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Productivity enhancement of a single basin and single slope solar still coupled with various basin materials

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ABSTRACT

In today's world, access to distilled water has become very constrained by the problem of growing demand. To solve the distilled water problem, a solar still with different arrangements of basin materials has been made at low cost. Evaporation and condensation are the basic principles of a solar still; the rate of evaporation is directly proportional to the temperature of the basin. The main technique to improve the basin temperature is to have the basin coupled with a helical copper coil, aluminium fins, a long hollow stainless steel tube and an iron plate. The experimental validation determines the increased nocturnal production in the solar stills. The performance of the conventional solar stills is compared with that of the basin integrated solar still. The solar still with various basin materials arranged in a lengthwise direction was more effective, compared with the one arranged breadthwise. The solar still is designed in such a way that the helical spherical coil, aluminium fins, stainless steel tube and an iron plate can fit into the same basin below 2 cm thickness, and decrease the preheating time.

Keywords: Performance; Stills; Desalination; Design; Water depth; Basin; Glass; Ambient; Solar radiation; Solar energy

1. Introduction

The solar thermal energy system utilises the energy of the sun, to heat the waste water from any source, to get a pure distillate. One of the popular apparatuses that harness the solar energy is the solar still [1]. A solar still's productivity can be enhanced when it is integrated with various basin materials separately or in combination [2]. The optimum tilt angle increases the maximum production rate of the solar still [3]. The increase of the inclination in summer and winter decreases the evaporative heat transfer coefficient [4]. The double-slope solar still is coupled with a mild steel plate and different wick materials, viz. light cotton cloth, coir mat, sponge sheet and waste cotton pieces. The light black cotton cloth is an effective wick material for the still with an aluminium rectangular fin arranged in different configurations. The theoretical values of the water and glass temperatures are compared with those of the Dunkle model and they showed a good result with the theoretical and the actual experimental values [5]. The active double-sloped still with harmonic vibratory excitation has the average daily efficiency (60%) and productivity of 5.8 l/m^2 d. The night-time production ranges from 38% to 57%. The optimum tilt angle increases the

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productivity of the system [6]. The clear transparency of the glass top cover during the experiment due to the force condensing system sucks the water vapour from the evaporator zone, condenses it in a separate zone, and does not allow it to condense on the glass cover inner surface [7]. An array of the simple solar stills' production cost (\$/m^3 distillate water) in remote areas in Oman is 74/1,000 gal (16.3 \$/m^3) [8]. The basin-type solar still integrated with the salt decreases the distilled water production [9]. The single-basin double-slope solar still with the different absorbing materials enhances the productivity of fresh water. The increase in the productivity of the fresh water decreases the effective insolation area of a solar still [10]. The single-basin solar still with the black volcanic rock avoids the corrosion problem and increases the productivity by 20%, compared with the coated and uncoated metallic wiry sponges [11]. The single- and double-basin solar stills with the same basin area tested in summer for different depths with wick, porous and energy storing materials (iron pieces) have the highest productivity for both basins [12]. The solar still with the jute cloth reduces the heat loss at the bottom and raises the saline water temperature to 74˚C compared with the conventional still saline water temperature of about 76˚C [13]. The maximum temperature of the brackish water is close to the melting temperature of the PCM. PCM (paraffin) increases the temperature difference between the inner glass cover surface and the unpalatable water surface, which induces a faster evaporation process [14]. The basin-type solar still with a water level of 1 cm and 3 cm test, showed that the minimum water level of 1 cm has the maximum productivity [15]. The saline water fed through a controlled transverse reciprocating spraying system to the corrugated steeped shape absorber of the solar still, gives an accumulated productivity of 6.355 l/m^2/10 h, and the efficiency of the system has improved to 77.35%, when compared with the conventional still [16]. The solar radiation intensity is proportional to the still productivity [17]. The water depths significantly depend on the heat transfer coefficients [18]. The decreases in the air flow rate do not change the system productivity [19]. A passive solar still with a separate condenser has a distillate productivity of 62% higher than that of the conventional still [20]. The experimental and theoretical results showed a discrepancy, due to the air bubbles that occurred between the wick and the partition plate and/or reabsorption of the condensate by the wick [21]. A basin-type solar still with external reflectors, which are inclined, slightly makes the reflected sunrays hit the basin material of the solar still. The experimental and the theoretical results show 6% deviation, especially on clear days [22]. In order to determine the effectiveness of the inclination of the external reflector with a basin-type solar still, a numerical analysis of the heat and mass transfer in the still is proposed. Any glass cover angle of the still with an inclined external reflector can increase the distillate productivity of the still. A basin-type solar still with a vertical external reflector would be smaller or even negligible for a still with a larger value for the glass cover angle [23]. A basin-type solar still with both the internal and the external reflectors increases with a decrease in the inclination of the glass cover [24]. The increase in the internal reflector's area and with the glass cover angle at any reflector angle increases the daily productivity [25]. In September, increasing the inclination angle of the external reflector from 0˚ or 10˚ to 20˚ or 30˚ has an adverse effect on the productivity. In October, a maximum difference of 8% at all inclination angles affects the productivity. June, July and August have an adverse effect on the productivity of the solar still, due to increases in the inclination angle of the external reflector from vertical to 30˚ [26]. The stepped solar still has the trays (5 mm depth × 120 mm width) integrated with the reflectors, and this, the distillate productivity of 75% higher than that of the conventional still. The daily efficiency of conventional stills, and the ones modified with internal reflectors is approximately 34% and 56%, respectively [27]. A vertical multiple-effect diffusion-type solar still, coupled with a flat plate reflector (angle 10˚) to determine the productivity decreases by 15%, with 1.5 times increase in the feed rate of the saline water to the wick or an increase in the diffusion gaps between partitions from 5 mm to 10 mm [28]. The distillate productivity of the still with an inclined external reflector (optimum inclination) compared with the conventional still distillate productivity is 29, 43 or 67%, and with a glass cover inclination it is 10˚, 30˚ or 50˚, respectively, and the length of the external reflector is half the still's length [29]. A one step azimuth tracking tilted-wick solar still with a vertical flat plate reflector has the productivity of 40, 57, 40 and 27% over the productivity of conventional tilted-wick still on the spring equinox, summer solstice, autumn equinox and winter solstice, respectively [30]. The structure of the first distilling cell of a vertical multiple-effect diffusion solar still is coupled with a flat plate reflector similar to the vertical single-effect diffusion solar still, and the experimental results and the theoretical predictions vary with about ±7% error margin except for the results on a cloudy day [31]. A solar still with reflectors integrated with black dye (α_w = 0.90) improves the water absorptivity [32]. A single-basin single-slope plastic (Plexiglas black 3 mm thick) solar still has a variation in its experimental efficiency from 10 to 34% [33]. For the increases in water depth (4, 6 and 8 cm) in the inverted absorber solar still integrated with refrigeration cycle has the highest productivity (6.4, 10.08 and 9.5 l/d). For the increases in water depth (4, 6 and 8 cm) in the inverted absorber solar still has the decrease in the productivity (3.41, 3.24 and 2.92 l/d). The nocturnal productivity was high compared with the daytime production in the inverted absorber solar still integrated with the refrigeration cycle [34]. The concentrator-coupled hemispherical basin solar still, with PCM (paraffin wax) and without PCM, has a productivity 4,460 $ml/m^2/d$ and 3,520 $ml/m^2/d$, respectively [35]. A single-basin solar still with PCM (stearic acid) doubled the convective heat transfer coefficient, and the evaporative heat transfer coefficient is increased by 27% on using 3.3 cm. In summer, the productivity of the solar still with and without PCM is 4.998 (kg/m^2 d) and 9.005 (kg/m^2 d), respectively. A low water depth of the basin on PCM (stearic acid) is more effective in winter [36]. The tilted-wick solar still with a flat plate bottom reflector has the highest productivity in the summer solstice (25%) and the lowest productivity in the winter solstice (10%) [37]. The tilted-wick solar still with an external flat plate reflector has the maximum productivity by inclining the reflector backwards in the winter and forwards in summer; the optimum inclination angle of the still in summer is (10˚) and in winter (50˚) [38]. The basin-type solar still with the flat plate external bottom reflector and the length of the external reflector is the same as the length of the basin surface, and the glass cover's inclination angle is fixed at 20˚ from the horizontal plane [39]. For a basin-type solar still with internal reflectors, when the angle of the glass cover is 20˚, the daily amount of distillate for the entire year averaged 22% [40]. The solar still at water depths (d_w) 0.01, 0.02 and 0.03 m^2 has the daily yield of 152, 1.931, 0.826 kg/m^2 d, respectively. The solar still daily yields lower than the inverted absorber solar still [41]. In the single-slope passive solar still, increasing the water depth decreases the productivity up to 0.1 m; for greater depths (0.1 m) the productivity becomes almost constant [42]. The comparison of the different basin materials integrated with solar stills is shown in Tables 1 and 2.

