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Performance of Corrugated Wick in "V" Type Solar Still

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ABSTRACT

This works reports performance of corrugated wick in a "V" type solar still. The still was tested in two configurations: plane wick integrated with drip system and corrugated wick integrated with drip system. A mathematical modeling has been proposed to validate experimental results. The experiment was performed in Tamilnadu, India climatic conditions (11˚ North 77˚ East). Experimental investigations on productivity and internal heat transfer are analyzed. The results indicate that the mean standard deviations between theoretical and experimental values are less than 7% (temperature of rippled wick), 3% (temperature of glass in rippled system), 6% (temperature of flat wick) and 3% (temperature of glass in flat system) an average for the working hours of the day. The distillate yield produced was 2800 ml/m^2/day by plane wick and 2200 ml/m^2/day by corrugated wick.

Keywords: Solar Still; Fresh Water; Glass; Corrugated Wick

1. Introduction

The distillation is one of the important methods of getting clean water from brackish and sea water using the free energy supply from the sun. The increase of population and human agricultural and industrial activity make the availability of fresh water in arid and semi-arid regions a problem of great importance all over the world. Solar distillation process has the advantage of zero fuel cost, but requires more space (for collection) [1]. Augmentation of distillate yield using wick was reported by many authors [2,3]. Velmurugan *et al.* has studied effect of different wick materials in the distillate yield. Minasian and Al-karaghouli have experimentally investigated an improved design of the single slope coupled to a wick in order to enhance still output. Phadatare and Verma [4] have studied the variation of productivity with respect to water depth and been concluded that productivity decreases with an increase of water depth. The energy absorbed by the absorber basin is mostly transferred to the water. As a result, water gets heated. In water filled system early hour radiations are used for acquiring latent heat of evaporation to a greater extent and then evaporated water gets condensed on the inner surface of the top cover by releasing its latent heat. So most of the water filled systems show high distillate yield after noon. Mrugavel and Srithar [5] have conducted experiments on basin type solar still with different wick materials and concluded optimized output using light cotton wick. The effects of climatic, design and operational parameters on the productivity of the wick-type solar still have been mentioned by Yeh and Chen [6]. Talbert *et al*. [7] and Tanaka *et al*. [8] have mentioned that the wick-type solar still has attractive performance against the basin-type solar still. In this work, a "V" type solar still was fabricated and tested. A comparative study was conducted with plane wick and corrugated wick. A transient theory has been proposed to validate the effect of wick shape in performance of the "V" type solar still.

2. Materials and Methods

A "V" type solar still was designed and fabricated as illustrated in **Figures 1-5**. The specification and operational parameters of solar still are shown in **Table 1**. A rectangular basin of dimension 2 m × 0.75 m × 0.05 m was designed and coated with black paint for good absorption. An inlet pipe of 13 mm was used for pouring water into the still. Heat loss was reduced by surrounding

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Figure 1. Photographic view of "V" type solar still.

Figure 2. Photographic view of corrugated absorber.

Figure 3. "V" type solar still without glass cover.

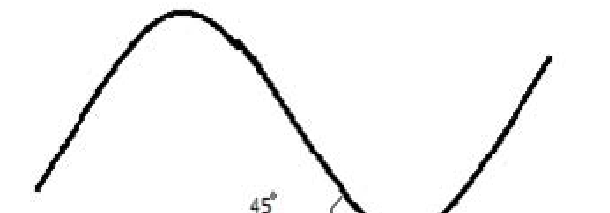

Figure 4. Corrugated wick.

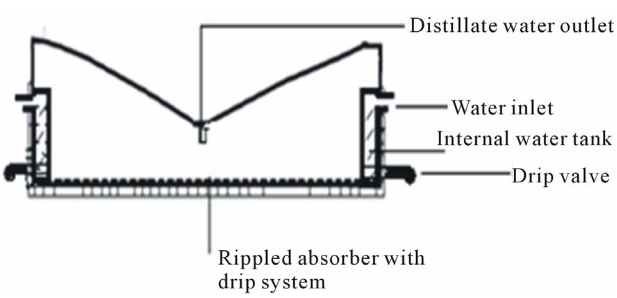

Figure 5. Schematic representation of "V" type solar still.

Table 1. Still technical and operation details.

