrating solar panel, waste thermal energy, or such external heat. However, in comparison to passive solar stills, passive solar stills possess a simple design, construction and operating system. Besides, they are also smaller in size and cost-efficient than passive solar stills. Basin-type solar stills could be categorized according to their cover design geometry into different types such as single-slope, double-slope glazing cover or pyramid-type, vertical or V-type solar stills and hemispherical solar stills.

Passive solar stills

Single slope basin solar still

A single-basin solar still is considered the conventional type of passive solar still and signified as the primary type of solar still (Katekar et al., 2020) (Fig. 7). The crucial role in the solar still productivity is the higher surface area that gives more distilled output. The optimal solar still is signified when its water depth is 1 cm. Scattered authors (Katekar et al., 2020) checked the possibility of various material types in enhancing the still productivity. They compared the productivity of different solar stills fabricated from aluminum and galvanized iron, and the results explored that 3.8 and 2.6 L/m^2 is the product for both types, respectively, per day. This could be attributed to the various thermal conductivity of the material since aluminum has higher thermal conductivity than galvanized iron stills. Also, solar still efficiency and productivity as well are independent of solar radiation, but the increase in the diffused radiation is leading to a minor decrease in such efficiency. The solar still basin unit should be insulated to increase the still efficiency. Further, the increase in ambient temperature and decrease in wind velocity recorded an increase in the still productivity.

The covering sheet inclination angle is one of the factors that also affects the efficiency and still yield. Scattered research examined that the best tilt angle is dependent on the location geometry that still works. For instance, Tripathi

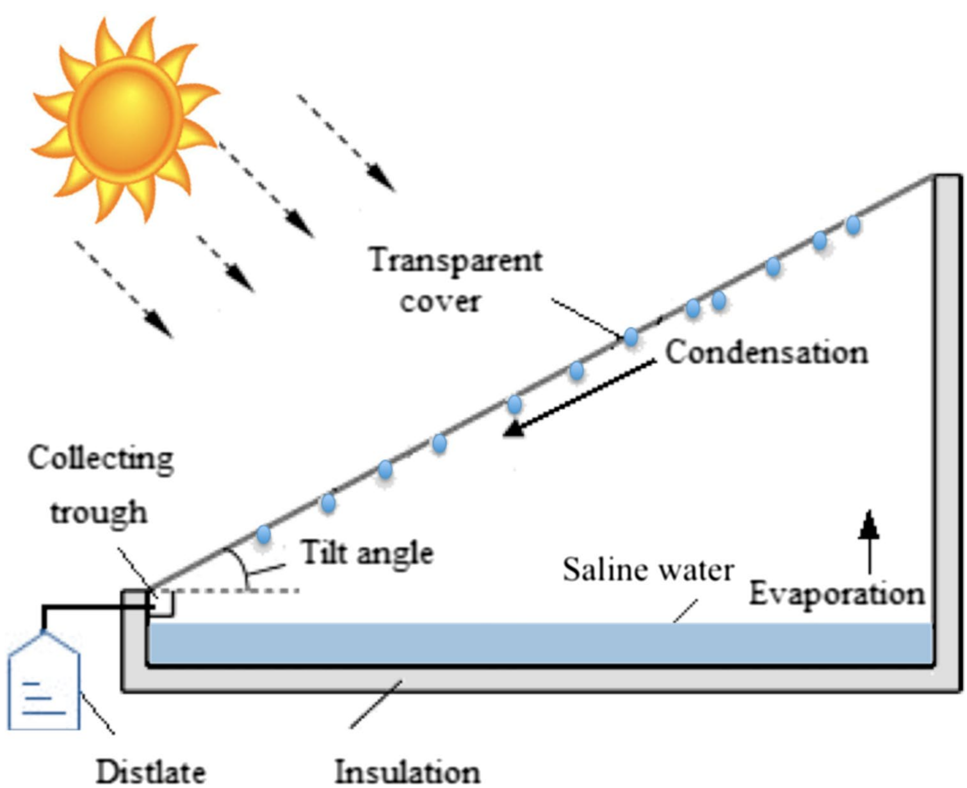

Fig. 7 Cross-sectional view of the single-basin solar still (Modified from Tony 2021a, 2021b, 2021c, 2021d)

and Tiwari (2007) reported that they designed a single-basin passive solar still with a tilt angle of latitude 28.6° located at Delhi, India, and the glass cover inclination angle of 15° shows better efficiency. Additionally, a survey by Dev and Tiwari (2009) also recorded solar still in Delhi at the latitude 28.6°, in the north; several inclination angles recommended that a 45° inclination angle improved the solar still productivity and according to their results reports the inclination angle is identical to the latitude angle of the location. Furthermore, Muhammed et al. (2007) designed the single-basin solar still in a western arid region of Pakistan located at a latitude of 33.7° North, and their recommendation for the tilt angle for the glass cover is 33.3°. While it could be recommended that the inclination angle might equal the location's latitude angle, the theoretical and experimental data reports are not consistently in accordance with that phenomenon**.**

The increase in the temperature of the feed water might also affect and enhance the productivity of the single still basin. Furthermore, the water depth also affects the still productivity. According to the study conducted by Let et al. (2021), the brackish water depth in the basin plays a significant role in the solar still productivity and efficiency. When the water depth changed from 12 cm to 10, 8, 6, 4, and 2 cm, the still productivity is increased. The worst still efficiency corresponded to a depth of 12 cm. However, the highest productivity was 34% that is linked to the 2 cm water depth. Also, Agrawal and Rana (2018) explored the water depth effect on sludge productivity and they confirmed the low water depth increases the productivity to 4.26 kg/m^2.day with an efficiency of 34.4%.

A two-basin solar still

A two-basin or maybe so-called double-basin solar still (Fig. 8) consists of two evaporator basins and fabricated from Plexiglass to allow solar radiation to pass through and reach into the lower evaporator. The lower evaporator is also made of Plexiglass from the same thickness, is painted in black color to absorb the incident solar radiation and is supported by steel frames. The backside of the upper basin thermally refuels the lower condenser. Both basins are located with a tilt angle to the horizontal. Two collecting troughs are used to collect the distillate from both the upper and lower condensers. The bottom of this still is also insulated. The upper basin is partitioned into three segments to avoid

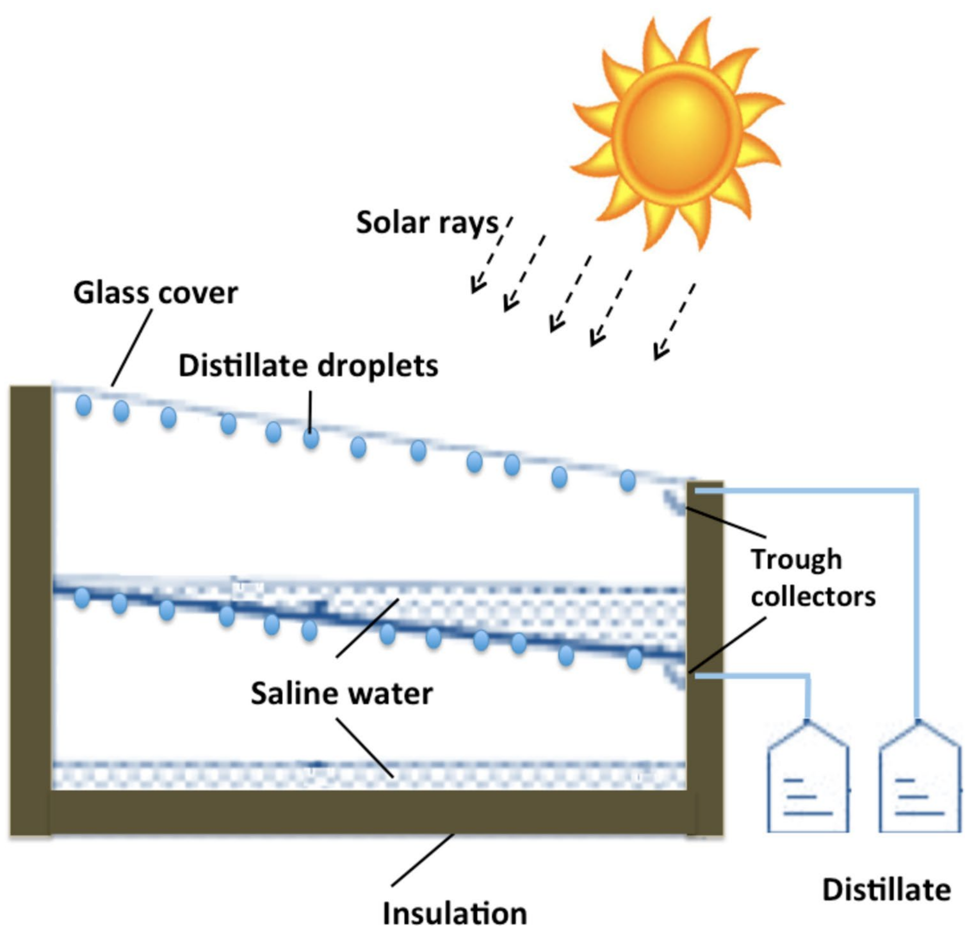

Fig. 8 Cross-sectional view of the double basin solar still (Modified from Karaghouli and Alnaser, 2004)

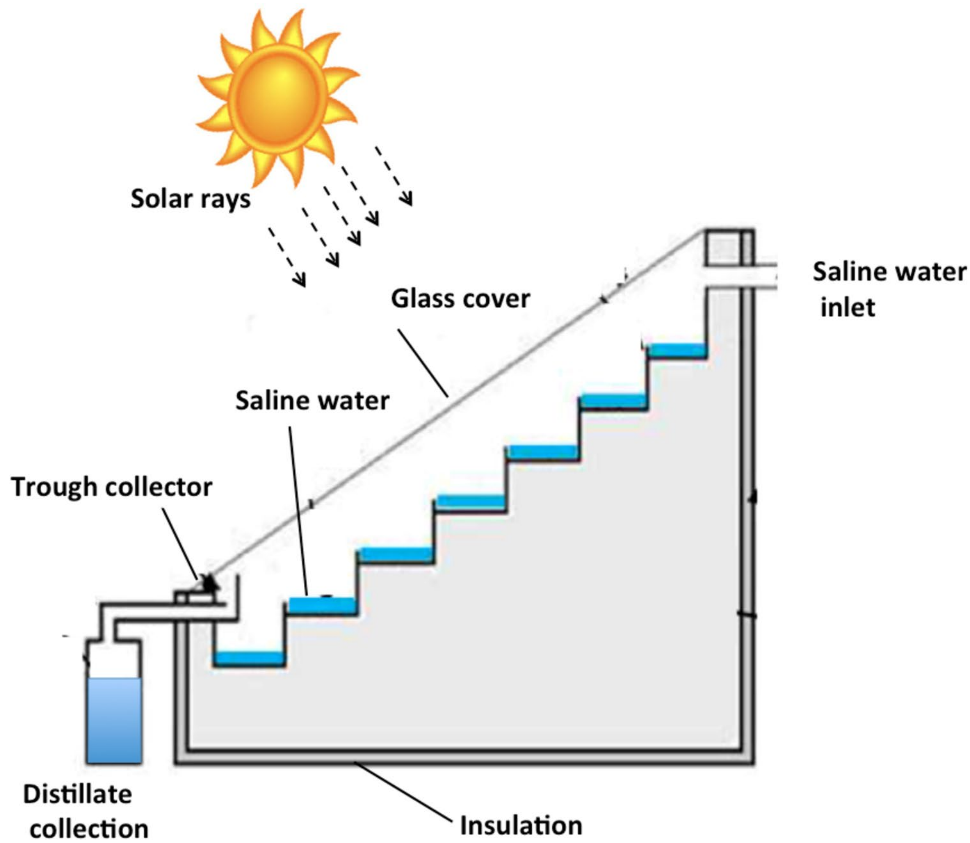

Fig. 9 Cross-sectional view of the simple stepped basin solar still (modified from Shmroukh and Ookawara, 2021)

the presence of dry spots on the higher portion of the inner glass cover.

Moreover, the two basins are sealed off to prevent water leakage into the boxes and stills. The brackish water feeding is carried out through the sidewall hole of the basin, as well as condensed water collection. Such a hole is closed with insulating material while still working to prevent any heat and vapor losses (Karaghouli and Alnaser, 2004).

