European Journal of Sustainable Development (2012), **1**, 2, 315-352 ISSN: 2239-5938

New Innovation of low cost solar still

[1]S H Sengar, [1]Y P Khandetod, [1]A G Mohod

Abstract

Different solar stills were developed and evaluated for comparison with other solar stills available in market. Comparatively more distilled water was obtained from the solar still having an area of 1m^2 fabricated in fiber or metal body with glass glazing like single slope ,double slope and wick type solar still. Average maximum temperature and humidity was more in double slope, single slope and wick type solar still and hence the average quantity of distilled water obtained as 1350 ml/day, 1550 ml/day and 2450 ml/day respectively. The plastic made up of *W*-shape solar still provided with 3 channels produce maximum distilled water as 2104 ml/day where as *W*-shape solar still with two channels erected on concrete and ground produced only 1012ml/day and 1443 ml/day respectively. L shape solar still produce average distilled water was 925 ml/day which was very low among the all type of solar still. Comparative cost of compact nature of solar stills like single slope, double slope and wick type solar still was more than Rs.7000/- which is four times more than newly developed *W*-shape 3 channel solar still. Comparative output from newly developed solar still was low but it has several advantages that it is cheapest, cost efficient and easy to clean. Concentration of pH, EC, TDS and ions in solar distilled water was found to be similar as conventional distilled water. The cost of W shape three channel solar still is recovered within 4 months 6 days only.

Keywords: **solar stills, chemical analysis, economics**

| [1] Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, DBSKKV, Dapoli, India

Methodology

Wick type, W shape and L shape of solar stills were designed on the basis of solar declination angle, slope of collector and available insolation. During theoretical design calculations of solar still (Plate 1), peak winter season was considered. In winter season, December month was selected for finding the solar declination angle (δ), Slope of collector (β), intensity of insolation on horizontal and vertical surface and value of Cos θ is shown in Table 1. The newly developed solar stills were evaluated for load test and compared with the output of single and double slope solar still available in market.

Table: 1. Details of design calculations for even type solar still.

S. N.	Particulars	Symbol	Design parameter of solar still
1	Solar declination angle	δ	$\delta = 23.45 \sin [0.9863(284 + n)]$ $\delta = -23.3$
2	Slope of collector	β	$\beta = (\Phi - \delta)$ $\beta = 40^{o}\ 48'$
3	Intensity of insolation on horizontal	I_c	$I_c = I_h \times \text{Cos}\ \theta$ $I_c = 450\ W/m^2$
4	Intensity of insolation on sloping surface	I_s	$I_s = I_h \times \text{Cos}\ \theta / \text{Cos}\ \theta_h$ $I_s = 594.5\ W/m^2$
5	Cosine of θ_h	θ_h	$\theta_h = 40^{o}.8'$

Wick Type Solar still

Wick Type Solar still was fabricated at the central workshop of the College of agricultural Engineering and Technology, Dapoli. The pictorials view with different component of wick type solar still is shown in Plate1.

The device was consisted of a base frame made up of angle irons of size 25mm x 25 mm x 4mm, which was 1m x 1m in size and formed the rigid base for the complete unit.

The main frame was also made up of angle irons of size 25mm x 25 mm x 3 mm, rested on the base frame and hinged from one side for the angle adjustment. The frame was enclosed with the 18 gauge and 24 gauge GI sheets and a thermacol was placed in between the two sheets as insulation from all sides

except from top. The absorber consisted of a corrugated sheet of 24 gauge and of 1m^2 area for increasing absorption of incident solar radiations. The unit was painted with blackboard paint for attaining higher absorption of incident solar radiations. The unit was covered with a glass cover of 5mm thick plane glass, fitted in aluminum frame having an area of 1m^2. The greenhouse effect was possible due to glass which entrapped long wave radiations. The collected water vapour got condensed on inner side of glass.

Device was basically divided into three components as heating chamber, cooling cover and collection unit. Inside the heating chamber, GI pipe was provided for continuous water supply with 15 pin holes of 3 mm drill. The pipe was connected to a storage tank for continuous water supply.

The jute was used as a wick material, which was laid on the corrugated absorber plate with sufficient open area for exposing the black ridge of corrugated absorber. The wick material absorbed the droplets of water coming out from GI pipe and carried this water along the length of the material by capillary action. During this process unused water was collected through the drain outlet and distilled water was collected separately from opposite side and collected in beaker.

The water which was evaporated at higher temperature inside the heating chamber got condensed on the glass surface. The channel was provided for its collection. Water vapour inside the heating chamber got condensed in small droplets of liquid due to low temperature of glass cover. The total cost of this solar still was Rs.7241/- shown in Table 2.

Low cost (*W-shape*) solar still

Low cost (*W-shape*) solar still frame was design and fabricated at the central workshop of the College of Agricultural Engineering and Technology (CAET), Dapoli. This still was fabricated using 25 mm diameter M.S. pipe to make the frame as shown in Plate 2. The pipes and corners were well polished and laminated in order to avoid corrosions as well as to protect the polythene sheet from damage. The size of basin was 2 m x 2 m was prepared with black plastic covered basin in soil (Plate-2), in which water was impounded. The UV stabilized 200 micron polythene sheet of size 4 x 2.5 m was wrapped properly over the frame so that it became leak proof. The distilled water-collecting channel made from GI sheet wrapped with plastic was attached below to the frame with the help of non-corrosive wires.

Published by ECSDEV, Via dei Fiori, 34, 00172, Rome, Italy

Table: 2. Materials used in wick type solar still

Sr.No.	Item	Specifications	Weight (kg)	Rate (Rs.)	Cost (Rs.)
1	M.S. Angle	25mm x 25mm x 4mm	9	60	540/-
2	M.S. Angle	25mm x 25mm x 3mm	12	60	720/-
3	GI Sheet	18 gauge	21	75	1575/-
4	GI sheet	24 gauge	2	75	150/-
5	Corrugated sheet	24 gauge	2	150	400/-
6	M.S. Flat	25mm x 4mm	3.5	45	158/-
7	GI pipe	63 mm diameter	2 m	200/m	400/-
8	M.S. rod	5 mm diameter	4	45	180/-
9	Bucket plastic pipe				100/-
10	Thermocol	25mm thick		30/Sheet	120/-
11	Hinges (2)	25mm x 25mm		30/Piece	60/-
12	Lambi		100 gm		50/-
13	Red oxide		100 gm		30/-
14	Blackboard paint		500 ml		50/-
15	Gromate			5/Piece	10/-
16	Cock (Plastic)			5/Piece	5/-
17	Araldite (2)			30/Piece	60/-
18	Glass with frame	1 m x 1 m			942/-
19	Nut and Bolts (10)				20/-
20	Labour Charges	30%			1671
		Total			**7241/-**

The collecting channels were fabricated so as to catch the condensed droplets of water inside the solar still. The material used for the fabrication of this unit is presented in Table 3. This (*W-shape*) solar still frame along with UV stabilized plastic as glazing kept over the basin dug on ground (Plate 2) and making it leak

proof by using soil cover. The water present in basin got evaporated due to higher temperature inside the heating chamber. Water vapour inside the heating chamber got condensed in the form of small droplets of water due to lower temperature on inner side of polythene. Condensed droplets of evaporated water were collected through three channels. Surrounding condensed water was collected through third channel from all sides at bottom (Plate 3). First two channels which fixed inside solar still (Plate 4)

Plate: 4. Two channel provision for W-shape solar still Plate-3 Third channel

W shape two channels solar still was also erected over the cement block (Plate 5) for performance of distilled water. The cost required to erect w shape solar still on ground and cement were Rs. 1848/- and 4000/-

(a)

Plate: 5. *W*-shape solar still on concrete with two channel

Low cost (*L-shape*) solar still

By using wooden strips and aluminum channel L shape solar still was developed with plastic glazing on soil for distilled water output through single channel. The size of L shape solar still was 2 m^2 (1.4m x1.4m). The total cost required to erect L shape solar still on ground was Rs.1000/-

Table: 3. Material used for fabrication of Solar Distillation unit

Sr. No.	Item	Specification	Quantity required	Rate of item	Total Cost (Rs.)
1	M. S. pipe(Low grade)	25 mm diameter	15.8 m	40/m	732/-
2	Polythene film		4 x 2.5 m	50/m^2	500/-
3	GI sheet	18 gauge	0.3 x 2.2 m	220/m^2	150/-
4	Red paint		100 gm	600/kg	60/-
5	Black paint		500 gm	240/kg	120/-
6	Cement	53 grade	5 kg	10/kg	50/-
7	Sand	Fine	10 kg		40/-
8	Welding rod	Short length	8 rods	12/rod	96/-
9	Labor charge		2 days	Rs.100/day	200
		TOTAL			**1848/-**

Results and Discussions

Performance Evaluation

Developed solar stills were evaluated for winter and summer months with load test at 40° angle. Devices were tested for comparison with the output of distilled water from single and double slope still units available in market.

Wick type

No load test

Wick type solar still having area 1m^2 (1m x 1m) is evaluated for no load test in winter. Maximum temperature was obtained at 1P.M.in solar still, where solar intensity was 503 W/m^2, inside temperature was 91°C, ambient temperature was 31°C and outside relative humidity was 45.6 per cent. The trend obtained in no load test during performance of bare still unit is shown in Table 4. It was observed from Fig 1 that as inside temperature increased, inside relative humidity decreased and vice versa. It was also observed that the temperature inside the solar still increased with outside solar radiation. In no load test in summer, maximum temperature was obtained at 2 P.M., where solar intensity was 618 W/m^2, inside temperature was 94°C, ambient temperature was 36.5°C and

Published by ECSDEV, Via dei Fiori, 34, 00172, Rome, Italy

outside relative humidity was 34.5%. The trend obtained in no load test during performance of bare solar still is shown in Table 5. It was observed (Fig 2) that as inside temperature increased, inside relative humidity decreased and vice versa. It was also observed that the temperature inside the solar still increased with outside solar radiation.

Table: 4. Performance of wick type solar still with no load test in winter

Time (Hrs)	Insolation (W/m^2)	Inside R.H. (%)	Inside Temp. (°C)	Outside Temp. (°C)	Outside R.H. (%)
8.00	98	88.6	22	18	89.5
9.00	156	78.5	46	24	78.3
10.00	212	65.4	59	27	65.4
11.00	423	58.5	65	28	52.3
12.00	446	52.1	79	30	44.8
13.00	503	46.9	91	31	45.6
14.00	444	37.6	89	31	44.7
15.00	398	38.5	78	28	53.1
16.00	234	45.9	70	27	56.9
17.00	120	53.6	64	27	67.8
18.00	37	61.7	62	24	78

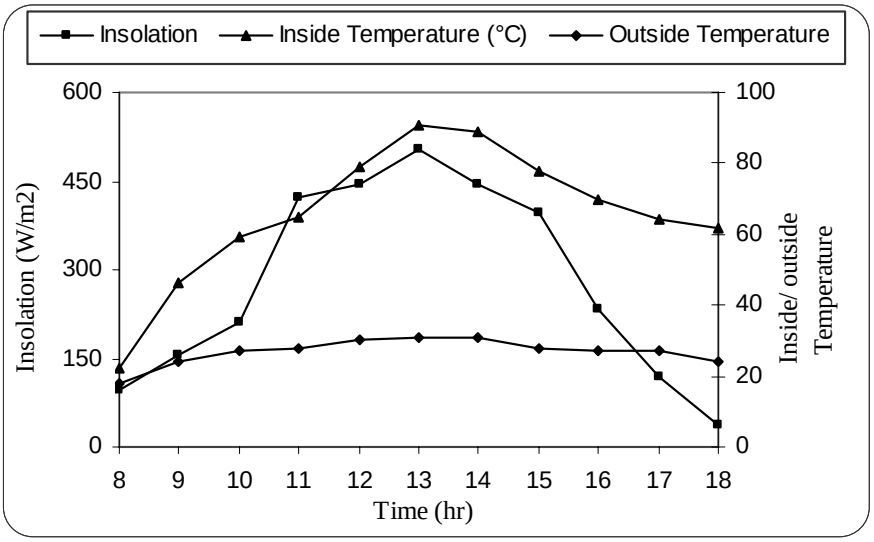


Fig. 1. Performance of wick type solar still no load test in winter

Table: 5. Performance of wick type solar still with no load test in summer

Time (Hrs)	Insolation (W/m^2)	Inside R.H. (%)	Inside Temp. (°C)	Outside Temp. (°C)	Outside R.H. (%)
8.00	233	89.7	35.5	23.4	79.1
9.00	343	71.1	47.1	26.9	66.5
10.00	453	56.4	57.0	29.1	50.3
11.00	546	48.2	65.2	31.1	46.5
12.00	555	39.5	76.5	34.2	40.9
13.00	598	36.1	87.3	36.0	36.7
14.00	618	36.8	94.0	36.5	34.5
15.00	603	36.9	91.4	36.4	35.4
16.00	489	49.0	83.5	32.7	48.9
17.00	357	51.1	74.4	30.0	52.2
18.00	232	56.3	66.8	28.5	59.8

