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(REVIEW ARTICLE)

Different glass cover designs for solar stills: A review

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Abstract

Water is the key for all kinds of life, and fresh water is the main resource for life on dryland generally and human beings specially. Transforming salty, saline, and brackish water into potable water is one of the solutions humanities has invented to overcome the lack of water. Solar stills are a simple, cheap tool used for that purpose with the aid of desalination concepts. Many kinds of stills have been invented with many designs and modifications to increase the productivity and efficiency of those stills. However, solar stills mainly consist of the same parts non-freshwater basin, a condensation surface, and the collection of fresh water. The present work focuses on the glass cover shapes, which is also the condensation surface, for simple (having no external additions) passive kinds of stills. Single slope solar stills (SSSS), double slope solar stills (DSSS), V-type solar stills (VSS), pyramid solar stills (PSS), tubular solar stills (TSS), conical solar stills (CoSS), spherical solar stills (SSS), and hemispherical solar stills (HSS) are all presented in detail. Reviews on different designs and factors affecting productivity and efficiency of stills have been observed and the way forward elaborated.

Keywords: Solar Stills; Glass Cover; Passive; Thermal performance; Desalination of water

1. Introduction

Life relies on liquid water. These are the simple words of the big conclusion reached by modern scientists in their search for other life on other planets. If there is no liquid water, life is impossible to create. Luckily, our plant is covered by more than 70 % of its surface with water. One percent of that is fresh water, which is used for drinking and agriculture. Rain, snow, and fountains cause this fresh water. Unluckily, these resources are consumed by increasing demands for water because of population growth, and it is reduced due to global environmental changes [1]. For this reason, humanity started to think out of the box to find solutions for these demands. One of these solutions is the desalination of brackish water. In this process, fresh water may be extracted from air in a difficult process [2] or by converting undrinkable water into drinkable water, which is by heating salt water with some kind of heat source, for which evaporation occurs. Water vapor leaves salt and contamination to condense on other surfaces to be collected. This process may occur passively or actively. However, for sure it is not sufficient to produce a large amount for agriculture or other big human use. Nevertheless, the benefits are that the fresh water produced has no need for energy to produce, and it is environmentally friendly with low maintenance demands.

One of the simplest ways to do such a process is by using solar stills. They are a very simple structure that uses solar heat to evaporate brackish water lying in a basin. The basin absorbs solar radiation and transfers it to the water. Vapor rises by the gravity difference effect to condenses on the glass covers of solar stills. Freshwater is collected and then used by consumers, while salty water is compensated from the external tank. Many modifications occurred to enhance

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efficiency, either by adding power or by some additional parts or matters to do the enhancement passively. Nevertheless, the noticeable thing is that all still consists of the same main parts.

The present review focuses on glass covers shape designs. These shapes are categorized to their basic figures and reviewed with the different factors studied for each literature. Productivity and efficiency for stills are the indicators used to find out whether modification in the literature is suitable or not. In the other hand, the review demonstrate shapes of glass covers for simple passive stills (stills consisting of basin and condenser only), for which no external additions or extensions accompanied, no solar tracking, and no solar reflectors.

1.1. Single slope solar stills (SSSS)

Single slope solar stills (SSSS), or sometimes called conventional solar stills, are the most widespread solar stills. It consists of a wooden box (mostly), with one side lower than the other. A glass cover connects the taller and lower sides of the box to seal the contents inside the box. This glass cover should always face the direction of the sunlight to obtain maximum yield. Tilt angle of the glass cover, which is also considered as the condensation surface, is relative to the position where potable water is to be produced. The horizontal bottom of the box is a basin for saline water that should be made of heat-conducting material and painted with a dark color to increase solar absorption. Literature found that this basin should be insulated to decrease heat losses from water containers and to increase productivity [3, and 4]. SSSS are easy and relatively cheap constructed stills. Good orientation is the only character that governs the evaporation process. Here are some literatures who dealt with this kind of still.

A performance study for SSSS used by Badran [5] to enhance, experimentally, the productivity of the Still by 51%. Combined enhancers to increase the basin solar absorptivity and reduce it to glass, which are asphalt basin liner and sprinkler. Ambient temperature is found to have a direct effect on productivity values. Night production reached 16% of total amount due to the temperature difference between glass cover and basin water. In addition, it is found that production can be increased by reducing water depth in water basin.

Tiwari and Tiwari [6] studied experimentally annual performance for SSSSs with different inclinations to reach the optimum one. Three values of 15, 30, and 45o inclinations studied as shown in figure (1). Solar fraction concept used in the analysis of validation of thermal modelling. SSSS with 15o shows an optimum annual performance and efficiency for New Delhi conditions. Solar fraction concept is used to validate thermal modelling. Inner glass temperature used to find thermal properties of humid air inside still, which shows better thermal modelling results than if using water temperature as used in [7].

Figure 1 Working stills with covers inclinations 15, 30, and 45o from left 1st, 2nd, and 4th [6]

Modi and Modi [8] evaluate, experimentally, double basin SSSS performance with addition of small piles of clothes and black cotton in upper basin to increase solar radiation absorptivity. Two similar stills built; one with wick piles, and the other without wick piles. Both stills subjected to same meteorological conditions for accurate comparison. Addition of wick piles show an enhancement by 18.03% and 21.46% for water depths of 1 cm and 2 cm respectively.

Hedayatizadeh et al. [9] introduced a comprehensive approach to model passive SSSS. Instead of using mean temperature of glass and water temperatures, heat balance applied to humid air inside enclosure, to have accurate results of thermophysical properties. Results show that the present procedure able to simulate SSSS behavior with more accuracy by comparing with experimental results.

Balachandran et al. [10] investigated, experimentally, performance of SSSS with rehash-cocked oil as external heat source to increase basin temperature that enhances palatable water productivity as shown in figure (2). Proposed solar still compared with conventional still to evaluate water productivity. Palatable water yield of proposed design reaches 3.77 l/m2 with 57.02% increment than conventional solar still of 3.02 l/m2.

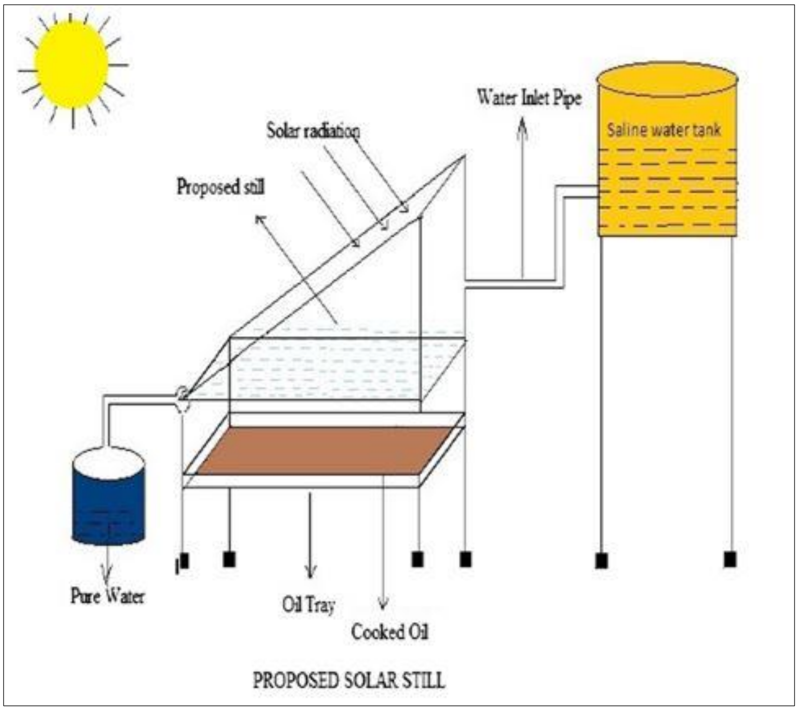


Figure 2 Proposed design for SSSS by [10]

1.2. Double slope solar stills (DSSS):

In this kind of stills, rectangular basin covered with a triangular glass cover. The increment in condensation surface area is proportional to the increase in evaporation surface area of the basin. DSSSs are like SSSSs, where both are easy to install, and need for orientation but DSSS differs in having more efficiency and more productivity, due to increment in condensation area. This can be seen in the following literature.