Table 1
Comparison of the productivity of various type solar stills, with and without fin material

SI no	Type of system	Construction details	Source, Date, Day	Modification	Results
1.	Conventional solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work, 03/01/2014,1	Nil	1.00 kg/m^2 d
2.	Single basin solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 27/01/2014,2	1. Helical copper coil length-wise direction	1.79 kg/m^2 d
				2. Helical copper coil breadth-wise direction	1.74 kg/m^2 d
3.	Single basin solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 28/01/2014,3	1. Aluminium fins length-wise direction	1.80 kg/m^2 d
				2. Aluminium fins breadth-wise direction	1.75 kg/m^2 d
4.	Single basin solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 29/01/2014,4	1. Stainless steel tube length-wise direction	1.67 kg/m^2 d
				2. Stainless steel tube breadth-wise direction	1.60 kg/m^2 d
5.	Single basin solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 30/01/2014,5	Iron plate	1.34 kg/m^2 d
6.	Single basin solar still	basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 31/01/2014,1	Helical copper wire and Aluminium fins	1.83 kg/m^2
7.	Single basin solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 03/02/2014,8	Helical copper wire and stainless steel tube	1.86 kg/m^2
8.	Single basin solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 04/02/2014,8	Aluminium fins and stainless steel tube	1.82 kg/m^2
9.	Single basin solar still	Basin area = 1 m^2 Slope = 13˚glass cover = 3 mm thickness	Present work 05/02/2014,8	Helical copper wire, Aluminium fins and stainless steel tube	1.92 kg/m^2

Table 2
Comparison of different basin materials integrated with the solar still

SI no	Type of still	Specifications	References	Integrating basin material	Results of yield
1.	Single-basin solar still	Basin area = 250 mm slope = 13° Glass cover = 5 mm thick	[1]	Sea water	0.25 $l/m^2/d$
2.	Solar still	Basin area = 1 m^2	[2]	Without air	The efficiency 100%
3.	Solar still	Basin area = 1 m^2 1. Tilt angle = 60° 2. Tilt angle = 25°	[3]	1. winter 2. autumn/spring	10 l/m^2 d 4.5 l/m^2 d
4.	Solar still	Basin area = 1 m^2 40° inclination	[4]	Acrylic cover	30% decrease in production
5.	Double slope solar still (Mild steel Plate)	Basin area = 2.3 m × 1 m slope = 30° Glass cover = 4 mm thick	[5]	Black cotton cloth	0.002 kg/s
6.	Active double-sloped solar still	Basin area = 2.064 m^2. polycarbonate glass cover = 30°	[6]	Backed helical wires	3.4 l/m^2 d
7.	Solar still	Basin area = 1 m^2	[7]	Back wall of the evaporator	28% increase in efficiency
8.	Simple solar still two slopes	Basin area = 1 m^2. slope = 23° insulation thickness = 0.1 m	[8]	Asphalt coating with shallow water basin	4.15 Kg/m^2 d
9.	Two sloped basin type solar still	Stainless steel basin area = 3 m^2. slope = 15, 25, 35, 45 and 55° glass cover = 4 mm thick	[9]	Black rubber mat	7 l/d
10.	Single-basin solar still with double slopes	Basin area = 3 m^2. slope = 10° Glass cover = 1.1×1 m^2	[10]	Black rubber mat Black ink Black dye	38% increase in production 45% increase in production 60% increase in production
11.	Single basin solar still	Basin area = 80 cm × 10 cm slope = 32° Glass cover = 4 mm thick	[11]	Coated metallic wiry sponges Uncoated metallic wiry sponges Black volcanic rock	38% increase in production 45% increase in production 60% increase in production
12.	Simple solar still	Basin area = 0.9 m×0.7 m×0.008 m slope = 30°. Glass cover = 4 mm thick	[12]	1. Single basin 2. Double basin	3.58 l/d 5.68 l/m^2d
13.	Regenerative solar still	basin area = 1 m× 0.5 m slope = 25° Glass cover = 0.003 m thick	[13]	Jute cloth	12% increase in production
14.	Single basin solar still	Basin area = 1 m^2 glass sheet = 0.003 m thick	[14]	PCM(2nd day) Paraffin wax Paraffin52–54 Paraffin C18 PCM(3rd,4th day)	40% increase in production 8% increase in production
15.	Solar still	Basin area = 128 cm × 75 cm × 50 cm glass sheet = 4 mm, 87% transmittance mm thick slope = 17°	[15]	1. Charcoal 2. Solar collectors and storage systems	11–18% more than black-paint 23–92% more than blackened rock-bed 194% at a cost some three times higher than the basin price

