Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.909329

54 (2015) 3236–3247
June

Taylor & Francis
Taylor & Francis Group

Review of the productivity of various types of solar stills

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Received 12 September 2013; Accepted 21 March 2014

ABSTRACT

People all over the world need and demand fresh water. To solve this problem, solar stills are made to enhance the productivity of drinking water. Solar stills can be made even by unskilled men, without any complex design and with readily available local materials. This article deals with the comparison of the various factors which influence the productivity of the solar still. This detailed review would also throw light on the scope for further research and recommendations in desalination.

Keywords: Desalination; Productivity; Materials; Fin; Pond; Sandy heat reservoir; Vapour adsorption basin; Regenerative effect; Wick; Vacuum

1. Introduction

As early as the fourth century, Aristotle described a method to evaporate impure water and then condense it for potable use. However, historically, the earliest documented work on solar distillation was by Arab alchemists in the sixteenth century. The first water distillation plant constructed was a system built at Las Salinas, Chile, in 1872. Every day, people living in remote areas or islands, where fresh water supply by means of transport is expensive, face the problem of water shortage. The solar still presents some specific advantages for its use in these remote areas or islands, due to its easy construction using locally available materials, minimum operational and maintenance requirements and friendliness to the environment. It is really very fortunate that, in times of high water demand, solar radiation is also intense. It is therefore beneficial, to exploit solar energy directly by installing solar stills. Two major advantages that favour the use of solar stills are: clean and free energy, and eco-friendliness [1].

The solar still is the best method in the field of desalination. The solar still is a device which converts wastewater into fresh distillate water, by the use of the energy which is freely and abundantly available in our planet. The optimum value of salinity in a mini solar pond is 80 g/kg of water. The average daily production of distilled water integrating mini solar pond and sponge cubes with the still has been found to be increasing. The maximum deviation of the theoretical analysis is less than 10% of the experimental analysis [2]. The optimum values of the flowing water thickness and the mass flow rate for this typical configuration of the Solar Still Pond-active solar still were obtained as 0.03 m and 0.0009 kg/s. The annual average values of the daily productivity and efficiency of the still with the shallow solar pond were found to be higher than those obtained without the shallow solar pond by 52.36 and 43.80%, respectively [3].

To enhance the productivity during the night, single-basin solar stills are coupled with a shallow solar pond. The monthly average of the daily productivity

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had minimum values of 3.0 and 1.570 ($kg/m^2 d$) in December, with and without the shallow solar pond, respectively. The maximum values of daily productivity are 6.68 and 5.29 ($kg/m^2 d$) in July with and without the shallow solar pond [4]. The emerging problem in many areas of the world is the shortage of drinking water. To supply the needed amount of potable water which is already a problem faced by many developing countries. The need for fresh water is becoming an increasingly important issue in many areas of the world. In arid areas, potable water is very scarce, and the establishment of a human habitat in these areas, depends strongly on how such water can be made available. The importance of supplying potable water can hardly be overstressed [4].

Fresh water is rapidly becoming the scarcest human resource on the planet. In fact, the United Nations predicts that by 2025, 63% of the world's population, some five billion people, will be living in water scarce areas. As per a survey, about 2% is locked up in glaciers and ice caps, mainly at the north and south poles, and 3% of the earth's water supply is fresh water. Polar ice caps will melt; the sea level will rise, and inundate much of the present land surfaces in the world. The rest of the world's supply of freshwater (less than 1%), found in water bodies like rivers, streams, lakes and ponds also contains a lot of impurities.

Ninety percent of urban sewage in the developing country is discharged into rivers and other water bodies. There is an enormous generation of waste, with only a part of it being treated. The untreated sewage and effluents are discharged into the rivers, turning them into sewers or sources of poisoned water [5]. The main objective of this work is to investigate a comparative study of various types of solar stills and their productivity, shown in Table 1.

2. Solar stills integrated with a mini solar pond

The optimum value of salinity in the mini solar pond is 80 g/kg of water. The average daily production of distilled water, integrating mini solar pond and sponge cubes with the still, has been found to be increasing.

The maximum deviation of the theoretical analysis is less than 10% of the experimental analysis [2]. The optimum values of the flowing water thickness and the mass flow rate, for this typical configuration of the Solar Still Pond-active solar still were obtained as 0.03 m and 0.0009 kg/s. The annual average values of the daily productivity and efficiency of the still with the shallow solar pond were found to be higher than those obtained without the shallow solar pond, by 52.36 and 43.80%, respectively [3].

To enhance the productivity during the night, single-basin solar stills are coupled with a shallow solar pond. The monthly average of the daily productivity had minimum values of 3.0 and 1.570 ($kg/m^2 d$) in December, with and without the shallow solar pond, respectively. The maximum values daily productivity is 6.68 and 5.29 ($kg/m^2 d$) in July, with and without the shallow solar pond [4]. A mini solar pond was used to preheat the saline water; hence, mini solar pond was integrated with these stills. These stills were operated with the mini solar pond and tested individually. To increase the water exposure area, sponges were used, and the productivity increased by 66%. When all modifications were put together, the productivity of the stepped solar still increased by 100%. The schematic diagram of the experimental set-up of solar still integrated with the mini solar pond is shown in Fig. 1 [5]. A mini solar pond, stepped solar still and wick type solar still are connected in series. Pebbles, baffle plates, fins and sponges are used in the stepped solar still for further productivity augmentation. The productivity during the day and night are calculated. It is found that the maximum productivity of 78% occurred, when fins and sponges were used in the stepped solar still. Pebbles store more thermal energy and release it after sun set. Hence, more night productivity is obtained, when pebbles are used in the solar stills [6].

