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Review article

Performance of solar still units and enhancement techniques: A review investigation

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ABSTRACT

Drinking water requirements are rapidly increasing while the availability of drinking water is decreasing. Overcoming this problem requires a sustainable energy source, such as solar energy, to desalinate untreated water. The most essential and simplest application of brackish water desalination is solar distillation. However, a limitation of the widespread use of solar distillation is its low yield. Therefore, several research attempts were made to enhance its productivity. Current work deals with a comprehensive review study on the solar distillation system. It presents the most critical factors and parameters affecting the productivity of solar stills and adjustments made to improve daily yield. Weather factors cannot be controlled but affect the performance of solar stills, such as solar radiation, ambient air temperature, and wind speed, while the operational and design parameters of solar stills can be manipulated, such as controlling the depth of the aquarium water and the thickness and angle of inclination of the glass cover. Improve evaporation and condensation mechanisms by increasing the basin water temperature and decreasing the distiller cover temperature, respectively, and tightening the thermal insulation to reduce heat loss to the surroundings. It was concluded that the productivity of solar stills may improve by increasing solar radiation and wind speed, as well as by decreasing the ambient air temperature. As for operational parameters, productivity improves as the depth of the water decreases and the thickness of the cover decreases. Designally, single-slope solar stills captured more solar radiation at both high and low-latitude stations than their double-slope solar still counterparts. Adding a packed layer to the basin's bottom or attaching a rotating shaft to the basin's surface can also enhance the solar distillation system. It has also been shown that the most effective design approach to improving the performance of solar stills is to use a slowly rotating drum inside the still, which can result in a 200–300 % increase in water production. The review will help researchers understand previous designs and develop a new set of characteristics to increase the solar still system's thermal efficacy and produce more distillate. Additionally, limitations are discussed along with suggestions for future research that might improve the productivity and performance of the basin solar still typical operating conditions.

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Nomenclatures:

Abbreviation	Items	Unit
WHO	World Health Organization	–
IWMI	International Water Management Institute	–
PCM	Phase change materials	–
AI	Artificial intelligence	–
LSTM	Long short-term memory	–
MFO	Moth Flame Optimizer	–
Cu_2O	Copper oxide	–

1. Introduction

Freshwater scarcity has emerged as a crucial concern and a top priority for worldwide efforts, as existing supplies are rapidly dwindling. The United Nations Environment Programme's data on freshwater shortages between 1995 and 2025, depicted in Table 1, reveals an anticipated substantial increase in the prevalence of these shortages by 2025 [1]. While developed regions generally have access to freshwater, obtaining it in remote and rural areas presents a significant challenge. Moreover, industrial development has led to heightened pollution levels in potable water [2,3]. Consequently, securing freshwater has become one of the most significant hurdles for people living in isolated and arid regions [4].

Supplying potable water to underserved regions can lead to economic benefits with lower healthcare and insurance expenses, which in turn reduces costs associated with establishing and maintaining freshwater facilities. An investment in water purification infrastructure may ensure the availability of potable water for households, ultimately saving lives among low-income populations in rural, urban, or even border military zones [5]. The World Health Assembly report indicates that more than a billion people lack access to safe drinking water, and most of this is in rural areas where constructing freshwater facilities is challenging [6]. 32.5 % of the world's urban population suffers from water scarcity, and scarcity is seasonal and permanent. India had the largest share of scarcity, followed by China, as shown in Fig. 1. The United Nations' research, as depicted in Fig. 2, reveals that many developing countries, for example, in the Middle East and North Africa, are grappling with freshwater scarcity issues. Rapid population growth, coupled with intensified agricultural and industrial activities, has contributed to the contamination and exhaustion of drinkable water resources, so the total per capita water withdrawals decreased from 2000 to 2018. Freshwater makes up about 2.5 % of the total water resources on Earth, while water covers about 70 % of the Earth's surface. Generally, seawater salinity levels range between 3500 and 4500 ppm. The World Health Organization (WHO) stipulates that the dissolved salt content of drinking water should not exceed 500 ppm., with a maximum of 1000 ppm permissible in certain situations [7]. As a result, seawater is not fit for human consumption, agriculture, or industry. Nevertheless, many countries use desalinated seawater as useable water [8]. Traditional desalination processes generate approximately 23000000 m^3 of drinking water daily worldwide [9]. However, these processes consume vast quantities of fossil fuels. To produce 13000000 m^3/day of useable water, according to reports received, 13000000 tons of oil must be burned every year [10]. In Russia, saltwater treatment processes are frequently employed in various industries and applications [11]. Desalination typically involves membrane-based techniques using semi-permeable membranes and distillation techniques utilizing phase change [12].

Reports from the Renewable Energy Policy Network for the 21st Century revealed that fossil fuels remain the primary energy source to satisfy global demand, accounting for 78.3 % of the total. Renewable energy sources make up 19.2 %, and nuclear fuel energy constitutes the remaining 2.5 % [13], as depicted in Fig. 3.

Next-generation energy infrastructure should prioritize affordability, dependability, and security while providing consistent energy access for people, especially in isolated and countryside locations. This can be realized by creating energy systems focused on green

Table 1
The ratio of water consumption and withdrawal to total available water [1].

Process	1995			2025		
	Agricultural	Industrial	Domestic	Agricultural	Industrial	Domestic
Water withdrawal						
Africa	63	8.1	4.4	53.1	18	6
Asia	80	6.9	9.9	72	9.5	15.2
Europe	37.4	14.7	44.8	37.2	14	45.8
North America	43.5	10.7	41.5	41.4	12.3	41.3
North America	58.6	17.2	15.4	44.2	22.7	23.8
Australia and Oceania	51	10.9	23.5	46.8	11.3	26.1
World	66.1	9.1	19.9	60.9	11.6	22.3
Water consumption						
Africa	63.8	1.5	0.8	60.5	3.4	1.3
Asia	91	1.5	2.3	88.4	1.8	4.1
Europe	71.4	5.6	15.3	66.8	4.3	22.3
North America	75.1	5	7.2	72.4	6	7.5
North America	76.4	4	3.2	67.4	4.7	8.3
Australia and Oceania	69.1	2.2	3.1	64.1	2.1	6.4
World	84.5	2.4	4	81.5	2.7	6.1

energy sources [14]. As a result, investigations have investigated utilizing renewable resources like sunlight to generate drinkable water. Solar power offers an environmentally responsible and long-lasting solution that can be applied in multiple manners, such as directly tapping into thermal energy without conversion, turning it into electricity, or using sun-powered technologies by capturing sunlight via photovoltaic cells on solar panels [15]. J.K. Choi et al. [16] highlighted that Earth receives an annual solar energy input equivalent to nearly tenfold the combined reserves of fossil fuels and uranium. The sun's energy received by Earth each year is estimated at about 82×10^{15} W, which surpasses the worldwide energy usage in 2006 by a factor of over 5200 [17]. Numerous countries benefit from considerable solar resources, especially in the MENA area [18]. Considering the consumption patterns and ecological consequences of using carbon-heavy fuels, merging solar power with seawater purification to create drinkable water offers a viable alternative. Solar water distillation units that produce clean water from saline sources exemplify one such use of solar technology. The current review includes surveying the distillation techniques using solar energy and freshwater augmentation techniques in solar still. This review seeks to assess prior research on solar stills and performance-influencing factors to identify significant parameters that influence the overall performance.

2. Distillation using solar energy

Solar distillation transforms various water sources, including saline, unprocessed, tainted, or semi-salty liquids, into safe, consumable water by tapping into costless solar power, eliminating fuel usage. The purification method features two distinct stages: evaporation and condensation, effectively removing unwanted substances such as minerals and microorganisms, resulting in clean drinking water. This approach contributes to mitigating climate change and reducing greenhouse gas emissions [19]. Solar desalination technologies mimic Earth's inherent water cycle, which includes evaporation and condensation processes. Figs. 4 and 5 showcase the inherent water purification cycle and individual solar desalination in that order.

2.1. Solar water still strategies

Solar desalination setups can be grouped into a pair of categories: passive and active. Passive devices depend exclusively on sunbeams as the power source and avoid using mechanical equipment or conventional power supplies. A key limitation of passive devices is their reduced effectiveness. To tackle the reduced output concern, an assortment of active solar distillation devices has been enhanced, offering extra heat energy to the basin water of the solar distiller from outside means. This heightens the vaporization velocity, resulting in better output levels. External methods may encompass sun-powered gatherers, solar energy boards, and focusing mechanisms combined with the apparatus parts [16]. A depiction of the various sun-powered device classifications can be found in Fig. 6.

A. Passive Solar Water Still

Passive solar stills represent a traditional method of distillation, relying solely on solar radiation as the energy source to heat saline water directly. These systems do not incorporate any mechanical devices or conventional energy sources. With a simple design, passive solar stills offer an economical solution for producing pure water without the need for bottles, filtration, pretreatment, or accessory components. However, due to their operation at low temperatures, passive solar stills exhibit limited productivity [20,21], as illustrated in Fig. 5.

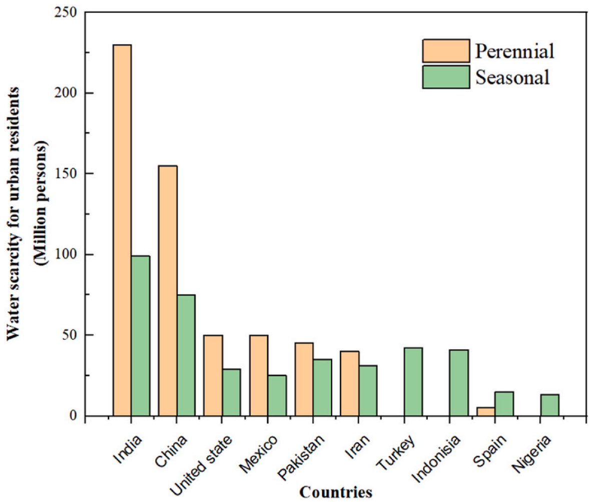

Fig. 1. Urban populations experience water scarcity at the national level International Water Management Institute (IWMI) [2].

