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Review

A Review of the Configurations, Capabilities, and Cutting-Edge Options for Multistage Solar Stills in Water Desalination

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Abstract: The desalination of saltwater is a viable option to produce freshwater. All the desalination processes are energy-intensive and can be carried out on a large scale. Therefore, producing freshwater using renewable energy sources is the most desirable option considering the current energy crisis and the effect that fossil-fuel-based energy has on our carbon footprint. In this respect, the tray-type still, one of several solar power desalination still varieties, is popular owing to its straightforward design, economic materials of construction, and minimal maintenance requirements, especially in isolated island regions with restricted energy and natural water supplies. The traditional tray-type solar power has a few drawbacks, such as the inability to recover latent heat from condensation, reduced thermal convection, a large heat capacity, and comparatively minimal driving power through evaporation. Therefore, the improvement of heat and mass transfer capabilities in tray-type stills has been the subject of many studies. However, there is a lack of a comprehensive review in the open literature that covers the design and operational details of multistage solar stills. The purpose of this paper is to present a thorough overview of the past research on multistage solar stills, in terms of configurations, capabilities, and cutting-edge options. In comparison to a unit without a salt-blocking formation, the review indicates that a multistage distillation unit may run continuously at high radiation and generate pure water that is around 1.7 times higher than a unit without a salt-blocking formation. The most effective deign is found to be "V"-shaped solar still trays that attach to four-stage stills, since they are less expensive and more economical than the "floor" (Λ-shape) design, which requires two collectors. Additionally, it can be stated that the unit thermal efficiency, solar percentage, and collected solar energy (over the course of a year) increase by 23%, 18%, and 24%, respectively, when the solar collectors are increased by 26% (at the constant inflow velocity of the water).

Keywords: review; multistage solar stills; solar still; water desalination; saltwater treatment

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1. Introduction

Water scarcity is the most significant risk to society's growth as the human population rises. The most essential component needed in any place on the Earth, including arid regions, is to assure a sustainable clean water for all purposes [1,2]. Currently, industrial activity is increasing in developing nations, accompanied by inadequate wastewater management and rising water contamination [3]. In order to meet the need for freshwater, many strategies, such as constructing dams, cloud seeding, reusing sewer water, and distillation technologies, have been suggested. Because of the little rainfall in the Gulf Cooperation Council (GCC) area, water desalination has emerged as an appealing and environmentally friendly method for providing fresh water [4–6]. In this regard, reverse osmosis, multistage flash, and multiple-effect desalination with or without vapour compression are the most utilised desalination techniques [7]. Several of the Sustainable Development Goals (SDGs) of the United Nations are applicable to desalination, which is the process of removing salt and other minerals from seawater or brackish water in order to generate potable water. First, desalination can support SDG 6, which aims to guarantee universal access to clean water and sanitation through sustainable management. In areas with limited access to fresh water, such as arid and coastal regions, desalination can help expand the availability of freshwater supplies. This could lessen water shortages and increase access to clean water. Desalination can also help with SDG 13, which calls for immediate action to prevent climate change and its effects. Climate change can exacerbate water scarcity and decrease the availability of freshwater resources because it raises temperatures and changes weather patterns. By supplying a consistent source of freshwater, even in the face of shifting climatic circumstances, desalination can assist to reduce the negative effects of climate change on water resources. The SDG 14 goal, to conserve and sustainably utilise the oceans, seas, and marine resources for sustainable development, can also be achieved in part by desalination. Desalination can lessen the demand on freshwater resources by using seawater as a source of freshwater and can support sustainable water management techniques [8–10]. Although effective, the primary disadvantage of the various desalination techniques is the considerable power needed to produce the requisite amount and purity of water [11,12]. Often, the required energy is provided by fossil fuel. According to estimates, around 9 × 106 tons of fuel are used yearly to produce 360 × 106 m^3 of clean water [13]. The environment is negatively impacted by this massive usage of fossil fuels, especially in terms of environmental pollution and greenhouse gas (GHG) releases. It is anticipated that the potential of distillation-based desalination will depend on the cost of energy and the environmental effects.

Numerous varieties of solar stills have been built and investigated so far, involving single passive basin [14–22], active single basin [23–25], multiple passive basins [26–28], multiple active basins [28], and ducted [29] and inverse absorbers [30]. Additionally, there are insightful studies of solar stills in the literature [30–32]. However, the practical use of most of these devices is challenging because of technical issues, financial viability, or negligible yield enhancement. As observed in typical manufacturing purification procedures, such as multiple-stage distillate, flash, and vapour condensing, it appears that using the latent thermal process from the compressed vapour and the eviction of the chamber perform essential functions in solar distillation units. The purpose of multiple-stage solar stills is to recover the latent heat of the condensed vapour.

In 2015, Velmurugana and Srithar [32] introduced a comprehensive review to evaluate the water productivity of solar stills based on different deign factors. The solar still is made up of multiple phases that are lined up in order. The solar absorption layer is located on the front wall facing the sun. The condensation heat recycling layers are created by the interior walls separating neighbouring unit stages. Due to its high thermal conductivity and partial immersion in the bulk water, the rear wall (far right) is employed to maintain a low vapour pressure during the final stage. Otherwise, inadequate heat dissipation results in a raised system temperature and a reduced cumulative efficiency if the rear wall's temperature cools down. To minimise the overall heat loss, the side walls are insulated. Capillarity attracts the brine from the bulk liquid into the capillary wick during operation. After that, solar energy is transformed into thermal power and supplied to the vessel wick holding the saltwater, producing vapour. Losses are reduced since power is not spent on heating the fluid because the solar power is confined where the evaporation occurs. On the inside wall, the vapour disperses and condenses. The condensation releases latent heat, which passes to the next vessel wick and causes vapour formation in the subsequent stage. High-efficiency solar vapour production is made possible by gaining thermal power from compression at each stage to vaporise the brine in the next stage [32].

In 2015, Yadav and Sudhakar [33] conducted a comprehensive review of different layouts of domestic solar stills including the single basin single and the double slope solar still and a hybrid solar still with a comparison of economic and performance parameters. Despite this, the open literature has not yet thoroughly evaluated the multistage solar stills for various layouts. This research aims to address this issue as a result. This study covers a variety of technological research and development methods of multistage solar still arrangements. Various design parameters are investigated for the multistage solar stills. These include the design of the still trays of the distiller (configuration), solar thermal cumulative efficiency, water productivity, and the cost of distilled water. With the aid of a complete understanding of the aforementioned elements, the multistage solar stills have room for improvement and may thus be used in a variety of applications. The outcome of this work might provide a guide for upcoming research on multistage solar stills, which have made some strides but still need improvement.

2. Literature Review on Multistage Solar Stills Studies

Solar stills have been widely used for the production of potable water for several decades and improvements in their design and operation have been clearly noticed. Figure 1 shows different types of multistage solar stills used in water desalination, which will be discussed in detail in the next sections.

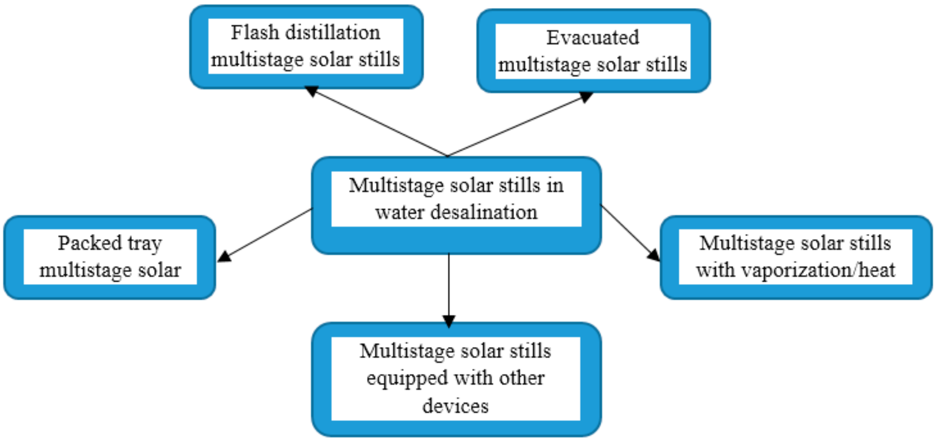

Figure 1. Types of multistage solar stills under consideration used in water desalination.

2.1. Packed-Tray Multistage Solar Stills

Figure 2 shows a schematic diagram of packed-tray multistage solar stills. In 1990, an innovative solar still for tandem distillation and heat recovery was created by Fernandez and Chargoy [34]. The lowest tray, which contains saltwater like the others, receives heat, and a diffusion of the distillate takes place. Condensation of the vapour from the warmest tray onto the top cooler tray results in the production of distilled water and an upward movement of heat. The thermocline moves higher during this exchange. Similar to greenhouse solar stills, it has been discovered that this process depends on the partial pressure differential of water vapour. To make the experimental findings obtained over the course of around 14 months of continuous operation fit appropriately, a simple numerical approach was developed and rectified using the field data.

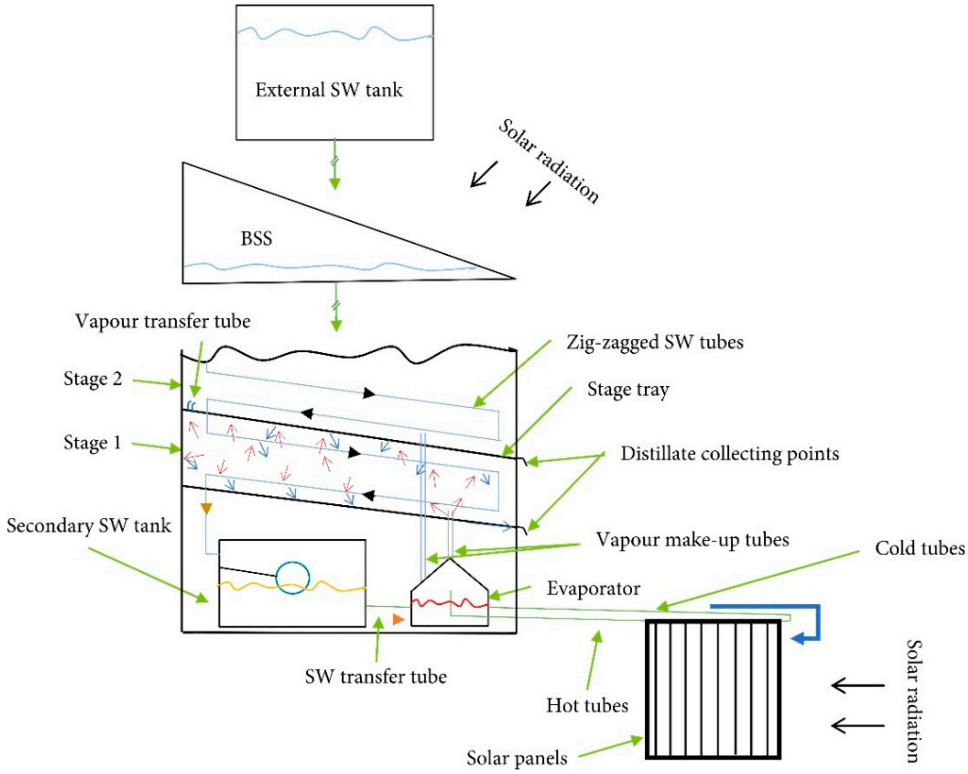

Figure 2. A schematic diagram of packed-tray multistage solar stills [35].

