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A review of a study on improving the performance of spherical solar stills

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HIGHLIGHTS

- Spherical solar stills are effective for increasing potable water in remote areas.
- Combining spherical stills with flat plate collectors boosts water efficiency to 7.620 kg/m²/day.
- Larger spherical tanks improve distillation yields.
- Solar tracking and cooling systems can boost water production by up to 37%.

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ABSTRACT

The urgent need for potable water has increased despite water covering much of the Earth's surface. Solar desalination, which uses solar energy to produce fresh water, is an eco-friendly and cost-effective solution, especially for remote areas lacking clean drinking water. This technology is valuable even in deserts with no other freshwater sources. However, conventional solar stills have low efficiency. To address this, various experiments have been conducted to enhance the daily output of solar stills by improving evaporation and condensation rates, which standard distillers cannot achieve. This innovation in using solar power thus finds its place even on desert sands where no other freshwater source is available, demonstrating the immense value of harnessing solar energy for such an important purpose as providing fresh water. This article reviews the latest techniques to boost water productivity and improve various solar distiller designs' overall performance and thermal efficiency. It concluded with recommendations for future research, highlighting strategies that showed significant promise. The combination of flat plate collectors with spherical solar stills was the most efficient, achieving a productivity level of 7620 ml/m^2/day. 57% increase due to the unique conditions created by rotating balls within the still. These findings underscore the potential of innovative design enhancements to improve desalination systems using solar energy significantly, and they encourage further research and development in this field.

1. Introduction

Water is a gift from nature and key to economic development and national well-being. Distilled water shortage is one of the major problems faced by less developed and developing countries worldwide [1–4]. About 97% of the world's water is in the oceans; in the polar regions, about 2% is stored as ice; 1% is fresh water, which meets the needs of plants, animals, and humans [5]. Due to various factors such as population growth, industrialization, and urbanization, water resource pollution has increased dramatically [6,7]. These activities negatively impact water quality and agriculture in rural areas. According to statistics, more than 750 million people suffer from distilled water problems [8]. The water shortage is expected to be about 60% in 2025 due to the rising global population. Consequently, by 2050, around one-half of people are expected to suffer from freshwater availability [9]. Access to safe distilled water is important on all levels: global, national, regional, and local. The only possible way to technologically and economically deal with the problem of water shortage is to desalinate the inexhaustible water sources in the seas and oceans that can properly provide for all human needs [10]. The desalination of saline water from its natural sources is one of the important alternatives in place worldwide [11]. Desalination techniques have been significantly developed in recent years. See Figure 1 Distribution of Earth's Water [12].

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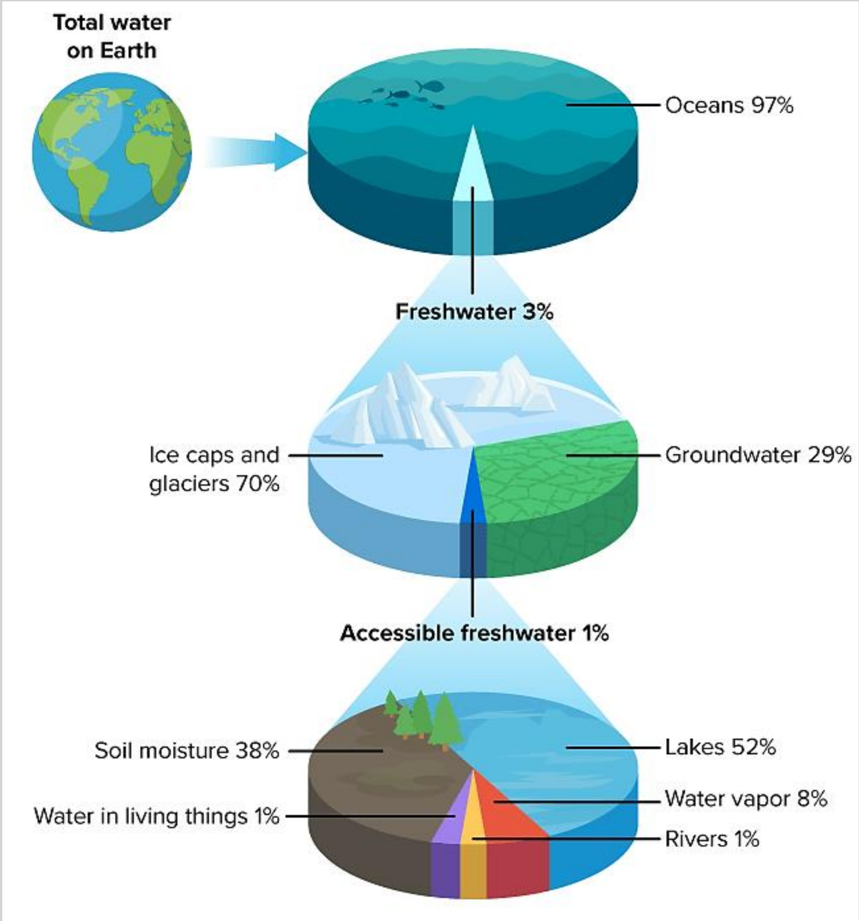

Figure 1: Distribution of earth's water [12]

The desalination process involves several steps, each requiring large amounts of thermal or electrical energy to separate salt from the water [13]. It must be taken into account that most of the energy required for desalination comes from various sources, often expensive and non-renewable, such as fossil fuels [14], wood, coal, or other consumable fuels [15], expensive, environmentally costly, and dirty. Therefore, using solar energy as an alternative energy source has huge economic benefits as it is available in most countries. Additionally, it could be used in arid and desert areas where solar radiation and salt water are abundant, especially given the high cost of delivering distilled water to desert areas [16]. Solar distillation is a promising and sustainable technology for producing distilled water from seawater, brackish water, or wastewater [17].

Based on previous research, a study evaluated the performance of various techniques used in spherical solar stills. An infusion of phase change materials and advanced components, including dynamic components like rotating balls, not to mention changes in wicks and pool flooring texture, we do not overlook even the outer cover, ranging from material type and thickness (polyethylene-based) to the studied integrated systems coupled with advanced modeling and optimization techniques. Every nook and cranny explored; every possibility exhausted.

This paper adds new information to the field by reviewing and condensing already written works in these fields, thereby informing interested parties with valuable information and pointing them towards areas that could be investigated further, which could aid in the growth and advancement of this sector. This literature is expected to guide future researchers who intend to achieve success in their work on spherical solar stills by obtaining maximum results and overcoming potential challenges that might hinder their progress. The following research aims to review useful information for improving the performance of spherical solar stills.

2. Solar distillation technologies

Solar distillation is simple: it mimics nature [18]. The sun's rays heat the water until it evaporates; as the vapor rises, it hits the cold glass surface above and condenses into liquid form. We have distilled water available [19]. This method eliminates tiny organisms (which can sometimes be harmful with more than 400 mg/L of salts) and heavy metals, all-important pollutants, without requiring extensive equipment or complicated procedures. It is a cost-effective method that is superior to many high-tech desalination methods [20].