B. Active Solar Water Still

Active solar water still usually classified into three types.

1. High-temperature units: These systems involve connecting the distillation apparatus to an external solar collector.
2. Preheated input systems: In this setup, the still's basin is supplied with heated water from multiple sources at a steady rate.
3. Nocturnal active production: This method involves providing the still's basin with heated water once daily, either by using stored solar power at night or tapping into waste heat from other sources.

Elevating the temperature of the basin water creates a more significant difference between evaporation and condensation areas, improving the efficiency of both processes. To achieve this, additional thermal energy can be obtained from sources like solar collectors. The connection between the solar still and collector can be either through natural circulation (thermosiphon) or forced circulation (using a pump). Active solar stills use external thermal energy (solar radiation) to boost the vaporization rate, resulting in higher productivity than passive solar stills. These systems consist of a glass cover, basin water, an external solar collector, and a pump. Saltwater is circulated between the distillation apparatus and the solar collector, where it acquires heat from the continuously falling solar radiation. This heated water then returns to the distillation unit. As the saltwater evaporates, it condenses on the transparent cover and is gathered before being directed into a collection channel [22], as illustrated in Fig. 7.

2.2. Working principle of solar still

Solar distillers utilize core concepts of evaporation and condensation. Sunlight passes through a glass layer and arrives at the container lining, where the sun's power is soaked up and conveyed to the briny water within the container through heat convection. A minor portion of this energy disperses into the environment. Ongoing heat conveyance elevates the brackish water temperature, leading to vaporization because of the greenhouse phenomenon. The transfer of energy from the water's surface in the container to the cover occurs via three methods—heat circulation (convection), radiant emission (radiation), and vaporization—with the latter being the most significant. The water vapor abandons detrimental contaminants and minuscule life forms in the container. This vapor turns back into liquid on the inner part of the see-through lid, discharging hidden warmth during the phase change (latent heat). The liquid then moves into a gathering channel and eventually into a predetermined receptacle. Fig. 5 illustrates a single-slope solar distiller [8].

2.3. Parameters affecting the performance of solar distillation

Solar still's performance function is based on three distinct variable categories: weather-related (climatic), procedural (operational), and structural elements (design) parameters, as illustrated in Fig. 8. The most critical weather-related factor is solar radiation, alongside other variables like air temperature and wind velocity. Structural elements (design parameters) can be effectively managed and enhanced, playing a vital role in solar stills performance. These elements encompass the depth of the water reservoir, the thermophysical properties of the materials involved in the manufacture of the structure of the solar distiller, the angle of inclination for the covering, and the dimensions and form of the evaporators, among others [23]. Procedural variables (operational parameters) involve aspects such as the evaporator's alignment, the saltiness of the water, and the initial temperature of the water in the basin [14].

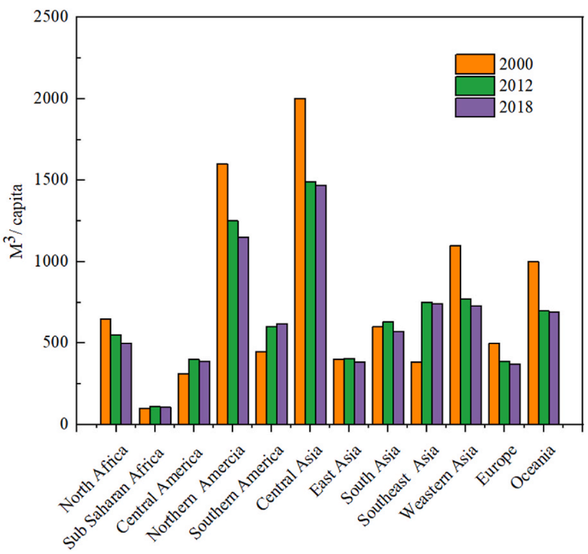

Fig. 2. Depletion rate of freshwater resources [3].

2.3.1. *Meteorological parameters*

2.3.1.1. Solar radiation intensity. Explorations into the influence of sunlight on the efficiency of solar distillation systems have been conducted by a variety of researchers. These inquiries revealed that, in the summertime, sunlight plays a crucial role in the functionality of these systems. Generally, their effectiveness grows with stronger sunlight [24]. Badran and Abu-Khader [25] experimentally and theoretically examined a specific type of solar still. They found that its performance improved alongside the strength of the sunlight intensity, peaking at noon. Al Muhanna [26] investigated a hybrid solar distiller equipped with an additional cooling system under extreme environmental conditions. This study showed that sunlight strength was a key factor in the system's efficiency, peaking at about 69.2 % at 2:00 p.m. Singw and colleagues [27] found that increased sunlight intensity led to improved solar still performance due to higher water temperatures, which promoted evaporation. Alwan's team [28] studied a unique solar still design in Russia during the summer of 2019, discovering that local weather conditions such as solar radiation intensity significantly affected the device's productivity, with the best results recorded in July 2019 with peak sunlight, as illustrated in Fig. 9.

2.3.1.2. Ambient air temperature. Various studies have explored the role of temperature in shaping the efficiency and output of solar distillation systems. H. Al-Hinai and colleagues [29] developed a model for anticipating the performance of a basic solar distiller by considering diverse weather, structural (design), and operational factors in the context of Oman's climate. Their findings showed that freshwater production rose by 8.2 % when the temperature shifted from 30 to 32 °C. K. Gang Xiao and associates [30] argued that higher ambient temperatures contributed to increased solar distillation results, as the growing temperature gap between the water and the cover intensified evaporation and the amount of distilled water. In contrast, Voropoulos et al. [31] and Omar O. Badran [32] discovered that decreasing the surrounding air temperature led to better productivity. These variations could be due to reduced air temperatures or faster air movements, which create a larger temperature disparity between the water in the basin and the solar still's glass covering.

2.3.1.3. Wind speed. The influence of wind velocity on the efficiency of solar distillers is relatively small, as productivity tends to increase when the temperatures of the cover decrease [33]. A lower transparent cover temperature results in a larger temperature gap between the cover and the water, which enhances heat transfer by convection within the solar distiller. Furthermore, the convective heat transfer from the cover to the surrounding environment rises when the convection and evaporation heat transfer from the water basin compensate for greater wind velocities [33]. In contrast, A. A. El-Sebaii [34] performed a theoretical analysis of how wind speed impacts the production of fresh water in Tanta's climate, using two multi-effect passive solar still models. The study discovered that daily productivity increased with wind speed. Soliman [35] examined a roof-type solar distiller under forced convection conditions to determine the effects of wind speed on productivity by integrating mass and heat transfer methods. When wind flows parallel to the 10° inclined glass cover at varying speeds, the yield of distilled water changes as the glass cover temperature drops. The evaporation rate rises as the temperature differential between the water basin and glass cover widens and wind speed increases. A. A. El-Sebaii [36] explored the impact of wind velocity on solar still performance with different water basin masses, finding performance improvements with increasing wind velocity. A. Safwat Nafeh et al. [37] investigated key factors influencing solar still performance in the Gulf of Suez's weather conditions. The mathematical model demonstrated a 13 % decrease in solar still productivity when wind velocity increased from 1 to 9 m/s. R.M. Reddy and K.H. Reddy [38] performed an analytical investigation of how wind velocity affects various heat transfer coefficients involved in the upward heat flow process of stationary solar distillers. The findings revealed that as wind velocity increases for specific ambient air and basin water temperatures, the radiation heat transfer coefficient between the water basin and the glass cover decreases. Furthermore, the wind velocity's impact on the evaporation heat transfer coefficient between the water basin and the glass cover is minimal.

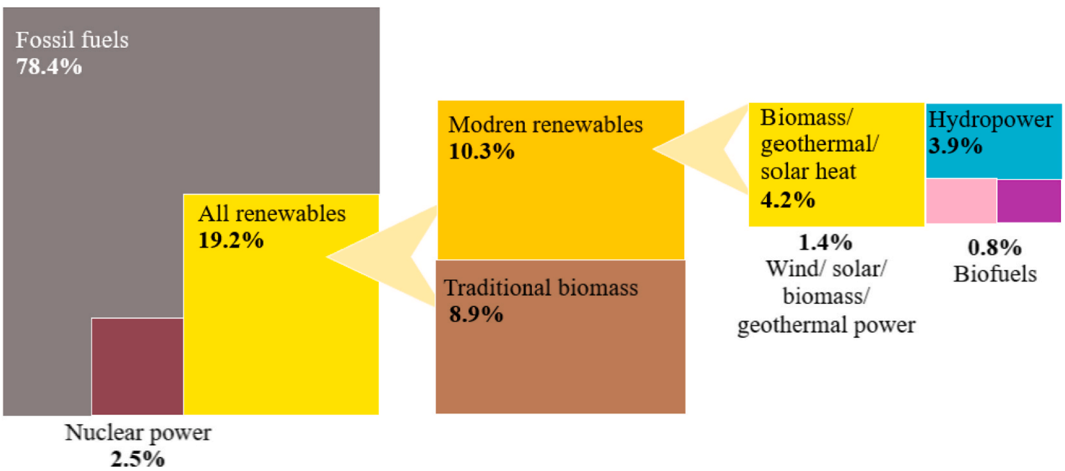

Fig. 3. Estimated the share of renewable energy consumption out of total global energy consumption [4].