In 1993, a mathematical-model-based simulation was proposed by Adhikari and Kumar [36] for analysing the transient efficiency of a multistage stacked-plate solar still. A three-stage solar still with an electric radiator to supply heat was used to validate the mathematical model. Numerical simulations have been performed to fully assess the efficiency of the unit heated by a solar collector that corresponds to the familiar environment of Delhi (India) to understand the established model fully. Following the typical days of Delhi's coldest and warmest months, the effects of the stage number and the fraction of collector size to bottom tray size (Ac/Ab, t) on distillation production have similarly been examined. The quantity of daily distillate produced is relative to the ratio of the collector size to the base tray size.

In 1995, a numerical approach for analysing the steady-state operation of a multiple-stage packed-tray solar still was given by Adhikari et al. [37]. The findings of the modelled trials on a three-stage device using an absorption-type electric heater as the warming source verified the concept. The model's output, which used the adjusted heat and mass transfer equations presented in prior research, produced findings that were mostly consistent with those of the trials. In order to compare the presentation of the projected multiple stages, a stacked-tray solar still with a multistage solar still of the diffusion type and numerical data were also included in the study.

In 1999, an economic study of a multiple-stage stacked-tray (MSST) solar still connected to a solar collector was created by Adhikari and Kumar [38]. The thermal model that the authors previously used to forecast unit operation has also been applied here; the procedure considered the transient heat and mass transport mechanisms inside the solar still. The growth in the total size of solar collectors indicates a rise in the annual average quantity of distillate produced. The impact is most apparent in hierarchical structures, which have more stages. However, it is possible to see a diminishing fractional rise in the distillate yield when the size of the solar collectors is improved. To determine the price per unit mass of distilled water, the economic evaluation was based on the life-cycle assessment of the unit, which considered the system's principal and maintenance charges. Finally, the techno-economic study demonstrated the necessity for system parameter optimisation to achieve the lowest cost of distilled water.

In 2000, an economic study of an MSST solar still connected to a solar collector by a heat exchanger was created by Adhikari et al. [39]. For assessing its distillate yield, several heat and mass transport effects have been taken into account. The economic analysis determined the expense of a component mass of purified water while accounting for system life, capital expenses, and maintenance costs. To better comprehend the created model, numerical simulations have been used to optimise a variety of design factors, including the quantity of stages, the size of the evaporation plane, and the size of the collector area. These parameters are all related to the climate of Delhi, India. The annual average quantity of distillate produced is proportionally affected by the number of stages in the distillate method and the size of the solar collector. The effect of the distillation machine's usable life on the cost per mass of filtered water has also been studied. The paper also discussed the sensitivity of the expense per unit mass of distilled water concerning the cost of the solar collector, the usable life of the distillation chamber, and other related characteristics.

In 2017, a multiple-stage set-tray solar saltwater distillation still was constructed and deployed by Chen et al. [40] in order to evaluate thermal processes and test water creation capabilities in both transient and steady-state modes. It was shown that the water production rate eventually reached a steady state after three hours, and that increasing temperature led to increased water production rates. The effectiveness of the heat transfer and the mass transfer at each stage varies from the previous stage. The efficiency at the secondary stage is the greatest, whereas the efficiency of the thermal process at the primary stage, the efficiency at the secondary stage, and the efficiency at the third stage all rise as time passes. As can be seen in Figure 3, there was a rapid improvement in the effectiveness of the secondary effect beginning at 9:30 h, which continued until it reached a maximum of 1.55 at 17:30 h. Additionally, the performance coefficient was more significant than 1 when the temperature was above 70 °C. The accumulative water production and performance coefficient are greater when the depth of the saltwater is decreased.

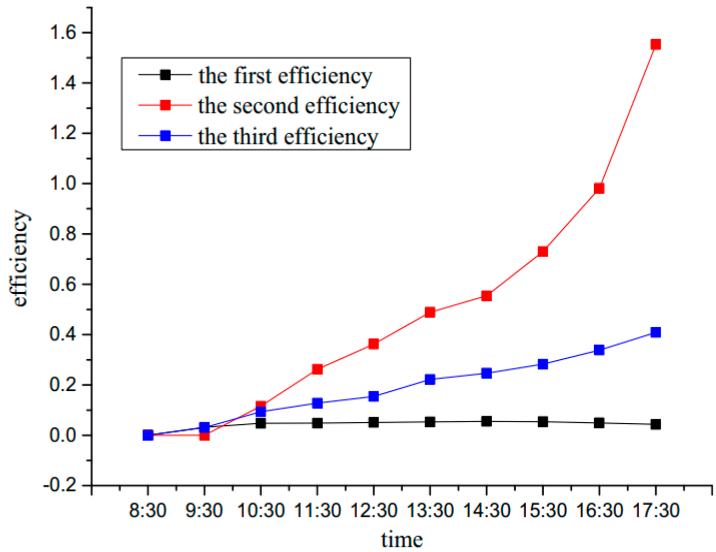

Figure 3. The thermal efficiency at each stage [40] (License Number: 5374111089644).

Table 1 shows a summary of studies outlined on packed-tray multistage solar stills.

Table 1. Review of studies outlined on packed-tray multistage solar stills.

Author	Location	Latitude	Multistage Solar Stills Type	Testing Period (h/Radiation (W/m^2))	Method	Studied Parameters	Remarks
Fernandez and Chargoy (1990) [34]	Mexico	latitude 19°25′ N, longitude 99°07′ W	Solar still built based on a packed-tray array for tandem distillate and thermal improvement.	September, October, and November	Experimental	Tray location	Even if there is a temperature variation between the trays, the tray below that does not allow distillation to begin, the trays in the stack's intermediate tiers are growing warmer.
Adhikari and Kumar (1993) [36]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Multiple-stage packed-tray solar still.	Coldest and hottest months	Numerical	Impacts of stages number and fraction of collector size to the bottom tray size (Ac/Ab, t)	The quantity of daily distillate produced is proportional to the ratio of collector size to the base tray size.
Adhikari et al. (1995) [37]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Multiple-stage stacked-tray solar still.	September, October, and November	Experimental and numerical	The number of stages	The daily distillate output grows in direct proportion to the stage number at which the purification procedure is carried out in the system.
Adhikari and Kumar (1999) [38]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	Multiple-stage stacked-tray (MSST) solar still connected to a solar collector.	September, October, and November	Experimental and Numerical	Area of solar collectors, stages number	The growth in the total size of solar collectors indicates a rise in the annual average quantity of distillate produced.
Adhikari et al. (2000) [39]	Delhi, India	latitude 77°13′ N, longitude 0.1956″ E	A heat exchanger is placed above multiple-stage stacked-tray (MSST) solar still that also includes a solar collector.	September, October, and November	Analytical	Number of stages and the size of the solar collector	The number of stages in the distillation process and the size of the solar collector both have a proportional impact on the average amount of distillate generated annually.
Chen et al. (2017) [40]	Chongqing, China	latitude 29°26′ N, longitude 106°53′ E	Multiple-stage packed-tray solar saltwater distillation still.	19–20 MJ/(D-m^2)	Experimental and analytical	Temperature, seawater depth.	When the temperature was high, it was discovered that the water generation rate and the operation coefficient were more significant. Additionally, as saltwater depth is reduced, both the cumulative water production and performance coefficient increase.

2.2. Flash Distillation Multistage Solar Stills

In 2008, the efficiency enhancement of the solar multiple-stage flash (MSF) desalination process employing Pinch technology was considered by Shaobo et al. [41], as shown in Figure 4. In this work, pinch analysis was used to study three distinct scenarios. The first scenario focuses on the assumption of not discharging the distilled water in each intermediate stage, while this has been considered in the second scenario. The third scenario assumed the discharging of distilled water after stage five. Finally, there were several pinch charts available. When the purified water is undischarged in each central stage, the system has an advanced gain out rate (GOR), approximately 17.5; however, the second and third stages have a lower GOR, approximately 9, which is true even though the stage temperature difference and pinch point temperature difference is the same. The system's GOR is around 9 points lower whether the distilled water is released at each stage or every five stages. At the same stage, these conditions are temperature differential (2 k) and pinch point temperature variation (2 k). The GOR is based on the MSF's operating temperature range, and the total temperature differences at the top stage and pinches point, as seen in Figure 5.

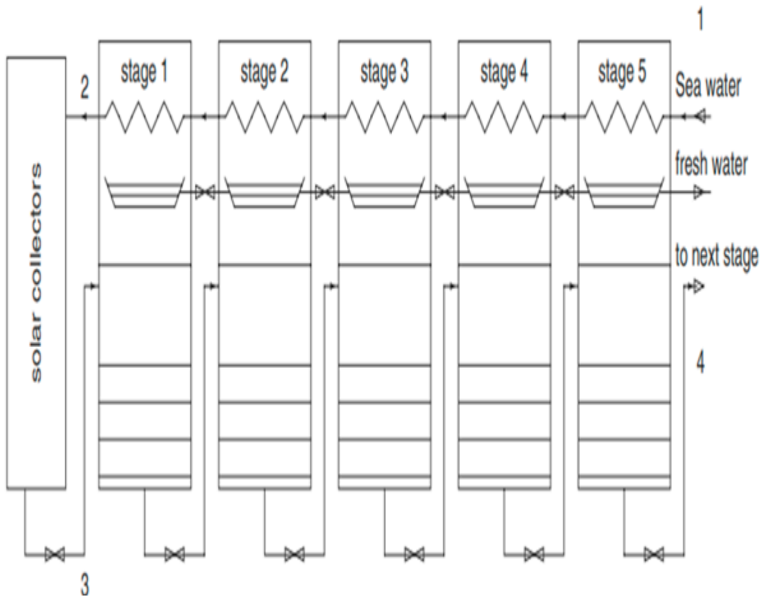

Figure 4. Diagram of the first five stages of the solar MSF distillation method [41] (License Number: 5373820787675).

