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# Recommendation proposal

# Development and evaluation low cost of solar still plant (Double slope single basin type, DSSB)

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## PART- I: General information

| | | |
|---|---|---|
| **01** | **Project Code** | |
| **02** | **Project Title** | Development and evaluation low cost of solar still plant (Double slope single basin type, DSSB) |
| **03** | **Name of Department Where the project was undertaken**<br>**a) Name of Department**<br><br>**b) Location of Project** | Department of Electrical and Other Energy Sources<br>Faculty of Agricultural Engineering<br><br>Department of Electrical and Other Energy Sources<br>Faculty of Agricultural Engineering |
| **04** | **Name of Scientist** | Dr. S. H. Sengar, Assistant Professor |
| **05** | **Name of Co-Scientist** | Dr. Y.P.Khandetod , Professor<br>Dr. A.G. Mohod, Associate Professor |
| | **Supporting Department** | Deptt. of Farm Machinery and Power, CAET, Dapoli |
| **06** | **Objectives** | 1. Development and evaluation of a pilot scale low cost solar still unit.<br>2. Development and evaluation of low cost solar still plant.<br>3. Economic evaluation of solar still plant. |
| **07** | **Year of start** | 2009-2010 |

## PART- II: Technical information

**Methodology:**

Three types [wick type, even type (W shape) and single side (L shape)] of solar stills were design 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 | $\delta$ | $\delta = 23.45 \sin [0.9863(284 + n)]$<br>$\delta = -23^{\circ}03'$ |
| 2 | Slope of collector | $\beta$ | $\beta = (\Phi - \delta)$<br>$\beta = 40^{o}\ 48'$ |
| 3 | Intensity of insolation on horizontal | $I_c$ | $I_c = I_h \times \text{Cos}\ \theta$<br>$I_c = 450\ W/m^2$ |
| 4 | Intensity of insolation on sloping surface | $I_s$ | $I_s = I_h \times \text{Cos}\ \theta / \text{Cos}\ \theta_h$<br>$I_s = 594.5\ W/m^2$ |
| 5 | Cosine of $\theta_h$ | $\theta_h$ | $\theta_h = 40^{o}.8'$ |

**Design Considerations**

**Solar collector for plant**

The solar collector was designed by using following assumptions:

1. The device to be situated at latitude of 17˚45' N ( latitude of Dapoli)
2. Minimum insolation on horizontal plane during winter, for 10th of December is 450 $W/m^2$ (Anna M. and S. Rangrajan,1980) and observed value of insolation on sloping surface was found to be 594 $W/m^2$

**Slope of collector (β)**

In order to calculate the optimum slope of collector, winter was taken as a midpoint. Angle of solar declination (δ) was calculated from following equation.

$\delta = 23.45 \sin [0.9863\ (284 + n)]$
where,
n = Number of days.
Slope of collector (β) is calculated by using following formula:
$\beta = (\Phi - \delta)$
where,
Φ = Latitude at test site,
= 17˚45' N
Positive value of β = Collector should be south facing.

**Intensity of insolation (Ic)**

Instantaneous insolation on the surface was approximately proportional to the cosine of angle of incidence (θ).

The angle of incidence for insolation falling on south facing roof at midday can be calculated by using following equation.

$$\cos\theta = \sin\delta \cdot \sin\Phi \cdot \cos\beta - \sin\delta \cdot \cos\Phi \cdot \sin\beta \cdot \cos r + \cos\delta \cdot \cos\Phi \cdot \cos\beta \cdot \cos\omega + \cos\delta \cdot \sin\Phi \cdot \sin\beta \cdot \cos r \cdot \cos\omega + \cos\delta \cdot \sin\beta \cdot \sin r \cdot \sin\omega$$

Where,
$\theta$ = Angle of incidence
$\Phi$ = Latitude of the test
$\beta$ = Slope of collector
r = Surface azimuth angle, for structure this can be considered as its orientation with respect to a north south axis. The angle varies from -180˚ to +180˚, zero is due to south, east is negative and west is positive.

The value of r = 0 was used for present calculation.

$\omega$ = the hour angle, is the angular displacement at the sun east or west. It is zero at a solar noon and changes 15˚ per hour. Morning is negative and afternoon is positive.

$\omega = 0$ is used for present calculation.

Following equation was used to determine the intensity of insolation on collector surface ($I_c$),

$$I_c = I_h \times \cos\theta$$

Where,
$I_h$ = Intensity of insolation on horizontal surface, $W/m^2$

For a horizontal surface, since $\beta = 0$ and hence, $\cos\beta = 1$ and $\sin\beta = 0$

Now,

$$\cos\theta h = \sin\delta \cdot \sin\Phi + \cos\delta \cdot \cos\Phi \cdot \cos\omega$$

Hence, level of insolation on sloping surface is calculated as:

$$I_s = I_h \times \cos\theta / \cos\theta h$$

**Wick Type Solar still**

Wick Type Solar still was fabricated at the central workshop of the College of agricultural Engineering and Technology, Dapoli. The pictorial 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.

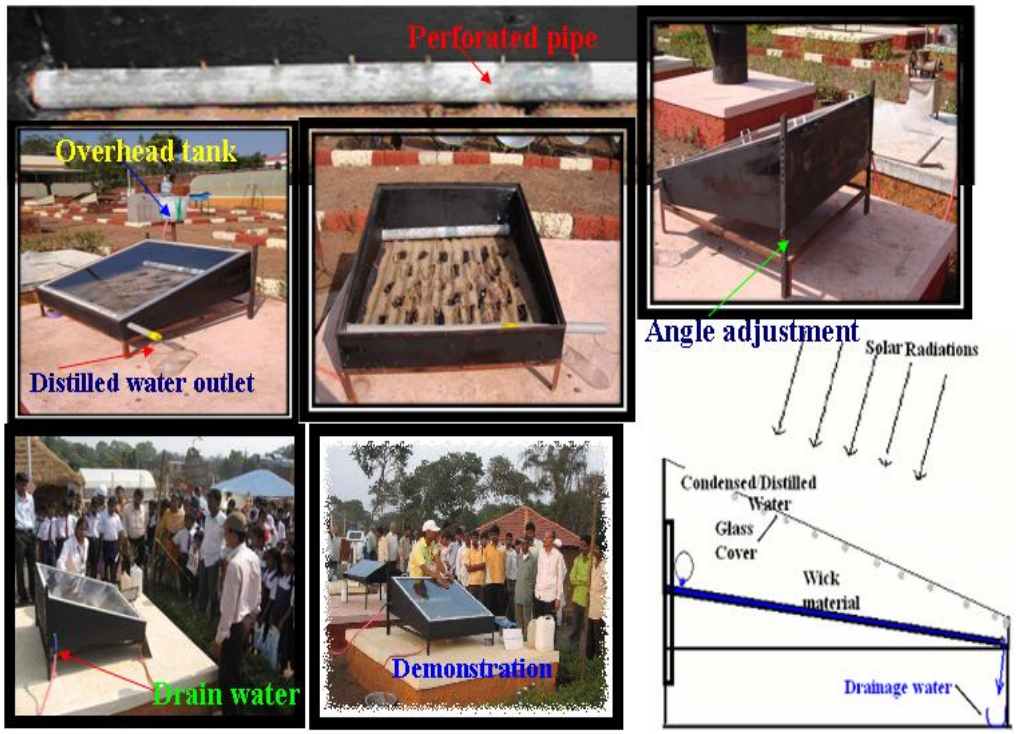



**Plate: 1. Wick Type Solar still**

**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 | | | | 100/- |
| 10 | Thermocol | 25mm thick | | 30/Sh | 120/- |
| 11 | Hinges (2) | 25mm x 25mm | | 30/Pie | 60/- |
| 12 | Lambi | | 100 gm | | 50/- |
| 13 | Red oxide | | 100 gm | | 30/- |
| 14 | Blackboard paint | | 500 ml | | 50/- |
| 15 | Gromate | | | 5/Piec | 10/- |
| 16 | Cock (Plastic) | | | 5/Piec | 5/- |
| 17 | Araldite (2) | | | 30/Pie | 60/- |
| 18 | Glass with frame | 1 m x 1 m | | | 942/- |