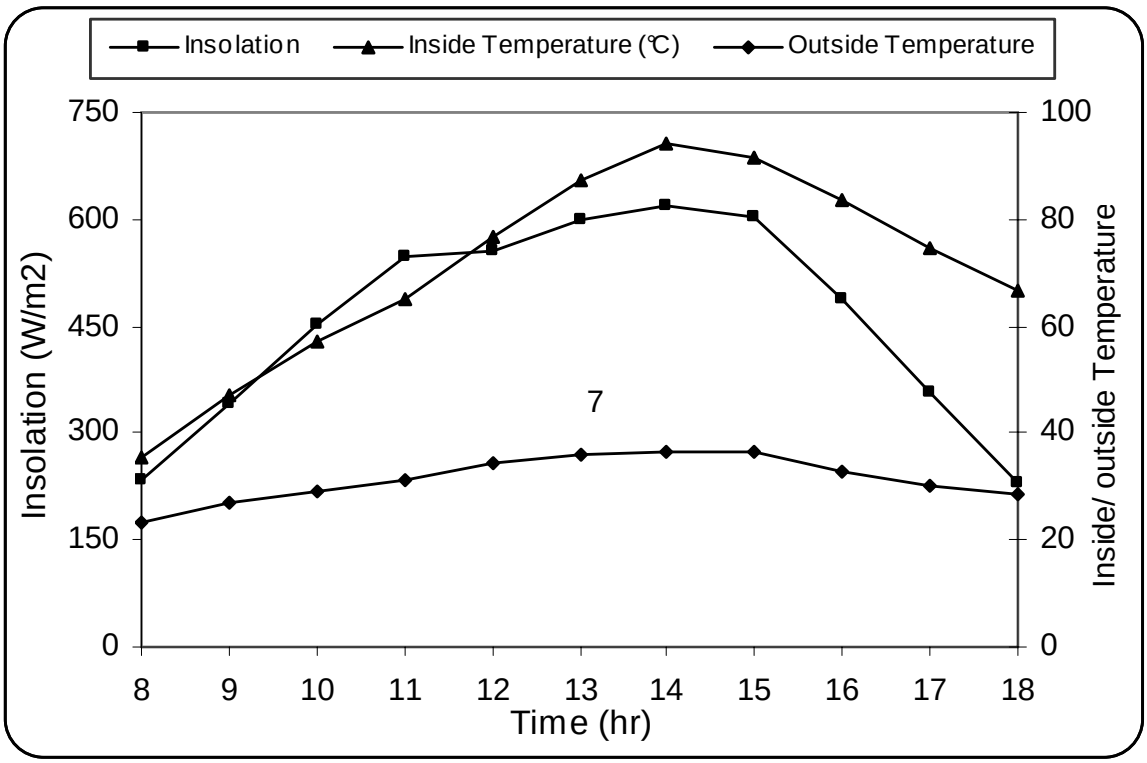


Fig. 2. Performance of wick type solar still no load test in summer

Load test in winter

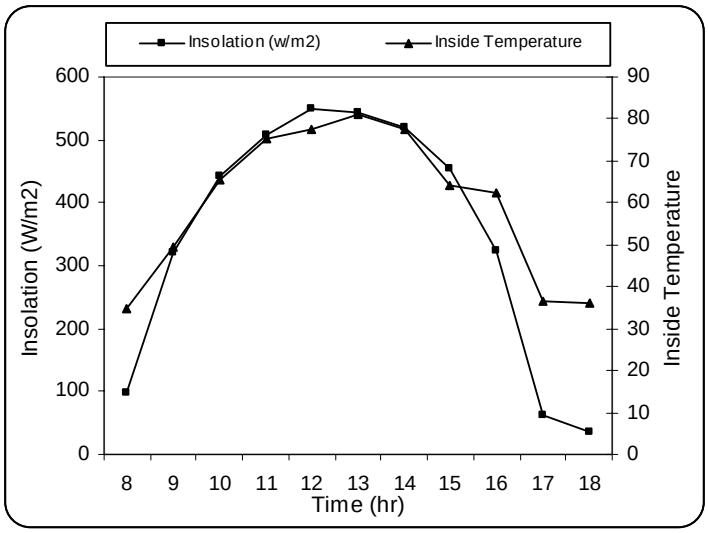
At 40° angle of collector, maximum temperature obtained at 1 P.M was 81.0°C, where solar intensity was 544 W/m^2 and ambient temperature was

32°C as shown in Table 6. It was also observed that the maximum wind speed was 7.6 m/s at 1P.M. and hence during that period the maximum distillation rate i.e. 300 ml/hour was observed.

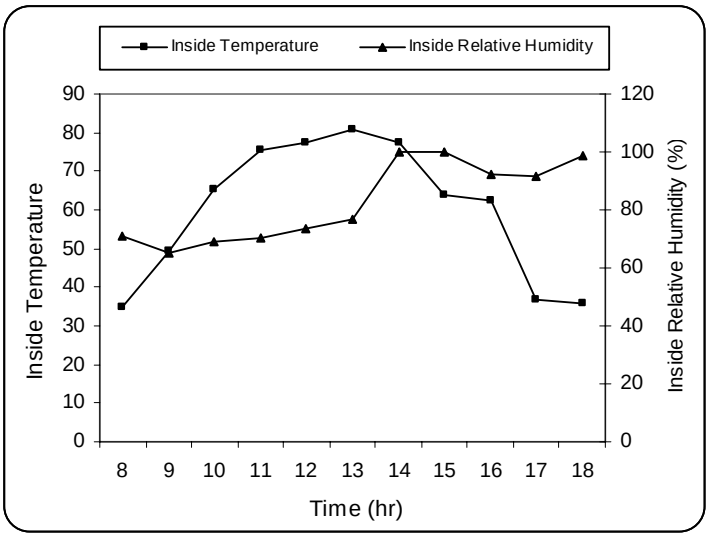
Table: 6. Performance of wick type solar still in winter

Time (Hrs)	Insolation	Inside R.H. (%)	Inside Temperature (°C)	Outside Temperature (°C)	Outside R.H. (%)	Wind speed	Cumulative Distillation (ml)
8.00	98	71	34.8	21.3	88.5	0	0
9.00	320	65.4	49.3	26.8	81.3	0	100
10.00	443	69	65.3	27.3	67	2.1	290
11.00	508	70.1	75.4	28.9	56.5	5.3	440
12.00	550	73.4	77.6	31.6	44.1	6.9	650
13.00	544	76.8	81	32	35.4	7.6	900
14.00	520	100	77.4	33.5	37	2.9	1200
15.00	453	100	64.1	35.1	38.5	2.5	1400
16.00	323	92	62.3	36.8	46.9	2.5	1650
17.00	61	91.6	36.7	30	58.6	0.5	1900
18.00	36	98.4	35.9	28.4	72.4	0.2	2150
Overnight distillation up to 8.00 a.m.							150
Total							**2300**

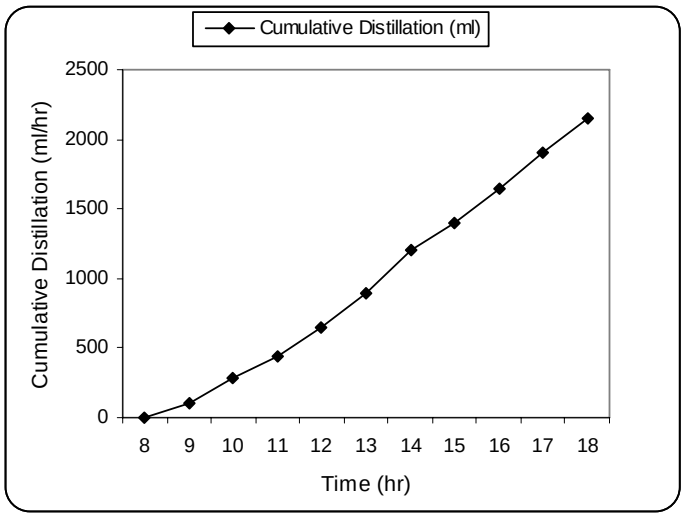
The trend obtained during performance showed in the Fig. 3 as in the beginning solar intensity increased, inside R.H. and temperature increased and once the R.H. attained 100% value, it remain unchanged invariant of solar intensity. Cumulative distilled water obtained from wick type solar still at 40° in winter was 2300 ml as shown in Table 6.



(a)



(b)



(c)

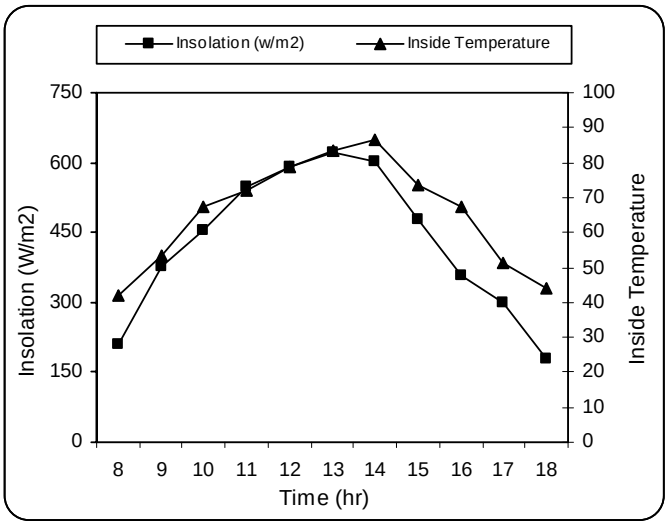
Fig. 3. Performance of wick type solar still with load in winter

Load test in summer

During the performance of wick type solar still with wick material at 40° angle of collector during summer, maximum temperature obtained at 1 P.M was 86.2°C, when solar intensity was 600 W/m^2 and ambient temperature was 38.0°C. The trend obtained as shown in Fig. 4 shows that distilled water obtained was minimum compared to winter. Maximum cumulative distilled water obtained was 2550 ml/day.

Table: 7. Performance of wick type solar still in summer

Time	Insolation (W/m^2)	Inside R.H. (%)	Inside Temp. (°C)	Outside Temp. (°C)	Outside R.H. (%)	Wind speed (m/s)	Cumulative Distillation (ml)
8.00	234	72.3	45.2	27.1	72.1	0	0
9.00	455	78.5	59.1	29.4	56.2	0.3	100
10.00	549	76.4	76.4	30.8	41.1	5.1	300
11.00	607	71.1	79.9	34.2	34.5	0.5	550
12.00	617	69.4	81.5	36.7	32.1	2.2	800
13.00	600	71.6	86.2	38	33.5	1.2	1000
14.00	601	75.3	82.4	37.3	38.6	0.1	1250
15.00	553	78.1	74.6	34.2	42.9	0	1500
16.00	421	83.8	70.4	31.3	50.1	4.3	1800
17.00	267	88.5	62.5	30.5	57	2.5	2100
18.00	165	89	57.1	30.1	69.3	1.6	2350
Overnight distillation up to 8.00 a.m.							200
Total							**2550**



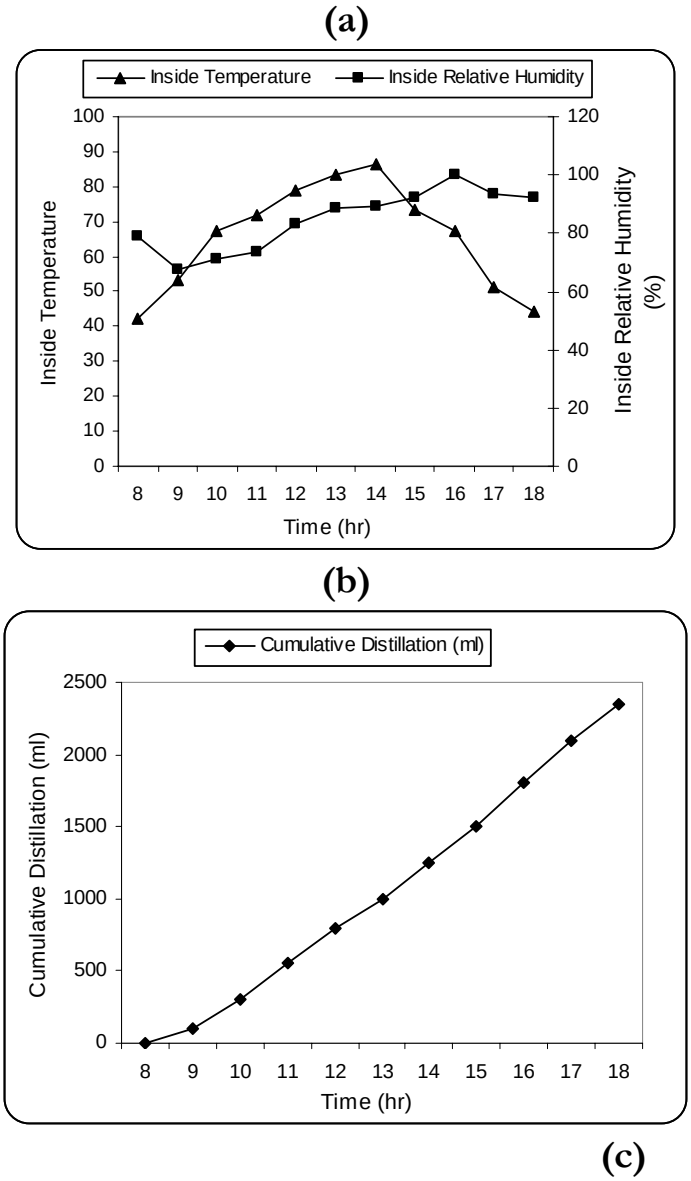


Fig. 4. Performance of wick type solar still with load in summer

Selection of poly film materials

Before using poly film as glazing material, it checked for its maximum transmitivity of solar radiation. Transitivity of polyfilm was checked out by using solarimter readings in W/m^2. The three type of polyfilm like plain polyfilm (silpolin), polyfilm antisulphur and UV stabilized polyfilm were selected for better transmitivity. The inside and outside solar radiations at same height were observed in clear sky condition for all selected polyfilm. It was observed that 76.83 % solar radiation were transmitted from UV stabilized 200 micron white polyfilm where as 65.73 % transmitivity observed in polyfim antisulphur and 69.97 % in plain polyfil (silpolin) shown in Fig.5 (a) and (b).