Simple stepped cascade stills

Efforts have been made to improve the classical solar still in Fig. 7. In this regard, stepped-type solar still has been introduced. A stepped-type solar still is shown in Fig. 9, which could be comprised of a high solar absorptive dark-colored stepwise basin instead of the flat basin design. Such design is recorded a higher efficiency than the flat step classical still. Stepped-type solar still is composed of a stepwise basin covered with transparent material in order to allow the incident solar radiation to penetrate into the saline water in the stepped basin. The saline water, just heated from the sunrays, evaporates and then condenses on the glass cover. Moreover, the outer structure of the basin is insulated in order to prevent the generated thermal energy from losses or scape. A trough collector is mounted to collect the condensed water into a distillate tank (Shmroukh and Ookawara, 2021).

Stepped solar stills could be used as a passive or an active still types. However, passive stepped stills possess many merits that standpoints on cost-efficient since there is no need for electrical pumping power besides the simplicity of design and the easy of operate. However, its notable low efficiency categorized by low freshwater production compared to the active stepped solar still is still an obstacle. Such drawback is due to the loss of the latent heat of condensation through the transparent cover (Shmroukh and Ookawara, 2021; Kabeel et al. 2012a, b).

Consequently, stepped solar stills applied as a desalination technology become a significant opportunity for potable water shortage issues in hot, arid regions such as The Middle East. For instance, Kabeel et al. (2012a, b) investigated the preheating of seawater in the north of Egypt. In such investigation, Kabeel and his co-workers compared the classical solar still with the stepped one. In their model, the modified stepped solar still possess wicks that were mounted on the vertical side to increase the seawater evaporation areas that exposed to solar radiation. Thereby, the still productivity is increased. They attained that the water depth affects the still productivity, which increases with water depth reduction. Also, the still daily efficiency is strongly exaggerated by the width and depth of the step tray. The stepped-type still efficiency could be increased to its maximal daily productivity with an increase reached to 57.3% in comparison to 33% for the conventional still type (when using 120 mm tray width and 5 mm tray depth). Furthermore, the wicks could increase the still productivity by up to 5% (Kabeel et al. 2012a, b).

Velmurugan et al. (2009) in Madurai, India, evaluated the performance of the solar desalination unit using a stepped solar still system equipped with a mini solar pond for inlet saline water preheating as a combined setup. In such technique they equipped the solar still with pebbles, wicks, baffle plates, sponges, and fins, which enhanced the productivity to 80%, whereas the daily desalinated water production reached up to 6.120 L/m^2.day. Also, Pillai et al. (2015) studied the stepped solar still performance in Bangalore, India. They performed the design with a basin supported with channels. The channels are involved in welded semi-circular pipes fixed at a constant slope to act as connected steps. The productivity of this system is recorded as 3.700 L/m^2.day.

Pyramid and triangular solar still

A pyramidal glass solar still designed with a top cover is in the shape of a pyramid (Fig. 10). There are two shapes of the available pyramid basin solar stills; one is triangular pyramid solar still and the other is a square pyramid solar still. The pyramid solar still possesses some merits over the conventional basin solar still. For instance, in conventional solar still, the still is required to be tracked to face the sun around the day to attain the maximal incident solar radiation around the day, whereas in the pyramidal glass solar still, it is not required. Also, the shading of the sidewall on the saline water surface inside the basin is less in the pyramid basin solar stills compared to the conventional type. Besides, the condensation process in the pyramid shape solar still is much higher in comparison to the conventional single slope solar still for the same basin area (Nayi and Modi 2018; Fath et al. 2003).

Hamdan and his co-workers (1990) conducted the experimental work-study using solar desalination via square pyramid solar still located at Amman, Jordan. The researchers constructed the basin with an area of 0.96 m × 0.96 m × 0.15 m, whereas the sides of pyramid-shaped cover were inclined at an angle 45°. Additionally, Fath et al. (2003) have carried out an experimental study in the south of Egypt (at Aswan city) based on a comparison between the pyramid-shaped solar still and single slope solar still. The results concluded from their work revealed that the annual average daily productivity of the still is 2.6 L/m^2.day. Such results verified that the pyramid solar still configuration could be an efficient alternative for single slope solar still.

Also, Kabeel (2009) has explored a concave-shaped basin solar still with pyramid-shaped top cover. The concave-shaped basin is supported with wick to enhance the daily productivity of the still. Their results attained showed that during the daytime the average distillate productivity of 4.1 L/m^2 could be collected. Their system efficiency recorded could be reached to 45% in comparison to 30% for the ordinary pyramid solar still with a cost efficiency reached to 28% of concave pyramid-shaped solar still which means the structure is also valuable from the financial point of view.

Ahsan et al. (2014) experimented on triangular solar stills and concluded the water depth is signified as a significant parameter that affecting the still productivity and efficiency. However, the overall conclusion for this unique triangular shape-type solar still is untorturable since its productivity

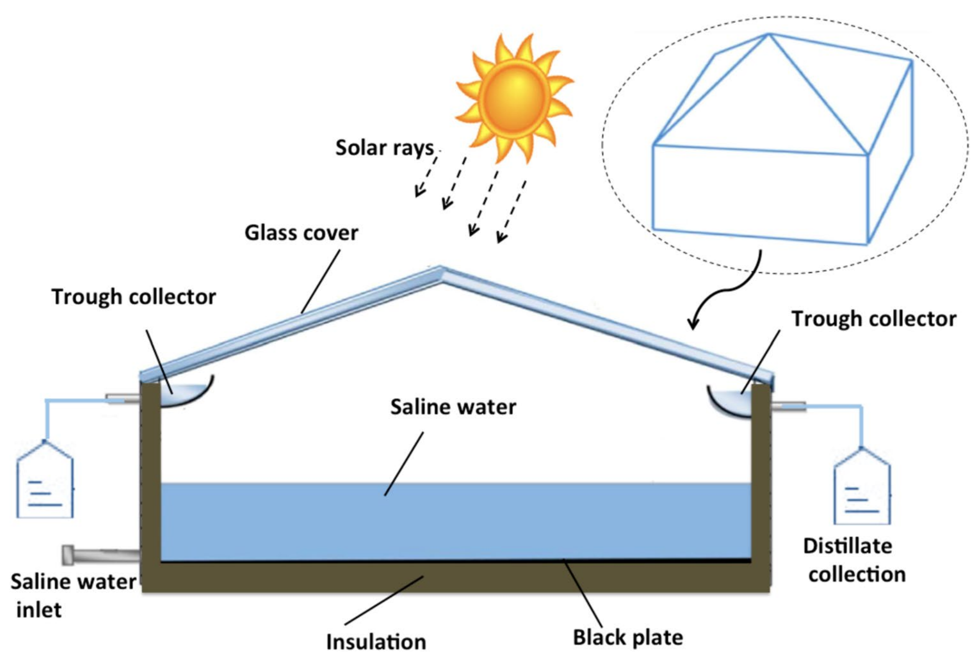

Fig. 10 Overview of the pyramid-type solar still (modified from Nayi and Modi 2018)

that might be reached to its maximum level in some days, but the annual performance is low due to heat loss from the system.

Conical hemispherical solar still

According to the literature (Gaad et al., 2015), conical hemispherical solar still is consisting of a bases that is constructed from galvanized iron and circular in shape with a diameter is equal to 100 cm, the cone 33 cm and basin area is equal to 0.8 m^2. The sides and the base of the still are painted black to well absorb the solar radiation and increase the still productivity. Moreover, all the sides and base of the still are insulated with (5 cm) foam. The condensing surface in the still unit is a 5 mm thickness of acrylic cover. The still cover is tilted with an angle according to the latitude of the location of experimental study (31º, of Sheben El Kom city, Egypt) to attain a maximal solar radiation as possible. Moreover, in order to collect the condensed water, channel is used from one side of the still. The schematic representation of such still is illustrated in Fig. 11. The experimental results revealed that the daily productivity for hemispherical conical still is 3.38 L/m^2. day compared to the conventional basin solar stills was 1.93 L/m^2.day at the same weather conditions.

Additionally, Ismail (2009) stated that the application of hemispherical solar still in his study yielded a distillate between 2.8 and 5.7 L/m^2.day, while the efficacy is declined to by 8% with the increase in the saline water depth in the still basin by 50%. However, Arunkumar et al. (2012) investigated the parameters affects the performance of the hemispherical conical still, whereas the temperature difference between water and glass significantly affects the still productivity. Thus, they recorded that the cooling water over the hemispherical cover increases the collected distillate; such criteria could be attained through the flowing air or water over the hemispherical cover since the driving force of solar still depends on the temperature difference between water and glass. This hemispherical still over the traditional flat, one could increase the process by 1.25 times. The output of the still when cooling is applied to the cover and in the absence of cooling are 4.2 and 3.5 kg /m^2.day.

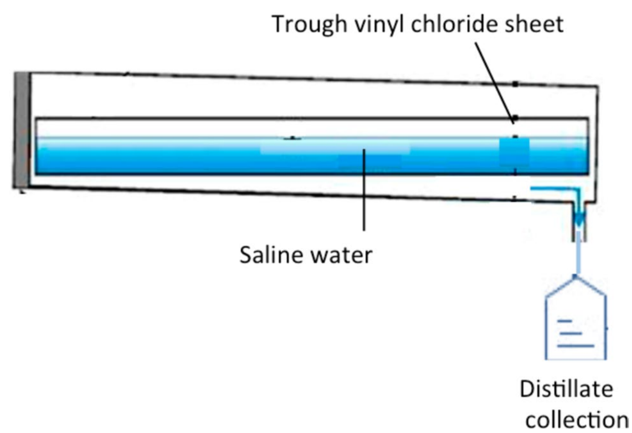

Fig. 12 Overview of the tubular-type solar still (modified from Sathyamurthy et al. 2016)

Wick-type solar still

A wicked solar still is categorized by a style of inclined solar still. Wicks are substances that could possess the capability of absorbing solar radiation to enhance the still efficiency and thus increase its productivity. Such materials are porous materials, which enables radiation absorbing pads (Manikandan et al. 2013; Awasthi et al. 2018). Kassem (2016). It is recorded from different experimental work conducted that the use of wick materials enhances the still productivity and the tilted of such substances could increase the evaporation rates. Aruna and Janarthanan (2014) reported that the still efficiency is associated with the floating tilted-wick type, the flowing water flow rate inside the still through the tilted-wick portion and the absorption capacity of the wick material surface.

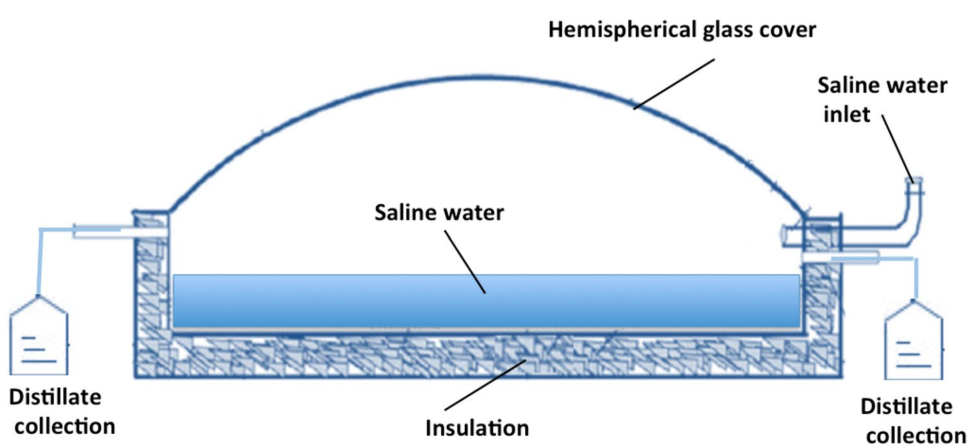

Fig. 11 Overview of the hemispherical conical-type solar still (modified from Sathyamurthy et al. 2016)

Wicked-type solar still could be categorized as various types such as multi-wick type still, which attains high productivity through using various types of wicked materials: an evaporating wick, a condensing wick and a polytetrafluoroethylene net sandwich. Moreover, the wicked-type solar still can be concave-wick-type solar still. Such type is based on the evaporation rate of water which increases with low height of water inside the basin. The still productivity could increase to attain 4.1 L/m^2 with the efficiency of 30% according to the research work conducted via Sivakumar and Sundaram (2013).

Tubular solar still

A tubular solar still (Fig. 12) is a type of stills that could be signified with its simple design and easily fabricated one. The previous research article cited in the literature Awasthi et al. (2018) exhibited that from experimental work suggested that the various cover materials might affect the still productivity. In such study the authors compared the vinyl chloride sheet and polythene film, including the fabrication cost and still productivity through the collected distilled water. They recorded that the polythene film exhibited better productivity due to its high durability. Moreover, they introduced a modification to suggest that tubular solar still as an efficient opportunity for humid air conditions.