| | | | |
|---|---|---|---|
| 19 | Nut and Bolts | | 20/- |
| 20 | Labour Charges | 30% | 1671 |
| | | **Total** | **7241/-** |

**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 the frame with the help of non-corrosive wires. 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) and first two channels which were fixed inside solar still (Plate 4)

**Plate: 2. Basin prepared in soil for W-shape solar still on soil**

**Plate: 3. Third channel from all bottom sides for W-shape solar still on ground**

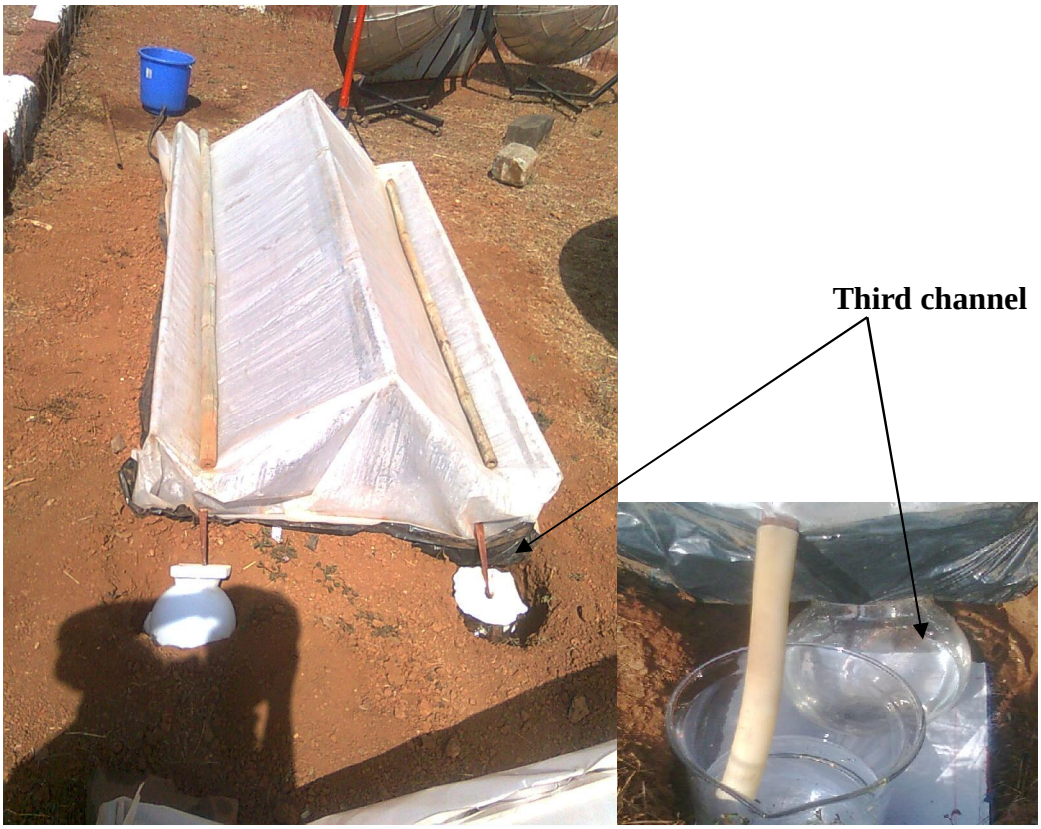



**Plate: 4. Two channel provision for W-shape solar still  Plate-3 Third channel**

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

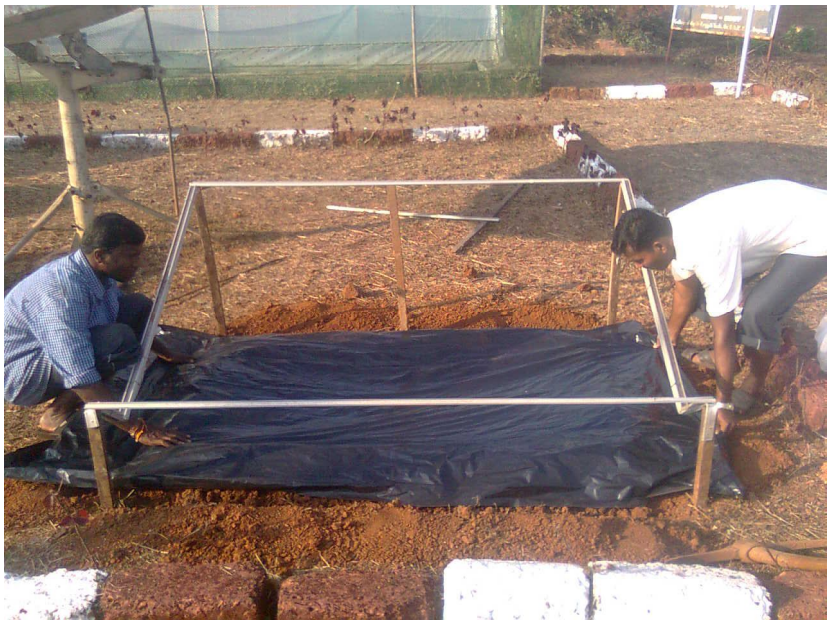
**(a)**

**(b)**

**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 shown in Plate 6. 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/-



**(a)**

**(b)**

**Plate: 6. Single sides (L shape) solar still.**

**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/-** |

**Energy Analysis**

Different types of solar stills produced distilled water in varying ranges though they had same or different basin area. For finding the reason of varying output of distilled water from same or different solar still, energy analysis was important and hence energy analysis of selected solar stills was carried out in following way.

**Energy Efficiency**

The energy efficiency of the stills was calculated considering distilled water as the output with corresponding solar radiation and unit area. The following equation was used to calculate the energy efficiency:

$$\eta_{energy} = \frac{(m_{ew} \times C_p \times \Delta T) + (m_{ew} \times L)}{I_s \times 10 \times 3600} \times 100 \quad (3.1)$$

Where,

$\eta_{energy}$ = Energy efficiency (%).

$m_{ew}$ = Mass of distilled water collected per day per square metre of collector Area (g).

Cp = Specific heat of water (J/g°C)

L = Latent heat of vaporization of water (J/g).

$I_s$ = Average solar intensity (W/m$^2$).