Zeroual et al. [11] studied experimentally partially cooling effect of still condenser. Two types of cooling are performed; first one by flowing water over north condenser surface (glass cover) which causes efficiency increment by 11.82%, while second way by applying intermittent shade over glass cover by using rectangular screen with 90 cm above north side which increase efficiency by 2.94% only.

Jegadeesh and Manivannan [12] compare experimentally between DSSS and multi slope (four) solar still, as shown in figure (3). To ensure precise comparison, it is still subjected to the same conditions of solar energy, wind speed, and ambient temperature. Both stills have 1.4 m2 of basin area. Results show that DSSS produces 3.1 l/day with an efficiency of 25.08%, while multi slop still produce 3.9 l/day with an efficiency of 29.5%. This can be regarded as the increase in condensation area by glass cover that reduces glass temperature and leads to increment in productivity.

Figure 3 DSSS and multi slope still studied by [12]

Dubey and Mishra [13] analyzed experimentally and theoretically three DSSSs with different tilt angles 15o, 30o, and 45o at meteorological conditions of Raghogarh, Guna, India as shown in figure (4). Analysis methodology of greenhouses by Kumar and Tiwari [14] used as a basis for computation. Best productivity attained by DSSS with 15o of 4.66 l/day after 14 hrs of observations with 52% from east side and 48% from west side. Efficiencies of stills were 23.69% for 15o, 29.24% for 30o, and 25.09% for 45o inclinations.

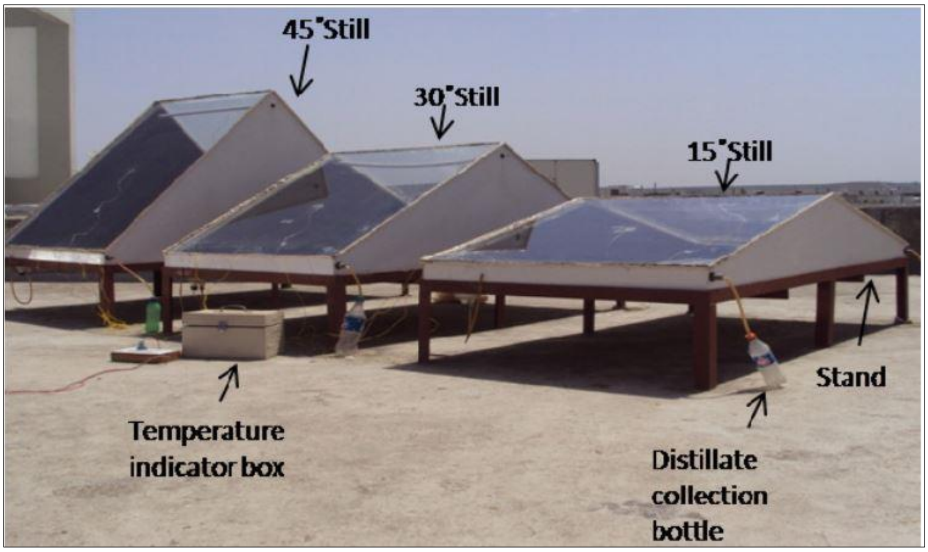


Figure 4 DSSSs of 15o, 30o, and 45o cover glass inclinations used by [13]

Shah and Damon [15] fabricated a DSSS with single basin of 1 m2 surface area as shown in figure (5). Inclination of still cover glass was 30o, with climatic conditions of Nagar, Gujarat, India. In order to increase solar irradiation intensity by brackish water, ink dye is added to the water. An increment of efficiency by 26.7% occurred compared to normal basin water.

Similar to Shah and Damon [15], Al-doori et al. [16] focused on increasing solar irradiation absorptivity increasing by using local rocks placed in DSSS basin. Rocks will additionally work as heat storage source after sunset to increase working hours range and potable water yield. Two kinds of rocks used: concrete and igneous. Concrete rocks increased freshwater productivity by 42% after 7 p.m., and maximum temperature reached 73.2 oC compared to 75.2 oC for basin without rocks. On the other hand, igneous rocks cause an improvement of 111% after 7 p.m. and maximum temperature of 71.6 oC compared to 77.3 oC for clear basin.

Figure 5 DSSS with basin covered with rocks used by [15]

Patel and Kumar [17] studied experimentally the effect of glass cover cooling and the effect of water depth in the basin for DSSS. Basin made from 3mm acrylic sheet, with 30o inclination of 3mm glass cover. Climatic conditions of Sultanpur, India, are the input variables to be measured for the experimental work such as; wind speed, solar irradiation, and ambient temperature. Results show that an increment in production as glass cover cooled, and another 20.46% increase in production as brackish water depth reduced from 4cm to 2 cm.

Moungar et al. [18] studied experimentally the addition of immersed fins into basin on potable water productivity of DSSS. The variables studied are fins number, fin height, fin spacing, and water depth in basin. Results show that fin spacing has no significant effect on productivity. Increasing fins height from 2cm to 5cm causes a productivity rise, but increasing is found when fins height is changed from 6cm to 8 cm. This is because of the effect on solar radiation absorbing shape factor, where increasing height that much shows observable result. Also decreasing in brackish water depth shows an increase in potable water productivity.

1.3. V-type solar stills (VSS)

In this kind of solar stills, both evaporation area and condensation area increased, since it look like a combination of two SSSS combined in the lower part of the stills.

Suneesh et al. [19] constructed 1.5 m2 VSS to analyze it experimentally as shown in figure (6). Climatic conditions as that in India taken, where water temperature, glass temperature, ambient air temperature, and solar irradiation recorded during sunny days. Two cases taken; tilt basin covered with wick and partially covered. It found that, and at all tilt angles, partial covered basin had higher yield and higher efficiency as shown in figure (7).

Figure 6 VSS constructed by [19]

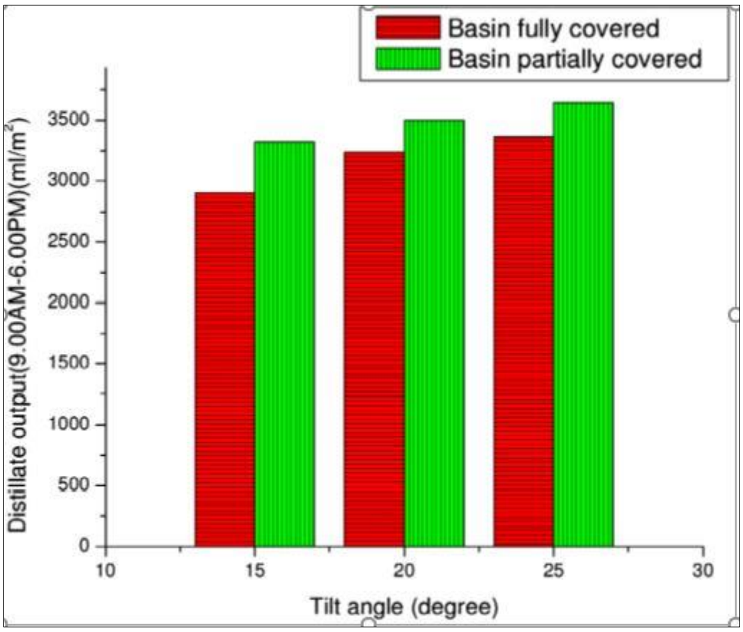


Figure 7 Yield of VSS taken by [19] at different tilts with the two cases studied

1.4. Pyramid solar stills (PSS)

There is two kinds of PSS; one with a rectangular base, and the other with triangular base. Because of its cheap cost, ease to install, and no need for accurate orientation, PSS is one of the most efficient stills. Sometimes, it is convenient to use concave basin shape with this kind of still. It is obvious from the name; a concave shape of basin causes an increment in solar radiation absorption that led at the end to increasing still productivity. The following literatures discussed experimentally PSS.