Weir solar still

Weir solar still could be inclined or cascade in style with a weir-shaped absorber plate. A weir is used to distribute saline water consistently to it. In such system the brine water after the distillate collection is subjected for circulation into the fresh saline water to increase its temperature. Thus, this technique is prominent for more evaporation. The study proposed by Sadineni et al. (2008) introduced the average distillate yield is 5.5 kg/m^2.day with an enhancement in efficiency by 20% in comparison to the conventional solar still. Moreover, the results conducted by Tabrizi et al. (2010), reported the output of the solar still is 5.5 kg/m^2.day. A weir-type cascade solar still is constructed, the experimental work is investigated by Tabrizi et al. (2010), and the distillate collected is at a yield of 7.4 kg/m^2/d.

Spherical solar still

Dhiman (1988) introduced the spherical-type solar still as an enhanced type of the conventional solar still as shown in Fig. 13. The still comprises a spherical glass cover that is fitted with a plate to contain the saline water. Such plate is a black in color and metallic, which is mounted horizontally at the still center (Alatawi et al. 2022). Saline water in the plate is condensed along the internal surface of the

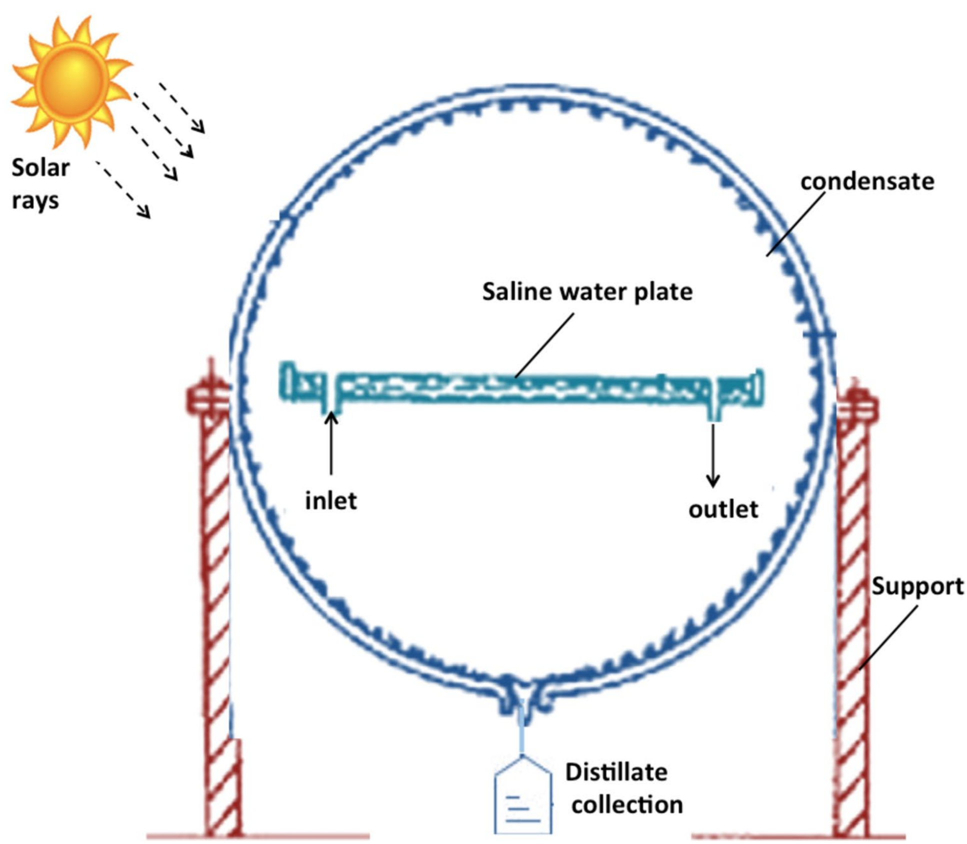

Fig. 13 Overview of the spherical-type solar still (modified from Dhiman 1988; Alatawi et al. 2022)

glass cover, and then the distilled water is collected from the bottom of the still. The experimental data revealed that an enhancement in the still productivity could be reached to 30% increase when using such still over the conventional one.

Active solar stills

Any of the above-mentioned passive solar still productivity is calculated by the temperature difference between the water in the basin and the internal glass cover surface. In such passive stills, direct solar radiation is used as the heating source to increase the saline water temperature inside the basin. Subsequently, the evaporation is occurred, thereby leading to a decline in the still productivity. Mainly, this is the main disadvantage of a passive solar still. Hence, to overcome the above issue, many active solar stills are introduced to provide an extra thermal energy to the still basin. The additional energy thus increases the evaporation rate, which further enhances the still productivity. Hot water could be fed into the solar still basin through an external mode such as solar collector panel. Water could be preheated prior to feeding to the solar still and submitted to the basin at a constant flow rate. Auxiliary external heating could increase the water temperature from 20–50 °C to 70–80 °C.

Active solar still supplemented with a flat plate collector

The effect of coupling a flat plate collector (FPC) with the conventional solar still enhances its performance since it works at a high-temperature distillation method as seen in Fig. 14. FPC might work in either forced circulation mode or natural circulation approach. In the forced circulation approach, a pump is supplemented to provide water. However, in the natural circulation style, water circulates and flows according to the water density variance. In both modes, extra thermal energy is added to the basin of the solar still.

Kiatsiriroat et al. (1987) used an FPC to enhance the conventional solar still productivity and the unit consists of a distillation unit with various parallel vertical plates. They concluded that whereas the number of plates increase, the distillate output enhanced and an increment in the distillate yield (34%) is attained. Additionally, Rai and Tiwari (1983) reported that the coupled single-basin still has a productivity enhancement. Also, the collected daily distillate from the forced circulation style still is higher than the uncoupled single-basin still by 24%.

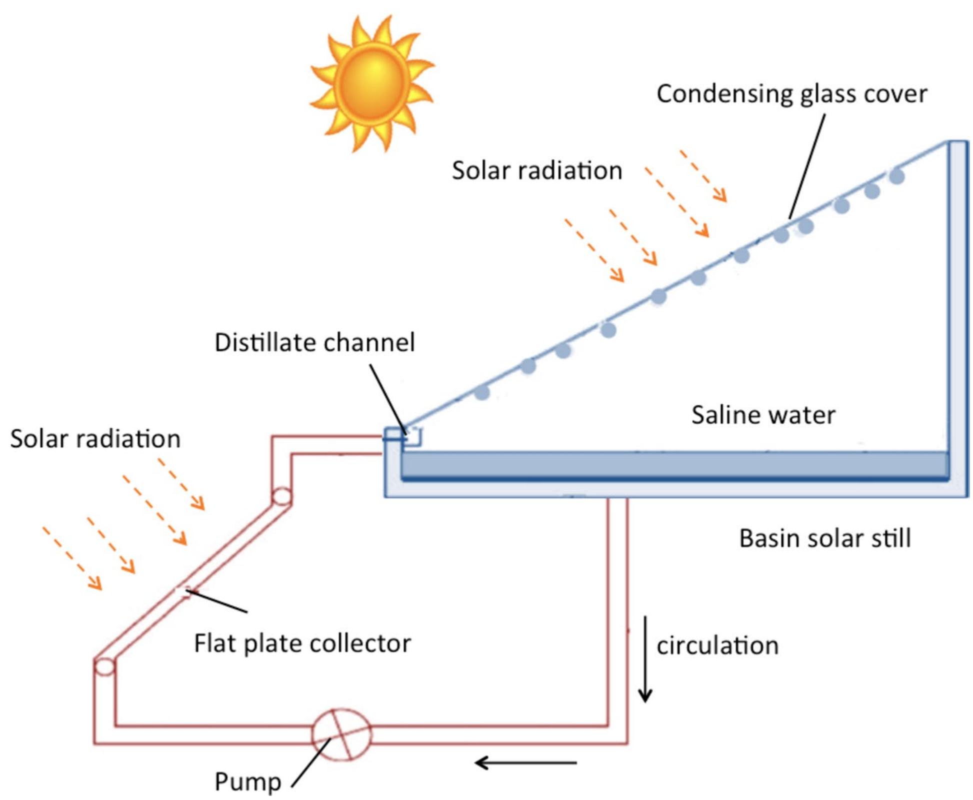

Fig. 14 Overview of the integrated active solar still with a flat plate collector (modified from Kumer et al., 2015)

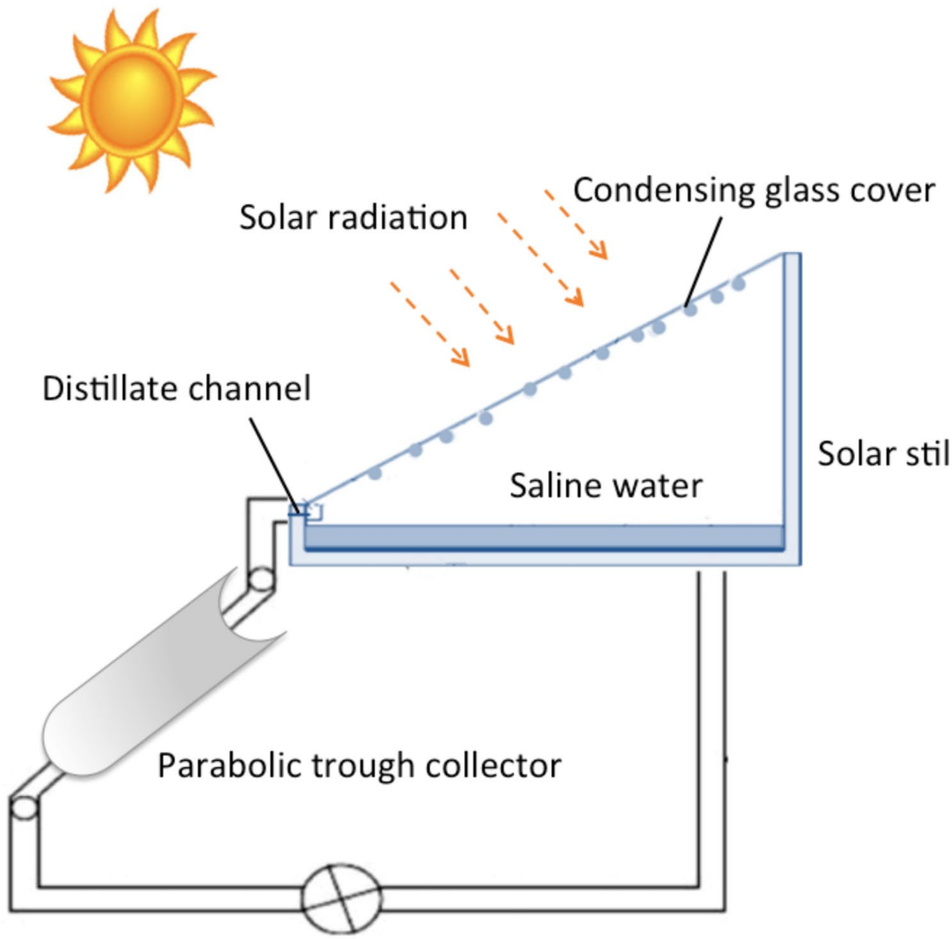

Fig. 15 Overview of the integrated active solar still with a parabolic trough collector (modified from Sampathkumar et al. 2010)

Active solar still supplemented with a parabolic trough collector and heat exchanger

Singh et al. (1996) and Abdel-Rehim and Lasheen (2007) introduced that supplementation of the solar still with a parabolic trough concentrator (PTC). In their investigation, the basin water temperature was raised by the augmentation of the basin solar still with parabolic trough collector. Their schematic representation is illustrated in Fig. 15. The system comprises a conventional still basin, parabolic trough, circulating pump and a heat exchanger. Their system showed an increase in the fresh water productivity by 18%, comparing it with conventional passive solar still.

Also, Bechir Chaouchi et al. (2007) used a tiny solar desalination unit combined with a solar concentrator via parabolic trough collector. Their installation is constructed from an evaporating surface where the saline water persists by using a boiler. Also, parabolic solar trough collector is used to focus the solar radiation into the saline water in the boiler. The supplement is connected with a condenser with a heat exchanger and a trough at the bottom to collect the distillate yield. The attained results verify the use of solar concentrators coupled with the solar still versus the conventional solar still that could compete them in conventional energies in solar desalination.