16.	Stepped basin still	Basin area = stepped basin still slope = 10°	[16]	Reciprocating spray feeding system mass flow rates of 3.64, 4, and 6.68 l/h	Mass flow rates of 3.64, 4, and 6.68 l/h 6.25, 6.355 and 6.05 l/m^2 increase in productivity
17.	Asymmetric green house type solar still	Basin area = 1 m^2 slope = 30° 35°	[17]	Flat-plate collector	36% increase in productivity
18.	Single slope, solar still	Basin area = 1 m^2, slope = 30° glass reinforced plastic sheet = 0.5 cm thick	[18]	Water depths from 0.04 m to 0.18 m	3.66% increase in productivity
19.	Stepped solar still	Basin absorbitivity = 0.9 insulation thickness = 20 mm	[19]	Heating and humidification greenhouses	4.92 L/m^2 63% increase in productivity
20.	Solar still	Basin area = 1×1 m^2. slope = 10°glass sheet = 1.1× 1.1 m^2 mm thick	[20]	Separate condenser basin 1 in the evaporation chamber basins (2 and 3) in the condenser chamber,	62% increase in productivity 60, 22 and 18%
21.	Vertical multiple-effect diffusion solar still	Basin area = 0.097 m^2 slope = 30°glass sheet = 5 mm thick	[21]	Flat plate reflector	13.3 kg/m^2 d
22.	Basin type solar stills	Basin area = 1 m^2. slope = 20° external reflector = 10°,	[22]	Internal and external reflectors	70% to 100% increase in productivity
23.	Basin type still in winter	Basin area = 1 m^2. slope = 30°N	[23]	External flat plate reflector	16% greater than that with the vertical external reflector 2.3 Times as large as that of the still with neither the internal nor the external reflector on a winter solstice day
24.	Basin type still in summer	Basin area = 1 m^2 slope = 30°N	[24]	External reflector	7% or 12% when the length of the external half of or the same as the still's length
25.	Simple solar still in winter	Basin area = 1.0 m^2 (1.54 × 0.65 m^2). slope = 33.3° N°	[25]	External reflector	2.45 times the nominal simple still
26.	Basin type solar still in various seasons	Basin area = 1.0 m^2 slope = 33.3° N°	[26]	Internal reflector	Increase ratio 19.9% and 34.5, 34.4, 34.8 and 24.7%
27.	Stepped solar still	Basin area = 1.0 m^2 slope = 31.07°N	[27]	With and without internal reflectors	75% and 57%, productivity
28.	Multiple-effect diffusion-type solar still	Basin area = 1 m^2, Azimuth angle of stills = 90° and 45° on a spring equinox and winter solstice	[28]	Flat plate reflector	Decreases about 15% with an increase in the diffusion gaps between partitions from 5 mm to 10 mm
29.	Basin type solar still with internal and external reflector	Basin area = 1 m^2, glass cover inclination of 10–50°	[29]	1. Internal reflector, 2. Conventional basin type still	1.29% productivity 2.43% productivity

Table 2 (*Continued*)

SI no	Type of still	Specifications	References	Integrating basin material	Results of yield
30.	One step azimuth tracking tilted-wick solar still	Basin area = 1 m^2, slope = 30°N.	[30]	Vertical flat plate reflector	41% productivity
31.	Vertical diffusion solar still	Basin area = 1 m^2, slope = 33.2°.	[31]	Flat plate reflector	5 or 6 times as large as that of a single-effect still
32.	Single basin solar still	Basin area = 1 m^2, slope = 45° glass sheet = 5 mm thick	[32]	Reflectors	Improves the still productivity considerably
33.	Plastic solar still	Basin area = 1.446 m^2. slope = 20°.	[33]	Water depth 2 cm	2.1 L/m^2/d
34.	Inverted Solar Still	Basin area = 400 mm length and 200 mm width, glass cover = 5/16 inches thickness	[34]	Refrigeration Cycle	Daily productivity 6.7 kg/m^2 d. Increase of the water depth from 4 to 6 cm increased the productivity by 57.5%.
35.	Hemispherical basin single slope solar still	slope of 11	[35]	Concentrator with phase change material	26% increase in productivity
36.	Single slope-single basin solar still	Basin area = 1 m^2, slope = 22.76°, glass cover = 0.3 cm mm thickness	[36]	PCM as a storage medium	9.005 (kg/m^2 d) with a daily efficiency of 85.3%
37.	Tilted wick solar still	Basin area = 1 m^2. slope = 30°.	[37]	Flat plate bottom reflector	Increase in the daily amount of distillate of a conventional tilted wick solar still about by 13%.
38.	Tilted wick solar still	Basin area = 1 m^2. slope = 10°. glass cover of 5 mm thickness	[38]	External flat plate reflector	Daily amount of distillate increase 21%.
39.	Basin type solar still	Basin area = 1 m^2. slope = 20°. glass cover of 3 mm thickness	[39]	Flat plate external bottom reflector	Distillate 41, 25 and 62% conventional basin type still on the spring equinox and summer and winter solstices
40.	Basin type solar still	Basin area = 1 m^2. slope = 40°.	[40]	Internal and external reflectors	Daily amount of distillate 48%
41.	Inverted absorber solar still	Basin area = 1 m^2 slope = 23°.	[41]	Water depth and total dissolved solid 0.01, 0.02 and 0.03 m	6.302, 5.576 and 4.299 kg/m^2
42.	Solar still	Basin area = 1 m^2 slope = 30°.	[42]	Water depth 0.02	32.57% and 32.39% more than water depth 0.18 m

1.1. Objective

(1) To carry out the performance of a solar still with different arrangements of various basin materials.
(2) To compare the results of the conventional still with those of the basin of the solar still integrated.