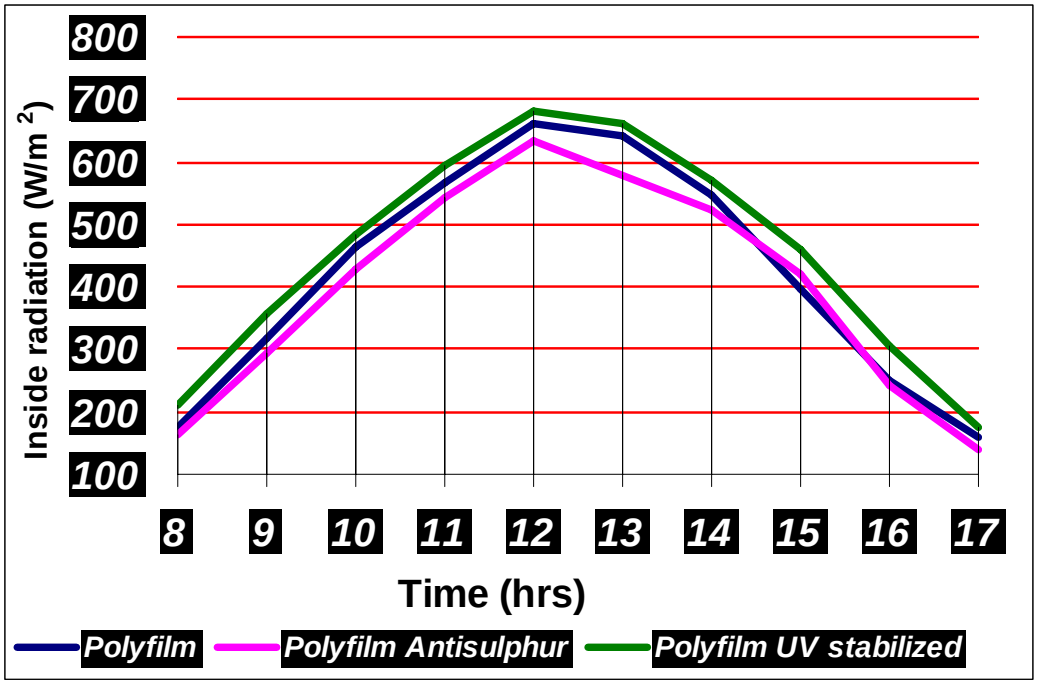


Fig.5. (a) Transmitivity of solar radiation inside poly film.

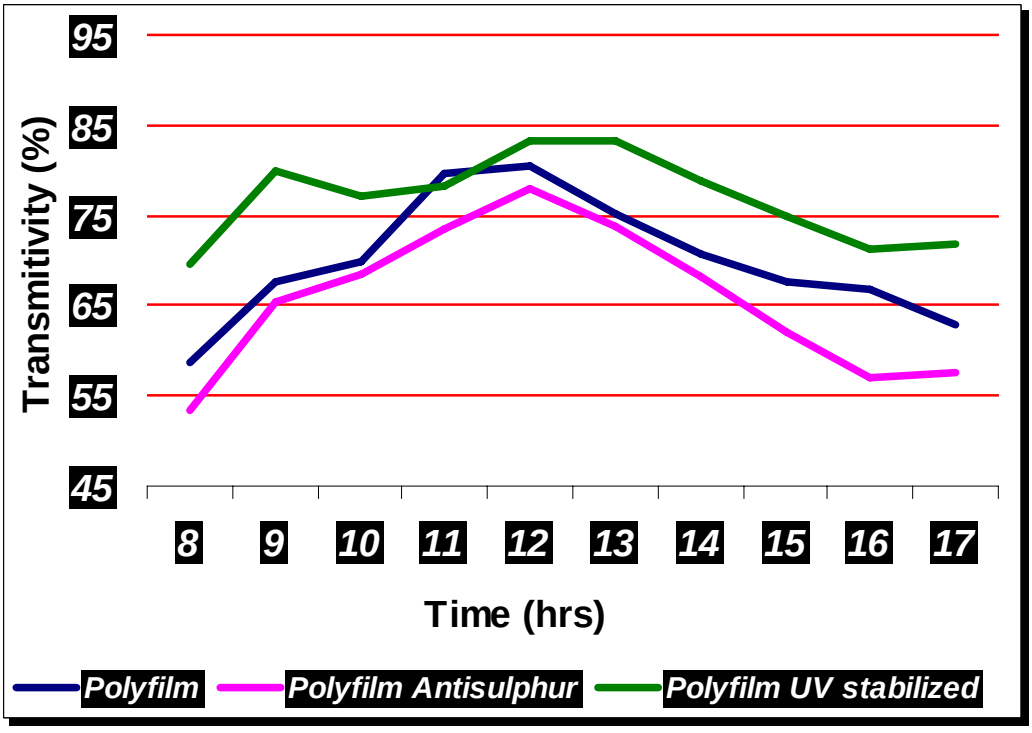


Fig.5. (b) Transmitivity of solar radiation inside poly film.

***W*-shape solar still on concrete two channels**

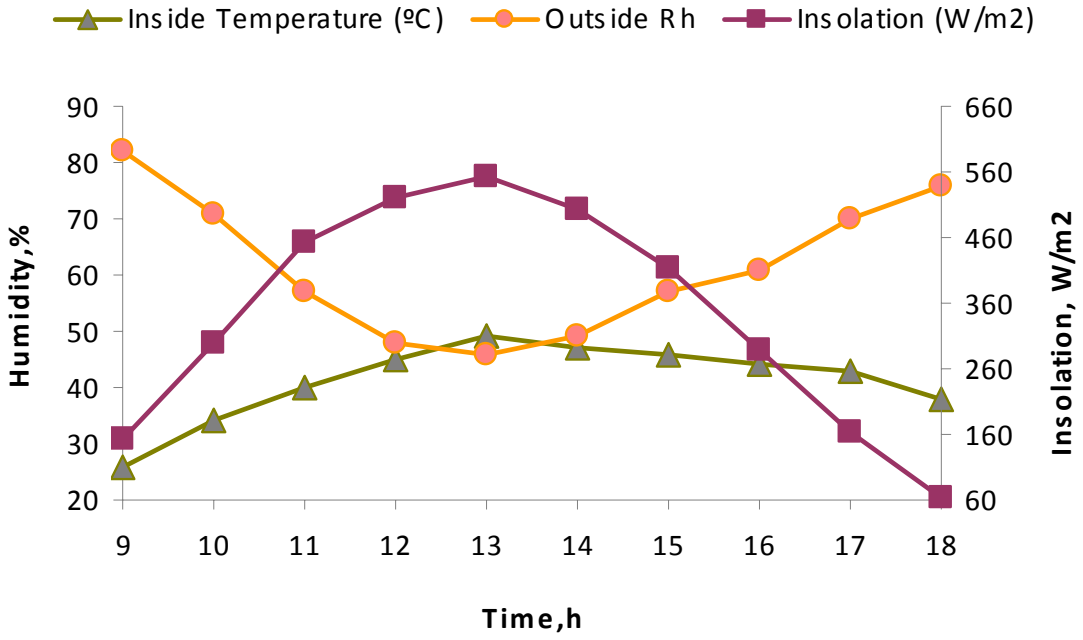
No load test

The low cost *W*-shape solar still with area of 2 m^2 (2m x 1m) was evaluated for no load test. The maximum average temperature was observed

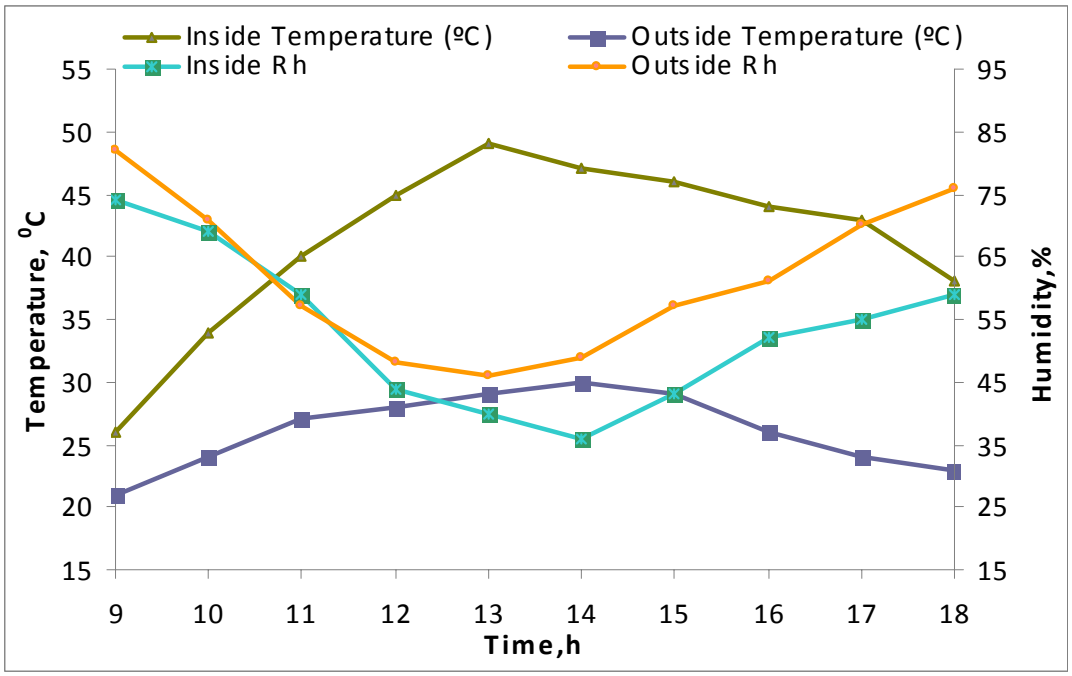
during no load test was 49 ºC at 1 p.m. and the same time solar intensity was 553 W/m^2, ambient temperature was 29 ºC, and outside relative humidity was 46 per cent. The trend obtained in no load test during performance testing is as shown in Fig 6 and Table 8. It is revealed from Fig 6 that the temperature inside the still increased with solar intensity in morning hours up to 1 P.M., and then started decline as day progressed.

Table: 8. Performance of *W*-shape solar still on concrete two channel with no load test in winter

Time (Hrs)	Insolation (W/m^2)	Inside Temp. (ºC)	Ambient Temp. (ºC)	Inside Humidity (%)	Outside Humidity (%)
9.00	152	26	21	74	82
10.00	301	34	24	69	71
11.00	454	40	27	59	57
12.00	521	45	28	44	48
13.00	553	49	29	40	46
14.00	502	47	30	36	49
15.00	415	46	29	43	57
16.00	287	44	26	52	61
17.00	163	43	24	55	70
18.00	63	38	23	59	76



(a)



(b)

Fig. 6. Performance of *W*-shape solar still on concrete two channels with no load test in winter

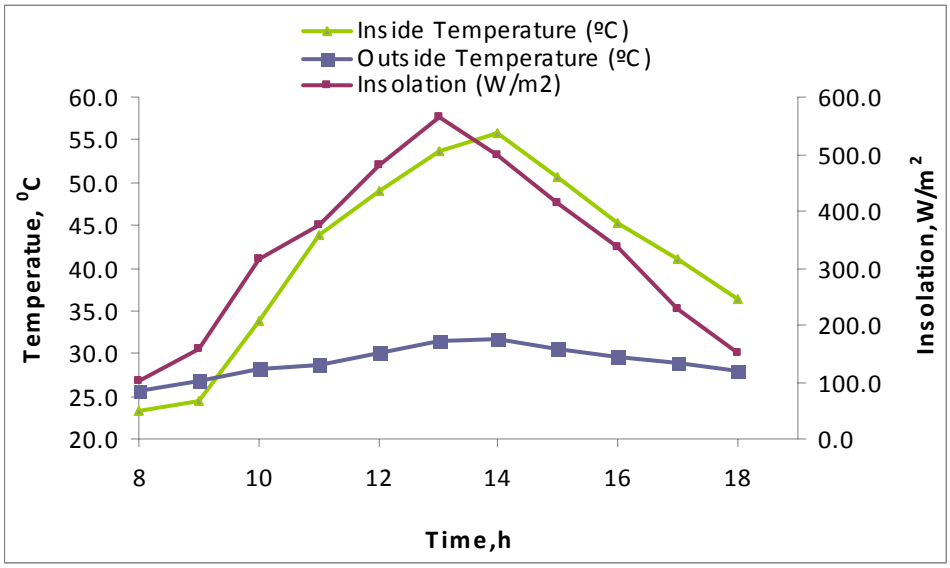
Load test

W-shape solar still with two channels was tested with impounding water depth in cement basin. The hourly cumulative distilled water obtained was observed with solar intensity, ambient temperature, relative humidity and inside temperature. shown in Table 9 and Fig 7.

