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Review

Inverted Solar Stills: A Comprehensive Review of Designs, Mathematical Models, Performance, and Modern Combinations

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Abstract: Fresh water is scarce, making it a worldwide issue. In order to address global freshwater demand, a filtration technique is needed. Solar distillation (SD) that purifies brackish and subterranean water has been proven to be a promising green technology. It produces distilled water which can be used as potable water for drinking and other purposes. The designs, operations, and configurations of several inverted solar stills are thoroughly examined in this article. All techniques for solar water distillation to separate saltwater from freshwater have the same fundamental idea. It has been demonstrated that for a specified mass of water in the top basin, the daily output of an inverted absorber double-basin solar still (IASS) grows with increasing water depth in the bottom basin. Nevertheless, as the water depth in the bottom basin rises from 1 cm to 5 cm, the output of an inverted absorber double-basin solar system falls by about 27%. At water depths of 4, 6, and 8 cm, the daily yields from inverted absorber solar stills paired with a refrigeration cycle (RIASS) were 6.4, 10.08, and 9.5 L/day, respectively. The results also showed a substantial rise in water temperature in the inverted absorber solar still as a result of lower bottom heat loss and larger absorptivity. In this study, the emphasis on energy, efficiency, and environmental concerns remains with the modified multi-wick basin-type inverted absorber solar panel. The performance of the inverted trickling solar still was assessed with a 60 ppm average salinity under various sun radiation, feed water flow rate, and existence conditions for natural convection. It was found that the still could produce 2.55 L/day m^2 of fresh water, a 15% increase. Brackish water with a salinity of 6000 ppm was used to test the still in November at tilt angles of 47° and 32°. Condensate production at the specified angles was 2.8 and 2 L/d, respectively. A total output of 6.907, 5.681, and 4.650 kg/m^2/day was also generated using the modified multi-wick basin-type inverted absorber solar still (MMWBIASS) at water depths of 1, 2, and 3 cm, respectively. With black cotton wicks, the MMWBIASS had a total thermal efficiency of 34.04%, 28.17%, and 23.61%.

Keywords: solar desalination; inverted solar still; modern combinations

1. Introduction

Worldwide, fresh water is becoming harder to find. This has developed into a serious problem and is a major obstacle for the whole planet. A total of 70% of the surface of the Earth is covered by water. Freshwater makes up just 2.5% of the total amount of water on Earth; the other 97.5% is saltwater. In the polar regions, around 70% of the freshwater freezes as icebergs; the remaining freshwater remains in deep water sources as moisture content or is unsuitable for human consumption. Only 1% of the world's freshwater supplies are fit for immediate human use, but rain and snow regularly replenish it. Therefore, a technology for water filtration is needed to confront the worldwide water shortage. Solar distillation is one approach for purifying salty and deep water (SD). It is an environmentally friendly method that is also quite effective for generating flavorful distilled water that can be consumed and utilized for multiple things.

Mechanism of the Solar Still

With a curved reflector, the single-slope solar still is commonly used with inverted absorber solar stills (IASS). It is a superior solar design since it has the benefit of heating the basin from all sides. All techniques for solar water distillation to separate saltwater from freshwater have the same fundamental idea. The majority of the sunlight that comes through the lid is absorbed by the saltwater in the trough; the remainder is absorbed by the lid and trough. The heated water causes the saltwater to evaporate. Evaporation from the liquid surface causes the humid air's water vapor density to rise. The water vapor that accumulates on the inner surface of the cover evaporates, releasing any latent heat it may have had. Gravity then causes the condensed water to drip downward to be collected in a collector [1].

2. Fabrication Details of the Solar Still

Scientists have been extensively working to increase the efficiency of solar stills for a long time. In recent years, a variety of solar still designs, including double-slope solar stills and multi-wick sun stills, have been developed [2,3].

In 1995, Badran and Hamdan created, built, and tested an inverted water trickle solar still [4]. This still was developed for solar distillation using flat plate collectors. The concept is based on the trickle of water that passes through a very thin layer on the absorber plate's back. A wire screen that has been welded to the plate aids in maintaining this layer's connection to the plate so that it may continue to perform as intended, in addition to impacting the surface tension force. The water will heat up and evaporate as it runs further down the plate if there is only a very small trickle of water traveling downwards along the plate. The adjoining compartment receives the vapor, which is then allowed to condense before being collected. The key features of this idea are the removal of the condensation on the glazing, which raises the amount of solar radiation that reaches the absorber plate, and in addition, the elevation of the temperature difference between the evaporator and the condenser, which ultimately raises the productivity of basin-type stills. It has been proven that an expansion of this size would be advantageous; a daily rise of 3.83 L per square meter was observed in production.

In 1997, an investigation of an inverted absorber double-effect solar still was conducted and reported by Suneja et al. [5]. Analytical formulas for the water temperatures and the condensing cover, as well as the hourly yield, were established. Equations for the energy balance were also developed, which will be discussed further in the next section. A normal day in Delhi has been modeled using a variety of mathematical computations. Consequently, a conventional double-effect solar still, sometimes referred to as a double-basin sun still, was employed to compare the results. It was found that the output of the conventional double-effect inverted absorber solar panel is still lower than that of the inverted absorber solar panel. Figure 1 demonstrates how an inverted absorber double-basin solar still's output capacity declines by around 27% as the water depth in the bottom basin rises from 1 cm to 5 cm.

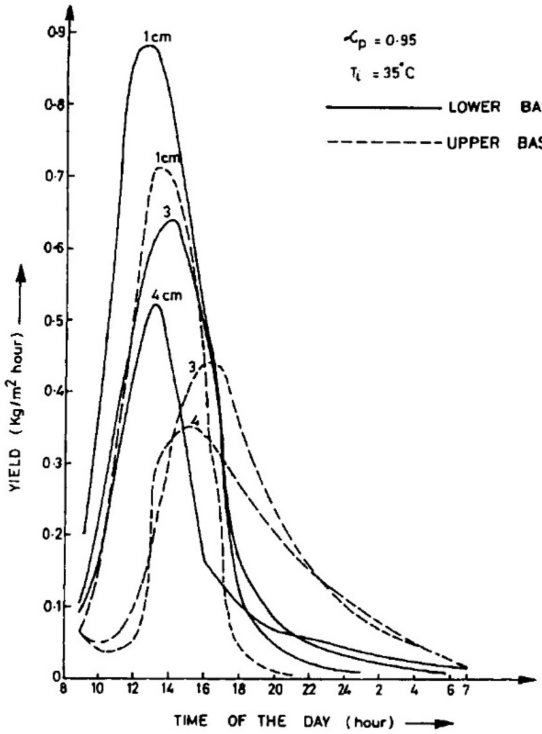

Figure 1. Water depth effect on the hourly variation of the double-basin inverted absorber solar still's yield. Reprinted/adapted with permission from Ref. [5]. 2022, Elsevier.

In 1998, a Runge–Kutta 4th-order approach-based computer simulation model for a multi-basin inverted absorber distiller unit was provided by Suneja and Tiwari [6]. Equations relating to the energy balance were solved using this model, which we will elaborate on further in the next section. Research has been done on how recycling the latent heat from the vaporization of the matching lower basins affects daily yield in order to maximize the potential effects. Figure 2 illustrates how increasing the number of basins beyond seven increases the yield very slightly.

In 1998, the inverted absorber solar still was the subject of research by Tiwari and Suneja [7]. Based on the design and environmental factors, analytical formulas were created for water temperature, condensing cover temperature, instantaneous thermal efficiency, and hourly yield. A numerical study was done for a solar still with a standard absorber and a solar still with an inverted absorber for a day with typical Delhi weather. It was demonstrated that the inverted absorber solar still produces almost twice as much as a typical solar still. Figure 3 shows the inverted absorber solar still with a significant rise in the temperature of the water as a result of less heat escaping from the still's bottom and more heat being absorbed by the inverted absorber plate. The daily production decreases as the depth of water rises, as shown in Figure 4.

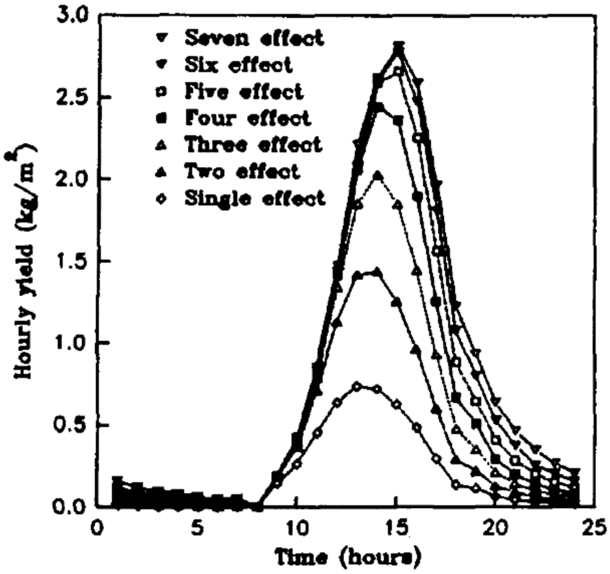

Figure 2. Hourly yield variation from multi-effect inverted absorber solar stills. Reprinted/adapted with permission from Ref. [6]. 2022, Elsevier.