3. Improving the performance of the stepped solar still

Conventional stills and stepped active solar stills integrated with a solar air heater collector were fabricated. A higher saline water temperature was achieved, due to the additional thermal energy supplied by hot air to the active stepped solar still, compared to the passive solar still. The productivity of the stepped still at a tray depth of 5 mm and without any modification is 30.4% higher than that of the conventional still. In this case, the productivity of the stepped still is increased approximately by 85% as compared to the conventional still. The glass cover cooling technique has proved to be an adequate and simple tool towards the improvement of the stepped solar still productivity (65% higher than the productivity of the conventional still). The productivity of the stepped still increases by integrating aluminium filling as a simple solar energy storage system, beneath the absorber plate (53% higher than the productivity of the conventional still). The water productivity of stepped

Table 1
Comparison of different designs productivity of type solar stills

S. No.	Type of still	Specifications	Reference	Modification	Results
1.	Solar stills	Basin area = 1 m^2, slope = 10°	[2]	Sponge and mini solar pond	Daily yield of 4.658 kg/m^2
2.	Single effect solar stills	Basin area = 1 m^2, slope = 10°	[3]	Shallow solar pond	Daily yield of 52.36%
3.	Active single basin solar still	Basin area = 1 m^2, slope = 10°	[4]	Shallow solar pond	Daily yield of 6.68 kg/m^2 d
4.	(1) Fin type single basin solar still	Basin area = 1,400 × 575 mm, slope = 10°	[5]	(1) Black rubber, sponge and sand	1.66% increase in productivity
	(2) Stepped solar still			(2) Mini solar pond, pebble, sponge and fin	2.99% increase in productivity
5.	Single basin solar still	Basin area = 1 by 0.5 m^2, slope = 10°	[7]	Mini solar pond, stepped solar still and Wick	78% increase in productivity
6.	Single slope passive solar still	Basin area = 0.5 m^2, glass sheet = 3 mm, thick slope = 31°	[8]	Stepped active solar still, solar air heater collector	The productivity of stepped still with improvement increased above 120% over conventional still
7.	Modified stepped solar still	Basin area = 1 m^2 (50 × 200 cm), slope = 30°, glass sheet = 3 mm thick	[9]	Wick	57.3% increase in productivity
8.	Stepped solar still	Basin area = 1,400 × 575 mm, slope = 9°55′, glass cover = 1.1 × 1 m^2	[10]	Fin, sponge and pebbles combination	98% increase in productivity
9.	Single basin solar still	Basin area = 1 m^2, slope = 10°, glass cover = 1.1 × 1 m^2	[12]	Wick type Sponges Fins	29.6% increase in production 15.3% increase in production 45.5% increase in production
10.	Single basin solar still	Basin area = 1 m^2, glass cover = 1.1 × 1 m^2	[13]	Industrial effluents as feed, fins	53% (2.54 L/8 h) evaporation rate increased
11.	Ethanol solar still	Basin area = 0.70 × 0.70 m, slope = 14°	[14]	Fin	15.5% increase in productivity
12.	Single-sloped basin type solar still	Basin size = 0.8 × 0.65 m, slope = 24°, glass cover = 3 mm thick	[15]	Multiple low thermal inertia floating porous absorbers	Output gain of 68% on clear day and 35% on partially clear day is obtained Twin reflector booster gives 79% gain over modified still without booster
13.	Single-sloped basin type solar still	Basin area = 0.5 m^2, slope = 24°, glass cover = 3 mm thick	[16]	Extended porous fins	Highest 7.5 L/m^2 output was obtained in the month of May
14.	Single basin solar still	Basin area = 1 m^2 (50 × 200 cm), slope = 30°, glass sheet = 3 mm thick	[17]	Finned corrugated and conventional solar stills	41% daily efficiency 40% daily efficiency 34% daily efficiency

(*Continued*)

Table 1
(*Continued*).