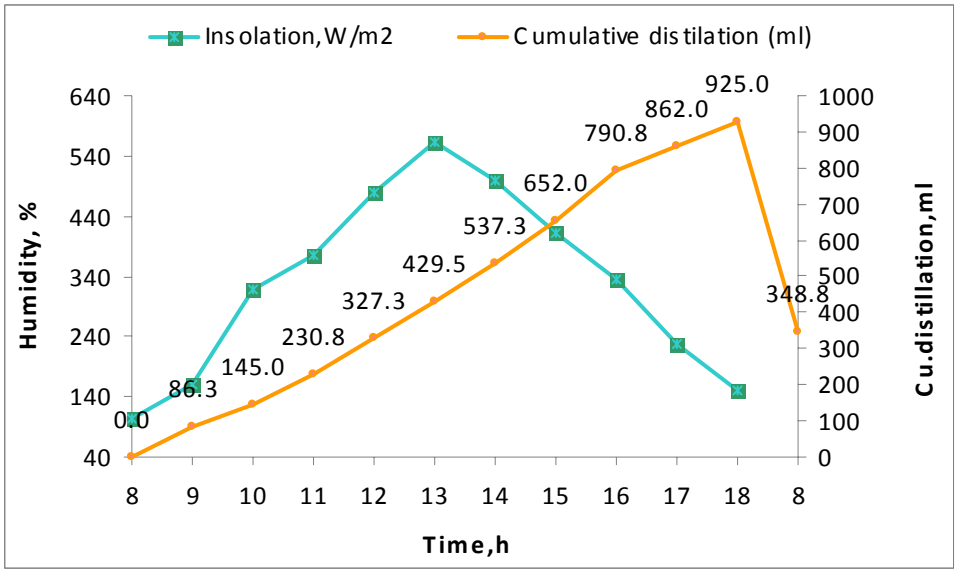
It was observed from Table 9 that maximum average temperature was observed at 1 p.m., when solar intensity was 523 W/m^2 and ambient temperature was 31.9 ºC, ambient R.H. was 48 per cent. Trend observed in load test during performance is shown in Fig 6. It was observed that inside temperature increased as the solar intensity increased and hence rate heat utilization for heating the water was more in noon time and accordingly evaporation was observed more after noon hours and then rate of condensation was increased than noon time as solar intensity decreased. Cumulative distilled water obtained from solar still in summer month was 1274 ml including day and night condensation. It was observed that maximum distillation rate obtained between 3 pm to 4 pm which was highest as 138 ml. Average overnight distillation observed in even type solar still unit was 348 ml which was due to higher condensation rate in night.

Table: 9. Performance of *W*-shape solar still on concrete two channels during load test in summer

Time (Hrs)	Insolation (W/m²)	Inside Temperature (ºC)	Outside Temperature (ºC)	Outside R.H. (%)	Cumulative desalination (ml)
8.00	103.3	23.3	25.7	75.3	0.0
9.00	159.3	24.5	26.8	68.5	86.3
10.00	317.5	33.8	28.2	65.6	145.0
11.00	376.8	43.8	28.7	61.6	230.8
12.00	480.8	49.0	30.0	57.6	327.3
13.00	523.1	53.8	31.4	52.1	429.5
14.00	499.0	55.8	31.6	50.4	537.3
15.00	413.3	50.8	30.6	54.8	652.0
16.00	336.3	45.3	29.5	59.9	790.8
17.00	228.3	41.1	28.8	63.8	862.0
18.00	150.5	36.3	28.0	67.4	925.0
Overnight distillation up to 8.00 a.m.					348.8
Total					1273.8



(a)



(b)

Fig. 7. Performance of *W*-shape solar still on concrete two channels during load test in summer

The maximum cumulative distillation obtained in summer season was 1273 ml, solar intensity played vital role in rate and quantity of distillation through the plant.

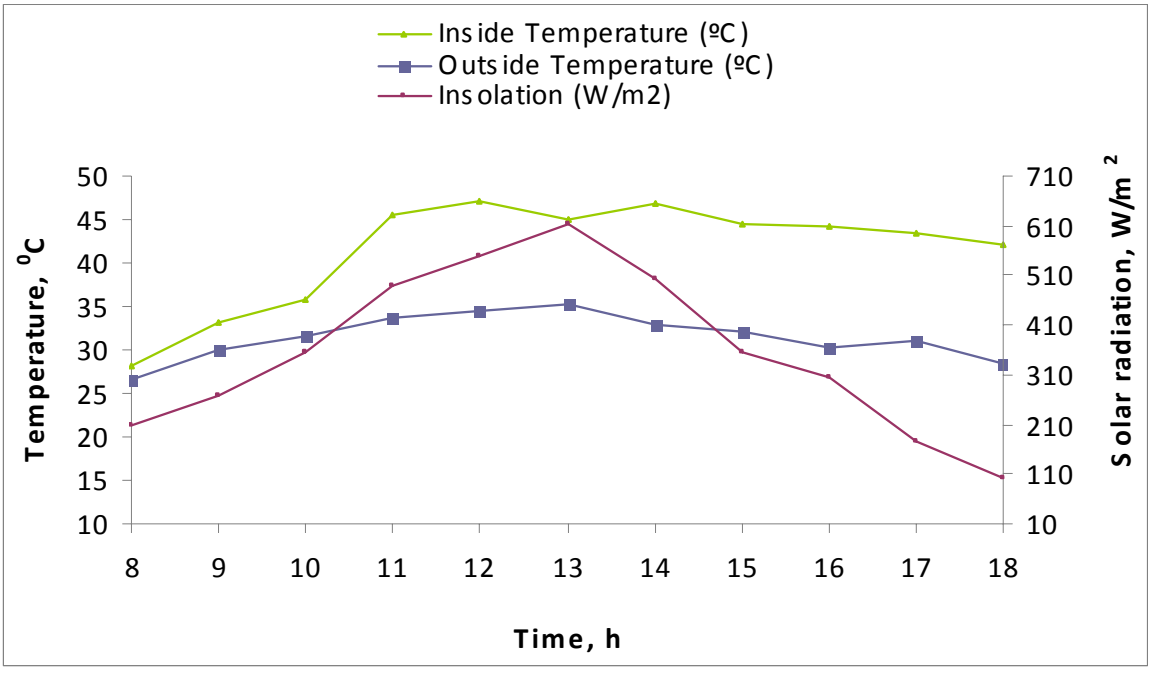
W- shape solar still on soil two channels

No load

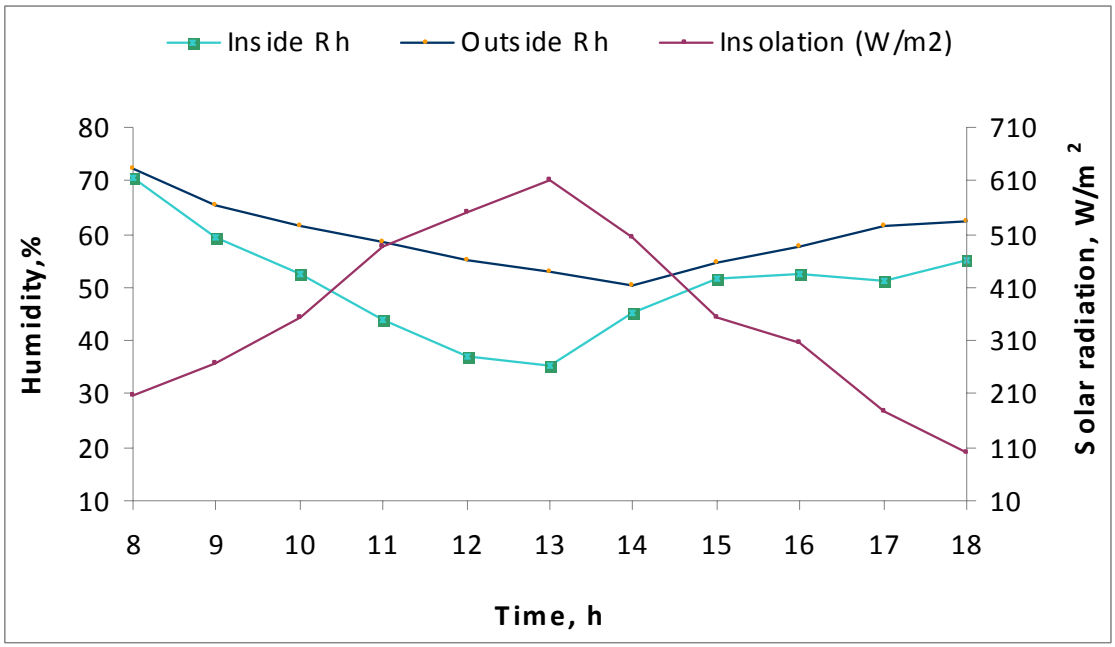
W-shape solar still with two channels was erected on ground and the collected distilled water with two channels was periodically observed along with solar energy, ambient temperature. Inside and outside humidity. The still was evaluated in summer for no load. In summer, maximum inside temperature reached in solar still was 45.1 °C where ambient temperature, solar radiation and relative humidity were found as 35.2,612 and35.2 respectively shown in Table 10 and Fig.8.

Table: 10. Performance of *W*-shape solar still on ground two channels during no load test in summer

Time (Hrs)	Insolation (W/m²)	Inside Temperature (°C)	Outside Temperature (°C)	Inside Rh	Outside Rh
8.00	208	28.2	26.6	70.5	72.1
9.00	268	33.1	29.9	59.2	65.4
10.00	355	35.8	31.5	52.4	61.5
11.00	487	45.4	33.6	43.8	58.7
12.00	549	47.2	34.5	37.2	55.2
13.00	612	45.1	35.2	35.2	52.9
14.00	502	46.8	33	45.4	50.4
15.00	355	44.4	32.2	51.7	54.6
16.00	306	44.2	30.2	52.6	57.8
17.00	177	43.4	31	51.4	61.4
18.00	102	42.1	28.5	55	62.5



(a)



(b)

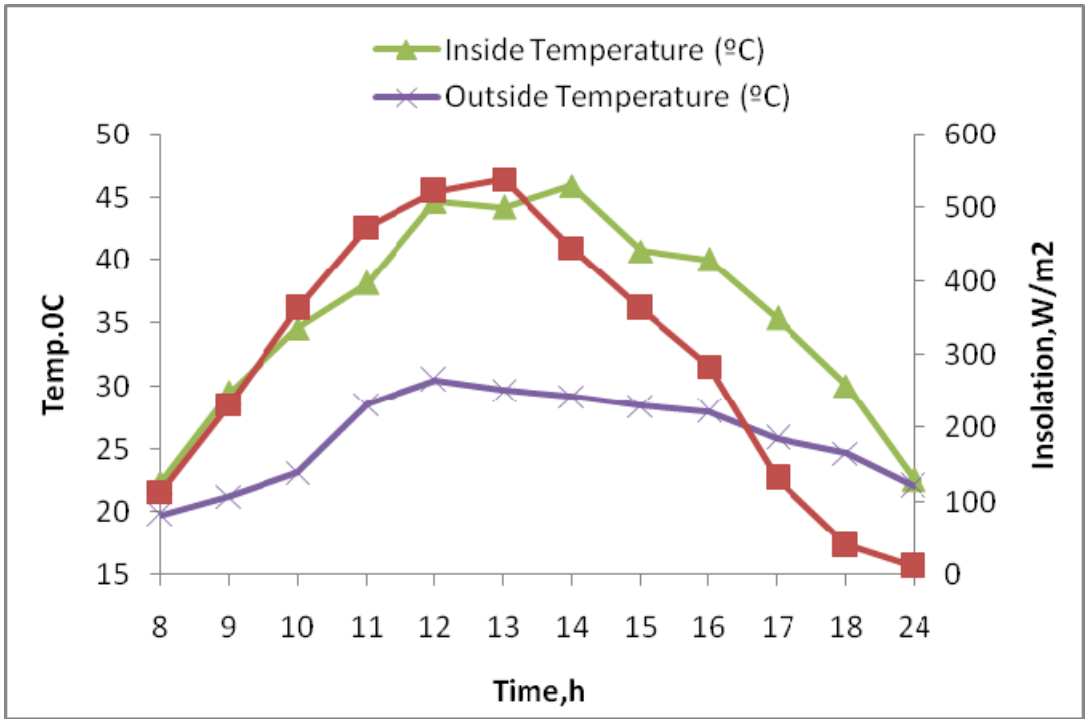
Fig. 8. Performance of *W*-shape solar still on ground two channels during no load test in summer

