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THE LATEST DEVELOPMENT IN WATER DISTILLATION: A REVIEW

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ABSTRACT. The global freshwater demand production is steadily growing due to demographic expansion and industrial expansion. The utilization of desalination technology is experiencing a rise in order to fulfill this growing demand. SSs, a type of desalination technology, possess the advantages of low maintenance and affordability. Nevertheless, their productivity is constrained. This paper aims to offer an extensive examination of different classifications of SS. This includes an analysis of designs that are both passive and active, as well as both single- and multiple-effect variations. Additionally, the paper will explore various enhancements aimed at increasing productivity, such as the implementation of reflectors, mechanisms for storing heat, fins, collectors, and techniques for improving thermal and fluid transport. The inclusion of greenhouse and photovoltaic-thermal SS is additionally encompassed within the scope of this study. The capabilities of PCM in improving performance are highly encouraging, suggesting the need for future research in these and related domains to promote wider adoption of SS technology.

KEYWORDS: Solar stills; Development; Productivity; Distillation.

1. INTRODUCTION

Insufficiency of water poses a significant worldwide dilemma. According to projections, by 2025, approximately 25% of the global population is expected to encounter water scarcity, while approximately 66% will face water-stressed conditions. According to a study, it is estimated that by 2030, approximately 50% of the worldwide populace will encounter significant hydrological scarcity [1]. Currently, regions in Africa are facing significant hydrological scarcity, impacting approximately 31% of the populace. Asia, America, and Europe follow this, where Severe water scarcity affects 25%, 7%, and 2% of the population, respectively [2-5]. The utilization of desalination is increasingly significant in addressing the need for potable water.

Numerous techniques exist for the desalination of seawater and brackish water. The category includes a range of techniques such as flash distillation, multi-effect distillation, membrane distillation, reverse osmosis, forward osmosis, ion exchange, capacitive deionization, electrodialysis, and seawater greenhouse technology [6,7]. The energy needed for desalination can be obtained from either traditional fossil fuels or alternative sources of energy such as biomass, wind, solar, geothermal energy, or industrial waste heat. SSs possess several advantages within the realm of solar desalination, namely their simplicity, affordability, ease of maintenance, and minimal ecological footprint. Nevertheless, it is important to acknowledge that these technologies also possess certain drawbacks, notably their subpar performance, which acts as a deterrent to their widespread adoption in commercial settings.

SSs function on the basis of the principles of evaporation and condensation. Solar energy is utilized to evaporate the brine contained within the SS, resulting in the collection of condensed water as the output of purified water. Within a dual-or multi-effect SS, the procedure above is iterated in a manner that utilizes the heat generated during condensation to facilitate a subsequent evaporation phase. The utilization of multiple effects has been observed to enhance performance; however, it is accompanied by a concomitant cost penalty. The utilization of dynamic elements, such as pumps and fans, presents an alternative approach to enhance performance; however, it also entails certain drawbacks in terms of increased expenses and heightened intricacy.

The quantification of a SS's performance can be assessed through the metrics of efficiency and productivity. The efficiency of a singular-effect still can be described as the proportion of stored thermal energy contained in the water that has been condensed to the overall quantity of solar energy that is received by the still. The concept of instantaneous efficiency pertains to the efficiency observed within a brief time interval, typically lasting 15 minutes. On the other hand, overall efficiency refers to the efficiency observed over the entire duration of a day. Productivity refers to the daily water yield per unit area of a SS. The level of production of a simple passive SS varies from approximately 2 to 5 liters per square meter per day. Therefore, a minimum area of 1 square meter is necessary to meet the fundamental requirements of an individual [8]. The following evaluation centers on the extant and developing methodologies aimed at enhancing the efficiency of SS. Numerous scholarly articles have been published on the topic of SS, particularly focusing on aspects such as creation and advancement [9-12], efficiency optimization [13-17], type of wick [18], and simulation [19]. However, the latest advancements, which encompass the utilization of novel materials like PCMs and nano-composites, hold the potential for substantial enhancements in efficacy. Consequently, this necessitates a comprehensive reassessment. In this paper, we provide a current and thorough examination of the latest advancements in SS technology.

This review examines various operating and design parameters that influence both efficiency and productivity. The impact of certain factors, such as weather and depth of water, on active and passive SSs is similar. Consequently, these aspects will be collectively examined within shared themes in Segment 2. In the subsequent segments, namely Segments 3 and 4, we proceed to examine the distinct parameters that influence the performance of stills, both passive and active, in the order mentioned. Segment 5 of this study examines SS designed in the style of greenhouses, which encompass active and passive variations.

Additionally, segment 6 provides an overview of the anticipated impact of emerging materials on the future advancement of SS technology. Segment 7 pertains to the economic facets. Ultimately, the concluding segments, namely segments 8 and 9, encompass the final remarks and suggestions for prospective endeavors.

2. KEY FACTORS INFLUENCING THE EFFICIENCY OF SS

2.1. WEATHER CONDITIONS

The primary climatic characteristic that impacts production is solar radiation intensity. Under the assumption of constant efficiency, daily productivity will exhibit a direct proportionality to sun irradiation, and the unit of measurement is kilojoules per square meter per day (kJ/m2.day). Nevertheless, the performance is also influenced by factors such as wind speed and ambient temperature. Tiwari et al. (2014) evaluated the impacts of different meteorological circumstances in distillation systems, active and passive, and showed that wind enhanced the execution to an identical threshold velocity of 4.5 meters per second, past which the output stayed consistent [20]. The reason for this phenomenon is that wind facilitates the process of heat transfer from the cover, leading to an increase in condensing up to a certain threshold velocity. Beyond this critical speed, the augmentation of condensation becomes minimal [21,22].

2.2. DEPTH OF WATER

In their study, Sourabh K. N. et al. (2021) employed various methodologies to enhance the performance of SS by optimizing water depth. They reported that the system exhibits high efficiency and produces a significant amount of distillate when operating at a shallow basin water depth of 1-2 cm. The productivity levels during workdays and non-workdays vary based on the depth of the basin water. The design, operation, and climatic parameters exert a substantial influence on the performance of a still. The relationship between salt concentrations in basin input water and productivity indicates that lower salt concentrations are associated with higher levels of productivity. The thermal performance of a stagnant liquid can be enhanced by incorporating NPs with different water depths. The utilization of paraffin as a PCM in SS has demonstrated its significance over alternative materials owing to its advantageous physical, chemical, and economic characteristics, which contribute to enhanced safety and reliability [23].

S.K. Singh et al. (2021) inferred that the SS's production exhibits an upward trend as the basin depth decreases, with the most favorable water depth falling within the range of 3 to 4 cm. Greater water depth leads to heightened nocturnal production as a consequence of its heightened heat-retention ability. The enhancement of productivity can be achieved through an elevation in the inlet water temperature, while the impact of wind speed on production is significant up to a crucial threshold. The efficiency of a system is also influenced by ambient temperature and solar radiation. The velocity of droplets is influenced by the angle of inclination of the cover's glass, which is calibrated at ±10◦ in relation to India's latitude [24].

3. PASSIVE SSs

A passive SS refers to a system whereby the processes of evaporating and condensing occur spontaneously. Passive SSs may be classified based on several factors, such as the structure and components of the evaporator (including wicks), alternative methods of storing heat, as well as the forms, and the quantity of basins. The utilization of numerous basins or wicks may facilitate the implementation of multiple-effect distillation, resulting in significantly increased production. First, we will begin by examining the fundamental principles of the SS, followed by an exploration of the several approaches available to optimize its efficiency.

3.1. SIMPLE SS WITH A SINGLE DISTILLATION PROCESS

The fundamental form of passive still, known as the single-slope, single-basin SS , serves as a benchmark for comparing more sophisticated designs. Numerous research has been conducted on the subject, exploring different factors such as the material type, the inclination of the glass lid, the cooling mechanism, the material employed within the SS for absorption purposes, the chemical makeup of the water used for feeding, and the kind of basin lining [25-30].