S. No.	Type of still	Specifications	Reference	Modification	Results
15.	Basin solar still	Basin area = 0.41 m^2, glass sheet = 0.5 cm thick	[18]	Sandy heat reservoir	75% increase in productivity
16.	Solar still	Basin area = 1 × 1 m^2, slope = 10˚, glass sheet = 1.1 × 1.1 m^2 mm thick	[19]	Vapour adsorption basin	Vapour adsorption distillate production rate was between basin 3.1 and 4.3 kg/m^2 Conventional still distillate production rate was between 1.9 and 2.3 kg/m^2
17.	Novel portable solar still	Basin area = 13 × 26 cm^2, slope = 30˚, glass cover = 6 mm Plexiglas	[20]	Heat pipe and thermoelectric module	7% Daily efficiency of the still
18.	Solar still	Basin area = 1.0 m^2	[21]	Vacuum	Water productivity about 100% The efficiency about 100%
19.	Wicks/solar still	Basin area = 0.5 m^2, slope = 30˚, glass sheet = 4 mm thick	[22]	Solar water heater	114% increase in productivity
20.	Single slope solar still	Basin area = 1 m^2, slope = 40˚, glass cover = 0.004 m	[23]	Evacuated tube collector	Daily energy and exergy efficiencies 33.0 and 2.5% Daily yield of 3.8 kg/m^2
21.	Wick-type solar still	U-shape section, slope = right-angled	[24]	Charcoal cloth	Indoor testing, from 37.7 to 28% efficiency decreased Outdoor testing 53.4–33.7% efficiency decreased
22.	Weir-type regenerative still	Basin area = 1.7 × 0.57 m, slope = 21.15˚	[25]	Absorber plate	20% increase in productivity
23.	Tilted-wick solar still	Basin area = 1.0 m^2	[27]	Inclined reflector	Daily amount of distillate 15% or 27% > vertical reflector
24.	Weir-type cascade solar still	Basin area = 0.45 m^2, slope = 30˚	[28]	Latent heat thermal energy storage system	4.85 kg/m^2 d for sunny 23 May 2009 3.4 kg/m^2 d partially cloudy day 13 May 2009
25.	Weir-type cascade solar still	Basin area = 0.72 and 0.45 m^2, slope = 30˚, glass cover = 3 mm thickness	[29]	PCM storage	Daily productivity 6.7 kg/m^2 d
26.	Basin type solar still	Basin area = 1 m^2, slope = 20˚, glass cover of 3 mm thickness	[30]	Flat plate external bottom reflector	Distillate 41, 25 and 62% conventional basin type still on the spring equinox and summer and winter solstices
27.	Tilted-wick solar still	Basin area = 1 m^2, slope = 10˚, glass cover of 5 mm thickness	[31]	External flat plate reflector	Daily amount of distillate increase 21%
28.	Solar still	Basin area = 1.2 m × 1.2, slope = 45˚, glass cover of 3 mm thickness	[33]	Concave wick evaporation surface	Maximum instantaneous system efficiency of 45% and average daily efficiency of 30%

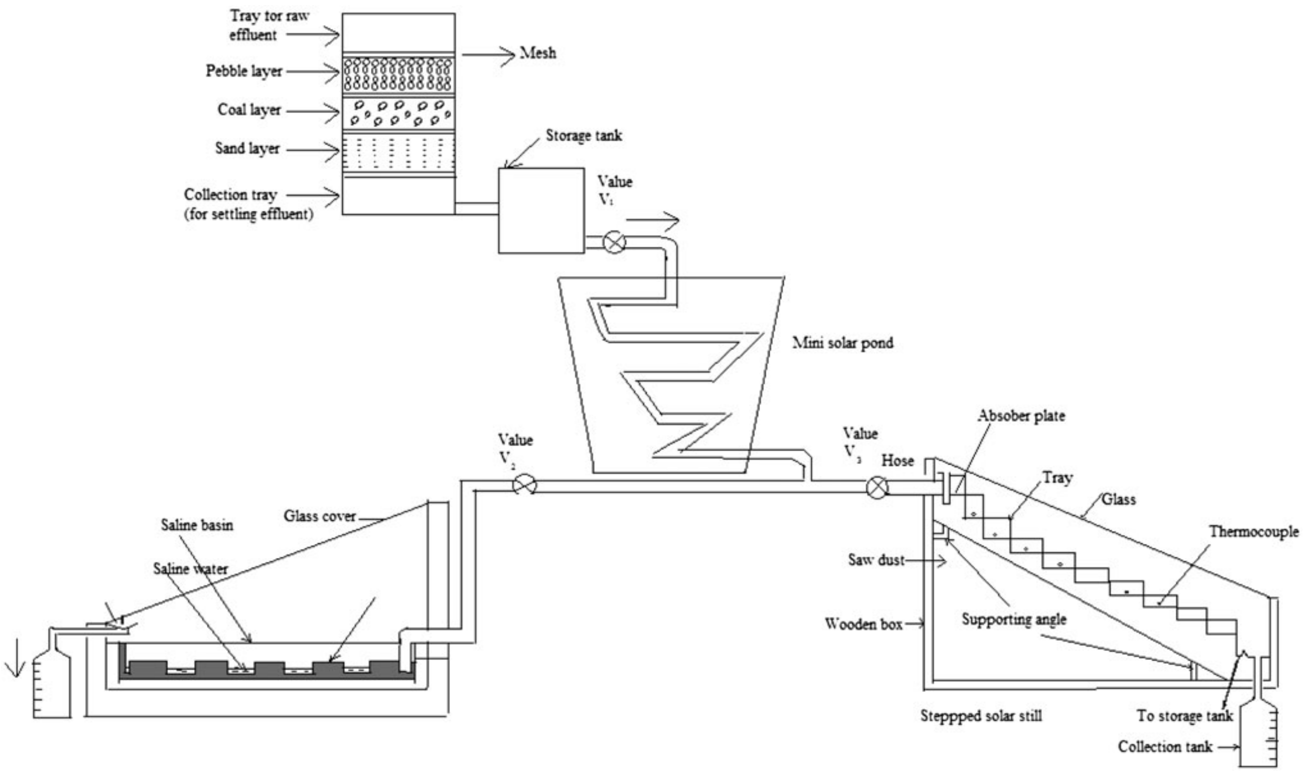

Fig. 1. Schematic diagram of the experimental set-up, taken from Ref. [5].

still increased by 112% over the conventional still, when both hot air and glass cover cooling were used [7].