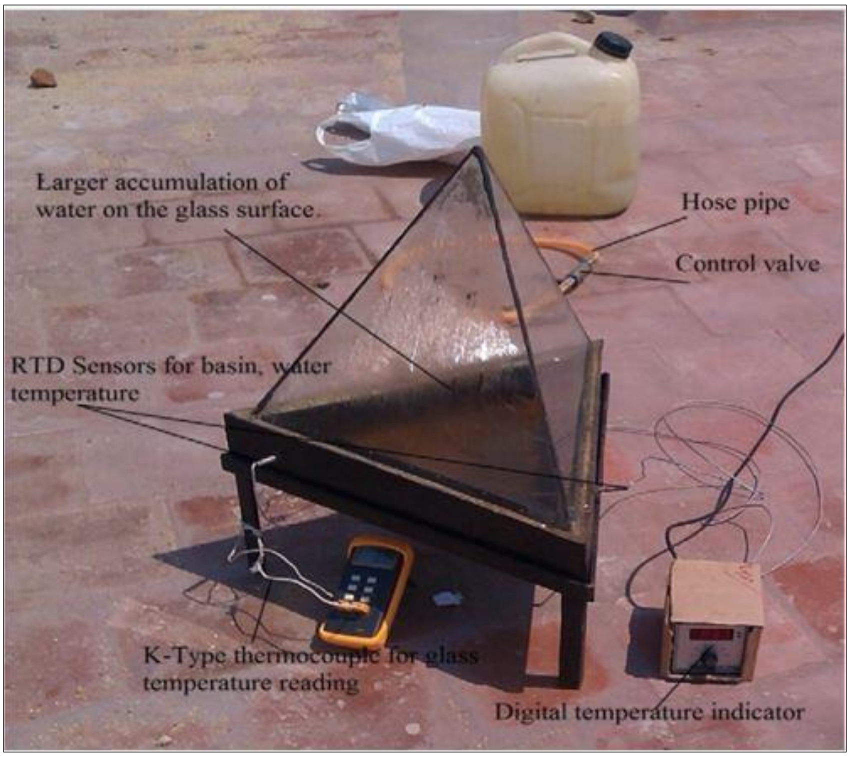


Figure 8 Triangular PSS used in [20]

Sathyamurthy et al. [20] presented experimentally some important parameters that affect the performance of triangular PSS. Figure (8) shows the experimental setup of the study. The parameters studied are water temperature, water depth, and wind velocity over glass cover. The study found that heat transfer by convection and evaporation are important to design a solar still system. In addition, the temperatures of water surface and cover glass are important to optimize the operating temperature range.

Arunkumar et al. [21] compare experimentally between productivity and efficiency of square PSS and HSS. To make the comparison accurate both stills had 1m2 basin area. Other variables such as ambient temperature, wind speed, water depth, and solar irradiation fixed for the stills as shown in figure (9). Comparison shows that HSS has higher efficiency and productivity than Square PSS. The explanation for this is due to fewer losses in solar radiation reached to basin that makes water temperature higher. Since the present article demonstrates different shapes of glass cover and [21] has two kinds of shapes, it will not be mentioned in HSS section.

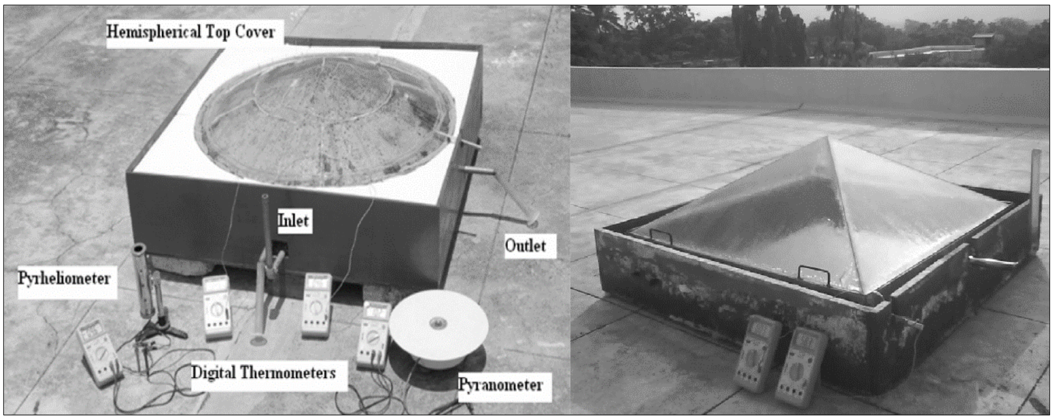


Figure 9 The two stills, square PSS and HSS used by [21]

Mazhanash [22] studied experimentally and numerically the enhancement of productivity of water recycling by distillation as shown in figure (10). CoSS, DSSS, VSS, and square PSS designs studied to improve in previous designs to create better efficiency models. By comparing with conventional SSSS, 57% increment in efficiency obtained by using suggested design with 0.47 kg/m2.hr. Stepped basin surface is used as the best shape to obtain maximum solar radiation. Experimental results compared with CFD results to obtain an agreement and reliability on results. After comparison of results for each design used, square PSS found to be more efficient for the conditions chosen as shown in table (1). Furthermore, table(2) lists a comparison of the different designs of solar stills

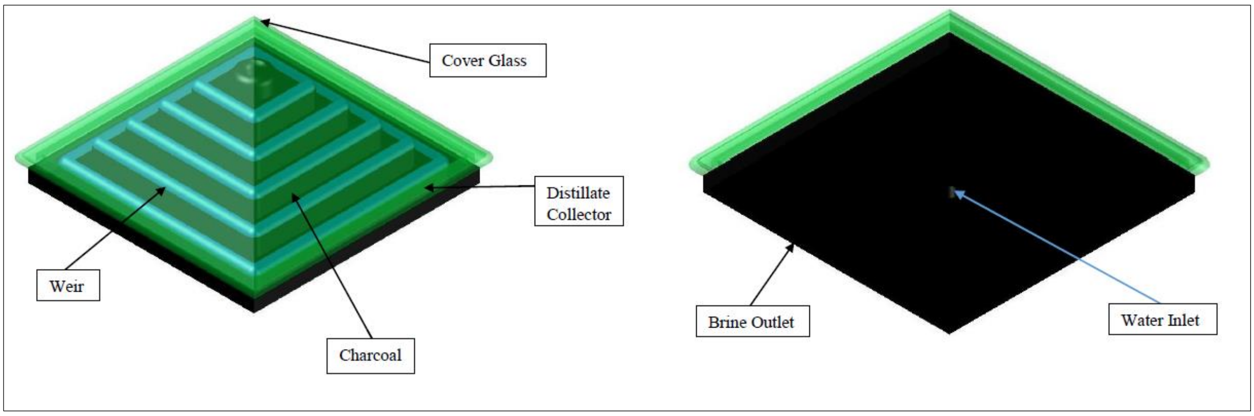


Figure 10 Square PSS simulated and tested by [22]