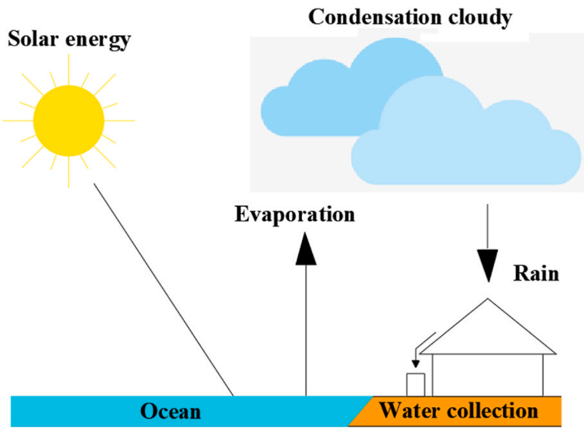

Fig. 4. Desalination process principle in nature [6].

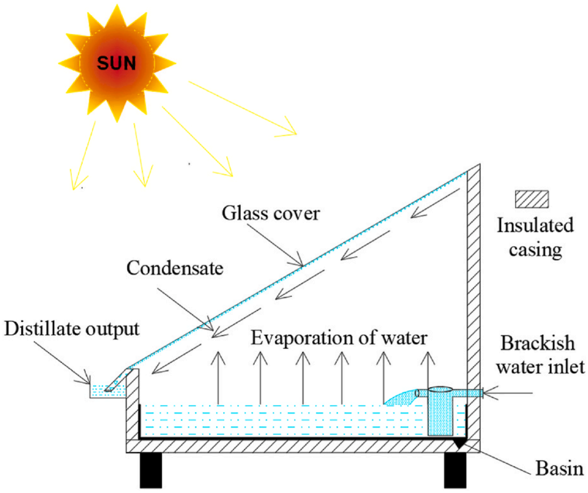

Fig. 5. Scheme for a passive single slope - single basin solar stills [7].

2.3.1.4. Dust and cloud. The influence of dust on solar stills was explored by Hottel and Woertz [39] in an experiment conducted in Boston. Their findings indicated a 1 % reduction in solar radiation intensity due to the presence of dust on glass covers inclined at 30°. Adel A. Hegazy [40] also examined the impact of dust build-up on the light transmittance of glass covers with varying angles. The study established a strong connection between dust accumulation and the angle of the glass, with increased dust leading to decreased light transmission. Zamfir et al. [41] performed an analysis to determine the effect of cloud cover on the average monthly performance of solar water collectors. The data revealed that clear days had higher efficiency compared to overcast conditions. El-Nashar [42] investigated the consequences of dust collection on the efficiency of evacuated tubes in flat plate water collectors, observing a 10 % decrease in light transmission during the summer and a 6 % decrease during the winter. The study further noted that a lack of cleaning resulted in a 70 % annual reduction in permeability [43].

2.3.2. Design and operation parameters

2.3.2.1. Single and double-slope solar stills. AL-Karaghouli and Alnaser [44] performed experimental and theoretical analyses on two single-sloping solar distiller designs (double basin and single basin), as shown in Fig. 10. Both types had the same basin area, resulting in an effective area of 0.45 m^2 for each. The double basin's solar still glass cover had a 12° tilt from the horizontal plane, while the single basin solar still's glass cover had a 36° tilt. The findings revealed a 40 % productivity increase for the double-basin solar still compared to the single-basin solar still. In another study, Eduardo et al. [45] built a laboratory-scale double-slope solar distiller with regulated water flow at varying glass temperatures. They compared this modified solar distiller to experimental data from single slope designs, finding no significant productivity differences between the double slope and single slope solar distillers with comparable glass cover and water temperatures. Garg and Mann [46] conducted experiments to examine the impact of design parameters on single-slope and double-slope solar distiller performance in dry-weather regions in India. They determined that single-sloped solar stills captured

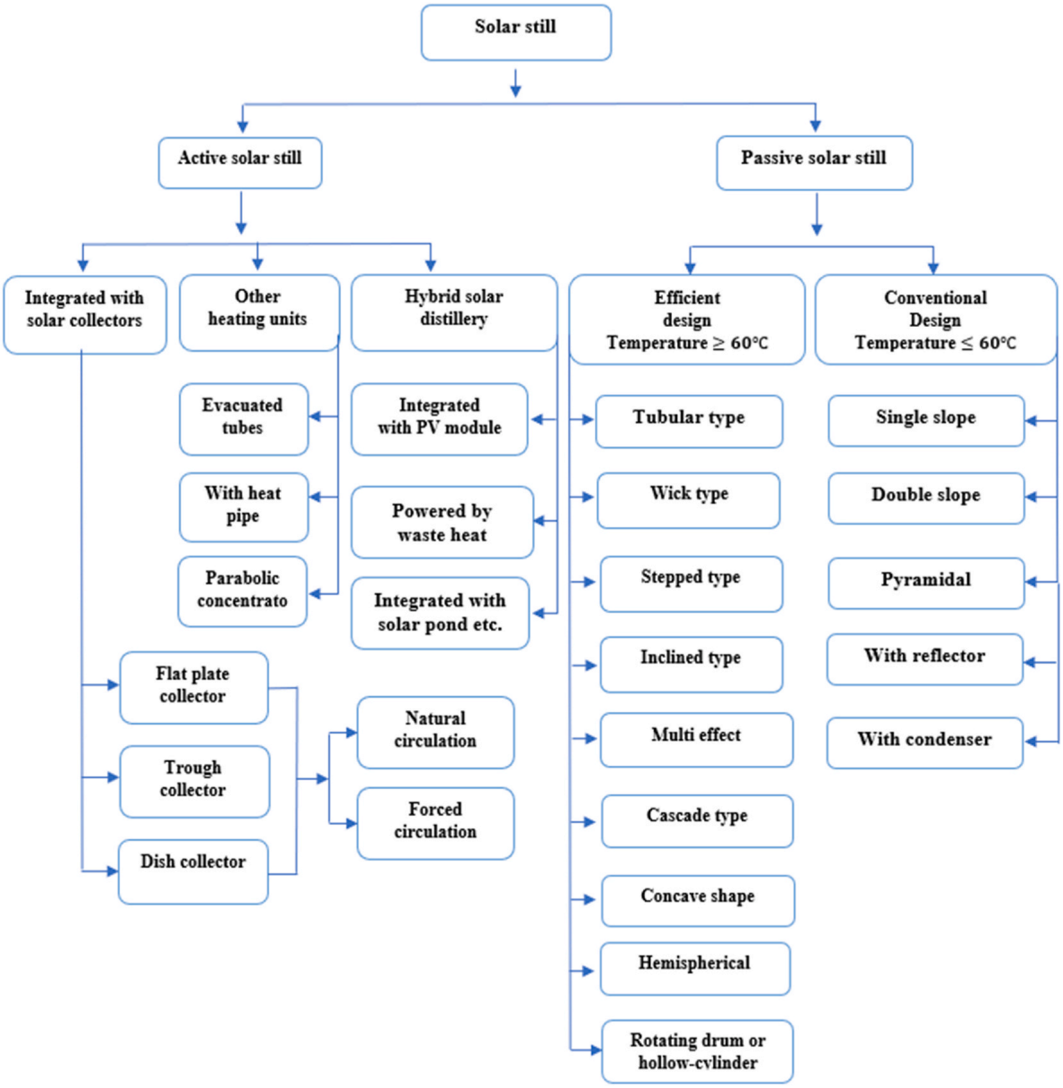

Fig. 6. Simplified classification of solar water still [3].

more solar radiation at both high and low-latitude stations than their double-slope solar distillation counterparts.

2.3.2.2. Construction materials for solar water distiller. In the construction of solar distillers, the materials most used are aluminum, wood, and galvanized iron. Ahmed and Benmoussat [47] obtained experimental results of a solar water distiller by studying the radiative properties of materials. They investigated various types of heat losses of solar stills and conducted the valuation of the solar water distiller. The experiment was tested in Tlemcen, Algeria, where they measured different temperatures of the solar water distiller. The results showed the values of natural convection in pure and simultaneous heat and mass transfer. Panchal and Shah [48] performed an experimental study using three similar solar water distillers. The first, a conventional distiller, was composed of iron sheets, while the other two contained galvanized iron and aluminum plates. They compared the productivity of the conventional solar water distiller to those with galvanized iron and aluminum plates under identical environmental conditions. The tests revealed that distillate water production increased by 15 % with the galvanized iron plate and up to 45 % with the aluminum plate, compared to the conventional solar water distiller. Bhardwaj et al. [49] developed a plastic solar distiller to supply families with fresh water. They combined the solar distillation device with a condenser comprising three plastic channels to boost productivity. The proposed design proved effective in providing fresh water for families.

2.3.2.3. Inclination of transparent cover. The angle of the solar still's transparent cover, and the depth of water in the basin are critical factors that influence solar still efficiency. The angle is dependent on direction and latitude, as covers that align with the latitude angle maximize annual solar radiation. This is essential since evaporation within the solar distillation unit relies on solar radiation intensity.

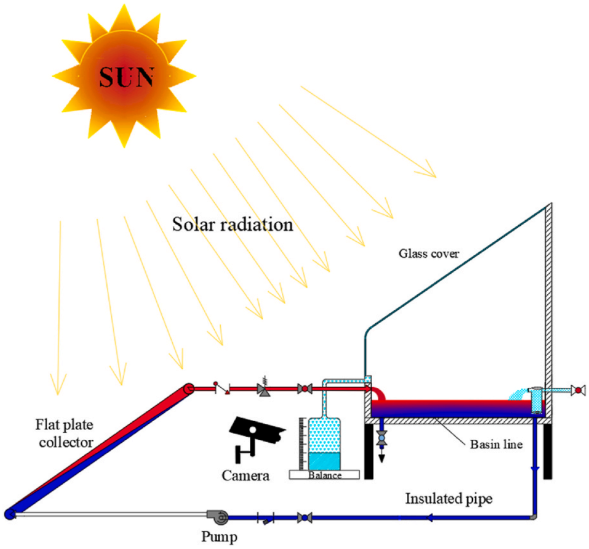

Fig. 7. Active solar distiller integrated with flat plate solar collector [7].