The impact on performance is influenced by the selection of materials, as shown by Panchal's (2011) study, which included conducting trials with several kinds of SS, such as those made of aluminum and galvanized iron. The study revealed that the aluminum SS exhibited a greater distillate production of around 3.8 liters per square meter per day. In comparison, the type of galvanized iron only produced 2.6 liters per square meter per day. This disparity in performance was attributable to the enhanced heat conductivity of the aluminum material [25].

The angular tilt of the glass surface exerts a substantial influence on several measures, including the output and the efficacy at any given moment. Nevertheless, various researchers arrived at disparate results regarding the most favorable disposition. While it may be proposed that the angle of inclination must be equivalent to the angle of latitude, this alignment needs to be regularly seen in the conceptual and empirical research that has been documented.

According to reference [26], the effectiveness of the system improves as the temperature of the incoming water supply rises. Zurigat (2010) examined the efficacy of an SS equipped with a double glass covering, including brine preheating and cover cooling. The study unveiled a significant improvement in efficacy as a result of an escalation in the rate of evaporation, leading to an increase in efficiency of up to 25% [27]

The overall productivity of the still is influenced by the makeup of the feed water used.

The output of single-basin stills is subject to variation based on the type of basin liner employed.

Several scholars have conducted studies to analyze and define the thermal capacity and transference of heat coefficients in SS. Rabbar (2013) observed the relationship between the rate of heat transfer through evaporation and convection is contingent upon the temperatures of the glass and water [28]. In their study, Narjes et al. (in 2011) modeled the solar desalination still's heat transfer coefficient using computational fluid dynamics. Their findings indicated that the rate of potable water generation remains relatively stable across varying radiation heat transfer coefficients. However, they observed that the water's temperature and the presence of a glass lid exerted an influence on this rate [29]. Sivakumar et al. (2015) conducted a conceptual analysis of a single solar slope, concentrating on the effects of the glass lid's and basin's heat capacity. According to the study, a decrease in the heat capacity of the glass cover and basin led to a 10.38% overall increase in yield.

Additionally, there was a drop in the destruction of exergy for the glass and basin, with reductions of 7.53% and 15.84%, correspondingly [30]. The study concluded that there exists an inverse relationship between heat capacity and production.

In conclusion, the output of a SS with a single-effect design varies between 2-4 liters per square meter per day for a basic iteration but can reach 3-5 liters per square meter per day for enhanced editions featuring upgraded basin liners or optimized geometries. The relatively modest numbers have compelled researchers to propose additional design alterations, which will be elaborated upon in the following discussion.

3.2. SOLAR REFLECTORS

One potential strategy for enhancing production involves augmenting the incident solar radiation captured by the SS. This task can be accomplished by employing a reflector. In their study, Hiroshi (2011) conducted trials utilizing a SS with a single basin equipped with both reflectors that are located inside and outside. Research has indicated that the production of distillate can be enhanced by adjusting the angle of the outer reflector, namely by tilting it rearward in the summer and onward in the other periods [31,32]. In a study conducted by Boubekri (2011), the author utilized numerical modeling techniques to investigate the effect of incorporating reflectors located inside and outside of SS. The objective was to assess the resulting increase in productivity, which was found to be 72.8 percent [33]. The overall conclusions indicate that maximum allowable tilt angles for both exterior and interior reflectors should not surpass 25°. Additionally, the optimal angle of inclination for the glass lid varies between 10° and 50° depending on the time of year.

3.3. SS WITH A WICKED AND STEPPED-BASIN DESIGN

Alternative methodologies encompass enhancing the transfer of heat and mass within the apparatus in order to augment earnings. One illustrative method involves the utilization of Wicks and stepped basins, which effectively enhance the retention and dispersion of evaporating water, hence resulting in an enhanced evaporation rate. The methodology, as mentioned earlier, has primarily been employed in single-basin distillation systems. Numerous study investigations have been conducted pertaining to thermal energy storage and exergy analysis in the context of SSs of the stepped type. Halimeh et al. (2013) performed a comparison study on the efficiency of energy and exergy of a cascade SS with a stepped design. The study revealed that the maximum energy efficiency achieved was 83.3%, while the maximum exergy efficiency reached 10.5%. The study revealed a clear relationship between solar irradiation and the brine temperature of brine water with the changes in energy and exergy. The presence of poor exergy efficiency indicates a significant degradation of exergy and a missed chance to generate valuable output. This decline was mostly associated with the absorber plate, therefore emphasizing its potential for enhancement [34].

In a study conducted by Agouz (in 2015), the stepped SS was enhanced by implementing a perpetual stream of water and utilizing a wick of cotton. The results demonstrated a significant improvement in productivity, with a 48% increase seen. In a study conducted by Samuel (2015), various wick materials, including wool, Jute fabric, cotton, nylon, coir mate, charcoal fabric, sponge, and water coral fleece, were tested. The findings indicated that water coral fleece exhibited superior performance compared to the other materials [35]. In a study conducted by Mahdi (2011), a SS with an inclined wick design was built and constructed. The use of a charcoal wick led to a substantial rise of around 53% in the daily productivity percentage [36]. The findings of this study indicate that the implementation of wicks and stepped evaporators has the potential to enhance production by a range of 20-53%.

3.4. FINS

The inclusion of fins at the base of an SS enhances its functionality by augmenting the heat transfer rate from the basin to the water [37]. Omara (in 2011) performed a series of experiments using traditional, ribbed, and grooved distillation apparatus. It was revealed that the still equipped with fins resulted in a 40% increase in production, while the corrugated still only yielded a 21% improvement compared to a standard still [38]. The research, as mentioned above, also demonstrated a positive correlation between the height of fins in a SS and its productivity, whereas a negative correlation was observed between fin thickness and production. Additionally, it was found that an excessive number of fins may lead to a decline in output.

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3.5. THERMAL ENERGY STORAGE

An alternative method for enhancing execution is the utilization of thermal energy storage. Storage of thermal energy media can assimilate thermal energy during periods of intense solar radiation and subsequently discharge the stored thermal energy when the radiation level diminishes. The SS has the potential to operate beyond sunset. A range of materials has been employed to accomplish the storage of both latent and perceptible heat. Several studies have explored placement strategies for heat storage materials, including those below the water surface, immersed within the basin, and underneath it.

3.5.1. Effective heat storage

Dudul Das et al. (2020) defined various methodologies to improve the efficiency of SS and increase distilled water production. Key aspects include modifying absorber plates, integrating condensers, using reflectors, incorporating dehumidification units, incorporating thermal energy storage materials, and implementing thermoelectric coolers. The majority of research was concentrated in the Middle East, Asia, and Europe, but several studies have been made in the Netherlands and the United Kingdom. Some significant findings include incorporating baffles to enhance water residence time within basins, allowing for increased water temperature and accelerated evaporation. Sponges are suitable materials for solid-state applications due to their high absorptivity and permeability. Integrating reflectors and condensers in basins can improve efficiency and output, especially in areas with low solar irradiance. An external reflector can adjust tilt angles to accommodate different seasons, and tracking mechanisms aligning with the sun's movement can enhance system output. Thermoelectric glass cover cooling can improve SS efficiency, but it is crucial to consider cost implications. Cuprous oxide NPs have shown enhanced efficacy in distillate output, and combining them with active systems like hoovers can significantly enhance productivity. PCM infused with NPs can also enhance SS efficiency, producing distilled water at a cost comparable to bottled water. Paraffin wax and sand can be highly efficient heat storage mediums in solar systems, mitigating overall costs [39].