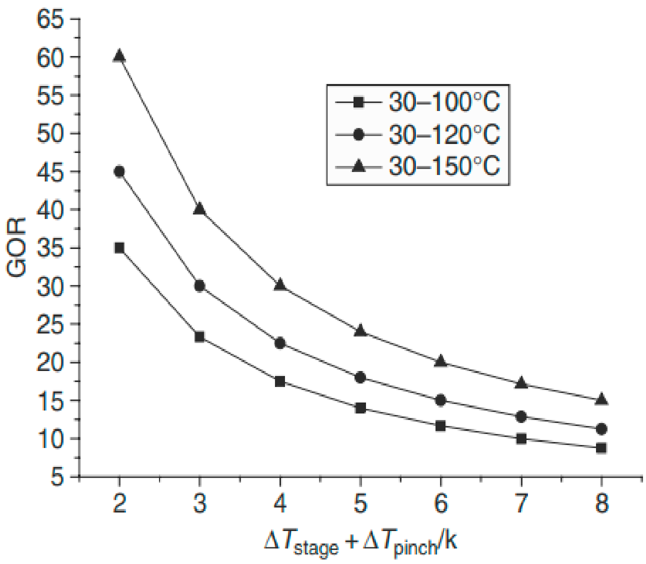

Figure 5. The GOR via the sum of the highest stages temperature variation and pinch point temperature change [41] (License Number: 5373820787675).

In 2012, the multistage flash (MSF) desalination plant was the subject of a mathematical model developed by Abdul-Wahab et al. [42]. The stages of the desalination process were described in the model using fundamental physics and chemistry concepts. The make-up flow, brine recycling flow, seawater flow, seawater temperature, concentration, top brine temperature (TBT), steam temperature, and plant load were among the model's inputs. The study showed that there was good agreement between the model forecasts and the outcomes of simulations and plant operating data. The created model was adequately precise, and forecasts made by the model could be trusted. In order to increase water output or decrease energy consumption, it may be advised to run the MSF desalination plant at various loads to determine the optimal set point.

In 2017, A brand-new design for a multistage flash (MSF) desalination plant driven by solar energy was demonstrated by Alsehli et al. [43]. An array of concentrating solar collectors and two thermal storage tanks, each with the capacity to provide the MSF with brine for a day, are used in the suggested layout. At about sunset each day, the system is set up so that the tanks switch off in their respective duties. By altering the mass fluxes, it is possible to account for seasonal variations in the amount of solar energy available while maintaining a constant top brine temperature (TBT). This concept was simulated using a dynamic model of heat and mass transfers, which led to an average daily output of 53 kg of distillate per square meter of solar collector area. The system uses 42,552 m^2 of solar collection space to produce 2230 m^3 of fresh water each day on average.

In 2018, a unique multiple-stage flash (MSF) desalination facility was examined by Al-Othman et al. [44] in the United Arab Emirates. Note, the UAE has made significant progress in using solar power to generate electricity. The simulation of a desalination plant looked at solar ponds and parabolic trough collectors (PTC) to provide all the energy needed for the MSF process. The simulation tool utilised for this investigation was Aspen HYSYS V8.8. The intention was to provide the water requirements of a small hamlet with a population of about 5000. The simulation attempted to produce 1880 m^3/day of desalinated water out of the 40,000 m^3/day of saltwater handled. The results indicated that two PTCs with a combined aperture area of 3160 m^2 could supply about 76% of the energy demands of the MSF. A solar pond supplies the left portion with a depth of four meters and a surface area of 0.53 km^2.

In 2018, Garg et al. [45] developed a numerical technique for an MSF distillation process using a BR (brine recycle) setup. A numerical model was built for the BR-nanofluid-based MSF's direct absorption solar collector (DASC). BR-MSF and DASC were connected via a heat exchanger. The gained output ratio measures total system performance (GOR). The research revealed that DASC may be utilised as a heat source for BR-MSF and delivers high GOR between 11 and 14. The DASC-based BR-MSF unit delivers greater GOR under the same circumstances (approximately 11% higher), as illustrated in Figure 6. In other words, a unit constructed on DASC operates thermally and 11% more efficiently than a system based on PTC.

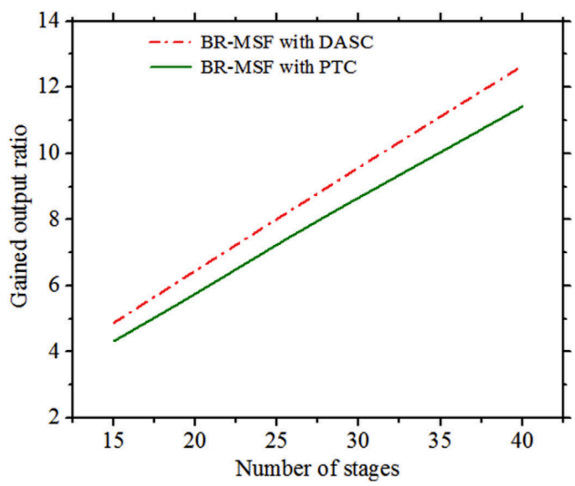

Figure 6. Difference of gain output ratio (GOR) with stage number for PTC-based and DASC-based BR-MSF distillation units [45] (License Number: 5374110867353).

Table 2 shows a summary of the studies outlined on flash distillation multistage solar stills.

Table 2. Review of studies outline on flash distillation multistage solar stills.

Author	Location	Latitude	Multistage Solar Stills Type	Testing Period (h)/Radiation (W/m^2)	Method	Studied Parameters	Remarks
Shaobo et al. (2008) [41]	Guangdong, China	latitude 22°31′ N, longitude 113°23′ E	Solar multiple-stage flash (MSF) distillation method using Pinch mode.	-	Analytical	The stage temperature difference and pinch point temperature difference.	When the distilled water is released at each stage or every five stages, the system has a GOR of about 9 points lower.
Abdul-Wahab et al. (2012) [42]	Muscat, Oman	latitude 23°36′ N, longitude 58°32′ E	Multistage flash (MSF) desalination.	-	Numerical	Brine recycle flow, seawater flow, seawater temperature, seawater concentration, top brine temperature (TBT), steam temperature, and the plant load.	It may be recommended for determining optimum set point of a running MSF desalination plant at different loads to maximise the water production or minimise energy consumption.
Alsehli et al. (2017) [43]	Riyadh, Saudi Arabia	latitude 24°46′ N, longitude 46°44′ E	Solar-powered multistage flash (MSF) desalination.	-	Experimental	Impact of using array of concentrating solar collectors and a pair of thermal storage tanks.	Still efficiency enhances with using array of concentrating solar collectors and a pair of thermal storage tanks.
Al-Othman et al. (2018) [44]	Sharjah, United Arab Emirates	latitude 25°20′ N, longitude 55°24′ E	New solar-powered multiple-stage flash (MSF) distillation unit.	-	Experimental	Impact of using parabolic channel collectors (PCC) and a solar pond.	The two PTCs, which have a combined space area of 3160 m^2, can deliver around 76% of the MSF's necessary power.
Garg et al. (2018) [45]	Punjab, India	latitude 30°56′ N, longitude 74°31′ E	Multiple-stage flash (MSF) distillation unit with saline recirculation (SR) configuration.	Min 500–Max 1000	Experimental and numerical	Top brine temperature, parabolic trough collector (PTC)-built on distillation unit.	Compared to a system based on PTC, the thermal operation of a unit built on DASC is roughly 11% greater.

2.3. Evacuated Multistage Solar Stills

In 2009, Ahmed et al. [46] presented multiple stages to evacuate solar distillate units to boost solar still productivity and effectiveness. The solar still operates due to increased evaporation in a vacuum. The system was optimised using a mathematical model. Fluent software simulated the still's heat–mass processes. The structural analysis used NASTRAN. Preliminary experiments indicated that internal pressure significantly affects solar still production. Figure 7 shows that when pressure increases, evaporation rates drop, reducing production. The specific height difference strongly affects the still's predicted production. Figure 8 depicts how height affects production.

In 2010, Shatat and Mahkamov [47] tested a multiple-stage water distillation still coupled to a 1.7 m^2 heat channel evacuated solar tube collector. The four-stage solar desalination system recovers latent heat from vaporization and condensation. On the test rig, 110 halogen floodlights were used to imitate sun radiation on a typical summertime day in the Middle East. Tests showed that the device was generating 9 kg/day of clean water and was 68% efficient. In the second phase, water production in a still with a 1 m^2

vaporization area in each stage was studied. Figure 9 shows that the addition of stages increases distillate yield.

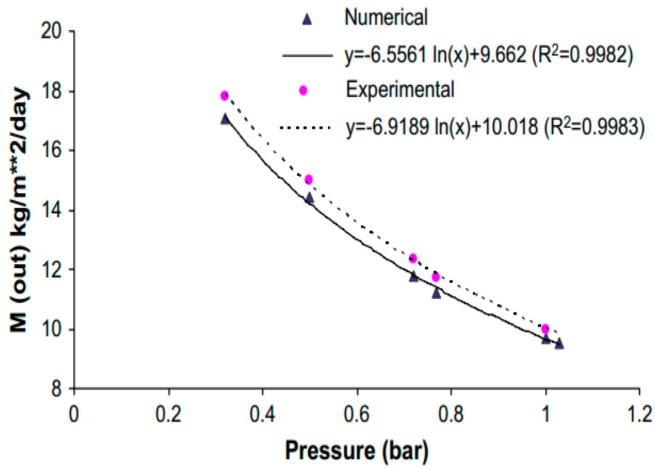

Figure 7. Difference in the still efficiency against inlet pressure [46] (License Number: 5374110080306).

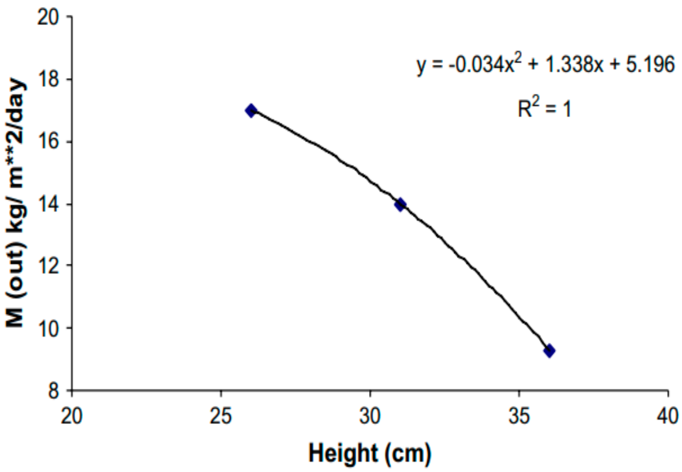

Figure 8. Difference in the approximate still yield with the still height [46] (License Number: 5374110080306).