Solar still combined with evacuated tube collector

Solar still supplemented with evacuated tube collector (ETC) for water heating purposes is more beneficial and possess higher efficiency than the flat plate collectors since the higher thermal water heating facility (Sampathkumar et al. 2010) (Fig. 16). Comparing the ETC with the FPC, the sun radiation is perpendicular on the FPC collector only at noon. However, the proportion of the sunlight arresting the collector surface is instead usually be reflected. Thus, this is unfavorable behind the solar noon. On the other hand, for the ETC that possess a cylindrical shape, most around the whole day, sun radiation is perpendicular to the surface of the glass. Thus, the ETC most likely declines the heat losses as vacuum is existing in the tubes. ECT combined with the solar still comprises two coaxial tubes with evacuated space between an outer surface of inner tube and inner surface outer tube of outer tube. Heat transfer carrier, fluid, enters the glass tube and leaves it through the annular space between the delivery tube and selective coated

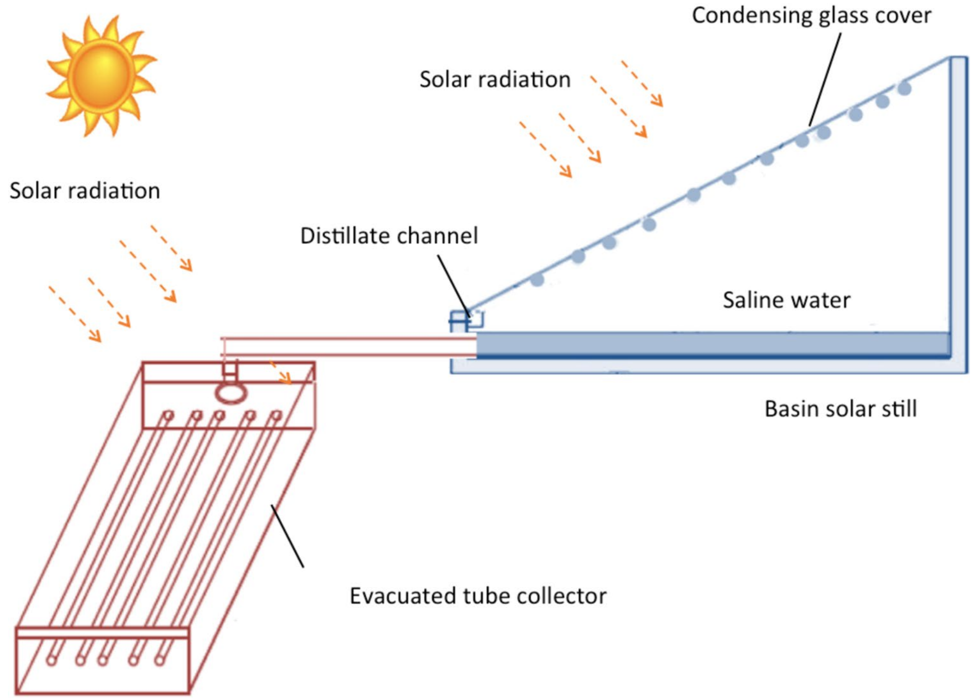

Fig. 16 Overview of the integrated active solar still with an evacuated tube collector (modified from Sampathkumar et al. 2010)

absorber, which is evacuated to minimize the convection heat losses. Tiwari et al. (2007) reported a comparison of using ECT augmented with the conventional solar still and the corresponding still combined with the FPC. Their results exhibited that the productivity enhancement reached 13.14 and 18.26% when solar still augmented with ECT or FPC, respectively, over the conventional solar still. Such data verified the effectiveness of the ETC.

Kargar Sharif Abad et al. (2013) introduced ETC as a high-performance thermal conducting device that could raise the solar still basin water temperature very quickly. The experimental data investigated the hourly maximum productivity of up to 875 mL/m^2 using the optimum water depth (40%) in the still.

Preheated water active and waste heat recovery solar stills

During the sunshine hours, the hot wastewater could be recirculated in order to recover the wastewater heat. Such recovery is carried out through passing wastewater at a constant flow rate and hence the basin is preheated. This

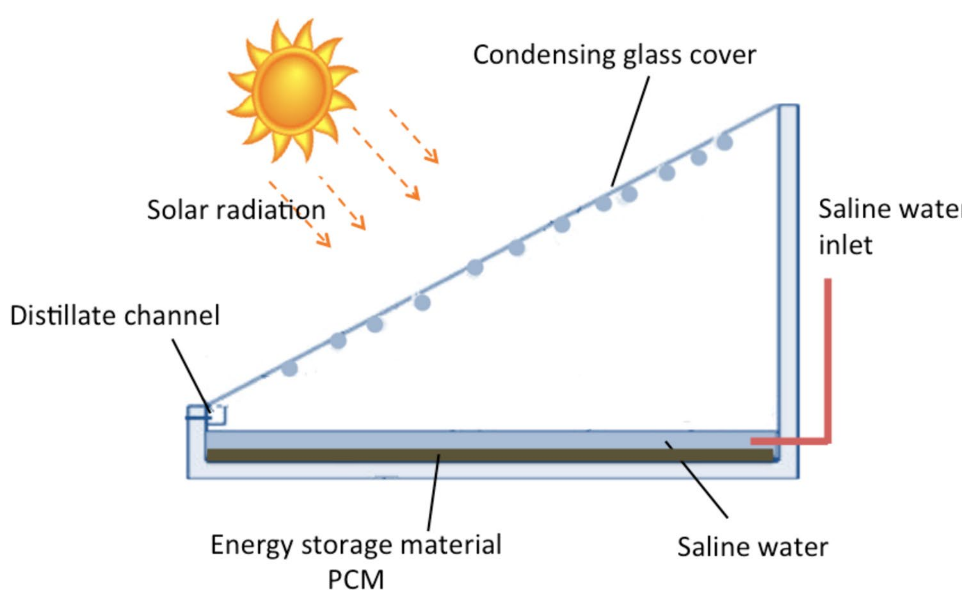

Fig. 17 Overview of the integrated active solar still with a PCM configuration (Solanki and Patel (2017)

methodology could increase the water basin temperature difference with the glass cover, which therefore leading to an enhancement in the evaporation and condensation processes. Gupta et al. (1988) found the application of such technology enhances the still productivity while keeping all the other parameters at its constant.

Solar stills performance improvement through design modification

Use of energy storage materials

The productivity of the solar still could be enhanced through a considerable amount of heat that could be stored in the phase change material (PCM) during sunshine hours (Fig. 17). PCM could supply a continuous extra thermal energy through the latent heat of PCM (Tony 2021b). After the sunshine, the heat stored through the PCM is used as a heat source to increase the effective time used in the desalination process for water evaporation. Moreover, the temperature difference between the brine and glass cover became higher since the ambient temperature declined through the night time than the daylight. Solar still productivity is enhanced to attain 9 kg/m^2.day on the sunrays over 5 kg/m^2.day without a PCM system (Nayi et al., 2018; Tony 2020b; Tony and Lin 2020a, b).

Sathyamurthy et al. (2014) used paraffin wax as a phase change material (PCM) to enhance the triangular pyramid-type solar still performance. Sathyamurthy and his co-workers conducted a comparative examination in India between the application in the PCM and without PCM. They preceded their study in a humid climate and incorporated the heat reservoir filled with PCM into the still. The experimental results from such work recorded a 20% enhancement in the system coupled with PCM and the distillate output improved to 4.3 L/day in 24 h with a daily efficiency of enhancement from 45 to 53% when the system incorporated with PCM compared to with no PCM use. Also, the temperature difference between the water and glass cover was recorded at 10–15.5 °C throughout the off-shine period from the stored energy in the PCM.

Arunkumar and Kabeel (2017) presented a combined solar still with PCM and compared their results with the system without PCM support. They reported that an enhancement in the solar still incorporated with PCM system performance as the daily yield recorded is 5.78 L/m^2 in comparison to 5.33 L/m^2 for the system without PCM.

Kabeel et al. (2017) explored the modified pyramid-type solar still incorporated with phase change material (PCM) in the v-corrugated absorber. In the work of researchers, identical solar stills are designed and constructed for experiments to compare the effect of using PCM. The result concluded that the PCM-equipped solar still provides a distillate capacity of 6.6 L/m^2.day in comparison to 3.5 L/m^2.day for the system with incorporated PCM. Thus, the use of PCM combined solar still system could overcome the intermittent nature of solar energy.

Use of porous materials

Scattered researchers established solar stills incorporated with different absorbing porous materials. It is noteworthy to mention that such absorbing materials create a significant role for enhancing the evaporation surface area besides the basin internal thermal storage. Sodha et al. (1980); Dutt et al. (1989) introduced solar stills with dye in the basin. Velmurugan et al. (2008) exhibited experiments in a single-basin solar still coupled with sponge cubes, a wick and fins. In their experiments, 450 sponges of dimensions 20 mm × 35 mm × 35 mm were applied in the still augmented with fins and the results verified that the use of porous materials enhances the still's productivity. Also, Kannan et al. (2014) investigated a solar absorption still augmented with various absorbing materials, namely, sponges, gravel, sand and black rubber pieces. The coupling of the vapor absorption solar still with sponge, sand and black rubber pieces enhanced the system productivity. Further, Philip et al. (2016) used spheres and different colored sponges to enhance the solar still efficiency. They filled each solar still with 127 g of rock salt. The experimental data revealed that solar still with spheres could improve the still productivity.

Air bubbled solar still

The effect of the simultaneous use of air bubbling in coupling with solar still is investigated as an enhancement aid of the overall still efficiency (Fig. 18). The solar still in this mode is augmented with forced air bubbling over water in the basin and glass cover to cool the flowing water surface (Kumer et al., 2015). Thus, such system style could be able to enhance both the evaporation and condensation processes. Moreover, this technique is also attaining higher distillate yield. Pandey (1984) applied the modified air bubbled system to improve the still productivity, and their experimental work results confirmed the productivity improvement over the conventional still type.

Use of fans

Solar power could still be incorporated with a fan to improve productivity, and the fan could be operated by a photovoltaic cell (PVC). In such mode, water vapor generation beneath the still glass cover is pushed out using a suction fan (Fig. 19). The condensate is then passed through a water-cooled condensation unit (Omara et al. 2017). This

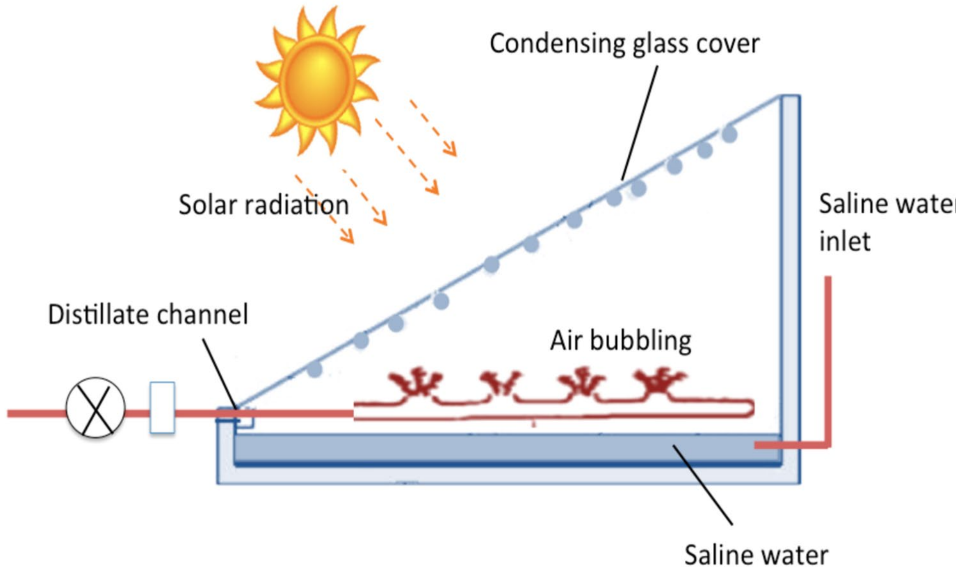

Fig. 18 Overview of the integrated active solar still with an air bubbling configuration (modified from Kabeet et al. 2015)