Certain substances can simultaneously store heat and absorb optical radiation. In a study conducted by Pankaj (in 2013), the impact of a buoyant permeable absorber within. The basin of a singular slope SS was examined both experimentally and theoretically. The outcomes demonstrated that a modified still setup yielded approximately 68% of the distillate yield. These findings align closely with the outcomes reported by Velmurugan [40], who investigated an SS consisting of only one basin and one slope, featuring a stepped design incorporating thermally efficient material for storing heat. Prior research has focused on the incorporation of an SS with rooftop thermal energy storage, resulting in stated production levels of approximately 3.5 liters per square meter per day [41,42].

A SS with a single basin and a double slope was built using feasible materials for storing heat energy, such as quartzite pebbles, red brick pieces, cement concrete pieces, washed stone, and iron scraps, according to research done by Kalidasa et al. (in 2010). The researchers concluded that the use of quartzite rock resulted in the maximum production, as indicated by their findings [43]. In their study, Kalidasa et al. (2011) conducted further research on the utilization of different wick materials and the determination of the minimal water mass required in the SS [44].

3.5.2. Latent heat storage

The utilization of PCM enabled the attainment of latent heat storage. The effects of earlier upgrades on Egypt's energy efficiency, production costs, and pure water productivity were studied by Mohamed Abdelgaied et al. (2022). Saving money on water production while improving sustainability, economic feasibility, and competitiveness can be achieved by utilizing solar heat and waste heat in desalination systems. The cost of producing pure water drops from 6.80 \$/m3 to 1.6 \$/m3 when compared to grid electricity-based systems, and the permeation rate of pure water increases as the input water temperature increases. From 46.6% to 61.8%, system efficiency is enhanced with a pre-cooling unit on the permeate flow loop. With an estimated improvement rate ranging from 33.11% to 43.18%, PCM improves pure water productivity. By raising the cumulative yield by as much as 43.2% and the output ratio by as much as 34.4%, thermal storage materials improve the overall efficiency and productivity of membrane distillation units. Multi-walled carbon nanotubes (MWNTs) are added to improve water flux, but salt rejection efficiency is decreased. With rates of 40.98% and 57.4%, respectively, the solar collector for preheating input water significantly improves pure water productivity. Pure water production costs only 0.0102 \$/L with this method, and the productivity of SSs can be increased by up to 116% with NF and 105.5% with thermal storage materials, particularly PCM [45].

Shahin Shoeibi et al. (2021) undertook an empirical investigation of several configurations of SSs during a four-day experimental period in Tehran (35◦41' N, 51•19'E) focusing on the utilization of porous absorber surfaces, nano-enhanced PCM, and nano-coatings. The absorber porous media utilized in this study was a bed of anthracite with a homogeneity coefficient of 0.0013 m. To increase the ability to conduct the heat of PCM, paraffin wax was supplemented with aluminum oxide and copper oxide NPs at concentrations of 0.1% and 0.3%, respectively. Furthermore, the CuO NPs were included in the black dye solution at a concentration of 10%. This mixture was then applied to the 12 pipes made of copper, aiming to improve both heat conductivity and solar intensity absorption. They discovered that in every instance of SSs, the benefit-cost ratio was more than unity. When compared to conventional SSs, the daily energy efficiency of the SS using CuO (0.3 wt%) nano-enhanced PCM showed a 55.86% improvement. CuO and Al2O3 nano-enhanced PCM's melting temperatures decreased by 2.1 and 1.8 degrees Celsius, respectively, and by 2.7 and 2.3 degrees Celsius, respectively, at concentrations of 0.1% and 0.3%.

When compared to saline water, the application of nano-coating on the copper pipes enhanced the quality metrics of distilled water, such as TDS, EC, TSS, turbidity, and pH, as well as thermal conductivity and solar intensity absorption [46].

T. Arunkumar et al. (2019) investigated the use of solar absorbing materials, including metallic, semiconductor, and carbon-based materials, in the photo-thermal conversion process in China. These materials effectively promote the evaporation of diverse aqueous solutions, such as seawater, artificial seawater, water from rivers, highly acidic water, and alkaline wastewater. The exceptional efficacy of plasmonic metals is attributed to the local surface plasmon resonance effect (LSPR). At the same time, carbon-based materials achieve enhanced heat retention, both of which play a significant role. The compounds Cu2O, Al2O3, SiO2, ZnO, TiO2, and carbon nanotubes (CNTs) were examined in solid-state systems (SSs) to enhance the thermal conductivity with bulk water. PCMs were discovered to improve energy storage capacity in SSs, but they have limitations, such as limited thermal conductivity and the need for appropriate encapsulation. NPs (NPs) were mixed into paraffin wax to improve heat transfer properties, resulting in lower melting and solidification temperatures for PCMs. Additional materials such as fins, pebbles, cotton cloth, and jute wick were incorporated into SS to increase evaporation surface area, and it was discovered that energy-efficient materials had a significant capacity for solar absorption, exceeding 96% and superior performance in minimizing heat loss when compared to energy exchange and storage materials. However, placing NPs inside liquids or incorporating them into black paint resulted in a slight increase in evaporation rate [47].

In their study, Omar et al. (2013) carried out trials using an SS equipped with PCM situated below the basin. The researchers observed that the inclusion of PCM resulted in improved productivity and efficiency of the SS. However, the study needed to provide precise performance data that would allow for meaningful comparisons. The efficacy observed in this study was comparatively higher than the reported efficiencies of Rahim (47.2%) and Zurigat (25%) [48,49]

In their study, Mohammad et al. (2011) conducted a thermal evaluation on an SS with a stepped design that incorporated a PCM consisting of paraffin wax positioned below the absorption plate. This integration of PCM resulted in enhanced SS output. Additionally, it was noticed that the time of residence increased as a result of the water distribution on the evaporation surface [50].

In their study, Swetha et al. (2011) carried out scientific investigations involving a solar single-slope still that utilized PCM consisting of the acid Lauric positioned underneath the basin. Their findings revealed a notable increase of up to 36 percent in distillate production [51]. This contrasts with the results reported by Silakhori (2011), who suggested that paraffin wax and acetamide exhibit greater stability in this context (refer to segment 6). In summary, latent heat storage has demonstrated superior performance [52], and it is advisable to choose PCM with a relatively low melting point, approximately ranging from 30-45^0 degrees Celsius [53], to align with the lower temperature range for operation often associated with passive stills. The optimal placement for the medium for thermal preservation is situated below the basin, while the most suitable components for this purpose are acetamide and paraffin.

3.6. NON-TRADITIONAL FORMS

The standard SS exhibits a rectangular shape when viewed from above and a trapezoidal shape when viewed from the side. Nevertheless, several other geometries have been documented for their application in passive SSs, as elaborated in subsequent segments [54-70].

3.6.1. Triangular stills

Multiple scholars have undertaken a range of assessments of triangular SSs, including thermal analysis, exergy analysis, and parametric analysis. The optimal production of the pyramid glass cover is achieved at an angle of 50°. In their study, Kianifar et al. (2012) performed an exergy assessment on a photovoltaic desalination system with a pyramid design, comparing its performance with and without the use of a fan positioned alongside the glass. The study revealed that the evaporation rate exhibited an increase in the system equipped with a fan. Additionally, the daily production experienced a notable enhancement of approximately 15-20%, while the exergy efficiency had a positive correlation with lower water depths [55].

A parametric analysis was undertaken by Ahsan (2014) on a passive triangular SS. The study involved the manipulation of water depth and several environmental conditions. The study suggested that there is a negative relationship between water depth and production on a daily basis [56,57]. Ravishankar et al. (2014) carried out experimental investigations within a triangular pyramid still and subsequently analyzed the various aspects that influence its performance. The study suggests that the highest level of productivity was observed at the lowest water depth, and it is implied that a wind velocity of approximately 4.5 m/s is necessary to generate a 15% improvement in output (refer to segment 2) [20].