Two types of solar stills are the conventional single-sloped solar still and a modified stepped solar still used simultaneously, both with saline water. The effect of the depth and width of trays on the performance of the stepped solar still, is examined. The maximum productivity of the stepped still is achieved at a tray depth of 5 mm and tray width of 120 mm, which is about 57.3% higher than that of the conventional still. The water depth for the conventional still is 5 mm and the tray width 100 mm; the glass temperature and basin water temperature of the stepped solar still are higher than those of the conventional still by about 0–2˚C and 0–10˚C, respectively. This is due to two reasons: (1) a smaller air volume is trapped inside the still chamber than in the conventional still, and therefore, heating up the trapped air will be much faster; and (2) the step-wise basin provides a higher heat and mass transfer surface area than the flat basin, leading to an increase in the basin water temperature of the stepped solar still. With the tray depth of 5 mm and the tray width of 120 mm, the glass temperature and basin water temperature of the stepped solar still are higher than those of the conventional still by about 0–4˚C and 0–3˚C, respectively. In this case, the daily efficiency and estimated cost of 1 Lof distillate for stepped and conventional solar stills are approximately 53%–0.039 $ and 33.5%–0.049 $ respectively [8].

A comparison of the percentage increase in production by various authors is shown in Table 2. The textile effluent is purified in an effluent settling tank. The textile effluent settling tank is large, and the fine solid particles are settled and clarified. The settled effluents are used as raw water in the stepped solar still. The stepped solar still consists of 50 trays with two different depths. First 25 trays with 10 mm height, and the next 25 trays with 5 mm height, are used. Fins, sponges, pebbles and combinations of the above, are used for enhancing the productivity of the stepped solar still. The production rate increased by 53.3% when fins are used in the stepped solar still. When sponges and pebbles are used, the productivity increased by 68 and 65%, respectively. A maximum increase in productivity of 98% occurs in the stepped solar still, when fins, sponges and pebbles are used in this basin, instead of the conventional stepped solar still. The theoretical analysis agrees well with the experimental results. The maximum deviation between the theoretical and experimental analyses is

Table 2
Comparison of percentage increase in production by various authors, taken from Ref. [13]

S. No.	Name of the paper and author	% Increase in production
1.	A solar still augmented with a flat plate Collector—Ali A. Badran, Ahmad A. Al-Hallaq, Imad A. Eyal Salman, Mohammad Z. Odat	52%, salt water is used feed
2.	Solar still productivity enhancement—A.S. Nafey, M. Abdelkader, A. Abdelmotlip, A.A. Mabrouk	20%, salt water is used feed
3.	Enhancement of solar still productivity using floating perforated black plate—A. Safwat Nafey, M. Abdelkader, A. Abdelmotalip, A.A. Mabrouk	40%, salt water is used feed
4.	Single basin solar still with baffle suspended Absorber—A.A. El-Sebaii, S. Aboul-Enein, E. El-Bialy	20%, salt water is used feed
5.	Desalination of effluent using fin type solar still—V. Velmurugan, C.K. Deenadayalan, H. Vinod, K. Srithar	75%, effluent water is used as feed

less than 10% [9]. Omara et al. modified the stepped solar still through internal reflectors. The effect of the reflecting mirrors on the vertical sides of the steps of the stepped still on the distillate yield rate and performance was investigated.

An experimental and theoretical investigation of the modified stepped solar still with trays (5 mm depth × 120 mm width), and the conventional solar still was carried out. Experimental distillate yield rate of the modified stepped solar still, with and without internal reflectors is higher than that of the conventional still by approximately 75 and 57%, respectively. The daily efficiency of the modified stepped still, with and without internal reflectors, and the conventional solar still is approximately 56, 53 and 34%, respectively.

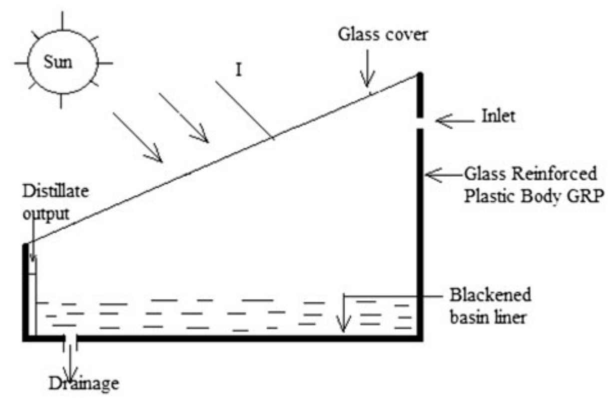

Fig. 2. Cross-sectional view of schematic arrangement of experiment, taken from Ref. [35].