Sl. no.	Climatic conditions	Parameter	Value
1	Clear sky	Solar radiation (W/m^2)	0 - 1110
		Ambient (˚C)	24 - 35
		Relative humidity (%)	22 - 55
		Average wind velocity (m/s)	1
2	Design	Basin absorptivity (α_b)	0.90
		Basin emissivity (ε_b)	0.90
		Absorptivity of cover (α_g)	0.05
		Reflectance of cover	0.05
		Transmittance of glass (τ_g)	0.90
		Specific heat of water (C_w)	4190 J/kg·k
		Length (m)	2
		Breadth (m)	0.75
		Tank volume	4L each
		Thickness of wick (m)	2×10^{-3}
		Base volume (L)	3
		Drip rate (ml/min)	10 - 15

the basin with a wooden case. The inter space between still and wooden case was filled with saw dust to reduce heat loss at low cost. The top cover of the still has been made by glass thickness of 3 mm (**Figure 1**). An inward slope of the glass cover was maintained towards the center of the still and the cover was cemented by chemical adhesive to minimize air leakage (**Figure 2**). An outlet is also provided to drain out distilled water and a 2˚ slope is maintained for the water collection channel for smooth outward flow of distilled water (**Figure 3**). The experiments were carried out in the time duration of 9 h - 18 h. The hourly variation of various temperatures like ambient (T_{amb}), glass (T_g) and wick (T_w) were recorded using calibrated K-type thermocouples. Commercial grade jute was used as wick because of wide availability and low cost. Accuracies and error percentage of various measuring instruments used in the experiment are shown in **Table 2**.

The solar radiation transmitted through glass cover is largely absorbed by the basin; hence, the temperature increases. Part of the energy absorbed by the basin is transferred by convection to the basin water. Evaporated water releases its latent heat of condensation on the glass cover and condensate trickles down and is collected by the trough. The objective of this work was to study the performance as well as comparison between two solar still configurations: plane wick integrated with drip system and corrugated wick integrated with drip system. The main advantage of the still was two vertically internally molded water tanks on either side; act as hot water reservoir from which wick is made wet by drip valve system. A mathematical modeling is proposed to validate experimental results.

Table 2. Accuracies and error for various measuring instruments.

Sl. no.	Instrument	Accuracy	Range	% Error
1	Pyranometer	±30 W/m^2	0 - 1800 W/m^2	3
2	Digital thermometer	±1˚C	0˚C - 100˚C	2
3	Thermocouple	±1˚C	0˚C - 100˚C	0.4
4	Anemometer	±0.2 m/s	0.4 - 30.0 m/s	1
5	Measure jar	±10 ml	0 - 1000 ml	2

3. Mathematical Model

The following assumptions are made in the mathematical modeling of the system. Heat loss is negligible across the side wall and basin liner of the system. Variation of incident angle of solar radiation is negligible. The glass plates and basin are assumed to be parallel. The energy balance of the glass cover and wick surface are necessary to model the system.

3.1. Energy Balance for Glass Cover

The energy received by the glass cover includes incident solar radiation and energy received from wick surface. The energy balance equation for the glass cover is given by,

Energy received by the glass cover = Energy lost from the glass cover

$$\propto'_g G(t) + \frac{h'_{wg}(T_w - T_g)}{\cos(\theta)} = h'_{ga}(T_g - T_a) \quad (1)$$

$$h'_{wg} = h_{cw} + h_{ew} + h_{rw} \quad (2)$$

The convective heat transfer coefficient from the wick surface h_{cw} is given by Dunkle's relation [9],

$$h_{cw} = 0.884\left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273.15)}{268900 - P_w}\right]^{1/3} \quad (3)$$

The partial pressure of water vapour in the air in N/m^2, is estimated for a given temperature (˚C) using the following correlation [10],

$$P = 7235 - 431.43T + 10.76T^2 \quad (4)$$

The evaporative heat transfer coefficient h_{ew} is given by,

$$h_{ew} = 16.276\times10^{-3} \times h_{cw} \times \frac{P_w - P_g}{T_w - T_g} \quad (5)$$

The radiation heat transfer coefficient h_{rw} is given by [11],

$$h_{rw} = \frac{\sigma(T_w^2 + T_g^2)(T_w + T_g)}{\frac{1}{\epsilon_w} + \frac{1}{\epsilon_g} - 1} \quad (6)$$

Heat transfer from glass to air is due to convection and radiation.

$$h'_{ga} = h_{cg} + h_{rg} \quad (7)$$

The convective heat transfer coefficient from the glass cover is given by [12],

$$h_{cg} = 2.8 + 3.0V \quad (8)$$

The radiative heat transfer from the glass to air is given by,

$$h_{rg} = \epsilon_{eff}\, \sigma\left((T_g)^2 + (T_s)^2\right)(T_g + T_s) \quad (9)$$

The sky temperature T_s is given by [13],

$$T_s = 0.0552T_a^{1.5} \quad (10)$$

3.2. Energy Balance for Wick Surface

Solar energy received by the wick surface is used for raising the temperature of wick surface together with water. Energy is lost from the wick to glass cover by convection, evaporation and radiation. Energy balance for the wick surface is given by,

