Potable Water Production by Single Slope Active Solar Distillation Unit—A Review

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Abstract A solar energy operated still unit, i.e., SDU is a recommended system which is much suitable to treat the brackish water with the use of heat of the Sun. The process of distillation is same as nature makes rain. The earliest use of solar systems for the purpose of water treatment was liberally used in 1551, and further the corresponding advanced still was used in 1882 by Arab alchemists and Charles Wilson, respectively. So, they started the new age of potable water production techniques and quite useful as the whole world facing the water scarce situations which are becoming more severe day by day. In this study, a wide classification and review of published research work have been done that is based on the concentrated and vacuum-type tube collectors connected solar still systems. This article covers various modifications which have been made in single slope distillation unit especially based on the compound parabolic concentrator and evacuated tube collectors.

Keywords Solar still · Single slope · Water productivity · Water yield

1 Introduction

The current situation in the world is quite tough in terms of the water quality and water quantity both because population is growing very fast, and the corresponding demand for the potable water is proportionally increasing day by day. So, the inhabitants are directly or indirectly related to this worse situation related to the water supply and demand. As the naturally available water is limited to reach as well as limited to use, the used water is further released in the form of brackish water in large quantity that also contaminates the freshly available water to our nearby sources. So, it is quite necessary to overlook such kind of aspects, i.e., the large amount of brackish water

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should be treated to make it a pure one in parallel occurrences, and solar still system is a quite suitable technology for that purpose [1]. In this field, many works have been done like reviews for the economy perspective and payout times, etc. [2], different performing observations related to the system efficiencies [3], newly reveled system performances [4, 5], conventionally simple design stills and its performances [6, 7] and further advanced designs that has implementation of various efficient materials along with or even without nano-formed metal oxides and its applications in still systems [8, 9]. The evacuated tube collectors (ETC) integrated systems are one of the interesting systems due to its better performance appearance in the system in terms of the higher-temperature establishment and corresponding increase in the distillate as well, and same observations have been studied by many researchers [10, 11]. In addition to these observations, some additional elements having concentrators associated with the system have been analyzed by the researchers [12, 13] and also reviewed for material conscious economic analysis [14] and performances of different stills [15].

Such solar systems in a larger scale are used in many countries for the generation of potable water and electricity as well such as USA and Arab countries had been established with solar energy conditioned water plants having 400 m^3 in a day potable water production capacity [16]. Solar still systems have better results and also more pure than the water obtained from other systems such as reversed osmosis water [17]. Further, solar still system performance is directly based on the solar exposure incident over the basin, and it was found that the roof over type SDU with diffuse operated channels performs better rather than conventional one as this design is much capable of maintaining higher basin temperature [18].

The better performance of the system will be further optimized by utilizing effective number of solar collectors, exposed basin area, etc. [19] In consequence with the increase in collector numbers, corresponding increase in the yield output appears but this increment will be interrupted after the optimized value of the yield output from the system. Further, a solar system has been developed to treat the most saline water, i.e., warmer seawater and found the system performance gets doubled and tripled at 25 and 45 °C. Such performance of the system was because of the combined effect of the atmospheric temperature, wind velocity, solar exposure (basin area) and the solar intensity over the system [20]. It is also recommended that the use of latent heat available to the water vapor can be further utilized to improve the systems performance [21].

It has been observed that for large annual freshwater, the most favorable inclination dedicated to FP solar receivers are twenty degrees and fifteen degrees for the still glass covers [22]. Better values of freshwater production appear during the months of April, May and October; this is due to favorable meteorological conditions. As one increases the mass of water, net yearly output will decrease due to the storage effect. Also, a solar system will be improved in its performances under the intensified solar insolation and by using a radiative cooling system [23]. A limitation related to the performance observed is representing the decrease in its overall efficiency for the corresponding increase in the systems temperature as comprised to the basin temperature. This is so because, improvement in the stills temperature also increases the thermal losses of the still toward the atmosphere of either sides. The still productivity also improves by increasing the ambient temperature, as it improves the overall system performance and greater temperature difference in between the water and ambient.

So, above all, the remotely located areas of societies will suffer the conventional power supply to operate the electrical appliances also, these areas are mostly unavailable, and supply generated by fossil fuels is very costly too. Hence, the distillation units should use an alternate source of energy such as energy from the Sun. Being the conventional water purification processes energy demanding, Bourouni et al. [24] have offered an analysis on a new system for water treating under the consideration of air vapor condensation (AEC) in association with solar thermal receivers. By coupling a distillation unit functioning by AEC with solar units, they have optimized the unitary cost of the pure water.

The objective of present study is to review the single-phased SDU and ETC, CPC or concentrators associated solar stills and based on material conscious performances. And, based on the review, a confined conclusion with suggestive future scope has been given.