Table 1 Comparison among various designs used in [22]

Design Criterion	Unit	Weight Factor	Single Slope Cascade		Cone Shape Cascade		Pyramid Shape Cascade		V Shape	
			Rank	Score	Rank	Score	Rank	Score	Rank	Score
Total Area Expose	m^2	4	1	4	2	8	3	12	4	16
Fabrication Complexity	n/a	2	4	8	2	4	2	4	4	8
Fabrication Cost	RM (MYR)	3	4	12	3	9	4	12	4	12
Operating Cost	RM (MYR)	3	3	9	3	9	2	6	2	6
Maintenance	n/a	2	2	4	3	6	4	8	4	8
Volume Flow Rate	l/s	3	3	9	3	9	3	9	3	9
Absorptivity	W/m^2	4	4	16	3	12	4	16	3	12
Residence Time	s	4	4	16	4	16	4	16	2	8
		Raw Score	78		73		83		79	
		Relative Weight	24.92		23.32		26.52		25.24	
		Rank Order	3		4		1		2	

Table 2 Comparison of the different designs of solar stills

S. No.	Cover kind	Ref.	Work kind	Work details	Remarks
1	SSSS	[5]	Exp.	Combined enhancers to increase basin absorptivity and decrease it for glass.	Increase productivity by 51%
2	SSSS	[6]	Exp.	Use different inclinations to reach optimum design.	15° inclination is better design
3	SSSS	[8]	Exp.	Use absorption materials in the basin with different depths	Increase productivity by 18.03% and 21.46%.
4	SSSS	[9]	Theo.	Use heat balance approach to have accurate results.	Simulation shows to be able to represent behavior.
5	SSSS	[10]	Exp.	Uses external heat source for basin.	Productivity increased by 57.02%.
6	DSSS	[11]	Exp.	Partially cooled glass cover by two methods.	Increase productivity by 11.82% and 2.94%.
7	DSSS	[12]	Exp.	Compare DSSS and multi slope solar still.	Increase efficiency by 4.42%

8	DSSS	[13]	Exp.	Compare the stills with different tilt angles.	Found efficiency for each angle.
9	DSSS	[15]	Exp.	Use ink dye to increase absorptivity.	Productivity increased by 26.7%.
10	DSSS	[16]	Exp.	Use two kinds of rocks in basin.	Increase productivity by 42% and 111%.
11	DSSS	[17]	Exp.	Studied glass cover cooling.	Increase productivity by 20.46%.
12	DSSS	[18]	Exp.	Use immersed fins in basin.	Using fins causes productivity increase.
13	VSS	[19]	Exp.	Use wick in basin surface.	Increase in efficiency.
14	PSS	[20]	Exp.	Studied different parameters.	
15	PSS-HSS	[21]	Exp.	Compare between two kinds of stills.	HSS has higher efficiency.
16	CoSS-DSSS-VSS-PSS	[22]	Exp.	Use different types of stills.	Stepped basin PSS has the best efficiency.
17	PSS	[23]	Theo.	Use Pascal language to simulate still with different tilt angles.	Productivity increased as the tilt angle increased.
18	PSS	[24]	Exp.	Use a corrugated basin surface.	Productivity increased by 47.7%.
19	PSS	[4]	Exp.	Studied using insulation for the basin.	Insulation has a positive effect on productivity.
20	TSS	[30]	Theo.	Correlates heat and mass transfer coefficients.	
21	TSS	[31]	Ex.	Use two kinds of basins.	Productivity increased by 24.47%.
22	TSS	[32]	Theo.	Studied different kinds of basins.	The case was found to have a 47% productivity increase.
23	TSS	[33]	Theo.	Studied heat and mass transfer in still.	
24	TSS	[34]	Exp.	Use two kinds of glass covers.	TSS has a 20% productivity increase than other design.
25	CoSS	[35]	Exp.	Find heat and mass transfer coefficients.	The tilt angle should be equal to position latitude.
26	CoSS	[36]	Theo.	Predict productivity of floating cone.	
27	SSS-PSS-HSS-TSS	[37]	Exp.	Compare different designs.	Hybrid design shows maximum productivity.
28	SSS	[38]	Theo.	Studied basin liner absorptivity on productivity.	
29	HSS	[40]	Exp.-Theo.	Compare between two kinds of stills.	Increase in productivity by 32.47%.
30	HSS	[41]	Exp.	Study cooling glass cover.	Increase efficiency by 8%.
31	HSS	[42]	Exp.	Study the effect of brackish water depth.	Productivity decreased by 8%.
32	HSS	[45]	Exp.	Added black ink to brackish water.	Productivity increased by 20-25%.

El-sebaii and Khallaf [23] performed a mathematical model by using Pascal language to analyze a square PSS. To validate the mathematical model, a validation done with experimental results of previous works. As expected, productivity changed from 4.22 to 4.43 l/m2 as tilt angle changes from 10o to 60o due to increment in condensation area related to inclination. Losses from still cover found to be related to cover area as it reduced from 8.8064 to 8.2304 W/m2. K with increasing cover area from 0.063 to 0.125 m2 due to changing tilt angle from 10o to 60o.

Abdelgaied [24] studied experimentally the effect of changing basin surface from flat into corrugated surface to enhance potable water productivity for square PSS. To have a good comparison, same size and shape PSS with flat plate basin surface constructed to be subjected to the same climatic conditions. Corrugated surface causes increment in solar irradiation absorptivity that finally causes enhancement in solar efficiency. Results show that corrugated surface basin produced 6.51 l/m2 compared to 4.4 l/m2 for the conventional solar still, with an increment rise by 47.7%. Efficiency grows up from 32.76% to 48.4% as corrugated surface used.

Manokar [4] studied experimentally the effect of brackish water depth with and without basin insulation for square PSS. Water depths change from 1 to 3.5 cm, where for each case insulation taken. Potable water yield from PSS without insulation changes from 3.27, 2.93, 2.26, and 1.59 kg/m2 to 3.72, 3.40, 2.70, and 2.08 kg/m2 with insulation for the water depth of 1, 2, 3, and 3.5 cm, respectively, which proves that decreasing water depth will increase productivity. In addition to this, insulation of water basin shown to has a positive effect on productivity due to thermal losses decrement

Vembathu Rajesh at al. [25] studied experimentally of using concave basin shape on square PSS, as shown in figure (11). Weir concave type basin with four glass triangular sheets is used. The idea is to increase efficiency by increasing the solar energy receiving area and decreasing glass cover temperature by increasing condensation area. Results show that the yield of fresh water was 4 l/m2 for daytime with an efficiency reached 38%, which is higher than conventional solar still.

Completing the work [25], Vembathu Rajesh at al. [26] added new variables to study the effect of them on the efficiency of the concave basin with square PSS. At first, the still runs normally without any addition as in [25], then the basin base is coated with black paint with white color at the sides. Another case of coating the basin with black paint as an absorbing material. The first case was taken for two heights of brackish water in the basin of 5 and 6 cm, while the second case was taken only for 5 cm. The second case shows a 38% increase in efficiency compared to other absorbing materials. In addition, the first case shows that 5cm height is more efficient than 6 cm.