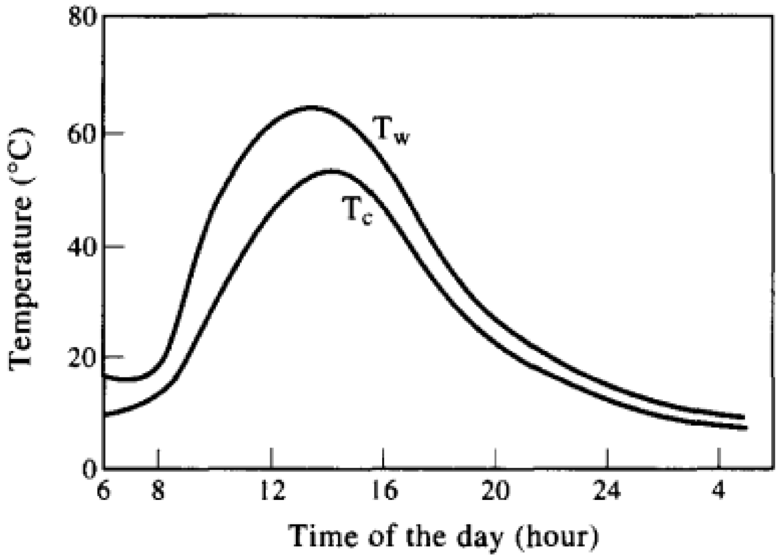

Figure 3. The hourly variation of the temperature of the water and condensing cover Reprinted/adapted with permission from Ref. [7]. 2022, Elsevier.

In 1999, an investigation of double-basin solar still's transient behavior was provided by Suneja and Tiwari [8]. In-depth research has been done on how the bottom basin's water depth affects how the system functions. Explicit formulas have been developed for the various part temperatures in the inverted absorber double-basin solar still, as well as its effectiveness. Numerical calculations employing climatic variables for an average winter day in Delhi have been done to clarify the analytical conclusions. Figure 5 illustrates how, for a given water mass in the top basin, the daily output of an inverted absorber double-basin solar still rises with rising water depth in the bottom basin.

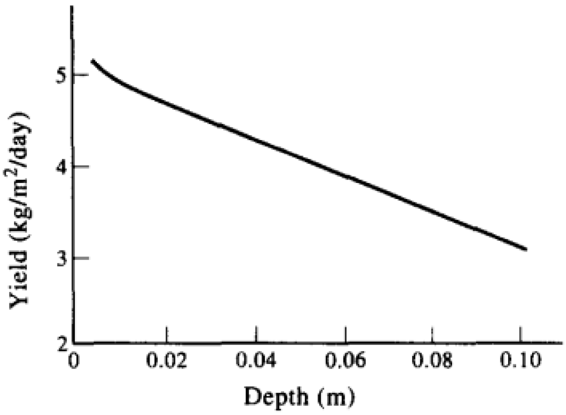

Figure 4. The yield variation with water depth. Reprinted/adapted with permission from Ref. [7]. 2022, Elsevier.

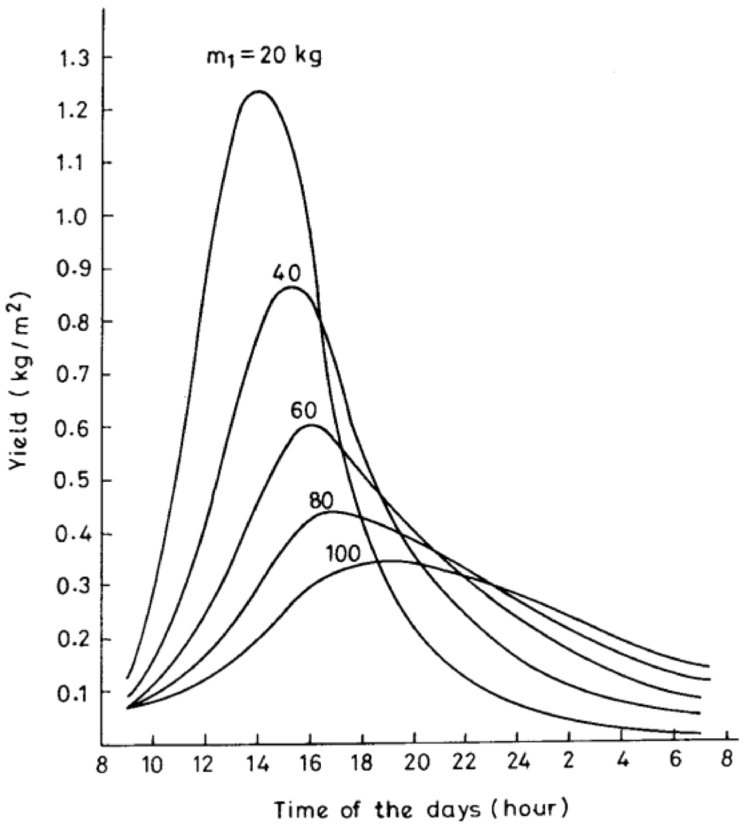

Figure 5. The lower basin water depth's effect on the hourly variation of the total yield. Reprinted/adapted with permission from Ref. [8]. 2022, Elsevier.

In 1999, Tiwari and Suneja [9] reported an analysis of a solar still with an inverted absorber. The condensing surface was still being wetted by water. Based on the design parameters and the climatic factors, analytical expressions for the yield and the instantaneous thermal efficiency, as well as the hourly change of several temperatures, including those of water, condensing cover, and flowing water, were developed. These expressions take into account the environmental conditions as well as the system's architecture. An inverted absorber solar still with water flowing over the condensing cover has been numerically calculated for a day's worth of weather in Delhi. The results were contrasted with a solar still that had an inverted absorber but no water flow over the condensing lid. It has been concluded that for an ideal water depth of 10 cm in the basin, a flow of water at a rate of

0.5 kilos per second increases the yield by roughly 11%. As the water depth in the basin increases, the yield decreases, which directly affects the low operating temperature.

In 2001, an experimental investigation of the inverted trickling solar still was reported by Badran [10]. This still was developed further and enhanced by adding a heat exchanger inside the condenser. The heat exchanger partially recovers the heat lost during the condensation process, which is then used to heat the saltwater supply. The productivity increased in the month of May, ranging from roughly 2.5 L/d to 2.8 L/d, as a consequence of this enhancement, insulating the still's sides, and growing the flow rate of the saline water supply. The saline water supply flow rate was increased, leading to improved productivity. This improvement, which comes out to around 12%, is mostly attributable to the production of condensate. Additionally, this productivity was raised by around 42%, which resulted in a flow rate increase of almost 50%. It is possible to create a combination of condensate and intermediate products with a rate of 8.2 L/d and a salinity of 7130 ppm. This mixture is appropriate for use in some forms of agricultural production.

In 2010, Abdul-Wahab et al. [11] conducted an experimental study on the inverted absorber solar still (IASS) in Muscat, Oman. A curved reflector is positioned beneath the basin of an IASS as an improved single-slope solar still design. This arrangement enhances the direct and indirect heating of the solar still's basin from both sides (that is, the top and bottom surfaces). The basin's reflector, which adds more heat to the system and boosts the temperature of the water and the condensing glass cover, outperforms the conventional single-slope solar still. According to testing results, the inverted absorber solar still may produce more than 3.5 L/m^2 over the course of a 12-h period, beginning at 7:00 in the morning and ending at 7:00 in the evening. It is revealed, after 16:00, that the IASS lacks the ability to store thermal energy for a lengthy amount of time. The thermal storage is lost to the environment through the enclosed air underneath the basin as a result of the decrease in the amount of reflected solar radiation.

In 2011, Dev et al. [12] constructed linear and nonlinear characteristic correlations of the inverted absorber solar stills (IASS), considering analytical formulations of instantaneous gain I and loss (iL) efficiencies using experimental data for the climatic conditions in Muscat, Oman. Figure 6 displays an illustration and a layout of the experimental setup. The outcomes demonstrated that the IASS exhibits expected nonlinear behavior. These findings were also contrasted with equations specific to SS that were discovered in comparable operational and climatic circumstances. Figures 7 and 8 show that the values of (instantaneous gain efficiency) increase as the water depth rises, whereas the values of instantaneous loss efficiency (iL) decrease as a result of the water's thermal storage effect. Since 0.01 m water depth has been discovered to have superior values of I iL and ew than other water depths, it may be advised for solar stills.

In 2011, Dev et al. [13] reported on an experimental evaluation of an inverted absorber solar still (IASS) and a single-slope solar still (SS). The researchers carried out the tests with various total dissolved solids and at various water depths (TDS). Additionally, experiments were done in order to discover the most likely weather in Muscat, which is located in Oman. A thermal model was also created for the IASS and tested using the outcomes of trials. A fair agreement was established regarding how the IASS operates during the day. It has been observed that the IASS is capable of creating a substantially higher water temperature when compared to the SS. Figure 9 shows the daily yields from the IASS at water depths (dw) of 0.01, 0.02, and 0.03 m to be 6.302, 5.576, and 4.299 kg/m^2 day, respectively. The daily yield from the SS, at 2.152, 1.931, and 0.826 kg/m^2 per day, respectively, is lower than the output from the IASS at the same relative water depths. The IASS's ideal operating depth in Muscat, Oman's climate was determined to be 0.03 m, and adding a reflector to the basin does not significantly improve its performance compared to the SS for seawater.