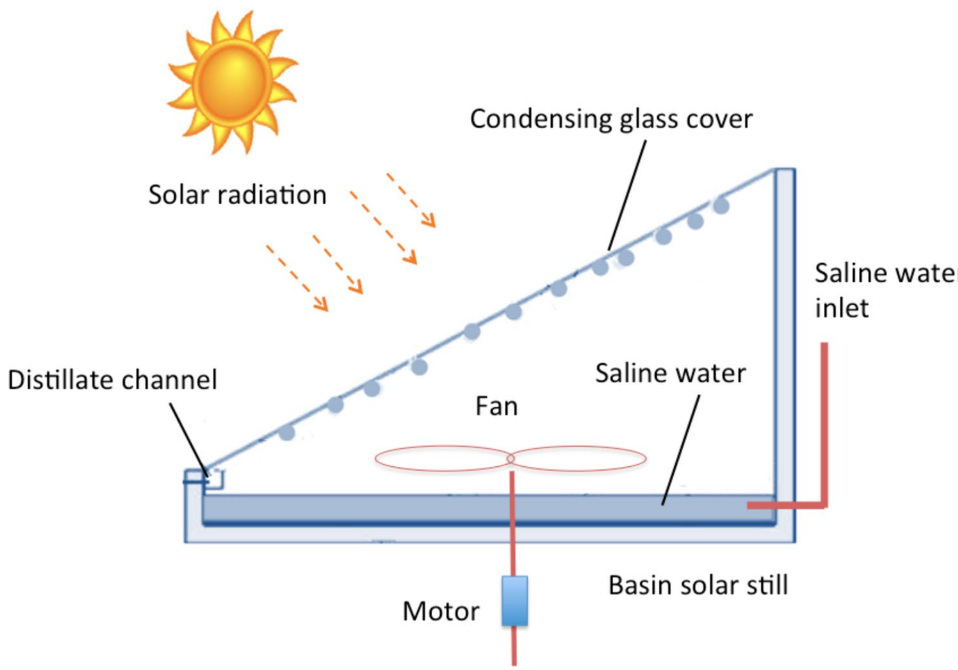

Fig. 19 Overview of the integrated active solar still with a fan (modified from Kabeet et al. 2012)

configuration is applied to decrease the air pressure in the basin, which could further attain a faster evaporation since the water evaporation temperature is declined. In the previous investigation of Kabeel et al. (2012a, b), the still productivity is enhanced by using a rotating water fan and the fan speed affects the still productivity. A photovoltaic system (PV) is applied to rotate the water fan. The fan rotational speed and the depth of saline water affect the still system performance. The system yield increased by 25% using a fan at a depth of 3 cm and a speed of 45 rpm. To add up, Omara et al. (2017) used a fixed fan inside the solar still. They checked various water depths to install the fan. Overall, the system is incremented by integrating the fan mounted at 22 rpm and at 3 cm depth. Meanwhile, the daily efficiency using a fan is increased by 39.8% compared to 36.7% in the solar still system.

Use of nanofluids

The solar still productivity yield could be incremented via nanoparticles addition to the base fluid (water). In this regard, the heat transfer coefficients could be improved by the thermophysical properties of base fluid (water) improvement. The suspension of nanoparticles into water that is called nanofluid is signified as a simple process that possess the benefit of enhances the thermophysical properties. Such nanoparticles could be added in various types such as aluminum oxide, zinc oxide, iron oxide and tin oxide (Lovedeep and Tiwari, 2016; Tony and Lin 2022a). This process is conducted through the suspension of nano-sized particles (1–100 nm) into the water in the basin. The included nanoparticles shape and concentration as well as the base fluid could affect the process performance. The exclusive thermophysical properties of nanofluids involve thermal conductivity, specific heat, viscosity and substantial heat transfer coefficient improvement.

Choi (Choi, 1995) introduced in 1995 a pioneered study on solar still enhancement via including nanoparticles in the base fluid that results in the improvement in its thermal conductivity. Further, Elango et al. in 2015 (Elango et al., 2015) established an experimental comparative study based on the improvement of solar still performance through the use of nanofluid and compared it with the solar system. Systems' productivity is investigated, and the comparison of using various nanoparticles at different concentrations is also highlighted.

Lovedeep and Tiwari (2016) comprised different aluminum oxide masses ranged from 35 to 80 kg into water as the used bases fluid. Their results showed a significance enhancement in the solar still yield and the system productivity ranged from 12.2% and 8.4% according to the amount of nanoparticles addition of 35 kg and 80 kg, respectively.

Photovoltaic-thermal (PVT) solar still

Electrical power is supplied to the solar stills to improve the still performance. Photovoltaic-thermal (PVT) water collector is applied in order to improve the desalination through solar still performances (Fig. 20). PVT is signified as tremendous promise since it is sustainable energy system, eco-friendly and electrical cost-efficient source. A PVT collector could simultaneously provide an enhanced desalination system through both water preheating and saline water temperature raising that increases the production of desalinated water. Such mode of solar still could provide criteria of enhancing the solar still yield (Naroei et al. 2018). Photovoltaic (PV) system could be also used to rotate the fan in the active fan coupled still (Kabeel et al. 2012a, b; Tony and Tayeb 2016; Tony and Mansour, 2019).

Manokar et al. (2018) conducted a comparative study using various single-basin solar distillation stills from the same fabrication to study the comparison of the cumulative water distillation. PVT among the studied configuration showed two times of the produced water compared to the conventional solar still. The experimental data showed that the productivity of the distillate attained is 7.3 kg/m^2.day, which verifies the sustainable production of an inclined

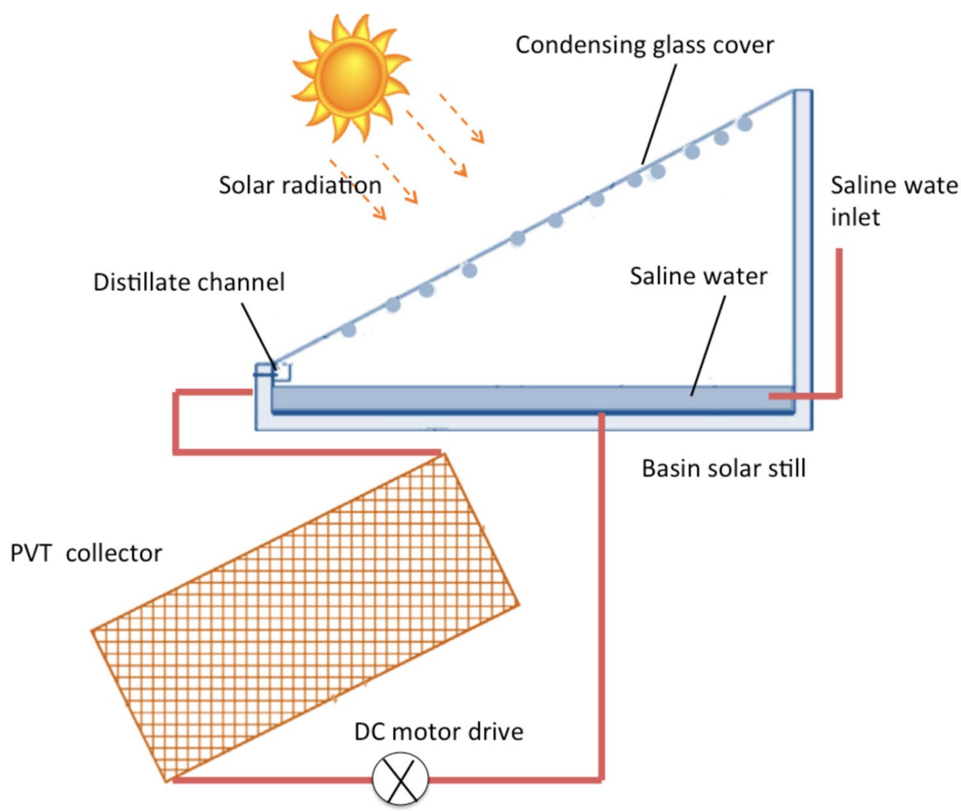

Fig. 20 Overview of the integrated active solar still with a PVT (modified from Naroei et al. 2018)

solar panel still with sidewall insulation. Such scattered work confirmed the integrated solar still that could be applied in coastal and rural areas, which endowed with solar energy to attain clean water.

Water flow over cover

It is estimated that the highest possible temperature difference between the solar still basin water and the glass cover is essential. The process could conduct through a thin uniformly moving water film over the still glass cover. Moreover, to increase the temperature difference between the hot water in the basin and the glass cover, hot water waste could be recycled, which might attain a high yield. Thus, the still productivity increases.

Tiwari and his co-workers in 1985 (Tiwari et al., 1985) found a flow water over the glass cover could propose an increase in the still productivity through recycling the hot water into the system. Suresh and Shanmugan (2019) proposed the enhancement of the solar still by flowing water over the glass cover. They concluded that such investigation could enhance the absorption effect of the structure and their theoretical results were confirmed with the experimental work. In their superior design, they found that the still productivity could reach to a daily production of 429 kg/m^2, which means 25% higher production than the conventional style.

The overall types of the solar stills as well as the suggested modifications to increase the performance are displayed in the diagram of Fig. 21.

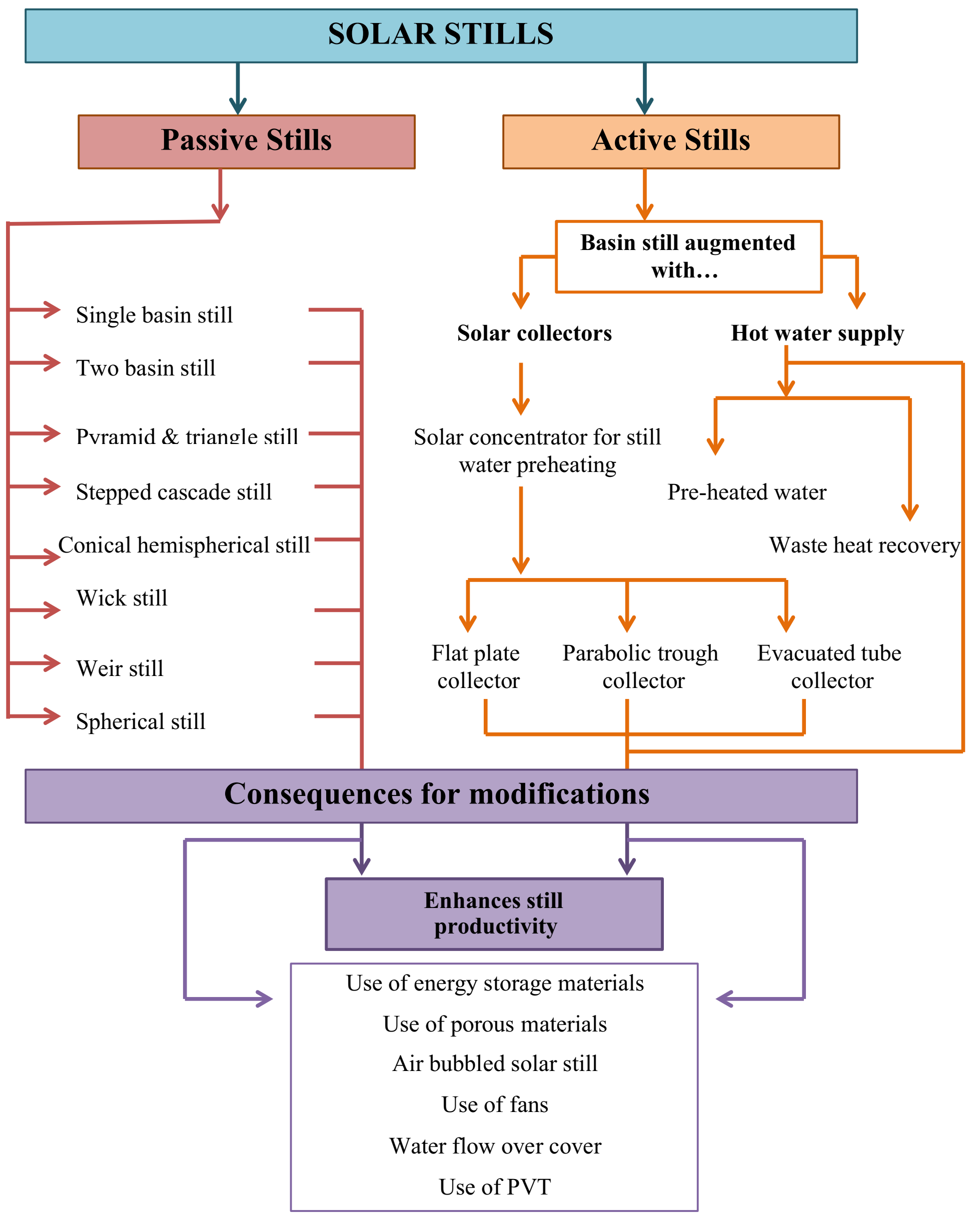

Fig. 21 Diagram presenting solar still types and the modifications potential to enhance the performance

Parameters affecting the productivity of solar stills

Either uncontrollable or controllable variables could enhance the solar still productivity. Such uncontrollable parameters are including solar radiation, ambient temperature and wind velocity. However, there are other controllable parameters as depth of water in the basin, glass cover thickness material and tilt angle, construction materials and insulation and temperature of water in the basin. The still performance could be enhanced through the controllable parameters.