**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 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 |

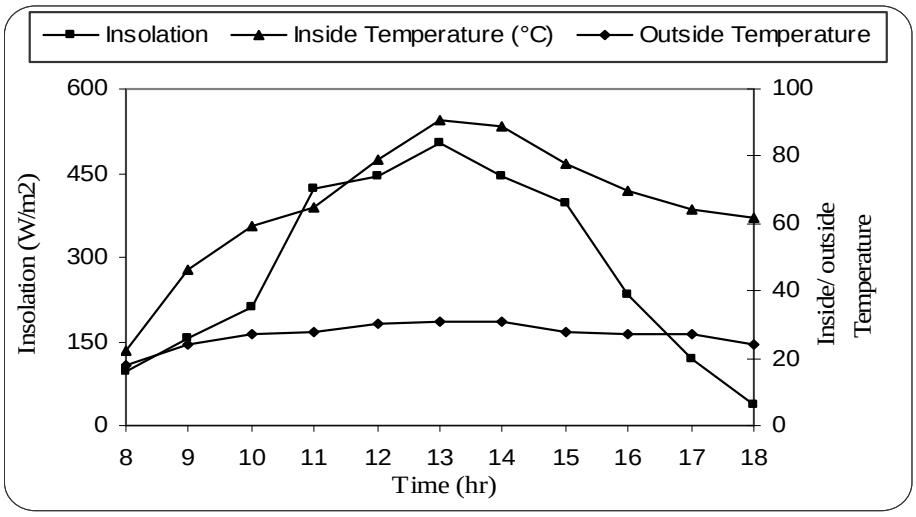



**Fig. 1. Performance of wick type solar still no load test in winter**

**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 |

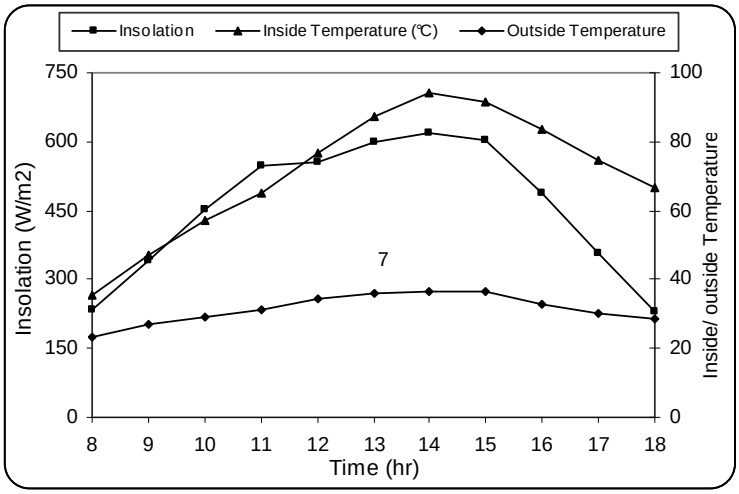



**Fig. 2. Performance of wick type solar still no load test in summer**

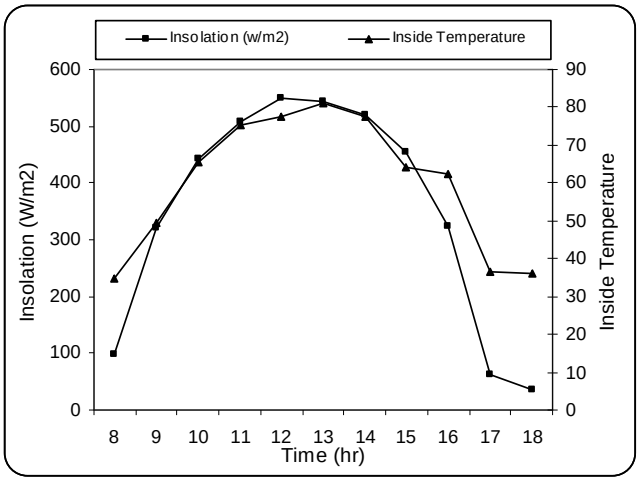
**Load test in winter**

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 (W/m$^2$)** | **Inside R.H. (%)** | **Inside Temp. (°C)** | **Outside Temp. (°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 40º in winter was 2300 ml as shown in Table 6.

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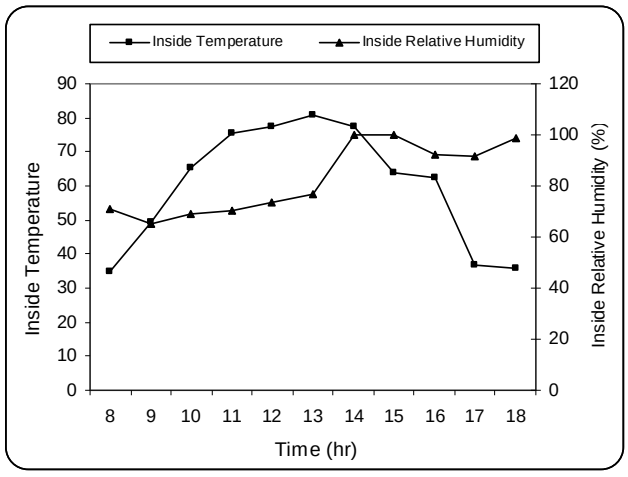


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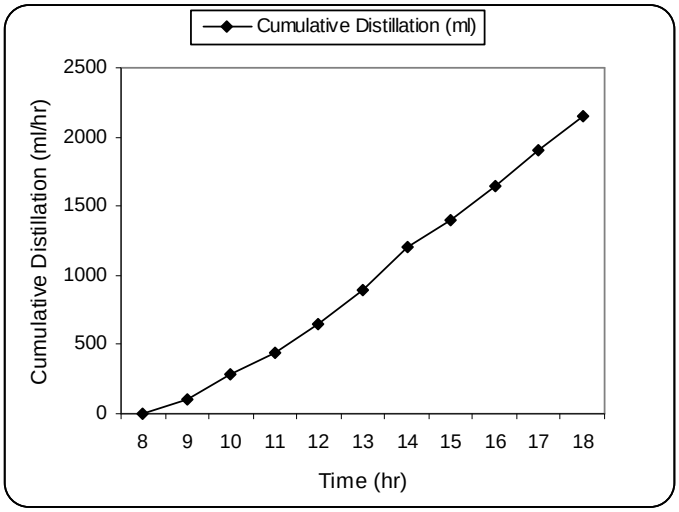



**(c)**

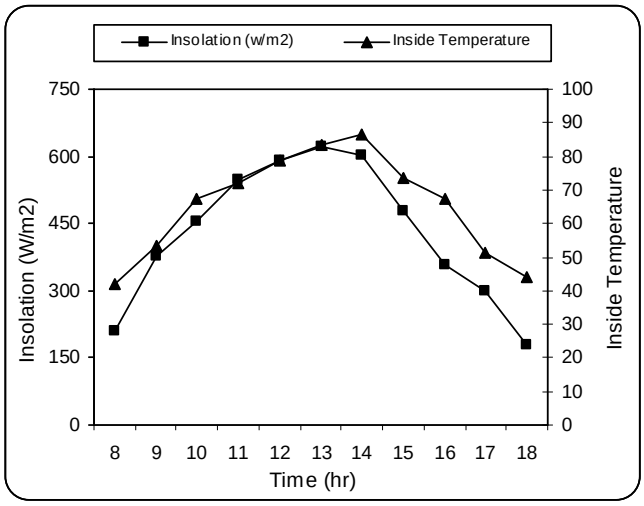
**Fig. 3. Performance of wick type solar still with load in winter**