Energy received by wick surface = Energy loss from wick surface

$$\propto'_w G(t) = (m_w c_w + m_{wm} c_{wm} + m_{bm} c_{bm})\frac{\mathrm{d}T_w}{\mathrm{d}t} \times \frac{1}{\cos(\theta)} + h'_{wg}(T_w - T_g) \times \frac{1}{\cos(\theta)} \quad (11)$$

Using energy balance equations of wick and glass, modified differential equation in T_w can be written as

$$\frac{\mathrm{d}T_w}{\mathrm{d}t} + C_3 T_w = C_4 \quad (12)$$

where,

$$C_3 = \frac{h'_{wg}(1 - C_2)}{m_w c_w + m_{wm} c_{wm} + m_{bm} c_{bm}} \quad (13)$$

$$C_4 = \frac{\propto'_w G(t)\cos'(\theta) + h'_{wg} C_1}{m_w c_w + m_{wm} c_{wm} + m_{bm} c_{bm}} \quad (14)$$

$$C_1 = \frac{\propto'_g G(t) + h'_{ga} T_a}{h'_{ga} + 1/\cos(\theta)} \quad (15)$$

$$C_2 = \frac{h'_{wg}/\cos(\theta)}{h'_{ga} + h'_{wg}/\cos(\theta)} \quad (16)$$

4. Result and Discussion

Initial temperature of water, wick and glass were assumed to be equal to ambient temperature and average wind speed was found to be 1 m/s. In theoretical modeling ambient temperature was taken as 30˚C. Experiments were conducted with Plane wick ($\theta = 0˚$) and corrugated wick ($\theta = 45˚$). The hourly variation of solar intensity and ambience temperature corresponding to March 2013 is presented in **Figure 6**, which have been used for computation. Radiation received was in the range of 0 W/m^2 to 1000 W/m^2. The ambient temperature is in the range of 24˚C - 35˚C. The fresh water productivity of the still is generally proportional to daily solar radiation. The measured ambient temperature is lower than other temperatures.

The temperature profile of corrugated-"V" type solar still is shown in **Figure 7**. Experimental variation of wick temperature was in the range of 30˚C - 65˚C. The mean standard deviations between theoretical and experimental values are less than 7%. Numerically calculated wick temperature was in the range of 30˚C - 68˚C. No significant variation was found between theoretical and experimental values of glass temperature. The variation was in the range of 30˚C - 52˚C. In both cases, the temperatures increases first and reaches a maximum and then decreases. Variation of experimental and theoretical values of glass and wick temperature for plane-"V" type solar still is shown in **Figure 8**. Experimental variation of wick temperature was in the range of 30˚C - 68˚C. The mean standard deviations between theoretical and experimental values are less than 6%. Numerically calculated wick temperature was in the range of 30˚C - 65˚C. Variation between theoretical and experimental values of glass temperature was negligible. The variation was in the range of 30˚C - 52˚C (exp) and 30˚C - 55˚C (the). On comparing **Figures 7** and **8**, wick temperature is higher for plane "V" type solar still. The solar radiation received was uniformly distributed over the absorber. The area of plane wick was less than that of corrugated wick. So the solar energy absorbed per unit area is higher and hence temperature is larger. The distillate output is independent of absorber area unless we provide any method of solar concentration. **Figure 9** presents the experimental results

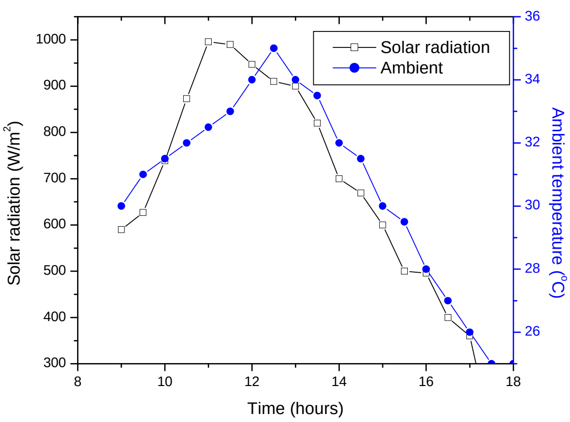

Figure 6. Solar radiation.