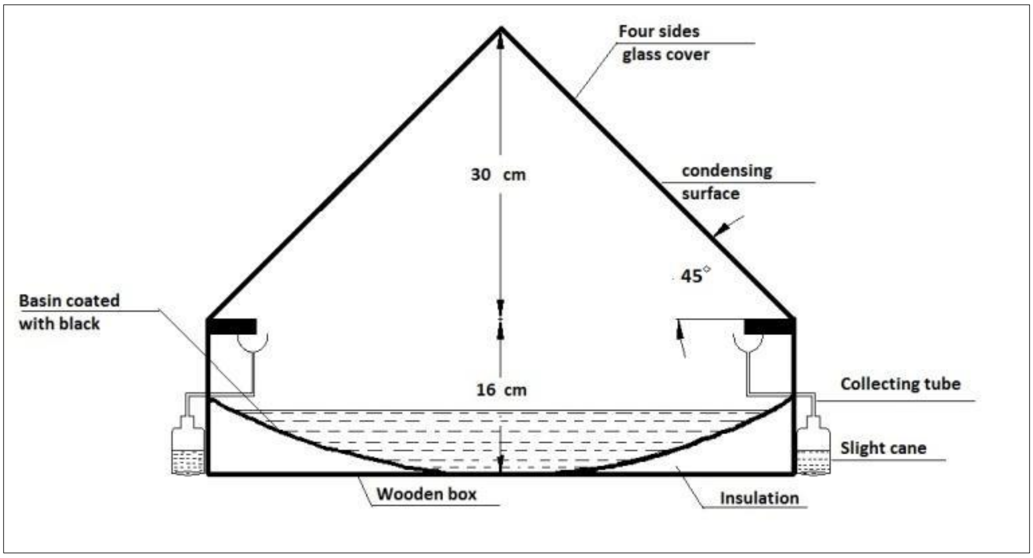


Figure 11 Concave basin PSS used by [25]

Similar to [25], Kabeel [27] also studied their concave basin for square PSS. It confirms the amelioration of drinkable water by using concave basins compared to conventional solar still. It also concluded that the temperature at glass cover sides is not equal and there is a difference especially until afternoon.

1.5. Tubular solar stills (TSS)

In this kind of stills, basin of solar stills places at the center of horizontal, inclined [28], or vertical transparent cylinder [29]. The basin received solar radiation through glass cover and humid air to be absorbed. After that, brackish water heated by convection and then evaporated to the medium inside still. Condensation occurred at the inner surface of the cylinder to be flowed by gravity and collected at the bottom surface of the cylinder. This kind of stills have the bigger condensation area compared to other kinds of stills.

Islam and Fukuhara [30] attempt to correlate heat and mass transfer coefficients and introduce new models for TSS by taking account the thermal properties of humid air inside the still. They developed new indoor experimental techniques to measure evaporation rate and production efficiency. It is found that heat transfer coefficients of evaporation, condensation, and convection can be correlated to temperature difference between glass cover and water basin temperatures. Formulas used for conventional SSSS overestimates convection heat transfer coefficients for TSS. Validation among correlations suggested and experimental results shown to agree.

Elshamy and Elsaid [31] experimentally investigated TSS with two different basin surfaces for two models. The first basin surface is flat, while the second one is semi-circular corrugated. The two TSSs subjected to the same climatic conditions of Giza Egypt. Productivity of the second TSS was 4.3 l/m2 with 24.47% increment than the first one.

Abd Al-wahid [32] studied theoretically changing of the shape of basin surface for TSS. Four cases of basin shape taken; half-cylindrical, half-cylindrical with hollow circular tubes, half-cylindrical with rectangular shaped tubes, and half-cylindrical with square tubes as shown in figure (12) below. Brackish water depths of 10 mm, 15 mm, and 20 mm are taken for each case. Results shown that productivity for enhanced shapes increase productivity especially for case 2 where increment reaches 47% compared to regular case (1) as shown in figure (13).

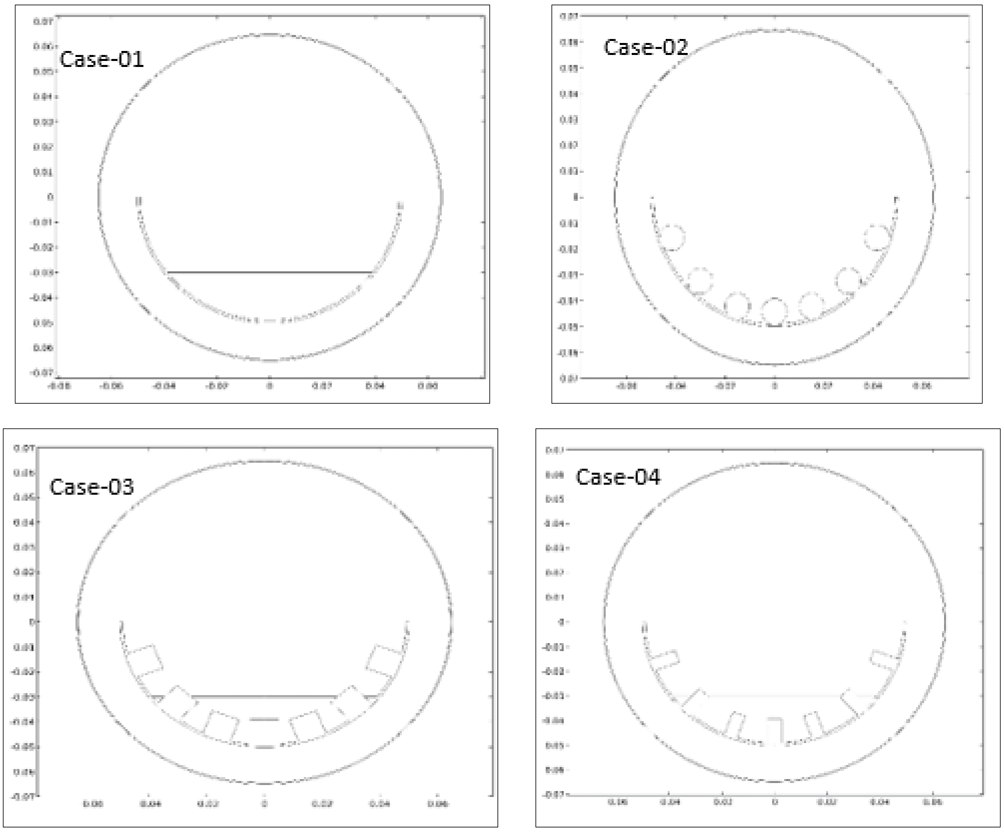


Figure 12 Cases of basin surface taken by [32]