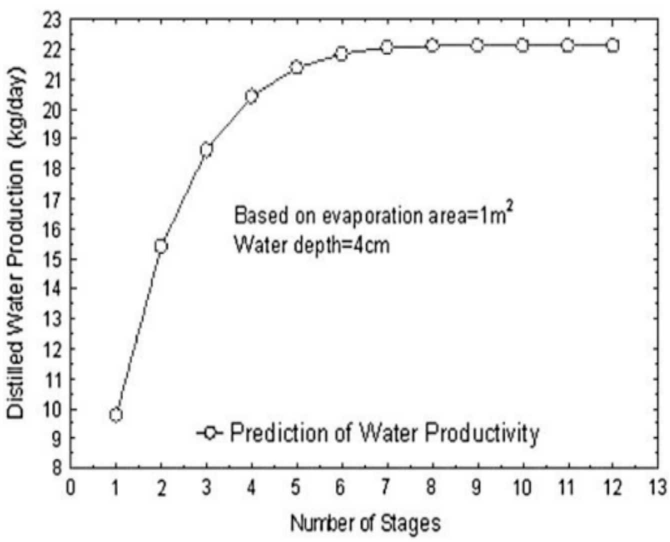

Figure 9. Resolve of rational stage number [47] (License Number: 5374110278260).

Figure 10 shows a multiple-stage evacuated solar desalination system designed in 2012 by Reddy et al. [48]. The solar desalination model is transitory. The influence of design and operational characteristics was evaluated to optimise the setup. A small layer of water in the stages improves evaporation, which boosts the distillate production. Figure 11 shows that ion activity and thermodynamically spontaneous liquid-to-vapor conversion diminish when the water salinity increases. The best number of stages, stage gap, and flow rate were found to be 4, 100 mm, and 55 kg/m^2/day throughout the year, respectively. India's March and December thermal efficiencies are 53.9% and 29.6%, respectively. The water productivity in March is 53.2 kg/m^2/day at 0.03 bar.

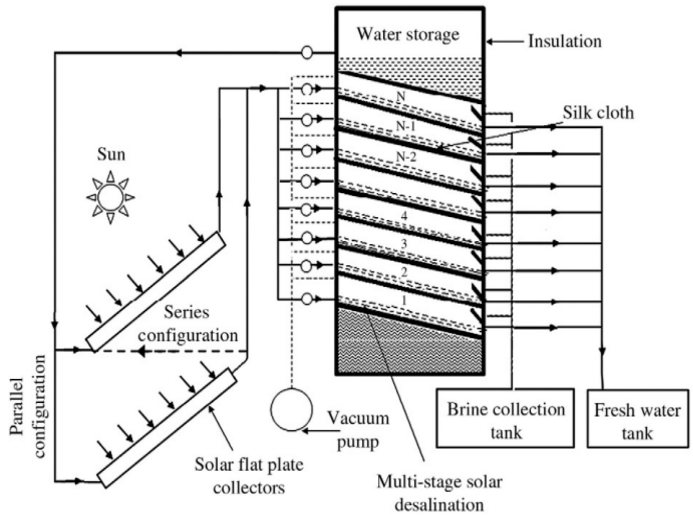

Figure 10. Multiple-stage evacuated solar distillation unit combined with flat surface collectors [48] (License Number: 5373821246523).

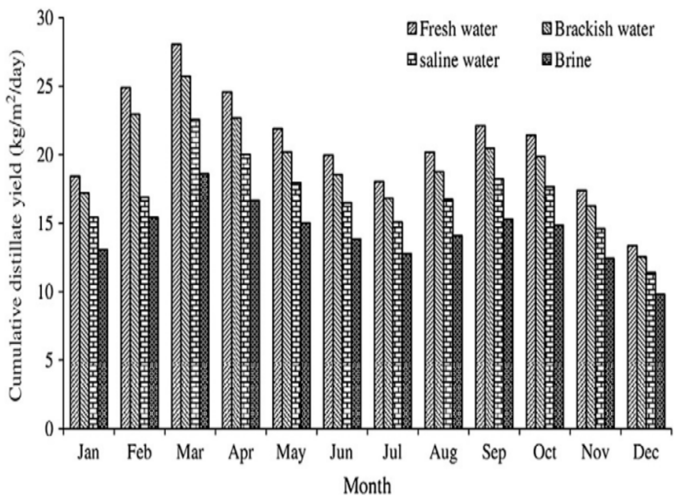

Figure 11. Monthly difference in distillation yield with brininess [48] (License Number: 5373821246523).

Table 3 shows a summary of studies outlined on evacuated multistage solar stills.

Table 3. Review of studies outlined on evacuated multistage solar stills.

Author	Location	Latitude	Multistage Solar Stills Type	Testing Period (h)/Radiation (W/m^2)	Method	Studied Parameters	Remarks
Ahmed et al. (2009) [46]	Kuala Lumpur, Malaysia	latitude 3°8′ N, longitude 101°41′ E	Multistage evacuated solar distillation system.	Min 100–Max 1198	Experimental and numerical	Internal pressure and characteristic height.	The smaller vaporisation rates at the higher-pressure levels were responsible for the decline in productivity that occurred when the pressure was raised. It was discovered that the height fluctuation distinctive of the still considerably affects the projected construction that the still produces. As a result, productivity drops very dramatically while working at greater heights.
Shatat and Mahkamov (2010) [47]	Durham, UK	latitude 54°46′ N, longitude 1°34′ W	Multiple-stage water distillation still attached to a heat duct evacuated solar channel collector.	Min 300–Max 1100	Experimental and numerical	Impact of using solar collector, and the number of stages.	The system generates around 9 kg of daily clean water and has a productivity of approximately 68% for solar collectors. However, the total efficiency of the laboratory test rig was determined to be at the level of 33%, owing to significant thermal waste in the unit. The quantity of distillate produced increases proportionally with the number of stages used in the process.
Reddy et al. (2012) [48]	Chennai, India	latitude 13°4′ N, longitude 80°14′ E	Multiple-stage evacuated solar distillation unit.	March and December	Experimental	Salinity of water, the number of stages, space between the stages, and flow velocity.	When there is a rise in the salt of the water, the distillate production goes down. Throughout the year, it was determined that the optimal values for the stages number, the space between the stages, and the provided flow velocity for the unit were 4, 10 cm, and 55 kg/m^2 day, respectively.

2.4. Multistage Solar Stills with Vaporization/Heat

In 1991, Goff et al. [49] constructed a distillation system with a pack of six rectangular parts, creating a thermal sequence. A slim layer of salty water is partly vaporized as it drips over a warmed vertical wall in every part (4 cm thick). The vapour that is created condenses on the opposing wall of the cell. The condensation generates heat, which is then utilised to disperse the film dripping into the following cell from the opposite side of the plate. Under the same sunlight circumstances, the system generates over 20 L/m^2 day of purified water, compared to a traditional "single basin" solar still with an output of 2.5 to 3 L/m^2 day. This solar distiller is constructed to be a modest, durable piece of equipment that any village artisan with basic technical skills can easily maintain and repair.

In 2000, Jubran et al. [50] reported creating a numerical approach to forecast the efficiency and thermal properties of a multiple-stages solar still with an enlargement nozzle and thermal improvement at each stage of the still, as shown in Figure 12. Additionally, a parametric examination of the suggested solar still was implemented using this model.

A cost study was conducted to provide some insight into the possibility of using the suggested still for producing drinking water. It was discovered that using an expansion nozzle and thermal improvement methods in the suggested solar still tend to increase the distillation efficiency of the still. The distillation efficiency of the solar still is 87%, and its daily production may reach 9 kg/m^2. This still's distilled water costs USD 25.6/1000 gallons per unit. The accumulative yield increases linearly as the number of stages and heat input increase, as seen in Figure 13.

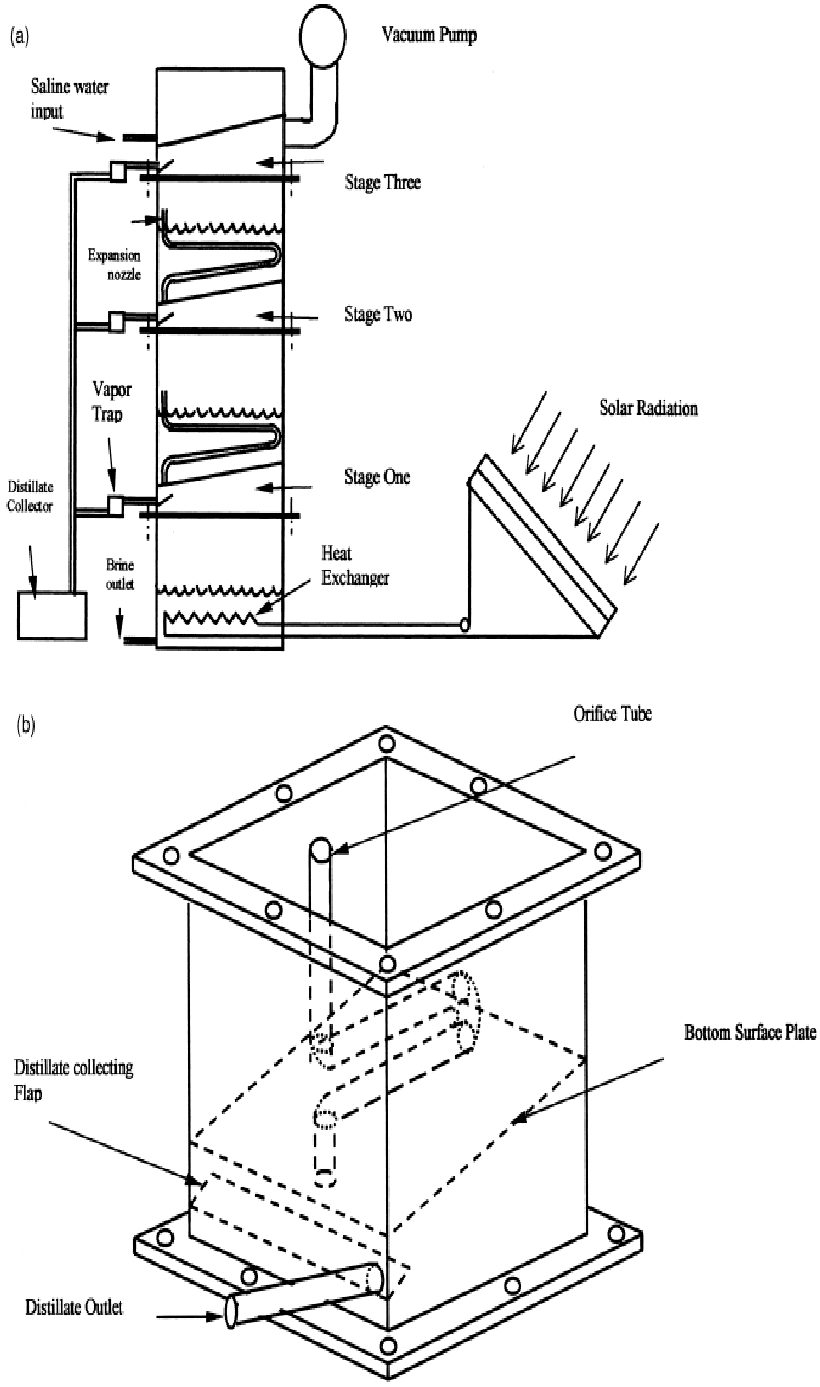

Figure 12. (**a**) Graph of the multiple-stage evacuated pack solar still. (**b**) Isometric view of one middle pack [50] (License Number: 5373790205227).