Climatic conditions

As the solar desalination system depends on the solar radiation, the increase in the intensity of solar radiation enhances the desalination of the still and the still productivity is increased (Tony et al. 2016). Generally, the solar stills attain the highest productivity around the solar noon since the solar radiation intensity reaches to its maximum temperature. Thus, this facilitates the water evaporation rate, which is accelerated. Moreover, according to the place and the time of the year that is controlled by the place latitude and time dependence, the intensity of solar radiation is varied. Such solar radiation intensity is a predictable value from mathematical simulation model (Taha 2010; Tony and Lin, 2022). Tony and Mansour (2020a, b) reported that the intensity of solar radiation, in a city in north of Egypt (Shebin El-Kom), is changed during the day and the maximum solar intensity was recorded around solar noon at the summer period rather than the winter season. According to Akash et al. (2000) investigation, the solar radiation intensity is significantly affecting the temperature of the receiving surface, thereby the heating system processes dependence such as solar desalination configurations should be affected.

Not only the sun radiation intensity plays a significant role in the solar still efficiency, but also the wind speed over the glass cover. Since the wind speed elevated, the convective heat transfer from the glass surface declines its temperature. From this regard, more distillate condenses on the internal surface of the glass cover of the still. Overall, the desalination process enhances and the solar still productivity is increased.

Surface area of evaporation and basin water depth

Solar still water depth is categorized as a significant parameter that affects distillate productivity. This is because the evaporation rate of the distilled water is reasonably associated with the surface area of water exposed to solar energy and should be evaporated. Consequently, enlarging the surface area of saline water located in the basin of the distiller enhances the efficiency of distilled fresh water generation. Scattered work studies investigated the effect of water depth in the solar still on the evaporation efficiency. The water depth in the basin is inversely proportional to the distill efficiency and clean water productivity (Tiwari et al., 2017; Ahsour and Tony 2020a, b, c). It is recorded that the lowest depth of water corresponds to the highest productivity at a stable solar radiation, and further, a dry spot is attained. Tiwari, Sumegha and Yadav (19,991) studied the varying of (0.02 m, 0.04 m, 0.06 m, 0.08 m, 0.10 m, 0.12 m and 0.14 m) in the water depth to check its effect on the productivity. They reported that the solar still's productivity is found declined with the water depth increase. Elango and Murugavel (2015) compared the water depth increase on both types of solar distillers, single- and double-basin solar stills, and their investigation found the water depth increase lowered the productivity in both types of solar stills. Overall, the recommended water depth in the basin is ranged from 2 to 6 cm in the all the investigated cases. Although, at the nighttime and off-sun periods, the opposite is occurred, the productivity increases with the increase in water depth since the overnight productivity followed a reverse trend. At nocturnal, the depth of the basin water increases the volume, and the volumetric heat capacity of water increases. Thus, a low evaporation rate is attained. Through the nighttime, the desalination process is continued since the heat energy absorbed by the water is released. Consequently, more volume of water absorbs more energy.

Slope of the cover

Notably, the cover slope of solar still is proportionally affecting the still productivity since the appropriate inclination of the cover maximizes the absorption of sunlight. Thus, the still productivity is enhanced by the increased flow of condensed droplets. The suitable angle of the slope of the cover is minimizing the reflection of sunlight from the cover as well as adequate quantity of condensed droplets trickles down to the collector instead of falling in the basin water. The change in slope accordingly affects the volume of air concerning the water surface and the glass condensing cover. This is due to the increase in the slope tendencies to increase the volume of air to be saturated as well; thereby, this results in a reduction in the still efficiency and productivity. Also, the increase in the cover slope increases the number of reflected radiations through the cover, which further results in a depletion in the distillate yield. However, the too low slope of the cover, the distillate droplets on the cover will increase and fall into the basin instead of the distillate-collecting trough, which is undesirable. To add up, the increase in the slope means an increase in the surface area of the cover that results in an increase in thermal losses. Previous investigators recorded that the efficient solar still productivity is attained when the slope of the cover is the same as the latitude of the place (Singh and Tiwari 2004; Akash et al. 2000; Khalifa and Hamood, 2009).

Material and thickness of the cover

The transmissivity of the cover and its thickness is signified as substantial factors that influence the still productivity. The thermal conductivity of the cover impacts the still yield. Dimri et al. (2008) compared different types of still cover materials, namely glass, plastic and copper, and the maximum still productivity. According to their experimental investigation, the maximum still productivity is corresponding to copper, and the lowest productivity is corresponded to the use of plastic materials cover. However, due to the economic cost opportunities, glass cover is preferred. The data available in the cited articles are in lack of covering the topic of the type of cover effects on the still yield.

On the other hand, the glass plays a significant role on the transmittance of the high-frequency radiation, i.e., high energy. Also, blocking low-frequency radiations makes it an excellent material to select. In the experimental work conducted by Ghoneyem and Ileri (1997), they changed the glass cover thickness from 3 to 6 mm to check their tendency in the quality of the still performance. According to their experimental results, they recorded using a 3-mm-thick glass cover could be achieving the maximum still productivity. Such result is attributed to the heat transfer from the top cover surface into the internal still area that is enhanced with the less thick cover. However, a too-thin layer of glass is unfavorable since it declines the condensation rate at the glass cover. According to the data cited in the literature, the optimal glass cover thickness is ranged from 3 to 5 mm.

The temperature difference of water and glass cover

The temperature difference between the water in the basin and the glass cover is directly proportional to the solar still's productivity yield. The temperature difference is acting as a significant driving force for the mechanism of a solar still. Previous investigation by Abu-Hijleh (1996) founded that the cooling of the top glass cover by water could achieve an enhancement in the efficiency of the still by 6%. Also, Al-Garni (2012) recorded an enhancement in the still yield when a cooling water film is applied to the glass cover. Additionally, Murugavel et al. (2010) investigated the increase in the temperature difference between the basin water and glass cover by an electric resistance heater to heat water. Thus, the higher temperature of water enhances the evaporation rate and reduced temperature of glass cover, which increases the condensation rate. From such scattered work by various researchers, it could be concluded that the higher the water–glass cover temperature difference, the much solar distillate is collected.

Insulation material and thickness

Through the sunshine periods, excess heat means the basin water absorbs energy. With good insulation to the still basin, high energy will be stored; nevertheless, it could be lost as waste heat. Several insulation schemes could be applied as proper insulation materials (Tony 2021a). For instance, Hashim et al. (2009) checked various insulating materials such as plywood, glass wool–plywood, hay–plywood and 5 mm thick air gap. They compared their performance with a solar still in absence of insulation. The still productivity yield increases from 82 to 126% according to the type of insulated system. Karaghouli and Alnaser (2004) and Sahoo et al. (2008) found that the insulation material increases the solar still productivity. Sahoo et al. (2008) found the thermocouple could be used as an insulation system. Abdallah and Badran (2008) investigated the various insulation thicknesses, and their comparative study revealed that the 6 cm insulated thickness increased the productivity to 80% compared to 3 cm thick. The insulation could be attributed to this reduces the heat loss to the surroundings.

Table 3 displays representative comparative data for the above-mentioned and discussed solar still system types and design performances of both passive and active still types for solar desalting systems. All the systems are evaluated through the distillate yield output and efficiency criteria on a daily basis. As seen from the comparative analysis, the coupled systems with solar heating showed an increment in the still productivity compared to the conventional or other active still types. Notably, it is explored that the systems that are based on the coupled solar dealing systems showed higher yield as well as higher performances than of the single-basin still system. It is noteworthy to mention the latitude of the place of testing differs according to the place of conducting the experiments, which means different temperatures and solar intensities also affect the performance. Accordingly, the application of the solar desalination system is recommended for desalting processes and freshwater generation through an environmental protection and sustainable regime.

Suggestions for future scope

The detailed above-mentioned literature survey illustrated the aspects related to the solar desalination system. In this regard, novel solar desalting systems should be investigated to focus on solar radiation and improve the still performances. The more and more feasible cost-efficient systems should also be investigated. More attention should be paid

Table 3 Comparison of performance of different types of solar desalting systems

Solar still regime	Test place (Latitude location)	Operating conditions	Results and/or concluding remarks	Refs
Pyramid solar still	Bundoora, Victoria, Australia/ (37.69° S, 145.06° E)	-Ambient T 27ºC, -Maximum T 39ºC, -SI: 1256 W/m^2 - Still coupled with multi-inflated vertical tubes	- Efficiency 49.9%, -Productivity 2.5 L/m^2/day	Peter, (2011)
Triangular prism solar still	Bundoora, Victoria, Australia/ (37.69° S, 145.06° E)	-Ambient T 27ºC, -Maximum T 47ºC; -SI: 1256 W/m^2 - still is one inflated vertical tube only	- Efficiency 35.8%, -Productivity 1.5 L/m^2/day	Peter, (2011)
Hemispherical solar still	Coimbatore, India (11.0° N, 76.95° E)	-Basin area: 0.95 m × 0.1 m, -Hemispherical cover: 0.945 m × 0.2 m × 0.003 m, -Water flow over the cover	- Efficiency increased from 34 to 42% by cover cooling	Arun Kumar et al. (2012)
Basin still and external reflectors	Kurume, Japan (33.31° N, 130.50° E)	-Direct and diffuse radiation on horizontal surface - Reflectors Inclination of glass cover is 20° from horizontal, - Inclination of external reflector is 10°	-Efficiency increased from 70 to 100% by using reflectors	Tanak, (2009)
Weir-type cascade solar still with PCM storage medium	Zahedan, Iran (29.45° N, 60.88° E)	Absorber plate: 15 steps and 60 cm width, Evaporation surface area: 0.45 m^2	- On typical sunny days, both stills with and without PCM storage medium have the same productivity. On cloudy days, still with PCM yields increased	Farshad et al., (2010)
Pyramid-shaped solar still with fan	Tafila, Jordan (30.83° N, 35.61° E)	Basin area: 0.95 m^2, glass cover: 6 mm thick with 0.88 transmissivity, Water depth: 6 cm Fan: small fan operated with photovoltaic panels at low power consumption of approximately10 W	Productivity increased by 25% with using fan compared to the conventional one It is cost-effective way to use solar-operated fan to enhance evaporation rate	Tammneh and Madhar Taamneh, (2012)
Double slope still connected to the FPC	Amman Jordan (31.95° N, 35.91° E)	Square basin: 0.96 m^2, 0.02 m, Water depth, 0.03 m thick insulation, Glass cover: 4 mm thick at 451 inclinations, FPC: 7 parallel tubes with 12 mm inside diameter of 1.34 m^2 area at 451 inclinations	Productivity 2.3 compared to 1.5 kg/m^2/d in conventional still Efficiency 22.26% compared to 28.56% in conventional still	Badran et al., (2005)
Single slope still coupled to PTC	Cairo, Egypt (30.04° N, 31.23° E)	PTC: stainless steel (314) sheet, 4 mm thick, 80 cm long, copper pipe of 7/ 8 in. on its focal line Glass wool insulation, serpentine heat exchanger	-Productivity increased by 18% in comparison with a conventional passive still	Zeinab and Ashraf, (2007)

Table 3 (continued)

Solar still regime	Test place (Latitude location)	Operating conditions	Results and/or concluding remarks	Refs
Hybrid PVT active solar still	New Delhi, India (28.61° N, 77.20° E)	Single slope still of basin area 1 m^2, glass cover of area 1.16 m^2 and 4 mm thickness at 30° inclination PVT: 36 cells of 0.55 and 1.20 m^2 area of 0.0127 m diameter copper tubes - FPC: 2 collectors of 1.9 and 1.25 m^2 of 451 inclinations with 10 copper tubes of 1.8 m length and 1.27 cm diameter	- Productivity increased 3.5 times over passive still - Water depth: 0.05 m	Kumar and Tiwari, (2008)
Double effect multi-wick-type still	New Delhi, India (28.61° N, 77.20° E)	- Still: wick materials are of black jute cloth and black polythene	-Improvement in the productivity with the supplement over the conventional still -With the increase in the mass flow rate, productivity declined	Singh and Tiwari, (1992)
Thermal–electrical solar still	Moscow, Russia (55°45′N)	- Aluminum foil is used as an insulator	- Productivity increased to 68% with using reflectors & external condenser - Improvement efficiency is 43%	Monowe et al., (2011)
Stepped solar still	Kafrelsheikh, Egypt, (31.07°N)	- Mirror reflector material is used	- Yield 6.35 L/m^2. d - Improvement productivity to 75% over the conventional still without reflectors, - Efficiency 56%	Omara et al., (2013)
Corrugated wick solar still	Kafrelsheikh, Egypt, (31.07°N)		- Distillate yield 4.1 L/m^2. d -Productivity 145.5% - Efficiency 58% - Still yield 180% higher than the conventional still	Omara et al., (2016, 2015)
Stepped solar still trays	Kafrelsheikh, Egypt, (31.07°N)	- 5 mm tray depth and 100 mm tray width are used	- Distillate yield 7.4 L/m^2. d, - Efficiency 108% ~59% - The productivity 165% higher than that the conventional still and efficiency is 66%	El-Samadony et al., (2015)

