PERFORMANCE STUDY OF SOLAR STILLS WITH VARIOUS ABSORBING MATERIALS AND A SENSIBLE HEAT STORAGE MEDIUM

by

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In this paper, the productivity of the solar stills is enhanced by placing different wick materials on the inner walls of the basin. The experiments are conducted with three different wick materials, namely cotton cloth, jute cloth, and sponges. The wick materials are painted with black to increase the absorptivity. The productivity of the still with cotton cloth, jute cloth, and sponges are 38.56%, 31.37%, and 24.50%, respectively, more than the conventional still. The stills are also tested with wicks and pebbles and compared with the conventional still. The productivity of the still with cotton cloth with pebbles, jute cloth with pebbles and sponge with pebbles are 55.66%, 43.68%, and 33.33%, respectively, more than the conventional still.

Key words: *wicks, productivity, cotton cloth, jute cloth, sponges*

Introduction

The basic necessity of the living organism is water. About 97% of the water available on the earth's surface is salty and 2% of the water is in the form of icecaps in the polar region. The life on earth is using only 1% of the water. The demand of fresh water is increasing day by day. In the next 20 years, the water demand will exceed the supply by 40%. Hence, to meet the increasing demand of fresh water, there is a need to convert the salty sea water into potable water and serve to the mankind. There are several methods to convert the impure water to pure water. One such method is the solar desalination with the use of solar stills. A solar still is a device used to convert the brackish water to pure water. The main drawback of the solar stills is its low productivity. It can produce only 2.5 to 5 L/m^2 per day.

Several researches have been made to improve the productivity of the solar stills. El-Sebaii *et al*. [1] used a baffle suspended absorber plate in a solar still and observed an 18.5-20% increase in the productivity. Naim *et al*. [2] used charcoal particle in a still and found 15% enhancement in productivity. Zeinab and Ashraf [3] used a package layer of glass ball to help the heating operation of saline water during daytime and after sunset to increase the potable water productivity by 5-7.5%. Naim *et al*. [4] used phase change materials such as emulsion of

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paraffin wax, paraffin oil, and water mixture and achieved 36.2% still efficiency. Nafey *et al*. [5] used black rubber and gravel in the still and the productivity was improved by 20% from 10 mm thick black rubber and increased by 19% from 20-30 mm gravel. Akash *et al*. [6] used black rubber mat, black ink, and black dye and the productivity increased by 38%, 45%, and 60% by the use of a black rubber mat, black ink, and black dye, respectively. Sakthivel *et al*. [7] used Jute cloth in the still and the productivity was increased by 20% more than the conventional still. El-Sebaii *et al*. [8] used sand as a sensible heat storage medium and with the addition of 10 kg of sand, the daily productivity and efficiency gets increased to 4.005 kg/m^2 per day and 37.8%. Abdallah *et al*. [9] used absorbing materials such as coated metallic wiry sponges, uncoated metallic wiry sponges and volcanic rocks and the productivity increased by 28%, 43%, and 60%, respectively, than the conventional still. Murugavel *et al*. [10] used different wick materials and fins and found that the aluminum rectangular fin covered with cotton cloth and arranged in length wise direction was more effective. Janarthanan *et al*. [11] used floating cum tilted wick solar stills and the efficiency of the closed-cycle system was maximum at low flow rate of water. Abdallah and Badran [12] coupled a Sun tracking system with a solar still and the productivity was improved by 22%. Badran [13] used asphalt liner and sprinkler in a still and observed a 29% increase in the output by the asphalt liner and 22% improvement by the use of sprinklers. Hilal *et al*. [14] conducted experiments in a single effect and double effect solar still and the productivity was 4.15 kg/m^2 per day and 6.1 kg/m^2 per day for single effect solar still, and double effect solar still, respectively. Omara *et al*. [15] performed experiments in a stepped solar still with trays (5 mm depth × 120 mm width) and the productivity was 7.5% higher than the conventional still.