Tiwari and Singh [50] analyzed different latitudes ranging from 13 to 28 N and examined the impact of factors such as solar radiation intensity, wind speed, water depth, and the slope of the transparent cover on solar still output. They determined that the ideal inclination angle for the highest yearly output coincided with the study's latitude. Akash et al. [51] performed an experimental study in Jordan using a basin-type solar still with varying glass cover angles (15, 25, 35, 45, and 55°), finding the optimal angle to be 35° in May, as shown in Fig. 11. AL-Jubouri [52] assessed the performance of single solar water distilleries in Baghdad city in August 2016, testing various glass cover inclinations (20°, 31°, 45°, and 50°) and basin water depths (1, 2, 3, 5, and 7 cm). Results indicated that daily potable water production increased as water depth in the basin decreased from 7 cm to 1 cm and the angle of inclination dropped from 50° to 20°. Maximum daily productivity was 495 ml/day (~2 lit/m^2/day) for a solar water distiller with a 1 cm deep basin and a 20° inclination angle. Hashim et al. [53] studied sun ray utilization in five distinct solar water distiller shapes, concluding that a symmetric double incline with an optimal 45° angle offered the highest accumulative distillate water output.

2.3.3. Transparent cover thickness of solar still

The clear cover plays a vital role in solar still design, as it allows sunlight to penetrate the unit, heating the water, causing evaporation, and resulting in drinkable water. The appropriate selection of the cover depends on its ability to transmit light and its thickness. Hettich Banchal [54] performed a study, both theoretical and experimental, on the influence of glass cover thickness on light transmission. Three solar stills of identical dimensions with varying glass cover thicknesses (4 mm, 5 mm, and 6 mm) were constructed and examined for heat and mass transfer under the same weather conditions in Mehsana City, India. Thinner glass covers led to increased distilled water production, with 27 % and 12 % more output for 4 mm and 5 mm thicknesses, respectively, compared to the 6 mm thick cover. The theoretical and experimental findings aligned well. Panchal and Shah [55] investigated how different glass cover thicknesses affected passive single-basin and single-slope solar stills during winter months from September 2010 to February 2011. They employed three solar water stills of the same size but with glass cover thicknesses of 4 mm, 8 mm, and 12 mm. The Dunkel model served as a basis for comparing heat transfer coefficients in solar water stills. The study spanning six months revealed that thinner glass covers contributed to increased distillate water production, evaporative heat transfer coefficient, water temperature, convective heat transfer coefficient, and overall efficiency of solar stills. Consequently, they chose a 4 mm glass cover thickness for their project.

2.3.4. Variation of the basin water depth

Basin water depth plays a crucial role in the productivity of solar distillation systems, impacting performance without requiring extra components or costs. M. K. Phadatare and S.K. Verma [56] explored the influence of water depth on the coefficients of mass transfer through evaporation and heat transfer in a single-slope solar distiller during summer. The 24-h study used five water depths from 4 cm to 18 cm, revealing that shallower depths resulted in better efficiency and output. The convective heat transfer coefficient increased with decreasing water depth and vice versa. S. Balamurugan [57] investigated the impact of varying basin water depths (2–12 cm) on heat and mass transfer in a single-slope plastic solar distiller. A 2 cm depth demonstrated the highest freshwater output (2.1 L/m^2/day) and optimal efficiency (around 34 %). Younis et al. [58] assessed a solar water distillery model, considering factors such as glass cover thickness, water depth, daylight percentage, solar radiation, ambient air temperature, wind speed, and relative humidity. The highest cumulative output distillate water (about 5 L/m^2/day) occurred with a 6 cm water depth, 6 mm glass cover thickness, and 52.1 % daylight percentage. Muafag Suliman K. Tarawneh [59] examined the effect of different saline water heights (0.5, 2, 3, and 4 cm) on water production and operational parameters under identical climatic conditions. The findings suggested that reducing basin water height increases water productivity, correlating closely with incident solar rays. Omar Khalil Ahmed et al. [60]

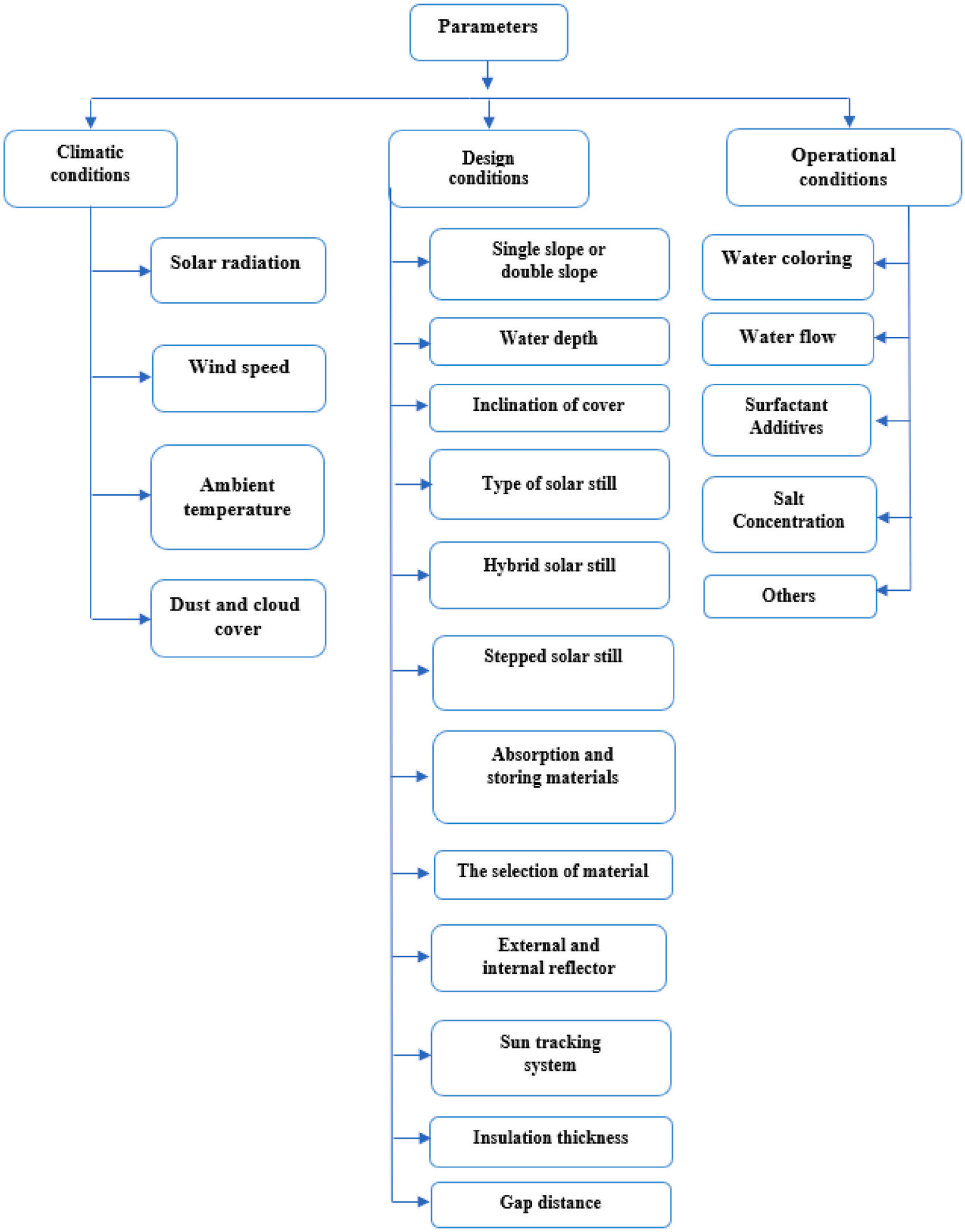

Fig. 8. Parameters affecting basin type solar still [8].

performed an experiment to determine the impact of water depth in the basin on cumulative distillate water in solar water distilleries. Also, from Table (2) it was noted that the efficiency of the distiller is affected by the depth of the basin water. The depth of 2 cm was more efficient than the other depths. The results indicated that a thinner water layer in the basin led to increased cumulative distillate water production. Local wind presence caused a slight decrease in solar water distillery performance. Using dye in the water reduced cumulative distillate water production, making the test unsuitable for enhancing distillery output unless specialized pigments absorbing significant solar rays are used, which would increase the solar water distillery's cost. An elevated salinity concentration in the water also resulted in reduced cumulative distillate water in the solar water distillery.

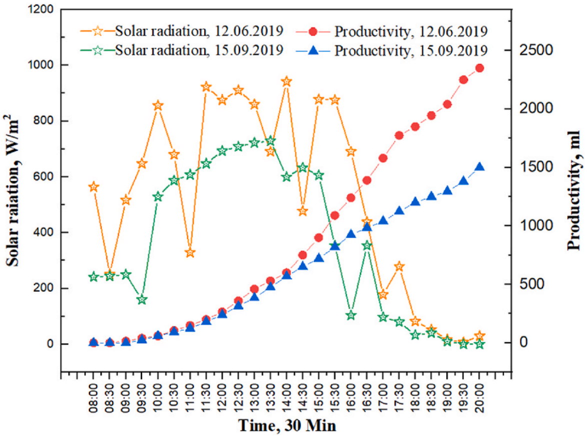

Fig. 9. The effect of local weather conditions (solar radiation intensity) on still's productivity [28].