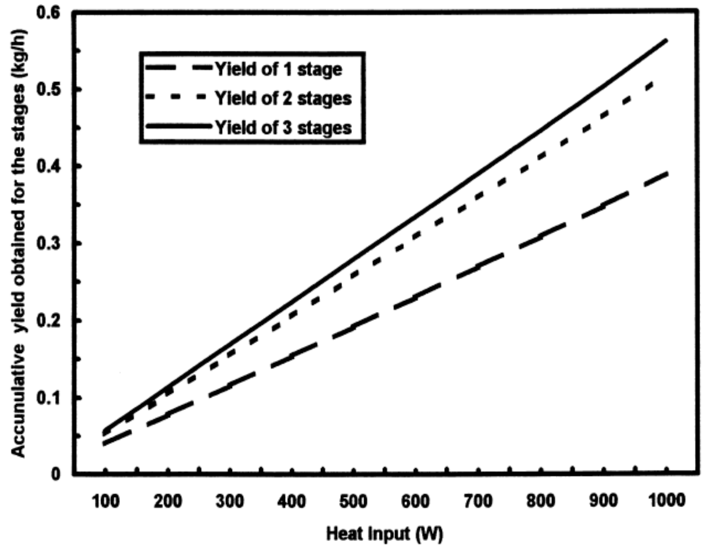

Figure 13. Accumulative yield of stages versus heat input [50] (License Number: 5373790205227).

In 2014, Liu et al. [51] developed a moderate-scale solar distillation unit with multiple stages of vaporization/thermal improvement operations. Four collecting units were connected. Under diverse working circumstances, the operational pressure, adjustment technique, climate, season, and highest collection temperature were tested. Figure 14 displays the summer and winter freshwater yields. The amount of freshwater extracted from the system is influenced by solar radiation. The freshwater yield using the free pressure setting method is slightly lower than the clean water yield using the stable pressure situation technique and similar solar radiation intensity. In summer and early winter, the maximum clean water productivities were 1.98 kg/(h m^2) and 1.37 kg/(h m^2), respectively. During July (summer), the all-day clean water production was 7.86 kg/m^2, which is 49.2% greater than in early winter, which was 5.27 kg/m^2. Although the all-day clean water production drops in early winter matched those of summer, less than 3 m^2 of solar panels may generate 12.2 kg of clean water daily. The clean water production will also rise as the peak collecting temperature rises due to the higher productivity of the heat recovery process. Additionally, as the maximum collecting temperature increases, the freshwater production will increase.

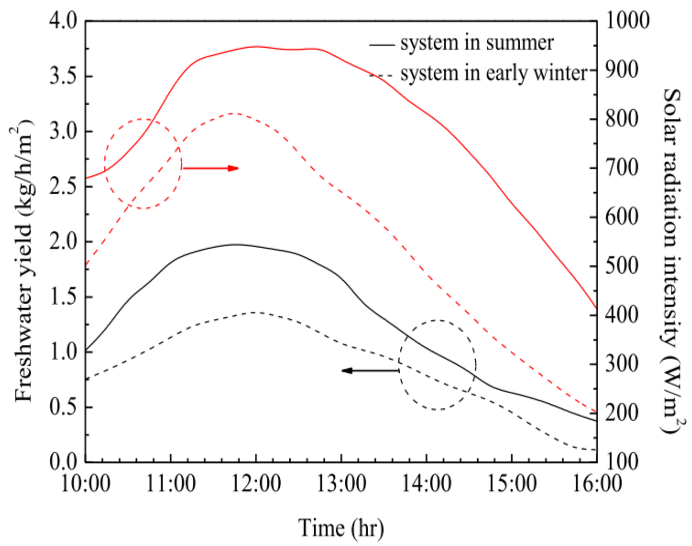

Figure 14. Clean water produced by the two various units in summer and early winter [51] (License Number: 5374100134875).

In 2014, Liu et al. [52] created a moderate solar distillation unit with multiple stages of vaporization/thermal improvement procedures. The four-unit device runs at barotropic and atmospheric pressure. A saltwater reservoir, a solar ray collection/distillation board, a fundamental CPC, and an all-glass evacuated channel collector are included in each of the four systems. In the latter three systems, heat is recovered by inserting copper heat exchangers into glass evacuated tubes. Solar energy, heat recovery (not in the first system), and seawater evaporation can all be used independently by each system to desalinate water. Overall, the planned system's freshwater field may reach 1.25 kg/(h m^2), and its overall thermal efficiency is nearly 0.9. As shown in Figure 15, freshwater production surpasses 1.26 kg/(h m^2) on a bright day and 0.7 kg/(h m^2) when overcast.

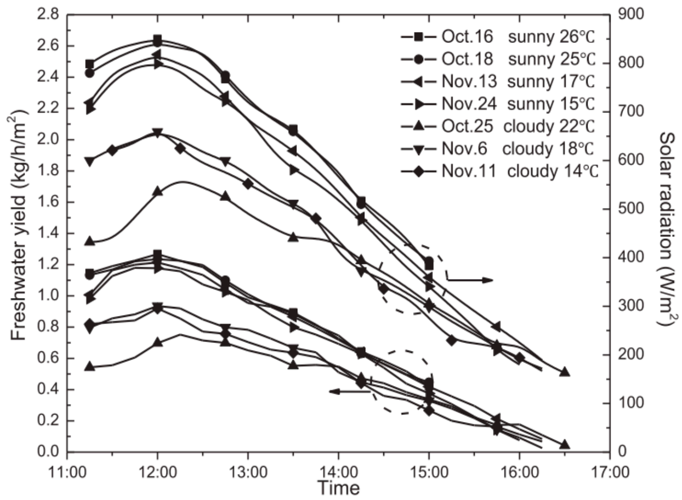

Figure 15. Clean water produced in 5 test days [52] (License Number: 5374110560616).

In 2018, Lee et al. [53] provided a theoretical study of a solar radiation multiple-stage direct contact membrane distillation (SMDCMD) unit with a power improvement system and dynamic working unit. Mid-latitude data from Busan, Korea was used. The dynamic operating scheme alters the number of module stages depending on each module's intake feed temperature, water output and thermal efficiency. In other words, the water output and thermal efficiency are both improved as a direct consequence of the dynamic operating scheme's ability to adjust the number of module stages it employs dynamically in response to variations in the temperature of the intake feed for each succeeding module. The average daily water production rises from 0.37 to 0.4 m^3/day in December, while thermal performance increases from 31% to 45%. The volume of the saltwater storage reservoir ranged between 16 m^3 and 28.8 m^3, and the solar thermal efficiency at various desirable input temperatures between 50 °C and 80 °C was evaluated in October and December, respectively. The water output per collector area varied from 350 m^2 to 550 m^2 (Figure 16).

In 2018, a solar distiller with four levels was successfully built by Abdessemed et al. [54]. The tested distiller is a poly-energy device. It may run on the energy from one of three distinct suppliers: electrical resistance (from the power grid or a photovoltaic section). The cylinder parabolic solar collector, which was used to collect the heat required for the distillation process, is connected to the four-stage still. The still trays used for testing came in two different shapes: "V" and other. The multiple-stage stills, which were evaluated practically in this study in the meteorological circumstances of the city of Batna, Algeria (35 degrees 45 min north, 6 degrees 19 min east), are one of the numerous technologies used in the desalination of water. Regarding the creation of purified water, "V"-shaped trays are the most successful method since they are less expensive and more cost-effective than the "floor" ("Λ"-shaped) trays, which need two collectors.

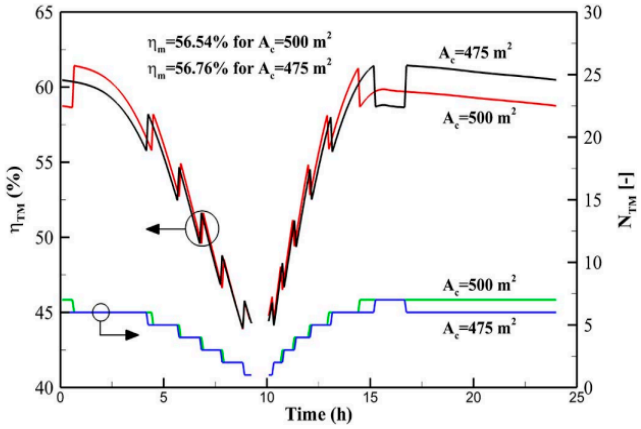

Figure 16. Typical daily thermal performance of the entire components used at each time (ηTM) and the total number of working units at each time for a continuous 24 h/day process at the 475 m^2 and 500 m^2 collector size and a reservoir volume of 19 m^3 in October [53] (License Number: 5373840183630).

In 2020, an evaluation of the heat and vapour transport in a model thermally localized multistage solar stills (TMSS) system with a changing device design and a prediction of its solar desalination efficiency were reported by Zhang et al. [55]. They showed that maximising the number of stages and the device shape make it possible to reach an ultrahigh solar thermal cumulative efficiency far greater than that of ordinary solar stills. Their modelling demonstrates that the capillary-supplied TMSS's efficiency is limited by the thermal energy lost to the environment during condensation and that significant efficiency increases may be achieved by reducing this loss. The third stage's energy reuse rate rises to roughly 80% due to the front wall's lack of radiative and convective heat loss, as seen in Figure 17.

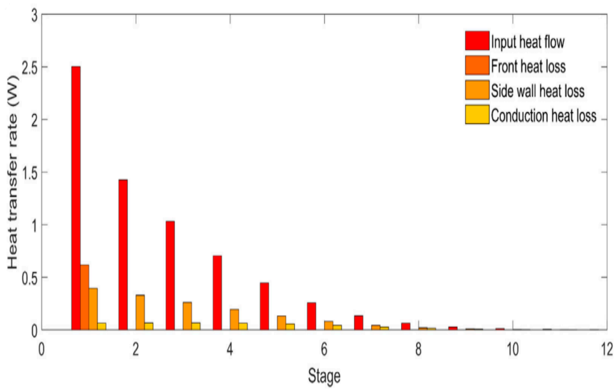

Figure 17. Heat transfer rate and different thermal losses at every system stage [55] (License Number: 5373820139387).