2. Experimental set-up

The basin of the still is made of a 2 mm galvanised iron (GI) sheet, selected due to its normal conductivity, low cost, easy portability and accident avoidance in the experiment. The condensing surface in the still is simply a $1.1 \times 1.1\ m^2$ sloping glass cover. From the plastic storage tank, saline water is given as input to the basin of the solar still, and makes the saline basin, which contains a salinity of 700 mg/l. Saline water flows through the flexible hoses and a valve (v1) controls the mass flow rate [1]. The distilled water condensed on the glass surface is collected by an anchor, attached at the bottom of the sloping cover and directed to a measuring jar. The distillate has a salinity of 20 mg/l, as shown in Fig. 1. The optimum cover tilt angle was selected as 13˚, which is the latitude of Chennai, Tamil Nadu, India. The increase of the tilt angle results in increased thermal losses from the cover. The condensate droplet of the inner surface cover falls into the basin, if the cover tilt angle is too low [3,4]. The glass covers faced south, during all the experiments, in order to receive the maximum solar radiation. The experiments were conducted at the Faculty of Mechanical Engineering, Institute for Energy Studies, Anna University, Chennai, from 08.30 am to 08.30 pm, in the months of January and February 2014. The whole experimental set-up is kept in the south direction to receive the maximum solar radiation throughout the year. The solar radiation, atmospheric temperature, basin temperature, glass temperature and distilled water yield rate were measured every 30 minutes. The solar radiation is measured by the pyrometer; K-type (50–150˚C) thermocouples connected to the digital thermometer are used to measure the temperature, and the yield is measured by the measuring jar, which has a capacity of 1,000 ml.

3. Results and discussion

3.1. Conventional solar still

The conventional solar still is one without the integration with the basin, as shown in Fig. 1. The parametric loss can be reduced by choosing the basin area of the still as $1.0\ m^2$ compared with other lower area. Saline water is given as the input to the basin of the conventional solar still, continuously from the plastic storage tank through the valve (v1) to keep the water depth constant. The minimum water depth of 2 cm is maintained in the solar still basin, in order to avoid the dry spots. The surface of the basin is painted black to increase the water absorptivity. The solar still is faced south in order to receive the maximum solar radiation in all seasons. The sunrise (solar radiation) falls on the basin containing the saline water through the transparent (glass) cover (5-mm thick) [1]. The glass cover tilt angle was chosen as 13˚, which is the test area of the latitude. Saline water gets evaporated

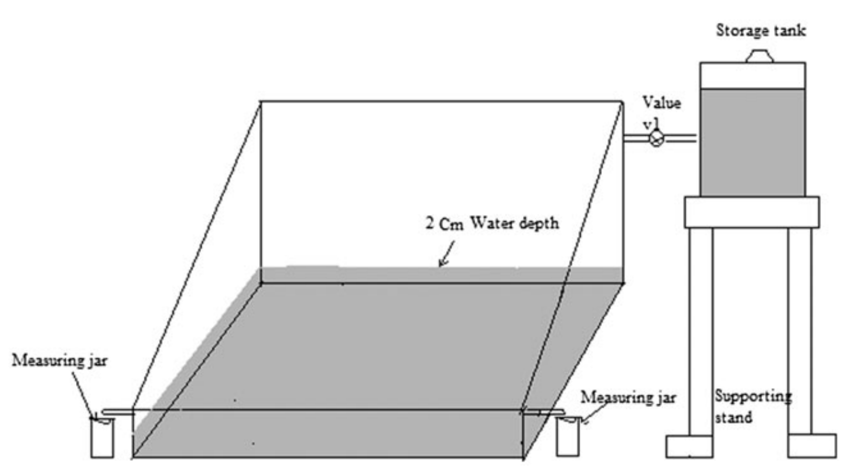

Fig. 1. Top view of the conventional solar still.

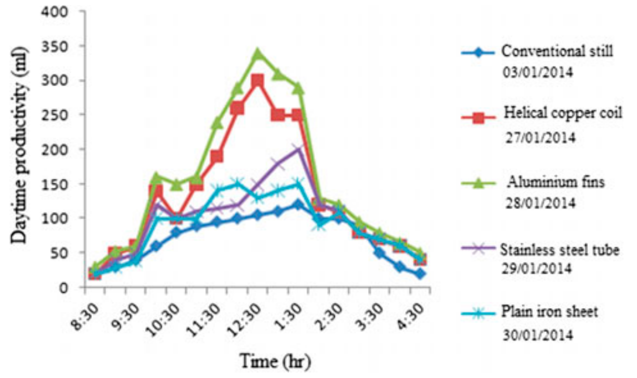

Fig. 2. Daytime productivity of the various basin materials integrated separately.

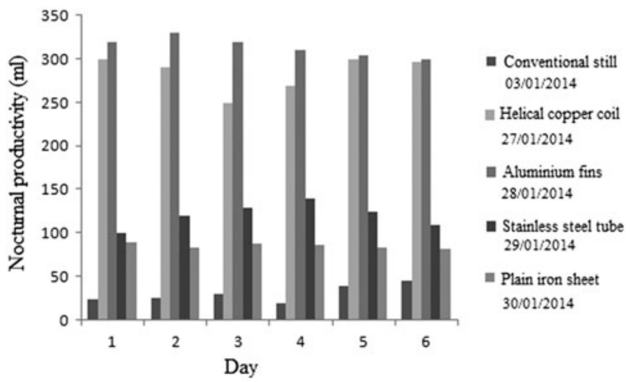

Fig. 3. Nocturnal productivity of the various basin materials integrated separately.

due to the effect of solar radiation and the formation of the water droplet (condensate), which occurred on the inner surface of the sloping glass cover, and runs down into the collector channel at the edges. The collector channel is directed to the measuring jar through the flexible hoses. Finally, the distillate is collected in the measuring jar. The daytime productivity increased in the conventional solar stills from 11.00 am to 03.00 pm, as shown in Fig. 2, and the nocturnal productivity decreased in the conventional solar stills from 04.00 pm to 08.30 pm, as shown in Fig. 3.