With Load

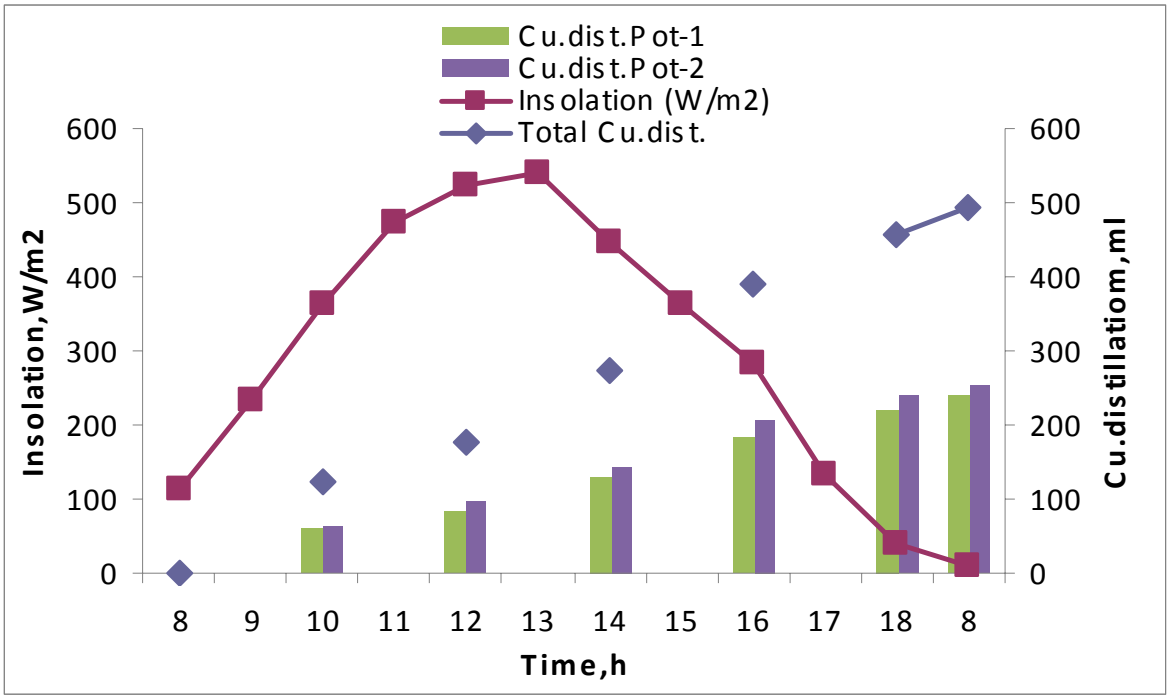
W shape solar still erected on ground with a provision of two channels for collections was evaluated for winter and summer depicted in Table 11 and Fig.9 and Table 12 and Fig.10 respectively. In winter maximum distilled water collected from 24 hour was only 950 ml which was very less comparing to distilled water obtained in summer as 1936.5 ml from same unit.

Table: 11. Performance of *W*-shape solar still on ground two channels during load test in winter

Time h	Insolation (W/m2)	Inside Temp. (ºC)	Outside Temp. (ºC)	Inside Rh (%)	Outside Rh (%)	Cu.dist .-pot-1 (ml)	Cu.dist.- Pot-2(ml)	Total Cu.dist. (ml)
8.0	114.3	22.4	19.8	76.6	75.6	0.0	0.0	0.0
9.0	232.0	29.5	21.3	73.8	69.8			
10.0	362.5	34.6	23.1	58.1	62.3	58.8	64.4	123.1
11.0	474.4	38.2	28.6	53.7	52.3			
12.0	522.1	44.7	30.5	48.8	49.5	82.5	95.6	178.1
13.0	538.8	44.2	29.7	50.1	48.6			
14.0	445.8	45.9	29.2	47.6	49.5	130.6	143.8	274.4
15.0	362.9	40.8	28.4	47.0	51.5			
16.0	284.1	40.1	28.0	50.1	54.4	183.8	205.6	389.4
17.0	132.1	35.4	25.9	58.0	56.3			
18.0	40.0	30.1	24.7	67.5	65.9	219.4	238.8	458.1
Overnight distillation up to 8.00 a.m.						239.2	252.8	491.9
Total								950



(a)

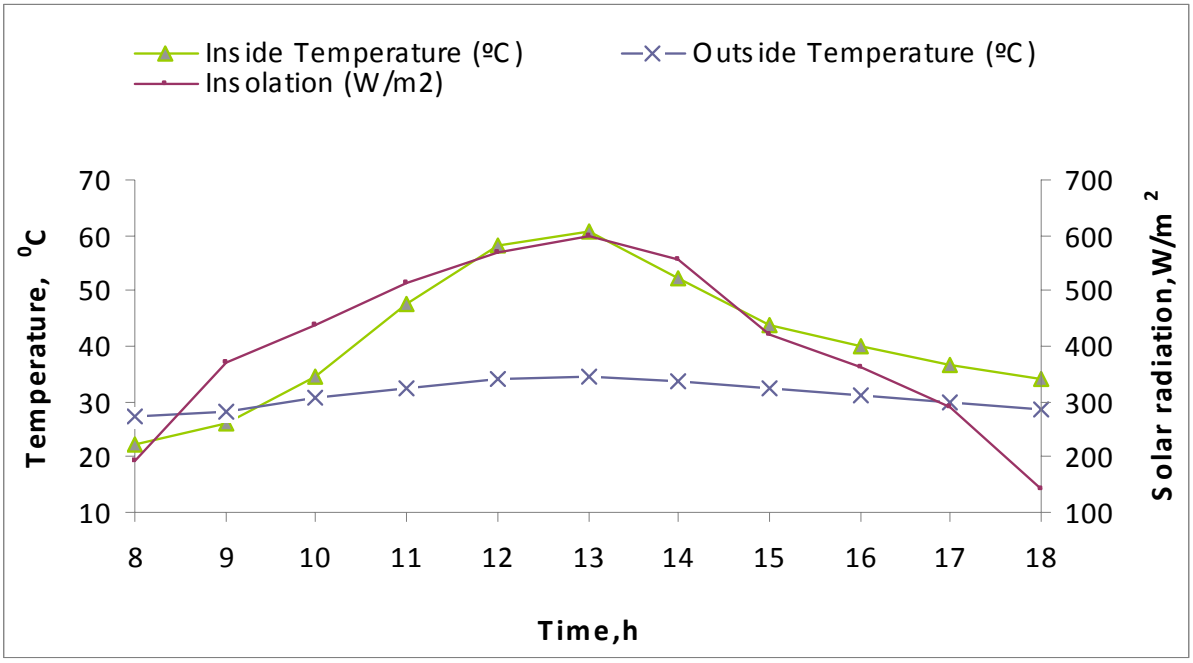


(b)

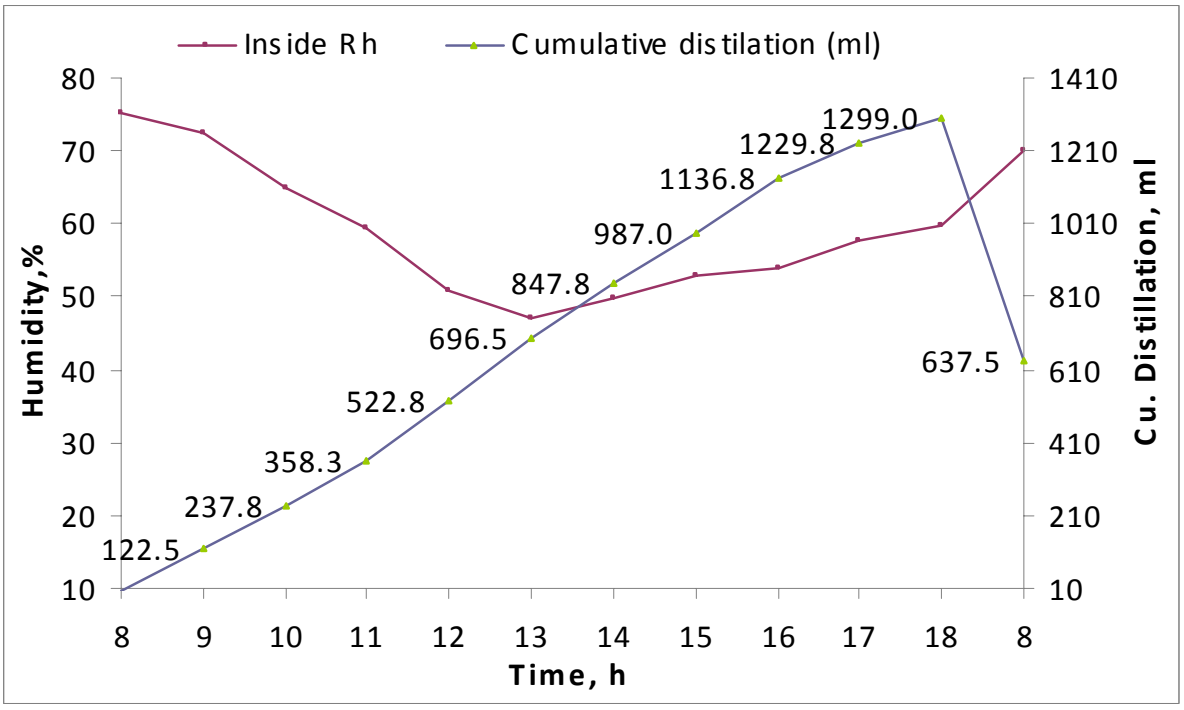
Fig. 9. Performance of *W*-shape solar still on ground two channels during load test in winter

Table: 12. Performance of *W*-shape solar still on ground two channels during load test in summer

Time	Insolation (W/m^2)	Inside Temperature (°C)	Outside Temperature (°C)	Inside Rh (%)	Cumulative distilation (ml)
8	195.0	22.2	27.3	75.1	0.0
9	371.0	26.2	28.4	72.6	122.5
10	438.0	34.7	30.7	64.9	237.8
11	516.0	47.4	32.3	59.4	358.3
12	568.0	58.2	34.0	50.8	522.8
13	600.0	60.7	34.6	47.0	696.5
14	555.0	52.4	33.8	50.0	847.8
15	420.3	43.8	32.3	52.9	987.0
16	364.0	40.0	31.1	54.0	1136.8
17	291.0	36.6	29.7	57.6	1229.8
18	140.8	33.9	28.6	59.7	1299.0
Overnight distillation up to 8.00 a.m.					637.5
Total					**1936.5**



(a)



(b)

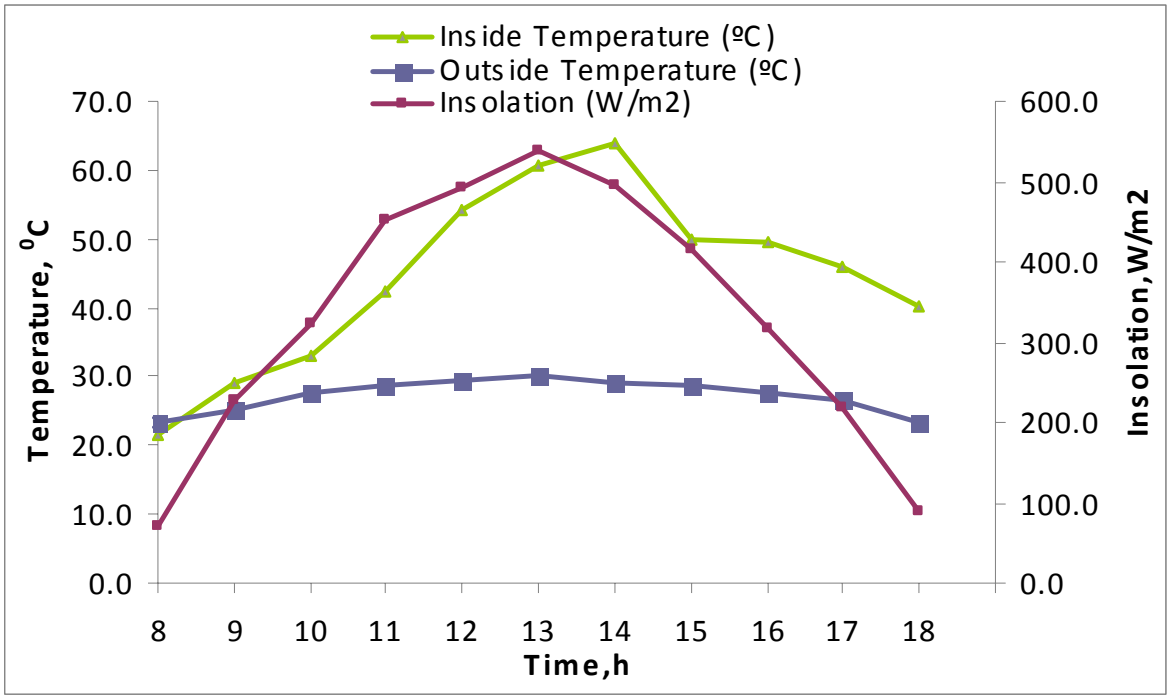
Fig. 10. Performance of *W*-shape solar still on ground two channels during load test in summer