4. Solar still with fin for enhancing productivity

In order to improve the productivity of the single basin solar still, fins, sponges and wicks were integrated at the basin of the still. The governing energy balance equations were solved analytically and compared with the experimental results. The experimental results gave very good agreement with the theoretical ones. The maximum deviation between the theoretical and experimental results was 10.1%. The average evaporation rate was only 2 L/m^2 for the still. When the wick type solar still was used, 29.6% productivity increased. The deviation between the theoretical and experimental results was 10.8%. A cross-sectional view of the basin type solar still integrated with a sponge is shown in Fig. 2. About 15.3% productivity increased due to capillary action of sponge which causes an increase in evaporation. The maximum deviation between the theoretical and experimental analysis was less than 6.2%. The ratio of the volume of sponge to that of the basin water was maintained as 20%. A cross-sectional view of the basin type solar still integrated with fins is shown in Fig. 3. Fins in the solar

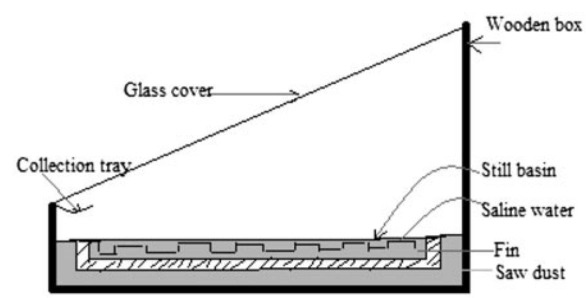

Fig. 3. Cross-sectional view of solar still with fins, taken from Ref. [10].

still increase the area of the absorber plate. Hence, the absorber plate temperature and saline water temperature increased. As the temperature difference between the water and glass increases, productivity increased. In this work, five fins with height, length and breadth of 35, 900 and 1 mm, respectively, were used. Yield was increased by 45.5% when fins were used. A good agreement had been achieved with the theoretical results. The deviation between the theoretical and experimental results was 10.8% [10]. Sponges, pebbles, black rubber and sand are used in the fin type single-basin solar still; fins act as an extended surface, and the temperature of the water increases for enhancing the yield. With the Fin, with sand and without sand in the solar still, the productivity increases from 0.34 to 0.36 L/m^2, when the solar intensity changes from 740 to 760 W/m^2. Obviously, this is because of the increase in the heat capacity of the basin plate due to the sand; when the wind velocity changes from 0.6 to 0.7 m/s, productivity changes from 0.2 to 0.19 L/m^2. An increase in the wind velocity decreases the productivity rate, and increases the convective heat losses at the top surface of the glass. A maximum increase in productivity of 75% occurs, when fin, sand and sponges are used in the single-basin solar still. The results show that the productivity increases considerably due to this modification. The economic analysis proved that the approximate payback period of such kinds of stills is 1 year. The average evaporation rate in the conventional solar still is 1.66 L/8 h lower compared to that of the fins integrated basin plate, viz., evaporation rate 53% (2.54 L/8 h) [11]. An indoor experiment was conducted on developing a mathematical model for predicting the productivity of an ethanol solar still of basin type [12]. An ethanol solar still contained a horizontal evaporating surface and a condensing surface inclined 14° to the horizontal plane. The fin integrated to the basin plate increases the performance of a solar still. The 10% ethanol solution was used as a feed to the solar still. The predicted still efficiency by the model could increase to 46%, when the number of fins that raised an effective absorptance was increased. The performance of the proposed modified still with porous fins in winter and summer experimental study was conducted lesser base heat loss due to the basin water is relatively cooler. About 56% higher day time distillate and 48% higher for 24 h duration was obtained in the month of February over the conventional still, whereas, in the month of May, 23% higher day time distillate and 15% higher for 24 h was achieved. The highest 7.5 kg/m^2 output was obtained in the month of May, in the case of the modified still made of expanded polystyrene foam, with good insulation property [13].

5. Single-sloped basin type solar still consisting of multiple low thermal inertia floating porous absorbers

The experimental and theoretical analyses of a single-sloped basin type solar still, consisting of multiple low thermal inertia floating porous absorbers, floating adjacent to each other on the basin water, with the help of thermocol insulation, are verified. An output gain of 68% on a clear day and 35% on a partially clear day is obtained by the modified still (Fig. 4).

With the use of a booster in the experiment shown in Fig. 5, during the first half of the day, that is up to 12:00 noon, the twin reflector booster had to be kept with the longer mirror facing south and the smaller mirror facing east, whereas after midday the booster had to be reoriented with the smaller mirror facing west and the longer mirror again facing south. The twin reflector booster gives 79% gain over the modified still without the booster. The water depth has an insignificant effect on the modified still due to the smaller depths [14]. In order to improve the

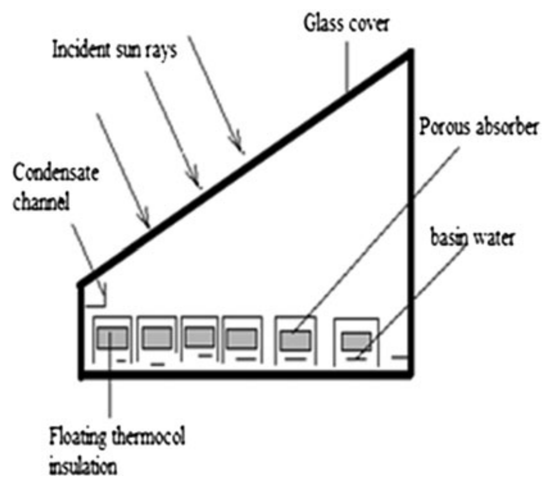

Fig. 4. Construction of the modified still, taken from Ref. [14].