4. Technique to improve the basin temperature: results of stills with the same water depth (2 cm)

4.1. Effect of the solar still integrated with a helical copper coil

The length of the helical copper coil is 60 m. The basin of the solar still integrated with a helical copper coil is shown in Fig. 2. The stretched helical copper coil acts as a thermal storage system, which increases the productivity of the solar still [6]. The study determines the factors improving the nocturnal production of the solar stills. The performance of the conventional solar stills is compared with that of the solar still, with the helical copper coil arranged in different arrangements; viz. in the lengthwise and the breadthwise directions. The solar still with the helical copper wire in the lengthwise direction was more effective, compared with the breadthwise one by 4–5%, as shown in Table 1 [6]. Compared with the conventional still, the solar still with the helical copper coil has higher productivity, as shown in Fig. 13. The stretched helical copper wires were painted black to improve the heat transfer rate. The salinity of the feed water is high; due to this, the depreciation of the material is high, to avoid this, the stretched helical copper wires are painted black. The experimental observation demonstrates that the collection process of the condensation is increased, which enhances the nocturnal

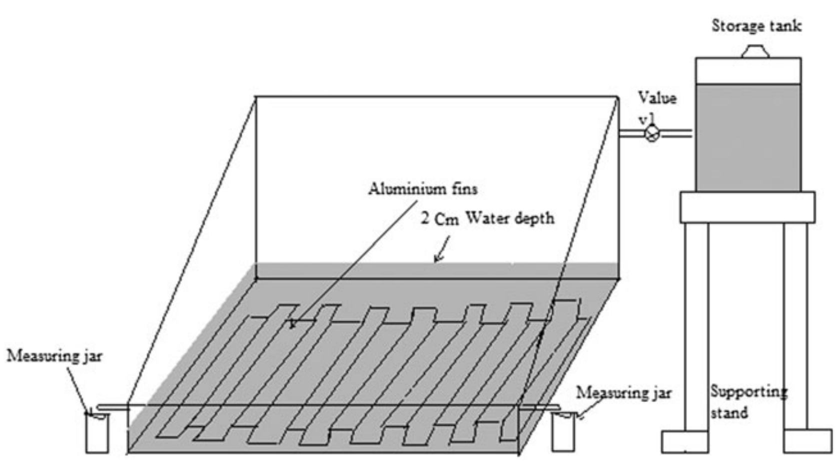

Fig. 4. Top view of the solar still integrated with aluminium fins.

productivity. Using good isolation, the stored energy capacity can be improved by increasing the water depth. The design parameters of the helical copper segment system are: the coil has a diameter of 1.8 cm, the copper wire has a diameter of 1.5 mm and the mass of the helical coiled wires is 4.55 kg.

4.2. Effect of the solar still integrated with aluminium fins

A new approach to enhance the contact surface area in the solar still, is by introducing seven aluminium fins with the height, length and breadth of 40 mm, 1,000 mm and 1 mm, respectively, as shown in Fig. 4. The aluminium fins act as energy storing material, and make the continuous process of desalination even after sunset. The solar still with aluminium fins arranged lengthwise was more effective compared with the breadthwise one by 4–5%, as shown in Table 1 [5]. The aluminium fin acts as an internal reflector due to its shiny surface; hence, some of the solar radiation received through the cover gets reflected; to avoid this, it is painted black, to improve the heat transfer rate. Compared with the conventional still, the solar still with aluminium fins has a higher performance, as shown in Fig. 2. The aluminium fin has the highest nocturnal production compared with the basin of the solar still integrated with the helical copper coil, plain iron sheet and stainless steel tube, as shown in Fig. 3.

4.3. Effect of the solar still integrated with a plain iron sheet

The basin of the solar still integrated with a plain iron sheet is shown in Fig. 6. The iron plate in the solar still divides the basin into two portions, a

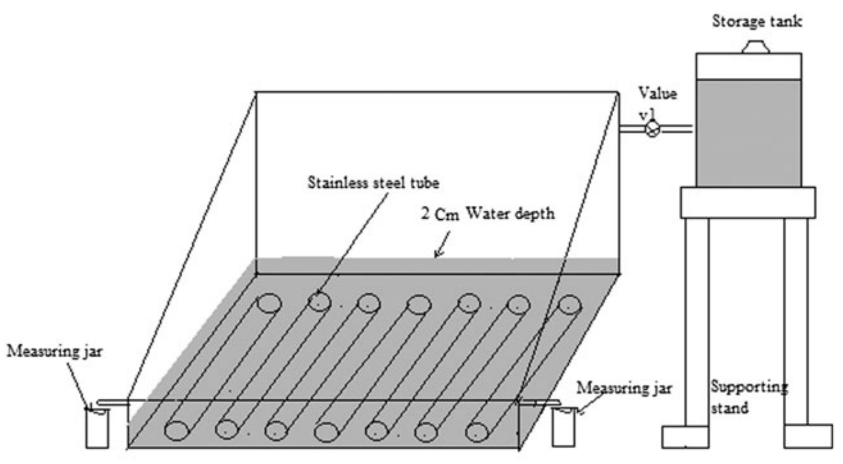

Fig. 5. Top view of the solar still integrated with a stainless steel tube.

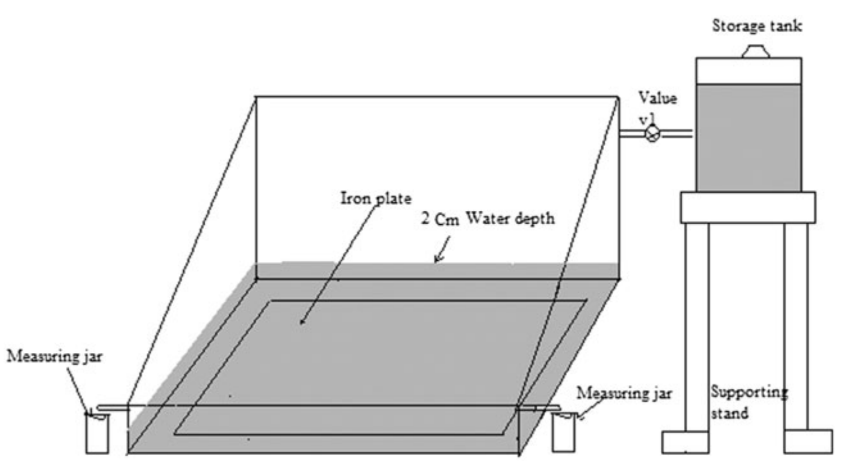

Fig. 6. Top view of the solar still integrated with an iron plate.

shallow zone and a heat storage zone [7]. The black painted iron plate area of 0.85 m^2 is chosen, due to its low cost as a heat storage medium, made in the suspension mode, at a height of 1.5 cm. Compared with the conventional still, the solar still with the plain iron sheet has higher productivity with high cost, as shown in Fig. 2.