Single side (*L*- shape one channel) solar still on soilWith Load

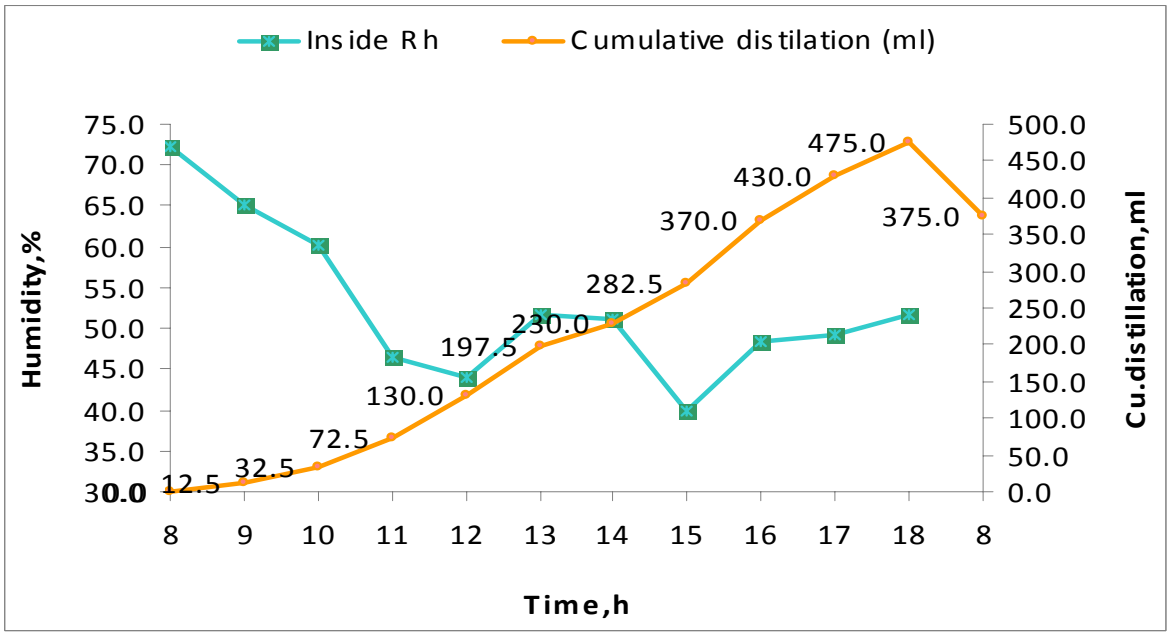
L shape solar still was erected on ground with single channel for collection provision. The still was evaluated in winter for load condition. In winter, maximum inside temperature reached in solar still was 63.8 ^{o}C where ambient temperature, solar radiation and relative humidity were found as 30.3, 540 W/m^2 and 51.8 % respectively shown in Table 13 and Fig.11. The Maximum distilled water collected from this unit in winter was only 850 ml in 24 hours.

Table: 13. Performance of L type still on ground during load test in winter

Time	Insolation (W/m^2)	Inside Temperature (^{o}C)	Outside Temperature (^{o}C)	Inside Rh	Cumulative distilation (ml)
8	70.0	21.5	23.4	72.4	0.0
9	229.0	28.9	25.2	65.2	12.5
10	324.0	33.0	27.5	60.3	32.5
11	453.5	42.4	28.6	46.4	72.5
12	493.0	54.4	29.5	44.0	130.0
13	540.0	60.5	30.3	51.8	197.5
14	495.0	63.8	29.0	51.0	230.0
15	416.5	50.1	28.7	39.8	282.5
16	317.5	49.7	27.7	48.3	370.0
17	218.5	46.0	26.5	49.1	430.0
18	88.5	40.2	23.4	51.7	475.0
Overnight distillation up to 8.00 a.m.					375.0
Total					850.0



(a)



(b)

Fig. 11. Performance of L type solar still on ground during load test in winter

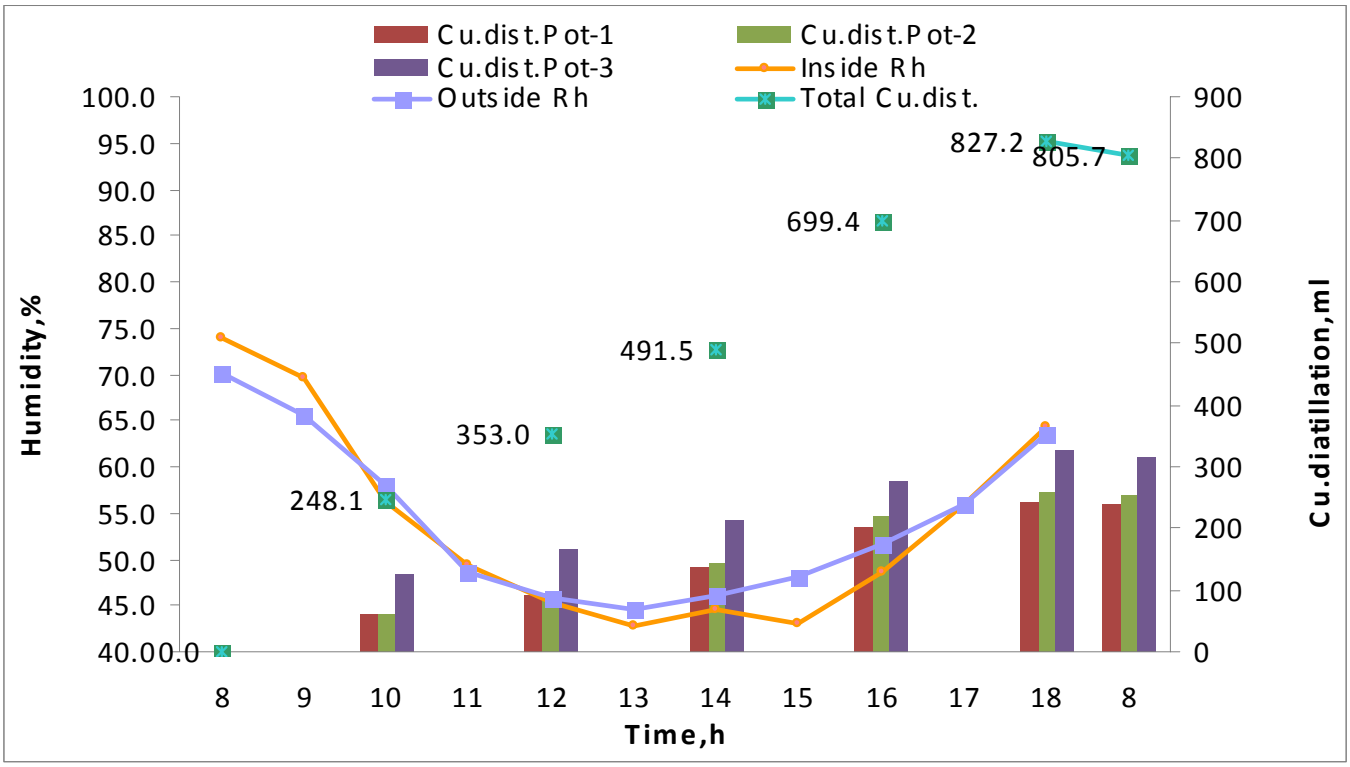
W- shape solar still on ground three channel Load in winter

W-shape solar still erected on ground with three channels for collection was evaluated in winter and summer for load test and respective data is depicted in Table 14 and Fig 12. Maximum distilled water collected from solar still erected

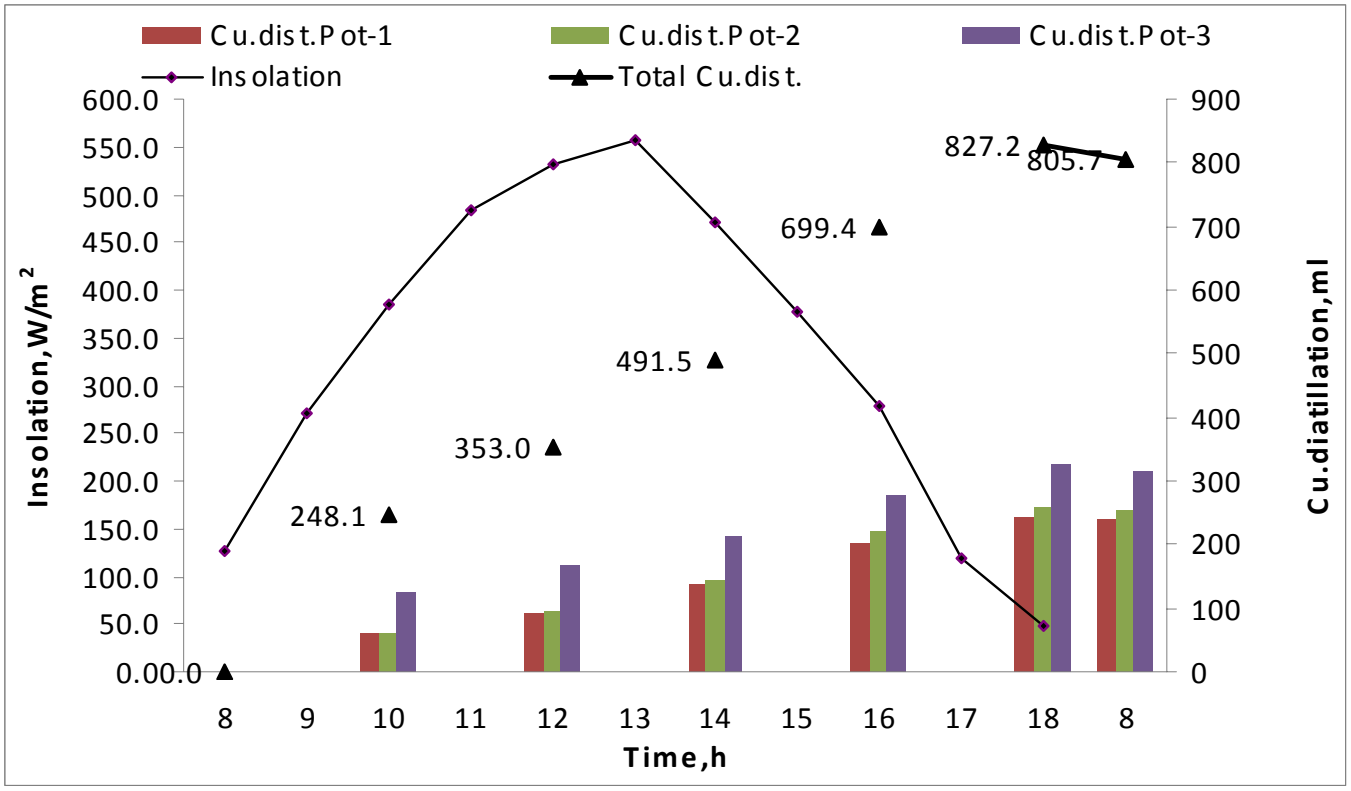
on soil with three channels was 1633 ml/day. The maximum average solar radiation available in winter during study was 556 W/m^2 and maximum average inside temperature, inside relative humidity were found as 46 ^{0}C, 73.8 % respectively. By providing one extra collection channel surrounding the bottom sides of solar still, 65 % increased was observed in total cumulative distillation.