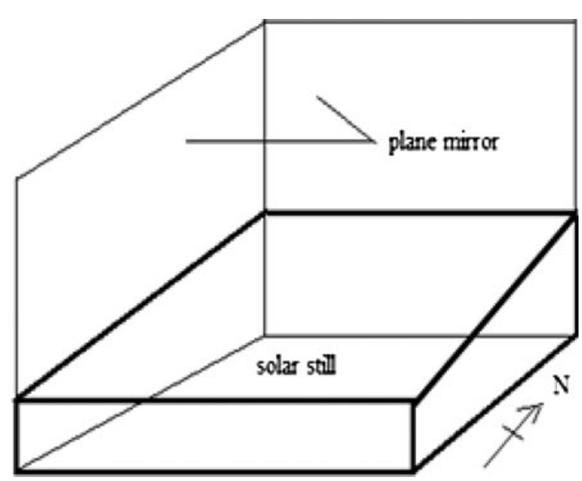

Fig. 5. Twin reflector booster applied to solar still, taken from Ref. [14].

productivity of the basin solar stills by increasing the surface area of the absorber, and rate of heat transfer between the saline water and absorber, in this experiment the performance of the finned and corrugated solar stills is tested and compared with that of the conventional still under the same Egyptian climate conditions. The daily productivity increased approximately by 20%, when fins were used, and by about 17% with the corrugated still. The daily efficiency for the finned, corrugated and conventional solar stills is approximately 41, 40 and 34% respectively. For 30 L the daily productivity increased approximately by 40%, when fins are used and by about 21% with the corrugated still. In this case the daily efficiency for the finned, corrugated and conventional solar stills is approximately 47.5, 41 and 35% respectively.

The results indicate that the productivity of the finned and corrugated solar stills is higher than that of the conventional still. With the use of lower depth quantity of saline water 30 L the productivity increased, when finned and corrugated solar stills are used, approximately by 40 and 21% respectively. The daily efficiency and estimated cost of 1 L of distillate for finned, corrugated and conventional solar stills is approximately 47.5%–0.041 $, 41%–0.047 $ and 35%–0.049 $, respectively [15].

6. Solar still with modification

The sandy heat reservoir is contrived under the basin liner, which remains unusable in conventional basin solar stills. The sandy heat reservoir acts as a heat source for the basin water during low intensity solar radiation and night time. More than 12% of the total water production is during this time. The cost of adding a heat reservoir to a conventional basin solar still is about 10% of the total construction cost. Hence, the increase in the overnight productivity compensates the cost of having an integrated heat reservoir. The heat reservoir is integrated with the basin solar still; it does not require pumping systems and operators to change to the night mode usage. The output distilled water is tested and proved to be suitable for drinking and domestic usage. Because of the simple and cost effective design, it is easy to add an integrated heat reservoir to other types of solar stills [17].

A vapour adsorbent pipe network comprising activated carbon methanol pair was integrated with the basin. The losses from the bottom of the still are reduced, due to the sensible heat absorption by the activated carbon and the latent heat of vaporization by the methanol. A novel solar still integrated with a vapour adsorption bed at the basin was designed, fabricated and characterized, to enhance the productivity of the still, when sponges, gravels, sand, black rubbers and some of their combinations were used. The performance of the novel still was compared with that of a conventional solar still. It was found that the distillate production rate in the vapour adsorption ranged between 3.1 and 4.3 kg/m^2, while in the conventional still the distillate production rate was between 1.9 and 2.3 kg/m^2. The maximum deviation between the theoretical and experimental analyses was less than 6% [18]. A thermoelectric module is used to improve the temperature difference between the evaporating and condensing zones. The result showed that ambient temperature and solar radiation are indirectly proportional to the still performance, but wind speed increases the reduction in the productivity. The result shows that higher water productivity temperature of the thermoelectric device was lower than that of the walls. During the experiments, the maximum daily efficiency of the still is 7% [19].

The vacuum inside the solar still reduces the convective heat transfer. The solar still productivity during typical summer and winter days, for a solar still with and without vacuum, is examined. The results prove that the vacuum inside the solar still increases the water productivity by about 100%, and also, the absence of non-condensable gases inside the still when complete vacuum is applied, enhances the efficiency by about 100%. In winter days, the water produced from a solar still without vacuum is 1.45 L/d, which increases to 3.39 L/d with the vacuum. In summer days, the productivity of water with vacuum is 8.07 L/d compared to 3.79 L/d for the case without vacuum [20]. Minimizing the water depth and saline water, thin film with the very low warming up period enhance the performance of the solar stills. At a mass flow rate of 9.33 L/h, the productivity increases with the reciprocating speed to reach 5 L/m^2 at 2 cm/s. This value deviated by 21.32% from the most achieved productivity value of 6.355 L/m^2 at the optimum speed value of 1.625 cm/s. An accumulated productivity of 6.355 L/m^2 over only 10 working hours at a high efficiency of 77.35% was gained [21].

The solar water heater is integrated with the desalination stills to evaluate the continuous production of the distillate. Wick solar stills achieved a higher performance at 20° base tilt angle as compared to 30°. The rate of water flow is low at 20° base tilt angle, which enhanced the evaporation process, and increased the time of exposure to solar radiation. The hot brackish water feed continued during night time and the two base slope angles of the wick still (20° and 30°) increased the water productivity by about 215% as compared to the conventional basin still [22]. The performance evaluation for yield, energy and exergy efficiencies has been found to be in the range of 5.1–54.4 and 0.15–8.25% respectively, during the sunshine hours for 0.03 m water depth, which decreases with the increase in depth. The natural circulation rate increases up to 44 kg/h in an individual tube, when the radiation is at its peak and at high basin water temperature (80.0°C). The best combination has been found to be the integration of 10 evacuated tubes with a water depth of 0.03 m (total 52.5 kg water mass) in the basin. The daily energy and exergy efficiencies have been obtained as 33.0 and 2.5% and along with the maximum daily yield of 3.8 kg/m^2 [23].