This shortage has prompted scientists to develop an advanced method of treating brine - desalination, which removes salt and minerals from brine to make it drinkable [21–23]. Figure 2 shows that two main categories of thermal desalination methods that rely on heat for vaporization are multistage flash (MSF), multiple effect distillation (MED), and thermal vapor compression (TVC). In MSF, water evaporates into steam after being heated in several stages, while in MED, it evaporates through several stages of condensation. TVC involves vapor compression: new water evaporation technologies such as solar distillation (SD), membrane distillation (MD), and humidification and dehumidification (HDH) all rely on solar energy [24–28].

Pressure or electricity is the force behind non-thermal desalination methods, which draw a line between salt and water. Popular methods include reverse osmosis (RO), electrodialysis inversion (EDR), and mechanical vapor compression (MVC). In RO, high voltage pushes water through a semipermeable membrane, while EDR uses voltage to move salts through an ion exchange membrane [29]. MVC mechanically compresses steam to promote water and salt separation [30]. New entrants in the non-thermal field, such as crystallization and ion exchange—offer alternative routes to salt removal, although they are not yet widely available [31]. As effective as they may be, these methods incur high costs due to infrastructural demands, tools, and fuel expenses [32]. This study, however, shifts its focus onto renewable energy pathways, notably solar distillation, which basks under Iraq's sun-soaked radiance, seeking a viable solution for water scarcity sans exorbitant resource outlay.

It can be collected as clean potable water after salts and other impurities are effectively removed through this distillation process [33]. This technique rids fresh water in areas abundant with sunlight. This feature makes it appealing for adoption into sustainable water management practices, especially when taken into consideration alongside its limited production of distilled water; this, in turn, would address the needs of populations living in regions where access to distilled water is a challenge [34]. A novel method to enhance the efficiency of solar distillation is the development of spherical solar stills. Spherical, these stills are designed to maximize sunlight exposure [35]. A design feature that inherently improves evaporation and condensation processes. Current research indicates that integrating a rotating ball as well as phase-changing materials into these stills can bring about a substantial boost in their performance. Moreover, mirrors are applied to reflect light onto the stills; hence, more productivity is realized through the evolution of technology, another innovative approach to enhancing solar distillation efficiency. The need for further enhancement and improvement of solar distillation methods is now more than ever a significant step toward adopting effective water management efforts that can address global water scarcity by ensuring all have access to clean and safe drinking water.

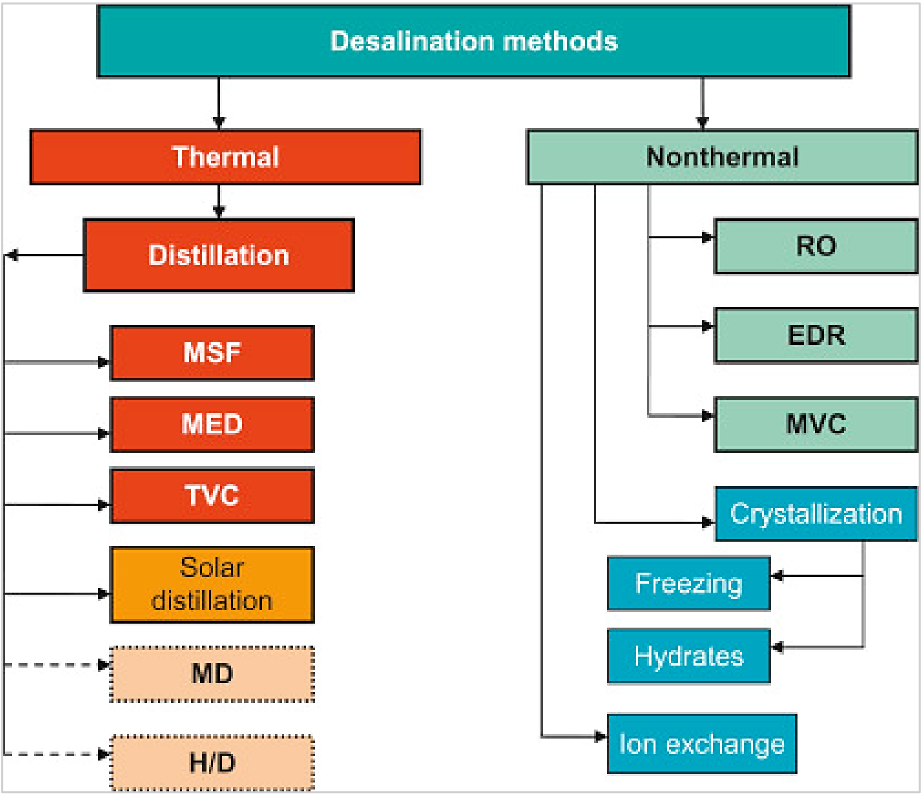

Figure 2: Diagram of desalination methods [28]

3. Solar distiller device

The two key elements in accelerating evaporation are increasing water temperature and exposing it well to solar energy. You can use a wide container covered with dark black paint [36–38]. The color choice for the container, a dark color like black, is pivotal for the maximum absorption of solar radiation. Black surfaces absorb more energy from the sun than light colors, significantly increasing heat production as they transform most of this absorbed radiation into heat energy [39]. A broad container increases the surface area in contact with solar radiation, leading to more molecules evaporating from water since most parts are directly heated by the sun [40].

An effective means to do this is to create a cool surface that comes close to the evaporating water vapor; usually, an evaporation pan with a transparent glass or plastic cover is used [41]. The sunlight can pass through these covers. Therefore, the angle of this surface should be adjusted to ensure that the condensed water droplets flow along a specified path into a channel. This way, the water can be collected easily. In addition, using a glass cover for such pans creates a closed system where heat is retained, thus favoring distillation [42]. This approach capitalizes on solar energy as a renewable resource and adopts an economical and sustainable production method for distilled water. Desalination efficiency can be significantly enhanced by optimizing various design elements, such as the color and size of the container, the positioning of the condensation surface, and solar energy [43].

4. Solar distiller classification

Solar stills are classified into two categories: single-effect and multi-effect stills. Each of these stills is further classified into active and passive types depending on the source(The need for any system to consume energy), such as heat used to evaporate water [44]. Passive solar still utilizes solar energy directly as a source of thermal energy only. On the other hand, active solar still uses external thermal energy sources such as solar collectors, waste heat, etc., and includes pumps, valves, and other devices [45]. The schematic representation of various solar still configurations is represented in Figure 3.

Indeed, numerous endeavors have been undertaken to augment the daily yield of solar stills by integrating additional systems. These enhancements often involve the combination of solar stills with various technologies, such as thermal solar collectors [46], heat exchangers [47], solar ponds [48], and hybrid photovoltaic/thermal (PV/T) systems [49].