2 Merits and Demerits of Solar Still

2.1 Merits

a. The solar-powered systems are almost free regarding maintenance.
b. The passively operated units are generally free from moving parts and vice versa for active solar stills and accordingly maintenance cost applies.
c. The mineral values are quite less, so better in use to such respective applications, otherwise for the drinking purpose it is required to add sort of mineral amounts as compared to others.
d. Yield produced for the given area is appreciably high in case of active SDU.

2.2 Demerits

a. Yield produced for the given area is quite low in case of passive SDU.
b. Maintenance cost is high for active solar still systems.
c. The vapor leakages are quite general for the system at its joints.
d. The maintenance personals are usually system known one, that is why it is easy to operate.

3 CPC Inbuilt Systems

The CPC inbuilt systems are highly concentrated devices due to converging ability of the distracted solar energy toward the targeted basin areas where the water masses are supposed to be evaporated for the distillation processes. This segment is specified toward the applicable combinations in the presented solar inbuilt systems with CPC as follows.

The efficient system as shown in Figs. 1 and 2 has been analyzed for its feasible performances in association with the CPC and FLR for the large water production in the large-scale potable water production power plant along with power generation as well. They have selected many typical sites within these partner countries. As the compound parabolic concentrator (CPC) has better reflectivity for a typical solar angle that can be focused on the focal point of the parabola, the concentrated heat is the main concern the system [25].

Further, a still system in association with CCC, TSS, as shown in Fig. 3 has been studied and also compared with the conventional systems on yield basis and found the better results for the combinations of CCC concentrator assisted to the system. The result was better due to the higher concentration ratio occurrences in these combinations [26].

Then, CT-SDU associated still system was studied, and integration of PCM makes the overall system more effective in terms of the appreciable performing parameters. So, PCM improves the system's performance due to its heat absorption and corresponding heat recovery nature in off shine time [27].

Fig. 1 Parabolic trough collectors [25]

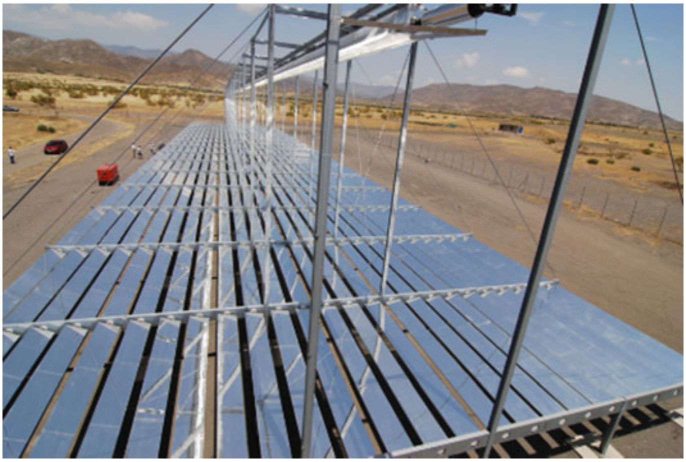


Fig. 2 Linear Fresnel reflector [25]

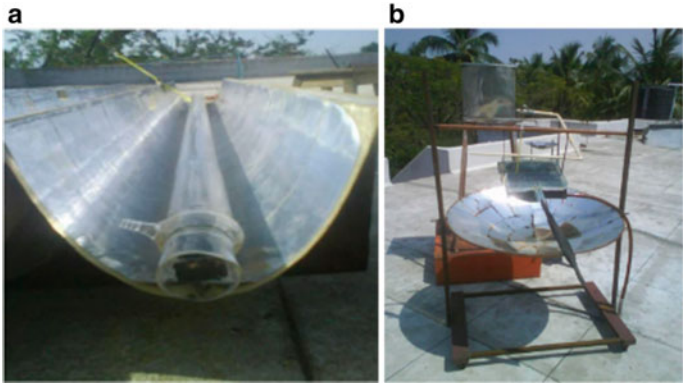


Fig. 3 **a** CCC solar still [26], **b** CPC–TSS-SDU [26]

The further corresponding study related to the TS, CPC and CTS in association with the still systems has been represented in Fig. 4 that shows the confined concentration of solar energy toward the still water. The system associated with CPC-CT to the pyramid structured still produces the better results as compared to the other combinations, as the larger area provided by the cover helps the improved yield output [28].

After that, a system with fractional covering of with PVT and integrated with the CPC has been analyzed for its lifetime operation, payback time, etc., for the double slope covering systems. Based on the observations, the single-phased still shows the inferior results than the -aced solar stills, as the still preferably double-faced system offers the extended area as well the larger water mass supports the performance of the system [29].