Table: 14. Performance of *W*-shape solar still on ground three channels during load test in winter

Time	Insolation (W/m2)	Inside Temp. (ºC)	Outside Temp. (ºC)	Inside Rh (%)	Outside Rh (%)	Cu.dist. Pot-1 (ml)	Cu.dist. Pot-2 (ml)	Cu.dist. Pot-3 (ml)	Total Cu. dist.
8.0	127.5	24.3	22.8	73.8	70.2	0	0	0	0
9.0	271.1	32.4	23.8	69.6	65.6				
10.0	386.0	36.1	25.6	56.3	58.0	60.3	62.4	125.4	248.1
11.0	484.7	40.4	29.6	49.3	48.7				
12.0	530.4	44.9	31.1	45.2	45.7	90.2	96.0	166.8	353.0
13.0	556.1	43.0	30.7	42.9	44.5				
14.0	470.2	45.7	30.2	44.5	46.0	136.3	144.2	211.0	491.5
15.0	377.3	39.7	29.7	43.0	48.1				
16.0	277.3	39.7	29.3	48.6	51.7	202.9	220.4	276.1	699.4
17.0	118.9	34.8	27.4	56.1	55.9				
18.0	48.0	30.8	26.3	64.2	63.5	243.5	256.9	326.8	827.2
Overnight distillation up to 8.00 a.m.						239.2	252.8	313.8	805.7



(a)



(b)

Fig. 12. Performance evaluation of *W*-shape solar still on ground with three channels in winter

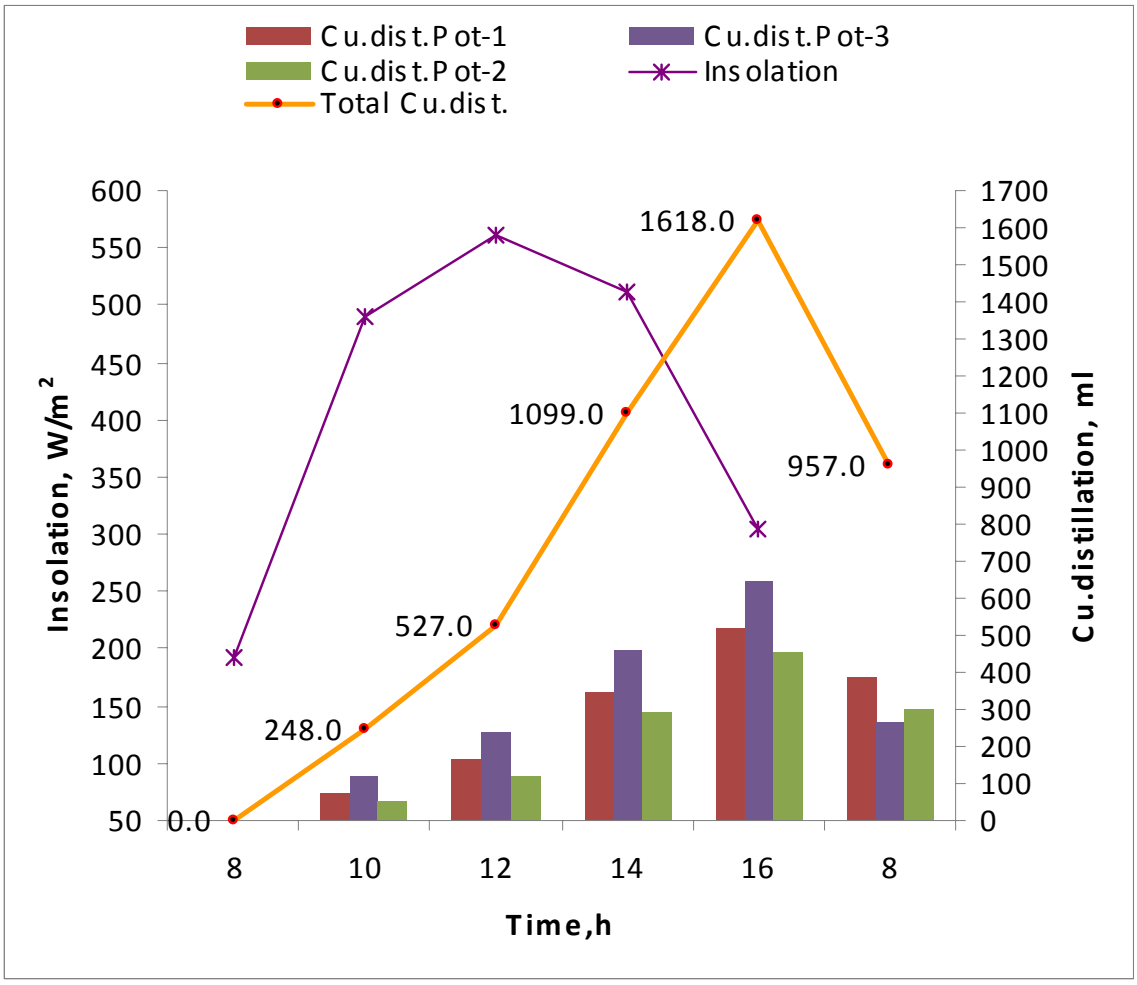
Load test in summer

W -shape solar still erected on ground with three channel provision was evaluated in summer for load test and respective data are depicted in Table 15 and Fig 13. Maximum distilled water collected from solar still erected on ground with three channels was 2575 ml/day. By providing one extra collection channel surrounding the bottom side of solar still, 55 % rise was observed in total cumulative distillation in summer.

Table: 15. Performance of *W*-shape solar still on ground with three channels during load test in summer

Time	Insolation (W/m2)	Outside Temp. (°C)	Cu.dist. Pot-1 (ml)	Cu.dist. Pot-2 (ml)	Cu.dist. Pot-3 (ml)	Total Cu. dist.
8.00	193.2	28.7	0.0	0.0	0.0	0.0
10.00	490.8	31.8	73.0	53.0	122.0	248.0
12.00	561.6	32.2	164.0	120.0	243.0	527.0
14.00	510.6	32.5	349.0	292.0	458.0	1099.0

16.00	304.0	31.2	518.0	453.0	647.0	1618.0
Overnight distillation up to 8.00 a.m.			384.0	303.0	270.0	957.0



(a)

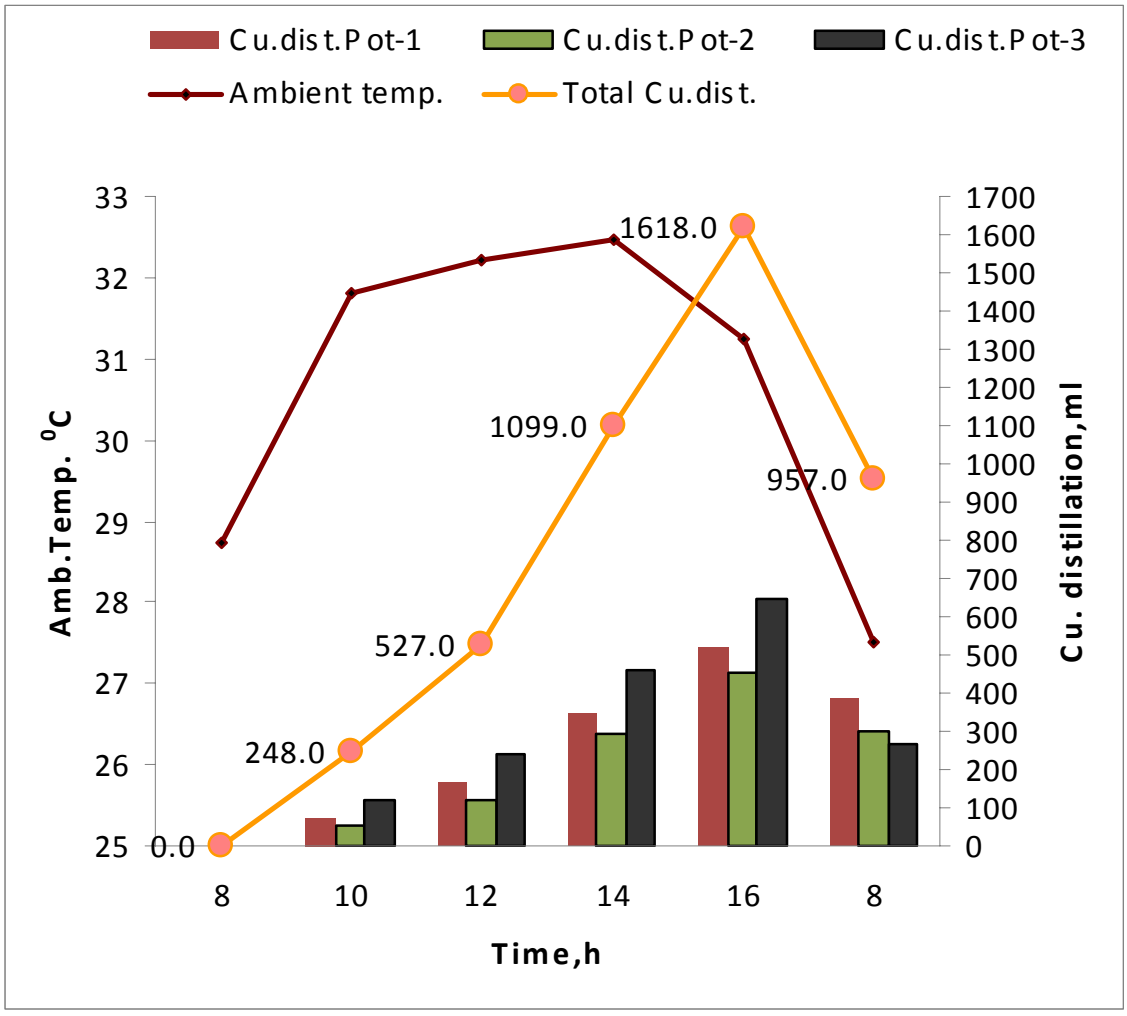


Fig. 13. Performance evaluation of *W*-shape solar still on ground with three channel in summer

Comparison of different solar distillation units

After evaluating the different solar stills, their results of cumulative distillation are compared and depicted in Table16. Comparatively more distilled water was obtained from the solar still having an area of 1m^2 fabricated in fiber or metal body with glass glazing like single slope ,double slope and wick type solar still. From Table 16 shows that average maximum temperature and humidity was more in double slope, single slope and wick type solar still and hence the average quantity of distilled water obtained as 1350 ml/day, 1550 ml/day and 2450 ml/day respectively. Reason behind the maximum output from single slope ,double slope and wick type solar still was proper insulation and glass glazing where as another solar stills made with plastic wrapping over the frame which itself acted as body of solar still and glazing for maximum energy collection.

When jute cloth was spread above the absorber in wick type solar still, it increased the evaporation rate than single and double slope still and hence comparatively more distilled water was obtained in wick type solar still.

This plastic made up of *W*-shape solar still provided with 3 channels produce maximum distilled water as 2104 ml/day where as *W*-shape solar still with two channels erected on concrete and ground produced only 1012ml/day and 1443 ml/day respectively. L shape solar still produce average distilled water was 925 ml/day which was very low among the all type of solar still.

Comparative lower distillation was observed in *W*-shape polythene based solar still though it has 2 m^2 areas. It might be due to the use of polythene as a glazing area and more heat loss through the unit. Comparative cost of compact nature of solar stills like single slope, double slope and wick type solar still was more than Rs.7000/- which is four times more than newly developed *W*-shape 3 channel solar still. Comparative output from newly developed solar still was low but it has several advantages that it is cheapest, cost efficient and easy to clean.

Table: 16. Average performance of solar stills in year

Sr. No.	Type	distilled water (ml/ day)	inside temperature (^{0}C)	inside humidity (%)	App.cost (Rs.)
	Available in market				
1	Single slope (1m^2)	1350	60	78	8000/-
2	Double slope (1m^2)	1550	70	82	7500/-
	Newly developed				
1	Wick type (1m^2)	2425	83.6	95	7241/-
2	W shape-2 channel on concrete 2 m^2)	1012	50.5	74.5	4000/-
3	W shape-2 channel on ground, 2 m^2	1443	53.4	75.5	1848/-
4	L shape, 2 m^2)	925	64.6	72	1000/-
5	W shape-3 channel on ground, 2 m^2)	2104	53.5	74.9	1848/-

Chemical Analysis

Chemical analysis of impure and pure water obtained from *W*-shape three channel solar still was carried for pH, EC, TDS and ions (Mg^{++}, Ca^{++}, Na^{+},

CO_3^-, HCO_3^-, Cl^-) concentration. The concentration of these substrates before and after desalination is given in Table 17.

Table: 17. Chemical analysis of impure and pure water sample

Chemical properties of Water	Tap Water	Distilled water obtained from Millipore unit	Distilled Water obtained from solar distillation unit
pH	7. 8	7.0	7.0
EC (μS/cm)	100	0.5	0.8 (0.520 mg/l)
TSS (%,^{0}Brix)	0.02	0	0
Mg^{++} (ppm)	0.00088	0	0.00036
Ca^{++} (ppm)	0.00090	0	0.00032
Mg^{++} + Ca^{++} (me/lit)	0.0018	0	0.00040
Na^+ (me/lit)	3.5	0	0.1
CO_3^- (me/lit)	0.6	0	0
HCO_3^- (me/lit)	0.2	0	0.15
Cl^- (me/lit)	1.6	0	0

It was observed from the results of chemical analysis of pure and impure water, given in Table 7 that there was drastic reduction in the pH, EC, Mg^{++}, Ca^{++}, Na^+, CO_3^-, HCO_3^- ions Carbonate, Bicarbonate etc. in the distilled water.