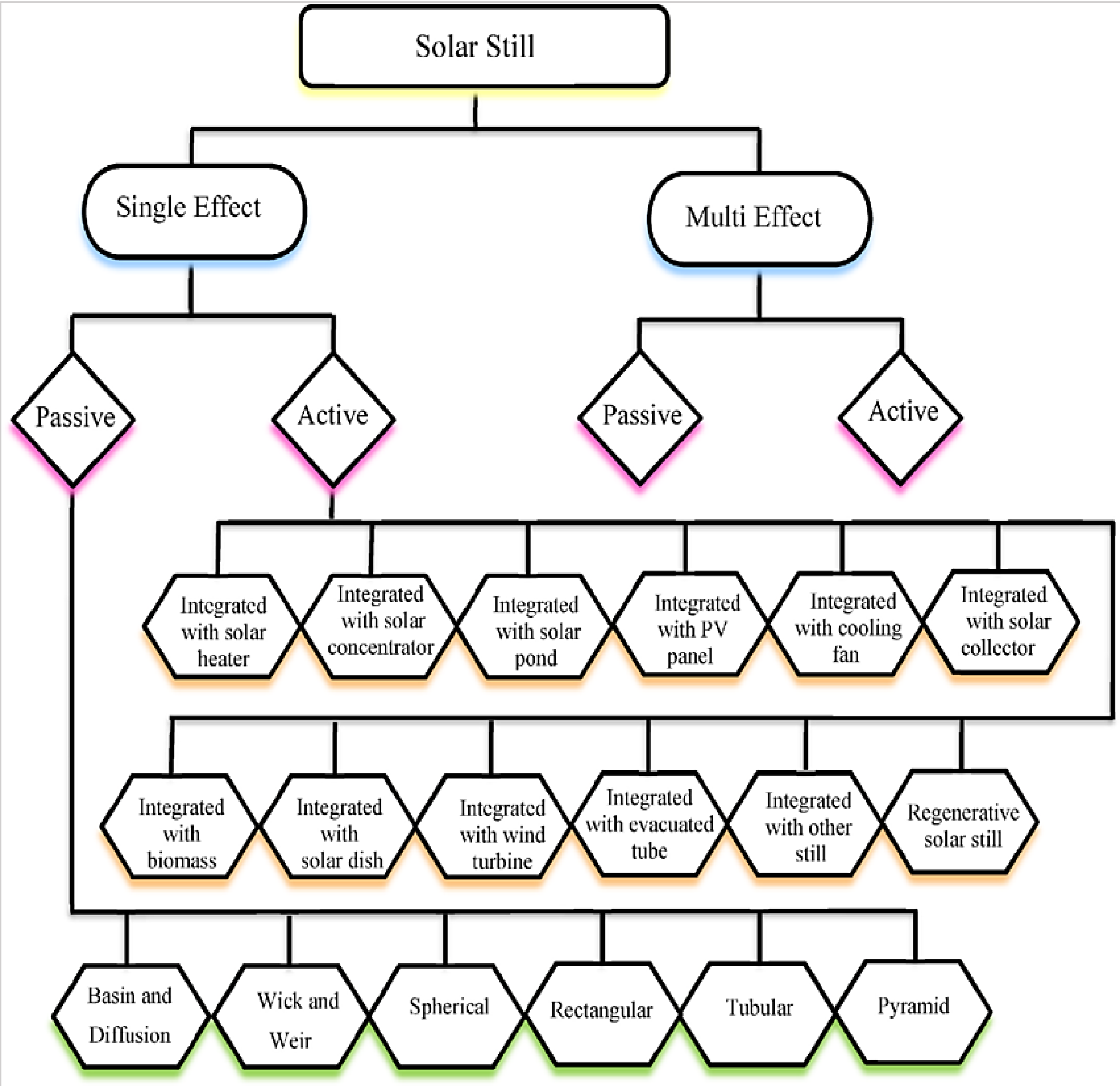

Figure 3: Various designs of single and multi-effect solar stills [44]

4.1 Passive solar still purification

The passive solar still is a low-tech, nature-friendly invention. It helps produce clean water using only the natural energy of the sun. The idea starts with letting water come into contact with solar radiation; this makes the water hot enough to evaporate due to the heat received from the sun's rays. When the vapor rises, it leaves behind all impurities, salts, heavy metals, and microorganisms [50]. The vapor then finds a surface (always cooler) to condense on; most of the time, this surface is a transparent cover, such as glass or plastic glass, like transparent acrylic [51]. This condensed water is what we collect as purified water at the end of the process. A simple setup involves a basin (where impure water is placed) and a transparent cover that allows sunlight in while trapping vapor inside. To enhance heat absorption, the interiors of basins are commonly painted black to ensure maximum absorption of solar energy. The design goal is always to convert as much radiation as possible into heat and speed up the evaporation process in return [52].

The evaporated water vapor ascends to a transparent vessel and returns by condensing under the clear cover. The cover is placed at an incline, ensuring that the droplets of condensed water trickle into a hollow container; hence, we collect distilled water [53–56]. This unsophisticated but very successful method does not require any external energy source. It is a good way to produce potable water, which is sought after without involving other power sources, making it feasible for remote areas where there might not be connectivity to the national grid [57].

These solar stills are easy to make using materials found in the locality; this means that people can easily access them even in resource-limited communities. Because they do not have greenhouse gas emissions (they are dependent on solar energy), passive solar stills have no negative impact on global warming, thus contributing towards environmental sustainability. They work without mechanical components and are simple in design and operation. They need only periodic checks and can treat different types of water, including seawater, brackish water, muddy distilled water, and all manner of dirty waters, ensuring provision all around for clean water and thus making them sustainable and versatile solutions for purifying water systems available anywhere they are needed [58].

4.2 Active solar still purification

Active solar still purification stands as a high-tech approach that, in the light of harnessing solar energy, transmutes brackish or impure water into water fit for drinking. Active solar stills differ from passive ones, where only natural evaporation and condensation occur; they need to include other energy sources or additional mechanical components for the process [59]. This innovation is especially useful in areas with limited access to distilled water and where production rates should be higher than those offered by passive systems [60].

The basic working principle of active solar still remains the same as passive ones — where impurities are removed by evaporation and condensation processes. However, active systems use additional energy inputs like heat exchanger or west heat recovery which help increase the temperature of water; thus, they expedite the rate at which water evaporates [61]. In some cases, pumps are used to enhance air movement, further speeding up evaporation [62]. A simple basin setup with just a glass cover used in passive stills might be upgraded to a more complex design that includes solar panels providing power for electric heaters or pumps. A more sophisticated basin construction can be adapted to take full advantage of heat absorption capabilities, while material selection may focus on those with high thermal efficiency indices [63].

Through these added components and technological improvements, active solar stills can achieve higher productivity levels, an important feature especially when considering use in larger-scale applications or areas where water demand is high [64]. There are quite a few advantages of active solar stills over passive ones, like faster rates for purification, which results in more water output even in not-so-common environmental conditions. With these benefits, active solar still purification can be seen as a bright prospect to alleviate the world water scarcity issue with a sustainable provision of distilled water [65–67].

