Influence of Coco Peat Powder on The Solar Still Productivity: An Exergo-Economic Study

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Abstract. Experimental and theoretical impact of the coco peat powder on the performance of conventional solar still (CSS) compared to MSS has been reported. Dunkle model was used in this experiment as the mathematical model. With the help of this model variation of partial pressure, internal heat transfer coefficients, yield, internal efficiency, and exergy efficiency has been evaluated. The average partial pressure for MSS is 94.19% higher than CSS in the experiment of 13 h. Use of coco peat powder the value of $h_{ev}$ and $h_{rw}$ were 9.63% and 2.53% respectively were recorded higher than the CSS. There was a rise of 30.89% of distillate output from the MSS when compared to CSS. It seems that the use of coco peat powder has enhanced the exergy efficiency by 28.14% of MSS when compared with CSS.

Keywords. Desalination; Conventional solar still; Coco peat powder; Energy analysis; Exergo-Economic analysis

1. Introduction
In the present scenario, the requirement of potable/fresh water is surging continuously. To meet the growing demand, groundwater has been intensively exploited. With increasing demand and decreasing per person accessibility of fresh water the problem of scarcity of water is faced globally, to serve the need of the growing population various efforts were made to develop the sustainable and economical ways of extracting fresh water from salty/dirty water. The conventional solar still (CSS) is one of the ways to transform salty water into fresh water. This device runs on solar energy which is a renewable source of energy. It is a passive, low-cost, and simple desalination device that has less running cost as compared to another method. The major drawback is that it's less efficient, productive, and requires a large surface area as compared to a conventional desalination system [1–4]. Basin water mass, area of evaporating surface, solar radiation, ambient temperature, and effective temperature difference between water and inner condensing cover are the pertinent parameters on which the performance of solar still depends [5–7]. Geometric dimension and temperature difference are in control due to the geometry provided to the still, rest parameter are not in human control. An extensive review on different active and passive solar still designs has been reported by Kabeel et al. [6]. To understand the impact of solar still characteristic length on its distillate output a detailed study has been reported by Ayoub et al. [8] and Jamil & Akhtar [9]. Dumka and Mishra [10] have studied the impact of varying salt concentration on the heat transfer characteristics of CSS. To understand the economic behaviour of different stills, Mukherjee and Tiwari [11] have developed and reported an economic model. Panchal [12] have reviewed the performance of CSS augmented with materials capable of storing energy (thermal). In a theoretical and experimental endeavour, Dumka and Mishra [13] have reported a substantial increase in the distillate output of CSS augmented with plastic balls which are in an envelope of jute cover. A comparative energetic and exergetic analysis of CSS and earth stills have been reported by Dumka and Mishra [14,15]. A CSS augmented with encapsulated salt to increase its thermal storage capability has been reported by Harris Samuel et al. [16]. Mayank et al. [17] have reported the optimization of solar distillation in distiller yield. Dumka and Mishra [18] have proposed a multiple regression analysis based model to forecast the theoretical yield of CSS.
From the above literature it has been observed that, the factors on which the performance of CSS strongly depends are: characteristic length, water surface area, heat capacity of water, and differential temperature between condensing-evaporating surfaces. In this experimental and theoretical study, coco peat powder was mix in the water to improve the productivity. The focus points on this research are as follows:

- To verify the cost and yield of CSS and MSS when augmented with coco peat powder.
- To experiment exergo-economics analysis of CSS and MSS.