Triangular SS has also been implemented in conjunction with reflectors. In their study, Arunkumar et al. (2010) conducted research on the thermophysical parameters of a pyramid-shaped SS equipped with mirror boosters. The investigation involved measuring the thermal conductivity and dynamic viscosity; the values obtained were 29.64 × 10-2 W m-2 C-1 and 20.2 × 10-6 N s m-2, correspondingly [58]. One notable discovery derived from the conducted research is that the distillate output shows a significant increase from 1.52 to 2.9 liters per square meter per day when using the mirror booster.

The overarching finding suggests that while triangular SSs may enhance productivity on some days, their year performance is not advantageous due to losses of radiation.

3.6.2. Tubular stills

Tubular SSs are created with the aim of streamlining the construction process. In their study, Amimul et al. (2010) developed a mathematical model for a tubular SS. The model incorporated thermal and fluid dynamics phenomena and introduced new equations to account for the presence of humid air in addition to the usual equations. In a study conducted by Zhili (2013), an experimental investigation was conducted using three tubular SS. The results indicated a direct relationship between the temperature and the output; as the temperature rises, the yield also increases [59]. In research carried out by Rahbar et al. (2015), The coefficient for convection heat transfer and output of water were analyzed utilizing computational fluid dynamics. The findings suggest that there is an inverse relationship between the temperatures of the glass and water, which impacts the overall performance of the system [60].

Regarding the material used for the cover, Amimul et al. (2012) performed trials on a cylindrical solar distillation apparatus outfitted with polyethylene film. The researchers made modifications to the trough arrangement and also investigated the creation of a direct correlation between coefficients of heat transfer and coefficients of mass transfer [61]. The implementation of a thin polythene sheet resulted in a notable enhancement of the mean cumulative coefficient of mass transfer due to condensation, reaching a value of 305 W/m2K. Consequently, this improvement positively impacted production levels.

3.6.3. Hemispherical stills

Hemispherical covers have been employed to enhance the solar energy absorption of the SS. Arunkumar et al. (2012) performed an empirical study on a hemispherical SS by contrasting its functionality in the presence and absence of water flow across the cover. A study revealed a significant improvement in efficiency when water flow was present in a still, with a 42% increase compared to a still without water flow, which only achieved 34% efficiency [62]. The efficacy achieved by Aboul [43] in SSs with two or three basins with a pyramid lid is similar to the result obtained. When comparing the efficacy of a hemispherical SS to Panchal's standard slope single-basin SS [33], The efficacy of the hemispherical SS is superior. The main conclusion about hemispherical sun stills is that increasing the depth of the water decreases both output and efficacy. Additionally, the rejuvenating impact enhances the amount of distilled water produced. Enhanced performance could be achieved by incorporating a reflector into the still, therefore warranting more investigation.

3.6.4. Multiple slopes

Similar to hemispherical SSs, SSs with multiple slopes are capable of harnessing sunlight from different angles. Several experiments were conducted on SS with dual inclinations to examine heat storage, explore different parameters, analyze the coefficient of heat loss, and consider the impact of orientation.

Parametric variation is crucial for optimizing system efficiency. Researchers have examined several characteristics, including architecture, functional, weather-related, and non-dimensional variables.

Rahul and his colleagues (2011) determined the characteristic equation for a dual slope passive SS by employing non-dimensional variables, including immediate effectiveness. Subsequently, they performed experiments on the distillation apparatus under the environmental circumstances prevailing in Delhi. The results indicate that non-linear characteristic curves exhibit greater precision compared to linear characteristic curves [63]. Hanane et al. (2012) performed studies utilizing an SS with a dual incline to desalinate saltwater. They investigated different operational parameters, including the temperature of water and glass. It was deduced that a greater thermal gradient between water and glass resulted in an increased output, producing an output rate of 4 liters per square meter per day [64].

Rajamanickam et al. (2012) completed an experiment using a double slope SS to investigate how the water level affects the coefficients of inner thermal and fluid dynamics. The output of 3.07 liters per square meter per day was found to be higher at a depth of 0.1 m. However, this result contradicts the findings of Hanane (2012), who claimed that the double-slope SS produced 4 liters per square meter per day [65]. Trad et al. (2013) performed an analysis of comparison of a symmetrical SS with a double slope and an asymmetrical SS. A study demonstrated that a SS positioned asymmetrically in a north-south alignment is more effective than a symmetrical one with a double-slope design [66].

The primary conclusions regarding the basic dual-incline solar distillation apparatus are that in order to maximize efficiency, it is crucial to maintain an optimal water depth and ensure that the still is asymmetrical with a north-south alignment.

3.6.5. Vertical stills

SSs are commonly designed in a horizontal configuration, where the horizontal dimensions greatly surpass the vertical measurements. Vertical SS, characterized by their tall structure, have additionally undergone evaluation. The examination of diverse factors, for example, the introduction of saltwater, the temperature at which the still releases output, the surrounding temperature, the temperature of the glass lid, and the outcome of the still, demonstrated that the system's effectiveness was affected by solar radiation, the surrounding temperature, and the alignment of the solar panels [67]. Additionally, it was noted that the utilization of a flat plate reflector resulted in an enhancement of productivity [68]. Nevertheless, the implementation of many divisions in a vertical SS has resulted in a productivity of about 3.45 liters per square meter per day [69,70]. The SSs listed are, nevertheless, far more limited in scope than other varieties. Single-basin regenerative stills with Jute fabric; single-basin stepped stills; single-basin triangular stills; double-slope stills; triple- and double-basin stills; and double-slope stills with revolving cylinders and condensers are a few examples of SS designs. However, as compared to the single-basin triangle SS with fan and mirror booster, the productivity of the single-basin greenhouse-type double-slope SS is higher. Vertical SSs usually have low outputs and are best suited for particular uses where a compact footprint is required.

3.7. PASSIVE SSS WITH MULTIPLE EFFECTS

Utilizing the heat of condensation, multiple-effect SSs can greatly improve efficiency by repeatedly evaporating water. Multi-effect SS can be categorized as either multi-wick or multi-basin.

3.7.1. SSs with multiple wicks

Sodha et al. (1981) examined an SS equipped with many wicks and covered with blackened, damp jute fabric to capture the maximum radiation from the sun. The evaluation relies on Dunkle's relationship and demonstrates a maximum efficiency of 34% for SSs with multiple wicks. This represents a four percent rise in efficacy compared to the type of basin still [71].

3.7.2. Multi-basin SSs

Additional studies examine the efficiency and output of multi-effect SSs employing numerous basins. Sangeeta et al. (1998) used an abstract framework that relied on ordinary differential equations to ascertain that the optimal quantity of basins in a reversed absorber still is 7 [72]. Tanaka (2002) conducted an experiment with an SS that utilizes multiple-effect diffusion coupling and is equipped with a reflector located near the base to determine the impact of the inclination angle. The findings indicated that the distillate yield was 13% higher compared to a traditional SS [73,74]. The ideal tilt angle for a multi-effect system situated in Muscat, Oman, with a latitude of 23.61°, has been calculated to be 23° [75]. In their study, Hilal et al. (2004) conducted a comparison between one-basin and multiple-basin stills to assess their productivity. They found that the multi-basin still had higher productivity, which they attributed to the reduction of thermal dissipation in the bottom basin due to the presence of the top basin [75]. In Sebaii's (2002) study, the output of a triple-basin SS of a three-basin SS was evaluated. It was determined that the daily productivity of the still exhibited an inverse relationship with the amount of water in each basin [76]. The productivity reached a value of 12.6 liters per square meter per day [77], surpassing that of any still, single or double. The yield and efficacy of a SS with two plastic basins were found to be very low [78] [79]. Madhlopa et al. (2009) Conducted an investigation to assess the impact of a condenser within an SS with multiple effects. They concluded that the final product of the altered still was 62 percent greater compared to that of the conventional still [80].