5. Spherical solar distiller

A new method of solar distillation with high efficiency is what we are calling spherical solar stills. These contraptions use the sun's power to cleanse water in a way close to nature. These stills' design promotes evaporation and condensation within a single sphere, allowing them to work more effectively by catching more sunlight, an innovation like no other[68,69]. Using spherical solar stills is quite practical in areas rich in the sun but lacking distilled water, as it offers a sustainable alternative resource for potable water instead of availability; such regions would be able to make use of what they have on hand without any additional cost or effort [70–72]. The spherical solar still's function is based on a peculiar, spherical design innovation. This design aims to heat saline or contaminated water enclosed within its curved walls [73]. The choice of such a design is due to its ability to trap sunlight: evaporation occurs at a faster rate because of this feature [74]. Moreover, the uniform distribution of sunlight throughout the day on the surface with a consistent temperature ensures the natural formation of elements during the purification process, where the vapor condenses on the inner side and collects purified water, leaving salts and heavy metals behind microorganisms [75–79]. The spherical shape helps produce distilled water without any energy input other than sunlight, which can eliminate impurities coming from saltwater resources via impure water. Dhiman [80] developed a mathematical model to predict the thermal efficiency of spherical solar stills.

The model is based on heat and mass transfer relationships derived from experimental results. Numerical simulations were performed to determine how the absorption of the tank lining in solar still affects distillation performance. The researchers developed a theoretical model of a spherical solar still and compared it with a conventional one to assess productivity and thermal efficiency improvements. They found that the spherical solar still was 30% more efficient than the conventional design. Weil While in, a theoretical study by Karroutea and Chaker [81] focused on the impact that the geometry of the transparent cover has on the performance of the solar distiller specifically on the amount of water that evaporates and condenses into the distiller to determine how variations in the shape of the glass cover affect heat balancing, they devised a theoretical model that was tailored exclusively for spherical solar distillers. Through the application of the fourth-order Runge-Kutta method, they were able to solve the equations that were produced, which enabled them to evaluate the temperatures of the water while still producing.

The spherical solar distiller was estimated to produce approximately 4620 ml/m²/day, which is in close accord with the findings from the experiment of 4280 ml/m²/day. This illustrates that theory and experience are in good agreement with one another. A single-slope solar distiller system, on the other hand, nevertheless had a maximum daily yield of 3120 ml/m²/day. In contrast, the utilization of a spherical solar distiller under comparable circumstances resulted in a 32.47% increase in production. This improvement can be related to the chilling effect caused by one side of the glass cover being exposed to shade, which increased the variation in temperature between the glass and the water. The findings of the experiments demonstrated that an increase in solar radiation produced a beneficial effect on the amount of solar energy that was produced. However, the presence of clouds significantly reduced productivity, and wind speeds above 4 m/s decreased production. Additionally, water vaporization in the glass still diminished the glass's transmissivity, adversely affecting solar energy absorption, suggesting the use of self-cleaning glass for optimal performance. On the other hand Kabeel et al. [82] compared spherical, hemispherical, and single-slope distillers' designs. The spherical distillation design yielded the maximum cumulative productivity, reaching 5.5 kg/m²/day. the solar radiation starts with 371 W/m² at 08:00 (morning time) and increased to 1000 W/m² at 12:00 (noon time), then it is decreased to 33 W/m² at 18:00 (sunset time). In contrast, the hemispherical design yielded 4.45 kg/m²/day, whereas the single-slope design yielded 3.1 kg/m²/day compared to the single-slope design, the spherical and hemispherical designs increased daily distillate yield by 77.42% and 43.55%, respectively. Spherical, hemispherical, and single-slope designs have 44%, 40.5%, and 35% efficiency. Main conclusion: spherical distillation yields more than hemispherical and single-slope distillation. For reliable distilled water production, a spherical solar still is recommended, the configuration as represented in Figure 4**.**

In the area of efficiency, spherical solar stills come out on top. Their unique geometric design ensures that they are consistently exposed to sunlight throughout the day, allowing them to produce water much faster than other conventional stills. Spherical solar stills offer a cost-effective and low-tech solution for distilled water in areas where resources are minimal. This can be locally produced; no electricity is needed, so there are no operational costs after construction. The materials for spherical solar stills are found within the locality, so they can easily be fabricated and installed at the point of use without needing skilled manpower**.**

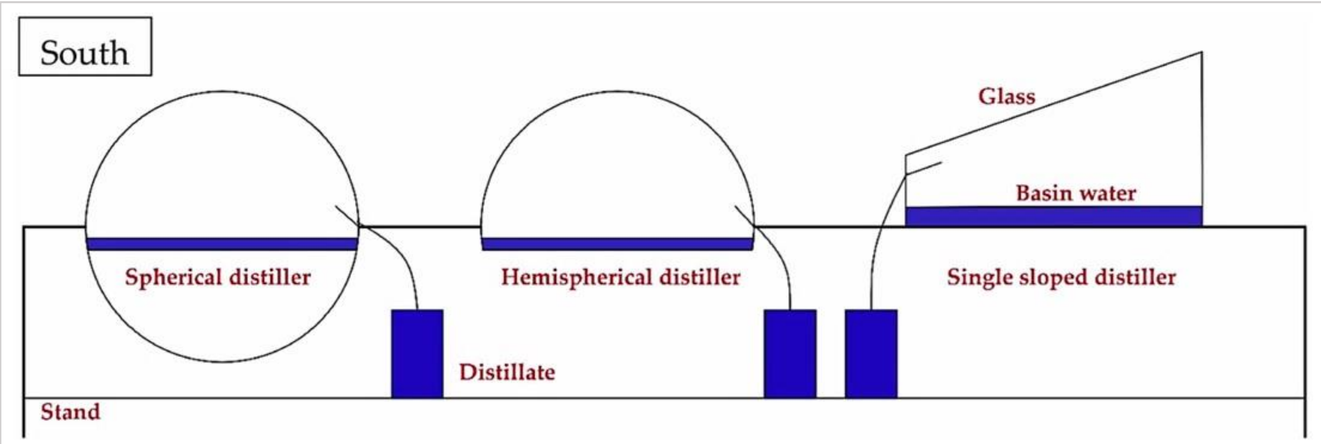

Figure 4: Diagram of three type solar distiller [82]

6. Enhancing spherical solar still performance: techniques and research

Spherical solar stills' invention is a promising choice for eco-friendly and workable water distillation technology. In these innovative devices, distilled water is obtained through solar power distillation. However, different research activities and methodologies are being developed to make them more effective. This paper delves into the approaches used to improve the performance of spherical solar stills (including ongoing efforts towards efficiency) and even those educational campaigns aimed at fostering wider adoption, all documented here.

6.1 Effect of configuration polyethylene cover solar still

Jayaprakash et al. [83] proposed a recently developed spherical solar still and evaluated its operating parameters and climatic conditions in Coimbatore, India (11°N). Nonetheless, the radiation received ranges from 458.92 W/m² to 1111.08 W/m² and 507.23 W/m² to 1086.93 W/m² for 0.107 mm and 0.176 mm covers. Two different thicknesses of low-density polyethylene (LDPE) coverings were considered for the efficiency evaluation of the solar system. Comparative LDPE casing thicknesses were 0.107 mm and 0.176 mm. They regularly collect data on air, water, and ambient temperatures and observe temperatures inside and outside the lid when exposed to fluctuating solar radiation. The effectiveness of solar stills with different roof thicknesses was evaluated by considering internal and external heat transfer modes. Calculate the production per square meter per hour. Nonetheless, spherical solar productivity was determined for two different thicknesses of LDPE panels, as shown in Figure 5. The results show thinner coatings have a higher average evaporation rate than thicker coatings. Despite its modest price, the system achieves a peak efficiency of 22%.