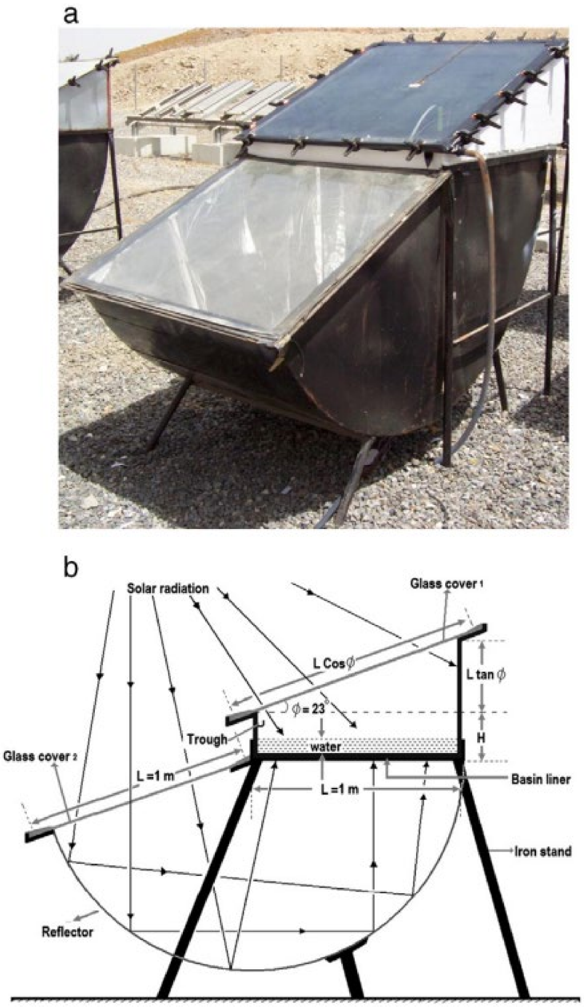

Figure 6. (**a**) A picture of the solar still with the inverted absorber (IASS). (**b**) An IASS schematic design. Reprinted/adapted with permission from Ref. [12]. 2022, Elsevier.

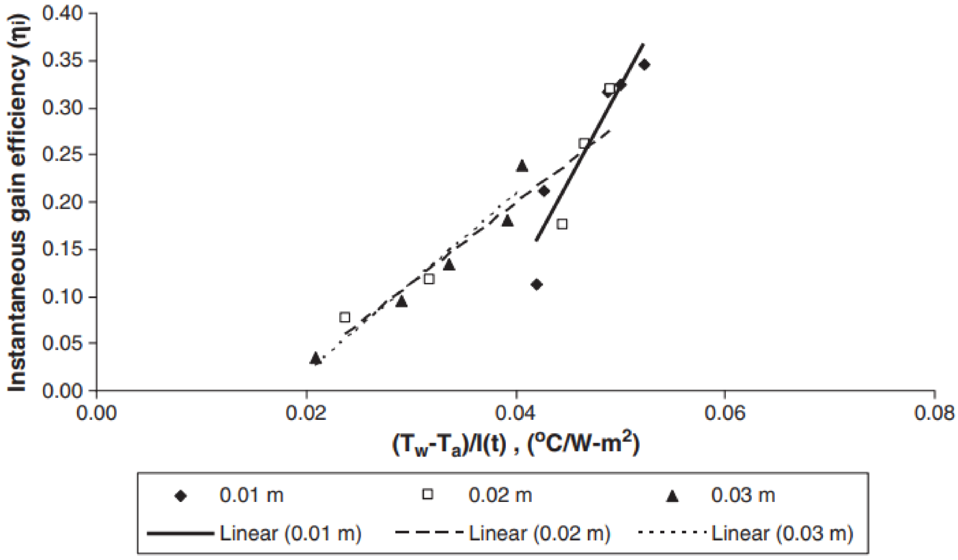

Figure 7. Seawater-based linear instantaneous gain efficiency curves for the IASS at various water depths. Reprinted/adapted with permission from Ref. [12]. 2022, Elsevier.

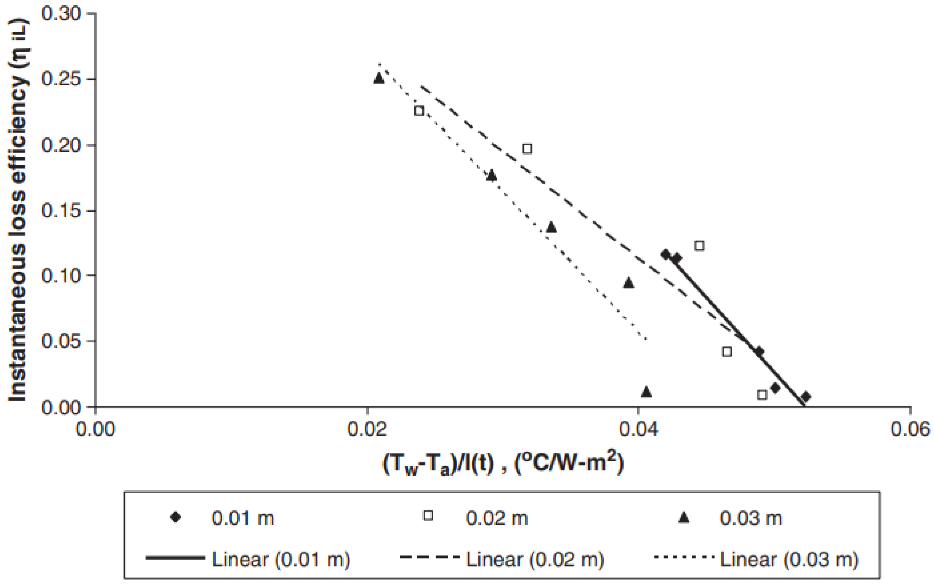

Figure 8. Seawater-based linear instantaneous loss efficiency curves for the IASS at various water depths. Reprinted/adapted with permission from Ref. [12]. 2022, Elsevier.

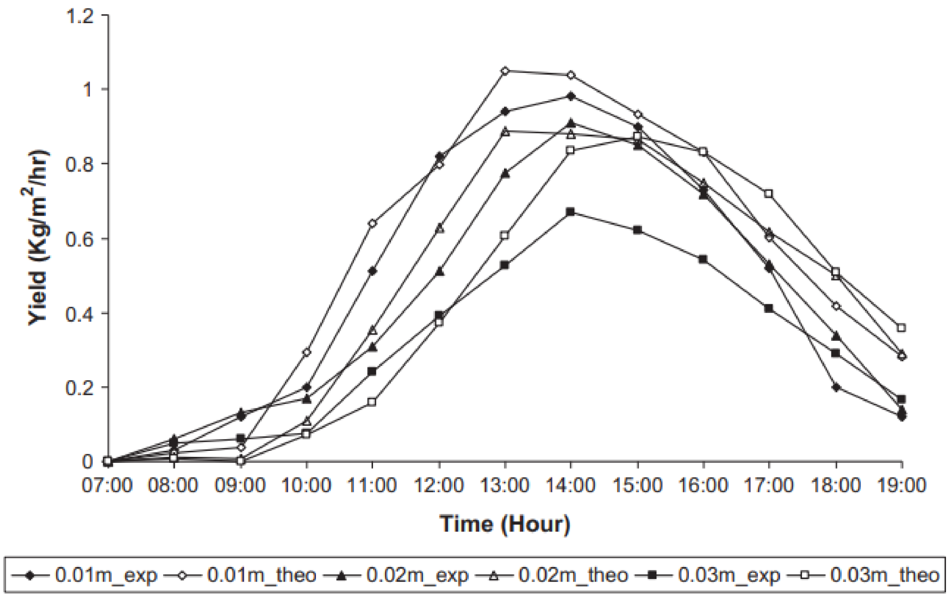

Figure 9. Comparing the actual and predicted yields for an inverted absorber solar still in July 2009 at different water depths. Reprinted/adapted with permission from Ref. [13]. 2022, Elsevier.

In 2012, Abdul-Wahab and Al-Hatmi [14] reported on an experimental study of an inverted solar still that was combined with a refrigeration cycle (Figure 10). Several feed saline water temperatures and water depths were used during the experiment. In Muscat, which is part of the Sultanate of Oman and has a climate typical of that area, experiments were conducted in the month of July. The daily production increased to 6670, 4940, and 3930 mL/day when the feed saline water was 35 °C. This is commensurate with the water depths of 8, 6, or 4 mm, respectively. However, when the feed saline water was 30 °C, it was discovered that the daily yields of distilled water generated were 9500, 10,080, and 6400 mL/day at water depths of 8, 6, and 4 mm, respectively. The results of this study were contrasted with those of previously published literature to better understand how effective solar stills may be. It was also found that the chilled inverted solar still could generate more potable water per day than the conventional inverted solar still, in contrast to the typical inverted solar still. Additionally, it was discovered that increasing the water depth could increase the daily production of the inverted refrigerated solar still, contrary to the conventional inverted solar still which exhibited the opposite behavior and where it was discovered that decreasing the water depth could increase the daily production.

