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Experimental study of modified dual slope hybrid photovoltaic (PV/T) solar thermal still

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ABSTRACT

Potable water and energy are the two basic requirements for everyday life of human. The world is now known to the crisis of potable water and availability of energy in daily life utilities. The greatest challenge in front of the people is to get the pure water for daily uses. In this paper experimental studies and a comparison of modified dual slope hybrid photo voltaic (PV/T) solar thermal still and a photo voltaic thermal (PVT) double slope active solar still with two flat plate collectors connected and integrated to the basin of solar still has been performed at KIET Group of Institutions Ghaziabad, India at Campus premises of hostel roof top in two steps, also a solar powered modified PMDC motor has been used to circulate the water in the basin to increase the yield of the system for water production. Hybrid photo voltaic-thermal (PV/T) generates electrical energy and heat. A modified dual slope hybrid photo voltaic thermal (PV/T) dual slope solar thermal still has been designed and fabricated to study the performance for water production. Experimental data for distillate yield, water temperature have been included. The methodology for the modification in design and fabrication of dual slope active solar still has been discussed in detail. The actual setup specifications in addition to the mode of performing the experiment also given in details with the results proven after comparisons. The model of modified distillation system for water production is validated with experimental data. It has been also proven that the yield obtained from modified dual slope hybrid photo voltaic (PV/T) solar thermal still significantly more in comparison to the previous dual slope solar stills in use. Actual photograph of the setup and site are included.

Keywords: Solar stills; Sand based solar stills; Dual slope modified solar stills; Wood based solar stills; Water production

1. Introduction

Energy and water are the two basic essentials for the civilized life of human. The world is now known to the crisis of potable water and availability of energy in daily life utilities. The greatest challenge in front of the people living in remote rural area is to get the pure water for daily uses. In present situation 17.86% of the world population is living in India but only 4% of this population is getting the fresh water for their daily [1–4]. In Year 2017, 71% of the total population of the world i.e. 5.2 billion people, used a safely managed drinking water. 89% of the global population i.e. 6.5 billion people using at least a basic service in terms of an improved potable water within the distance of 30 min to get the water by any hygienic source of water. 84 million people on the earth are not obtaining a basic drinking water and also 159 million people are using surface water. On the whole, at least 2 billion people are using water with

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severe contamination. Contaminated water is responsible to transmit diseases like polio, typhoid, dysentery, diarrhea and cholera.

Approximately 50,2000 people dies due to the reason of using contaminated water. By the year 2025, approximately half of the world's population will be living in water based crises areas. In most of the cases one of the problem is lack of sense of sanitation habits. These habits usually spread contaminations in water [5].

The international charity Water Aid last year ranked India as worst in the world for access to safe water [8]. To overcome this issue there are lot of efforts have been carried out to obtain the pure and potable water. Present problems are to develop large scale water purification systems, majorly the devices or systems developed for water purification are so much energy consuming , not ecofriendly and also economically non-viable. At a very small scale, we may treat the water with the help of solar distillers because solar distillers are environment friendly and economically viable [9].

Solar desalination is the most acceptable method for water purification especially in remote or isolated locations where an adequate amount of solar energy is accessible and a sufficient amount of water is available and other types of sources of energy are not available [6,7]. As per the prediction of Hayek and Badran [10] the drinkable water can be produced at low cost with the help of solar stills because they are comparatively economical to fabricate and easy to operate and maintain.

Commonly conventional single basin passive solar stills are not used because of poor yield, approximately 2–3 L/ m^2 in a day and poor thermal efficiency approximately 30% maximum variable solar intensity according to the location of the solar still [11–14]. To meet the requirement of potable water several researchers put their efforts to design, fabrication and development of solar stills.

Different types of designs such as the double-basin, multi-effect, inverted trickle, multi-basin, regenerative type, with reflectors, spherical, triangular and pyramid type solar still have been proposed and developed to enhance the distillation efficiency of conventional solar stills [3].

Diwedi and Tiwari [15] studied many types of designs of solar stills. As per Al Faruq et al. [16], report has been found that a conventional solar stills typically produce approximately 3.76 L/m^2 d. Also a study on the basis of parameters on a conventional Two-sloped single-basin solar still under real climatic conditions and put a report as average annual yield of nearly of 4.0 L/m^2 d under optimum design conditions. And use of passive solar stills for potable water and active solar stills for commercial purposes are used on the point of view of economic viability [17–20].

According to Abdullah [21], it has been found that the yield may increased by 36% if the coupling of a flat plate solar collector with a solar still is being done. The potable/fresh water productivity has been increased with an average of 18 percent by using solar energy concentrator and a heat exchanger. As per the study the performance of a solar still augmented with a flat-plate collector. It has been concluded that the yield of distilled water has been increased up to 231% in case of tap water as an input inlet by 52% as in the case of saline water as feed to the still [22–27]. Dwivedi and Tiwari [15] concluded that the cost of potable water produced from dual slope solar still is of Rs. 0.28/L is less in comparison to single slope passive solar still of Rs. 0.39/L.