7. Solar still with wick type

The floating blackened jute wick unit was arranged to appear not more than ½ cm above the water level in the solar still. To control the expected salt accumulation on the wick surface, the jute cloth was prepared in a corrugated shape. The use of a tracking system in the solar still outputs was almost doubled. The corrugated shape of the jute wick cloth type solar still solves the problem of salt scale formation on the basins. The dryness of a portion of the wick of the tilted type solar still during sunny hours was completely solved. Floating wick fibres make the entire surface of the cloth irradiated by the Sun wet at all times. The floating-wick type solar still can produce a higher output when compared with both the conventional basin-type and tilted-wick type solar stills with fewer problems in operation and maintenance [24]. The distillate productivities for the double- and single-pane glass covers are approximately 2.2 and 5.5 $L/m^2/d$ in the months of August and September in Las Vegas, respectively. The productivity of the weir-type still with a single-pane glass was also compared with that of the conventional basin types tested at the same location. The productivity of the weir-type still is approximately 20% higher. The weir-type designs avoid the scale formation on the absorber surface in the case of an inclined still. The reduction in the performance with a double-pane glass compared with a single-pane glass was investigated; the reduced temperature difference between the evaporating water and condensing glass in a still with double-pane glass used both as transparent cover and condensing surface, the productivity reduced [25]. Charcoal cloth was used as an absorber/evaporator material for saline water transport; the daily efficiency of the still was about 53% on clear days in summer. The lower the water input to the wick type, the higher the efficiency. In the indoor testing still, the efficiency decreased linearly with an increase of salinity of the input saline from 37.7 to 20% as the NaCl salt concentration increased from 0 to 10% by weight [26]. With the inclined reflector, the daily amount of distillate of a still is 15 or 27% greater than that the vertical reflector length which is half of or the same as the still's length, and this augmentation is almost the same as the results for a basin type still with an external reflector. The inclined reflector still's inclination, and the reflector's inclination should be set at 15° from the vertical, in order to increase the distillate productivity [27]. The increase in the residence time weir on each step, leads to a forced flow; the weirs are to keep the water film shallow, avoiding dry spots. Paraffin wax was used as the phase change material; hence, it acts as latent heat thermal energy storage. The thermal performances of the stills were compared on typical sunny and partially cloudy days; the result proved that the total productivity on sunny days was the same, but higher productivity was seen on partially cloudy days. For a partially cloudy day, the still with the latent heat thermal energy storage system had a higher productivity. For sunny areas, the still without latent heat thermal energy storage system is preferred, because of its simplicity and economy in operation. For the lower possible flow rate, the maximum productivity obtained (0.055 kg/min) are about 4.85 and 5.14 kg/m^2 d for still with and without latent heat thermal energy storage system on a sunny day (23 May 2009) [28]. During the off-shine, particularly at night, the use of the heat storage system, with 18 kg mass (2 cm thickness) of paraffin wax on the absorber plate keeps the operating temperature of the still high enough to produce distillate water. The results of the theoretical and experimental tests were compared, for the still with and without the phase change material. Important parameters affecting the performance of the still, such as the water level on the absorber plate and the distance between the water and glass surfaces, were theoretically investigated. The daily productivity was theoretically found to be 6.7 and 5.1 kg/m^2 d, for the still with and without phase change material, respectively. The theoretical results showed that the productivity of the still with phase change material was 31% higher than that without phase change material [29].

The solar still's inclination is fixed at 30° and the reflector's length is the same as the still's length at 30°N latitude. The bottom reflector can reflect the sunrays to the evaporating wick, and increase the distillate productivity of the tilted-wick still, when the reflector's inclination is larger than about 15° on the spring and autumn equinox and winter solstice, and 25° on the summer solstice, and the average distillate value for four days is the greatest, when the reflector's inclination is about 35° and about 13% greater than that of a conventional tilted wick still.

Adding a bottom reflector increases the daily amount of distillate, and is the highest on the summer solstice (25%) and lowest on the winter solstice (10%). The daily amount of distillate for four days, average value is the greatest when the reflector inclination is 35˚, and about 13% greater than that of a conventional tilted wick solar still [30].

The inclination angle of the reflector would be less than 25˚ throughout the year. Inclining the reflector backwards in winter and forwards in summer, the daily amount of distillate can be increased. The optimum inclination angle of the still would be smaller in summer (10˚) and larger in winter (50˚).

Both the use of a vertical reflector and the adjustment of the still inclination increase the daily amount of distillate throughout the year. Adjusting the inclination of both the still and reflector in any season, an increase over a conventional tilted wick still would average about 21%, throughout the year [31].