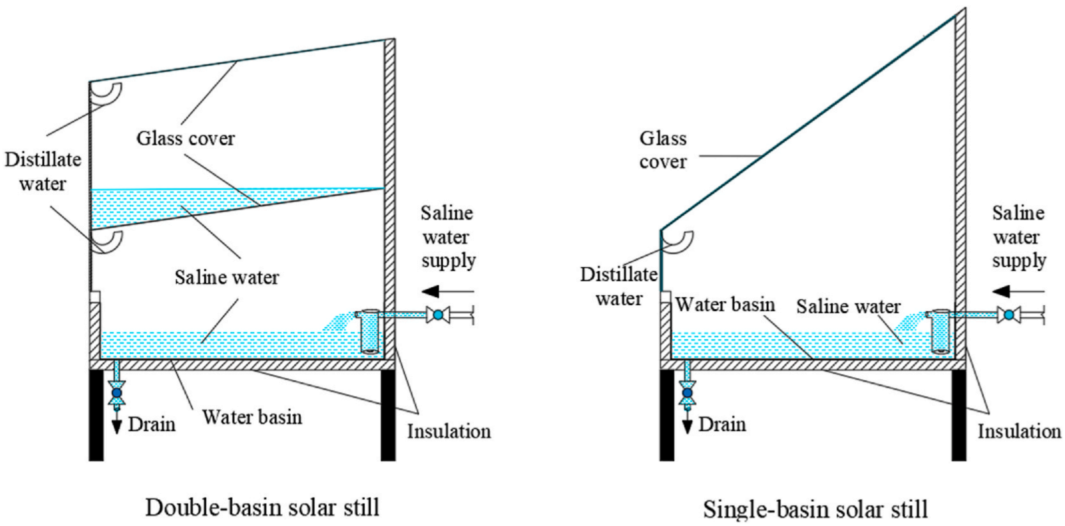

Fig. 10. Cross section of single and double solar stills [44].

2.3.5. Different thermal insulation materials

Effective thermal insulation is crucial for solar still designers to achieve high efficiency by minimizing heat loss from the sides and base, ensuring the storage of absorbed thermal energy. The insulation material, when dry, must tolerate high temperatures and possess sufficient strength to avoid compression under the weight of the basin water [61]. Abdul Jabbar N. K and Ahmad M. H [62] performed an experiment examining the impact of varying thermal insulation thicknesses (30, 60, and 100 mm) on solar distiller productivity, comparing the outcomes with a solar distillation system without insulation. The study revealed that insulation thickness significantly influenced solar distiller productivity up to 60 mm, affecting daily productivity by over 80 %. Hashim et al. [63] conducted an experimental comparison of five identical double-slope single-basin solar water stills with different insulation materials to determine the most effective insulator under Basrah's climate conditions. The daily distillate water output of solar still No. 3, featuring a glass wool-insulated basin, outperformed the non-insulated solar still No. 1 by 130 %, the glass solar still No. 5 with a 5 cm air gap-insulated basin by 32 %, the plywood-insulated (4 mm thick) solar still No. 2 by 26 %, and the hay-insulated (5 cm thick) solar still No. 4 by 126 % from January 29 to February 19, 2008.

3. Freshwater augmentation techniques in solar still

3.1. Addition of condensing unit

Husham M. A [64] performed research to assess the impact of merging a passive built-in condenser into a standard solar still and its consequences on the daily production of distillate water. The study established that the inclusion of a built-in condenser resulted in a 16.7 % rise in daily distillate water production when contrasted with traditional solar still. Pandey and Rai [65] scrutinized the

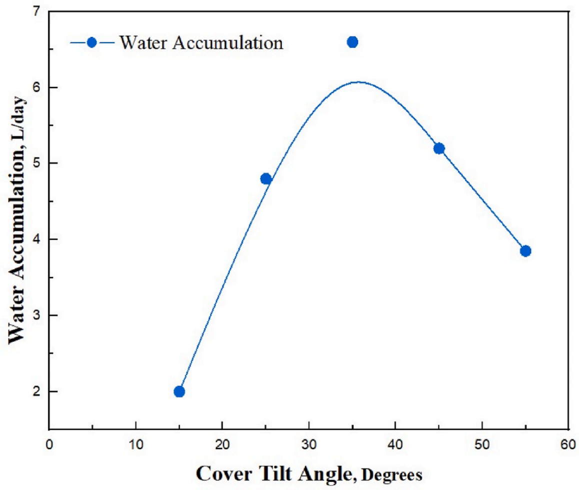

Fig. 11. The effect of the cover inclination angle on distillate production [51].

Table 2
The effect of water depth on the efficiency of the solar still [60].

Time (Hour)	Efficiency %		
	2 cm Thickness	4 cm Thickness	8 cm Thickness
6	0	0	0
8	10.03	6.25	2.01
10	16.33	5.95	2.10
12	22.76	15.41	5.04
14	37.07	27.59	11.67
16	36.51	37.20	27.59
18	30.35	32.99	35.54
20	24.17	32.14	33.91
Daily Efficiency %	**22.15**	**19.69**	**16.84**

implications of implementing an external condenser on the freshwater generation of a single-slope solar still. Their comparison between a conventional solar still and one equipped with an additional condenser demonstrated that the enhanced solar still achieved 19 % better efficiency, as illustrated in Fig. 12. Alawee [66] aimed to augment the freshwater output of conventional solar still by

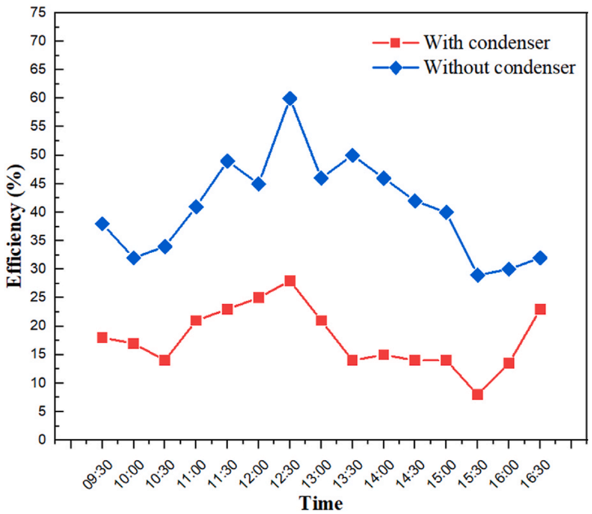

Fig. 12. Change of efficiency versus time with and without a condenser [65].

enlarging the condensation surface area, thus accelerating the condensation progression. In this investigation, two variants of solar stills were created: a standard solar still and an advanced version. The outcomes indicated that under analogous environmental conditions, the advanced solar still accomplished an 18–24 % growth in distillation compared to the standard solar still. Ahmed [67] executed an experimental inquiry to explore the influence of an internal condenser on the heat efficiency of a single-slope solar still. The solar still was evaluated with and without the inclusion of the internal condenser. The advanced solar still incorporated a double-pass internal condenser, with daily freshwater generation rates of 5.5 and 5.9 kg/m^2 for the initial and subsequent methods, respectively. Other investigations concentrated on innovative strategies and concepts to amplify solar still productivity by optimizing evaporation and condensation operations. A theoretical and experimental study [68] sought to optimize the evaporation process inside a solar distiller by combining basin water with copper nanoparticles and installing a cooling duct, which was cooled by four Peltier elements (thermo-electric units), to optimize the condensation process. The combination of these two mechanisms resulted in productivity enhancements of 38.5 % and 92.6 %, respectively. Al- Dabbaset al [69] presented an innovative single-slope solar still integrated with an external finned condenser and cooling water tank. The performance of the innovative solar still was compared with the traditional model. The results showed that the modified still increased productivity by about 300 % over a conventional still with 80 fins, a water flow rate of 400 L/h, and a cooling water volume of 250 L. The ideal flow of cooling water is 50 L/h.

3.2. Energy absorption and storage materials

Many techniques have been employed to enhance the amount of solar radiation that reaches the solar still's surface, such as augmenting the solar energy absorbed. Incorporating paraffin wax into the basin water of solar still raises the energy needed for evaporation by capturing additional solar radiation [70], as illustrated in Fig. 13.

Salah Abdullah et al. [71] explored the impact of introducing various absorptive materials (sponges, metallic, and black volcanic rocks) into single-slope solar still's basin water on daily freshwater output. The findings revealed that black rocks were the most effective at absorbing and storing solar energy, increasing production by around 20 %. Murugavel and Srithar [72] conducted an experimental study to assess double-slope solar still's performance using assorted wick materials, such as cotton cloth, sponge sheets, cotton fragments, and coir mate. The outcome demonstrated that solar still featuring aluminum fins wrapped in cotton cloth exhibited superior productivity and performance at a depth of roughly 2 cm. Murugavel [73] examined the solar still's performance using various materials in the basin water, including sponge sheets, jute cloth, cotton cloth, quartzite rock, and washed rock. The black cotton cloth displayed the best performance and productivity. Paraffin wax has been utilized as an energy storage material in passive solar stills for brackish water desalination. Energy storage materials (sensible and latent) are deemed acceptable substitutes for energy supply in distillation plants, which can be incorporated into solar stills to store energy during sunlight hours and release it at nighttime to boost production. PCM has been employed to store energy in the form of latent heat in a single solar basin [74]. Mohammed Asbik et al. [75] performed exergy analyses on a passive solar still combined with a heat storage system. The outcomes showed an increase in water productivity and a decrease in external exergy efficiency with potential thermal storage. Radwan [76] investigated the transient performance of a solar distiller combined with phase change material in the solar still basin for agricultural greenhouse heating and humidification. The experimental outcomes indicated that the airflow rate directly influenced daily yield, with a total freshwater productivity of approximately 4.6 L/m^2 and an efficiency ratio of around 57 %. El-Sebaii et al. [77] presented a mathematical model of solar still in with and without phase change materials. Theoretical results showed that the yield is directly proportional to the PCM mass. The summer yield was 9.005 L/m^2/day, and the thermal efficiency was 85.3 % with a PCM thickness of 3.3 cm, while the