In 2020, using solar power, Huang et al. [56] demonstrated a thermal multistage distiller. The distiller has a multistage evaporator–condenser and thermal concentrator. The thermal concentrator can powerfully convert solar radiation into heat for high-temperature vapour creation and lessen radiation loss, thanks to its strong solar absorptance of 0.935 and low emittance of 0.15. The concentric expansion evaporator–condenser architecture of the multistage distiller decreases heat losses and water diffusion resistance. Under conditions of three thermal concentrations and 1 kW m^{-2} sun intensity, a six-stage distiller generated 2.2 kg m^{-2} h^{-1}. Water was produced at a rate of 3.9 kg m^{-2} per day at 415 Wm^{-2} in outdoor rooftop trials. The thermal efficiency of each stage rises with solar intensity. With a thermal concentration increase from 1 to 4 at 600 W m^{-2}, the distiller's GOR increased from 1.22 to 1.41 (Figure 18).

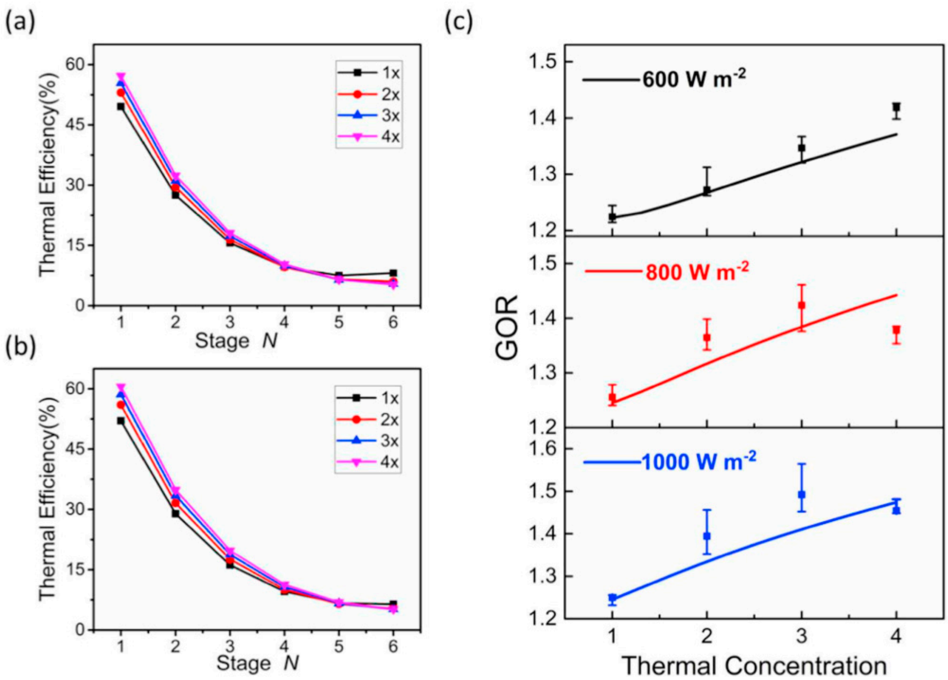

Figure 18. Designed thermal productivity of each stage under various radiation intensities: (**a**) 600 W m^{-2} and (**b**) 1000 W m^{-2}; (**c**) the GOR under various radiation intensities and heat loading, the dots correspond to the measured data, and the lines are the findings from theoretical model [56] (License Number: 5373840497196).

In 2020, Ghorbani et al. [57] connected a flat surface solar field to a multiple-stage distillation machine to aid in the desalination of water. The entire process was modelled using HYSYS and MATLAB. Additionally, different PCM (phase change material) volumes on the TES unit with stearic acid PCM and varied MFRs of incoming water into the flat surface collectors were investigated. A given area of collectors with a 45.5% increase in input water MFR produces 45.5% more clean water, 25.6% more solar useable electricity, and 10% more collector productivity. However, the solar percentage drops by 19.5%. While the boiler's annual energy production reduces by 47.4%, the number of solar collectors increases by 26% at a given mass flow rate of incoming water, increasing the collector efficiency, solar percentage, and annual solar energy collected by 23%, 18%, and 23%, respectively (Figure 19).

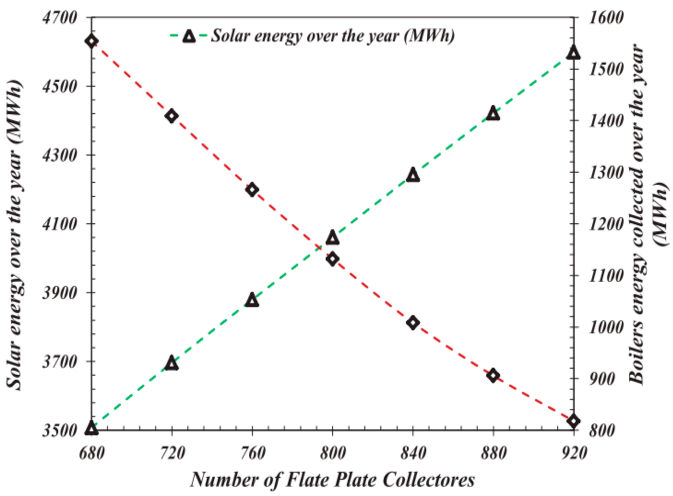

Figure 19. Differences in the amount of energy provided by the boilers and solar collectors to the inlet water against the number (size) of collectors [57] (License Number: 5374100710273).

In 2022, Li et al. [58] discovered that a multiple-stage purification apparatus with a three-dimensional ribbed evaporation layer would enhance the vaporization performance. The ribbed layer produced higher evaporation flow with reduced temperature and heat loss. Under 1 kWm^{-2} radiation intensity, the single-stage device evaporated 1.19 kg m^{-2} h^{-1} with 81.5% energy conversion productivity. The ribbed evaporation layer improved multi-stage latent heat transmission and use. The ten-stage device's steady evaporation rate was 4.12 kg m^{-2} h^{-1}, 1.6 times the original single-stage device.

Table 4 shows a summary of the studies outlined on multistage solar stills with vaporization/heat.

Table 4. Review of studies outlined on multistage solar stills with vaporization/heat.

Author	Location	Latitude	Multistage Solar Stills Type	Testing Period (h)/Radiation (W/m^2)	Method	Studied Parameters	Remarks
Goff et al. (1991) [49]	Tunisia	latitude 36°48′ N, longitude 10°10′ E	Six rectangular cells forming a thermal series.	May Min 200–Max 830	Experimental	Number of stages	Still efficiency increases with an increasing number of stages.
Jubran et al. (2000) [50]	Kuala Lumpur, Malaysia	latitude 3°8′ N, longitude 101°41′ E	Multiple-stage solar still with an growth nozzle and heat improvement in each stage.	Min 120–Max 1200	Numerical	Impact of using growth nozzle and thermal improvement methods.	The daily solar still production may be as high as 9 kg/m^2, and the efficiency of the distillate process is 87%.
Liu et al. (2014) [51]	Shanghai, China	latitude 31°13′ N, longitude 121°28′ E	Innovative modest-sized combined solar distillation unit with multiple stages vaporization/heat improvement procedures.	Min 200–Max 900	Experimental	Solar radiation, running pressure, using pressure-modifying technique, climate condition, period condition, and highest collecting temperature.	The clean water production will also increase as the peak collecting temperature increases due to the higher productivity of the heat recovery process. Additionally, as the maximum collecting temperature rises, the freshwater production will rise.
Liu et al. (2014) [52]	Shanghai, China	latitude 31°13′ N, longitude 121°28′ E	Innovative modest-sized combined solar distillation unit with multiple stages vaporization/heat improvement procedures.	Autumn Min 50–Max 810	Experimental	Design of the system.	The developed system has a total efficiency that is very near 0.9, and the clean water area of the unit may reach as high as 1.25 $kg/h.m^2$.
Lee et al. (2018) [53]	Busan, Korea	latitude 35°10′ N, longitude 129°3′ E	Solar-powered multistage through interaction membrane distillation (SMDCMD) unit.	October and December	Experimental and numerical	Number of module stages.	The capacity of the dynamic operating scheme to dynamically modify the number of module stages it uses in response to variations in the temperature of the intake feed for each succeeding module directly leads to an improvement in the water output and thermal efficiency.

Table 4. *Cont.*

Author	Location	Latitude	Multistage Solar Stills Type	Testing Period (h)/Radiation (W/m²)	Method	Studied Parameters	Remarks
Abdessemed et al. (2018) [54]	Batna city, Algeria	latitude 35°33′ N, longitude 6°10′ E	Solar distiller with four floors.	Average 971.22	Experimental	Impact of using "V"- and "Λ"-shaped trays.	Producing distilled water using trays as a "V" is the most effective method. Trays in the form of a "V" are more cost-effective than those in the shape of a "U," which need two collectors.
Zhang et al. (2020) [55]	Cambridge, USA	latitude 42°22′ N, longitude 71°6′ W	Multistage solar stills (TMSS) system with varying device configurations.	Average 1000	Experimental	Stage number.	Because there is no longer any heat loss by radiation or convection on the front wall, the rate of energy reuse during the third stage is increased to around 80%.
Huang et al. (2020) [56]	Wuhan, China	latitude 30°34′ N, longitude 114°16′ E	Thermal concentrated multiple stages distiller.	15 October Min 600–Max 1000	Experimental	Impact of using concentric expansion evaporator–condenser structure.	The multistage distiller that utilises a concentric expansion evaporator–condenser construction can effectively improve the latent heat of vapour while simultaneously cutting down on heat losses and the resistance to water diffusion.
Ghorbani et al. (2020) [57]	Amol, Iran	latitude 36°28′ N, longitude 52°21′ E	Coupled a horizontal plate solar area to a multiple-stage distillation unit.	Min 100–Max 1000	Experimental and numerical	Area of solar collectors.	The annual increases in collector thermal efficiency, solar percentage, and solar energy captured are, respectively, 23%, 18%, and 23% when the total number of solar collectors is raised by 26% while keeping the mass flow rate of incoming water constant.
Li et al. (2022) [58]	Hangzhou, China	latitude 30°15′ N, longitude 120°9′ E	Multiple-stage purification unit with a 3D ribbed vaporization sheet.	Average 1000	Experimental and numerical	Impact of ribbed evaporation layer.	In multistage devices, the productivity of latent heat transmission and use was significantly improved thanks to the ribbed evaporation layer. As a result, the steady vaporization rate of the 10-stages unit reached 4 kg^{-2} h^{-1}, almost 1.6-fold that of the system's first stage.

2.5. Multistage Solar Stills Equipped with Other Devices

Figure 20 illustrates the results of an investigation carried out in 2015 by Feilizadeh et al. [59] into the outdoor operation of a basin-form multiple-stage solar still as well as the impact of the collector over basin area (CBA) ratio on the distillate output. For the first time, the CBA's impact was investigated in outdoor tests. This is in comparison to the previous designed systems of multiple-stage solar stills. A still was connected to one, two, or three flat-plate solar collectors to make up the system. The findings showed that the basin connected to a single solar collector (CBA = 3.45) generated 11.56 kg distillate over the winter. Production grew by 96% when a second collector (CBA = 6.9) was added to the unit, but only by 23% when a third one (CBA = 10.35) was added. As the stage number grew, the overall daily distillate output fell, as illustrated in Figure 21. Cleary, there is an optimum number of stages to be determined based on economics. In contrast, adding a second or third collector resulted in production increases of 48% and 23%, respectively, during the summer months.