2. Experimental setup

Two similar CSS are designed and fabricated from FRP having a thickness of 5 mm. The wall heights of CSS on higher and lower sides are 0.48 and 0.2 m, respectively. The solar stills were covered with a glass condensing cover (4 mm) having a 15.6° inclination with the ground. A 1 m×1 m×0.1 m GI tray was kept in both the stills to carry brackish/salty water. One of the CSS is augmented with the coco peat in the basin (MSS) whereas, the other is kept as such for comparison. The diagrammatic representation of CSS and CSS augmented with coco peat powder are shown in Figure 1 and Figure 2, respectively. The coco peat powder will serve three purposes:

- Increases the water surface area via capillary action
- Thin film evaporation
- Heat localization

To record water, glass, and ambient temperatures K 7/32-2C-TEF have been used. For the recording of these temperatures DTC324A-2 has been deployed. The intensity of solar radiations has been recorded with the help of a solar power meter (TM-207). A graduated glass cylinder has been used to measure distillate. For 40 kg basin water mass, the experiments were performed for a continuous 13 h i.e. from 9:00 h in the morning till 21:00 h at night. Hourly observations made during the experiments are:

- Outer and inner glass, basin water, and ambient temperatures
- Solar radiation
- Yield

| Instrument       | Accuracy (a) | Range             | Standard Uncertainty (u) |
|------------------|--------------|-------------------|--------------------------|
| Solar Power meter| ±10 W/m²     | 0 - 1999 W/m²     | 5.77 W/m²                |
| Thermocouple     | ±0.1°C       | -100 - 500°C      | 0.06°C                   |
| Graduated Cylinder| ±1 ml       | 0 - 250 ml        | 0.6 ml                   |

In the observations, Type B [20] uncertainty has been considered with an assumption of uniform data distribution. Eq. 1 has been used to evaluate standard uncertainty:

\[ u = \frac{a}{\sqrt{3}} \] (1)
The value of \( u, a \), and range of instruments are listed in Table 1.

3. Theory
From water to glass the rate of convective heat transfer can be evaluated as [10]:

\[
\dot{q} = h_{cw} \times (T_w - T_{ci})
\]

In the case of CSS, due to natural convection the Grashof number (Gr) tells the regime of flow.

The functional relationship among \( Nu, Gr, \) and \( Pr \) is \( Nu = C(Gr \times Pr)^n \). The moist air properties were deduced by using the Tsilingris [21] thermo-physical property relations. The quasi-thermal model proposed by Dunkle [22] has been used to evaluate \( h_{cw} \).

Knowing \( h_{cw} \), value of \( h_{ew} \) can be evaluated.

\[
h_{ew} = 0.016273 \times h_{cw} \times \frac{(P_w-P_{ci})}{(T_w-T_{ci})}
\]

The theoretical yield is evaluated as [23]:

\[
m_{ew} = \frac{h_{ew} \times A_s \times (T_w - T_{ci}) \times 3600}{l}
\]

The radiative heat transfer coefficient within the still can be calculated as [24]:

\[
h_{rw} = e_{eff} \times \sigma \times [(T_w + 273.15)^2 + (T_{ci} + 273.15)^2] \times [T_w + T_{ci} + 546.2]
\]

The \( \dot{q}_{1w} \) and \( h_{1w} \) from evaporating to condensing surface are obtained as:

\[
\dot{q}_1 = \dot{q}_{cw} + \dot{q}_{ew} + \dot{q}_{rw}, h_{1w} = h_{cw} + h_{ew} + h_{rw}
\]

Most influencing heat transfer mode within the still can be known by fractions of energy which are as follows:

\[
F_{ew} = \frac{q_{ew}}{q_1}; F_{cw} = \frac{q_{cw}}{q_1}; F_{rw} = \frac{q_{rw}}{q_1}
\]

The instantaneous efficiency (thermal) of solar still can be written as [25]:

\[
\eta_i = \frac{m_{ew} L}{I(t) A_S}
\]

Exergy efficiency is calculated using the given mathematical formula i.e. [14,26]:

\[
\eta_{Ex} = \frac{\dot{E}_{ex}^{\text{evap}}}{\dot{E}_{x,m}}
\]

where,

\[
\dot{E}_{ex}^{\text{evap}} = A_s \times h_{ew} \times \left(1 - \frac{T_a+273}{T_w+273}\right)
\]

\[
\dot{E}_{x,m} = A_s \times I(t) \times \left[1 - \frac{4}{3} \times \frac{T_a+273}{T_w+273} + \frac{1}{3} \times \left(\frac{T_a+273}{T_w+273}\right)^4\right]
\]

