# Productivity Enhancement of Single Slope Solar Still Using Ground Energy

Dhananjay R. Mishra[1]* and Anil Kr. Tiwari[2]

[1]Jaypee University of Engineering and Technology, A.B. Road, Guna-473226 M.P.
[2]National Institute of Technology, Raipur, Raipur-492010, Chhattisgarh. India

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**Abstract**

In present work, the real situation near the seashores where wet sand is available in abundance with brackish water is being simulated and experiments were conducted. The experimental results are helpful for the coastal area where there is abundance of saline water but lack of potable water. The simulated performance of solar earth water still, suitable for very wet ground like beaches or swamps has been investigated. The still is essentially a single slope FRP still with a number of large holes in the bottom. Daily distillate output of this stills are reported. The three experimental arrangements were compared for the heat and mass transfer within the single slope solar still and the yield in the month of March at Raipur (Latitude 21.16N and longitude 81.42 E) India. It has been observed that the daily distillation yield is more in second case where surrounding mass of sand has been converted as heat storage that enhances heat and mass transfer. One more interesting conclusion is the fact that in still wet sand nearly behaves as a free water surface.

**Key wards:** Earth water still, Solar distillation, passive solar distillation ,Glazing effect; Sand Bed Solar Still.

*Corresponding author : dm30680@gmail.com

## 1. Introduction

Conventionally single slop basin solar still and earth water stills are a device to produce distilled water, by condensation of moisture in the ground. Earth solar still is essentially a conventional basin solar still, without a bottom , place directly on the ground. The moisture on the surface of the ground gets evaporated at the high surface temperature, attained by the incidence of sunlight; the moisture is replaced by diffusion from below the surface and the surrounding soil [1] .The pioneering experiments on the solar earth water stills were conducted by Kobayashi in the suburbs of Tokyo, Mt. Mihara, Mt. Fuji and Quetta desert in Pakistan [2]. In Tokyo, where the still was placed on sand with high moisture content, the highest recorded daily yield was 1.1 l/m$^2$ and the yield during the night hours was, irrespective of the weather close to 0.2 l/m$^2$. In the desert area at the top of Mt. Mihara the still was placed at a depth of 4 to 5 ; the daily yield was l/m$^2$. With the limited data of experiments during the rainy season it was estimated that the daily yield of the still at Mt. Fuji in good weather would be around 0.5 l/m$^2$ in the experiments in Quetta desert of Pakistan, the still was placed at a depth of 10 , and a daily yield of 0.4 l/m$^2$ was obtained. It was also observed that distillation occurred only during the night; the reason ascribed by Kobayashi was that only during the night the temperature of the cover was lower than that of the surface of the soil. Ahmadzadeh has reported the output of the still at the Agricultural School of Pahlavi University, which is 20 km north of Shiraz, Iran as follows [3].

Annual as well as seasonal performance analysis for the different water depths in a single slope solar still reported by Tiwari and Tiwari[4]. Experimental study of the enhancement parameters on a single slope solar still productivity was reported by Badran [5] An excellent review on the use of renewable energy in various types of distillation system and a survey of various types of solar thermal collectors and applications were presented by

| Depth of placement | Daily output |
|---|---|
| 0.00 m | 0.00 l/m2 |
| 0.08 m | 0.74 |
| 0.28 m | 1.00 l/m2 |

Kalogirani [6,7]. Effect of coal and Metal chip on conventional still was reported by Mishra and Tiwari[8]. Different parameters affecting still design reported by M. S. Sodha. Thermal modeling and characterization of solar still were presented by Tiwari [9], Tiwari and Noor [10] Tiwari and Prasad [11] and Tiwari et al. [12]. Tripathi and Tiwari [13] analyzed the distribution of solar radiation, using the concept of solar fraction inside a conventional single slope solar still by using simulation model for a given solar azimuth, altitude and latitude angles and longitude of the place. This present work aim to find out the correlation for the sand bed solar still that includes practical validation along with the comparison of efficiency & performance of sand bed solar still on ground surface.