Utilizing multi-effect SSs is advised to optimize profits. The drawback lies in the amplified maintenance endeavor and expenses commonly linked to the supplementary basins.

Fig.1 summarizes the average productivity of different passive types SSs.

4. ACTIVE SSS

Active SSs incorporate supplementary elements, such as solar collectors, condensers, coolers, or other mechanisms, to enhance their efficiency. Generally, the operation of this equipment necessitates the use of pumps, fans, or other energy-driven devices. Active SS, in contrast to passive SS, usually necessitates the utilization of energy.

4.1. SOLAR COLLECTORS

External solar collectors can be utilized to augment or substitute the outer layer of the still's collector. The source material outlines the subsequent utilization of diverse categories of collectors.

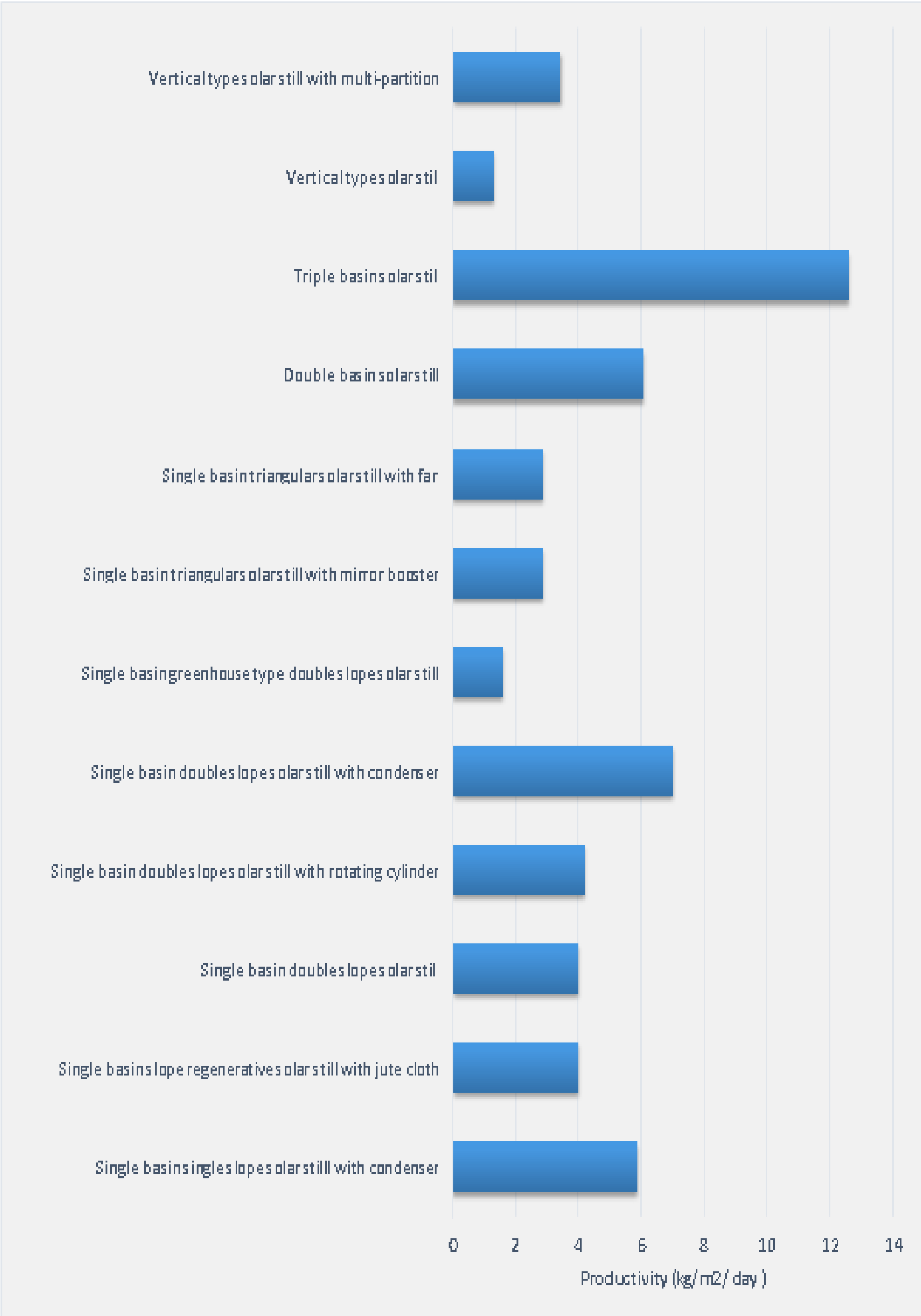

Fig. 1. Productivity of different passive types SS

4.1.1. Flat plate collectors

Utilizing a collector amplifies the amount of heat supplied to the still, thus necessitating the augmentation of produced thermal energy to facilitate condensation. This process has been accomplished utilizing a humidification tower and a condensation lid. In their study, Farhad et al. (2015) examined the exergy and energy of a photovoltaic desalination system using a flat-plate solar collector. They conducted an experimental and theoretical analysis. Their findings revealed that extending the height of the humidification tower resulted in a decrease in exergy efficiency. Additionally, they observed that exergy efficiency increased when the ambient air temperature decreased and the diameter of the tower decreased [81].

The performance of the SS may be influenced by its shape, similar to passive SSs, albeit in a distinct manner. Arslan et al. (2012) performed trials utilizing different types of SSs, including circular box SS, rectangular box SS, and single tube SS combined with a solar collector. According to the evidence, the circular box SS demonstrates higher efficiency than a cylindrical tube or rectangular box [82]. In contrast, the results for passive SSs indicated that the most optimal form was rectangular. This is capable of being attributed to the decreased surface area of the circular box, resulting in lower heat loss.

In addition to passive SSs, external collectors have been employed in conjunction with various performance enhancement methods, such as evaporators with multiple levels or stages, reflectors, and thermal energy storage materials. Rajaseenivasan (2014) combined a flat plate collector with an altered SS that included Jute fabric and obsidian gravel. This modification was aimed at improving the rate at which the still evaporates and its capacity to store heat, resulting in a 60% increase in distillate production compared to the conventional version [83]. Boubekri discovered that the output of distilled product is higher in a SS with a single basin and a single slope, featuring a Jute fabric and a flat plate collector in comparison to a singular basin and slope SS, along with a collector. In their 2012 publication, Kabeel et al. conducted an experimental investigation and theoretical representation of a flat-plate collector stepped evaporator (Fig. 2) for desalination purposes. The study indicated that preheating the feed water slightly improves productivity, but it significantly decreases system efficacy [84]. Badran et al. (2007) created a setup for the experiment using a SS with one slope and a mirror attached to the inside, linked with a flat plate collector, and boosted the production by 36 percent [85]. However, Badran's SS with mirror [85] had lower productivity in contrast to a SS that has only one basin and one slope, and utilizes a flat plate collector [86,87].

Various researchers have employed interior collectors, in addition to external collectors, to enhance heat transfer efficiency. The primary discoveries regarding the utilization of flat plate collectors indicate that incorporating reflectors and a copper condensate shield enhances the rate at which evaporation occurs and improves the general efficacy of the system of desalination.

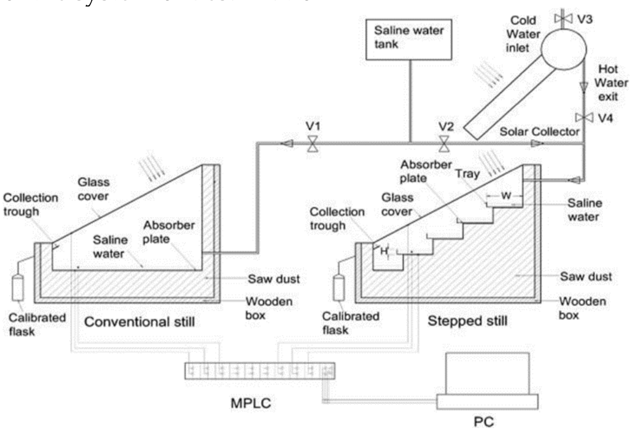

Fig. 2. Visual representation of a stepped SS system with a single basin and a collector [84].