**Load test in summer**

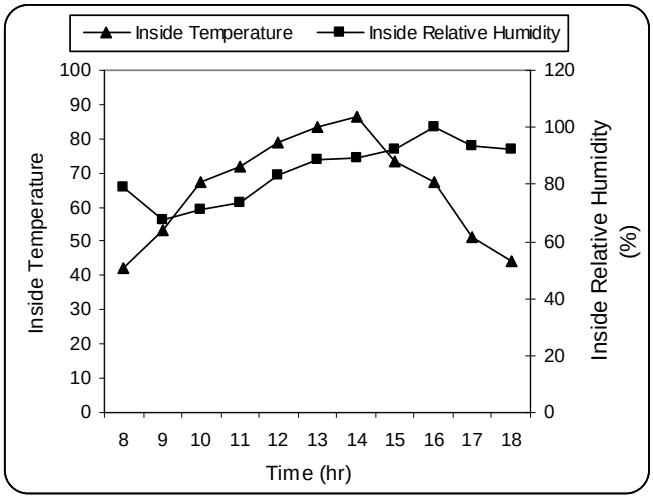
During the performance of wick type solar still with wick material at 40° angle of collector during summer, maximum temperature obtained at 1 P.M was 86.2°C, when solar intensity was 600 W/m$^2$ and ambient temperature was 38.0°C. The trend obtained as shown in Fig. 4 shows that distilled water obtained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




**(a)**

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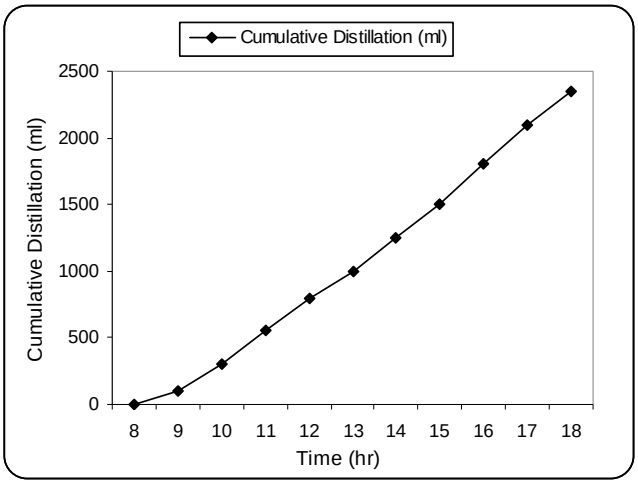



**(c)**

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

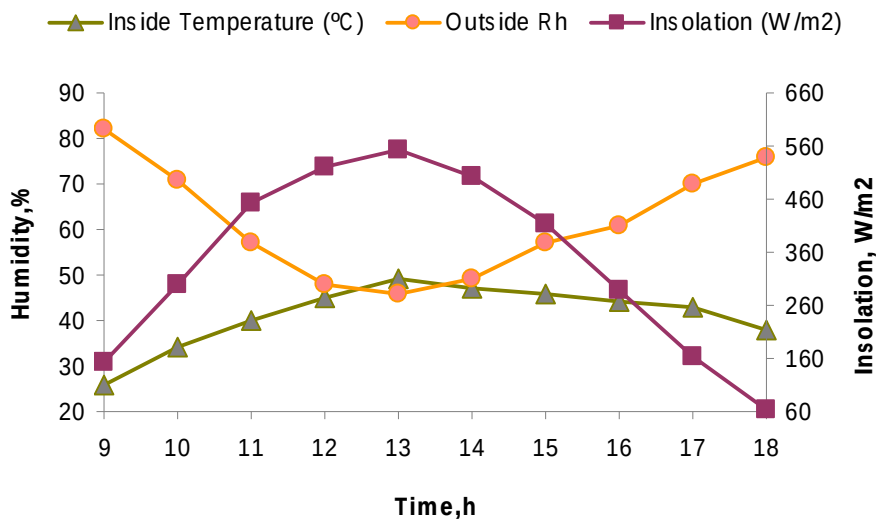
***W* -shape solar still on concrete two channels**

**No load test**

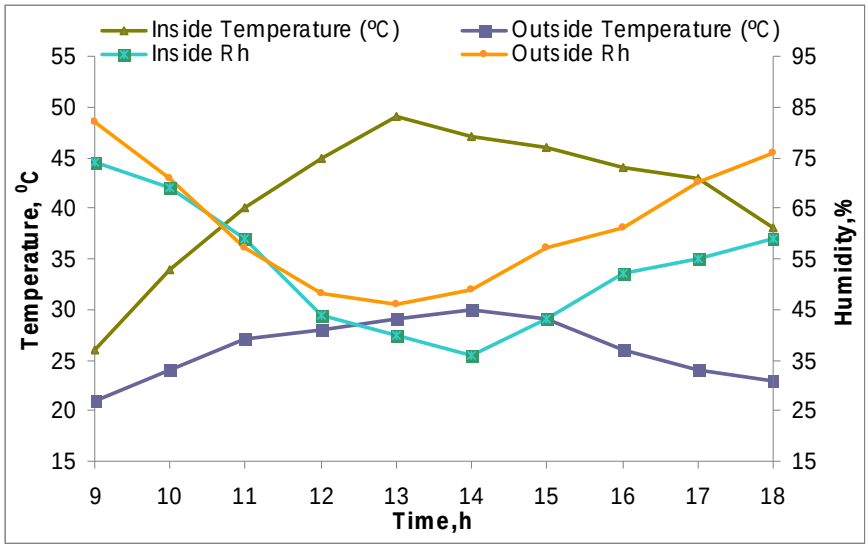
The low cost *W*-shape solar still with area of 2 $m^2$ (2m x 1m) was evaluated for no load test. The maximum average temperature was observed during no load test was 49 ºC at 1 p.m. and the same time solar intensity was 553 $W/m^2$, ambient temperature was 29 ºC, and outside relative humidity was 46 per cent. The trend obtained in no load test during performance testing is as shown in Fig 5 and Table 8. It is revealed from Fig 5 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. 5. Performance of *W*-shape solar still on concrete two channels with no load test in winter**

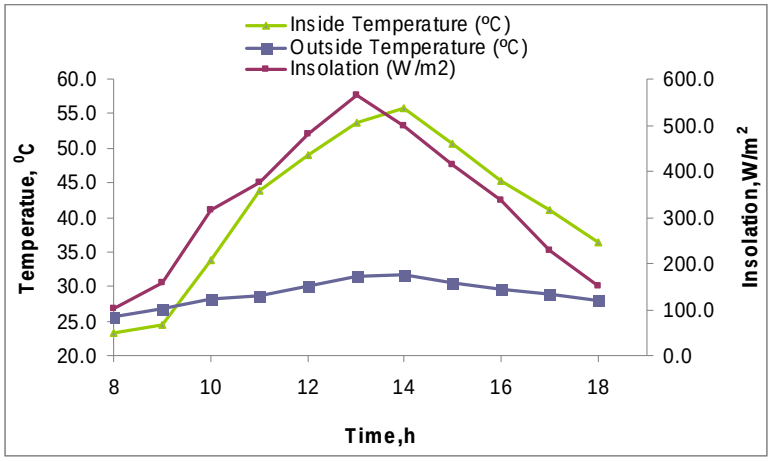
**Load test**

*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 6.