**Nomenclature**

$A_t$ Effective area

$\dot{q}_{cw}$ Rate of convective heat transfer

$\dot{q}_{ew}$ Rate of evaporative heat transfer

$\dot{q}_{rw}$ Rate of radiative heat transfer

$h_{cw}$ Convective heat transfer coefficient

$h_{ew}$ Evaporative heat transfer coefficient

$h_{rw}$ Radiative heat transfer coefficient

$h_l$ Total heat transfer coefficient

$L$ Latent heat of vaporization

$P_g$ Partial pressure on inner glass surface

$P_w$ Partial pressure on water surface

$T_g$ Temperature of glass surface

$T_w$ Temperature of water basin

$\triangle_t$ Time interval of the experiment

$M_{ew}$ Theoretical yield

Emissivity of structure of solar still

Steffens Boltzmann constant

**2. Experimental setup**

Three distinguished experimental setups solar still 1(S1), solar still 2 (S2) and solar still 3(S3) are being schematically shown in Figure 1, 2, and 3 the photographs are shown in Figure 4,5 and 6 respectively.

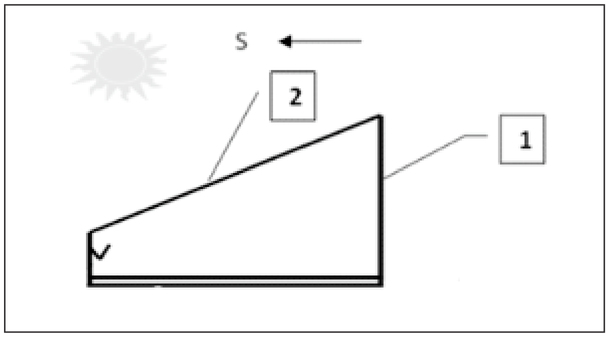


Figure 1: Schematic arrangement of solar still - 1 (S-1)

Conventional solar still and solar water-earth stills (S-1,S-2 and S-3) was fabricated with basin area 1m 1m, FRP single basin single slop solar still

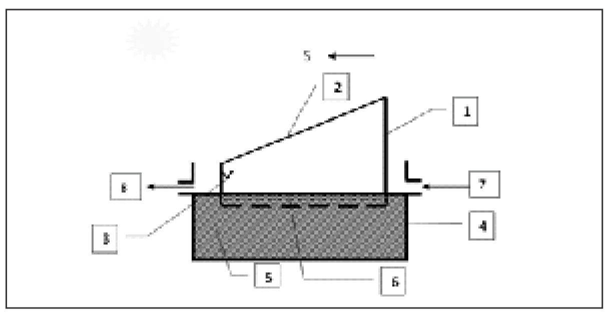


Figure 2: Schematic arrangement of solar still - 2 (S-2) without Black polythene

The name if the parts in both Figure 2 and Figure 3 are 1. FRP single basin single slope solar still with 25 holes of 2.5 diameter each in bottom 2. Glass cover 3. Drain to collect condensate water 4. GI sheet tray 5. Wet sand 6. Black coal powder spread over upper surface of sand within still 7. Transparent polythene cover spread over wet sand around solar still -3 (S-3).

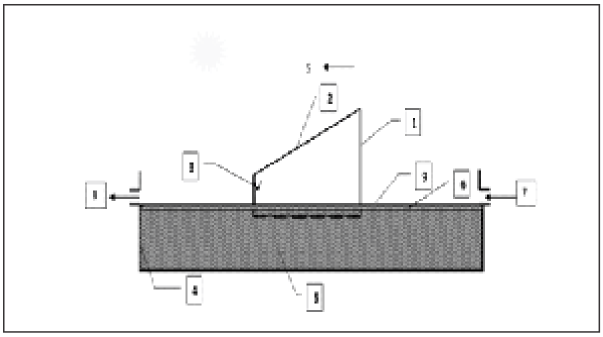

Figure 3: Schematic arrangement of solar still-3 (S-3) with black polythene sheet around it.

Solar still -3 is with and solar still-2 is without black polythene sheet (10 micron thickness) that is covering the surrounding earth surface to enhance the heat storing capacity of earth mass in which still basins are buried. Experimental setup S-2 and S-3 are identical with only the difference a blackened surface is covered with the polythene sheet.

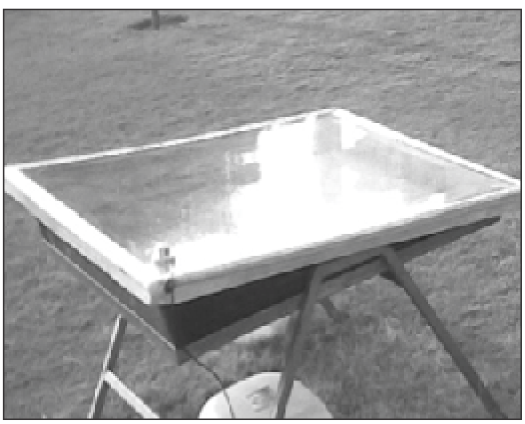

Figure 4: Photograph of conventional solar still-1 (S-1)

Figure 5: Photograph of solar Still-2 (S-2) without polythene.