4.1.2. Evacuated tube collectors

The evacuated tube collector is made up of many glass tubes with absorber surfaces inside. A SS with a single slope design and a forced-mode evacuated tube collector was built by Shiv et al. (2014). Using the combined model increased both temperature and yield. The achieved energy efficiency was roughly 33.8% [88]. The efficiency of an SS with an integrated collector and evacuated tube was compared to a conventional model in research by Eugenio et al. (2007). Comparing the integrated model to the traditional model, the researchers found that the integrated model produced less fresh water [89].

4.1.3. Solar ponds

The solar pond is divided into three distinct regions: a top convective region, a non-convective region, and the bottom convective region. The solar pond serves as a reservoir for thermal energy. Integrating a solar pond with the still facilitates the preheating of the feed water, leading to a rise in profits. Multiple researchers endeavored to assess the efficacy of solar ponds equipped with distillation apparatuses in relation to various alterations. As indicated subsequently. Sebaii et al. (2011) investigated the heating effectiveness of a functional singular basin SS that was linked to a small solar pond. It was discovered that this system exhibited superior productivity and efficiency in comparison to a conventional still. Furthermore, they determined that this system could serve as a source of boiling water for multiple purposes [90].

4.1.4. Concentrating collectors

A solar concentrator captures solar radiation over a wide surface and concentrates it into a smaller receiver area. This solar concentration will enhance the desalination process within the still. A study has been conducted to examine the correlation between the velocity of the air, surrounding temperature, intensity of sunlight, and performance and production. In their study, Javad et al. (2011) conducted an experiment using concentrators linked to active SS. They discovered that the production of freshwater decreased as wind speed rose but rose with higher environmental temperature and radiation of the sun [91]. In her study, Zeinab (2014) conducted examinations on solar desalination. Utilizing an altered configuration that involved a parabolic trough concentrator for solar energy. The results showed an improvement in productivity yield of approximately eighteen percent [92,93].

Scientists furthermore experimented with concentrators equipped with thermal storage of energy. Arunkumar et al. (2013) constructed a SS that was connected to a concentrator, both with and without PCM. The productivity output experienced a 26 percent boost when using the PCM [94].

Arunkumar (2011) conducted a study that demonstrated enhanced production as a result of utilizing the concentrator [95]. In their study, Farshad et al. (2010) examined a SS that was connected to a concentrator and a heat reservoir. The purpose of this system was to provide fresh water even during periods of low sunlight, such as at night or on cloudy days [96]. During the overnight period, a water production of 12% was noted.

The general conclusions of SSs with concentrators indicate that the rate of output per hour of the still can be enhanced by including PCM.

4.1.5. Air heater

Connecting an air heater to the solar distillation system enhances the temperature of the water in the basin, so accelerating the evaporation rate. In their study, Sampathkumar et al. (2012) examined different active SSs and determined that the inclusion of an air heater resulted in a production boost of up to 70% [97]. The productivity of this system is significantly greater when compared to systems that utilize flat plate collectors, evacuated tube collectors, and concentrators. To enhance production, SS has undergone design revisions, including the incorporation of heat storage and water spraying mechanisms, along with the addition of an air heater. In order to examine the impact of thermal preservation, Abdulha (2013) carried out a test using a SS with a stepped design equipped with a solar thermal energy storage and solar air heating.

Additionally, Abdulha suggested a technique to enhance the execution by including an aluminum infill as a thermal energy storage medium located below the absorber. The study revealed that the combination yielded a 53 percent increase in earnings compared to a traditional setup [98]. In a study conducted by Zahaby et al. (2011), they conducted an experiment to enhance the efficacy of SSs equipped with air heaters. They achieved an efficiency of 77.4% utilizing a reciprocating water supply system [99]. The main conclusions drawn from these studies indicate that the integration of an air heater into a still system leads to increased efficiency and production, but only when accompanied by arrangements for storing thermal energy and spraying water.

Younes et al. 2022 [100] carried out an extensive review of the techniques for reducing the losses of the back walls in solar stills. In their thorough review, they discussed, clarified, and evaluated state of the art about the many methods—such as spinning wicks, vertical wicks, drums, trays, discs, and so on—that are employed to lower losses in the rear wall of solar distillers. The relevance of rotating parts was illustrated by a variety of outputs, including the following: drum distiller (9.22 L/m2/d & 350%), moving wick solar still (9.17 L/m2/d & 315%), vertical disc distiller (16.5 L/m2/d & 617.4%), and vertical wick distiller (7.2 L/m2/d & 154%).

Finally, Fig. 3 shows the average ratios of the enhancement of Productivity through Different Active SS Types. Besides, Table 1 presents a comprehensive examination of SSs discussed in this paper. It displays the primary categorization, alterations made, the percentage increase in output resulting from the modifications, and the ultimate daily productivity achieved (if data is available).

5. AN ECONOMIC EVALUATION OF SSS.

Several researchers have determined that the utilization of SS for desalination is a cost-effective method [5-7]. Although there are many research publications on SS, only a small number of them incorporate cost evaluation of any kind. The costs differ significantly based on the geographical location and the accessibility of construction supplies.

6. CONCLUSIONS

Sun stills utilize sun energy to evaporate water directly, offering a straightforward method of solar-powered desalination. Nevertheless, the objective of deploying SSs on a commercial level continues to be challenging primarily due to their restricted production capacity. In order to achieve successful implementation, researchers are actively exploring various advancements in SSs, focusing on factors such as operation requirements, construction, setup of the system, and supplies.

Climatic variables are operating conditions that are not directly controlled by the creator but can impact the placement of the SS. The velocity of the wind has a positive correlation with output until it reaches 4.5 meters per second, beyond which there is no additional augment. One more important factor to consider is the water depth, which should ideally be minimized while ensuring there is enough water to prevent the still from becoming dry. The output can also be affected by the temperature and quality of the feed water. The maximum anticipated production from a basic single-effect SS, when parameters are optimized, is approximately 5 liters per square meter per day. The output can be augmented by utilizing wicks or absorbers, such as Jute fabric or black granite pebbles. However, those adjustments have consistently failed to produce productivity exceeding 6.5 liters per square meter per day.

When it comes to conformation, it is prudent to select the appropriate angle's inclination regarding the glass. Nevertheless, another research produced somewhat varying suggestions: the slope angle is occasionally selected to be equal to the latitude angle, while in other cases, it exceeds this value. Unorthodox forms, for example, a variety of slopes, including tubular, hemispherical, and triangular stills, have undergone testing — excluding exhibiting evident benefits. The incorporation of fins, grooves, and particulates such as pebbles can effectively promote heat transfer and enhance the efficiency of SS. These improvements can include the use of carefully chosen materials to implement improved optical absorbance, thermal insulation, and thermal energy storage. The introduction of nanomaterials combined with PCM shows considerable potential for thermal energy storage, and latent heat storage is generally superior to sensible heat storage. The thermal storage media can be positioned in relation to the basin in a variety of ways, offering a multitude of combinations in addition to the extensive range of PCM choices. The melting point of the PCM and the water's temperature should be taken into consideration while selecting a PCM. Most researchers chose paraffin, which has a melting point below 60°C, as their PCM. Placing the PCM exactly beneath the basin liner is the best method.

Applying active and multi-effect ideas results in the highest improvement in SS performance. The collection of solar energy for evaporation and the distribution of heat for condensation are the two main limitations of the result. A range of solar energy collectors, including evacuated tubes, solar ponds, and flat plate collectors, can be utilized to enhance performance. When compared to conventional stills, a solar-pond-equipped SS exhibits an 80% boost in productivity, making it an especially intriguing option. These innovative concepts typically call for the use of pumps and fans, which frequently require electricity, raising expenses and complicating problems.