6.2 Integration Shapes of Solar Stills

Karroute and Chaker [84] In this study, researchers investigated how changes in glass cover design affect the amount of solar energy absorbed by a solar still. Three different types of distillation systems, namely single-pitch single-tank, double-pitch single-tank, and spherical still systems, were studied to determine which geometry was operationally most appropriate. To solve the equations, we use the fourth-order Runge-Kutta method to study the thermal equilibrium of these solar stills while maintaining a constant position with solar radiation (810-1050) w/m^2. The numerical analysis results show very clearly that the spherical solar still system generates more energy than the single-tank double-chute or flat-plate solar still. Therefore, solar radiation has become a key component affecting solar productivity. More specifically, the daily output of the single-slope solar still system shown in Figure 6a and the triangular device shown in Figure 6b is approximately 2.990 kg/m²/day. In comparison, the daily output of the dual-slope solar still system is approximately 3.970 kg/m²/day. The spherical solar still system shown in Figure 7a the traditional and Figure 7b the modified device showed higher efficiency with an average production of 5.050 kg/m²/day

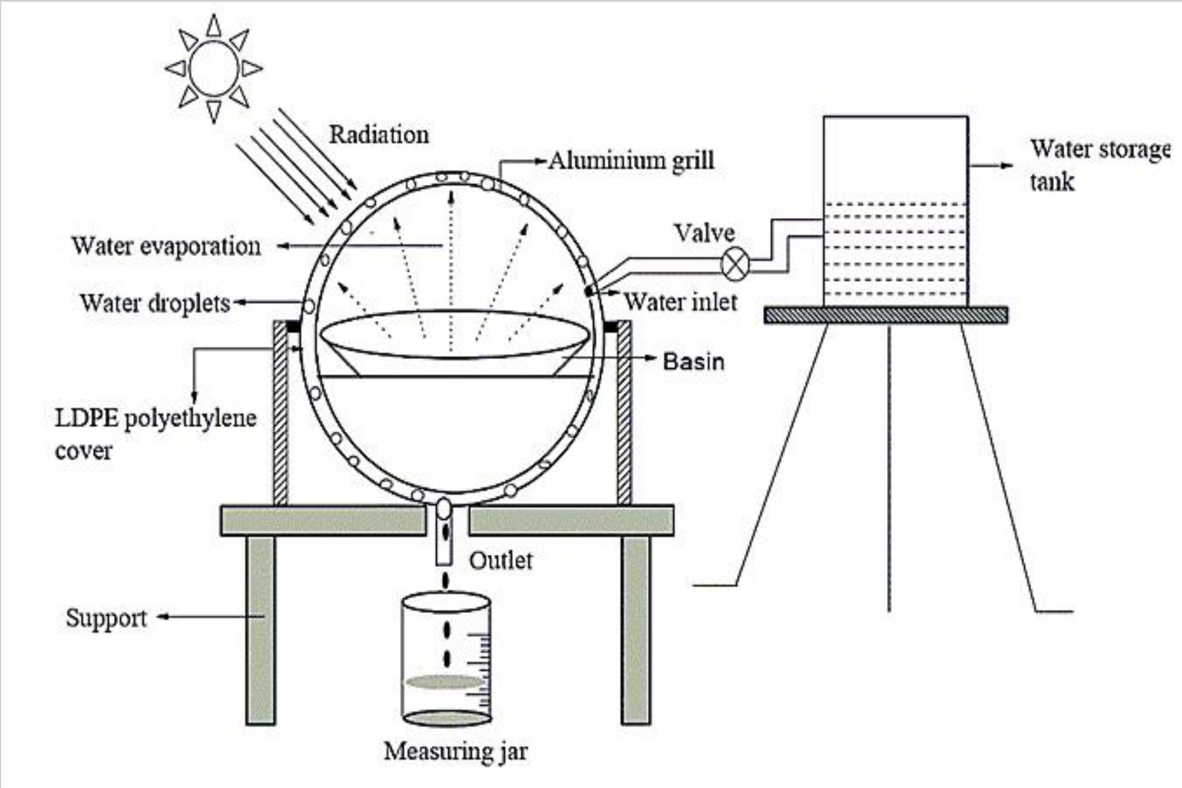

Figure 5: Test- rig of spherical solar distiller [83]

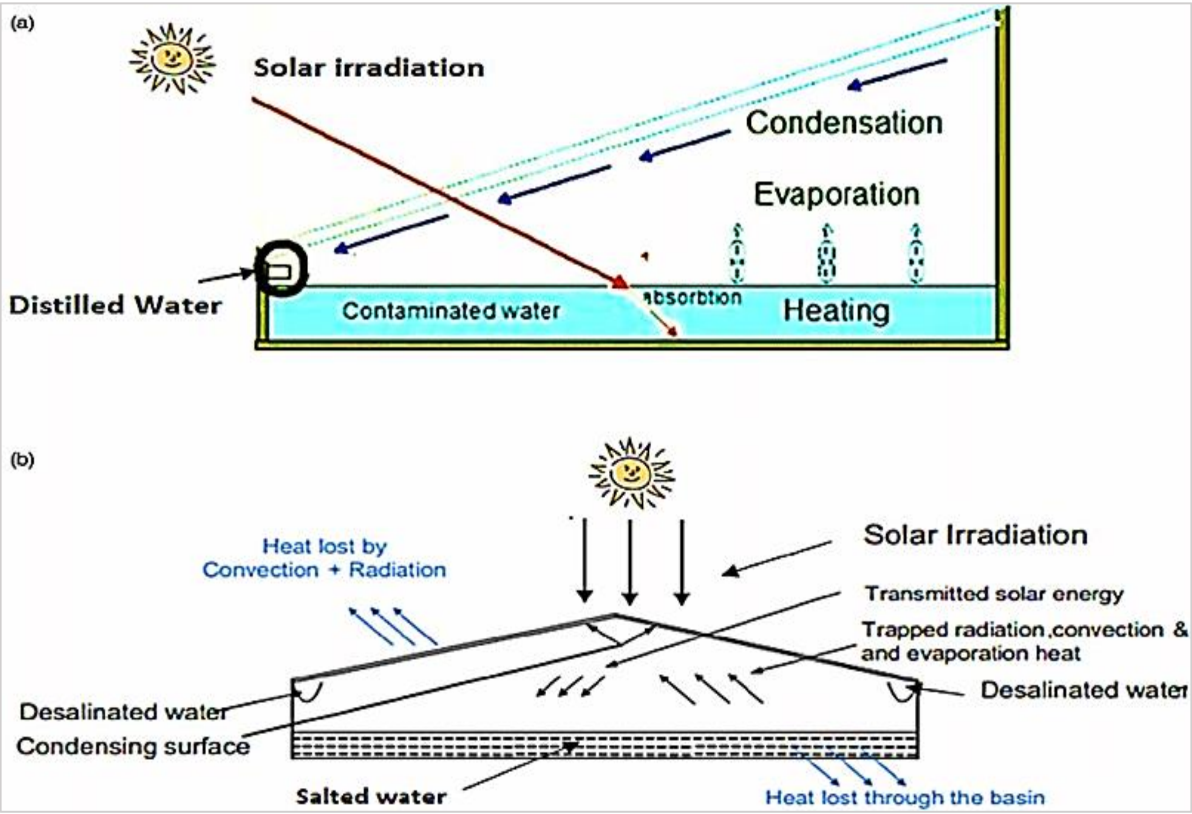

Figure 6: Conventional slop and triangular solar distiller system [84]