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 ($W/m^2$) | 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 |

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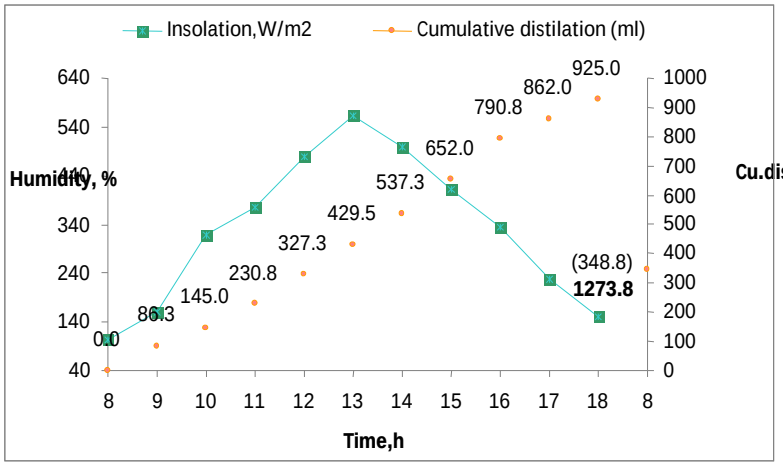



**(b)**

**Fig. 6. 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.

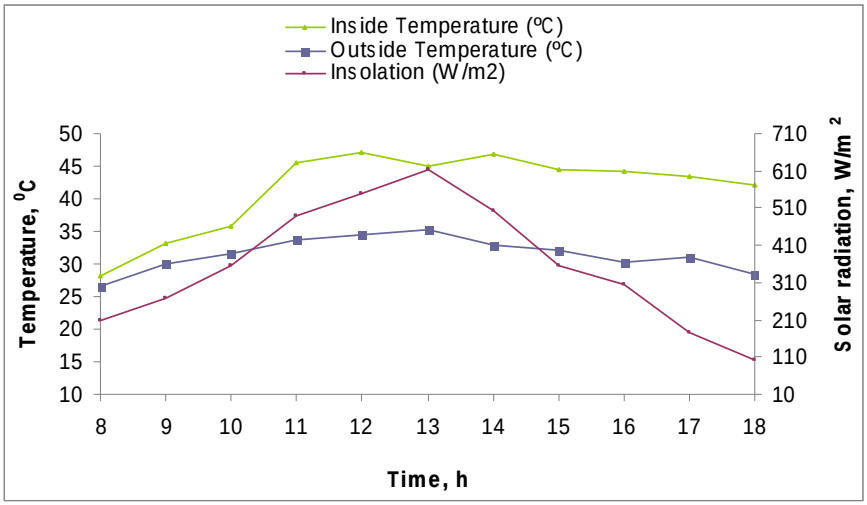
***W*- shape solar still on soil two channels**

**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 $^{o}$C where ambient temperature, solar radiation and relative humidity were found as 35.2,612 and35.2 respectively shown in Table 10 and Fig.7.

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

| Time (Hrs) | Insolation ($W/m^2$) | Inside Temperature ($^{o}$C) | Outside Temperature ($^{o}$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 |

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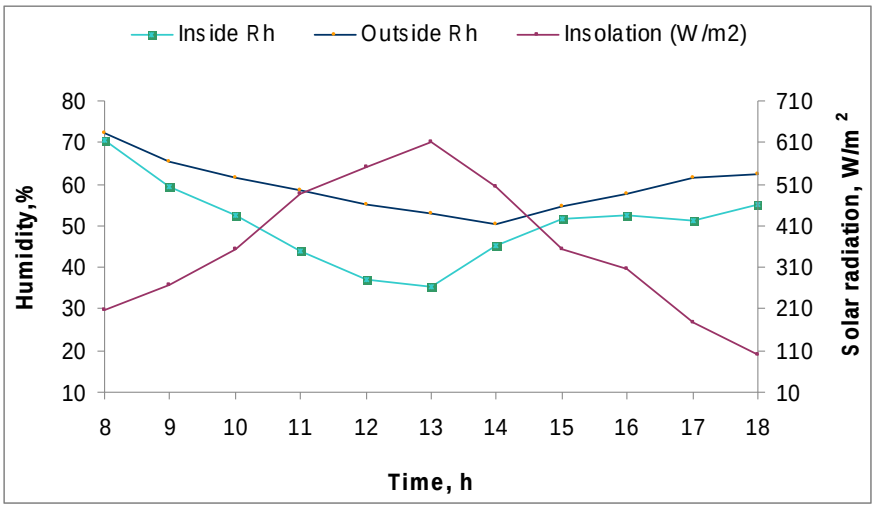



**(b)**

**Fig. 7. Performance of *W*-shape solar still on ground two channels during no load test in summer**

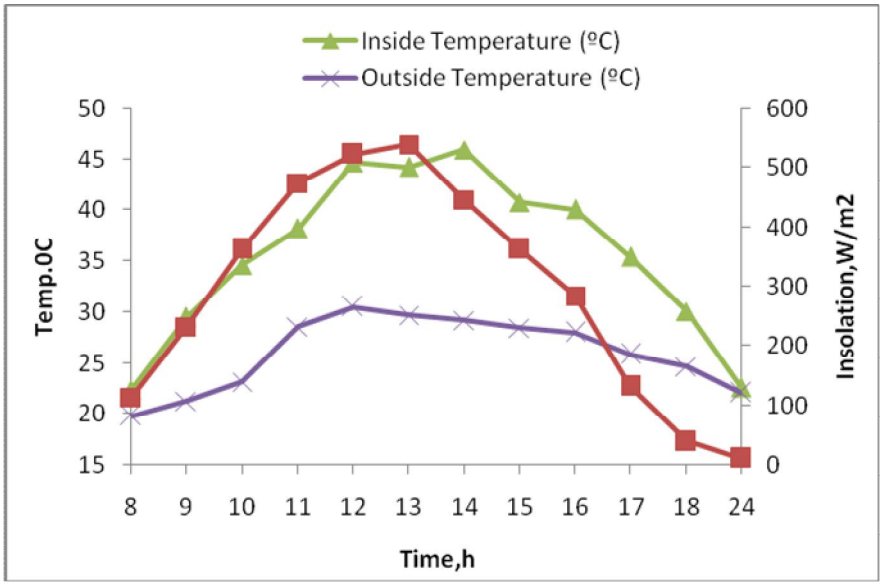
**With Load**

*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.8 and Table 12 and Fig.9 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 |