4.4. Effect of the solar still integrated with a stainless steel tube

The basin of the solar still integrated with a stainless steel tube is shown in Fig. 5. The stainless steel hollow tube acts as a heat storage medium, utilising the solar radiation in the morning and releasing the heat during the night. The hollow tube is painted black, to avoid corrosion. The design parameters of the stainless steel tube system are: the tube has a diameter of 1.8 cm; a tube thickness of 1.5 mm; and the mass of tube is 4.55 kg. The basin of the solar still integrated with the stainless steel tube has the daytime productivity increased from 01.30 pm to 02.00 pm, as shown in Fig. 2.

4.5. Effect of the solar still integrated with the helical copper coil and aluminium fins

Similar to Section 3.1, the gap between the aluminium fins is filled with the helical copper coil, and they form the layer of energy storage material, which is shown in Fig. 7. The contact surface area and the nocturnal productivity increased in the solar still from 04.00 pm to 08.30 pm, as shown in Fig. 8. Among the combinations of the two basin materials integrated into the solar still, the helical copper coil and aluminium fin gave the best results (helical copper coil and stainless steel tube, aluminium fin and stainless steel tube), as shown in Table 1. The basin of the solar still integrated with the stainless steel tube has the daytime

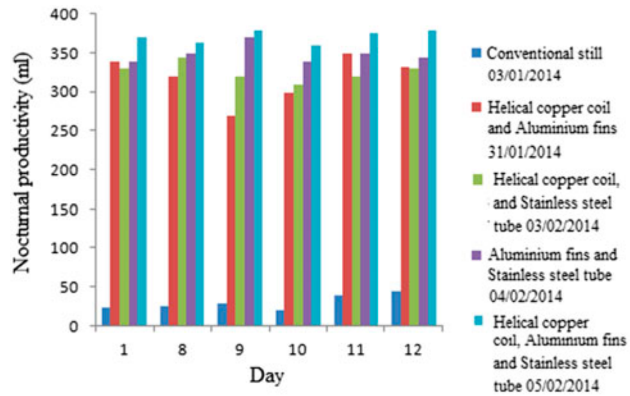

Fig. 8. Nocturnal productivity of the various basin materials integrated in combination.

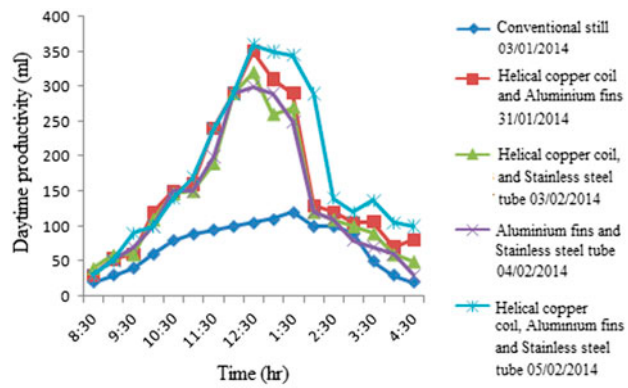

Fig. 9. Daytime productivity of the various basin materials integrated in combination.

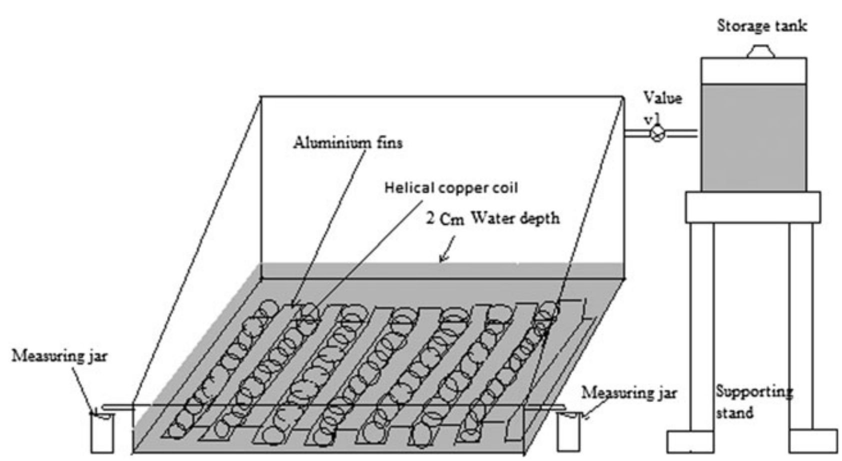

Fig. 7. Top view of the solar still integrated with a helical copper coil and aluminium fins.

productivity increased from 11.30 am to 01.00 pm, as shown in Fig. 9.

4.6. Effect of the solar still integrated with the helical copper coil and stainless steel tube

Similar to Section 3.1, the combination of the helical copper wire and the stainless steel tube with the solar still is shown in Fig. 10. The decrease of the preheating time required for the saline basin water is shown in Fig. 9, which is from 09.00 am to 03.30 pm, and the nocturnal productivity increased in the solar still from 06.00 pm to 08.30 pm, as shown in Fig. 8.

4.7. Effect of the solar still integrated with the aluminium fins and stainless steel tube

Similar to Section 3.2, the gap between the aluminium fins is filled with the stainless steel tube as shown in Fig. 11, and it increases the contact surface area. The nocturnal productivity increased in the solar still from 04.00 pm to 08.30 pm, as shown in Fig. 8. Hence, the productivity is enriched. The daytime and nocturnal productivity of the various basin materials integrated in combination, is higher, compared with the daytime and the nocturnal productivity of the various basin materials integrated separately (the helical copper coil and a plain iron plate).

4.8. Effect of the solar still integrated with the helical copper coil, aluminium fins and stainless steel tube

The basin of the solar still integrated with a helical copper coil is shown in Fig. 12. The helical spherical coil, aluminium fins and stainless steel tube were added to the basin, in order to increase the productivity. The bottom and side heat losses are much less. The helical spherical coil, aluminium fins and stainless

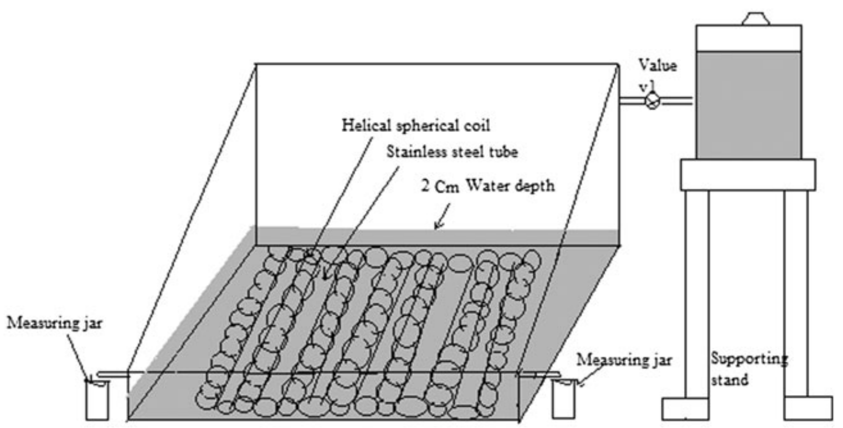

Fig. 10. Top view of the solar still integrated with a helical copper coil and stainless steel tube.