Cost economics

During evaluating performance of solar distillation unit, different direct benefits were derived. These benefits were indicators of technical feasibility of plant. Subsequently the economics of the plant was evaluated in the term of cost per liter of distilled water through electrical backup in distillation unit. Hourly benefits of the plant are considered and payback period of distillation unit was made. The total cost that of the investment spread over the entire useful life of the plant, including initial cost, operation cost, maintenance and interest are taken in consideration for payback period.

Considering the average distilled water obtained from even type *W*-shape solar still as 2.1 liter for 250 days a year. It produced 526 liters of distilled

Published by ECSDEV, Via dei Fiori, 34, 00172, Rome, Italy

water yearly. By considering the wholesale market value of distilled water (Rs.10/lit) and total income generated while producing 526 liters of distilled water is tabulated in Table 18.

Table: 18. Details about cost analysis of solar still

Sr. No.	Particulars		Amount (Rs.)
1	Total Revenue		5260
2	Cost of Device		1848
3	Cost of Energy		Nil
4	Cost of Polythene		` 500
5	Cost of Labor, Operation and Maintenance for trouble free operation of unit	Per year	` 300
		After every 5 year	` 800

It was observed from the Table 20, the cost of unit is recovered within 4 months 6 days only, i.e. the payback period of the unit was only 1/3rd year and after that period the unit will produce net profit. Area of newly developed solar still is double than other two distiller but pay back period is minimum it may due to the lower cost of unit. All economic indicators are summarized in Table 20, as Benefit Cost Ratio (BCR) was 2.56, whereas Net Present Worth (NPW) was Rs.38958.

Table: 19. Payback Period Analysis of distillation unit

Year	Cash outflow	PW of Cash outflow (at 12 % discount rate)	Cash inflow	PW of Cash inflow (at 12 % discount rate)	NPW
A	**B**	**C**	**D**	**F**	**F-C**
0	1848	1848	0.0		-1848.0
1	**300**	270.3	5260.0	4738.7	**4468.5**
2	300	243.5	5260.0	4269.1	4025.6
3	300	219.4	5260.0	3846.1	3626.7
4	300	197.6	5260.0	3464.9	3267.3
5	800	474.8	5260.0	3121.6	2646.8
6	300	160.4	5260.0	2812.2	2651.8
7	300	144.5	5260.0	2533.5	2389.0
8	300	130.2	5260.0	2282.5	2152.3
9	300	117.3	5260.0	2056.3	1939.0
10	800	281.7	5260.0	1852.5	1570.7
11	300	95.2	5260.0	1668.9	1573.7
12	300	85.8	5260.0	1503.5	1417.8
13	300	77.3	5260.0	1354.5	1277.3
14	300	69.6	5260.0	1220.3	1150.7
15	800	167.2	5260.0	1099.4	932.2
16	300	56.5	5260.0	990.4	933.9
17	300	50.9	5260.0	892.3	841.4
18	300	45.8	5260.0	803.8	758.0
19	300	41.3	5260.0	724.2	682.9
20	0	0.0	5260.0	652.4	652.4
TOTAL		**2929.1**		**41887.1**	**38958.0**

Table: 20. Economic indicators for solar distillation units

Type	Cost (Rs.)	Net Present Worth	BCR for first year	PBP
Even type distillation unit	**1848/-**	**38958**	**2.56**	**4** months **6** days

Conclusions

1. Newly developed *W*-shape solar still with three channel erected on soil was economical for the average output of 2104 ml/day distilled water.
2. Concentration of pH, EC, TDS and ions in solar distilled water was found to be similar as conventional distilled water.

References

Adhikari, R.S., Kumar, A., Sodha, G.D., 1995. Simulation studies on a multi-stage stacked tray solar still. J. Solar Energy 54(5), 317.

Ahmed, S.T., 1988. Study of single effect solar still with an internal condenser. Int. J. Solar Wind Tech. 5 (6), 637.

Anna, M. and S. Rangarajan, 1980. Solar Radiation over India, Allied Publisher Privet Ltd., New Delhi : 404

Ashok Kumar and J.D. Anand., 1992. Modeling and performance of a tubular multiwick solar still. Energy-an international journal, 17(11):1067-71.

Aybar, H. S. *et al.*,2005. An experimental study on an inclined solar water distillation system. Desalination 180, 285-289

Bapeshwar, V., Tiwari, G.N., 1984. Effect of water flow over the glass on the performance of a solar still coupled with a flat plate collector. Int. J. Solar Energy 2, 277.

Barrera, E., 1992. A technical and economical analysis of solar water still in Mexico. J. Renewable Energy 2 (4), 489.

Bassam, A., Hijleh, K.A., Mousa, H.A., 1997. Water film cooling over the glass cover of a solar still including evaporation effects. J. Energy 22, 43.

Bassam, A., Hijleh, K.A., Rababa'h, H.M., 2003. Experimental study of a solar still with sponge cubes in basin. J. Energy Convers. Manag. 44 (9), 1411.

Bhatt, R. N., 1996. Performance evaluation of solar still, unpublished B. TechThesis.1996

Brenidorfer, B. *et al.*, 1995. Solar dryer; their role in post harvest processing, Commonwealth Secretariat Marlborough house, London, Swly 5hx.

Bongirwar, D. R., 1998. Utilization of solar energy in agricultural sector. Industrial products finder

Bouchekima, B., 2003. Solar desalination plant for small size use in remote arid areas of South Algeria for the production of drinking water. Desalination 15x.

Bouchekima, B., 2003. Solar desalination plant for small size use in remote arid areas of South Algeria for the production of drinking water. Desalination 156, 353-354.

Chafik, E., 2003. A new type of seawater desalination plants using solar energy. Desalination 156, 333-348.

Clark, J.A., 1990. The steady-state performance of a solar still. J. Solar Energy 44 (1), 43.

Coffey, J.P., 1975. Vertical solar distillation: technical note. J. Solar Energy 17, 375.

Cooper, P.I., 1969. Digital simulation of transient solar still processes. J. Solar Energy 12 (3), 313.

Cooper, P.I., 1970. The transient analysis of glass covered solar still. Ph.D. Thesis. University of Western Australia, Australia.

Dutt, D. K., A.. Kumar; J. D. Anand, G. N. Tiwari., 1994. Improved design of a double effect solar still. Teri Information and Energy Digest,4(1):55

EI-Swify, M.E. and M.Z. Metias, 2002. Performance of double exposure solar still. Renewable Energy, 26(4):531-547.

Fraca, K. B., 2001. Design and performance of small scale solar powered water desalination system. Teri Information and Energy Digest, 11(2): 118

Gourds, J. and H.Cracken., 1985. Under standing solar stills. Verginia, USA, VITA,45.

Jigneesh, N. and Rangacharyulum, M., 1989. Development of low cost solar water still for drought-hit areas. Renewable Energy and Enviroment Proceeding of Natural Solar Energy Convention, Udaipur, India, 1-3 December: 271-5.

Ihalawela, P. H. C. A. and Careem, M. A., 2007. A cheap automatic solar water distiller. Proceedings of the technical sessions 23, 41-45.

John, S., *et al.*, 1989. Studies on wick type solar still with removable glass cover. Renewable Energy for Rural Development: Proceeding of the National Solar Energy convention Hydrabad, India 1-3, December: 295-9.

Kothari, S. and Sengar, S.H., 2007. Performance evaluation of solar stills. Bioved,18(1,2): 35-37

Kumar, S. and G.N. Tiwari, 1996. Performance evolution of an active solar distillation system. Energy-an International Journal,21(9):805-808.

Lawrence, S., Gupta, S., Tiwari, G.N., 1988. Experimental validation of thermal analysis of solar still with dye. Int. J. Solar Energy 6, 291.

Lawrence, S.A., Tiwari, G.N., 1990. Theoretical evaluation of solar distillation under natural circulation with heat exchanger. J. Energy Convers. Manag. 30, 205.

Lawrence, S.A., Gupta, S.P., Tiwari, G.N., 1990. Effect of heat capacity on the performance of solar still with water flow over the glass cover. J. Energy Convers. Manag. 30, 277.

Lof, G.O.G., Eibling, J.A., Bloemer, J.W., 1961. Energy balances in solar distillation. J. Am. Inst. Chem. Eng. 7 (4), 641.

Malik, M.A.S., Tiwari, G.N., Kumar, A., Sodha, M.S., 1982. Solar Distillation. Pergamon Press, Oxford, UK.

Mouchot, A., 1869. La Chaleur Solavie et ses Applications. Gauthier-Villars, Paris.

Mukherjee, K., Tiwari, G.N., 1986. Economic analysis of various designs of conventional solar stills. J. Energy Convers. Manag. 26, 155.

Murugavel, K.K. *et al.,* 2008. An experimental study on single basin double slope simulation solar still with thin layer of water in the basin. Desalination 220, 687-693

Nayak, J.K., Tiwari, G.N., Sodha, M.S., 1980. Periodic theory of solar still. Int. J. Energy Res. 4, 41.

Nebbia, G., Mennozi, G., 1966. A short history of water desalination, In: Proceedings of International Symposium, Milano, pp. 129.

Patil, C.B. and Patil, V.H., 1989. Weekly Rainfall Probabilities In North Konkan Coastal Zone of Maharashtra State. Research Bulletin Agromet No.5 Regional Agricultural Research Station, Karjat, Konkan Krishi Vidyapeeth, pp-3

Rahman, M. H. *et al.* 1997. Pilot solar desalination plants in Bangladesh. In: 23rd WEDC conference, p.178-181.

Rai, G. D. 1991. Solar Energy Utillization, Khanna Publications, 4th edition,pp.197

Rai, S.N., Tiwari, G.N., 1982. Single basin solar still coupled with flat plate collector. J. Energy Convers. Manag. 23, 145.

SAFI, M. J., 2004. Solar Ponds For Thermal Desalination And Membrane Distillation, Engineering School of Tunis- TUNISIA, 14(9): 28-54

Singh, P.P. and Mannan, K. D., 1983. Some studies on solar distillation. Prock of National Solar Energy Convention, Hydrabad, India.

Seshadri, C. V., *et al.*, 1995. Design of low cost solar still. Teri Information and Energy Digest, 5(1): 139

Singh, A. K. and Tiwari, G. N., 1992. Experimental validation of passive regenerative solar still. International Journal of Energy Research, 16(6): 497-506

Sinha, S. and Kumar, S., 1993. Economics evaluation of passive and active solar distillation systems.In N.K. Bansal (eds.):7-12 New Delhi: Tata Mcgrawhill.

Sinha, S., Tiwari, G. N. and Sodha. M. S., 1992. Techno-economic analysis of solar distillation system. International Journal of Energy Reserch.16 (5):365-372.

Spiegler, K.S. and Y.M. El-Sayed. 2001. "The Energetics of Desalination Processes."
Desalination. 134: 109-128.

Srivastava, S. C., 1984. Solar still. Rural Technology Journal, 1 (2-3): 34-40

Tyagi, S. and Rathore, N. S., 2000. Performance evaluation of Solar distillation plants. Commercialization Aspects of Renewable Energy Sources.46-48

Thanvi, K.P. and Pande, P. C., 1988. Development of solar still for rose water production: Proceeding of the National Solar Energy Convention, Hydrabad, India, 1-3 December

Thanvi, K.P., 1982. Design and Development of a multibasin tilted type solar still. Allied Publisher, New Delhi.

Thavi, K. P. and Pande, P. C., 1990. Development of inclined solar dryer with alternative materials. Renewable Energy and Environment proceeding of Natural Solar Energy Convention, Udaipur, India, 1-3 December:271-5

Tiris, C. M. Tiris., Y. 1998. Effect of collector Orientation on Solar Energy availability. Teri Information and Energy Digest,9(2)

Tiris, C. M. Tiris, Y. Erdalli and M. Sohmen, 1999. Experimental studies on a solar still coupled with a flat plate collector and a single basin still. Teri Information and Energy Digest,9(3)

Tiwari, G. N. and S. Suneja, 1998. Performance evaluation of an inverted absorber solar still. Energy Conservation and Management: an International Journal, 39 (3/4):173-180.

Tiwari, G.N., S. Sinha and P. Saxena, 1993. Standard Testing procedure for solar distiller unit. RERIC International Energy Journal, 14(1):17-24.

Tiwari, G.N. and Tiwari A.K., 2008. Solar distillation practice for water desalination systems. p.244-248.

Tiwari, G. N. *et al.*, 2003. Present status of solar distillation. Solar Energy 75, 367-373

Vanuatu Renewable Energy and Power Association, Feb- 2006. A Demonstration of Solar Stills to Desalinate Seawater Phase- 2, Project Proposal, pp-17

Venkatesh, A. and Chaturvedi, A. K., 1989. Experimental observations on a portable solar still. Solar Energy Society of India, 3(1):9-13

Wagh, A., 1991. Solar water heating system for apartments. IREDA News, 10(1):21-22