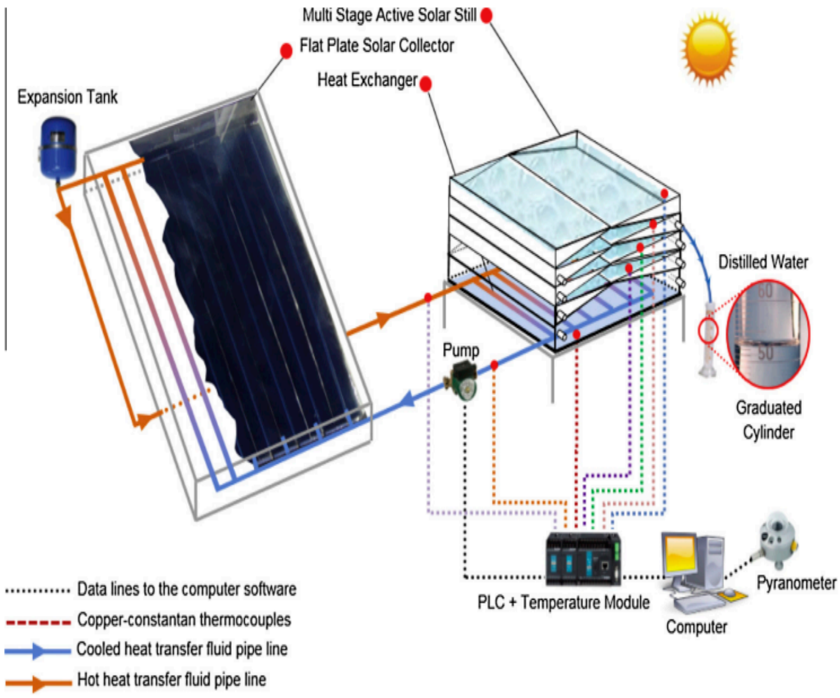

Figure 20. A diagram of the investigational device [59] (License Number: 5373800957472).

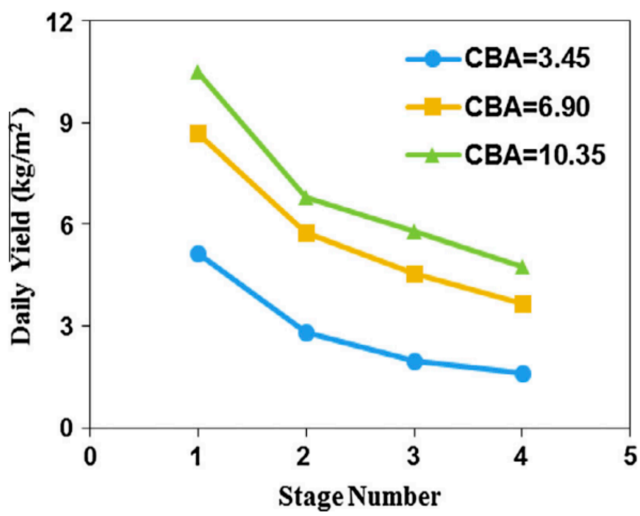

Figure 21. Differences in the daily distillation creation per unit area of the basin by different stages in the units with CBAs of 3.45, 6.90, and 10.35 [59] (License Number: 5373800957472).

In 2015, Feilizadeh et al. [60] studied the impact of input energy on a multistage solar still. A PLC-controlled electric heater was used to replicate solar collector input energy. Figure 22 shows that freshwater output is a quadratic function of a collector over basin area (CBA). Stages 1–4 generated 36%, 26%, 20%, and 18% of the total yield, respectively. Again, there is an optimum number of stages to be determined based on economics. The impact of thermal energy storage (TES) on system performance was discovered by contrasting the way energy was fed based on the daily solar radiation pattern with the impulsive pattern (feeding all the energy at the beginning of the experiment). TES increased still production by 5–10%.

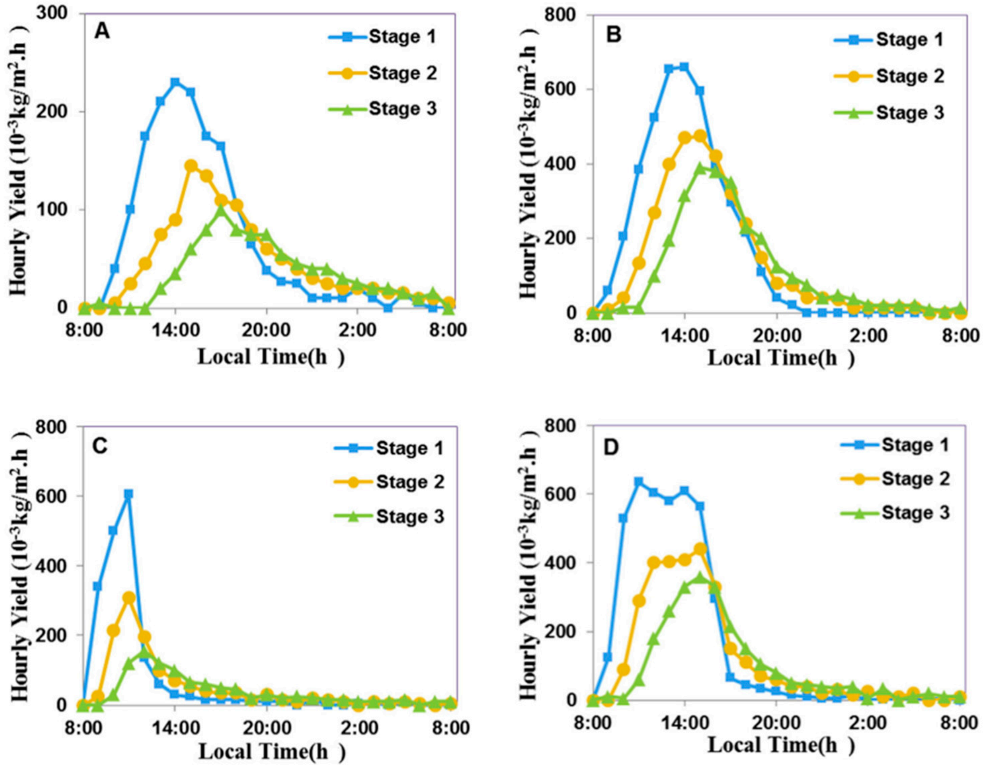

Figure 22. The rate of the clean water production when (**A**) 13 MJ energy was supplied, based on the regular solar irradiation design; (**B**) 27 MJ energy was consumed, based on the daily solar irradiation design; (**C**) 13 MJ energy was consumed spontaneously; (**D**) 27 MJ energy was consumed spontaneously [60] (License Number: 5373830138142).

In 2016, Bait and Si-Ameur [61] designed a multistage distillation system using SOLIDWORKS, and then ran numerical and economic analyses. The goal was to evaluate the viability of such a device in a semiarid environment (Batna–Algeria). The geometrical configuration considered in this work was based on literature reviews and experiments. As a first stage, a zero-dimensional statistical model based on mass and energy equilibrium was analysed before beginning a 3D CFD research in ANSYS FLUENT. After a careful study, the hot-stage radiation term was found to be 3.23%. As the evaporation area grew above 1 m^2, a curve formed. Figure 23 shows that when the evaporator and condenser temperatures converge, distillate increases.

In 2020, Xu et al. [62] showed that optimising the overall heat and mass transport in a multistage configuration plays a main role in the additional refinement of the overall performance. This thoughtful approach also surges the flexibility of material choices for the thermally localized multistage solar stills (TMSS) design. With a production rate of 5.78 L m^{-2} h^{-1} under the sun's illumination and more than 75% of the total production being collected through condensation, researchers experimentally demonstrated a record-high solar-to-vapor conversion efficiency of 385% using a low-cost and salt-free accumulation TMSS architecture. Additionally, to provide a thorough physical understanding and an optimisation principle for TMSS systems, their work significantly enhanced the performance of currently available passive solar desalination technologies for portable and affordable drinking water.

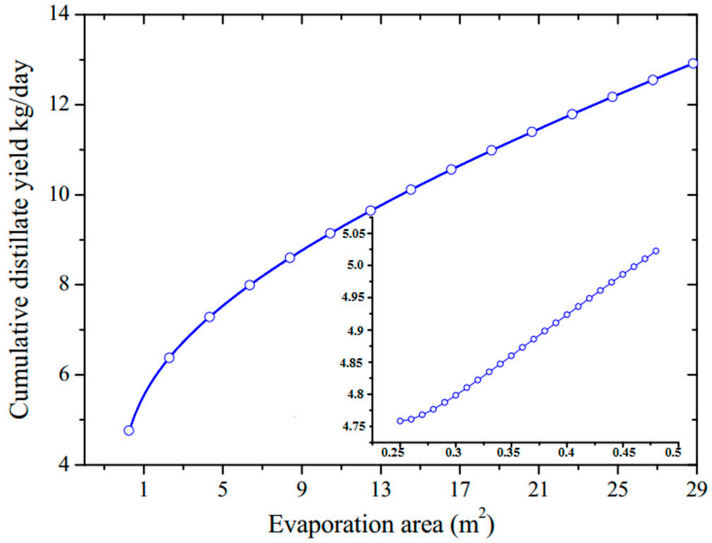

Figure 23. Impact of the increased evaporation size on distillation yield (stage 1) with a primary studied interval [61] (License Number: 5374100438125).

In 2022, Wang et al. [63] developed a solar hydroponic seeding unit paired with multiple interfacial distillate systems to produce crop irrigation water. The tubeless design was found to reduce the irrigation expenses. A four-stage desalination prototype was tested outdoors. Experimental findings confirmed the accuracy of a thermodynamic technique based on each component's energy and mass transfer connection. The model evaluated temperature, water creation, vaporization performance, GOR (gain output ratio), and optical and thermal losses. Increasing irradiation and decreasing interlayer distance improved evaporation efficiency and GOR. Under 1000 W/m^2 light, the ten-stage unit's GOR reached 2.64, and the first-stage unit's evaporation efficiency reached 84.2%.

In 2022, Wang et al. [64] developed a floating planting device powered by concentrated solar power. Desalinated freshwater irrigated hydroponic crops, saving land and using ocean resources. An experimental system was created with an optimised structure to study the impacts of operational factors on inlet temperature, water generation rate, GOR, and exergy performance. Desalination units' indoor steady-state temperature differential was found to increase with irradiance. With 900 W/m^2 irradiances, the system achieved 1.7 GOR and 6.1% exergy efficiency. Actual weather findings showed that the system's daily water production would hit 9.51 kg/m^2 day with azimuth tracking, 97% greater than passive operation.