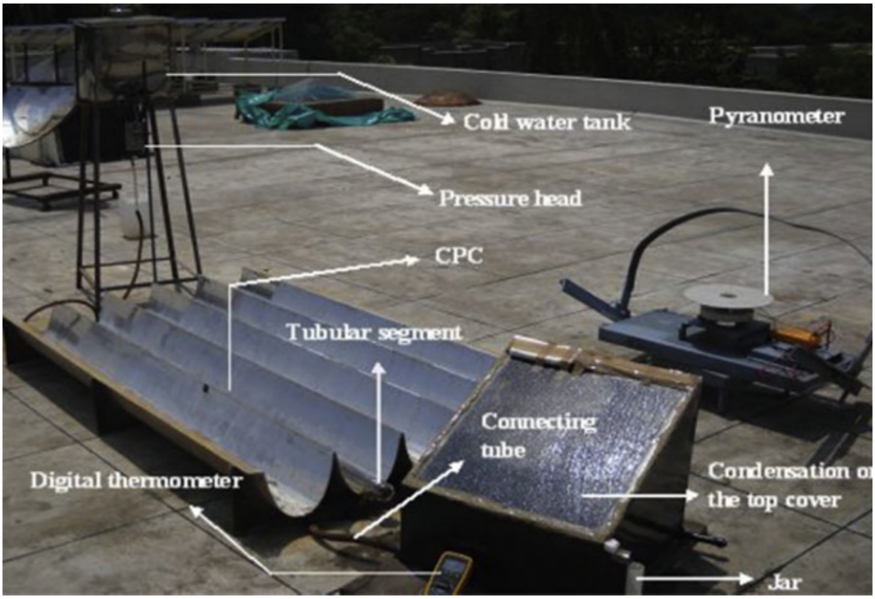


Fig. 4 CPC-CTSS-SDU [28]

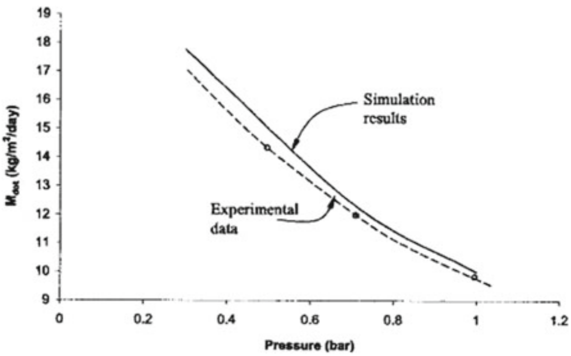
Moreover, the systems associated with the PV modules and concentrators of parabolic profile attached to stills have been observed to find the optimum yield performance and corresponding energy and exergy performances through the system. Based on the observed values of the system, it is easily predicted that the double exposed cover still system performs better having the optimum water height into the basin as 0.31 m or somehow greater than that and performed results are better due to the higher capabilities of sensible heating of the water and further utilization of it in the corresponding production of potable water.

4 ETC Inbuilt Systems

The ETC inbuilt systems are highly performed devices due to converging ability of the distracted solar energy toward the targeted basin areas under the confined tubular chamber of evacuated cross section where the water masses are supposed to receive the accumulated heat for the distillation processes. This segment is specified toward the applicable combinations in the presented solar inbuilt systems with ETC as follows.

In this context, a multi-step or staged basin system equipped with the confined tubular section having the evacuated section inside attached with the still system as shown in Fig. 5 was analyzed and compared with a conventionally operated solar still system and found the appreciable amount of distilled water into the collection jar.

Fig. 5 Yield versus internal pressure curve



The results are so observed due to the efficient heating of water inside the ETC tube and successfully conveyed to the basin water for the further desalination process, and also the result was so because evaporation rate is lower at high pressure [30].

And Fig. 6 shows a still connected with ETC having the heat reconsideration aspects inside the still system that improves the overall system performance as well considerably [31]. Further, it has been observed as the system runs properly within the daytime and increased output appeared for the peak solar radiations toward that system, and advanced improvement in the system's performance in terms of yield appeared while the cold water overflowed to the covering of the system [32] as the cold water increases the intermediate temperature differences between two surfaces, i.e., water and glass.

After that still with ETC connection as referred in Fig. 7 represents a sophisticated combination of separate solar water heater interconnected with still chamber for the further utilization of hot water in desalination purpose. The combined system is

Fig. 6 Five-staged SDU-ETC [31]

Fig. 7 Solar still assisted ETC heat chamber [33]

deliberately performing the simultaneous operations related to water heating and desalination processes efficiently. And, the results obtained by this system have been matched with experimental values. It is noticed that the temperatures and yield have been enhanced [33].