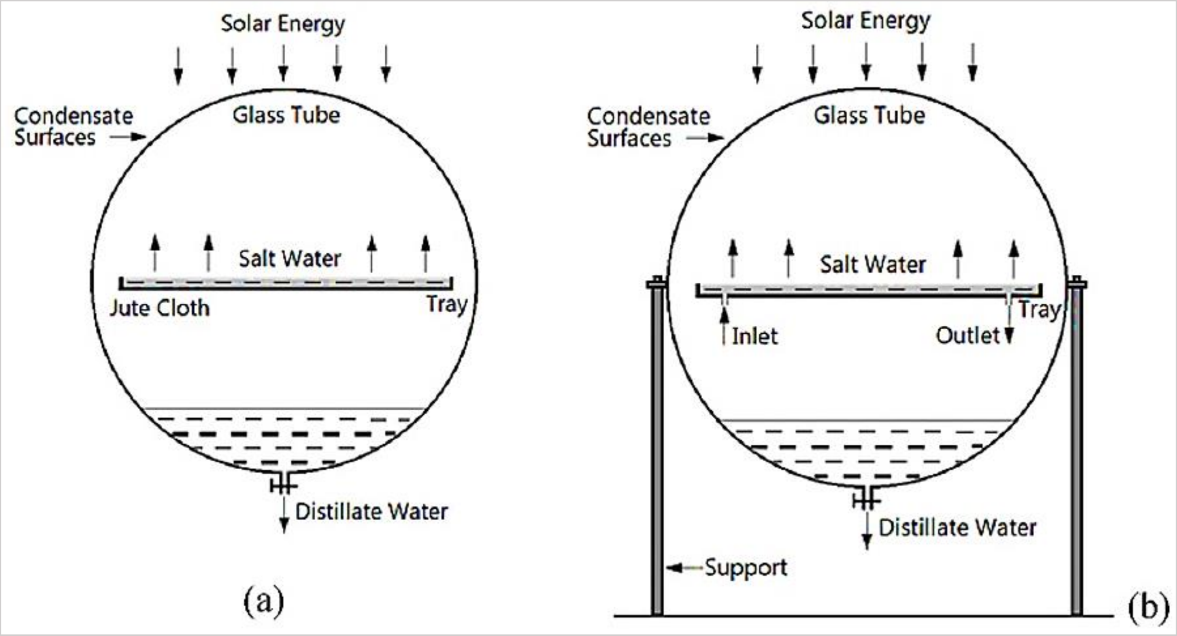

Figure 7: Test -rig spherical solar distiller system [84]

6.3 Stepwise basin

Abdullah et al. [85] introduced new designs of Solar Distler, including hemispherical and pyramidal designs with chambers. They stepped pools, as shown in Figures 8 and 9, which extend the traditional solar still design. An experiment was conducted to evaluate how these design improvements affected the performance characteristics of an improved solar still. With maximum solar radiation of 650 w/m^2. The study found that incorporating hemispherical and stepped chamber designs into the modified still significantly increased productivity, up to 57.1% compared to the pyramidal solar still. Research conducted during a typical winter season examined the impact of additional design changes on both categories. The spherical container produced more distilled water, yielding 31.6% on the first day and 57.1% on the second.

Figure 8: The pyramid still after manufacturing and the three-dimensional view [85]

Figure 9: The spherical still after manufacturing and the Three-dimensional view [85]

These results indicate that solar distillation systems have the potential to be widely used to produce distilled water in arid regions around the world, which has significant implications for solar distillation applications.

6.4 Add marital coating

Al-Hamadani et al. [86] proposed a study on a solar distillation system, as shown in Figure 10. The radiation intensity of Iraqi Kut reaches 930W/m^2, making it ideal for solar applications such as solar distillation plants. This study aims to evaluate the yields with and without coal—the Semi-Spherical Solar Still (SS-SS). The (SS-SS) configuration consists of a square aluminum pool with a length of 0.3 meters and an area of 0.09 square meters, as shown in Figure 11. Researchers coated the pool's absorbers with black paint to increase the absorption of solar energy. The results showed that the productivity of the system without coal (SS-SS) was higher than that with coal, especially at pool water depths of 1.5 cm and 2 cm. The carbon-free SS-SS yield was 2.700 kg/m²/day with a total radiant power of 593.5 W/m^2 in 6 hours.

On the other hand, the one using coal (SS-SS) produces 2.5 kg/m²/day with a total irradiance of about 5845 W/m^2 at 1.5 cm dbw. At 1.5 cm depth at 3:00 PM, the efficiency was 58% without coal and 70% with coal. The brine content in (SS-SS) was initially 999.54 ppm before desalination and decreased to 4.06 ppm after treatment. The results show that (SS-SS) can produce distilled water.

Figure 10: Snapshot of Semi Spherical Solar Still (SS-SS) [86]

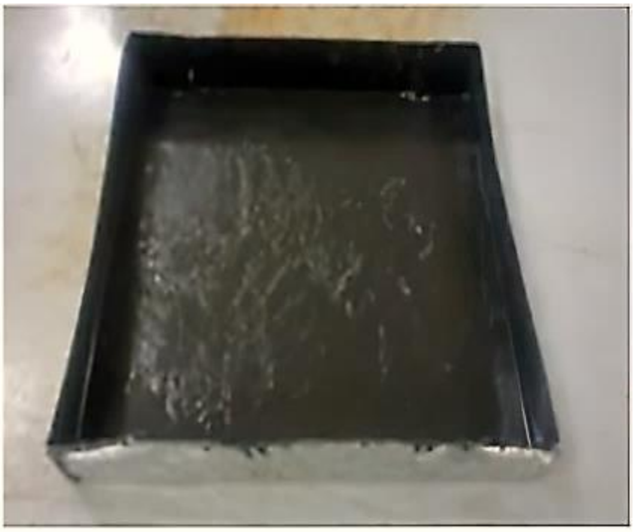

Figure 11: Water storage basin [86]

6.5 Flat plate collector

Abidat and Rebiai [87] studied the effect of coupling a flat plate collector with a spherical solar still system on distilled water production. The efficiency of a typical desalination system and a spherical system were compared after determining the transient heat budget of various solar systems, including plate stills, spherical stills, plate stills with collectors, and spherical solar still systems with collectors, solar radiational 650 w/m^2 a fourth-order (Runge-Kutta) method to solve differential equations. The percentage increase in distilled water production can be determined by connecting a flat plate collector to a spherical solar still system. Results show that adding a collector still increases the efficiency of a solar by 30-50%. It is worth noting that the yield of a separate ramp maintained in combination with a collector is approximately 5.190 kg/m²/day. In contrast, the corresponding value for a spherical ramp maintained with a collector is approximately 7620 ml/m^2/day.