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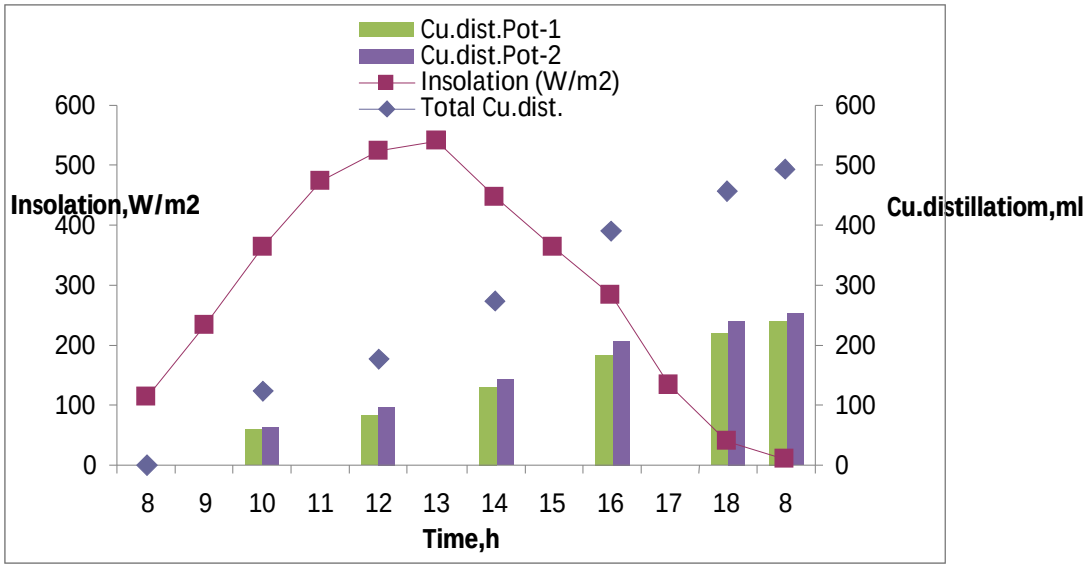
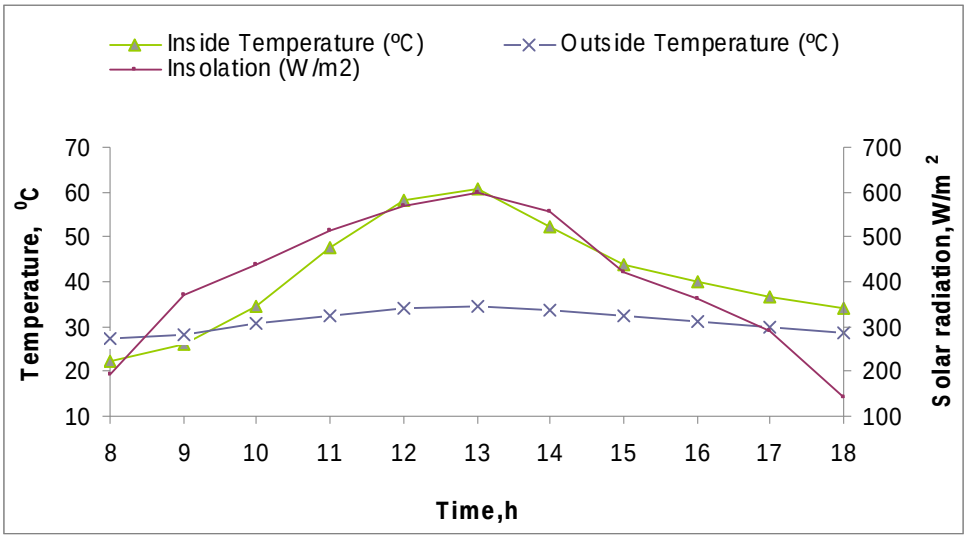



**(b)**

**Fig. 8. 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 (ºC) | Outside Temperature (ºC) | 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** |

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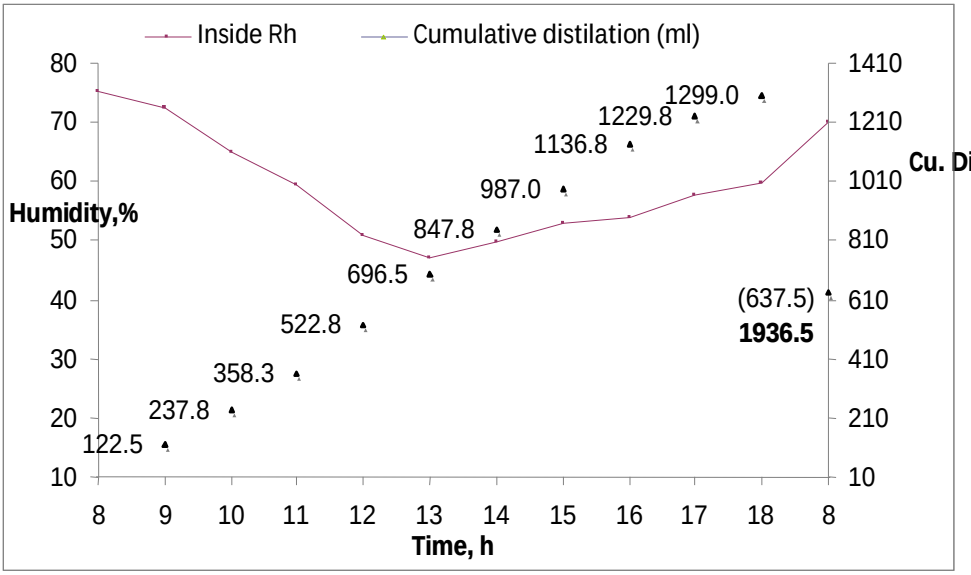



**(b)**

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

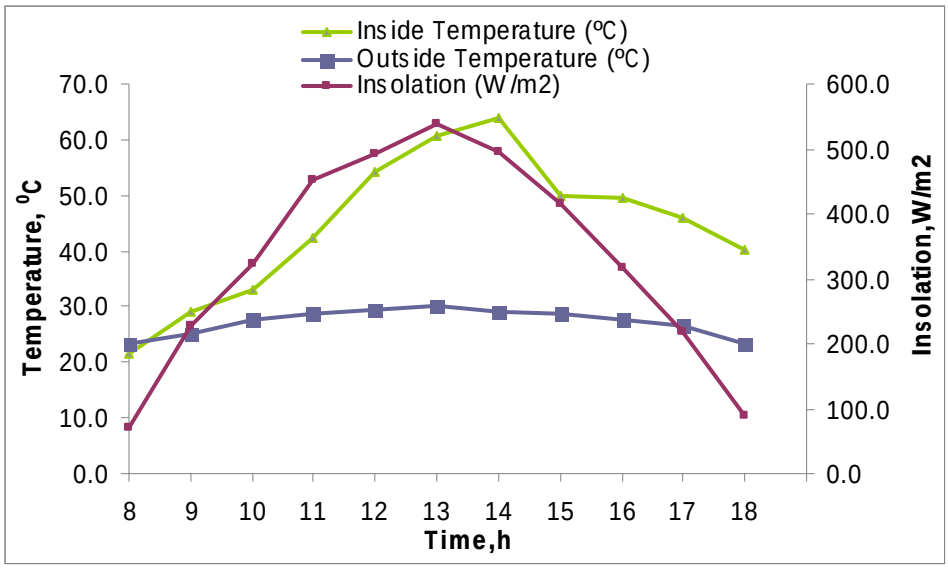
**Single side (*L*- shape one channel) solar still on soil**