When thermal energy is withdrawn from photo voltaic (PV) module, it is then called as hybrid (PV/T) system. The actual concept of working of the hybrid PV/T system is that there is a conversion of solar radiation into electrical energy with its peak efficiency range of 9–12.75%. This efficiency is depending on the type of solar-cell and thermal energy dissipated as heat to air or water. So hybrid photo voltaic thermal (PV/T) collectors are to be introduced to generate electricity and thermal power [28] simultaneously. If there is an increase in electric efficiency by 2% with the mass flow rate of 0.01 kg/s then the thermal efficiency will be 60% [29].

It has been observed that the thermal energy is dissipated from the all sides of the water tank of dual slope active solar still, to overcome this problem various methods have been tried out like use of rubber, jute and cloths etc. to stop the thermal energy dissipation [30]. The thermal capacity by using these methods increased thermal efficiency in a small amount.

2. Origin, objective of the work

Solar still is a device which utilizes the solar energy to extract potable water from saline water. This set up can be used efficiently and effectively in remote locations where electricity is not available.

It was observed that to increase the productivity of the solar still by increasing the temperature of water available in the solar still is as one of its parameter to enhance the output of solar still i.e. the distilled water.

To raise the temperature of inlet water in the solar still the double slope solar still connected with two flat plate collectors and one of them is photo voltaic (PV) integrated. In addition to this a layer of local soil has been mixed with the wooden granules and small amount of straw. After that the dual slope solar still was kept in the semi open box type structure to maintain the thermal energy and to increase the water yield. The flat plate collectors making an angle of 30° with horizontal, optimized for 28.7529° N, 77.4993° E latitude of KIET Group of Institutions, Murad Nagar, Ghaziabad (India). To reduce the cost and effective use of power to drive the modified first generation PMDC motor used has been provided the 40 W_p PV Module.

3. Modifications in design and fabrication of dual slope active solar still

Main objective of this research work is to enhance the yield of the double slope solar still and to arrange distilled water for isolated civilization including the design and development of second generation dual commutator PMDC motor.

A cross sectional view of a symmetrical double slope solar still is shown in Fig. 1, which explains the energy interactions between the different parts of the dual slope solar sill. The cross-sectional view of fabricated symmetrical modified hybrid photo voltaic thermal (PVT) double

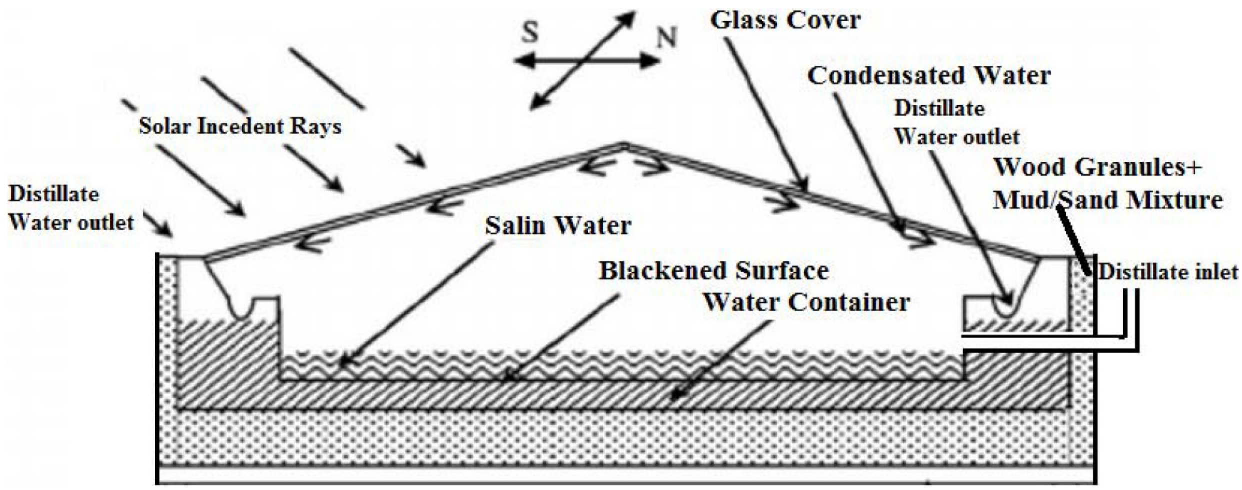

Fig. 1. Cross sectional view of a symmetrical modified dual slope solar still.

slope active solar still is shown in Fig. 2. The fabricated system consists of three components namely double slope solar still, PV integrated FPCs and DC water pump.

Single basin double slope solar still of basin area of 2.2 m × 1.2 m has been fabricated by using FRP -fiber reinforced plastic having low thermal conductivity with the wall thickness of 0.0051 m. The lower wall height from East-West has been kept 0.23 m in addition to it, a layer of local soil has been mixed with the wooden granules with the breath of 50 mm and small amount of straw as shown in Fig. 2.