6.6 Integrated with solar reflector

Modi et al. [88]. Proposed a new improvement that combines a tilted reflector with a spherical tank solar still. We developed a solar still with a spherical water tank and tested its efficiency with different amounts of water from 1L to 5L. Daily production increased proportionally with the amount of water in the tank and was measured at 3.5409 kg/m²/day and 4.786 kg/day. Water volumes of 1 liter, 2 liters, 3 liters, 4 liters and 5 liters are 6.717 kg/m²/day, 7.474 kg/m²/day, and 8.259 kg/m²/day, respectively. For the cases where the water volume is 1 liter, 2 liters, 3 liters, 4 liters, and 5 liters, the daily average efficiency of the spherical tank solar still is 19.56%, 23.92%, 30.83%, 34.49%, and 39.06% respectively. The range of solar radiation (DNI) should be 1000 W/m^2 to 1200 W/m^2. Experimental results show that the distillation yield increases as the amount of water in the tank increases.

6.7 Reflector and cooling cover

Sharma and Modi [89] explored various methods to improve Spherical Solar sill (SSS) yield. Installing reflectors, specifically parabolic reflectors, could significantly increase productivity. When comparing different designs, they found that using reflectors with basins increased productivity due to increased radiation. Additionally, cooling the condenser portion of the solar still (usually the upper part of the sphere) can increase productivity. Preheating feed water or brine can also increase productivity.

Additionally, creating a vacuum in a solar still can increase productivity by 50 to 70 percent. Mixing nanofluids with water improves thermal conductivity, thereby increasing evaporation rates and efficiency by 50 to 70 percent. Thicker cover glass also improves productivity; a 6mm thickness is more productive than a 2mm thickness. Increased water surface area increases evaporation rates, increasing productivity by 20% compared to traditional solar stills. While a tracking system is not required for spherical solar stills, efficiency can be improved using a reflector system. However, tracking systems are expensive and often sit idle due to budget constraints.

6.8 Rotating part, wick martial

By integrating rotating spheres, Alsehli [90] developed a novel solar still design called the Rotating Sphere Solar Still (RSSSS). This study evaluated the performance of (RBSSS) compared to Conventional Systems (CS) based on various factors. The study investigated how different spin speeds (0.5 to 3 rpm) and the wicking material's content affect the spinning balls' behavior. Solar irradiance decreases as time progresses. At its peak, around 12:00, the solar radiation was 1000 W/m^2. The experiment started at 8:00. However, the instant solar intensity was 600 W/m^2. The results showed that a rotational speed of 1 rpm resulted in the highest yield of RBSSS. The improved distillation productivity significantly increased by 37% compared to (CS), with an efficiency of 51% compared to 33% for (CS). Running the RBSSS at one revolution per minute using moisture-wicking material resulted in a 57% increase in output. In this case, RBSSS shows improved exergy efficiency (3.73%) and energy efficiency (56%). (CS) consistently maintains energy and exergy productivity of 33% and 2.98%, respectively.

6.9 Rotating part, wick, phase change material (PCM)

The study by Essa [91] in Kafrelsheikh, Egypt, compared the performance of a Modified Spherical Solar Distiller (MSSD) with ordinary spherical solar stills in terms of energy, exergy, economic, and environmental factors. This study examines the case of different rotation rates of a modified spherical solar still ranging from 0.25 to 1.5 rpm. They also studied the effects of placing a piece of black jute-wicking material on top of a moving ball and placing insulation underneath it. We analyzed two types of thermal storage materials: desert soil, copper sand, and a combination. Studies have shown that the most efficient rotation speed of MSSS remains at 0.75 revolutions per minute, resulting in a 40% increase in output compared to conventional systems. Maximum solar radiation values approached approximately 1050 W/m^2 at its zenith around 12:00. When using wicking material, operating at 0.75 rpm, distillate production increased by 57%. Optimum performance is achieved when MSSS is run at 0.75 rpm with a wick (a combination of copper pellets and desert sand). The distillation process produces 7.160 kg/m^2/day, 103% more than traditional designs, and has an efficiency of 59.5%.

Furthermore, MSSD with thermal storage materials exhibits significantly higher exergy efficiency compared to conventional designs, the same way Essa [92] developed a Modified Spherical Solar Distiller (MSSD) to overcome the shortcomings of conventional systems (CS). A thorough examination was carried out to compare its performance with a reference spherical distiller (CS). Solar radiation values approached approximately 1050 W/m^2. The study investigated important parameters affecting productivity, such as rotation speed ranging from (0.2 to 1.2) rotations per minute, the kind of wick material on the revolving ball, and the utilization of phase change materials beneath the ball, such as desert sand, copper grits, or a mix of both. The (MSSD) achieved a 40% higher yield than the (CS) with an ideal rotation speed of 0.8 rpm. Moreover, adding wick material at a rate of 0.8 rpm boosted distillate output by 57%, leading to a notable 103% enhancement compared to the (CS) (7.160 vs. 3.525) kg/m^2/day. This setup achieved a remarkable efficiency of 59.5%.

6.10 Chitosan aerogel, graphene nanoplatelets, aluminum cans

Arunkumar et al. [93] developed photothermal absorbers (PTA) by Combining Chitosan Aerogels And Graphene Nanoplatelets (CAGNPs) to solve these problems. Solar radiation was measured using a solar meter with a power range of 0–250 W/m^2. A Soy Wax (SWAX)--based Thermal Energy Storage Material (TESM) is incorporated into a Spherical Solar Distiller (SSD). Waste aluminum beverage cans are reused for heat storage (TESM). Three identical structures were built and evaluated for efficiency. The conventional SSS achieved a distilled water production of 1.6 kg/m^2/day in 9 hours. By adding SWAX, distilled water production increased to 3.0 kg/m^2/day compared to conventional, Significant improvement. 18. New forms of desalination systems are proposed. Furthermore, the synergistic effect of CAGNP and SWAX in SSD resulted in significant improvements, with distilled water production reaching 4.1 kg/m^2/day. The exergy efficiencies of traditional SSD, SSD-PCM, and SSD-CAGNP-SWAX are 1.21%, 1.69%, and 1.85%, respectively. On the other hand, Mohsenzadeh et al. [94] studied a new floating seawater desalination system. Use a low vacuum to remove salt during the evaporation chamber process. They conducted experiments to evaluate effectiveness. With solar radiation 550w/m^2. The revised design utilizes the absorption of solar heat to increase evaporation rates and prevent salt accumulation on the pool surface through the interface of evaporation and radial water circulation. A barrel-shaped basin with multiple layers of porous foam and hydrophilic cellulose fabric ensures improved capillary water distribution. Solar stills have external condensation coils attached to their tank structures, completely submersed in water and floating in saltwater reservoirs such as the ocean. This design improves the normal renewal of the condensing coil, resulting in higher condensation rates. Use cost-effective hemispherical clear acrylic panels to capture sunlight hitting your pool from all angles. The system's overall efficiency was evaluated under various conditions, with Australian purified water production reaching 4300ml/m^2/day in summer and distillation efficiency reaching 35.6%. Table 1 presents analyses of different techniques aimed at enhancing the effectiveness of a spherical desalination system, summarizing the key innovations and their impact on system performance.