The solar energy received at still basin, wet sand surface temperature, and output of potable water from all stills were observed every half an hour for 48 hours in the month of March at Raipur, India. Analytical expressions for water temperature (wet sand surface temperature) and other design parameter like water depth, absorptivity of basin liner, wind velocity, bottom insulation and cover inclination were studied.

Figure 6: Photograph of solar still-3 (S-3) with

blackened top surface and covered with polythene around it.

Both stills are facing due south for receiving best possible solar insolation. The following are the observations made every half an hour:

- Distillate yield for 48 hours for both stills.
- Solar radiation on horizontal surface (by means by SP-Light Silicon Pyranometer.
- Atmospheric temperature (in shade) by MDTI-039T digital temperature meter.
- Temperature at the centre of glass cover.
- Temperature of top surface of wet sand (S-1) and (S-2) by MDTI-039T digital temperature meter that has been called as water temperature.
- Transmission factor of glass (allowing for absorption), corresponding to solar radiation by pyranometer.
- Parameters, characterizing sand viz. thermal conductivity, density and specific heat.

## 3. Heat Transfer Within Solar Still

There are three modes possible for heat transfer from water surface to condensing cover these are Radiative, Convective and Evaporative Heat Transfer.

### 3.*1 Radiative Heat Transfer Coefficient*

The rate of radiative heat transfer ($\dot{q}_{rw}$) from water surface to the condensing cover can be obtained as

$$q_{rw} \quad T_1^4 \quad T_2^4 \qquad (1)$$

where, $T_1 = (T_w + 273), K$ $\qquad T_2 = (T_g + 273)\,K,$

Equation (1) can be approximated by

$$\dot{q}_{rw} \quad h_{rw}(T_1 \quad T_2), \qquad (2)$$

where, $$h_{rw} \quad \frac{T_w \quad (273)^4 \quad T_g \quad (273)^4}{T_w \quad T_g} \qquad (3)$$

and $\frac{11}{w} \quad \frac{}{g} \quad 1^{1}$ and $= 5.67 \quad 10^{-8}\,\mathrm{W/m^2\,K^4}$

### *3.2 Convective Heat Transfer Coefficient*

The convective heat transfer coefficient ($h_{cw}$) can be obtained from

$$h_{cw} \quad 0.884 \;(T_w \quad T_g) \quad \frac{(P_w \quad P_g) \;\; (T_w \quad 273)}{2.689 \quad 10^5 \quad P_w}^{\frac{1}{3}} \qquad (4)$$

The values of and (for the range of temperature 100C to 900C) can be obtained at water and inner condensing cover temperature from the relation.

$$PT(T) \quad \exp \; 25.317 \quad \frac{5144}{T \quad 273} \qquad (5)$$

The rate of convective heat loss $q_{cw}$ in ($W/m^2$) from water surface to the inner condensing cover can be obtained as,

$$\dot{q}_{cw} = h_{cw}(T_w\text{-}T_g) \qquad (6)$$

### *3.3 Evaporative Heat Transfer Coefficient*

The rate of evaporative heat loss from water to inner condensing cover is given by

$$\dot{q}_{cw} = 0.0166 \quad h_{cw}(P_w\text{-}P_g) \qquad (7)$$

Eq. (7) may be rearranged as

$$\dot{q}_{cw} = h_{cw}(T_w - T_g) \qquad (8)$$

$$h_{ew} \quad \frac{\dot{q}_{ew}}{T_w \quad T_g} \qquad (9)$$

and this evaporative heat transfer coefficient can be expressed as

$$h_{ew} \quad 0.016 \quad h_{cw} \quad \frac{P_w \quad P_g}{T_w \quad T_g} \qquad (10)$$

Using Eqs. (1), (2) and (3) the total heat transfer coefficient can be written as

$$h_1 \quad h_{rw} \quad h_{cw} \quad h_{ew} \qquad (11)$$

The rate of heat transfer from water surface to the inner condensing cover can be obtained as

$$\dot{q} = h_1(T_w\text{-}T_g) \qquad (12)$$

*3.4 Theoretical Amount of Condensate*

The yield in kg can be calculated as:

$$M_{ew} \quad \frac{\dot{q}_{ew} \quad A_t \quad t}{L} \qquad (13)$$

where $L$ for temperature higher then , and for operating temperature less then., = time interval of the experiment one hour.