Interior of the basin is black color painted to increase the absorption of solar radiations. Top of the basin has been covered from each side with glass of thickness 0.0043 m, inclined at an angel of 15° and oriented to due east and west direction to receive the maximum solar radiations. A rubber gasket has been provided in between the top of the basin and glass cover. Further, it is sealed using window sealing paste to prevent vapor leakage to outside and to prevent water ingress in to the solar still. The condensed water is then collected in a galvanized iron channel fixed at the lower end side of both glass covers. The distilled water is continuously drained through the flexible pipes and collected in both the collection pots placed outside of the solar still on both sides. A set of two thermocouples are provided to measure and record the inner chamber temperature. One inlet pipe is also fixed in the side of the wall to feed the unfiltered water in the basin. Another set of thermocouple is kept along with the local soil mixture with the wooden granules and small amount of straw.

The complete unit shown in Figs. 3 and 4 is mounted on an angle iron structure. In modified hybrid active solar still, the water in the basin gets heated with both the methods i.e. directly and indirectly through flat plate collectors.

All specifications of fabricated (PV/T) modified double slope hybrid solar still are shown in Table 1.

A set of two flat plate collectors are connected to the basin of modified dual slope solar still by using fairly insulated pipes. The option to change the connections arrangements have been provided by connecting the two flat plates in parallel and series combinations by setting two valves provided. Each solar collector has an effective area of 2.0 m^2.

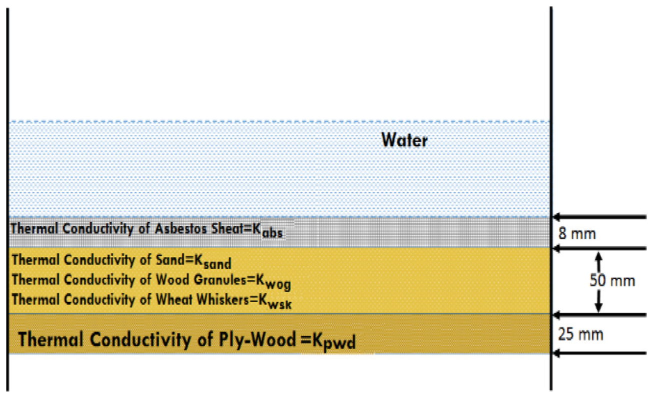

Fig. 2. Modified dual slope active solar still cross-sectional view for different thermal conductivities.

The whole absorber is encased in an aluminum metallic box with 0.1 m glass wool insulation at base and side to reduce thermal losses. Toughened glass of 0.004 m thickness are mounted on the top of the boxes by using aluminum frame and screw. The rubber seal is placed between the metallic box and glass cover as well as between glass and aluminum frame. Glass to glass photo voltaic module of 36 cells has been connected at bottom side of the collector. The solar PV module size is of dimension of 0.55 × 1.25 m^2. The heat energy from the back side of module is utilized to heat the water flowing through riser tubes and solar radiations are passed through the unpacked area of the module. The complete system is made air/vapor tight by using the silicon rubber sealing material because of its long lasting decaying property.

First generation PMDC pump of 40 W is used to circulate the water in the module. The power supplied to first generation PMDC motor is directly by the solar PV module without adding any charge controller or any power electronics components. The pump is operated when there are sun shine hours and directly connected with PV module for DC electrical power input supply.

Fig. 3. Integrated flat plate collectors (FPCs) and modified double slope solar still.

Fig. 4. A view of hybrid PV/T modified dual slope solar still.

4. Measurement methodology and measuring instruments

Following are the instruments are used during the experiment to measure various parameters:

(i) Thermocouples (copper constantan): Copper constantan thermocouples are used to measure the temperature of water, condensing cover and vapors. A digital temperature indicator having a least count of 0.1°C is connected with the thermocouple. A proper calibration procedure has been adopted.

(ii) Mercuries thermometer: We use mercuries thermometer to measure and record the surrounding air temperature of least count 1.0°C. We avoid the direct sun exposure of the mercuries thermometer so keep it under the shaded area.

(iii) Digital solarimeter/pyranometer: A Digital solarimeter is a pyranometer, is a type of measuring device used to measure the combined direct and diffuse solar radiations. Calibrated solarimeter with pyranometer has been used to measure total radiations and diffuse solar radiations with the least count of 2.0 mille W/cm^2.

(iv) Distill water measurement: The collected distillate output is measured by using marked cylinder with the least count of 1.0 ml/L.

(v) Clamp meter/current meter: it is the Instrument which has been used to test short circuit current, load current, open circuit voltage and load voltage. The least count for current measurement is 0.10 A and voltage measurement is 0.015 V.