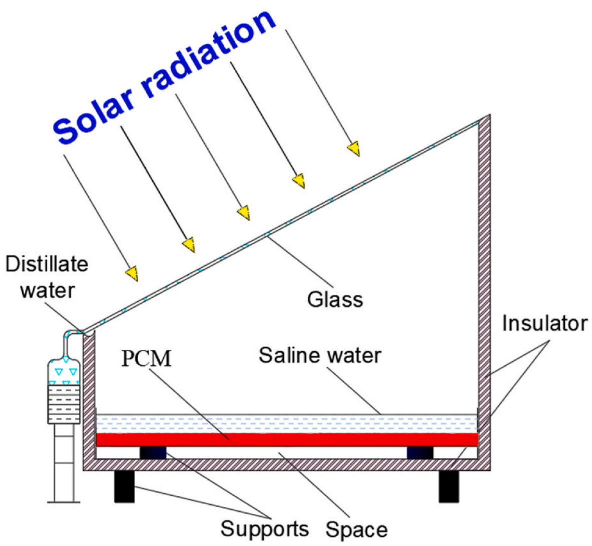

Fig. 13. Modified solar still [70].

conventional solar energy was still 4.998 L/m^2/day. The results also showed that the PCM was more efficient in winter with lower water depths. Dinesh M et al. [78] attempted to improve the productivity of a single-slope solar still by increasing the absorption and heat transfer capacity. To achieve that, two models were constructed, the first modified and the second traditional. The modified model used thermal energy storage materials (black glass balls, white marble stone, and black granite) in equal quantities in the water basin. The study showed that the production of the modified still reached 2.5 kg/m^2, while that of the traditional still was 1.4 kg/m^2. The thermal efficiency of the modified still improved by about 72.5 % over that of the traditional still, while the exergy efficiency of the modified and traditional still reached about 12.5 % and 5 %, respectively.

3.3. Integration of solar still and heat pump

By enhancing the temperature disparity between the water in the basin and another cooler surface within the solar still, the condensation and evaporation rates can be boosted, subsequently improving the solar still's freshwater output, as shown in Fig. 14 [79]. Hanin bin Halima et al. [80] explored the effects of incorporating a heat pump into a solar still to raise the temperature of the basin water. They situated the condenser within the solar still's basin water and the evaporator beneath the solar still cover to expand the condensation surface area. The study revealed that the optimal daily freshwater production was 13.5 kg/m^2, and the distillation rate within the evaporator was 75 % greater compared to the condensation on the glass cover. Ramadan bin Salama [81] carried out an experiment combining a heat pump and a solar still, examining three different scenarios: a solar still oriented southward, tracking solar radiation intensity, and positioning it either indoors without sunlight or outdoors in the sun. The findings indicated that the sun accounted for 0.666 of the contribution due to the heat pump when paired with the solar still, allowing for continuous production throughout the day and night. The temperature of the basin water reached 60 °C with sunlight and 46 °C without sunlight. Mohanraj M. et al. [82] proposed a new hybrid thermal system for heating water for domestic use in addition to producing fresh water. This system consists of combining a single-slope distiller with a heat pump and a heat storage tank. The results showed that the proposed system achieved a productivity ranging between 14.0 and 16.0 kg/day. The system can provide more than 100 L of hot water for home use at a temperature ranging from 46.8 to 52.8 °C. The cost of producing 1 L of pure water was US$0.054, and the payback period was 21 months.

3.4. Addition of heating unit

Solar-powered water heating systems represent a significant application of solar power. These setups typically employ flat plate or evacuated tube solar water collectors [84]. The former includes a glass cover, copper or stainless-steel tubes, and a galvanized iron plate that functions as the absorber of solar energy [85]. Solar water collectors are available in two varieties: non-concentrating and concentrating. Non-concentrating solar heaters can be designed with either flat plates or evacuated tubes. Generally, evacuated tube solar water collectors generate higher temperatures than their flat plate counterparts. Sampathkumar et al. [86] merged a water heater with glass evacuated tubes and a single basin still, leading to a productivity boost of up to 72 %. They developed a theoretical model that aligned well with the experimental outcomes. The payback period for this setup was calculated to be 235 days. Shanmugasundaram and Janarthanan [87] conducted an experimental study on the output of a double-slope, single-basin solar still combined with a narrow solar pond. The observed results were in close agreement with the predicted ones, with the peak efficiency of the solar still without the coupled solar pond reaching 54 % and with the solar pond at 71 %. X. Liu et al. [88] created a low-temperature multi-effect solar still by connecting the solar still with evacuated tube collectors. The system's design consisted of evacuated tube collectors, a flash tank, a heat storage tank, a multi-effect solar still, electric heating, and cooling. Mathematical and economic models were developed to assess the solar still's performance. The cost of distilled water was found to decrease as both the area of evacuated tube solar collectors and the temperature of the collector outlet water increased. Selcuk Selimli et al. [89] further improved

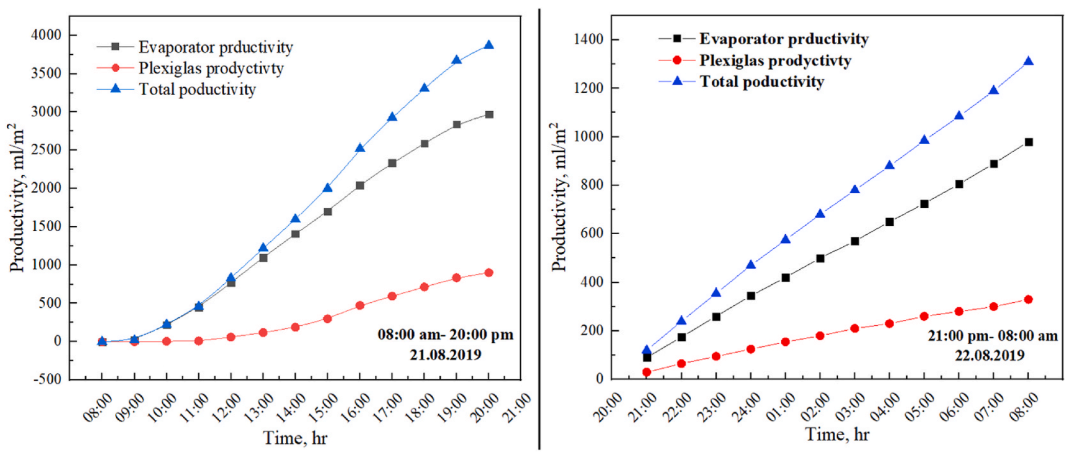

Fig. 14. Modified solar still [83].

productivity by experimentally linking the still pond to the evacuated tube of the solar collectors. The rate of natural distillation increased by 137.5 % for the distillate water. Using direct and scattered sunlight, flat plate solar collectors remain effective even during cloudy conditions [83]. These collectors, commonly used in residential solar water heaters, consist of heat pipes attached to a flat plate covered by glass, which captures solar energy [90]. The thermosiphon mechanism circulates water between the collector and an insulated storage reservoir. Advantages of this type of collector include dependable performance, affordability, low upkeep, and straightforward integration with building structures. Various research projects have explored the efficiency of flat plate solar collectors for water heating. One study investigated a design featuring narrow rectangular absorption channels, which enhanced thermal performance but increased costs due to higher electricity consumption for pumping through the duct [91]. Kamal A.R. Ismail [92] compared experimental and theoretical models of flat plate solar water heaters equipped with heat pipes. The study showed lower instantaneous thermal efficiency during morning hours but superior efficiency during the afternoon when the collector heat pipes reached operational temperatures. Walaa Mousa Hashim [93] designed a flat plate collector measuring 125 cm × 110 cm x 25 cm, with a 15.9-m-long coiled tube on its surface. The experiment tested two water flow rates, finding that a flow rate of 5.3 L/min resulted in the highest water heating, heat gain, and thermal efficiency. Bukola Olalikan Pulagi [94] analyzed a flat plate collector featuring water tubes arranged across its surface and discovered that increased heat transfer rates led to enhanced thermal efficiency. M. A. Farahat et al. [95] developed two traditional solar water stills incorporating a flat plate collector and thermal storage, as illustrated in Fig. 15. The still with thermal recovery doubled daily output compared to the conventional one. S. F. A. Shah et al. [96] introduced a stepwise basin and gravel as a thermal storage material to improve evaporation time. B. P. Singh [97] integrated a solar water heater with a single-slope solar still, resulting in a 120 % increase in productivity. Omar Badran [98] compared theoretical and experimental data, highlighting that active solar stills can enhance freshwater production. A.K. Sethi and V.K. Dwivedi [99] performed exergy and thermal efficiency analyses on a double slope solar still combined with a flat plate collector and forced circulation. Hasan Mousa et al. [100] designed a solar still that produced hot water and distilled water from brackish feed water, noting the significant impact of feed water salinity on productivity. Nithin. P. K and Hraiharan. R [101] experimented on a double-effect solar still combined with a flat plate collector, determining the optimal water depth for maximum yield. H. N. Panchal [102] tested a double basin solar still with black sandstone pebbles, finding that daily productivity increased by 56 % and 65 % with the integration of pebbles and vacuum tubes, respectively. Ganesh A. et al. [103] conducted an investigative study on the production of a single-slope, single-basin solar still integrated with a box solar cooker. The solar cooking box is equipped with a mirror to enhance the intensity of solar energy. The observed results showed that the productivity of the modified still reached 5.5 L/m^2.day and 3.9 L/m^2.day from the traditional solar still, an improvement of 41 %. The cost of producing a liter for the modified and traditional solar still was 0.0091 and 0.0101$, respectively.