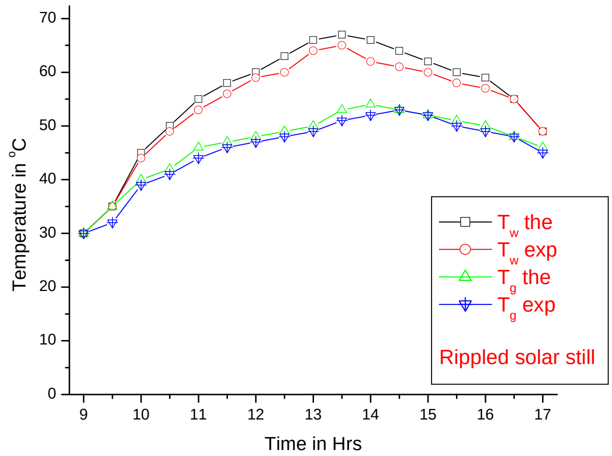

Figure 7. Variation of temperature (corrugated-"V" type solar still).

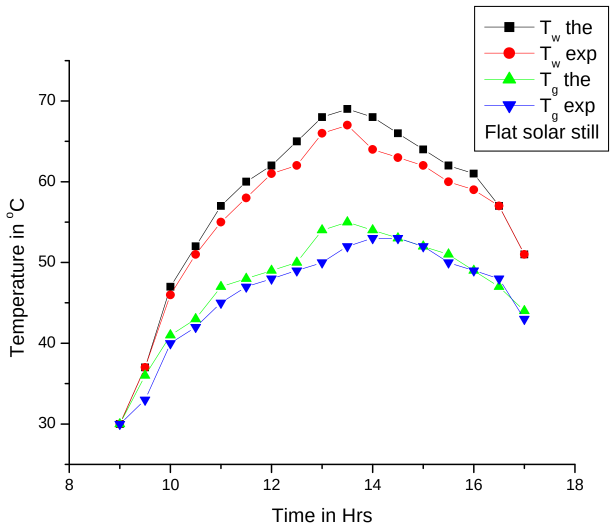

Figure 8. Variation of temperature (plane-"V" type solar still).

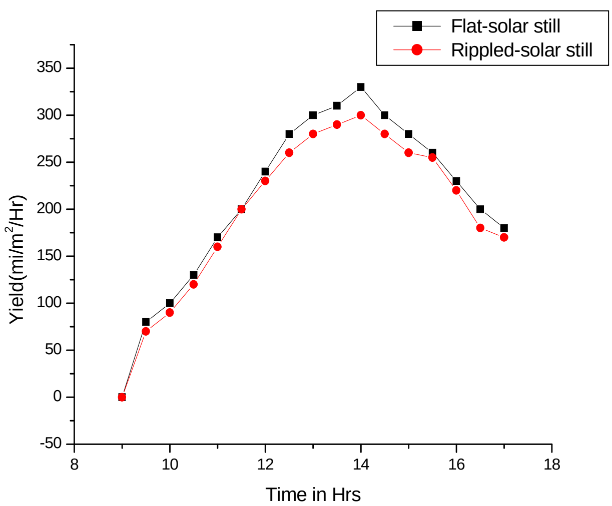

Figure 9. Variation of output.

of the hourly yield for corrugated and plane mode. The total amount of daily productivity obtained by the plane-"V" type solar still was 2800 ml/m^2/day. Finally, with corrugated absorber, productivity decreased to 2200 ml/m^2/day.

5. Conclusion

In the present study, several conclusions can be obtained as follows: 1) solar radiation received is independent of absorber area, 2) structural modification of wick/m^2 has no significance, 3) in wick-type solar stills, plane wick with drip system could be efficient, 4) the wick temperature for the plane wick is higher than that of the corrugated wick and the still output is higher for the plane system, 5) a change in the angle (0˚ - 45˚) causes decrease in distillate yield by 600 ml/m^2/day, and finally 6) the proposed mathematical model gave good match with experimental results.

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Nomenclature

C: Specific heat (J/kgK)
h': Heat transfer coefficient (W/m^{2}K)
G: Intensity of solar radiation-diffused (W/m^2)
m: Mass flow rate (kg/s)
p: Pressue (N/m^2)
T: Temperature (K)
t: Time (s)
V: Velocity of wind (m/s)
α': Fraction of solar radiation absorbed
θ: Angle of the ripple
ε: Emissivity
h_{wg}: Heat transfer coefficient (water-glass) (W/m^2·K)
h_{ga}: Heat transfer coefficient (glass-ambience) (W/m^{2}K)
σ: Stefan-Boltzman's constant, W/m^2·K^4

Subscripts

g: Glass
w: Water
a: Ambient
cw: Convective from water
ew: Evaporative from water
rw: Radiative from water
cg: Convective from glass
rg: Radiative from glass
eff: Effective
S: Sky
wm: Wick material
bm: Base material