Table 1
Specifications of photovoltaic-thermal (PV/T) modified dual slope hybrid active solar still

Used components	Specifications
Flat plate collectors	
Type of collector used	Tube in plate type
Total number of collectors	2
Each collector area	2.00 m^2
Material of tubes	Copper tubes
Thickness of the plates	0.002 m
Outer diameter of riser	0.01268 m
Thickness of the outer riser	0.558 × 10^{-3} m
Spacing in between two risers	0.113 m
Thickness of insulation of collectors	0.101 m
Collector weight	48.68 kg
Collectors angle	30°
Cover glass thickness	0.0042 m (Toughened glass type)
Motor used for water pump	First generation PMDC shunt motor (18 V, 40 Watts and 2850 rpm)
PV module (under standard test conditions)	
Area of single solar cell	0.007 m^2
Size of PV module	1.25 m × 0.55 m
Number of solar cells	36
Packing factor (β_c)	0.44
Efficiency of module	12%
Max power rating P_{max}	40 W
Solar still	
Length	2.20 m
Width	1.20 m
Lower height	0.22 m
Higher height	0.48 m
Thickness of glass cover	0.004 m

5. Method of experiment

Experimental measurements have been performed to evaluate the performance of the modified dual slope solar still under the real time conditions in the field. Before the commencement of test the basin has been filled with brackish water to a desired level i.e. (0.027 m) 24 h before to bring the water in steady state. Both the glass covers were cleaned and made free from the dust/dirt particles before/ during the study. The tests started at 7:00 am and continued till 7.00 am on next day. During the experiments the following parameters were measured hourly.

(i) solar intensity on east $[I_s(t)_E]$ and west $[I_s(t)_W]$ glass covers
(ii) solar intensity on collector panels , $I_c(t)$
(iii) ambient air temperature, T_a
(iv) basin liner temperature, T_b
(v) water temperature inside still, T_w
(vi) vapor temperature inside still, T_v
(vii) inner glass cover temperature of east $[T_{giE}]$ and west $[T_{giW}]$ side
(viii) outer glass cover temperature of east $[T_{goE}]$ and west $[T_{goW}]$ side
(ix) hourly yield from east $[m_{ewE}]$ and west $[m_{ewW}]$ cover side
(x) open circuit voltage (V_{OC})
(xi) load voltage (V_L)
(xii) short circuit current (I_{SC})
(xiii) Load current (I_L).

For the purpose to maintain the nearly uniform level of water in the basin, the collected hourly distillate yield was refilled back through the opening provided in wall of the basin. The experiments were performed for 0.027 m water depth (54.0 kg water mass approximately) on the typical days (i.e. 09–22 October 2017) of the month for the following configurations of the system.

(i) The forced mode when both the collectors are connected in series.
(ii) The forced mode when both the collectors are connected in parallel.
(iii) Natural mode when both the collectors are connected in parallel.

6. Observations and analysis of experiment

Experiments have been performed to evaluate the working performance of the modified solar still under the field conditions. Before the commencement of tests, the basin was filled with brackish water to a desired level (0.025 m) 24 h before to bring the water in steady state. The tests started at 7:00 am and continued till 7:00 am on the next day. During the experiments the following parameters were measured at the intervals of 1 h.

(i) solar intensity on east and west side glass covers
(ii) solar intensity on collector panels
(iii) ambient air temperature
(iv) basin liner temperature
(v) water temperature inside solar still
(vi) vapor temperature inside solar still
(vii) inner glass cover temperature of east and west side
(viii) outer glass cover temperature of east and west side
(ix) hourly yield from east and west cover side

A modified dual slope active solar still has been installed after certain modifications.

During experiment values contain hourly data of solar intensity (using digital solarimeter), temperatures (using thermocouples) namely water, inner and outer surface of glass cover, vapor temperature, distillate yield (using measuring cylinder), ambient temperature (using thermometer), and open and load parameters of PV module (using Tong meter). It has been observed that the temperature of the water and glass cover have same trends. This phenomenon is because of increase of solar irradiance in the morning time and the decrease in the afternoon time. It is also observed that the rate of increase in temperature as well as decrease in temperature of the cover is faster in comparison of the temperature of water. It is because of the fact that the basin water in the still has higher thermal inertia than that of the glass cover. Because of this water tends to gain/gain/lose the heat absorbed from incident solar radiations during the day time is at relatively slower rate as opposed to that of the solar still glass cover. It is also observed that during the morning sunshine hours in between 7:00 am to 8:00 am, the outer glass surface is at high temperature in comparison to the inner glass surface temperature. It is because of low intensity solar radiations during sunrise, gets encountered in beginning primarily first by the outer surface and hence absorbed. It is also noticed that the east side glass cover temperature is higher than the west side glass cover in morning hours and vice versa for the afternoon hours, it is because of due to changing position of the sun from east to west side.

As a result the hourly yield of potable distilled water has been obtained from east side and west side of condensing cover which is an opposite phenomenon. It is also observed that the hourly yield increases with increase in solar radiation. However there is a difference in yield of water distillation because of time difference between minimum radiation to maximum radiation and minimum yield to maximum yield, his is due to the water mass available in the basin stored. We obtained maximum hourly yield nearly at 2:00 p.m. when the ambient temperature is at its maximum. The open circuit voltage value varies from 19.28 to 18.14 V and short circuit current values varies from 1.3 to 2.1 A, with increase in solar radiation of maximum. 720 W/m^2 with ambient temperature value of maximum 34°C. This phenomenon the as per the expected trend of output.