Table 1: Presents analyses of different techniques aimed at enhancing the effectiveness of a spherical desalination system

Modifications	Position/year	Maximum yield %	Conclusions	Ref.
Single Effects in Spherical-Type Solar Still				
Theoretical model	India/ 1988	30%	Compared the daily production of a solar still with that of a standard solar still. Increase output productivity by 30%	[80]
Cooling cover geometry	Algeria/ 2014	32.47%	Study The cooling effect of one side of the desalination system increased productivity by 32.47%.	[81]
Comparative three modification design solar stills	Tanta, Egypt/2024	77.42%	Main conclusion: spherical distillation yields more than hemispherical and single-slope distillation. For reliable potable water production, a spherical solar still is recommended.	[82]
Investigated two varying thicknesses of low-density polyethylene cover	Coimbatore India/2009	22%	LDPE covers with thicknesses of 0.176 mm and 0.107 mm were compared. At regular intervals, it indicated that the average evaporation rate was higher for thinner top covers compared to thicker ones.	[83]
Changes in glass cover geometry	Coimbatore India/2011	5050 ml/m²/day	It was concluded that the new shape increased the production rate by 5050ml/m^2/day when comparing the traditional shapes of the solar still with the spherical.	[84]
Chamber stepwise basins	Amman Jordan/2021	57.1%.	Integrating semi-spherical and chamber stepwise designs into the altered distills resulted in a production boost of up to 57.1%.	[85]
Charcoal	Kut Iraq/2018	70%	The efficiency was 58% without coal and 70% with coal at a water depth of 1.5 cm.	[86]
Coupling a spherical solar still with a flat plate collector	Algeria/2013	30-50%	The spherical slope, still paired with a collector, attained around 7.62 L/m²/day.	[87]
parabolic reflector with a spherical basin	Gujarat India/2019	39.06%	The solar basin, shaped like a sphere, attained daily average efficiencies of 19.56%, 23.92%, 30.83%, 34.49%, and 39.06% for water volumes of 1 L, 2 L, 3 L, 4 L, and 5 L, correspondingly. Shows that the distillation yield rises as the amount of water in the basin increases.	[88]
Parabolic reflectors and cooling cover with nanofluid	Gujarat India/2016	70%	Additionally, thicker glass covers increase output; a 6mm thickness increases output more than a 2mm thickness.	[89]
Rotating ball spherical solar still and wick	Taif Saudi Arabia 2023	%57	Incorporating wicking material while running the RBSSS at 1 rpm increased output by 57%. Furthermore, when subjected to these conditions, the RBSSS demonstrated enhanced exergy efficiency (3.73%) and energy efficiency (56%). Conversely, the CSSS sustained exergy and energy efficiencies of 2.98% and 33%, respectively.	[90]
Black jute wick and rotating ball and placing thermal storage materials	Kafrelsheikh Egypt/2024	103%	The modified device, operating at an ideal rotating speed of 0.75 rpm, increases distillate output by 57%, yielding 7160 ml/m^2/day using dry sand and copper pellets.	[91]
Black jute wick and rotating ball and PCM	Tanta, Egypt/2024	57%	The study found significant productivity improvements when incorporating wick material, phase change material (PCM), and adjusting rotation speed. The MSSS operated at 0.8 rpm and showed a 40% increase in productivity. Additionally, with wick material at the same speed, distillate production increased by 57%, resulting in a 103% improvement over the CSSS.	[92]
A mixture of chitosan aerogel and graphene nanoplatelets	Gyeongbuk, Republic of Korea/2023	1.85%	PCM and CAGNP-SWAX increased the SSS freshwater yield and exergy to 4100 ml/m^2/day. In contrast, the energy efficiency of conventional desalination systems decreased.	[93]
New floating seawater desalination system	Australian /2021	35.6%.	The design enhances condensing coil renewal, boosting condensation rates. Utilizing cost-effective acrylic panels, it achieves high efficiency, producing Australian purified water and distillation at 35.6%.	[94]

7. Conclusion

Spherical solar desalination innovations aim to improve performance by optimizing design, material selection, and thermal storage. These advancements enhance distilled water production in sunny regions like Coimbatore, India, and Kut, Iraq. Thinner LDPE coatings improve evaporation rates, while PCM and insulated tanks store excess heat, ensuring high productivity despite energy demands. The solar tracking system aligns stills with the sun's orbit, increasing water production by 30%. Other methods include using reflectors, cooling mechanisms, and alternative designs like hemispherical and pyramidal stills with stepped chambers. Even at low rotational speeds, these designs have shown increased productivity by 57.1% and 37%, respectively, compared to conventional systems.

1) Flat plate collectors and spherical solar stills can increase efficiency by up to 7.620 kg/m^2/day, compared to 5.190 kg/m^2/day for non-spherical designs. Larger water volumes in spherical tanks lead to higher distillation yields, reaching 8259.6 ml/m^2/day. Wicking materials and thermal storage substances, such as desert sand and copper particles, also contribute to increased productivity. Researchers are exploring further improvements in these systems.
2) Advanced materials in distilled water production have significantly increased output, achieving 4.1 kg/m^2/day and energy efficiencies of up to 1.85%. Floating desalination systems with low vacuum technology and external condensation coils have proven effective, especially during the summer, producing 4300 ml/m^2 per day at 35.6% efficiency.
3) Flat plate collectors and spherical solar stills have demonstrated high productivity, reaching 7.620 kg/m^2/day. The sun's unique conditions still increased production by 57%. New research using advanced materials like soy wax and graphene

nanosheets has shown that spherical solar stills can produce 4.1 kg/m^2/day. This indicates they could be a long-term solution to the lack of water in dry, hot places.

Author contributions

Conceptualization, **F. Jodah**; data curation, **F. Jodah** and **W. Alawee**.; formal analysis, **F. Jodah** and **W. Alawee**.; investigation, **F. Jodah**.; methodology, **F. Jodah**.; project administration, **W. Alawee** and **H. Dhahad**.;resources, **F. Jodah**.; software, **F. Jodah** and **W. Alawee**.; supervision, **W. Alawee**, **H. Dhahad**, **Z. Omara**.; validation, **F. Jodah** and **W. Alawee**.; visualization, **F. Jodah**.; writing—original draft preparation, **F. Jodah** and **W. Alawee**.; writing—review and editing, **F. Jodah**, **W. Alawee** and **H. Dhahad**. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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