3.5. Addition of rotating cylinder inside solar still

This passage outlines a variety of techniques for enhancing the efficiency of solar stills. One method involves enlarging the evaporative surface and speeding up water evaporation by adding a rotating cylinder within the still, creating a thin saltwater layer on the cylinder surface that evaporates and renews during each cycle. A modified solar still can be combined with an external solar heater to increase the basin water temperature beneath the cylinder and expedite the productivity process at the start of the day, and the improvement rate of the modified model reaches 300 % compared to the traditional model, as shown in Fig. 16 [104,105]. Essa et al. [106] increased water distiller productivity by incorporating rotational discs into a traditional solar distiller. Eight rotational speeds were tested, and the greatest improvement was found at 0.05 and 0.1 rpm. Abdallah et al. [107] examined solar still with a rotating wick operated by a photovoltaic solar panel, showing that the improvement rate was 300 % compared with traditional solar still, the maximum thermal efficiency was 73.5 % and 76.5 %, and 47 % decrease in distilled water production cost compared to conventional solar still. Other researchers, such as Abdel-Rehim and Lasheen [108], explored two modifications for solar still systems, including a

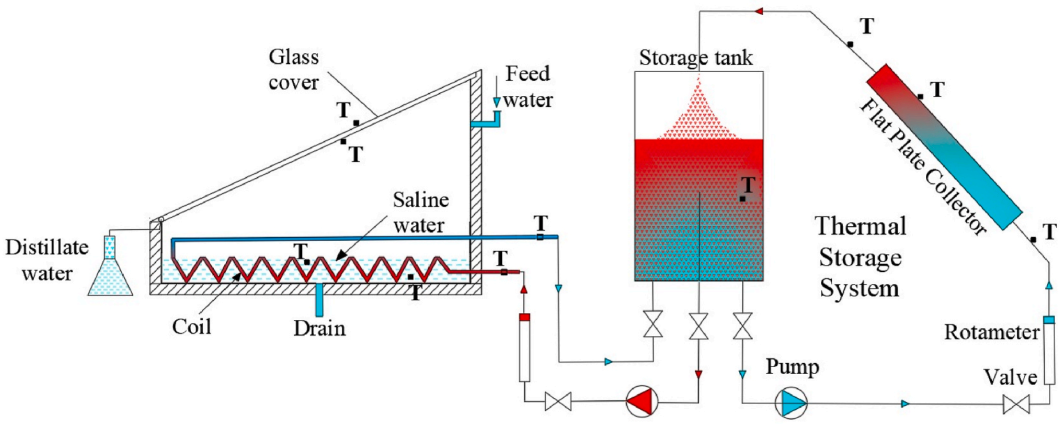

Fig. 15. Schema diagram of the experimental setup [95].

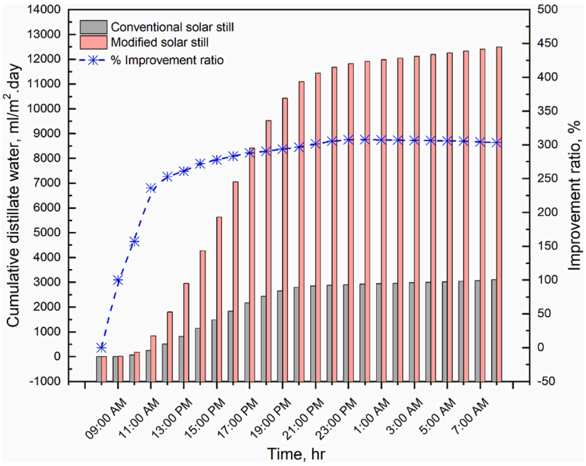

Fig. 16. Improvement rate of the modified model compared to the traditional model [104,105].

packed layer in the basin and a rotating shaft to disrupt the basin water surface's boundary layer. Ayoub et al. [109] proposed a modification involving a slowly rotating hollow cylinder within the still to create thin water films on its surface, resulting in rapid evaporation and continuous regeneration. This improvement increased productivity by over 200 %. Malaeb et al. Ayoub and Malaeb [110] examined the economic viability and operation of a simple improvement to solar stills by introducing a slowly rotating drum. The new distiller resulted in a 200–300 % increase in water output, and cost calculations indicated that the new distiller could be more affordable compared to other distiller types. A.S. Abdullah et al. [111] presented a study to improve the thermal performance of the solar still in several cases using a rotating cylinder inside the water basin in the first stage. The following case includes a rotary drum still integrated with an outdoor solar water heater and outdoor condenser. The final stage included studying the effect of adding the copper oxide nanoparticles on the performance of the modified distillation device. Different rotation speeds ranging from 0.02 to 4.0 rpm were tested. The results showed that the specified speed was 0.1 rpm. Freshwater productivity was recorded at 9.22 and 2.05 L/m^2 for modified and traditional distillers, and the cost of 1 L of distillate was about 0.039 and 0.05 dollars, respectively. An experimental study [112] was conducted to improve the performance of transparent tubular solar still combined with a black rotating drum (nanoparticle coating) and phase change materials. The compact system is installed inside a parabolic solar concentrator. The effect of different drum rotation speeds on the performance of the modified still was studied. Experimental results showed that the use of a rotating cylinder inside the tubular solar still led to improved productivity compared to the traditional solar still and that the use of phase change materials (paraffin wax) at a rotation speed of 0.3 rpm led to an improvement in productivity of about 218 %, with a thermal efficiency of approximately 64 %. The cost of producing distilled water from the modified solar still was 0.024$, and 0.029$ from the traditional solar still.

4. Artificial intelligence and distillation technology

Accurate prediction of clean energy data using artificial intelligence technology (AI) is important and useful information in many clean energy generation applications and its optimal management, such as wind turbines, solar panels, solar collectors, solar distillation, and others. In the field of solar distillation, several studies aimed to employ AI in solar distillation processes. To improve the performance of single-slope solar still, Rayouf A. et al. [113] coated the surface of the still's basin with titanium dioxide dyes. The system was tested at three basin water depths and for different time intervals. To evaluate and predict the performance of the solar still, the Artificial Intelligence-Levenberg-Marquardt method was used. The results showed that AI models (neural networks and machine learning algorithms) have high accuracy in predicting the performance of the solar still, and that there is good agreement with the data of the experimental study. Shibiao F. et al. [114] conducted an investigative study to use AI to predict the performance of solar stills with different designs (hemispherical, multi-slope), by developing an algorithm to automatically detect the flow of steam and thermal energy within the still space to solve the problem of the difficulty of obtaining data for gases and liquids. The study was conducted in two stages. In the first stage, the different solar stills were exposed to external sunlight, and by pairwise comparison, the performance of each still was analyzed. In the second stage, a trained neural network was used to analyze the images and determine the best design. The results showed that the best design is hemispherical regarding productivity and thermal efficiency. Ammar H. et al. [115] developed an AI model to predict the performance of two solar still models: the first is a modified model (a single slope still combined with an external condenser and vacuum tubes), and the second is a traditional model. The AI model consists of a hybrid long short-term memory (LSTM) system as an independent model, which is optimized and fine-tuned using the Moth Flame Optimizer (MFO) as a modified model. The two artificial intelligence models were applied to the two solar still models using experimental data for both stills. The results showed that the productivity of the modified solar still improved by about 177 % compared to the traditional solar still. The modified AI model had a higher accuracy than the traditional independent model, about 99 %.

Finally, Table 3 briefly summarizes the most important technologies used to enhance the yield of solar stills with different designs

Table 3
Freshwater augmentation techniques in solar stills.