Figure 10. A refrigerated inverted solar still photograph [14].

In 2013, Abdul-Wahab and Al-Hatmi [15] completed a comprehensive study to compare the efficiency of inverted absorber solar still integrated with a refrigeration inverted absorber solar still (RIASS) and an inverted absorber solar still (IASS) in identical operational and meteorological conditions. Comparatively speaking, it was concluded that the RIASS was capable of producing more potable water than the IASS. The results of the study indicate that the productivity of the IASS and feed depth have an inverse connection. Consequently, the IASS was able to increase its daily productivity by reducing the amount of water in the basin. Reports from the RIASS, on the other hand, suggested the opposite behavior. The RIASS generated daily yields ranging from 6.4, 10.08, and 9.5 L/day depending on the depth of the water, which was between 4 and 8 cm. Figure 11 shows that the comparable daily yields obtained from the RIASS were higher than those obtained from the IASS which were 3.41, 3.24, and 2.92 L/day.

In 2013, for the climatic conditions of Jaipur, Rajasthan, Sain et al. [16] investigated the efficiency of an inverted absorber and single-slope solar still at different depths of water with total dissolved solids. Investigations into the connections between yield production and solar radiation at various depths were made. Additionally, the observations of an inverted absorber solar still (IASS) and a single-slope solar still (SSSS) were contrasted and compared. Further, the usage of reflectors increased the IASS's overall effectiveness.

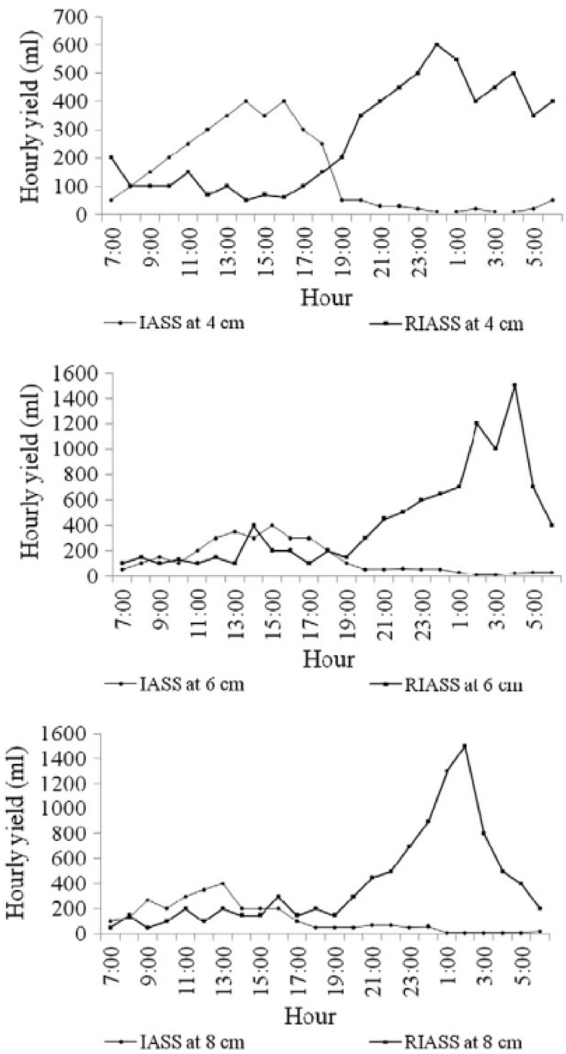

Figure 11. IASS and RIASS hourly yields with regard to time and at various water depths. Reprinted/adapted with permission from Ref. [15]. 2022, Elsevier.

In 2014, Badran et al. [17] conducted an experimental examination of an inverted trickling solar still. The main component of the still was an absorber plate that was inverted and covered in black at the very top. A saltwater solution came from the plate's back and was connected to the plate. The velocity of water flow was maintained at a low level to increase the water's temperature and create vapor. Another compartment that had a heat exchanger, to offer heat recovery, was the location of the condensation that took place. The distillation apparatus was evaluated using saltwater with a salinity of 6000 ppm throughout the month of November at tilt angles of 47 and 32 degrees. At the aforementioned angles, the amount of condensate that could be collected decreased to 2.8 and 2 L/d, respectively. Because of the decrease in the amount of salt in the input water, this sort of production increased by 18% compared to the work that was done in the past. However, the production of the intermediate header, which is saline water with a lowered salinity of 3600 ppm, was cut by 13% as well. In order to make accurate projections on the performance of the still, computer simulation software was built.

In 2016, the performance of an existing inverted trickling solar still was recreated by Badran and Jaradat [18] and tested in various conditions of sun exposure, feed water flow rate, and the presence of natural convection. The still was made to absorb water as it passed over an absorber plate with a layer of jute cloth connected to the rear, desalinating highly salinized water in the process. The heat exchanger's dimensions were expanded to their absolute maximum so that the effect of this alteration could be assessed. This change was the most significant one that was made. At an average salinity of 60 ppm, it was found that the still's production increased by 15% to 2.55 L of fresh water per square meter per day. The main advantage of the still is the creation of an additional product known as an intermediate header, which has nearly double the productivity of the condensate header. In other words, the intermediate header is about twice as productive as the condensate header. As an illustration, if brackish water has a salinity of 12,000 ppm, the intermediate product will have a salinity of nearly 9000 ppm and a productivity of roughly 5.53 L/day m^2. The daily efficiency of the still also increased to 23.7%, an 8.6% increase over the efficiency recorded during the previous operation.

In 2018, an inverted absorber multi-effect solar still's energy and exergetic analyses were investigated by Shanazari and Kalbasi [19]. A new benchmark for gauging the efficacy of the first law thermodynamics was created for multi-effect solar stills. Energy and exergy balance correlations were established for water basins, condensing surfaces, and absorber plates to assess the irreversibility of the various components. Results confirmed that when the number of impacts increases, less energy is lost via the absorber plate, water basins, and condensing covers in a particular basin. However, going from one to ten basins results in a 337% increase in the overall irreversibility of the water basins. Energy balance calculations revealed that when the impact rose from one to ten, the heat flow to the ambient environment was reduced by 74.8%, increasing the first law's efficiency by 174.6%. Figure 12 demonstrates that while the global second efficiency decreased by 20.6%, the total yield, irreversibility, and overall second efficiency all increased with an increase in impact from one to ten.

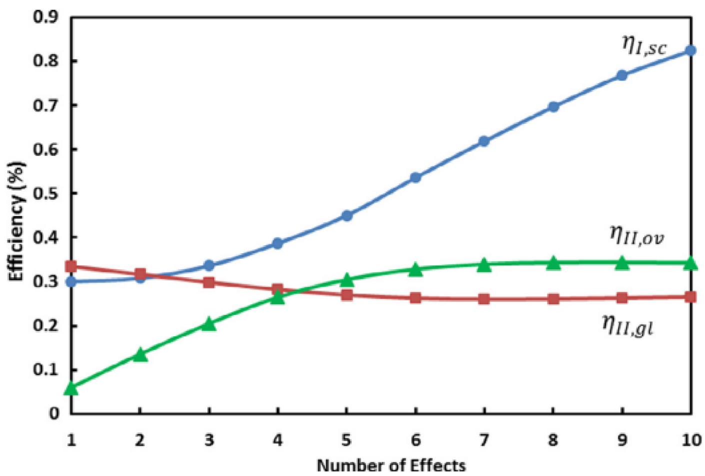

Figure 12. Efficiency variations of the first and second laws in relation to the number of impacts. Reprinted/adapted with permission from Ref. [19]. 2022, Elsevier.

In 2020, Karimi et al. [20] investigated a solar still that consisted of a basin with a curved inverted reflector placed below the basin. In the solar still, which was under investigation, the glass cover of the condenser included a few photovoltaic cells embedded inside it. As a consequence, the system generates both potable water and electrical power concurrently. The solar cells' temperature, the condenser glass cover temperature, the water temperature, and the absorber temperature could be determined by creating an energy balance for each of the system's individual components. In addition, both the thermal and electrical efficiency of the system are discussed. The outcomes of the present study's simulations are in agreement with the experimental data obtained from earlier investigations. The findings of a parametric analysis indicate that a rise in water depth lowers freshwater productivity while having almost no impact on the amount of energy produced. Increasing the use of solar cells results in less creation of freshwater but leads to the increased generation of energy. Both the amount of freshwater produced and the amount of power generated are increased when the wind speed and basin area are both raised. Additionally, increasing the number of solar cells may improve the system's electrical efficiency, but it can lower its thermal efficiency; as a result, the system's total efficiency might suffer. The effect that water depth has on electrical efficiency is almost nonexistent; nevertheless, it does have a negative impact on thermal efficiency and the system's total efficiency.