**4. Result and Discussion**

The variation in receiving the solar radiation and ambient temperatures during experimental two days have been shown in Figure 7 that has been observed during 6 AM to 6 AM of March 16-17, at Raipur (Latitude 21.16N and longitude 81.42 E) India. The other observational data that has been observed are; glass cover temperature and the temperature of water /wet sand. The Figure 5 proves both experimental days as a shiny solar day because the peak solar radiation of the order of 976 W/m2 and 983 W/m2 was received at noon time of both the days that is a good enough amount to be useful for any solar thermal application. Whereas the ambient maximum ( ) and minimum ( ) temperature was attained at 5PM and 6AM of both days respectively.

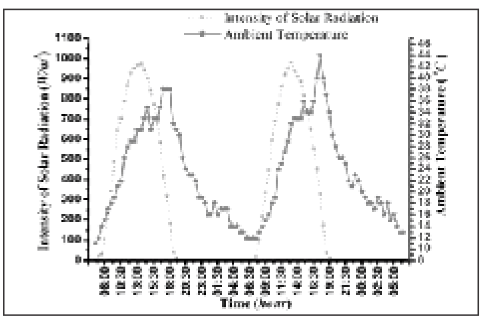


Figure 7: Hourly variations of solar Radiation incident and Ambient Temperature

The Half hourly variation of the of the actual yield of conventional and modified solar earth still is represented in Figure 8, which shows that the net output of distillate yield is better in case of ground solar still.

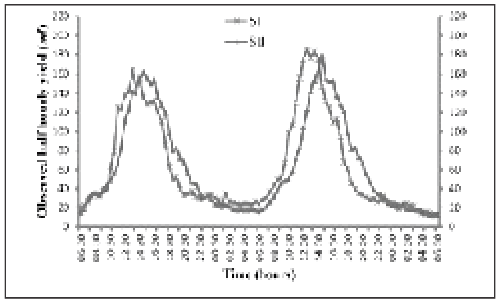

Figure 8: Observed half hourly distillate yield of S-1 & S-2 solar earth- water still.

This can be readily understood in terms of the large heat storage capacity of water in still -2 (S-2). It is also seen that the phase of yield lags that of solar irradiance; the phase lag is more in case of the conventional solar still. This supports the conclusion of Figure 8 that the heat capacity of wet sand in solar still.

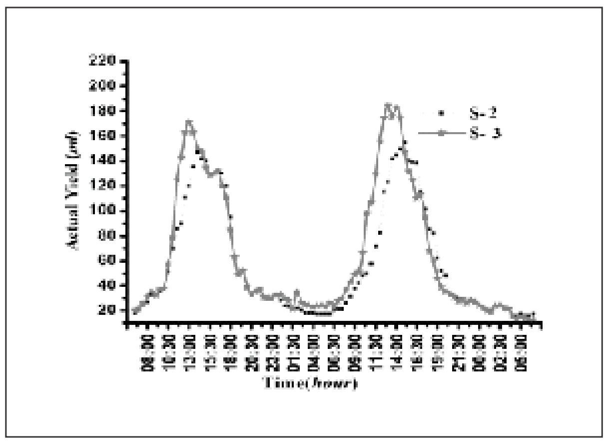


Figure 9: Half hourly variation of actual yield in sand bed solar still –2 (S-2) and sand bed solar still covered with black coal power and polythene (S-3)

sounding it. yield for 48 hours in the case the S-3 and S-2 still it was recorded as 6.200 liters and 6.135 liters respectively.

Half hourly yield of solar still-2 and solar still-3 shown in Figure 9 which shows the actual yield of the S-2 is less as compare to the S-3 keeping all input weather condition same, where Figure

10 shows half hourly variation of water temperature in solar still-2 (S-2) and solar still-3 (S-3) .

Figure 11 shows inner glass surface temperature with respect to time of solar stills S-2 and S-3, inner glass surface temperature observed lower in case of solar still-3 (S-3) as compare to solar still-2 (S-2). Figure 12 and Figure 13 shows the behavier of actual and theoretical yield in solar still -2 (S-2) whose surrounding was not covered with the polythene and solar still-3 (S-3) polythene sheet was covered around it.