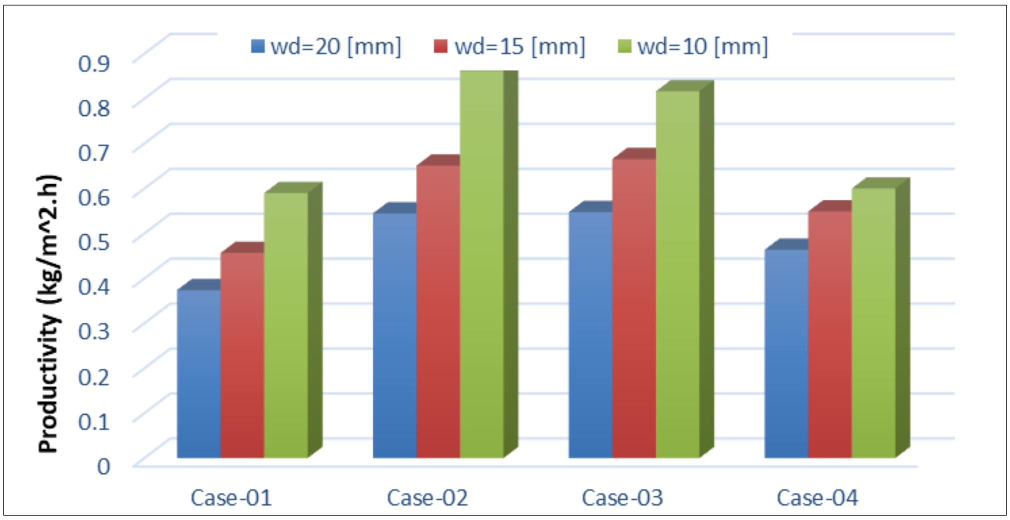


Figure 13 Productivity for the four cases of [32] with different water depths

Rahbar et al. [33] investigated numerically if a 2D simulation to compute heat and mass transfer in TSS. Results show acceptable agreement between simulation and experimental data in literature. Simulation shows a recirculation region inside humid air zone circulating clockwise direction, and that condensation occurs mainly at the upper half of cylindrical cover. They suggested numerical correlations to estimate water productivity according to different operational conditions. Glass cover temperature has an inverse relation to TSS efficiency while brackish water temperature shown to have direct relation.

Rahbar et al. [34] studied experimentally and numerically the comparison between two solar stills: on regular TSS, and another TSS with replacing upper half of the cylinder with two inclined surfaces to form a PSS. Simulation is done to understand humid air motion inside solar enclose, and to evaluate local entropy value all over still. Experimental work was done over seven days, where solar radiation, ambient temperature, and water productivity was investigated. Results indicated that TSS has a 20% increase than the second PSS since it has a bigger condensation area. According to experimental work, two correlations proposed to predict freshwater yield in presented systems.

1.6. Conical solar stills (CoSS)

Dependency on still orientation was the key for many efforts to increase still efficiency. Therefore, using stills without orientation criteria is one of the solutions made by literature. PSS, SSS, and HSS were kinds whom overcome this problem. CoSS is an addition to this group of stills. One the other hand, limitations of cost and complex design appear as a new problem. Here some literatures whom taking in mind the effectiveness of CoSS experimentally.

Gad et al. [35] Attempt experimentally to find the heat transfer coefficient in CoSS. In their work, decreasing the shadow effect, and increasing solar irradiation was the plan of the work. A new conical glass cover designed and built in Sheben El-Kom – Egypt, where climatic conditions of that city used. A surface area of brackish water basin of 0.8 m2 with a tilt angle for the cone of 31o as shown in figure (14). Tilt angle is equal to latitude of experiment position to maximize solar irradiation. A freshwater product of 3.38 l/m2 measured, which is more than that measured by conventional solar still of 1.93 l/m2 for the same area and same conditions. Heat transfer coefficient calculated to be 66 and 32 W/m2.oC for conical and conventional stills respectively. Calculations were done by using both evaporation rate measuring and Chilton-Colburn analogy.

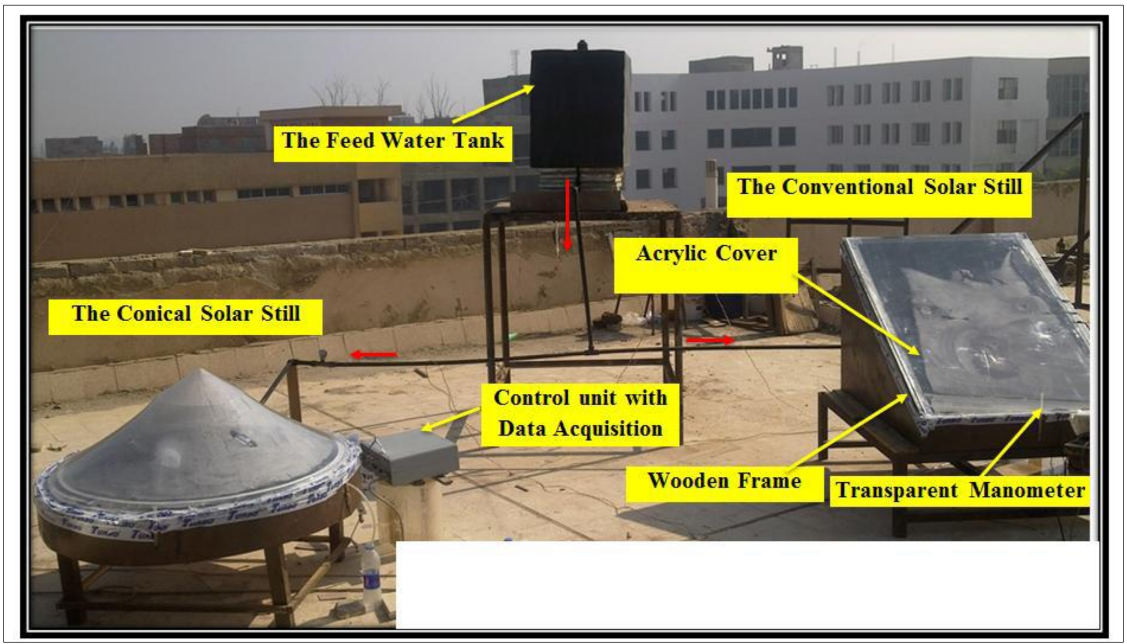


Figure 14 Conical and conventional stills used in experimental work of [35]

Minasian and Al-karaghouli [36] presented numerical study to predict productivity of floating CoSS to desalinate marsh water as shown in figure (15). The proposed design is a conical transparent glass cover with blackened cotton of the same shape inside it. The cotton should be soaked in brackish water of marsh, so it rises through cotton by capillary. The structure is carried by a base, so CoSS stays vertically and cotton always in touch with marsh water. A regression done to relate solar irradiation, wind speed, and ambient temperature to obtain glass cover temperature, cotton surface temperature, and in the result obtaining productivity of the still. Analysis shows that regression by using daily solar irradiation is a good predictive method for yield calculation with good accuracy.

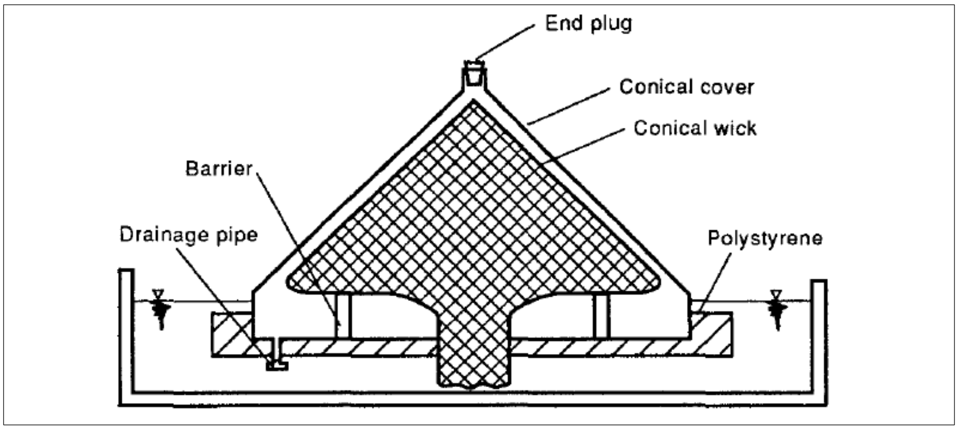


Figure 15 Proposed floating PSS by [36]

1.7. Spherical solar stills (SSS)

For this kind of stills, basin shaped circulars put horizontally inside a big transparent sphere as the condensation surface. No need for direction in this kind of still, where solar irradiation is equal in all directions. Sphere used here is not complete, because it has an orifice in the bottom for collecting potable water, holder for the basin, and for compensation brackish water piping. This still has a big condensation area compared to evaporation area. However, spheres used here, especially that made from glass, are expensive and hard to replace if it is broken. Some researchers used SSS listed down here.