For the cost analysis the CRF and SFF are been obtained using the following equations [27,28]:

\[
\text{CRF} = \frac{(i+(i+1)^n)^{n-1}}{(i+1)^{n-1}}
\]

\[
\text{SFF} = \frac{l}{(i+1)^{n-1}}
\]

Here is \( n \) and \( i \) are taken as 15 year and 12% respectively. After calculating CRF and SFF the value of ASV, AC and CPL (cost per litre) are been calculated.

\[
FAc = \text{CRF} \times P
\]

\[
\text{ASV} = \text{SFF} \times S
\]

\[
AC = FAc + AMC - ASV
\]

\[
\text{CPL} = AC / AY
\]

4. Results and discussions
Figure 3 shows the variation of \( I \) with respect to time. At the beginning, its value was recorded as 610 W/m² which gradually increases to a peak value of 1000 W/m² by 13:00 h. By 20:00 h it becomes zero and remains same thereafter. The variation of \( T_w, T_{ci}, \) and \( T_a \) for CSS and MSS as a function of time is shown in Figure 4. In CSS, the \( T_{ci} \) is higher than \( T_w \) till 12:00 h due to large heat capacity of water in
CSS. Then $T_w$ increases and maintains it lead till the end of experiment. Till 16:00 h the water temperature in MSS is more than CSS due to heat localization and thin water film. Thereafter, it reduces due to low solar radiations and release of stored energy by water in CSS. The maximum value of $T_w$ and $T_{ci}$ for CSS and MSS are 66.9°C & 58°C and 70.4°C & 60°C, respectively.

![Figure 3: Variation of $I$ as a function of time](image1)

![Figure 4: Temperature variations as a function of time](image2)

![Figure 5. Variation of $h_{ew}$ as a function of time](image3)

The variation of $h_{ew}$ from water to glass as a function of time for stills is graphed in Figure 5. Use of coco peat powder results in the improvement of $h_{ew}$ of MSS by 9.63% than that of CSS. Variation of $h_{ew}$ from water to glass as a function time is shown in Figure 6. In CSS, the value of $h_{ew}$ initially decreases till 11:00 h due to the reduction in $\Delta T$. Evaluated value of $h_{rw}$ as a function of time for both
CSS and MSS have been graphed in Figure 7. It has been observed that the mean value of $h_{rw}$ of MSS is higher by 2.53% than CSS.

The variation of $h_{1w}$ vs. time is shown in Figure 8. It is clear for the Figure 9 that the strongest mode of energy transfer from water to glass is $h_{ew}$ followed by $h_{rw}$ and the least contribution is that of $h_{ew}$. Hence, the nature of $h_{1w}$ has been almost similar to that of $h_{ew}$ (Figure 5). Figure 10
represents how the yield from CSS and MSS varies with time. The cumulative yield obtained from MSS was 30.89% more than that obtained from CSS.

Figure 9: Variation of energy fractions as function of time

Figure 10: Distillate output variation as a function of time

Figure 11: Internal efficiency variation as a function of time

Figure 11 shows how $\eta_i$ varies with time for both MSS and CSS. Data till 17:00 h has been shown as after this time the value of $I$ decreases at a much higher rate than the yield which will results in non-
practical results. The use of coco peat powder has remarkably increased the mean value of $\eta_i$ for MSS over CSS by 4.23%.