In 2021, by incorporating wicks into the process, Singh and Sharma [21] proposed a technique that enhanced solar still production; the results were discussed for a number of months. It investigated how the surroundings and the operating circumstances affected the efficiency of the modified multi-wick basin-type inverted absorber solar still (MMWBIASS). The study was conducted at the Mathura-based Sachdeva Institute of Technology in Uttar Pradesh, India. The rate of yield production, the amount of heat taken in, and the overall thermal efficiency all increased greatly. The MMWBIASS increased both the gaining rate and the heat intake offered by the solar still by accounting for the intake provided by the surfaces of the glass, the reflector, and the hanging wicks. The production for the black cotton wick was 6.907 kg/m^2 day at a depth of 0.01 m in the MMWBIASS, which is significantly more than the combined output of 5.703 kg/m^2 day for the jute wick. In contrast, the MMWBIASS with the jute wick and the black cotton wick in the same basin situation had overall thermal efficiencies of 27.68% and 34.04%, respectively (Figure 13).

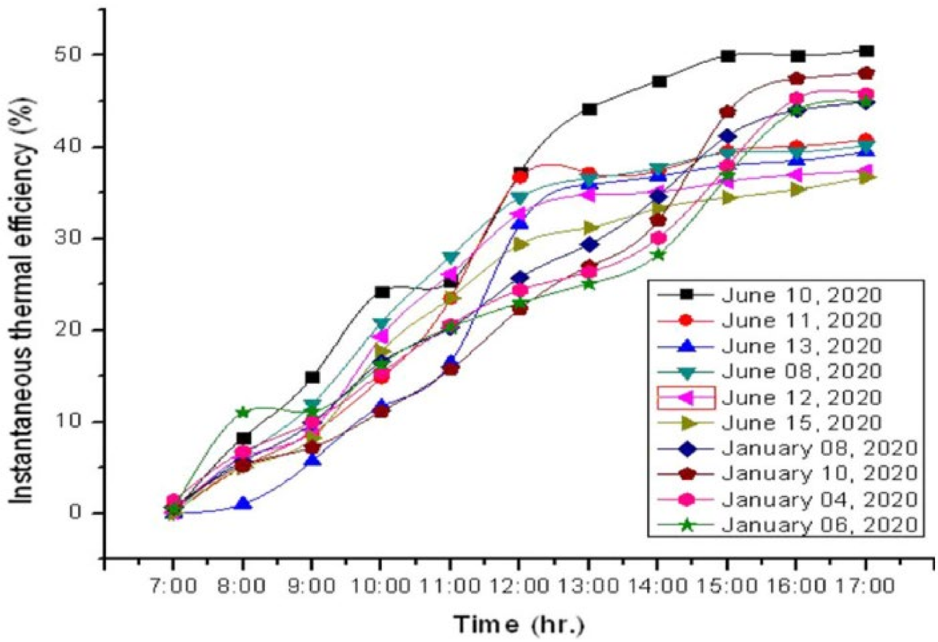

Figure 13. Variation of ηi with respect to time during the trial day for wicks (black cotton and jute cloth) in the months of June 2020 and January 2020. Reprinted/adapted with permission from Ref. [21]. 2022, Springer nature.

In 2021, Singh and Sharma [22] revealed their findings using a thermal model of an altered multi-wick basin-type inverted absorber solar still (MMWBIASS). In order to calculate the temperatures of the glass covers, water, distillation yield, and wick, mathematical formulae were evaluated throughout the investigation. Experimental validation of the thermal model led to a consensus between its theoretical and experimental implications. The instantaneous efficiency of the solar still was also studied using cotton wicks of a dark hue in the environmental circumstances of Farah, Mathura, Uttar Pradesh (U.P.), India (27.3223° N; 77.7599° E) (Figure 14). The findings indicated that the overall yield from the MMWBIASS may attain values of 6.907, 5.681, and 4.650 kg/m^2 day when the water level in the basin is 1, 2, and 3 cm, respectively. Under the same basin environment, the overall thermal efficiency for MMWBIASSs with black cotton wicks was 34.04%, 28.17%, and 23.61%, respectively.

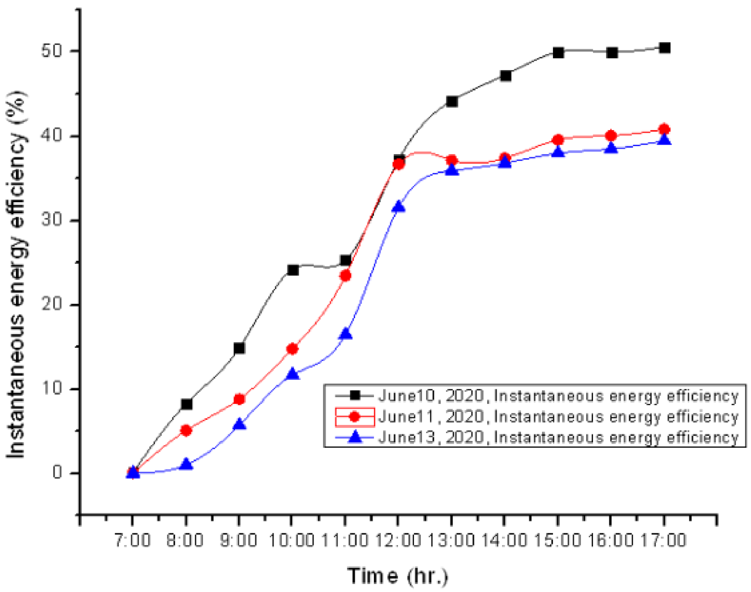

Figure 14. Hourly variations in experimental η_{inst} for specific days in June 2020. Reprinted/adapted with permission from Ref. [22]. 2022, Springer nature.

In 2021, Javadi et al. [23] conducted research on the Abadan Combined cycle power plant in Iran 4E (Energy, Exergy, Economic, and Environmental). In order to enhance the performance of the Abadan Combined cycle power plant, the researchers proposed three distinct configurations in which the Abadan Combined cycle power plant would be combined with a solar power tower system. The hybrid power plant was studied with three different ways of using the solar tower system: first, to preheat the fuel that is going into the combustion chamber; second, to preheat the air that is going into the combustion chamber; and finally, to use it in the dual pressure heat recovery steam generator that is part of the power plant. The findings of the hybrid system show that the system in its first configuration has an energy and exergy efficiency of 42.56% and 39.42%, and has the lowest starting cost among the three configurations. Additionally, the emissions from the combined power plant are reduced by 8041 tons per year thanks to this method. The findings indicate that the second arrangement achieves the best levels of energy efficiency and exergy efficiency, respectively, with values of 51.38% and 41.75%. This method reduces emissions by 34,563 metric tons per year and cuts yearly fuel usage by 11 million dollars, saving the world a total of 11 million dollars. When compared to the previous configurations, the system in its third configuration generates the most amount of power (370.4 MW) and has the greatest energy efficiency (47.8%) and exergy efficiency (40.97%).

In 2022, Singh and Sharma [24] investigated the energy, exergy, environmental, and economic effects of a modified multi-wick basin-type inverted absorber solar still (MMW-BIASS). The behavior of the MMWBIASS can be examined and evaluated by utilizing productivity, energy, exergy, and enviro-economic techniques by installing ten hanging wicks at varying salinity levels in the basin. This enables the evaluation and analysis of the MMWBIASS's behavior. According to the results of this study, one way to increase the solar still's effectiveness is to suspend wicks made of black cotton and jute cloth so that water can be kept in the strap layer of the wicks on a constant basis. In Mathura, India, experiments on MMWBIASSs with a basin area of 1 m^2 have been conducted under various climatic conditions. The costs per kilogram of distilled product per year were found to be Rs. 0.91 (0.012 USD) and Rs. 1.03 (0.013 USD), respectively, and the development technique reduced CO_2 emissions by 42.99 tons for black cotton wicks and 37.08 tons for jute wicks. Using black cotton and jute wicks, the highest immediate energy efficiency was attained (Figure 15), 15.27% and 11.88%, respectively.

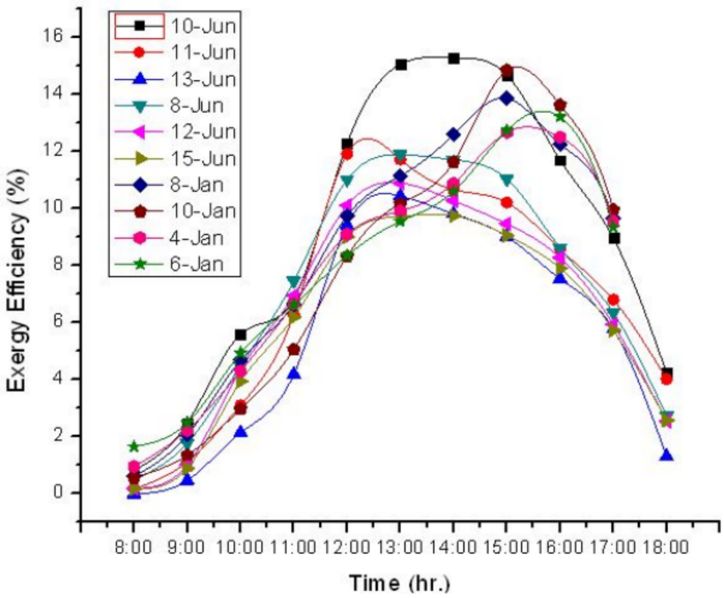

Figure 15. The hourly variation of the exergy effectiveness of a black cotton and jute wick for various water depths. Reprinted/adapted with permission from Ref. [24]. 2022, Springer nature.