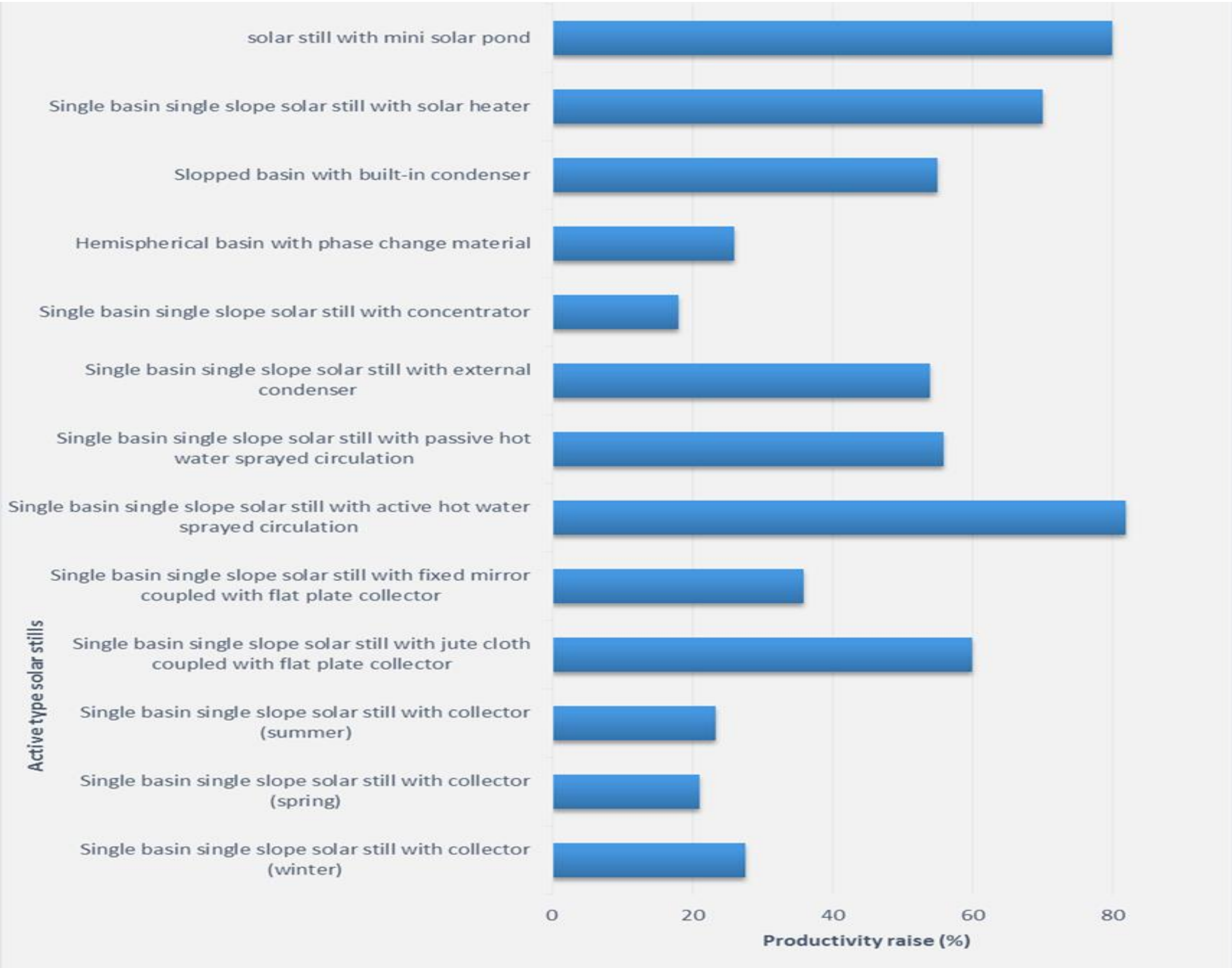

Fig. 3. Enhancement of Productivity through Different Active SS Types

Table 1. A comprehensive examination of SSs discussed in this paper. It displays the primary categorization, alterations made, the percentage increase in output resulting from the modifications, and the ultimate daily productivity achieved (if data is available)

Authors	Classification	Modifications	Location	Latitude Longitude	Increase in output (%)	Productivity (L/m^2.day)	Observation / Findings/ Advantages
Sourabh Kumar Nougriaya et al. [23]	Passive and active SS	Coupling the SS with FPC (Fiber Reinforced Plastic)	Vasudevanallur, Tamil Nadu, India	9.25°N, 77.4333°E.	35	2.920 L/m2.day	The correlation between the depth of water and the efficacy of SSs emphasizes the need for optimal water depth for maximum distillate yield. They suggest design modifications and material improvements to enhance performance while preserving sustainability.
S.K. Singh et al. [24]	Passive and active SS	the use of black rocks, coated and uncoated sponges, incorporation of dyes, vacuum technology, heat-storing materials, and the use of reflectors.	New Delhi, India	28.6139°N, 77.2090° E	305%	13.692 L/m2.day	SSs' productivity can be improved by adjusting design parameters, insulation thickness, operating conditions, absorbing materials, and PCMs. Increasing insulation thickness can increase efficiency by 7% to 180%. Absorption materials and PCMs can also improve basin absorptivity.
Panchal et al. [25]	Singular effect passive	The basin liner is made of aluminum SS and galvanized iron.	Ahmedabad India	23.0225° N, 72.5714° E		3.8	The use of galvanized iron type SS resulted in higher production due to an increase in thermal conductivity.

Authors	Classification	Modifications	Location	Latitude Longitude	Increase in output (%)	Productivity (L/m².day)	Observation / Findings/ Advantages
Rajamanickam et al.[27]	Passive with a singular effect	A cooling system consisting of an individual basin with a dual glass cover.	Muscat, Oman	23.5880° N, 58.3829° E	20		The efficiency was enhanced by preheating the water and then cooling the cover of glass.
Hiroshi Tanaka. [31]	Passive	Internal and external reflectors	Fukuoka, Japan	33.5902° N, 130.4017° E	48%		The addition of both internal and external reflectors proved to be more productive than solely adding an internal reflector.
Boubekri et al. [33]	Singular effect passive	Solar reflectors	Constantine Algeria	36.3570° N, 6.6390° E	72.8		The optimal output requires an inclination angle of less than 25^{O}.
Samuel et al. [35]	Singular effect passive	Diverse wicks	Tamil Nadu, India	11.1271° N, 78.6569° E			Water coral fleece is the most effective material for wicking.
Madhi et al. [36]	Singular effect passive	Angled wick	Karbala, Iraq Tamil	32.6027° N, 44.0197° E	53		Enhancement of evaporation rate.
Dudul Das et al.[37]	Passive SS	The implementation of a cogeneration system that combines a combination of SS with semitransparent PV modules, evacuated tube collectors, and a PV/T integrated distillation system for the production of	Jordan	31.9522° N, 35.2332° E.	23% -285%	2.31 L/m2.day - 9.02 L/m2.day	various solar distillation methods, including baffles, sponges, reflectors, condensers, thermoelectric glass cover cooling, cuprous oxide nanoparticles, and PCMs, highlighting their ecological suitability and efficiency.