![Variation of exergy efficiency as a function of time](image)

**Figure 12:** Variation of exergy efficiency as a function of time

**Table 2.** Installation cost and salvage value of different components of CSS and MSS (in Rs.).

| Component            | CSS   | MSS   | S |
|----------------------|-------|-------|---|
| FRP Solar Still      | 6000  | 6000  | 600|
| Glass                | 500   | 500   | 0 |
| Putty                | 100   | 100   | 0 |
| Bubble wrap          | 100   | 100   | 0 |
| Cloth                | -     | 50    | 0 |
| Coco peat powder     | -     | 150   | 0 |
| **Total Cost**       | **6750** | **6850** | |

**Table 3.** Values of different cost and factors for CSS and MSS.

|                | CSS    | MSS    |
|----------------|--------|--------|
| CRF            | 0.1468 | 0.1468 |
| SFF            | 0.0268 | 0.0268 |
| FAC            | 983.7224 Rs. | 1005.7 Rs. |
| ASV            | 16.0945 Rs. | 16.0945 Rs. |
| AMC            | 147.5584 Rs. | 150.8619 Rs. |
| **AC**         | 1115.2 Rs. | 1140.5 Rs. |
| **AY**         | 878.1   | 1150.1 |
| **CPL**        | **1.27 Rs./l** | **1.00 Rs./l** |

The variation of $\eta_{EX}$ for CSS and MSS vs time is shown Figure 12. The use of coco peat powder has increased $\eta_{EX}$ of MSS by 28.14% in contrast to CSS. With the help of Table 2 and Table 3 one can see that the use of coco peat has reduced the per litre cost of distillate by 21.26% in comparison to CSS.

5. **Conclusions**

- Productivity of MSS is 30.89% more than its CSS counterpart.
Coco peat powder has remarkably increased the water and glass temperature difference between MSS as compared to CSS.

For total heat transfer coefficient $h_{1w}$ played a vital role. Use of coco peat powder in the still improved $h_{1w}$ of MSS by 9.63% compared to CSS.

The use of coco peat powder has reduced the CPL of distillate from MSS by 21.126% as compared to CSS. Hence, the coco peat powder in CSS can boost its distillate output and can make it more efficient and economic.

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Nomenclatures

$A_s$ basin water area (m$^2$)
$c_p$ specific heat at constant pressure (J/kg-K)
$C$ constant
$D$ characteristic length of solar still (m)
$F_{12}$ view factor
$F_{cw}$ convective energy fraction
$F_{ew}$ evaporative energy fraction
$F_{rw}$ radiative energy fraction
$G$ acceleration due to gravity (m/s$^2$)
$Gr$ Grashof Number
$h_{cw}$ convective heat transfer coefficient from water to glass (W/m$^2$-K)
$h_{ew}$ evaporative heat transfer coefficient from water to glass (W/m$^2$-K)
$h_{tw}$ total heat transfer coefficient
$I(t)$ incident solar radiation on inclined cover surface (W/m$^2$)
$L$ latent heat of vaporization (J/kg)
$m_{ew}$ distillate output (kg/m$^2$-h)
$N$ Constant
$Nu$ Nusselt Number
$P_{ci}$ saturated vapor pressure on inner glass surface (Pa)
$P_{w}$ saturated vapor pressure on water surface (Pa)
$Pr$ Prandtl Number
$q_{cw}$ convective heat transfer rate from water to glass (W/m$^2$)
$T_a$ ambient temperature (°C)
$T_{ci}$ inner glass cover temperature (°C)
Temperature of water surface (°C)
Standard uncertainty

Abbreviations

- **AC**: annual cost (Rs.)
- **AMC**: annual maintenance cost (Rs.)
- **ASV**: annual salvage value (Rs.)
- **AY**: annual yield (l)
- **CSS**: conventional solar still
- **CPL**: cost per litre (Rs./l)
- **CRF**: capital recovery factor
- **FRP**: fibre reinforced plastic
- **FAC**: first annual cost (Rs.)
- **Rs.**: Indian national rupee (1=69.69 Rs.)
- **MSS**: modified solar still
- **S**: salvage value (Rs.)
- **SFF**: sinking fund factor