In 2022, Javadi et al. [25] conducted research on a multi-generational system for the production of hydrogen, fresh water, and electricity. The system included a concentrated solar power tower cycle, a steam-methane reforming cycle, a hydrogen-gas turbine, and a reverse osmosis desalination cycle. Each cycle of the multi-generational system is evaluated on its own, and then the results of those evaluations are put through a series of 4E analyses conducted by means of EES software. This is done in order to improve the overall performance of the system and reduce its adverse effects on the surrounding environment. After determining the appropriate values for each constituent, the system was put through the bulk of the calculating process. A total of 12.9 megawatts of electrical power, 96.18 kg per second of potable water, and 5.2 kg per second of hydrogen are all produced by the multigenerational system. The findings of the 4E study indicated that the overall energy efficiency of the system was 50.18%, and the exergy efficiency of the system was 51.91%. The amount of exergy that was destroyed over the whole system is 324,351 kJ/s, with the combustion chamber of the methane reforming cycle and the reformer being the locations where the most exergy destruction took place across the entire system.

A summary of the associated studies of inverted solar stills is depicted in Table 1 with details.

Table 1. A summary of study outlines on the inverted solar still.

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Badran and Hamdan (1995) [4]	Amman, Jordan	latitude 31°57′ N, longitude 35°55′ E	Inverted water trickle solar still	April	Experimental	Water type	The main components of this concept are the elimination of condensation on the glazing, which increases the amount of solar radiation reaching the absorber plate, as well as the elevation of the temperature difference between the evaporator and the condenser, which ultimately increases the productivity of basin-type stills. Combining the condensate with some of the intermediate products may improve productivity if the product's salinity is impaired. If the feed was saltwater in this instance, the productivity might be improved to 5.8 L/m^2/day of brackish water.	The size of the developed inverted water trickle solar still is the main issue and, therefore, might feasibly be expanded.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Suneja et al. (1997) [5]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Inverted absorber double-basin solar still	Min 100–Max 998	Numerical	Water depth, absorptivity of the absorber plate, and initial water temperature	It has been found that, for a given water mass in the top basin, the daily yield of an inverted absorber double-basin solar still grows as the water depth in the bottom basin increases.	The yield of an inverted absorber double-basin solar still rises by around 10% for a given quantity of absorptivity and water depth, while the yield of an inverted absorber single-basin solar still rises by about 12% when the starting water temperature rises from 22 °C to 35 °C. The yield of an inverted absorber double-basin solar still declines by around 27% as the water depth in the bottom basin increases from 1 cm to 5 cm. The yield of a typical double-basin solar still increases by around 10% and about 43% as the absorber's absorptivity goes from 0.45 to 0.65. Thus, it can be stated that the standard double-basin inverted absorber solar panel's output is still less than that of the inverted absorber solar panel.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Suneja and Tiwari (1998) [6]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Multi-basin inverted absorber distiller	Min 100–Max 998	Numerical	The effect of the reuse of latent heat of the vaporization from the lower basins	This design is characterized by recycling the latent heat of the vaporization from the matching lower basins which improve the daily yield.	It has been estimated that adding more than seven basins will only marginally boost production.
Tiwari and Suneja (1998) [7]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Inverted absorber solar still	Min 100–Max 998	Numerical	Water depth	A normal solar still only produces about half as much as an inverted absorber solar still.	As a result of less heat leaving from the bottom of the still and more heat being absorbed by the inverted absorber plate, it has been determined that inverted absorber solar stills cause a considerable increase in water temperature. Additionally, with increasing water depth, the daily production falls.
Suneja and Tiwari (1999) [8]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Inverted absorber double-basin solar still	Min 100–Max 998	Numerical	Water depth	The system produces the highest possible overall output when the water depth in the bottom basin is at its shallowest point. In addition, in contrast to the traditional solar distillation system, the suggested system would only need a minimal amount of money to operate and maintain since the absorber is inverted.	With increasing water depth in the bottom basin, an inverted absorber double-basin solar still produces more power each day.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Tiwari and Suneja (1999) [9]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Inverted absorber solar still	Min 100–Max 998	Numerical	Water depth	The yield is observed to rise by roughly 11% when there is a flow of water at the rate of 0.5 kg/s for an ideal 10 cm depth of water in the basin.	The yield drops as the water depth in the basin rises, directly affecting the low operating temperature.
Badran (2001) [10]	Amman, Jordan	latitude 31°57′ N, longitude 35° 55′ E	Inverted trickle solar still	May	Experimental	The heat exchanger inside the condenser insulates the sides of the still and feeds the flow rate	Expanded the flow rate of the saline water supply and increased productivity by adding a heat exchanger within the condenser. In turn, the productivity was raised from roughly 2.5 L/d to 2.8 L/d by insulating the still's sides and increasing the flow rate of the saltwater supply. For a 50% flow rate increase, productivity was boosted by roughly 42%.	According to the research, the inverted trickling solar still has a straightforward construction and a productivity range of 1.7 to 3.83, depending on the salinity of the feed water. When desalinating excessively saline water, production is severely impacted. Consequently, it has been recommended to combine the condensate with some of the intermediate products.
Abdul-Wahab et al. (2010) [11]	Muscat, Oman	latitude 23°37′ N, longitude 58°35′ E	Inverted absorber solar still with a curved reflector	September	Experimental	Reflector, insulation under the basin	Under the basin of an IASS, an improved single-slope solar still design is a curved reflector. This configuration improves the basin's direct and indirect heating from both sides (that is, the top and bottom surfaces).	The IASS's inability to hold thermal energy for an extended period of time is discovered after 16:00. The decrease in the amount of solar radiation that is reflected causes the thermal storage to be lost to the environment through the enclosed air underneath the basin.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Dev et al. (2011) [12]	Muscat, Oman	latitude 23°37′ N, longitude 58°35′ E	Inverted absorber solar still	July Min 125–Max 995	Analytical and experimental	Water depth and thermal storage effect	While the values of instantaneous loss efficiency (iL) drop due to the water's thermal storage effect, the instantaneous gain efficiency increases as the water depth rises. It was found that the lower water depth is 0.01 m with better values of ηi, ηiL, and mew over other water depths; hence, 0.01 m water depth can be endorsed for solar stills.	The inverted absorber solar still exhibits nonlinear behavior.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Dev et al. (2011) [13]	Muscat, Oman	latitude 23°37′ N, longitude 58°35′ E	Inverted absorber solar still	July Min 125–Max 995	Experimental	Water depth, reflector under the basin	When compared to a single-slope solar still at the same relative water depths, the inverted absorber solar still has the ability to significantly raise the water temperature. The basin's performance in comparison to the SS for seawater is not greatly enhanced by the addition of a reflector. At water depths (dw) of 0.01, 0.02, and 0.03 m, the IASS yields are 6.302, 5.576, and 4.299 $kg/m^2/day$, respectively. The optimal water depth for the IASS is 0.03 m, and adding a reflector beneath the basin does not significantly worsen its performance compared to the SS for seawater.	The inverted absorber solar still has a constraint after 16:00 h. Due to the low input of solar light from the bottom, the temperature of the water drops more quickly. This could be a result of the bottom heat loss, which is the reverse heat flow from water to enclosed air in the reflector assembly, and then from there to ambient air. Convection heat loss from the metallic basin to the air enclosed by the reflector assembly is another way to describe this. As the ambient temperature drops further, this bottom heat loss rises. Due to heat storage being lost via the metallic bottom to the ambient air, this phenomenon impacts the nocturnal yield output.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Abdul-Wahab and Al-Hatmi (2012) [14]	Muscat, Sultanate of Oman	latitude 23°37′ N, longitude 58°35′ E	Refrigerated inverted solar still	July	Experimental	Refrigeration cycle, water depth	In comparison to the standard inverted solar still, the chilled inverted solar still may produce more potable water each day. Contrary to the typical inverted sun still, which displayed the opposite behavior and where it was implied that reducing the water depth might improve the daily production, increasing the water depth could enhance the daily production of the inverted refrigerated solar still.	The high initial cost and large land requirements for installation as well as the output are quite dependent on the existing solar radiation.
Abdul-WahabandAl-Hatmi (2013) [15]	Al Khoud, Oman	latitude 23°37′ N, the longitude of 58°35′ E	Inverted absorber solar stills paired with a refrigeration	—	Experimental	Water depth	The inverted absorber solar stills paired with refrigeration (RIASS) were capable of producing more potable water than IASS. At 4, 6, and 8 cm of water depth, the RIASS daily yields were 6.4, 10.08, and 9.5 L/day, respectively. The IASS's respective daily yields were 3.41, 3.24, and 2.92 L/day, which were less than the RIASS's.	The high initial cost and large land requirements for installation as well as the output are quite dependent on the existing solar radiation.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Sain et al. (2013) [16]	Jaipur, Rajasthan	latitude 26°55′ N, longitude 75°52′ E	Inverted absorber and single-slope solar still	June	Experimental	Ambient temperature, inverted-type absorber plate, water depth, and reflector	Ambient temperature improves productivity by around 12% to 23%. The thermal efficiency of a single-slope solar PV rose by 7% when an inverted absorber plate was utilized. The output falls by 5% as the water depth rises from 0.01 to 0.03 m; the solar still productivity may rise by 3% with the use of reflectors. Thus, the usage of reflectors increased the IASS's overall effectiveness.	Despite the enhancement of overall efficiency, the inverted absorber and single-slope solar still have a propensity for salt deposition, scale, and corrosion.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Badran et al. (2004) [17]	Amman, Jordan	latitude 31°57′ N, longitude 35°55′ E	Inverted trickle solar still	November Min 580–Max 1000	Experimental and numerical	Brackish water, feed water flow rate	The major part of the still was an absorber plate that was upside-down and had a black top. Condensation occurred inside a heat exchanger between a 47 and a 32-degree inclination to provide heat recovery. The maximum condensate collection rates at the aforementioned angles were 2.8 and 2 L/d, respectively. By employing brackish water, the inverted trickle solar still's production is somewhat increased. When the water's salinity was changed from saltwater (35,000 ppm) to brackish water, the productivity rose from 2.5 to 2.8 L/d (6000 ppm). Productivity rose significantly when the feed water flow rate was reduced to 0.7 g/s.	It is not useful to deal with a high saline water. This is due to the decrease in the amount of product water.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Badran and Jaradat (2016) [18]	Amman, Jordan	latitude 31°57′ N, longitude 35°55′ E	Inverted trickle solar still	September Min 450–Max 1090	Experimental	Length of the heat exchanger and flow rate.	The intermediate header is about twice as productive as the condensate header. The daily efficiency of the still also increased. Statistically, productivity climbed by 15% while efficiency rose by 8.6%. This occurred as a result of the increase in the heat exchanger's length, which increased the heat transfer area. The still was more productive at a flow rate of 1.0 g/s than at a flow rate of 1.8 g/s.	Dealing with highly saline water is useless. This is because there is less product water.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Shanazari and Kalbasi (2018) [19]	Iran	latitude 51°24′ N, longitude 15.6348″ E	Inverted absorber multi-effect solar still	-	Numerical	Number of basins	When additional basins are added, there is an initial rise in the overall exergy loss, but then there is a subsequent drop. A gentle decline in total exergy loss may be seen as the result of this change. Simply expanding the number of basins from seven to ten results in a meager 0.7% reduction in the overall exergy loss. It was discovered that elevating the number of basins from one to ten results in a rise in the overall irreversibility from 15.67 to 17.3 MJ, which is a rise of 10.4%.	The productivity of an inverted absorber multi-effect solar still depends on a number of factors. Production was negatively correlated with wind speed, condenser emissivity, condenser thickness, and salinity of the water, whereas ambient temperature, sun intensity, and evaporation area were directly correlated with productivity. Due to the irreversibility of the various system components, there is a necessity to investigate the influence of the number of basins and the number of effects on the exergy loss using the thermodynamics first law for different locations.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Karimi et al. (2020) [20]	Zahedan, Iran	latitude 29°29′46″ N, longitude 60°51′46″ E	Basin solar still with a curved inverted reflector under the basin	-	Experimental	Wind velocity, basin area, number of photovoltaic cells, and water depth	There were a few solar cells inserted in the condenser's glass cover. The technology simultaneously produces electrical power and potable water. An increase in the water depth reduces freshwater productivity while having essentially no effect on the amount of energy produced, according to the results of a parametric analysis.	Increasing the use of solar cells reduces the amount of freshwater produced but increases energy production. Moreover, while adding more solar cells may boost the system's electrical efficiency, it may also reduce its heat efficiency.
Singh and Sharma (2021) [21]	Mathura, India	latitude 27°29′ N, longitude 77°40′ E	Modified multi-wick basin-type inverted absorber solar still	June and January Min 10–Max 880	Experimental	Wicks of black cotton and jute, water depth	The rate of yield production, the amount of heat taken in, and the overall thermal efficiency all rose noticeably. In the modified multi-wick basin-type inverted absorber solar still (MMWBIASS), the yields with black cotton and jute wicks were 2.994 kg/m^2 day and 2.847 kg/m^2 day, respectively, at a water level of 0.01 m. As a result, even though BCW was utilized instead of JW to make the display, the output increased by 4.91%.	Detailed research is required to better evaluate absorbing material and the distance between each shelf to enhance the productivity of fresh water.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Singh and Sharma (2021) [22]	Mathura, India	latitude 27°29′ N, longitude 77°40′ E	Modified multi-wick basin-type inverted absorber solar still	June Min 280–Max 850	Experimental	Water depth	The instantaneous efficiency of the solar still was studied using cotton wicks of a dark hue. The overall output at 1, 2, and 3 cm of water depth on a specific day in June 2020 was 6907, 5.681, and 4.650 kg/m^2 day, respectively. The yield was higher at the shallower water depth. It has been noted that as the water level rises, so does the yield of the modified multi-wick basin-type inverted absorber solar still (MMWBIASS).	To increase the production of fresh water, a thorough analysis of superior absorption materials and the space between shelves is needed.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Javadi et al. (2021) [23]	Iran	latitude 30°20′ N, longitude 48°18′E	Combined cycle power plant	—	Experimental	Combined cycle	Three distinct configurations in which the Abadan Combined cycle power plant would combine with a solar power tower system were tested. The system in its first configuration had the highest energy and exergy efficiency, at 42.56% and 39.42% respectively, as well as the lowest starting cost among the three configurations. Additionally, the emissions from the combined power plant were reduced by 8041 tons per year thanks to this method.	There is a necessity to carry out process optimization to elevate the exergy losses of the developed configurations and enhance energy efficiency.
Singh and Sharma (2022) [24]	Mathura, India	latitude 27°29′ N, longitude 77°40′ E	Multi-wick basin-type inverted absorber solar still	June and January Min 10–Max 880	Experimental	Black cotton and jute wicks, water depth	The maximum instantaneous energy efficiency was achieved with jute cloth and black cotton wicks, respectively, at 15.27% and 11.88%. With jute and black cotton wicks at 0.01 m of water depth, the total multi-wick basin-type inverted absorber solar still (MMWBIASS) efficiency was measured at 27.68% and 34.04%, respectively.	A careful examination of excellent absorption materials and available space between shelves is required to maximize the production of fresh water.