Floating cum tilted-wick type solar still has been presented, by incorporating the effects of water flowing over a glass cover, heat capacity of tilted-wick water surface and floating-wick water surface, and for these explicit expressions is derived. The numerical and experimental results of different temperature components of the proposed still are examined. The results showed that the relative standard deviations between the theoretical and experimental results are less than 8% (glass cover), 2% (tilted-wick water surface), 1% (floating-wick water surface) and 2% (flowing water at the lower end of the glass cover) on an average, for the working hours of the day. From the numerical results, the following conclusions have been drawn: (1) glass cover temperature decreases significantly; (2) the effect of water flowing over the glass cover has a remarkable effect on the production of distillate output during peak sunny hours and (3) the water flow rate of 1.5 m/s is the optimum, and beyond it, the efficiency decreases [32]. The concave wick surface was used for evaporation, whereas the four sides of a pyramid shaped still were used for condensation. A jute wick enhanced the evaporation surface area by absorbed solar radiation. Due to the capillary effect, the concave shaped wick surface increases the evaporation area.

The daily average distillate productivity of the solar still with a concave wick evaporation surface *l* is 4.0 L/m^2, and the maximum instantaneous system efficiency is 45% and average daily efficiency 30%. The maximum hourly yield was 0.5 L/h m^2 after solar noon [32].

The numerical analysis of the effect of the vertical flat plate external reflector on the distillate yield rate of the tilted-wick solar still was studied. The geometrical method to calculate the solar radiation reflected by the external reflector and absorbed on the evaporating wick, was examined. For four days (spring and autumn equinox and summer and winter solstice days) the numerical analysis of the heat and mass transfer in the still was conducted to predict the distillate productivity. The external reflector can increase the distillate productivity in all but the summer seasons, and the increase in the daily amount of distillate averaged over the four days is predicted to be about 9% [33].

Among the wick type solar stills, the floating wick type solar still has provided the maximum yield. The regenerative effect, i.e. with an optimum water flow rate of 1.5 m/s over the condensing glass cover enhanced the productivity of floating cum tilted-wick type solar still in significant manner. Jute wick and charcoal wick, cotton cloth and floating perforated black aluminium plate as an absorber medium in the basin have remarkable effect on the productivity of the still [34].

8. Reduction in water depth

The passive single slope solar still of 30˚ in summer climatic condition for 24 h on five different days for five different water depths from 0.04 to 0.18 m. The behavioural variation in the internal heat transfer coefficients with respect to the water depth in the still is proposed. It is understood that the heat transfer coefficients depend significantly on water depths. It is also observed that the nocturnal distillation is significant, in the case of higher water depths, because of the reduced ambient and the stored energy within it. A cross-sectional view of the schematic arrangement of experiment is shown in Fig. 2.

Convective and evaporative heat transfer coefficients are important for varying water depths, to optimize the same for the highest yield in summer climatic condition, for a single slope passive solar distillation unit. This will be useful for designing efficient solar distillation systems. It has also been seen that the highest output and efficiency are at lower depths [35]. Five different brine depths, namely, 1, 4, 6, 8 and 10 cm experimental also examined. The decreasing trend in productivity with the increase in brine depth and showed that the still productivity could be influenced by the brine depth by up to 48% [36]. The method to increase the productivity is to decrease the volumetric heat capacity of the basin [37].

9. Solar still with reflector

The basin type solar still with a flat plate external bottom reflector, extending from the front wall of the still, in addition to the internal (two sides and back walls) reflector, was theoretically analysed on three days (the spring equinox and summer and winter solstices) at 30˚N latitude.

To calculate the direct solar radiation reflected by the external bottom reflector and then absorbed onto the basin liner, a geometrical model is examined. A numerical analysis of heat and mass transfer in the still is performed. The distillate productivity increased by the external reflector can reflect the sunrays to the basin liner.

The results of the daily yield rate of the still with the internal and external bottom reflector is predicted to be 41, 25 and 62% greater than that of a conventional basin type still, on the spring equinox and summer and winter solstices.

The external reflector's inclination can be adjusted according to the seasons, when the glass cover's inclination angle is fixed at 20˚ horizontally and the length of the basin liner is the same as the length of the external reflector.

The effect of the internal reflector is greatest on the winter solstice and smallest on the summer solstice, while the effect of the external reflector is the greatest on the summer solstice and smallest on the winter solstice.

10. Scope for the future research

Further research of the solar still may be focussed on the following factors:

(1) A composite material with higher thermal conductivity for the basin material.
(2) Studying the effect of the water depth with nanomaterial in the solar still.
(3) With the diffused radiation in indoor condition, examine the effect of a simple solar still coupled with black wick material.
(4) Innovative single model solar still design should be done, which supports all types of vegetation in the world at minimum cost.
(5) Black colour material with higher thermal conductivity for the absorbing material, which acts as energy storing material enhances productivity at night.
(6) Theoretical, experimental, numerical and simulation results should be comparable with the minimum loss such that the model can be designed for fabrication.

11. Conclusion

As a result of the above revision on the various types of solar stills, the following conclusion can be drawn:

The comparative studies on the various designs of type solar stills with their productivity are depicted in Table 2.

A solar still integrated with floating porous absorbers, extended porous fins, effluent using fin type, fin plate, sponges, pebbles, black rubber, sand, wick, depth of water, latent heat, concentrator internal and external reflectors, concave wick evaporation surface, and reciprocating spray feeding and separately or their combination, can enhance the productivity of the solar still.

The review representing the specific inferences drawn from the analysis of various type solar still by various authors will pave the way for the common person to grasp the previous designs, and performance and to fabricate an ultra-new design with optimum design parameters, for increasing the productivity.

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