In 2022, a solar-driven passive multistage distillation (MSD) apparatus with a practical salt-resistant construction was created by Cheng et al. [65] to allow the quick and automated exclusion of high-loading saline by a gravity drive. Experiments in the lab and computer simulations were used to perfect the construction. Consequently, the four-stage apparatus' consistent freshwater production rate reached 1.98 kg m^{-2} h^{-1} when exposed to a radiation intensity of 1 kW m^{-2}. The freshwater yield of the MSD device was 1.7 times larger than that of a device that did not have a salt-blocking structure. Thus, it can be said that the MSD device can function normally even when exposed to a significant amount of light, resulting in a greater yield of freshwater than that of a device that does not have a salt-blocking component. The unit could perform reliably at a high radiation intensity of 4 kW m^{-2} through a vaporization rate of 8.26 kg m^{-2} h^{-1}.

Table 5 shows a summary of studies outlined on multistage solar stills equipped with other devices.

Table 5. Review of studies outlined on multistage solar stills equipped with other devices.

Author	Location	Latitude	Multistage Solar Stills Type	Testing Period (h)/Radiation (W/m^2)	Method	Studied Parameters	Remarks
Feilizadeh et al. (2015) [59]	Shiraz, Iran	latitude 29°370′ N, longitude 52°320′ E	A basin-type multistage solar still equipped with solar collector.	February 25, March 12 and 13	Experimental	Impact of using the basin collector.	Adding a second or third collector resulted in production increases of 48% and 23%, respectively, during the summer months.
Feilizadeh et al. (2015) [60]	Tehran, Iran	latitude 35°32′ N, longitude 51°7′ E	Active multistage solar still.	July	Experimental	Effects of the amount and mode of input energy.	The productivity still only rose by 5–10% when TES was used.
Bait and Si-Ameur (2016) [61]	Batna city, Algeria	latitude 35°33′ N, longitude 6°10′ E	Multistage distillation system.	Average 971.22	Experimental	Geometrical configuration.	Because the yield follows a curved shape, it is possible to conclude that the amount of distillate rose even though the temperatures were lower.
Xu et al. (2020) [62]	Shanghai, China	latitude 31°13′ N, longitude 121°28′ E	Multistage solar stills	Min 200–Max 900	Experimental	The overall heat and mass transport in multistage solar stills.	Enhancing the overall heat and mass transport increases the flexibility of material choices for the TMSS design.
Wang et al. (2022) [63]	Guangzhou, China	latitude 23°7′ N, longitude 113°15′ E	Solar hydroponic seeding unit merged with multiple-stage interfacial distillate system.	Average 1000	Experimental and analytical	Radiation and layer gap.	Both the evaporation efficiency and the GOR have the potential to greatly improve with an increase in the amount of irradiation and a reduction in the amount of space between the layers.
Wang et al. (2022) [64]	Beijing, China	latitude 39°55′ N, longitude 116°22′ E	Drifting planting unit built on multiple stages increasing film extraction process operated by concentrated solar power.	Average 900	Experimental and numerical	Different operating parameters.	According to the actual weather, the system's daily water output could reach 9.5 $kg/m^2/day$ under an azimuth-following condition, which is 97% greater than the state of operation in which it is completely passive.
Cheng et al. (2022) [65]	Hangzhou, China	latitude 30°15′ N, longitude 120°9′ E	Solar-driven passive multistage distillation (MSD) unit with an efficient salt-resistant shape.	Average 900	Experimental and numerical	Impact of salt-blocking structure.	The MSD device produces a yield of freshwater that is more than 1.7 times greater than that of a device without a salt-blocking component because it can operate normally even when exposed to a significant amount of light.

3. Critical Evaluation of Studied Configurations of Multistage Solar Stills in Water Desalination

A type of water desalination device called a multistage solar still uses sun energy to transform saltwater or brackish water into fresh water. Multistage solar stills can be constructed in a variety of ways, including packed-tray multistage stills, flash distillation multistage stills, evacuated multistage stills, and multistage solar stills with heat and vaporization.

Packed-tray multiple trays can be placed on top of one another in multistage solar stills, and each tray has packing material to increase the surface area for heat transfer. A larger yield of fresh water is produced as water travels through each tray and is heated by solar energy before evaporating and condensing on the packing material in the following tray. The limited surface area of the packing material, however, places restrictions on the volume of water that may be handled in this configuration.

Flash distillation multistage solar stills are made up of a number of connected chambers, each with a different pressure from the one before it. Fresh water is created when the heated and vaporized water that results from the water flowing through the chambers is condensed in the chamber after it. Larger amounts of water can be processed with this setup, but maintaining the pressure differential between the chambers necessitates the use of an expensive vacuum pump.

Flash distillation multistage solar stills are comparable to evacuated multistage solar stills, but evacuated multistage solar stills have a vacuum-insulated container that lowers heat loss and boosts efficiency. This setup, nevertheless, is pricy and necessitates frequent maintenance.

A heat exchanger is used in multistage solar stills with vaporization and heat recovery to transport heat from the vaporised water to the incoming seawater. This system is expensive and requires a lot of maintenance, but it can reach high efficiency and has a lot of potential for expansion.

Overall, the decision to use a multistage solar still depends on a number of variables, including the cost, the required daily water output, and the accessibility of maintenance resources. To choose the configuration that will work best for a given application, it is critical to thoroughly weigh the benefits and drawbacks of each option. Furthermore, a critical evaluation of the multistage solar still configurations has assured the prosperity of "V"-shaped trays as the most effective method for producing purified water. These trays are less expensive and more practical than "floor" ("Λ"-shaped) trays, which require two collectors.

4. Recommendations for Future Directions

Based on the presented summary of Tables 1–5, the revised studies have paved the way for visualising the designs of multistage solar stills, thermal performance indicators, and water production cost. A set of recommendations for further research can be illustrated in the following:

1. The study made an effort to examine the novel configurations of multistage solar stills by examining their solar thermal efficiency, water production, and cost of distilled water; however, the analysis of energy and exergy was not specifically covered. Additionally, the complete cost of the multistage solar stills as well as their payback period were not addressed. These are the limitations of the current study that the following investigation should fully emphasize.
2. Though combining solar units with distillation units can be beneficial, the sustainability, financial, and ecological concerns of such units are still required to be assessed concurrently with advanced thermodynamic implements such as exergo-economic and exergo-environmental techniques. Further, the optimization of such units through implementing new development methods could have a significant advantage.

3. Recommendations for additional study are made to improve the projected multistage solar stills' level of preparedness, resulting in greater access to this technology for a broader population, particularly in isolated coastal areas.
4. To advance solar desalination technology, more research should be carried out, particularly in the areas of coupling with heat storage and diverse waste heat sources. Additionally, the effects of the most recent combinations of adjustments should be analysed to select the best designs of multistage solar stills that achieve the highest thermal performance at a reduced cost.
5. There has not yet been a comprehensive investigation of how climate change may affect the overall effectiveness of multistage solar stills. This study may assist in determining if using these technologies in certain regions of the globe is realistic.
6. The use of solar cells, Fresnel lenses, and electric heaters should increase the rate of evaporation.
7. By adding reflectors to direct additional sunlight towards the solar still, it is possible to increase the distillate output of the still by using a solar tracking technique, which is more efficient than using a stationary still.
8. Insulation is essential for preventing heat loss and keeping the solar still's temperatures high. The thermal efficiency of the still can be considerably increased by using high-quality insulation materials, such as foam or fiberglass.
9. Before entering the solar still, saltwater can be pre-treated to remove contaminants, such as suspended particulates or dissolved gases, and lessen fouling on the stills' surfaces. This can lengthen the still's lifespan and increase its water production.
10. The brine solution can be regularly circulated through the solar still using a recirculating system, which will promote more evaporation and condensation and boost the still's water productivity.
11. The productivity and efficiency of multistage solar stills can be considerably impacted by its design. To achieve the best performance, variables including the surface area, the separation between stages, and the spacing of the condensation surfaces should all be optimised.
12. A larger population would have easier access to these technologies as a consequence of the expected advancements in multistage solar still technology, especially in remote coastal locations. To increase the effectiveness of heat and mass transmission, it is very important to use inexpensive materials during the preparation phase.

5. Conclusions

This paper thoroughly analyses several multistage solar still designs, operations, and configurations. In this regard, from a wide number of theoretical and experimental studies of multistage solar stills, we can derive the subsequent conclusions:

1. The multistage distillation unit can operate steadily at high radiation, creating clean water that generates about 1.7 times higher than a unit without a salt-blocking formation.
2. Real weather conditions show that the regular water produced in the unit reaches 9.5 kg/m^2 for each day at a typical azimuth condition, which is 97% higher than the entirely passive function condition.
3. The evaporation process improved the productivity of latent heat and consumption in multiple-stage units.
4. The evaporation performance and GOR could be considerably enhanced by boosting radiation and reducing interlayer layout.
5. The high temperature of the saline solution provides a higher distillation and higher rates of GOR.
6. The water generation rate and the operation coefficient in the standard state increase as the unit temperature increases, whereas the operation efficiency passes one at 70 °C.
7. A solar still tray with V configuration of four floors is cheaper than the Λ shape, which needs double the collectors.

8. The unit's efficiency is inversely proportional to the pressure because the evaporation rates decelerate at the compressed condition.
9. Enlarging the solar collectors by 26% (at the constant inlet velocity of the water) enhances the unit thermal efficiency, solar percentage, and collected solar energy (during a year) by 23%, 18%, and 24%, respectively.
10. Generating clean water using a stable pressure is higher than the free pressure for the same irradiation intensity, and the water generation is directly proportional to the collector temperature.
11. The multiple stages of distilled water with homocentric growth evaporation and condensation processes can competently improve the latent heat of the steam and decrease the thermal losses and water dispersion challenge.
12. The distillate water is inversely proportional to the salinity. The best value of the stages, space between the stages, and the provided flow rate for the unit were detected as 4, 100 mm, and 55 kg/m^2 day, respectively, during the year.

In order to increase the effectiveness of the multistage solar stills, further research is required. This will make it easier for more people to utilise this technology, especially in remote coastal locations. Furthermore, the upcoming research should place emphasis on revising the economic perspectives of multistage solar stills, the payback period, and exergy and energy analysis.

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Abbreviations

GCC	Data Gulf cooperation council
GHG	Greenhouse gas
MSST	Multistage stacked tray
PTC	Parabolic trough collectors
CBA	Collector over basin area
TMSS	Thermally localized multistage solar stills
GOR	Gain output rate
TES	Thermal energy storage
SMDCMD	Solar-powered multistage direct contact membrane distillation
CFD	Computational fluid dynamics
PCM	Phase change material
CPC	Compound parabolic concentrator
BR	Brine recirculation
DASC	Direct absorption solar collector
MSD	Multistage distillation

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