Table 3 (continued)

Solar still regime	Test place (Latitude location)	Operating conditions	Results and/or concluding remarks	Refs
Air-bubbled solar still	New Delhi, India (28.61° N, 77.20° E)	- Single-basin solar still	- Distillate increased by 7.1% with ambient air bubbling of air, - Distillate increased by 33.5% with bubbling of ambient air after drying, - Distillate increased by 47.5% for bubbling of dry ambient air + cooling of glass cover - Distillate increased by 30.5% for cooling of glass cover only Distillate of compared reference, 33.5 and 47.5%	Pandey, (1984)
Single solar still connected with a PTC with fan	Sana'a, Yemen (15.36° N, 44.19° E)	-Solar radiation 1150 w/m^2, -T maximum 70 °C - Solar still: 190 cm and 50 cm, covered by 6 mm^2 transparent glass, -Fan: on the covering glass to increase the cooling rate	- Modified solar still increased by 177% compared to the conventional still - Distillate 0.67 L/m^2/hr. compared to unmodified 0.38 L/m2/hr	Aqlan et al., (2021)
Basin still with PTC and nanofluid	Tehran, Iran (35.72° N, 51.33° E)	- SI: 800 W/m^2, - T maximum 50 °C, - Working fluids contains Al_2O_3, Cu, CuO, TiO_2 & MWCNT) nanoparticles in oil as the base fluid had been used. The obtained results lead to	- Productivity (15.28 kg/h—15.46 kg/h) with nanofluid use -Efficiency (14.9% to 15.2%)	Rafiei et al., (2022)
Solar still with PCM	China (35.86° N, 104.19° E)	- PCM: NaCl aqueous solution contained micro capsulated phase transition material as the working fluid was used for thermal - Spray flash evaporation process into PCM addition	- Improved the water output ratio by 23.1% - lowering system energy consumption by 18.3%	Chen et al., (2021)
Solar still with a flat plate solar collector		- SI: 672 W/m^2 - The vacuum desalination system is coupled with an inner condenser and is driven by a solar energy source	Productivity 154.14 kg/d -Efficiency 1.36%	Wang et al., (2021)
Tubular solar still with PVT and PCM	Suez, Egypt (29.96° N, 32.54° E)	- Surface cooling is used	- Surface cooling should be managed carefully or lowering the performance - Efficiency improved by 46.85% compared with conventional tubular still system -Efficiency increased by 70% with fin use	Alatawi et al., (2022)

T: temperature, SI: solar radiation; PCM: phase change material; FPC: flat plate collector; PTC: parabolic trough collector for eliminating deposit, scaling and fouling concerns in future related research studies in order to attain economic, feasible, productive, novel solar desalting units. We investigate new design aspects to attain a greater temperature deviation between the basin cover and saline water, besides enlarging the evaporative surface area. Augmentation of the solar concentrating collectors with a tracking system to increase the solar radiation could be supplied. Developing new effective materials could enhance the performance rather than the nanoparticle's addition to the base fluid. Self-sustainable and long-lasting still also must be considered for a sustainable future.

Conclusion

A review of the research advances for the solar desalting over the solar still systems is explored. The research works dealing with various modifications for the conventional solar stills in order to enhance the productivity are investigated. A summary of the work studied is also presented to display the improvements conducted, and their corresponding still efficiency is attained. The most important parameters that enhance the efficiency include the climate conditions, basin water depth, basin cover slope, thickness and its material of construction, the temperature difference of water and glass cover and insulation material and thickness. It is summarized that the basin water depth increases the rate of evaporation, consequently increasing the still productivity. Also, the climate conditions and the latitude of the testing place could play a significant role and the basin cover tilt angle should be equal to the latitude angle of the location in order to attain a maximum solar radiation.

Moreover, cooling of the water on the glass could also control the heat loss, which further increases the still productivity yield. The insulation thickness should be in an optimal thickness to prevent or reduce heat loss and further enhance the efficiency of the still. Porous absorber materials showed an interment in the still yield.

Some modified and advanced design is illustrated using some advances and modifications to improve the efficiency and decrease the loss of radiation. Such advanced designs include the pyramid triangular solar still, tubular, double-basin, hemispherical and spherical solar still. The integrated system stills, such as coupling with a PVT, PCM and solar collectors, is efficient in improving the performance of the system.

From the future prospects regard, enhancing solar distillation technology could be attained via coupling with external equipment, arrangements of various variables and the application of novel designs with using advanced materials. This could reach to a practical and real scale of solar still applications.

Acknowledgements "The authors extend their appreciation to Prince Sattam bin Abdulaziz University for funding this research work through the project number (PSAU/2023/01/219422)."

Author contributions The authors are collected the data and contributed data comparative and analysis, calculations and final manuscript representation and writing.

Funding Prince Sattam bin Abdulaziz University through the project number (PSAU/2023/01/219422)."

Data Availability All data generated or analyzed during this study are included in this published article.

Declarations

Conflict of interest The authors confirm that there is no conflict of interest to declare.

References

Abad HKS, Ghiasi M, Mamouri SJ, Shafii MB (2013) A novel integrated solar desalination system with a pulsating heat pipe. Desalination 311:206–210

Abdel-Rehim ZS, Lasheen A (2007) Experimental and theoretical study of a solar desalination system located in Cairo Egypt. Desalination 217(1–3):52–64. https://doi.org/10.1016/j.desal.2007.01.012

Aboelmaaty N, Elhuseen H (2022) A detailed review of solar desalination systems with different enhancement methods. SVU-Int J Eng Sci Appl 3:49–63

Ahsan A, Imteaz M, Thomas UA, Azmi M, Rahman A, Daud NNN (2014) Parameters affecting the performance of a low cost solar still. Appl Energy 114:924–930

Akash BA, Mohsen MS, Nayfeh W (2000) Experimental study of the basin type solar still under local climate conditions. Energy Convers Manage 41:883–890

Alatawi I, Khaliq A, Heniegal AMA, Abdelaziz GB, Elashmawy M (2022) Tubular solar stills: recent developments and future. Sol Energy Mater Sol Cells 242:111785

Al-Karaghouli AA, Alnaser WE (2004) Performances of single and double basin solar-stills. Appl Energy 78:347–354

Aqlan AM, Aklan M, Momin AE (2021) Solar-powered desalination, a novel solar still directly connected to solar parabolic trough. Energy Rep 7:2245–2254

Al-Garni AZ (2012) Productivity enhancement of solar still using water heater and cooling fan. J Solar Energy Eng. https://doi.org/10.1115/1.4005760

Arunkumar T, Kabeel AE (2017) Effect of phase change material on concentric circular tubular solar still-Integration meets enhancement. Desalination 414:46–50

Arunkumar T, Jayaprakash R, Denkenberger D, Ahsan A, Okundamiya MS, Tanaka H, Aybar H (2012) An experimental study on a hemispherical solar still. Desalination 286:342–348

Ashour E, Tony MA (2015) Using a low-cost agriculture waste for cationic dye removal from an aqueous solution: equilibrium sorption. ERJ Eng Res J 38:73–79

Ashour EA, Tony MA (2017) Equilibrium and kinetic studies on biosorption of iron (II) and iron (III) Ions onto eggshell powder from aqueous solution. Appl Eng 1:65–73

Ashour EA, Tony MA (2020) Eco-friendly removal of hexavalent chromium from aqueous solution using natural clay mineral: activation and modification effects. SN Appl Sci 2:1–13

Ashour A, Tony MA, Purcell PJ (2014) Use of agriculture-based waste for basic dye sorption from aqueous solution: kinetics and isotherm studies. Am J Chem Eng 2:92–98

Awasthi A, Kumari K, Panchal H, Sathyamurthy R (2018) Passive Solar still: recent advancements in design and related performance. Environ Technol Rev 7:235–261

Badran OO, Al-Tahaineh HA (2005) The effect of coupling a flat-plate collector on the solar still productivity. Desalination 183(1–3):137–142. https://doi.org/10.1016/j.desal.2005.02.046

Chaouchi B, Zrelli A, Gabsi S (2007) Desalination of brackish water by means of a parabolic solar concentrator. Desalination 217:118–126

Chen Q, Xu G, Xia P (2021) The performance of a solar-driven spray flash evaporation desalination system enhanced by microencapsulated phase change material. Case Stud Thermal Eng 27:101267

Choi SU, Eastman JA (1995) Enhancing thermal conductivity of fluids with nanoparticles. Argonne National Lab. (ANL), Argonne, IL (United States)

Dev R, Tiwari GN (2009) Characteristic equation of a passive solar still. Desalination 245:246–265

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

Dimri V, Sarkar B, Singh U, Tiwari GN (2008) Effect of condensing cover material on yield of an active solar still: an experimental validation. Desalination 227:178–189

Dutt DK, Kumar A, Anand JD, Tiwari GN (1989) Performance of a double-basin solar still in the presence of dye. Appl Energy 32:207–223

Elango T, Murugavel KK (2015) The effect of the water depth on the productivity for single and double basin double slope glass solar stills. Desalination 359:82–91

El-Samadony YAF, Abdullah AS, Omara ZM (2015) Experimental Study of Stepped Solar Still Integrated with Reflectors and External Condenser. Exp Heat Trans 28(4):392–404. https://doi.org/10.1080/08916152.2014.890964

Farshad FT, Dashtban M, Moghaddam H, Razzaghi K (2010) Effect of water flow rate on internal heat and mass transfer and daily productivity of a weir-type cascade solar still. Desalination 260(1-3):239–247. https://doi.org/10.1016/j.desal.2010.03.037

Fath HES, El-Samanoudy M, Fahmy K, Hassabou A (2003) Thermal-economic analysis and comparison between pyramid-shaped and single-slope Solar still configurations. Desalination 159:69–79

Gad HE, El-Din SS, Hussien AA, Ramzy K (2015) Thermal analysis of a conical solar still performance: an experimental study. Sol Energy 122:900–909

Gupta RH, Rai RN, Tiwari GN (1988) Transient analysis of double basin solar still with intermittent flow of waste hot water in night. Energy Convers Manage 28(3):245–249

Hamdan MA, Musa AM, Jubran BA (1999) Performance of Solar still under Jordanian climate. Energy Convers Manage 40:495–503

Hashim AY, Al-Asadi JM, Wathiq AT (2009) Experimental investigation of symmetrical double slope single basin solar stills productivity with different Insulation. J Kufa-physics 1.2 (2009)

Ismail BI (2009) Design and performance of a transportable hemispherical solar still. Renewable Energy 34:145–150

Kabeel AE (2009) Performance of Solar still with a concave wick evaporation surface. Energy 34:1504–1509

Kabeel AE, Hamed MH, Omara ZM (2012a) Augmentation of the basin type solar still using photovoltaic powered turbulence system. Desalin Water Treat 48:182–190

Kabeel AE, Khalil A, Omara ZM, Younes MM (2012b) Theoretical and experimental parametric study of modified stepped solar still. Desalination 289:12–20

KabeelTeamahAbdelgaiedAziz AEMAMGBA (2017) Modified pyramid solar still with v-corrugated absorber plate and PCM as a thermal storage medium. J Cleaner Product 161:881–887

Kannan R, Selvaganesan C, Vignesh M, Babu BR, Fuentes M, Vivar M, Skryabin I, Srithar K (2014) Solar still with vapor adsorption basin: Performance analysis. Renew Energy 62:258–264

Kassem TK (2016) Optimization the performance of single basin solar still with corrugated wick surface at high places. Int Res J Eng Technol 3:1094–1024

Katekar VP, Deshmukh SS (2020) A review on research trends in Solar still designs for domestic and industrial applications. J Clean Prod 257:120544

Kiatsiriroat T, Bhattacharya SC, Wibulswas P (1987) Performance analysis of multiple effect vertical still with a flat plate solar collector. Sol Wind Technol 4:451–457

Kumar PV, Kumar A, Prakash O, Kaviti AK (2015) Solar stills system design: a review. Renew Sustain Energy Rev 51:153–181

Le TH, Pham MT, Hadiyanto H, Hoang AT (2021) Influence of various basin types on performance of passive Solar still: a review. Int J Renew Energy Dev 10:789–802

Manikandan V, Shanmugasundaram K, Shanmugan S, Janarthanan B, Chandrasekaran J (2013) Wick type solar stills: a review. Renew Sustain Energy Rev 20:322–335

Manikandan V, Shanmugasundaram K, Shanmugan S, Janarthanan B, Chandrasekaran J (2014) Energy, exergy and entropy analysis of a single-slope floating-cum-tilted wick-type solar still. Int J Ambient Energy 35:2–12