The schematic arrangement of two flat plate collectors for series-forced mode, parallel-forced mode and in natural circulation is shown in Figs. 5 and 6, respectively.

The outputs of the solar still vary directly with the solar radiation incident and the ambient temperature which may be observed from Tables 2–5.

Temperature variation on hourly basis and total yield obtained from solar still-series-forced mode, parallel-forced mode and in natural circulation mode can be understood from Fig. 7.

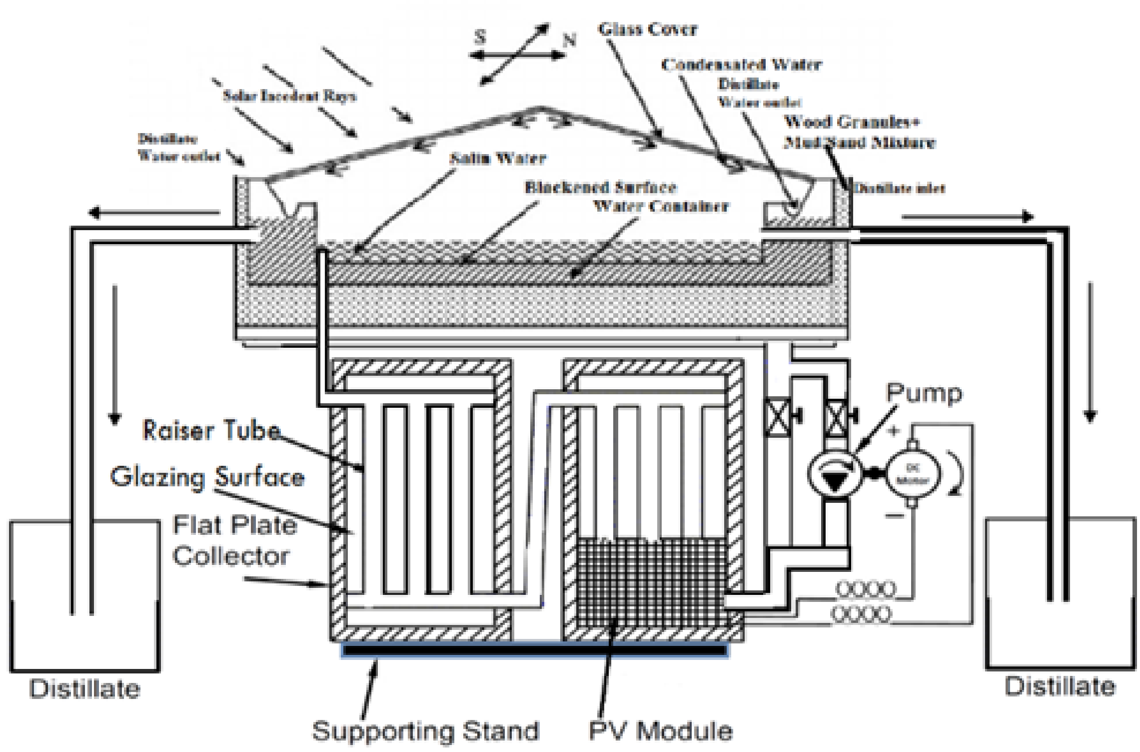

Fig. 5. Modified solar still in forced circulation mode with FPCs connected in series.