Freshwater augmentation techniques in solar stills	Studies	Improvement method	The freshwater productivity and/or thermal and exergy efficiency	The cost of producing a liter of distilled water ($)
Addition of Condensing Unit	[65]	Integrated a passive built-in condenser into a conventional solar still.	$+\uparrow$ 16.7% higher production rate compared to conventional solar still.	–
	[66]	A separate condenser was added to the single slope solar still.	$+\uparrow$ 19% higher production rate compared to conventional solar still.	–
	[67]	Increased the surface area of condensation of the solar still by integrating reflective plates to the distillate base.	The modified still gives about $+\uparrow$ 18% *to* 24% higher distillate than the conventional still.	–
	[68]	Added internal condenser to single slope solar still.	Freshwater productivity increased from $+\uparrow 5.5\ to\ 5.9\ kg/m^2$.	–
	[69]	The nanofluid copper oxide (Cu_2O) is added to the basin water and integrated with an external thermoelectric condensation channel.	Daily productivity, energy, and exergy efficiency are improved by about 82.4 %, 81.5 %, and 92.6 %, respectively.	0.021
	[70]	External condensing unit	Freshwater productivity increased from $+\uparrow 4.116\ to\ 12.350\ kg/m^2$.	–
Energy absorption and storage materials	[71]	Paraffin wax cells (PCM) are embedded in the water basin	Freshwater productivity increased from $+\uparrow 3.79\ to\ 5.06\ L/m^2$.	0.035
	[72]	Added various absorbent materials (sponges, metallic and volcanic rocks black.) in the basin water of a single-slope solar still	The most effective materials were black rocks, which improved production by approximately $+\uparrow$ 20%.	–
	[73]	Added various absorbent materials such as (aluminum fins covered by cotton cloth, sponge sheets, pieces of cotton, and coir mate) in the basin water solar still.	$+\uparrow$ Light black cotton cloth with aluminum fins covered with cotton cloth was most effective ($3.58\ L/m^2.day$)	–
	[74]	Various absorbent materials (sponge sheets, jute cloth, and cotton cloth) were added, and porous materials (rock of quartzite and washed rock) were also tested in the basin water solar still.	$+\uparrow$ The black cloth of cotton had more performance and productivity($7\ L/m^2.day$)	–
	[75]	Added PCM nanocomposite with different inclination angles (10°, 20° and 30°)	$+\uparrow$ The best thermal efficiencies at 10° were recorded as 47.6 %, 51.1 %, and 52.0 % for models without PCM, with PCM, and with Cu-PCM nanocomposite, respectively.	–
	[76]	Added PCM in the basin water of solar still	Latent heat storage of the PCM increases water productivity and reduces exergy efficiency.	–
	[77]	Added PCM in the basin water of solar still	Freshwater productivity increased from $+\uparrow 4.6\ to\ 4.9\ kg/m^2$ Thermal efficiency increased from $+\uparrow$ 57% *to* 61%.	–
	[78]	Added PCM in the basin water of solar still	Freshwater productivity increased from $+\uparrow 4.99\ to\ 9.00\ kg/m^2$. Daily efficiency increased to 85.3 %	–
	[79]	Using different energy storage materials in solar stills	Daily distillate production increased from 1.4 to 2.5 kg/m^2. Energy efficiency increased from 4.99 % to 12.55 %. Thermal efficiency is 72.6 % higher than traditional solar still.	–
Integration of Solar Still and Heat Pump	[80]	Single-slope solar still integrated with photoelectric diffusion-absorption refrigerator	Daily distillate production increased from 1.33 to 5.18 kg/m^2.day.	0.046
	[81]	Single-slope solar still integrated with a compression heat pump	Daily production was 13.5 kg/m^2, and average annual production was 9.9 kg/m^2/day. The daily productivity of a modified solar still is 75 % higher than that of a conventional solar still.	–
	[82]	Single-slope solar still integrated with a compression heat pump	Daily distillate production increased from 1.6 to 6 kg/m^2.day.	–
	[84]	Single-slope solar still integrated with a compression heat pump and PCM	The average monthly productivity was 14.3 kg/day	0.054
Addition of a heating unit	[87]	Integrated the evacuated tube and solar water collectors with the single basin solar still	$+\uparrow$ 72 % higher production rate compared to conventional solar still.	–
	[88]	Double Slope Single Basin Solar Still Coupled with Shallow Solar Pond.	Thermal efficiency increased from $+\uparrow$ 54% *to* 71%.	–
	[83]	Integrated the solar still pond with the solar vacuum tube	$+\uparrow$ 62.5 % higher production rate compared to conventional solar still.	

(*continued on next page*)

Table 3 (*continued*)

Freshwater augmentation techniques in solar stills	Studies	Improvement method	The freshwater productivity and/or thermal and exergy efficiency	The cost of producing a liter of distilled water ($)
	[96]	Solar still integrated with a flat plate collector and thermal storage.	The productivity in August, September, November, and December is increased by $+\uparrow 75\%, 94\%, 121\%,$ *and* 109%, respectively.	–
	[97]	Single-slope active solar still coupled with flat solar water collector panel	The average daily productivity acquired from testing was 2.24 lit/m^2 while theoretical results predicated 3.78 lit/m^2; hence the efficiency of the still detected was 60 %.	–
	[98]	Single slope solar still integrated with a solar water heater	$+\uparrow$ 120 % higher production rate compared to conventional solar still.	–
	[99]	Single slope solar still integrated with a solar water heater	$+\uparrow$ Improving the thermal efficiency of the active solar still compared to the traditional solar still. *from* 16% *to* 38%,	–
	[100]	Double slope solar still integrated with a flat plate solar water collector	The exergy efficiency varied from (0.26–1.34) %, and the daily thermal efficiency of solar still varied from (13.55–31.07) %.	–
	[101]	The water solar still integrated with an evacuated tube solar collector.	The modified solar still could produce 0.15 L of distilled water/hr.	–
	[103]	Integrated vacuum tubes with the desalination section.	The modified still can give about $+\uparrow$ 56% *to* 65% higher distillate than the conventional still.	–
	[104]	Integrating solar still with a solar cooker	Freshwater productivity increased from $+\uparrow 3.9$ *to* $9.00\ kg/m^2$. The improvement rate is about 41 %.	0.0091
The addition of a rotating shaft or cylinder inside the solar still	[105, 106]	Modified solar still based on the use of a rotating hollow cylinder inside it and integrated with an external solar water collector, with a typical rotation speed of 0.5 rpm.	Freshwater productivity increased from $+\uparrow 3.1$ *to* $12.5\ kg/m^2$. $+\uparrow$ 300 % – 400% higher production rate compared to conventional solar still.	0.026
	[107]	Modified solar still integrated with rotational discs (flat discs and corrugated discs with and without wick material).	The improvement rate was 124 % compared with traditional solar still, and the maximum thermal efficiency was 54 % and 50 %.	–
	[108]	Solar still augmented with a rotating wick	The improvement rate was 300 % compared with traditional solar still, and the maximum thermal efficiency was 73.5 % and 76.5 %.	0.027
	[109]	The improvement included a rotating shaft, fitted to the surface of the basin water (0.1 rpm).	The efficiency of the improved solar distillation system by packing layer thermal storage system was augmented by 5 %, 6 %, and 7.5 % in May, June, and July. While by rotating shaft (0.1 rpm) and the PV-scheme was augmented by 2.5 %, 5 %, and 5.5 % in May, June, and July.	
	[11, 110]	The improvement included a slowly rotating hollow cylinder inside the solar still; the limiting speed was 0.25 and 0.5 rpm	$+\uparrow$ 200 % – 300% higher production rate compared to conventional solar still.	0.035
	[112]	The improvement included a rotating drum inside the basin water solar still); the limiting speed was 0.1 rpm	Freshwater productivity increased from $+\uparrow 2.05$ *to* $9.2\ kg/m^2$. $+\uparrow$ 350% higher production rate compared to conventional solar still.	0.039
	[113]	The improvement included transparent tubular solar still combined with a black rotating drum (nanoparticle coating); the limiting speed was 0.3 rpm	$+\uparrow$ 218% higher production rate compared to conventional solar still, with a thermal efficiency of approximately 64 %.	0.024

and shapes. From this table, the most effective technology is the single slope rotary hollow cylinder stills, integrated with external solar water collectors, which achieved an improvement rate of 400 % [104,105]. In contrast, the cost of producing a liter of distilled water was about 0.026$. The least expensive solar still per liter is integrated with a solar cooker [103]. The annual cost of yield per liter was 0.0091$, and the average daily yield was 9 L.

5. Significant of current work

Based on the previous works dealing with improving the performance of solar distiller systems, it is revealed that most of the investigations present the results of the standard systems using fins above the basin surface, where these investigations are numerically and experimentally performed. Moreover, the literature review shows that the studies presented the performance of single basin and single slope solar still using PCM and porous media together are not done [116,117]. In Reality, Iraq is one of the countries that spends a large amount of electrical power on water purifiers, and thus, it spent a high cost in this issue [118–120]. However, Iraq has a large value of solar energy, which can be used for water distillation [121]. To overcome this issue, the solar distiller water displays one of the best remedies for applications that generate pure water during the year. This system may be employed in the sites that suffer from pure drinking water. Based on the above, there is no previous work showing the enhancements in the performance of single basin and single slope solar water distillers. Therefore, this work aims to show the latest enhancements in the performance of various kinds of solar water still systems.

6. Conclusions

The most important factors in the performance of solar stills are climate, operational, and design parameters. It has been observed that productivity is directly affected by the intensity of solar radiation, ambient air temperature, and wind speed. Single-slope solar stills are more effective than double-slope solar stills. In addition, the productivity of the still is inversely related to the depth of the water. The productivity of solar stills is enhanced by using thermal storage materials (such as stone and paraffin wax). This review also seeks to assess prior research on solar stills and performance-influencing factors to identify significant conclusions.

1. Employing black sandstone pebbles and vacuum tubes in double basin solar stills substantially raised daily productivity in comparison to a regular double basin solar still.
2. Incorporating rotational discs, both with and without wick materials, into solar distillers expanded the evaporation area and reduced saline water thickness, resulting in higher productivity than standard solar distillers.
3. Adding a packed layer to the basin's bottom or attaching a rotating shaft to the basin water's surface can also enhance solar distillation system productivity.
4. Utilizing a slowly rotating hollow cylinder within solar distillers increased productivity by over 200 %.
5. The optimal rotational speed of the cylinder is inversely related to water distillation and should range between 0.25 and 0.5 rpm, depending on specific climate conditions.
6. Boosting the evaporative surface area by placing a slowly rotating drum inside the still can yield a 200–300 % increase in water production.
7. Environmental parameters, basin water temperature, glass cover temperature, and base plate temperature are crucial factors to consider in solar distiller experimental research.
8. The material selection for the solar distiller, such as Aluminum or Galvanized iron plate, can also impact solar radiation's maximum absorbance.

According to the fields covered by this investigation, it is recommended to study and evaluate the performance of a single-slope solar distillation system integrated with a system that enhances its evaporation and condensation mechanisms, such as absorption cooling systems. It is necessary to choose the appropriate location for the distillation system to operate under perfect climatic conditions that cannot be controlled, unlike operating and design conditions.

Availability of data and material

Data will be made available on request.

Ethical statements

All subjects gave their informed consent for inclusion before they participated in the study.

Funding

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CRediT authorship contribution statement

Naseer T. Alwan: Visualization, Software, Resources, Investigation, Data curation, Conceptualization. **Bashar Mahmood Ali:** Visualization, Software, Resources, Investigation, Data curation, Conceptualization. **Omar Rafae Alomar:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation. **Nabeel M. Abdulrazzaq:** Software, Resources, Data curation, Conceptualization. **Obed Majeed Ali:** Visualization, Software, Resources, Project administration, Data curation, Conceptualization. **Raad M. Abed:** Software, Resources, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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