Manokar AM, Winston DP, Kabeel AE, Sathyamurthy R (2018) Sustainable fresh water and power production by integrating PV panel in inclined Solar still. J Clean Prod 172:2711–2719

Monowe P, Masale M, Nijegorodov N, Vasilenko V (2011) A portable single-basin solar still with an external reflecting booster and an outside condenser. Desalination 280(1-3):332–338. https://doi.org/10.1016/j.desal.2011.07.031

Mansour SA, Tony MA, Tayeb AM (2019) Photocatalytic performance and photodegradation kinetics of Fenton-like process based on haematite nanocrystals for basic dye removal. SN Appl Sci 1:1–8

Massachusetts water resources authority, (2007) Water Quality Update, Boston

Murugavel S, Sivakumar J, Riaz Ahamed KKSK, Chockalingam KS (2010) Single basin double slope solar still with minimum basin depth and energy storing materials. Appl Energy 87(2):514–523. https://doi.org/10.1016/j.apenergy.2009.07.023

Naroei M, Sarhaddi F, Sobhnamayan F (2018) Efficiency of a photovoltaic thermal stepped solar still: experimental and numerical analysis. Desalination 441:87–95

Nayi KH, Modi KV (2018) Pyramid solar still: a comprehensive review. Renew Sustain Energy Rev 81:136–148
Omara ZM, Kabeel AE, Younes MM (2013) Enhancing the stepped solar still performance using internal reflectors. Desalination 314:67–72. https://doi.org/10.1016/j.desal.2013.01.007
Omara ZM, Kabeel AE, Abdullah AS, Essa FA (2016) Experimental investigation of corrugated absorber solar still with wick and reflectors. Desalination 381:111–116. https://doi.org/10.1016/j.desal.2015.12.001
Omara ZM, Abdullah AS, Dakrory T (2017) Improving the productivity of Solar still by using water fan and wind turbine. Sol Energy 147:181–188
Panchal HN, Shah PK (2011) Charperformance analysis of different energy absorbing plates on solar stills. Iranian Iranica J Energy Environ 2:297–301
Pandey GC (1984) Effect of dried and forced air bubbling on the partial pressure of water vapour and the performance of Solar still. Sol Energy 33:13–18
Philip P, Samuel V, Thenmozhi J, Nagaraj D, Ramesh M, Muniaraj N, Arunachalam (2016) Determination of critical density in Culex tritaeniorhynchus Giles 1901 (Diptera: Culicidae) as a deciding factor influencing the transmission of Japanese encephalitis virus in southern India. ENTOMON 41(2):125–138. https://doi.org/10.33307/entomon.v41i2.172
Pillai R, Libin AT, Mani M (2015) Study into solar-still performance under sealed and unsealed conditions. Int J Low-Carbon Technol 10:354–364
Rafiei A, Loni R, Mahadzir SB, Najafi G, Sadeghzadeh M, Mazlan M, Ahmadi MH (2022) Hybrid solar desalination system for generation electricity and freshwater with nanofluid application: energy, exergy, and environmental aspects. Sustainable Energy Technol Assess 50:101716
Rai SN, Tiwari GN (1983) Single basin solar still coupled with flat plate collector. Energy Convers Manage 23:145–149
Sadineni SB, Hurt R, Halford CK, Boehm RF (2008) Theory and experimental investigation of a weir-type inclined Solar still. Energy 33:71–80
Sahota L, Tiwari GN (2016) Effect of Al2O3 nanoparticles on the performance of passive double slope solar still. Sol Energy 130:260–272
Samee MA, Mirza UK, Majeed T, Ahmad N (2007) Design and performance of a simple single basin solar still. Renew Sustain Energy Rev 11:543–549
Sampathkumar K, Arjunan TV, Pitchandi P, Senthilkumar P (2010) Active solar distillation—A detailed review. Renew Sustain Energy Rev 14:1503–1526
Sathyamurthy R, Nagarajan PK, Kennady H, Ravikumar TS, Paulson V, Ahsan A (2014) Enhancing the heat transfer of triangular pyramid solar still using phase change material as storage material. Front Heat Mass Transfer (FHMT) 5:1–5
Sathyamurthy R, Harris Samuel DG, Nagarajan PK, Arunkumar T (2016) Geometrical variations in solar stills for improving the fresh water yield—A review. Desalin Water Treat 57:21145–21159
Shanmugan S, Manikandan V, Shanmugasundaram K, Janarathanan B, Chandrasekaran J (2012) Energy and exergy analysis of single slope single basin solar still. Int J Ambient Energy 33:142–151
Shmroukh AN, Ookaara S (2021) Stepped solar stills' development and improvement for seawater desalination. SVU-Int J Eng Sci Appl 2:26–36
Sahoo BB, Sahoo N, Mahanta P, Borbora L, Kalita P, Saha UK (2008) Performance assessment of a solar still using blackened surface and thermocol insulation. Renew Energy 33(7):1703–1708. https://doi.org.10.1016/j.renene.2007.09.009
Singh AK (2021) An inclusive study on new conceptual designs of passive solar desalting systems. Heliyon 7:e05793
Singh AK, Tiwari GN (1992) Performance study of double effect distillation in a multiwick solar still. Energy Conversion Manag 33(3):207–214. https://doi.org/10.1016/0196-8904(92)90127-I
Singh HN, Tiwari GN (2004) Monthly performance of passive and active solar stills for different Indian climatic conditions. Desalination 168:145–150
Singh SK, Bhatnagar VP, Tiwari GN (1996) Design parameters for concentrator assisted solar distillation system. Energy Convers Manage 37:247–252
Sivakumar V, Sundaram EG (2013) Improvement techniques of Solar still efficiency: a review. Renew Sustain Energy Rev 28:246–264
Sodha MS, Kumar A, Tiwari GN, Pandey GC (1980) Effects of dye on the performance of a solar still. Appl Energy 7:147–162
Solanki B, Patel J (2017) Recent developments in solar desalination with thermal energy storage. Int J Eng Res Appl 7:28–36
Suresh C, Shanmugan S (2019) Effect of water flow in a solar still using novel materials. J Therm Anal Calorim. https://doi.org/10.1007/s10973-019-08449-5
Tabrizi FF, Dashtban M, Moghaddam H, Razzaghi K (2010) Effect of water flow rate on internal heat and mass transfer and daily productivity of a weir-type cascade solar still. Desalination 260:239–247
Taha ATH (2010) Estimation of hourly global solar radiation in Egypt using mathematical model. Misr J Agric Eng 27:2033–2047
Tahoun BA, Mansour S, Tony MA (2022) Development and characterization of conjugated Polyaniline/Co-doped ZnO nanocomposites for enhanced dye oxidation from wastewater. ERJ Eng Res J 45:101–110
Taamneh Y, Taamneh MM (2012) Performance of pyramid-shaped solar still: Experimental study. Desalination 291:65–68. https://doi.org/10.1016/j.desal.2012.01.026
Tayeb AM, Tony MA, Mansour SA (2018) Application of Box-Behnken factorial design for parameters optimization of basic dye removal using nano-hematite photo-Fenton tool. Appl Water Sci 8:1–9
Thabet RH, Tony MA, El Sherbiny SA, Ali IA, Fouad MK (2020) Catalytic oxidation over nanostructured heterogeneous process as an effective tool for environmental remediation. IOP Conf Series: Mater Sci Eng 975:012004
Thabet RH, Fouad MK, Ali IA, El Sherbiney SA, Tony MA (2021) Magnetite-based nanoparticles as an efficient hybrid heterogeneous adsorption/oxidation process for reactive textile dye removal from wastewater matrix. Int J Environ Anal Chem 103(11):2636–2658
Tiwari GN, Garg HP (1985) Effect of water flow over the glass cover of a single basin solar still with an intermittent flow of waste hot water in the basin. Energy Convers Manage 25:315–322
Tiwari GN, Sahota L (2017) Advanced solar-distillation systems: basic principles, thermal modeling, and its application. Springer
Tiwari AK, Tiwari GN (2007) Annual performance analysis and thermal modelling of passive Solar still for different inclinations of condensing cover. Int J Energy Res 31:1358–1382
Tiwari GN, Dimri V, Singh U, Chel A, Sarkar B (2007) Comparative thermal performance evaluation of an active solar distillation system. Int J Energy Res 31:1465–1482
Tiwari M, Bajpai VK, Sahasrabuddhe AA, Kumar A, Sinha RA, Behari S, Godbole MM (2007) Inhibition of N-(4-hydroxyphenyl)retinamide-induced autophagy at a lower dose enhances cell death in malignant glioma cells. Carcinogenesis 29(3):600–609. https://doi.org/10.1093/carcin/bgm264
Tony MA (2020a) Central composite design optimization of Bismarck Dye oxidation from textile effluent with Fenton's reagent. Appl Water Sci 10:1–9

Tony MA (2020b) From biomass residue to solar thermal energy: the potential of bagasse as a heat storage material. Euro-Mediterranean J Environ Integrat 5:1–9

Tony MA (2020c) Zeolite-based adsorbent from alum sludge residue for textile wastewater treatment. Int J Environ Sci Technol 17(5):2485–2498

Tony MA (2021a) Nexus approach: ZSM-12 derived from industrial waste into microencapsulated in organic wax for solar energy storage system. Energy Sour, Part a: Recov, Util, Environ Effects. https://doi.org/10.1080/15567036.2021.2001119

Tony MA (2021b) Recent frontiers in solar energy storage via nanoparticles enhanced phase change materials: Succinct review on basics, applications and their environmental aspects. Energy Storage 3:e238

Tony MA (2021c) Solar concentration for green environmental remediation opportunity—international review: advances, constraints and their practice in wastewater treatment. Int J Environ Anal Chem 103(11):2568–2600

Tony MA (2021d) An industrial ecology approach: green cellulose-based bio-adsorbent from sugar industry residue for treating textile industry wastewater effluent. Int J Environ Anal Chem 101:167–183

Tony MA (2022) Valorization of undervalued aluminum-based waterworks sludge waste for the science of "The 5 Rs' criteria." Appl Water Sci 12:1–30

Tony MA, Lin L-S (2020a) Iron recovery from acid mine drainage sludge as Fenton source for municipal wastewater treatment. Int J Environ Anal Chem 102(6):1245–1260

Tony MA, Lin L-S (2020b) Performance of acid mine drainage sludge as an innovative catalytic oxidation source for treating vehicle-washing wastewater. J Dispers Sci Technol 43(1):50–60

Tony MA, Lin L-S (2021) Iron coated-sand from acid mine drainage waste for being a catalytic oxidant towards municipal wastewater remediation. Int J Environ Res. https://doi.org/10.1080/15567036.2021.2001119

Tony MA, Mansour SA (2020a) Solar photo-Fenton reagent with nanostructured iron oxide for Bismarck dye oxidation: an Egyptian apparel case study. Int J Environ Sci Technol 17:1337–1350

Tony MA, Mansour SA (2020b) Sunlight-driven organic phase change material-embedded nanofiller for latent heat solar energy storage. Int J Environ Sci Technol 17:709–720

Tony MA, Tayeb AA (2016) Response surface regression model in optimization of alum sludge drying facility: solar-Fenton's reagent dewatering. Int J Chem Eng Appl 7:331

Tony MA, Purcell PJ, Zhao Y, Tayeb AM, El-Sherbiny MF (2015) Kinetic modeling of diesel oil wastewater degradation using photo-Fenton process. Environ Eng Manag J (EEMJ) 14:11–16

Tony MA, Tayeb A, Zhao YQ (2016) An alternative arrangement for the alum sludge management: minimizing waste with low-cost solar techniques. Am J Chem Eng 4:30–37

Velmurugan V, Gopalakrishnan M, Raghu R, Srithar K (2008) Single basin solar still with fin for enhancing productivity. Energy Convers Manage 49:2602–2608

Velmurugan V, Pandiarajan S, Guruparan P, Subramanian LH, Prabaharan CD, Srithar K (2009) Integrated performance of stepped and single basin solar stills with mini solar pond. Desalination 249:902–909

Wang L, Zheng H, Zhao Y, Ma X (2021) Solar-driven natural vacuum desalination system with inner condenser. Appl Therm Eng 196:117320

Wilf M, Awerbuch L (2007) The guidebook to membrane desalination technology: reverse osmosis, nanofiltration and hybrid systems: process, design, applications and economics. Balaban Desalination Publications

World Health Organization (WHO), Desalination for Safe Water Supply, World Health Organization, Geneva, 2007.

Zhao YQ, Keogh C, Tony MA (2009) On the necessity of sludge conditioning with non-organic polymer: AOP approach. J Residuals Sci Technol 6:151–155