Table 1. *Cont.*

Author	Location	Latitude	Inverted Solar Still Type	Testing Period (Hours)/Radiation (W/m^2)	Method	Studied Parameters	Merits	Limitations
Javadi et al. (2022) [25]	The U.S.	latitude 38°53′ N, longitude 77°1′ E	Multi-generation system for hydrogen	—	Analytical	Multi-generation system	The multi-generation system for hydrogen comprises a concentrated solar power tower cycle, a steam-methane reforming cycle, a hydrogen-gas turbine, and a reverse osmosis desalination cycle. The multi-generational system produces 12.9 megawatts of electrical power, 96.18 kg per second of potable water, and 5.2 kg per second of hydrogen.	Most of the exergy destruction takes place across the entire system.

3. Mathematical Modeling and Equations

In this section, we discuss the mathematical modeling and the relevant equations for the solar stills system. We start with the work presented by Badran and Hamdan, in [4], in which the authors considered some assumptions in order to simplify the analysis of their work. They assumed the steady state operation of the solar still, constant solar radiation, and that the absorber and condenser steel sheet plates have a low thermal resistance. They managed in [4] to write the energy balance on the solar still as

$$(\tau\alpha)_e\, G = q_b + q_{ca} + q_s + q_w,$$

where $(\tau\alpha)_e$ and G represent the effective transmittance-absorbance product and the solar radiation, respectively. In addition, $q_b,\ q_{ca},\ q_s,$ and q_w represent the heat transfer from the lower condenser plate, heat transfer from cover to ambient, heat transfer from sides of the still, and heat gain by water, respectively, and are calculated by [4]

$$\begin{aligned} q_b &= h_0(T_v - T_a), \\ q_{ca} &= U(T_c - T_a), \\ q_s &= h_0(T_p - T_a), \\ q_w &= \left(\tfrac{\dot{m}}{A}\right) C_{pw}(T_{s,o} - T_{s,i}), \end{aligned}$$

where the notations $h_0,\ T_v,\ T_a,\ U,\ T_c,\ T_p,\ \dot{m},\ A,\ C_{pw},\ T_{s,o},$ and $T_{s,i}$ stand for heat transfer coefficient due to wind on the inside of the condenser plate, vapor temperature, ambient temperature, combined convection and radiation heat loss coefficient from cover to ambient, cover temperature, local plate temperature, mass flow rate of water at the outlet header, area of still, the specific heat of water, outlet saline water temperature, and inlet saline water temperature, respectively. The value of h_0 was given in [4] as $h_0 = 5.7 + 3.8\ V$, where V is the wind speed.

The equations for the productivity and the efficiency of the still were written in [4] as:

$$\dot{m}_c = \frac{q_e A}{h_{f_g}}, q_e = q_b \text{ on the lower condenser plate},$$

$$\eta = \frac{q_e}{G},$$

$\dot{m}_c$, q_e, h_{f_g}, and η represent the mass flow rate of condensate, heat transfer with evaporation, heat of vaporization, and efficiency, respectively.