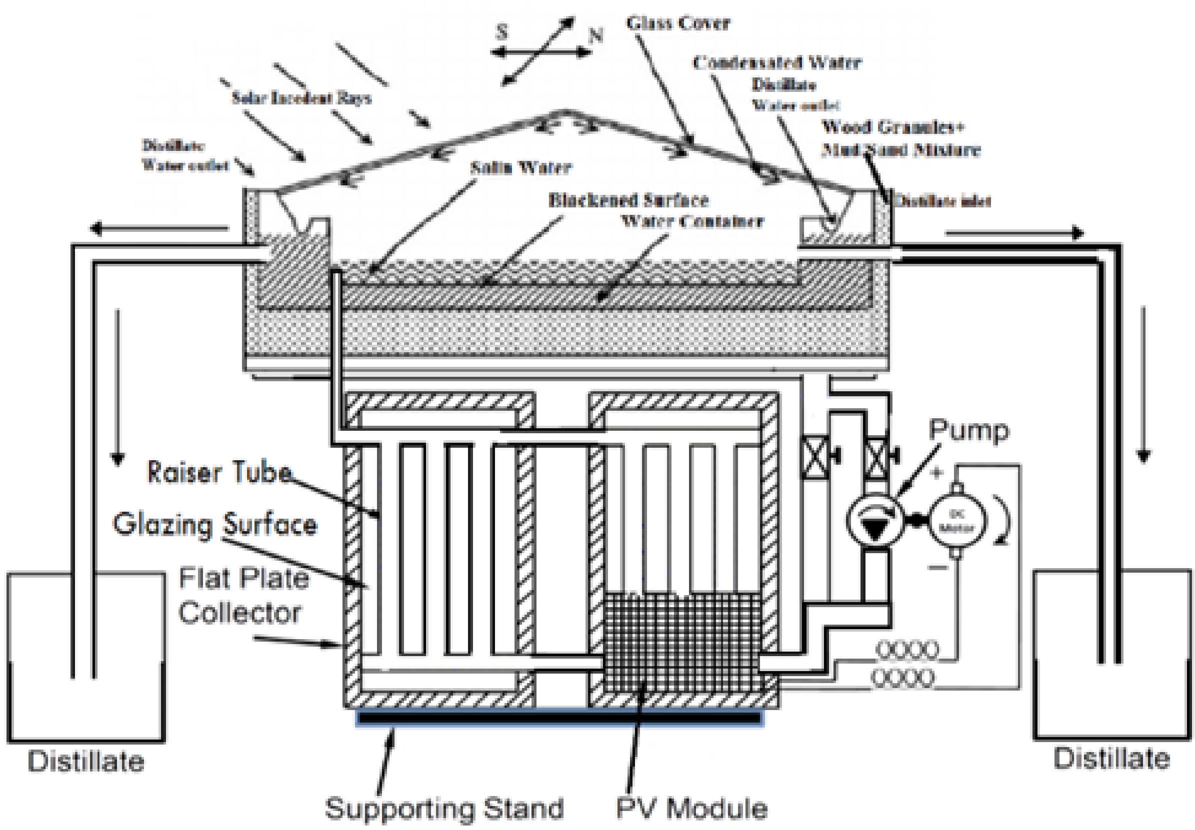

Fig. 6. Modified solar still in forced circulation mode with FPCs connected in parallel.

Table 2
Real time observation for forced mode with flat plate collectors connected in series combinations for the day on 09 October 2017 at 0.025 meter water depth (50 kg water mass in distillation basin). Highest Temp.: 35°C, Lowest Temp.: 23°C

Time	$I_{s(t)}E$, (Wm^{-2})	$I_{s(t)}W$, (Wm^{-2})	$I_{c(t)}$, (Wm^{-2})	T_a (°C)	T_v (°C)	T_b (°C)	T_w (°C)	$T_{gi}E$ (°C)	$T_{gi}W$ (°C)	$T_{go}E$ (°C)	$T_{go}W$ (°C)	$m_{ew}E$ (kg/h)	$m_{ew}W$ (kg/h)	Total water yield kg/h
7:00	0	0	0	23	25	24	24	24	24	25	25	0.000	0.000	0.000
8:00	300	170	290	25	28	27	26	27	26	29	27	0.020	0.022	0.042
9:00	500	290	490	27	40	30	37	36	32	35	33	0.018	0.029	0.047
10:00	550	410	610	30	42	32	44	41	37	38	36	0.084	0.064	0.148
11:00	600	510	680	32	47	38	54	46	46	47	45	0.173	0.153	0.326
12:00	670	650	740	33	53	46	61	56	55	56	54	0.317	0.421	0.738
13:00	610	610	690	33	59	50	66	57	57	59	60	0.482	0.529	1.011
14:00	460	550	610	35	58	58	67	56	56	57	65	0.595	0.597	1.192
15:00	340	460	450	34	57	63	65	55	57	56	63	0.564	0.527	1.091
16:00	190	290	290	33	55	60	59	51	55	50	60	0.462	0.451	0.913
17:00	130	190	200	32	49	53	50	48	51	48	52	0.361	0.375	0.736
18:00	0	0	0	31	40	38	46	41	47	40	44	0.324	0.312	0.636
19:00	0	0	0	30	31	29	35	30	34	30	36	0.300	0.278	0.578
20:00	0	0	0	29	28	28	30	27	32	30	35	0.214	0.210	0.424
21:00	0	0	0	27	27	27	30	26	29	28	30	0.158	0.176	0.334
22:00	0	0	0	26	25	26	28	25	24	25	29	0.086	0.078	0.164
23:00	0	0	0	25	25	24	26	24	24	24	25	0.056	0.056	0.112
0:00	0	0	0	25	24	24	25	23	23	23	24	0.051	0.052	0.103
1:00	0	0	0	25	24	23	24	22	23	23	23	0.047	0.048	0.095
2:00	0	0	0	25	23	22	23	22	22	22	22	0.038	0.041	0.079
3:00	0	0	0	24	23	22	23	22	22	22	22	0.030	0.036	0.066
4:00	0	0	0	24	23	22	22	21	21	21	21	0.024	0.028	0.052
5:00	0	0	0	24	23	22	22	20	21	21	21	0.018	0.020	0.038
6:00	0	0	0	23	22	21	22	20	21	21	21	0.011	0.019	0.030
7:00	0	0	0	23	21	21	22	20	21	20	20	0.010	0.014	0.024