**With 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.10. 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 |

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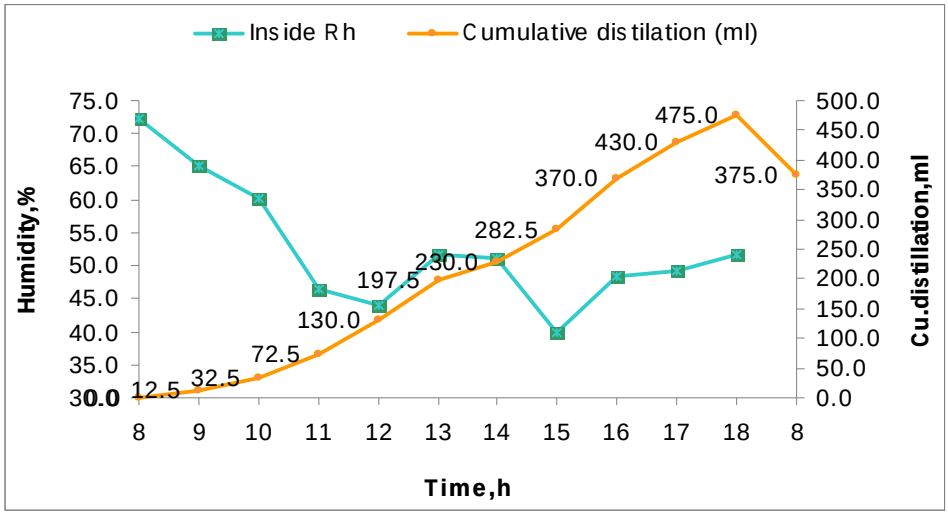



**(b)**

**Fig. 10. Performance of L type solar still on ground during load test in winter**

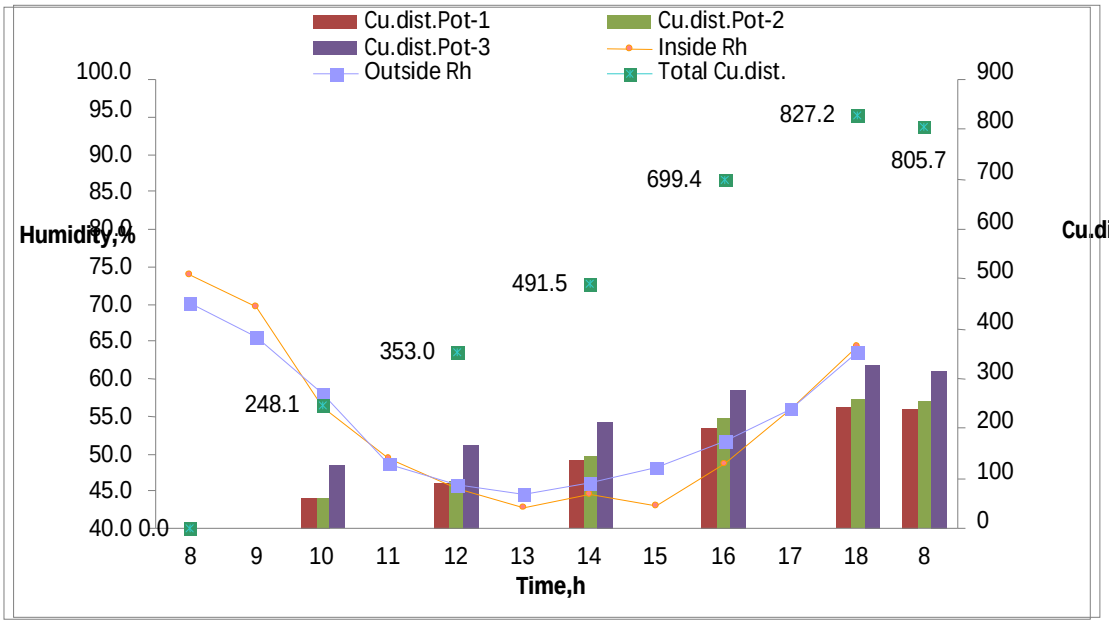
***W*- shape solar still on ground three channel**

**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 11. 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 |

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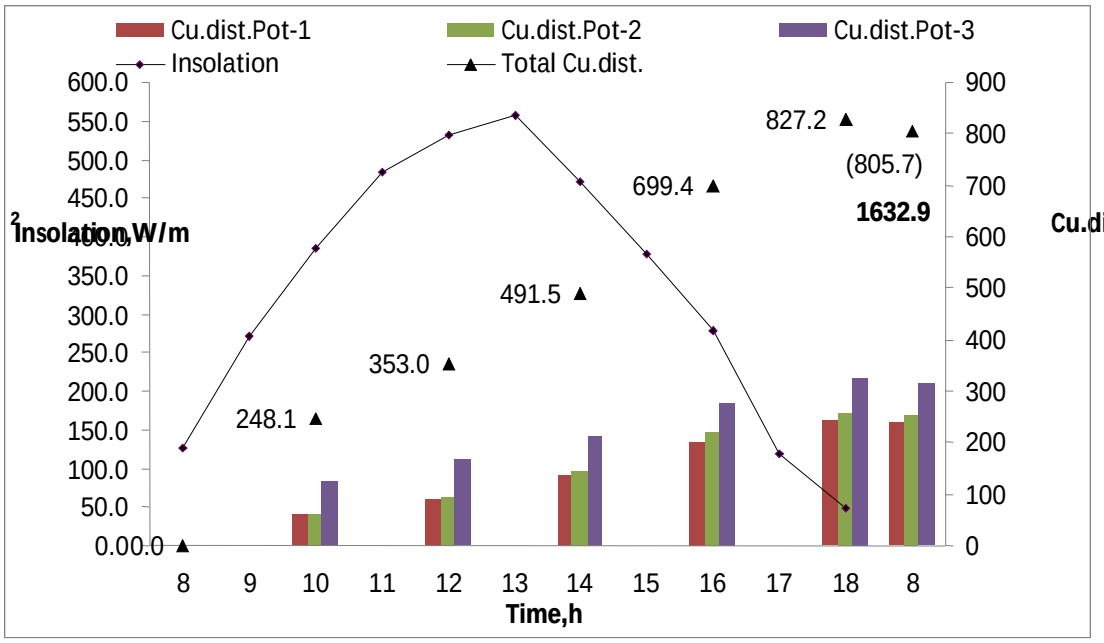