Later on, still system with ETC and different types of PCM materials, its combinations and performing comparisons has been done in this study as represented in Fig. 8. In this study, it is an experimental type, and results are in favor of the black color or black basin linear. The result was so improving due to the better heat receiving and storing capabilities in comparison with others, and this system is also capable of desalinating the high saline water with high efficiency [34].

Then after, a new design of solar still that consists of ETC integrated a heat absorbing capable pipe inside it and recommended as a new version of ETC, i.e., with heat pipe and much more sufficient in instant solar heat receiving and as well as heat transmitting for the further use of desalination processes. This system results comparatively better output with higher efficiency as well as the corresponding distillate productivity under the solar peak hour conditions [35].

Also, a new design assisted a vacuum or low-pressure generating pump system assisted to the still system of two-side facing or opened to receive the solar radiations inside the basin chamber. The value addition due to low-pressure generating pump and the overall performance of the system improves accordingly. Further, the additional heat absorbing materials like stole gravel or pebble make the overall system a step ahead in the performance and corresponding yield in comparison with other systems of combinations. It also concludes the calcium stones which gives thew highest freshwater output due to the good porosity of stones by which more solar energy is stored [36].

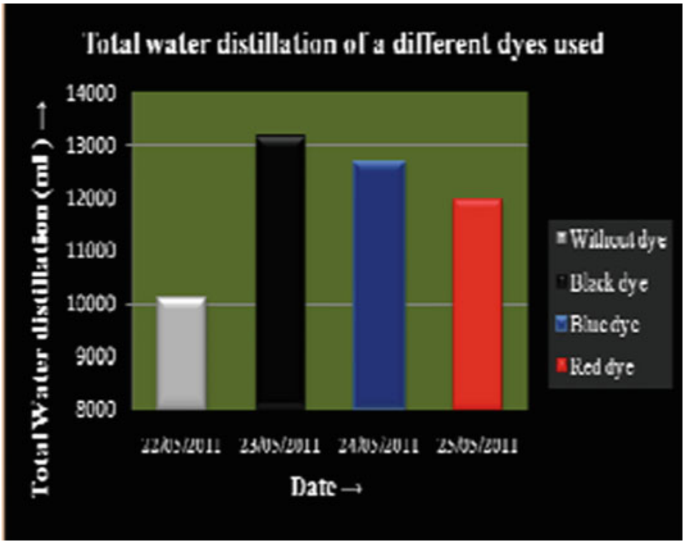


Fig. 8 Total water distillation using different dyes [34]

Further, a multistage still design assisting five numbers of staging steps in the basin chamber along with the parallel operated solar collectors along with the system has been modeled and analyzed and found more productive yield than other still systems or the combining still systems. Further, as the result was quite high, so the economy of the system and the productive cost of the yield appeared appreciably low in comparison with others [37].

Finally, a serried combinations of different still systems have been analyzed experimentally under the associative combinations of ETC, inclined stepped basin chamber that has a capability to remove the excessive or over floated salt or deposited salt over the basin water [38]. Also, Singh and Samsher [39] analyzed the energy matrix and enviroeconomics for the solar still associated with ETC and found better results with less ill effects on environment due to lower CO_2 emissions and lifelong working due to self-sustainability. Further, Singh and Samsher [40, 41] observed for different combinations of ETC in SDU and recommended better future for such associations to improve the overall performance of the system with further study of active solar stills [42] in view of performance improvements related to the overall system.

5 Conclusion and Future Scope

So, the present observations are clearly representing that there is a research gap for the utilization of self-sustainable use of these technologies or in a passive scenario for the production of potable water. However, a concise review of SDU incorporated with ETC and concentrators has been discussed. As of importance point of view, both the elements are its own specialty depending upon the material utilized to make it smarter in the respective field.

CPC can produce higher heat due to concentrating the solar heat from a wide area to a focused absorber but higher heat has a drawback of higher heat losses. On the other hand, ETC has least heat losses in terms of radiation losses only due to its evacuated glaze layer fabrication, and the smart selective absorber coating sandwiched in between the glaze or moreover coated over the inner glaze outer surface of the tube makes the system much effective.

The overall system must be installed in such a way that gives the optimum performance of each elements utilized in it with least heat losses. Suitable materials should be adopted that have sensitive response toward heat transmission without any system disturbances as thermal expansion, heat absorption, chemical reaction or other side effects on the system that affects the system performance directly or indirectly. Moreover, the passive solar stills have much more capabilities to make the operations easier for a long period of time due to low maintenance, less embodied energy, self-sustainability, etc. Solar still compatible design with optimum performing combinations is required to maintain the gap in supply of freshwater against the corresponding demand of that by various fields of society.

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