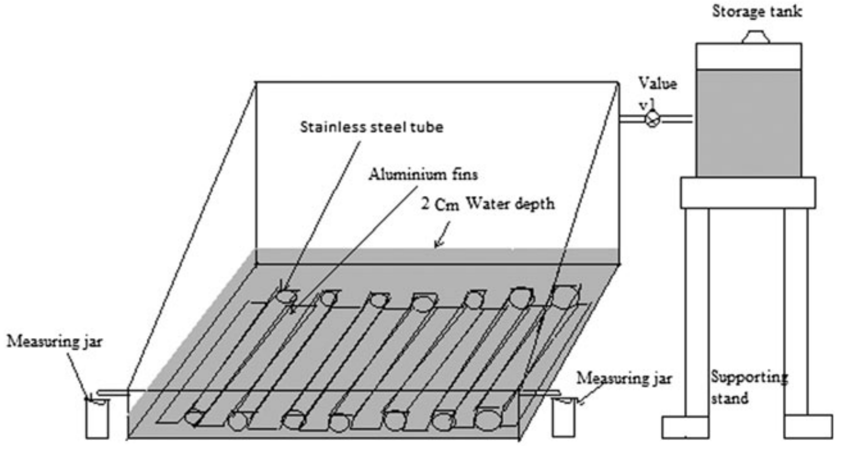

Fig. 11. Top view of the solar still integrated with aluminium fins and stainless steel tube.

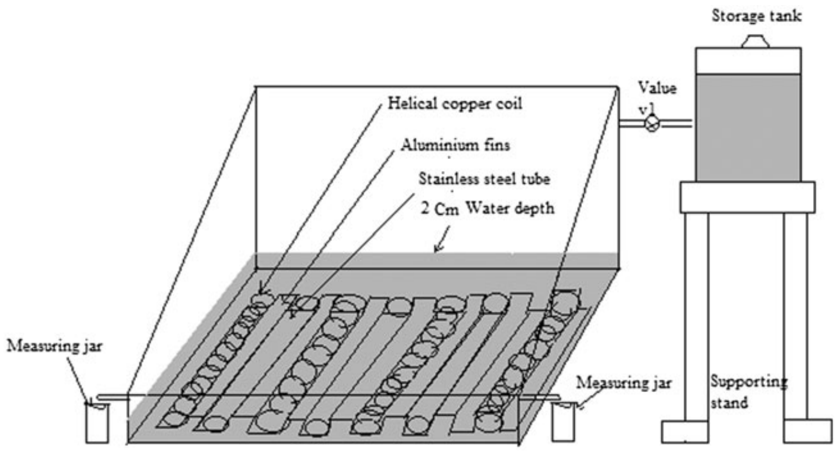

Fig. 12. Top view of the solar still integrated with a helical copper coil, aluminium fins and a stainless steel tube.

Table 3
Effect of the basin integrated solar still on productivity and cost

Basin of the solar still integrated with	Productivity (%)	Cost ($)
Helical copper wire	75	0.1023
Aluminium fins	74	0.0981
Stainless steel tube	60	0.0932
Iron plate	34	0.0997
Helical copper wire and aluminium fins	86	0.1238
Helical copper wire and stainless steel tube	83	0.1141
Aluminium fins and stainless steel tube	82	0.1102
Helical copper wire, aluminium fins and stainless steel tube	92	0.1355

Note: The cost of 1 l of water from the conventional solar still is 0.029 $ compared with the cost of 1 l of water from the solar still integrated are shown below.

steel tube form the medium to provide a large evaporation surface, and utilise the latent heat of condensation, and the nocturnal productivity increased in the solar still from 04.00 pm to 08.30 pm, as shown in Fig. 8. The average daily productivity has been 92%, higher than that of the conventional solar still, which was augmented by integrating the helical copper wire, aluminium fins and stainless steel tube at the basin. The effect of the integrated basin of the solar still on productivity is shown in Table 3.

5. An economic analysis of the solar stills

5.1. An economic analysis calculation for the conventional solar still

The total fixed cost of the conventional solar still includes the sum of the insulation, the basin material, the paint, the flexible hoses, a valve and the auxiliary system. The total fixed cost of the conventional solar still is $F = 25$ $. The total cost of the conventional solar still C is equal to the sum of the fixed cost and the variable cost. Assuming that the variable cost V equals 0.3 F per year [43] and the expected still life is 10 years, then $C = 25 + (0.3 \times 25 \times 10) = 100$ $. The minimum average productivity of the solar still is 1.00 l/d from the experimental result. Chennai is a suitable hot place, where the solar still can operate for 335 d. The total productivity of the solar still lifetime = 1 × 10 × 335 = 3,350 l. The cost of 1 l of water from the conventional solar still = 100/3,350 = 0.029 $ (Fig. 1).

5.2. An economic analysis of the solar still integrated with a helical copper coil

The total fixed cost of the solar still integrated with a helical copper coil $F = 150$ $. The total cost of the conventional solar still C is equal to the sum of the fixed cost and variable cost. Assuming that the variable cost V equal 0.3 F per year [43] and the expected still life is 10 years, then $C = 150 + (0.3 \times 150 \times 10) = 600$ $.

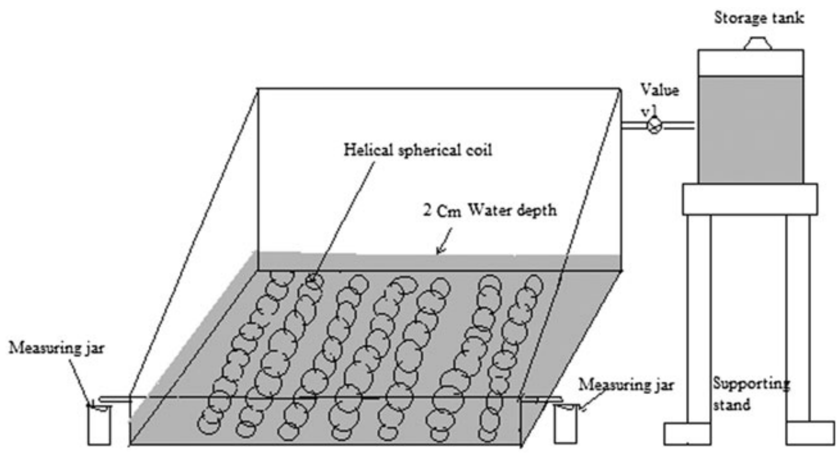

Fig. 13. Top view of the solar still integrated with a helical copper coil.