**(b)**

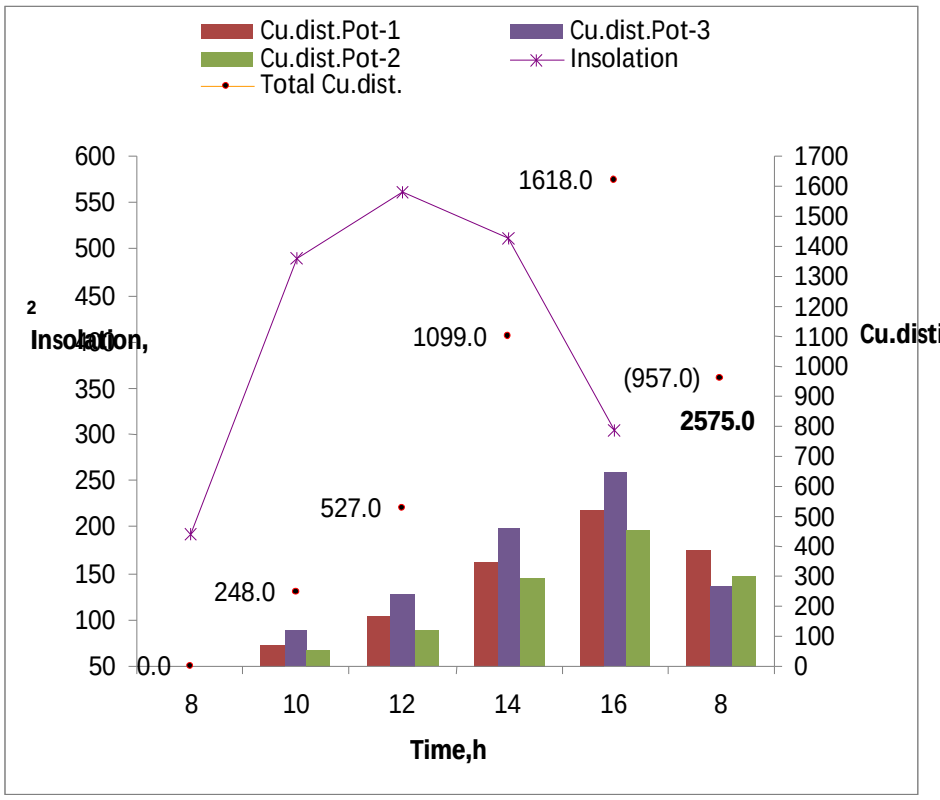
**Fig. 11. Performance evaluation of *W*-shape solar still on ground with three channels in winter**

**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 12. 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. (ºC) | 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 |

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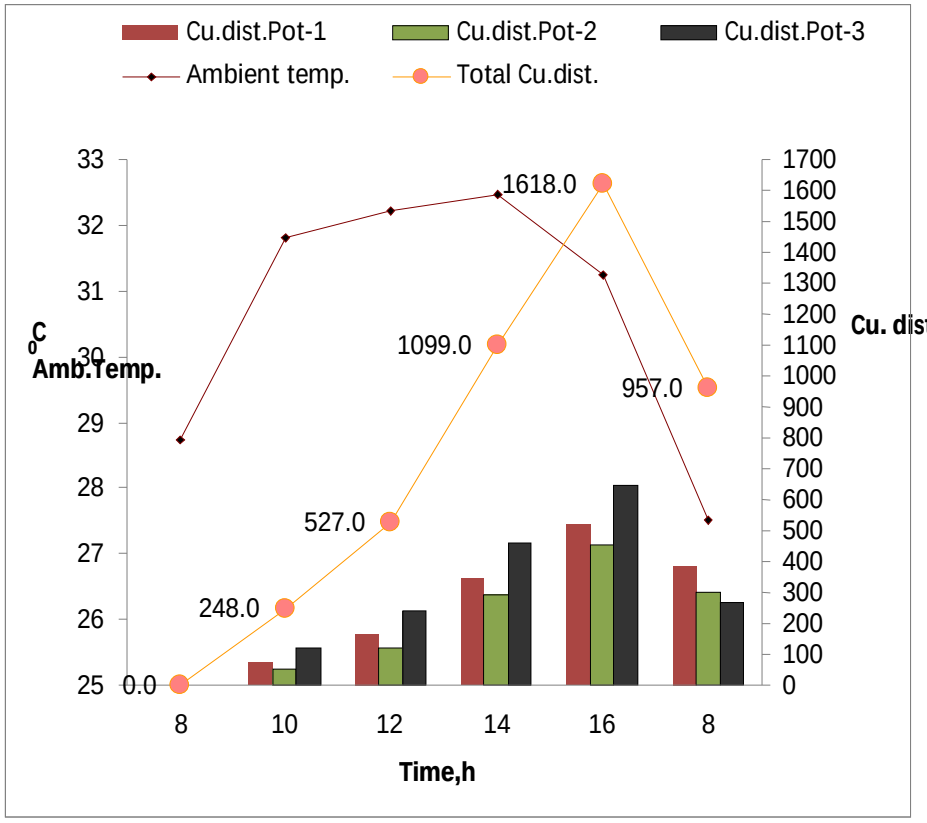


**Fig. 12. Performance evaluation of *W*-shape solar still on ground with three channel in summer**

**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 (1$m^2$) | 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/- |

**Comparative energy analysis**

After analysis of data obtained from load tests, energy and exergy efficiencies were calculated for each solar still. It was observed that the wick type still had the highest energy efficiency among all the stills which was 24.59 per cent. Next to it was the double slope type still with energy efficiency of 21.56 per cent. Following it were single slope type solar still, 'W' shaped solar still on soil basin and on concrete basin with energy efficiencies of 21.10 per cent, 10.23 per cent and 10.21 per cent respectively. Table 17 shows the energy efficiencies of various solar stills.

**Table 17: Energy Efficiencies of various solar stills.**

| Type of Solar Still | Energy Input (J) | Energy Utilized (J) | Energy Efficiency (%) |
|---|---|---|---|
| W shape-2 channel on concrete, 2 $m^2$ | 11121122.56 | 1136026.36 | 10.21 |
| W shape-2 channel on ground, 2 $m^2$ | 11225142.86 | 1149046.56 | 10.24 |
| W shape-3 channel on ground, 2 $m^2$ | 11225142.76 | 1212202.35 | 10.9 |
| Wick type, 1$m^2$ | 11225142.86 | 2760709.30 | 24.59 |
| Commercial Single slope, 1$m^2$ | 11225142.86 | 2368769.99 | 21.10 |
| Commercial Double slope,1$m^2$ | 11225142.86 | 2420749.86 | 21.57 |

It can be observed from the results that solar stills with a glass cover had comparatively higher energy efficiencies than those with polythene cover. Further, the solar still with wick material had higher energy efficiencies than the stills with impounded water as wick material facilitates evaporation by increasing the surface area for evaporation of water. It was also observed that stills with smaller size had comparatively higher energy efficiencies. This is due to the fact that heat loss from the still was comparatively lower than the other still, owing to the lesser area.

**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 18.

**Table: 18. Chemical analysis of impure and pure water sample**

| Chemical properties of Water | Before Distillation (Tap) Water) | Conventional Distilled water | After Distillation (Distilled Water) |
|---|---|---|---|
| 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 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 19.

**Table: 19. 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 |

**Table: 20. 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: 21. 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 |

It was observed from the Table 21, 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 21, as Benefit Cost Ratio (BCR) was 2.56, whereas Net Present Worth (NPW) was Rs.38958.

**Results**

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.

**Recommandation**

Dr. B.S.K.K.V. developed *W*-shape three channels solar still erected on ground using 200 micron UV stabilized clear poly ethylene film is recommended for production of 2 lit/day distilled water in Konkan region.

**f'kQkjl%**

**Mk- ck-l k-dk-d-fo- fodfl r MCY; vkdkjkp nku'k ek;dku tkMhp vfr fuyfdj.k ljf{kr lykLVhd ¼rhu ukY;k vlyy½ vkPNknu oki:u tfeuhoj mHkkj.kh dyY;k lkjty 'k/nhdj.k l;=kph dkd.k foHkkxk l kBh 2 fy- ifr fnol 'k/n ik.kh ikIrh l kBh f'kQkjl dj.;kr ;r vkg-**

Scientists involved

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