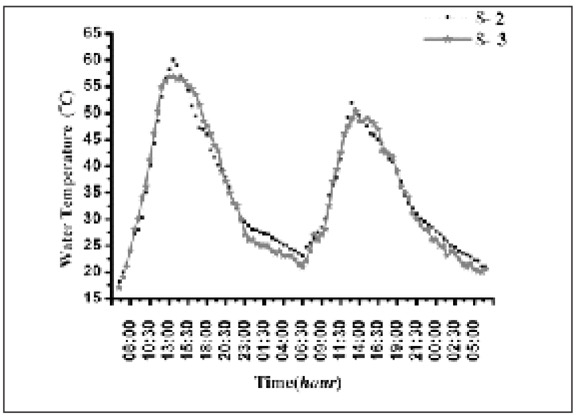


Figure 10: Half hourly variation of water temperature of solar still-2 and solar still- 3

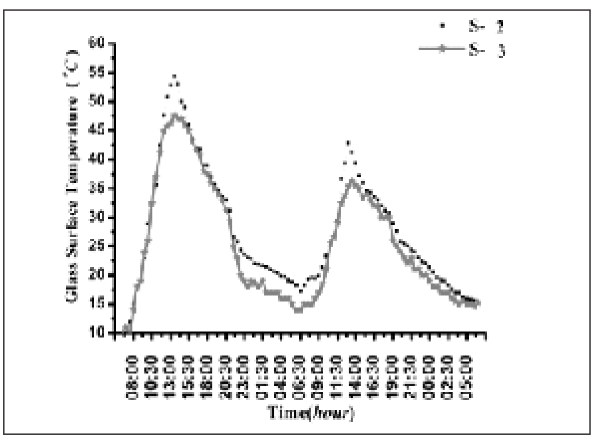


Figure 11: Half hourly variation of inner glass temperature of solar still-2 and solar still -3

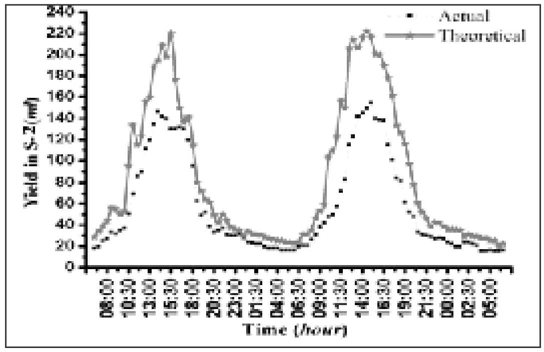


Figure 12: Half hourly variation of actual and theoretical yield in solar still-2(S-2).

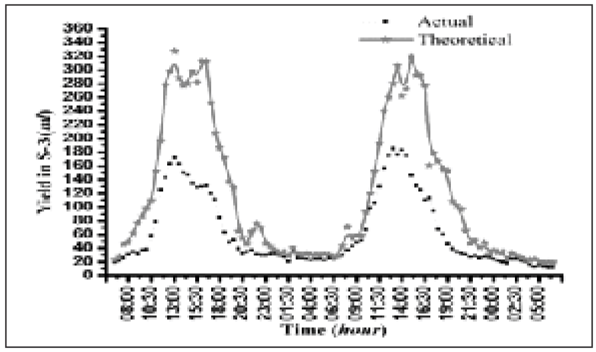


Figure 13 Half hourly variation of actual and theoretical yield in solar still-3 (S-3)

## 5. Conclusions

In this present work three arrangements of solar still naming conventional solar still -1(S-1), sand bed earth solar still-2 (S-2) and sand bed earth solar still-3 surrounding surface covered with the black polythene (S-3) has been compared for its output of distillate in liters per day. Not only the yield but also other various related things like water temperature, glass temperature has been observed. The other parameters like internal heat transfer coefficient, evaporative heat transfer coefficient and theoretical yield for S-1, S-2 and S-3 have been predicted and validated with the experimental data. It has been observed that the third solar still-3 (S-3) remains always ahead as for as yield is concerned. Finally in two days of observation the third still (S-3) gives more yield as compare to second solar still (S-2)(6.200 liters in comparison to 6.135 liters) per area in 48 hours. This yield can be increased significantly by increasing the area of basin. One more interesting fact that in still wet sand nearly behaves as a free water surface.

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