In the present investigations, experiments are conducted in four single basin solar stills (SBSS) with equal dimensions. Wick materials such as cotton cloth, jute cloth and sponges were fixed on the inner walls of the basin. The productivity of the stills with wicks and the stills with wicks and pebbles were compared with the conventional still.

Experimental set-up

Four SBSS are fabricated with 1.2 mm thick mild steel plate. The sizes of the basin are 0.5 m × 0.5 m × 0.15 m. Ordinary window glass of thickness 3 mm is used as transparent covers. The covers are inclined at an optimum angle of 25 ° with the horizontal. Thermocole of 5 mm thickness is used as insulation.

The experiments are conducted with three different wick materials such as cotton cloth, jute cloth, and sponges. The wicks are painted black to maximize the absorptivity. The productivity of the three stills with wick is compared with the conventional still. The wicks are fixed on all the inner walls of the still basin. Also, the experiments are conducted with wicks and pebbles in the basin. The diameter of the pebbles used ranges from 20-30 mm. The mass of the pebbles used is 1 kg for all experiments. Collection troughs are provided at the bottom to collect the distillate. Provisions are made to supply the saline water, drain the basin water and insert thermocouples. Figure 1(a) shows the photographic view of the fabricated experimental set-up of a SBSS with jute cloth and fig. 1(b) shows the photographic view of the wicks and pebbles used in the still.

The experiments are conducted simultaneously in four different stills for the same basin condition at the University V. O. C. College of Engineering, Thoothukudi (8^0 48^I N and 78^0 07^I E), Tamil Nadu, India, for three days July 21-23, 2014 with wicks in the basin. Also, the experiments are conducted for three days July 24-26, 2014 with wicks and pebbles in the basin. The readings were taken from morning 6 a. m. to the next day morning 6 a. m. for every one hour interval. Solar power meter, digital anemometer and mercury thermometer were used to mea-

Figure 1(a). Photographic view of a SBSS with jute cloth (non-working model without glass cover)

Figure 1(b). Photographic view of the wicks and pebbles used in the still; (a) black paint coated sponges, (b) black paint coated jute cloth, (c) black cotton cloth, and (d) pebbles

sure the incident radiation, wind velocity and ambient temperature, respectively. The K-type thermocouples with multi channel digital display unit were used to measure the temperatures of lower glass cover surface, saline water, and absorber plate.

Theoretical simulation

Since the meteorological ranges are almost the same as in previous work done by Velmurugan *et al.* [16], same correlation and constants are taken for this work also.

The energy balance equation for the absorber plate, saline water, and glass of the solar still can be written: Energy received by the basin plate is equal to the summation of the energy gained by the basin plate, energy lost by convective heat transfer between basin, and water and side losses.

$$I(t)A_b\alpha_b = m_b c_{pb}\frac{dT_b}{dt} + Q_{c,b\text{-}w} + Q_{loss} \quad (1)$$

The absorptivity of the still α_b is taken as 0.95. The convective heat transfer between basin and water was taken:

$$Q_{c,b\text{-}w} = h_{c,b\text{-}w}A_b(T_b - T_w) \quad (2)$$

The convective heat transfer coefficient between basin and water was taken as 135 W/m^{2}K.

The heat loss from basin to ambient is taken as:

$$Q_{loss} = U_b A_b(T_b - T_a) \quad (3)$$

where U_b is taken as 14 W/m^{2}K.

The energy balance for the saline water is:

Energy received by the saline water in the still (from Sun and base) is equal to the summation of energy lost by convective heat transfer between water and glass, radiative heat transfer between water and glass, evaporative heat transfer between water and glass and energy gained by the saline water.

$$I(t)\alpha_w A_w + Q_{c,b\text{-}w} - Q_{c,w\text{-}g} + Q_{r.w\text{-}g} + Q_{e,w\text{-}g} + m_w c_{p,w}\frac{dT_w}{dt} \quad (4)$$