Arunkumar et al. [37] Constructed many designs of stills to compare among them. SSS, square PSS, HSS, TSS, spherical basin solar still, double basin solar still, and concentrator coupled single slope solar still constructed and studied experimentally for the same ambient conditions. SSS used in [37] can be shown in figure (16). Figure (17) shows that SSS has the least yield ever among the seven stills constructed. However, the combination between PSS and TSS shows the highest productivity.

Figure 16 SSS constructed in [37]

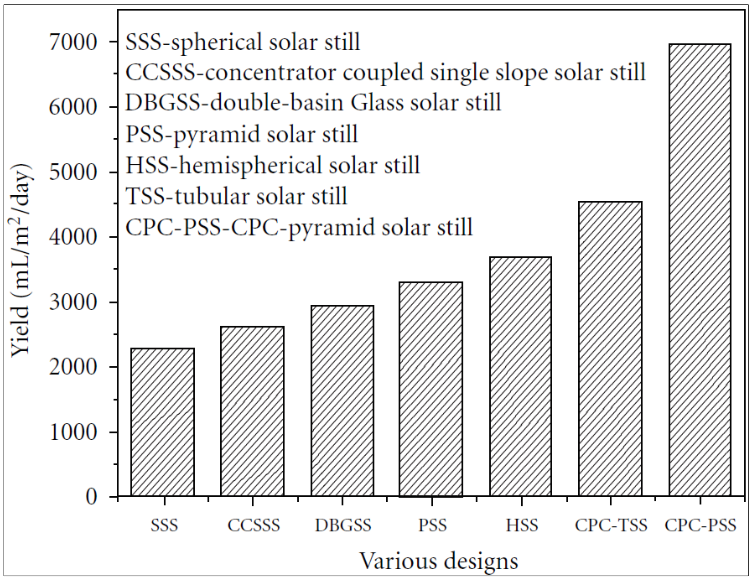


Figure 17 Yields for different stills used in [37]

Dhiman [38] conducted, numerically, a mathematical approach for SSS. The results of calculations are validated to [39], and to find the effect of basin liner absorptivity on desalination yield. By comparing it to SSSS, SSS is more efficient though the cost criteria as shown in figure (18). The same conditions are taken for both stills.

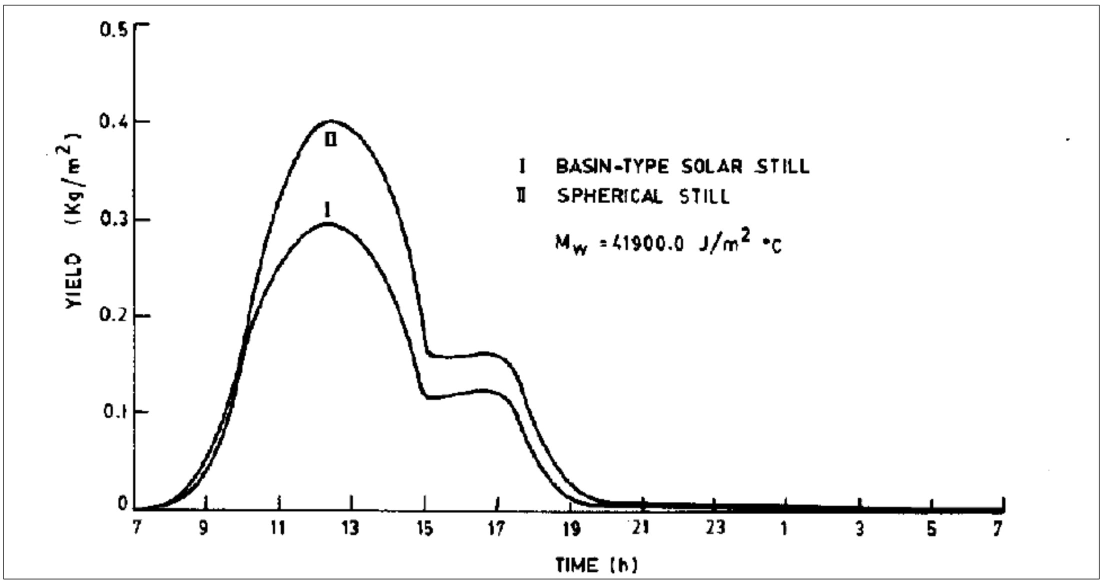


Figure 18 Hourly variation of yield for conventional solar still and SSS by [38]

1.8. Hemispherical solar stills (HSS)

HSS is one of the promising designs of solar stills. Its big surface area is considered as a good positive point to increase productivity. It consists of circular basins covered by hemispherical transparent cover. This design is very simple, despite its expense, and does not need for orientation.

Following literatures studied this kind of still experimentally and numerically.

Karroute and Chaker [40] compare numerically and experimentally the effect of glass cover changing from SSSS to HSS. An increment in yield production of about 32.47% reached that change due to the change. The increment regarded into the increment in condensation surface area and the no need for positioning of the still in the sun direction.

A schematic diagram of HSS used by [41] shown in figure (19). Two cases were taken for the study; with and without covering. As expected, efficiency increased from 34% to 42% due to cover cooling. The study also discussed air and ambient temperatures, solar radiation incident, water temperature, and cover temperature.

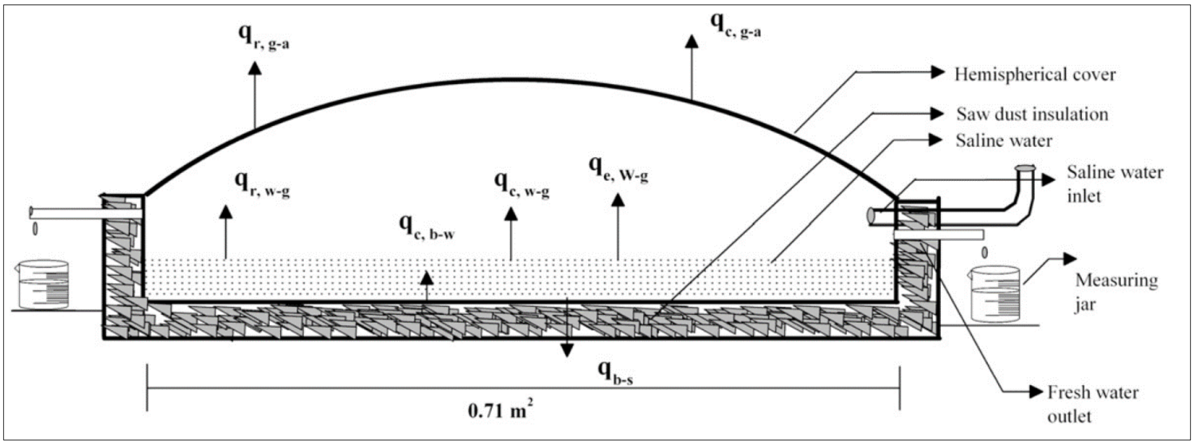
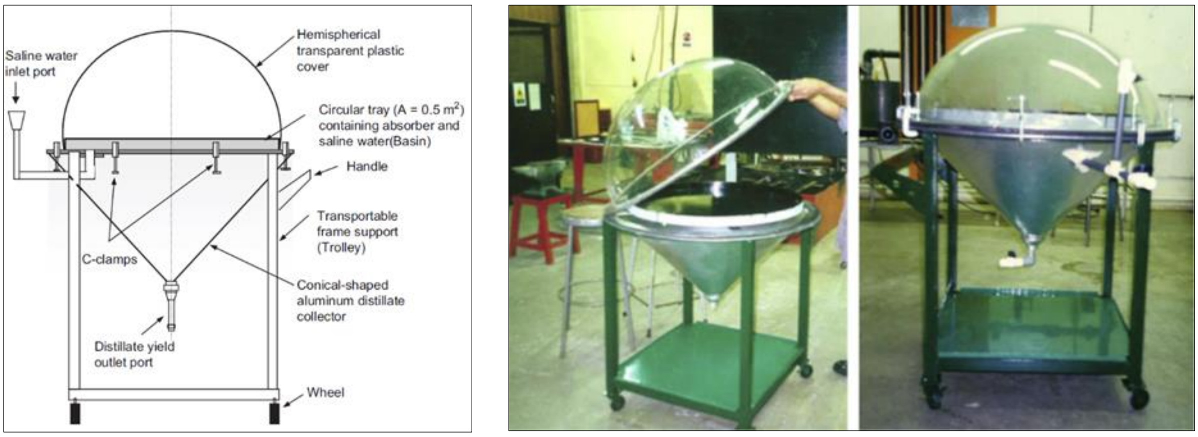