The minimum average productivity of the solar still is 1.75 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.75 × 10 × 335 = 5,862.5 l. The cost of 1 l of water from the solar still integrated with a helical copper coil = 600/5,862.5 = 0.1023 $.

5.3. An economic analysis of the solar still integrated with aluminium fins

The total fixed cost of the solar still integrated with the aluminium fins F = 143 $. The total cost of the solar still C is equal to the sum of the fixed cost and variable cost. Assuming that the variable cost V equals 0.3 F per year [43] and the expected still life is 10 years, then C = 143 + (0.3 × 143 × 10) = 572 $. The minimum average productivity of the solar still is 1.74 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.74 × 10 × 335 = 5,829 l. The cost of 1 l of water from the solar still integrated with aluminium fins = 572/5,829 = 0.0981 $.

5.4. An economic analysis of the solar still integrated with a stainless steel tube

The total fixed cost of the solar still integrated with a stainless steel tube F = 125 $. The total cost of the solar still C is equal to the sum of the fixed cost and the variable cost. Assuming that the variable cost V equals 0.3 F per year [43] and the expected still life is 10 years, then C = 125 + (0.3 × 125 × 10) = 500 $. The minimum average productivity of the solar still is 1.60 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.60 × 10 × 335 = 5,360 l. The cost of 1 l of water from the solar still integrated with a stainless steel tube = 500/5,360 = 0.0932 $.

5.5. An economic analysis of the solar still integrated with a plain iron sheet

The total fixed cost of the solar still integrated with a plain iron sheet F = 112 $. The total cost of the solar still C is equal to the sum of the fixed cost and the variable cost. Assuming that the variable cost V equal 0.3 F per year [43] and the expected still life is 10 years, then C = 112 + (0.3 × 112 × 10) = 448 $. The minimum average productivity of the solar still is 1.34 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.34 × 10 × 335 = 4,489 l. The cost of 1 l of water from the solar still integrated with a plain iron sheet = 448/4,489 = 0.0997 $.

5.6. An economic analysis of the solar still integrated with the helical copper coil and aluminium fins

The total fixed cost of the solar still integrated with the helical copper coil and aluminium fins. F = 193 $. The total cost of the solar still C is equal to the sum of the fixed cost and the variable cost. Assuming that the variable cost V equal 0.3 F per year [43] and the expected still is life 10 years, then C = 193 + (0.3 × 193 × 10) = 772 $. The minimum average productivity of the solar still is 1.34 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.86 × 10 × 335 = 6,231 l. The cost of 1 l of water from the solar still integrated with the helical copper coil and aluminium fins = 772/6,231 = 0.1238 $.

5.7. An economic analysis of the solar still integrated with the helical copper coil and stainless steel tube

The total fixed cost of the solar still integrated with the helical copper coil and stainless steel tube $F = 175$ $. The total cost of the solar still C is equal to the sum of fixed cost and variable cost. Assuming that the variable cost V equal 0.3 F per year [43] and the expected still life is 10 years, then $C = 175 + (0.3 \times 175 \times 10) = 700$ $. The minimum average productivity of the solar still is 1.83 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.83 × 10 × 335 = 6,130 l .The cost of 1 l of water from of the solar still integrated with the helical copper coil and stainless steel tube = 700/6,130 = 0.1141 $.

5.8. An economic analysis of the solar still integrated with the aluminium fins and stainless steel tube

The total fixed cost of the solar still integrated with the aluminium fins and stainless steel tube $F = 168$ $. The total cost of the solar still C is equal to the sum of the fixed cost and the variable cost. Assuming that the variable cost V equals 0.3 F per year [43] and the expected still life is 10 years, then $C = 168 + (0.3 \times 168 \times 10) = 672$ $. The minimum average productivity of the solar still is 1.82 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.82 × 10 × 335 = 6,097 l. The cost of 1 l of water from the solar still integrated with the aluminium fins and stainless steel tube = 672/6,097 = 0.1102 $.

5.9. An economic analysis of the solar still integrated with the helical copper coil, aluminium fins and stainless steel tube

The total fixed cost of the solar still integrated with a helical copper coil $F = 218$ $. The total cost of the solar still C is equal to the sum of the fixed cost and the variable cost. Assuming that the variable cost V equals 0.3 F per year [43] and the expected still life is 10 years, then $C = 218 + (0.3 \times 218 \times 10) = 872$ $. The minimum average productivity of the solar still is 1.92 l/d from the experimental result. Assume that the solar still can operate for 335 d. The total productivity of the solar still life time = 1.92 × 10 × 335 = 6,432 l. The cost of 1 l of water from the solar still integrated with the helical copper coil, aluminium fins and stainless steel tube = 872/6,432 = 0.1355 $. Compared with the conventional still, the solar still integrated with the helical copper coil, aluminium fins and stainless steel tube has higher productivity with high cost, as shown in Table 3.

6. Conclusion

In comparison with the conventional still, the solar still coupled basin materials have higher performance, improved heat transfer and stability. The coupled basin materials are designed in such a way that the helical spherical coil, aluminium fin and stainless steel tube can fit into the same basin; the main aim is to decrease the preheating time, and thus make the basin material act as a fin. The series of experiments done from January to February 2014, with the helical spherical coil, aluminium fins and stainless steel tube arranged in the lengthwise direction was more effective, compared with the breadthwise one, by 4–8% increase in productivity. The experimental observation demonstrates that the collection process of the condensation has increased. Using good isolation, the stored energy capacity can be improved by increasing the water depth.

The solar still with aluminium fins has higher productivity compared with the one with the helical spherical coil and stainless steel tube. The combination of the helical spherical coil, aluminium fins and stainless steel tube was introduced for a higher heat medium, which enriches the yield rate of the single-basin and single-slope solar still by a 92% increase in productivity, compared with the conventional still. The efficiency and the estimated cost per litre of the distillate for the solar still with the helical copper coil, aluminium fins and stainless steel tube are approximately 92% and 0.1355 $, respectively.

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