Authors	Classification	Modifications	Location	Latitude Longitude	Increase in output (%)	Productivity (L/m².day)	Observation / Findings/ Advantages
		water and power.					
Pankaj et al.[40]	Passive	Single slope with permeable absorbers	Allahabad, India	25.4358° N, 81.8463° E	68	2	Because of the porous absorber's low thermal inertia, a higher operating temperature is achieved.
Manivel et al. [41]	Passive	Heating system for roofs	Tamil Nadu, India	11.1271° N, 78.6569° E		4.5	Because the feed water temperature is raised by roof heating, the evaporation and condensation process extends into the night for an additional couple of hours.
Kalidasa et al. [43]	Singular effect passive	Diverse wicks	Tamil Nadu, India	11.1271°N, 78.6569° E			A more efficient heat storage material than red brick pieces, cement concrete pieces, washed stone, and iron scraps.
Mohamed Abdelgaied et al.[45]	Passive SS	The use of thermal storage materials and preheating technologies	Tanta, Egypt	30.7865° N, 31.0004° E	116%	6.97 L/m2.day	The study reveals that nano-zeolite can enhance water permeability, salt removal rates, thermal efficiency, and cost-effectiveness in membrane distillation systems. This leads to increased productivity, higher purity, and reduced operational expenses, making it a crucial factor in advancing environmentally friendly desalination technologies.
Shahin Shoeibi et al.[46]	Passive SS	Utilizing anthracite media in saline water enhances the absorption of solar energy.	Tehran, Iran	35°41' N, 51°19' E	55.8% and 49.5%		Using porous media and nano-coated copper pipes in solar desalination significantly improved water productivity, energy efficiency, and environmental benefits. The investment was financially feasible, leading to a favorable economic outcome.
T.Arunkumar et al.[47]	Passive SS	The use of oil serpentine loops, external solar collectors, and	Kunming, China	24.8797° N, 102.8332° E			Carbon-based nanomaterials, metallic nanoparticles, and porous polymers effectively capture solar radiation, enhancing productivity and water transport

Authors	Classification	Modifications	Location	Latitude Longitude	Increase in output (%)	Productivity (L/m².day)	Observation / Findings/ Advantages
		nano-encapsulated PCMs					in solar desalination systems, thereby promoting sustainable and environmentally friendly technologies.
Omara [48]	Passive	Corrugated with fins SSs	Egypt	26.8206° N, 30.8025° E	The value for finned is 40, while the value for corrugated is 21.		Finned SS is more efficient than regular and corrugated varieties.
Mohammad Dashtban et al. [50]	Passive	Using PCM in a cascade solar system	Zahedan, Iran	29.4519° N ,60.8842° E		6.7	The efficiency of the still was enhanced by the incorporation of PCM.
Kianifar et al. [55]	Unconventional	Triangular	Mashhad, Iran	36.2972° N, 59.6067° E	20	3.1 2.9	Increased exergy efficiency is achieved at shallower water depths.
Arunkumar et al. [58]	Unconventional	Triangular with mirror booster	Tamil Nadu, India	11.1271° N, 78.6569° E			The low annual productivity is a result of the radiation losses.
Amimul et al. [61]	Unconventional	Tubular SS	Selangor, Malaysia	3.5092° N, 101.5248° E		5	The temperature differential between the water and the glass cover determines the rate of water production. The heat transfer coefficient for evaporation is higher than that of convection.
Hanane et al. [64]	Unconventional	Multiple inclines	Tipaza, Algeria	36.5907° N, 2.4434° E		4	The SS must have an asymmetrical structure oriented from south to north.
Minasian et al. [67]	Unconventional	Vertical floating SS, wick type	Baghdad, Iraq	33.3152° N, 44.3661° E	43		Wicks were made of jute. Results were 85 percent higher than those of basin-type SSs.
Hiroshi et al. [69]	Passive with multiple effects	Various effects of using mirror	Fukuoka, Japan	33.5902° N,130.4017° E		35	Productivity derived from predictions is 50% higher than productivity derived from experiments.
Sebaii et al.[70]	Unconventional	Vertical SS	Tanta, Egypt	30.7865° N,31.0004°		4.2	At least 3.5 square meters is ideal for vertical SS.

Authors	Classification	Modifications	Location	Latitude Longitude	Increase in output (%)	Productivity (L/m².day)	Observation / Findings/ Advantages
				E			
Sodha et al.[71]	Passive with multiple effects	Various wick types	New Delhi, India	28.6139°N, 77.2090° E	34	2.5	All surfaces exposed to sunlight will be perpetually moist in this configuration.
Tanaka [73]	Passive with multiple effects	Utilising a reflector to achieve multiple effects	Fukuoka, Japan	33.5902° N, 130.4017° E	13		The optimal inclination angle for a multi-effect solar still is 23 degrees.
Hilal et al.[75]	Passive with multiple effects	Dual and single-effect	Muscat, Oman	23.5880° N,58.3829° E		6	Double-effect SSs offer a greater level of output compared to single-effect SSs.
Cappelletti [78]	Passive with multiple effects	Plastic	Foggia, Italy	41.4622° N,15.5446° E		1.8	The yield rate and productivity could be much higher, making it not advisable.
Madhlopa [80]	Multi-effect passive solar stills	Utilizing a condenser achieves multiple effects.	Blantyre, Malawi	35.005° E 15.786° S,	62		These types of SS exhibit increased productivity at the expense of higher maintenance costs.
Arslan [82]	Active	Open cycle mode with multiple active stills	Yozgat, Turkey	39.8210° N, 34.8086° E	12.37	When compared to rectangular boxes and single tubes, circular box SS produces more yield.	
Rajaseenivasan et al.[83]	Active	A flat plate collector integrating jute fabric and black pebbles.	Tamil Nadu, India	11.1271° N, 78.6569° E	60	5.7	The rate of evaporation and the heat capacity of the still both increased.
Badran et al.[85]	Active	A flat plate collector with a mirror.	Amman, Jordan	31.9539° N, 35.9106° E	36		The productivity was significantly lower when compared to the solar system with a flat plate collector.

Authors	Classification	Modifications	Location	Latitude Longitude	Increase in output (%)	Productivity (L/m².day)	Observation / Findings/ Advantages
Shiv et al. [88]	Active	Forced mode operation of an evacuated tube collector	Delhi, India	28.613° N, 77.209° E	3.9	For best results, maintain a water depth of 0.03 meters and a mass flow rate of 0.06 kg/s.	
Zeinab et al.[92]	Active	A parabolic trough with only one inclination.	Cairo, Egypt	30.0444° N, 31.2357° E	18		The productivity of the system exceeds that of traditional stills.
Shiva et al. [93]	Active	Stand-alone point focus	Tehran, Iran	35.696° N, 51.423° E	5.12	Productivity is unaffected by air temperature or water salinity.	
Arunkumar et al. [94]	Active	A concentrator that is connected to copper balls filled with PCM.	Tamil Nadu, India	11.1271° N, 78.6569° E	26	4.4	This research employs Paraffin as PCM.
Tabrizi et al.[96]	Active	Using a sandy thermal storage	Zahedan, Iran	29.4519° N, 60.8842° E	75		It was possible to achieve distillate yield even during the night using a heat reservoir.
Sampathkumar et al.[97]	Active	Air heater	Tamil Nadu, India	11.1271° N, 78.6569° E	70		The rise in temperature of the water in the basin directly correlates with an increase in the rate of evaporation.
Abdullah et al. [98]	Active	Stepped solar	Tanta, Egypt	30.7865° N, 31.0004° E	48		The use of a cooling cover improves the efficiency of SS.

7. Potential Areas for Research in the Future

The overview mentioned above proposes the subsequent research directions:

- Potential future investigations could involve the integration of diverse NPs with PCM beneath the basin. This could enhance the efficiency of water yield, thermal qualities, and heat transfer characteristics and enable continuous freshwater production even at nighttime.
- To minimize radiation loss of the glass in a triangle SS, building techniques must be innovatively employed.
- The program for modeling and simulating SSs must be designed considering the stated parameters.
- Glass is commonly employed as the enclosure in the majority of stills; however, the upkeep of glass can be burdensome.
- Additional investigation can be conducted to substitute the glass with a different materials while maintaining the same level of performance.

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