Figure 19 Schematic diagram for HSS used in [41]

Figure 20 shows a schematic and a photograph for HSS used by Ismail [42]. With 0.5 m2 as a basin surface area, and a daily yield from 2.8 to 5.71 l/m2 day, a still efficiency of 33% reached with a corresponding conversion ratio near 50%. The effect of water depth in basin studied with a conclusion of efficiency decrement about 8% when brackish water depth increased by 50%.



(a) (b)

Figure 20 A schematic figure (a), and a photograph of the HSS used in [42]

Selvakumar et al. [43] analyzed experimentally the addition of nanoparticles by coating them into the basin surface to increase solar productivity. This addition causes an increase in solar energy absorption by the basin, which leads to an increase in yield.

Panchal et al. [44] conducted experimentally HSS to produce fresh water. Experimental environments were climatic. In addition, productivity of 3.5 l/m2 reached the day. Efficiency of HSS is 18% with converting capability reaching 45%.

Solanki [45] used HSS to study experimentally the effect of addition black ink into saline water and study its effect on the absorptivity of water. The study had two lines in experiments; first one is by changing saline water depth with constant portion of ink, second one is by fixing water depth and changing ink concentration. Results show an increment in freshwater productivity up to 20% by adding 1.25% black ink, and up to 25% when adding 2% dark ink.

To step forward in the design of solar stills, Panchal and shah [46] simulate numerically HSS. Simulation done by using ANSYS CFD program. Validation done by comparing with experimental results of actual undergoing HSS. A good agreement reached by authors, which indicates how simulation is a powerful tool to analyze such problems.

1.9. Review papers

Since the main benefit from review papers is to demonstrate literature in a certain field, it is necessary to list main reviews on the same or related area of present work.

Muftah et al. [47], Rabadia [48], Murugavel et al. [49], Manokar et al. [50], Velmurugan and Srithar [51], and Kabeel and El-Agouz [52] reviewed the main factors affecting solar still productivity for basin type. These factors shown to be affecting the yield of fresh water are solar radiation, wind speed, ambient temperature, dust and cloud cover. While the main design parameters shown to have the main effect on productivity are Water depth, inclination angle, orientation, type of solar still, material selection, using energy storage materials, whether the still is hybrid or not, using tracking system, gap distance, and insulation thickness. Some other factors discussed such as coloring the brackish water, surface additives, salt concentration, water flow, and other factors. Cost of solar stills are also discussed.

Manchanda and Kumar [53] reviewed passive solar stills for many designs and factors affecting productivity. The review followed developments of solar still designs compared to SSSS. Designs such as Concave PSS, PSS, SSS, HSS, DSSS, TSS, VSS, and stepped basin SSSS shown and discussed comprehensively. Such as [47] and [48], [53] discussed parameters causing freshwater yield increment.

Durkaieswaran and Murugavel [54] reviewed special designs for passive solar stills where the following shapes listed: SSSS, DSSS, PSS, HSS, SSS, VSS, and TSS. This review is very close to the present work, where some of the references are mentioned and some are not.

Vala and Kanabar [55], and Nayi and Modi [56] reviewed in details solar stills with PSS. The review focused on different designs, additions, parameters, and cost for each design. They found that PSS is more efficient in productivity than conventional SSSS, while the design is simple with relatively simple cost. No orientation is needed for these stills in contrast, where SSSS needs accurate orientation and accurate inclination.

Sharma and Modi [57] reviewed techniques to improve productivity in SSS and HSS. Since glass cover is constant for this purpose, additions escorted with simple design to increase efficiency. Using reflectors to increase solar irradiation, cooling glass cover, preheating of inlet water, providing vacuum, using Nano-fluids, using wick materials, using solar tracking systems, and choosing proper glass thickness are the main techniques discussed here.

Panchel et al. [58] reviewed parameters effecting on freshwater productivity by TSS. The parameters are solar intensity, water temperature, glass temperature, and working principles. Some techniques to enhance still productivity listed also like using external solar concentration mirror, using vacuum, and using different kinds of basin surface.

2. Conclusion

Reviewing previous literature shows that stills are either conventional glass cover designs (SSSS, DSSS, and VSS), or non-conventional glass cover designs (PSS, CoSS, HSS, SSS, and TSS). The following important points concluded:

- Solar stills are a practical passive device, which uses solar energy to desalinate brackish water to have fresh drinkable water.
- Solar stills are not suitable for mass production, like agriculture and community production, where they may be cast-off for personal use.
- Although they have a low solar efficiency, expansion in advanced designs shows promising results.
- The key for maximum productivity is by increasing brackish water basin temperature and by decreasing glass cover temperature.
- Increasing surface area of glass cover has a positive effect on productivity process, since it decreases glass cover temperature. HSS is found to be the best glass cover with the largest condensation surface area.
- Orientation of SSSS, DSSS, and VSS is a very important factor to obtain maximum solar radiation.
- In addition to previous point, slope of glass cover affects the condensation process, and it is also a factor to optimize solar energy obtained. Inclination of glass covers will maximize productivity, if this inclination equals latitude of desalination place.
- PSS, HSS, CoSS, and SSS shown to be stills that do not need for orientation, due to their symmetrical design (except for triangular PSS that is obviously not symmetrical).
- Sometimes literatures studied the effect of sides facing sunlight and sides not facing it (for symmetrical designs mentioned in point above), but this does not deny symmetrical nature of that stills.
- HSS, TSS, CoSS, and SSS shown to be the most expensive designs, while SSSS, DSSS, and VSS are the cheapest.
- Cooling glass cover temperature may be obtained by spraying water on external surface or by increasing outer wind speed.
- Increasing basin temperature can be done by increasing solar absorption by basin, such as using fins, water dye, and using of different materials such as rocks or asphalt.
- Using materials as energy storage increases productivity and still efficiency in addition to increasing working hours of still even after sunset.

In addition to previous points, scope for further work enlisted

- Non-conventional designs should be used widely and considered for future studies.
- Applying active methods to non-conventional designs may increase productivity and efficiency.
- Energy storage materials should be added to the new designs to increase working periods.
- Ways to decrease glass cover temperature are crucial in increasing productivity.
- A new design should be invented by considering different geometrical shapes or a combination of them.
- New transparent materials may be considered for use in stills.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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