Table 3
Real time V_{OC}(Volt), I_{SC}(Ampere), V_L(Volts) and I_L(Ampere) observation for forced mode with flat plate collectors connected in series combinations for the day on 15 October 2017 at 0.025 meter water depth (50 kg water mass in distillation basin). Highest Temp.: 35°C, Lowest Temp.: 23°C

Time (h)	V_{OC} (V)	I_{SC} (A)	V_L (V)	I_L (A)
7:00	15.1	0.6	9.2	0.5
8:00	19.3	1.3	11.8	0.8
9:00	18.7	1.8	14.3	1
10:00	18.5	2	15.5	1
11:00	18.1	2.1	15.5	1
12:00	18.1	1.9	15.3	1
13:00	18	1.6	15	1
14:00	17.9	0.9	11.9	0.9
15:00	15.4	0.6	9.7	0.6
16:00	15.1	0.6	9.2	0.5

7. Conclusion

Modified solar still output has been increased compared to the previous old solar stills. Daily yield of drinkable water distilled and collected as 8.979 kg, 9.742 kg and 6.373 kg has been obtained from series mode, parallel mode and natural circulation mode, respectively with the modified dual slope collector. The yield is highest for the parallel forced mode configuration is 9.742 kg for the month of October in nearly similar climatic conditions. The increment of thermal efficiencies can be accredited to the factors 1.0: The inlet water tubes are kept above the water level of the water tank. 2.0: Addition of layer of local soil has been mixed with the wooden granules with the breath of 50 mm and small amount of straw reduced the heat losses from the Water tank, providing a high level of insulation and thermal energy storage system due to which the heat sustained in the Water for a longer time. 3.0: Small increment of the depth of the water level so that the heat stored in the water enhances the productivity of the water distillation in addition to the time of water distillation. The water distillation continues even during the non-sun shine hours. Hence it can be concluded that the above modification of solar still reduces the heat losses during the operation and enhanced productivity. Most importantly there are no such power electronics devices are employed to control the charge and the PV cell module has been directly connected to the Modified PMDC Motor for electrical inputs. It has been proven that the same setup is running without fail.

Table 4
Real time observation for forced mode with flat plate collectors connected in parallel combinations for the day on 15 October 2017 at 0.025 m water depth (50 kg water mass in distillation basin). Highest Temp.: 35°C, Lowest Temp.: 23°C

Time	$I_{s(t)E,}$ (Wm^{-2})	$I_{s(t)W'}$ (Wm^{-2})	$I_{c(t)'}$ (Wm^{-2})	T_a (°C)	T_v (°C)	T_b (°C)	T_w (°C)	$T_{gi}E$ (°C)	$T_{gi}W$ (°C)	TgoE (°C)	$T_{go}W$ (°C)	$m_{ew}E$ (kg/h)	$m_{ew}W$ (kg/h)	Total water yield kg/h (Parallel)
7:00	0	0	0	23	22.4	22.4	22.3	20.6	20.5	21.1	22.2	0	0	0
8:00	260	160	240	27	28.3	28.1	27.3	26.3	25.4	27.4	26.8	0.018	0.021	0.039
9:00	360	280	420	29	41.4	31.7	36.4	35.8	34.7	34.7	31.6	0.05	0.037	0.087
10:00	580	460	620	30	46.6	35.8	44,8	40.3	38.3	37.7	35.6	0.141	0.164	0.305
11:00	680	520	720	32	51.7	39.6	54.3	47.6	44.8	45.3	41.7	0.253	0.317	0.57
12:00	680	660	780	34	54.2	52.1	62.7	52.3	50.1	49.7	47.4	0.397	0.398	0.795
13:00	660	700	740	34	60.2	54.7	67.3	55.3	55.6	55.6	56.7	0.686	0.691	1.377
14:00	500	620	640	34	59.7	58.2	67.4	54.6	55.1	50.2	55.4	0.726	0.793	1.519
15:00	300	480	460	33	57.4	61.7	64.5	54.1	55.2	49.3	54.7	0.527	0.59	1.117
16:00	180	320	300	32	52.4	59.5	58.3	51.3	46.5	46.5	50.2	0.513	0.416	0.929
17:00	120	200	160	31	51.5	52.3	48.4	47.5	48.7	42.7	47.3	0.358	0.371	0.729
18:00	0	0	0	31	47.3	48.6	42.6	40.3	40.3	39.7	42.3	0.267	0.267	0.534
19:00	0	0	0	31	41.4	39.7	40.3	38.3	37.4	35.2	35.1	0.213	0.182	0.395
20:00	0	0	0	31	36.1	33.4	36.7	34.3	32.7	33.4	33.3	0.154	0.164	0.318
21:00	0	0	0	30	35.2	31.7	35.6	33.5	31.9	32.6	31.2	0.093	0.098	0.191
22:00	0	0	0	30	34.2	31.6	34.2	31.3	30.7	31.2	30.2	0.072	0.074	0.146
23:00	0	0	0	30	33.3	30.6	33.7	30.6	30.1	31.1	30	0.063	0.07	0.133
0:00	0	0	0	29	33	30.1	33.2	30.4	29.8	31	29.7	0.057	0.059	0.116
1:00	0	0	0	29	32.7	29.7	33	30.2	29.7	30.8	29.1	0.046	0.05	0.096
2:00	0	0	0	28	32.5	29.1	32.8	29.6	29.1	30.5	28.8	0.041	0.048	0.089
3:00	0	0	0	28	31.9	28.7	32.1	28.7	28.3	29.5	28.1	0.038	0.041	0.079
4:00	0	0	0	27	31.1	28.1	31.7	28.1	27.8	28.8	27.7	0.031	0.032	0.063
5:00	0	0	0	26	29.7	27.4	30.4	27.3	27.1	28.1	27	0.028	0.029	0.057
6:00	0	0	0	25	28.3	26.7	29.3	26.8	26.7	27.5	26.6	0.019	0.02	0.039
7:00	0	0	0	24	27.4	26.1	28.6	25.7	25.4	26.7	25.4	0.009	0.01	0.019