The authors in [4] wrote their own program in Basic, computed the productivity and the efficiency using the above equations, and reported their findings, which we have elaborated on in the previous section.

In [5,7,8], in order to write the mathematical model and equations for the energy balances, the authors assumed that the glass cover heat capacities as well as the heat capacities of the absorbing material, condensing covers, and insulation are all negligible. They also assumed that the solar distiller unit is vapor leakage proof and the area of the aperture is the same as that of the absorber plate and the concentration ratio is 1:1. The last assumption was that the inclination of the glass cover is small. With the aforementioned assumptions, the authors [5] presented the energy balance equations as follows.

Absorber plate (p): $\tau_{g_1}\tau_{g_2}\alpha_p r^N I = h_{cpw_1}(T_p - T_{w_1}) + h_{rpg_2}(T_p - T_{g_2})$.

Glass plate (g_2): $U_r(T_{g_2} - T_a) = h_{rpg_2}(T_p - T_{g_2})$.

Water Mass (m_1): $h_{cpw_1}(T_p - T_{w_1}) = (m_1 C)_w \frac{dT_{w_1}}{dt} + h_{w_1}(T_{w_1} - T_{c_1})$.

Condensing cover (c_1): $h_{w_1}(T_{w_1} - T_{c_1}) = h_{c_1}(T_{c_1} - T_{w_2})$.

Water Mass (m_2): $h_{c_1}(T_{c_1} - T_{w_2}) = (m_2 C)_w \frac{dT_{w_2}}{dt} + h_{w_2}(T_{w_2} - T_{c_2})$.

Condensing cover (c_2): $h_{w_2}(T_{w_2} - T_{c_2}) = h_{c_2}(T_{c_2} - T_a)$.

With some algebra, the authors ended up with the following two differential equations.

$$\frac{dT_{w_1}}{dt} + a_1 T_{w_1} + a_2 T_{w_2} = f(t),$$

$$\frac{dT_{w_2}}{dt} + b_1 T_{w_1} + b_2 T_{w_2} = g(t),$$

where

$$a_1 = \frac{U_{w_1 w_2} + U_{w_1 a}}{m_1 C};\ a_2 = \frac{U_{w_1 w_2}}{m_1 C};\ f(t) = \frac{(\alpha\tau)_{eff}\ I(t) + U_{w_1 a} T_a}{m_1 C}; (\alpha\tau)_{eff} = \tau_{g_1}\tau_{g_2}\alpha_p r^N \frac{U_{w_{1a}}}{U_{pa}};$$

$$b_1 = \frac{-U_{w_1 w_2}}{m_2 C};\ b_2 = \frac{U_{w_1 w_2} + U_{w_2 a}}{m_2 C};\ g(t) = \frac{U_{w_2 a} T_a}{m_2 C};$$

$$U_{w_1 w_2} = \left(\frac{1}{h_{c_1}} + \frac{1}{h_{w_1}}\right)^{-1};\ U_{w_1 a} = \left(\frac{1}{h_{cpw_1}} + \frac{1}{U_{pa}}\right)^{-1};\ U_{pa} = \left(\frac{1}{h_{rpg_2}} + \frac{1}{U_r}\right)^{-1};$$

$$U_{w_2 a} = \left(\frac{1}{h_{w_2 a}} + \frac{1}{h_{c_2}}\right)^{-1}$$

Below, we explain the notations and symbols that are used above:
$g_{1(2)}$: glass lower (upper) basin; p : absorber plate; τ : transmissivity;
α : absorptivity; r : reflectivity;
I : solar intensity; N : average number of reflections;
T : temperature; a : ambient conditions;
$w_{1(2)}$: water mass in lower (upper)basin;
U_r : back loss coefficient;
$c_{1(2)}$: condensing cover in lower (upper) basin;
$m_{1(2)}$: mass of water in lower (upper) basin;
h_{c_1} : convective heat transfer coefficient from c_1 to water mass in upper basin;
h_{c_2} : convective heat transfer coefficient from c_2 to ambient;
C : specific heat of water; t : *time*;
h_{cpw_1} : convective heat transfer coefficient from absorber plate to water mass in lower basin;
h_{rpg_2} : radiative heat transfer coefficient from absorber plate in glass upper basin;
$U_{w_1 w_2}$: overall heat transfer coefficient from water mass in lower basin
to water mass in upper basin;
$U_{w_{1(2)}a}$: overall heat transfer coefficient from water mass in lower (upper) basin to ambient;
U_{pa} : overall heat transfer coefficient from absorber plate to ambient.

Under certain additional assumptions, the aforementioned differential equations were solved in [5,8] and the numerical results and discussions were presented as we have mentioned earlier.

Suneja and Tiwari, in [6], added three additional assumptions to those listed above from [5,7,8] in order to write the mathematical equations for the energy balance on the absorber they considered. More specifically, they assumed that the inclination of the receiving surface is 45°, no temperature gradient exists across the water mass or the condensing cover, and lastly, they considered a quasi-steady state case. Apparently, authors in all other related work, such as the work in [9–25], imposed various assumptions in order to write the energy balance and thermodynamic governing equations, and, therefore, similar types of mathematical models and equations to the ones mentioned above were stated.

In order to solve the resulting set of differential equations the authors stated in their work, they resorted to mathematical methods and numerical schemes. For instance, as mentioned earlier in the previous section, the authors in [6] used the Runge–Kutta 4th-order method in order to solve the differential equations they listed in their work. In general, such numerical techniques and mathematical tools play a substantial role in solving the various problems that appear in different applications in applied sciences and engineering (see, e.g., [26–32]).

4. Recommendations for Future Work

The in-depth analysis of the aforementioned assessment demonstrates that solar desalination is the most cost-effective method of saline water distillation around the globe as freshwater demand increases day by day in the current era of fast population expansion and industrial development. Many different solar still designs, such as double-slope solar stills and multi-wick solar stills, have been created recently. The basic concept behind all methods of solar water distillation to separate freshwater and saltwater is the same. This article takes a close look at the configurations, operations, and designs of many inverted solar stills. The following suggestions for more study include:

1. In order to improve the productivity of a solar still, a computational fluid dynamics (CFD) study of an inverted solar still that has a separate condenser section should be carried out.
2. Research should be done on how well an inverted solar still working in conjunction with rainwater collection performs on a wide scale.
3. Future work should focus on preheating the saltwater at varying temperatures and developing an inverted solar still that uses a variety of phase transition materials.
4. With the addition of a heat exchanger, inverted solar still systems should be used to investigate higher-temperature water-based nano-fluids containing metallic nanoparticles that have superior thermophysical characteristics.
5. The design of an inverted solar still requires some creativity in order to cut down on the amount of radiation lost through the glass. In this regard, the majority of stills have a glass cover, however, maintaining glass is difficult. It may be possible to replace the glass with different materials without sacrificing performance with more research.
6. The rate of evaporation should be accelerated by the incorporation of solar cells, Fresnel lenses, and electric heaters.
7. It is possible to employ a sun tracking method, which is more effective than using a stationary still, to boost the distillate production of the still by using reflectors.

5. Conclusions

Several inverted solar still designs, functions, and configurations were examined in-depth in this research. Revision of the related studies on various inverted solar still designs allowed for the identification of design advancements made in this process, including the creation of complex structures and hybrid systems. This has enhanced energy efficiency while reducing CO_2 emissions and improving overall water production. However, the main problem with inverted solar stills continues to be the low output of fresh water, which explains its low commercial use. Despite the development of a modified multi-wick basin-type inverted absorber solar still designed with black cotton wicks and jute cloth, it seems that water productivity has not exceeded 7 kg/m^2 day with 1 cm of water depth. Additionally, the overall productivity benefits from the decrease in water depth, which must be adjusted to produce the maximum quality while preserving adequate water. To improve solar still systems, especially those integrated with other industrial processes such as cycle power plants, more research is required to develop a prosperous design of optimum operating conditions, system configuration, and construction materials. Indeed, it is important to look into better absorbent materials and spacing between each shelf. Overall, we list our main conclusions as the following:

1. With increased water depth in the bottom basin, an inverted absorber double-basin solar still (IASS) produces more energy each day.
2. At 4, 6, and 8 cm of water depth, the RIASS generated 6.4, 10.08, and 9.5 l of water per day, respectively.

3. The findings showed that, despite the reduced bottom heat loss and large absorptivity, the water temperature in the inverted absorber solar still greatly enhanced the yield.
4. The performance of the inverted trickling solar still was assessed in conditions of varied sun exposure, feed water flow rate, and natural convection, with an average salinity of 60 ppm.
5. When the water level was 1, 2, or 3 cm, the MMWBIASS generated 6.907, 5.681, and 4.650 kg/m^2/day, respectively.
6. Using black cotton wicks, the MMWBIASS had an overall thermal efficiency of 34.04%, 28.17%, and 23.61%, respectively.
7. In November, the still was examined using brackish water with a salinity of 6000 ppm and tilt angles of 47° and 32°. Condensate was generated at the given angles at a rate of 2.8 and 2 L/d, respectively.

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