Table 5
Real time V_{OC}(Volt), I_{SC}(Ampere) , V_L(Volts) and I_L(Ampere) observation for forced mode with flat plate collectors connected in parallel combinations for the day on 15 October 2017 at 0.025 meter water depth (50 kg water mass in distillation basin). Highest Temp.: 35°C, Lowest Temp.: 23°C

Time	V_{OC}(V)	I_{SC}(A)	V_L(V)	I_L(A)
7:00	–	–	–	–
8:00	11.2	0.6	6.2	0.4
9:00	19.2	1.2	9.9	0.9
10:00	19	1.7	15.1	1
11:00	18.4	2	16.3	1
12:00	18.1	2.2	17.3	1
13:00	17.1	1.9	15.8	1
14:00	17.9	1.7	15.3	1
15:00	18	1	12.4	0.8
16:00	14	0.75	10	0.6

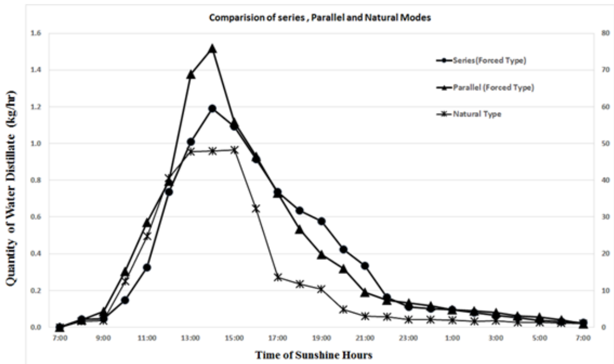

Fig. 7. Comparison of variation of hourly total quantity of water distillate and water temperature in different operational mode of hybrid modified double slope active solar still.

Symbols

A_b — Area of basin (m^2)
A_c — Area of collector panel (m^2)
A_g — Area of condensing glass cover (m^2)
F' — Flat plat collector efficiency factor
h_1 — Total internal heat transfer coefficient (W/m^2 °C)
h_{cw} — Internal convective heat transfer coefficient (W/m^2 °C)
h_{ew} — Internal evaporative heat transfer coefficient (W/m^2 °C)

h_{rw} — Internal radiative heat transfer coefficient (W/m^2 °C)
h_o — Heat transfer coefficient between outer condensing cover and ambient air (W/m^2 °C)
$I_{s(t}$ — Solar intensity on still glass covers (Wm^{-2})
$I_{c(t)}$ — Solar intensity on collector panels (Wm^{-2})
k_g — Thermal conductivity of condensing cover (W/m °C)
L_g — Thickness of condensing cover (m)
L — Latent heat of vaporization (J/kg)
M — Mass of water in the basin of solar still (kg)
— Hourly distillate yield (kg/m^2)
T_a — Ambient air temperature (°C)
T_b — Basin liner temperature (°C)
T_w — Water temperature inside still (°C)
T_v — Vapor temperature inside still (°C)
T_{gi} — Inner glass cover temperature (°C)
T_{go} — Outer glass cover temperature (°C)
UL — Overall heat transfer coefficient for flat plate collector (W/m^2 °C)
U_{EW} — Internal radiative heat transfer coefficient between east and west condensing cover (W/m^2 °C)
U_{bw} — Heat transfer coefficient between basin liner and water (W/m^2 °C)
U_{ba} — Heat transfer coefficient between basin liner and ambient air (W/m^2 °C)
U_a — Overall heat transfer coefficient between outer condensing cover and ambient air (W/m^2 °C)
v — Air velocity (m/s)

Subscripts

E — East side
W — West side
C — Collector plate
w — Water
c_i — Inner condensing cover
c_o — Outer condensing cover
a — Ambient
b — Basin liner

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