The mass of water, m_w, in the still is taken as 4 kg, 5 kg, and 6 kg for the first, second and third iteration, respectively. The absorptivity of the water, α_w, is taken as 0.05.The convective heat transfer between water and glass:

$$Q_{c,w\text{-}g} = h_{c,w\text{-}g}A_w(T_w - T_g) \quad (5)$$

The convective heat transfer coefficient between water and glass is:

$$h_{\mathrm{c,w-g}} = 0.884\left[(T_{\mathrm{w}} - T_{\mathrm{g}}) + \frac{(P_{\mathrm{w}} - P_{\mathrm{g}})(T_{\mathrm{w}} + 273)}{268.9 \cdot 10^{3} - P_{\mathrm{w}}}\right]^{1/3} \tag{6}$$

The radiative heat transfer between water and glass is:

$$Q_{\mathrm{r,w\text{-}g}} = h_{\mathrm{r,w\text{-}g}} A_{\mathrm{w}} (T_{\mathrm{w}} - T_{\mathrm{g}}) \tag{7}$$

The radiative heat transfer coefficient between water and glass is:

$$h_{\mathrm{r,w\text{-}g}} = \varepsilon_{\mathrm{eff}} \sigma [(T_{\mathrm{w}} + 273)^{2} + (T_{\mathrm{g}} + 273)^{2}](T_{\mathrm{w}} + T_{\mathrm{g}} + 546) \tag{8}$$

where

$$\varepsilon_{\mathrm{eff}} = \left(\frac{1}{\varepsilon_{\mathrm{w}}} + \frac{1}{\varepsilon_{\mathrm{g}}} - 1\right)^{-1} \tag{9}$$

The effective sky temperature:

$$T_{\mathrm{sky}} = T_{\mathrm{a}} - 6 \tag{10}$$

Energy gained by the glass cover (from Sun and convective, radiative and evaporative heat transfer from water to glass) is equal to the summation of energy lost by radiative heat transfer between glass and sky and energy gained by glass:

$$I(t)\alpha_{\mathrm{g}} A_{\mathrm{g}} + Q_{\mathrm{c,w\text{-}g}} + Q_{\mathrm{r,w\text{-}g}} + Q_{\mathrm{e,w\text{-}g}} = Q_{\mathrm{r,g-sky}} + m_{\mathrm{g}} c_{\mathrm{p,g}} \frac{\mathrm{d}T_{\mathrm{g}}}{\mathrm{d}t} \tag{11}$$

The evaporative heat transfer between water and glass is:

$$Q_{\mathrm{e,w\text{-}g}} = h_{\mathrm{e,w\text{-}g}} A_{\mathrm{w}} (T_{\mathrm{w}} - T_{\mathrm{g}}) \tag{12}$$

The evaporative heat transfer coefficient between water and glass is:

$$h_{\mathrm{e,w\text{-}g}} - (16.273 \cdot 10^{-3}) h_{\mathrm{c,w\text{-}g}} \frac{p_{\mathrm{w}} - p_{\mathrm{g}}}{T_{\mathrm{w}} - T_{\mathrm{g}}} \tag{13}$$

The radiative heat transfer between glass and sky is:

$$Q_{\mathrm{r.g-sky}} = h_{\mathrm{r,g-sky}} A_{\mathrm{g}} (T_{\mathrm{g}} - T_{\mathrm{sky}}) \tag{14}$$

The radiative heat transfer coefficient between glass and sky is:

$$h_{\mathrm{r,g\text{-}sky}} = \varepsilon\sigma \frac{(T_{\mathrm{g}} + 273)^{4} - (T_{\mathrm{sky}} + 273)^{4}}{T_{\mathrm{g}} - T_{\mathrm{sky}}} \tag{15}$$

Initially, the time interval is assumed as 5 second and water temperature, glass temperature, and plate temperature are taken as ambient temperature. The change in basin temperature, $\mathrm{d}T_{\mathrm{b}}$, increase in saline water temperature, $\mathrm{d}T_{\mathrm{w}}$, and glass temperature, $\mathrm{d}T_{\mathrm{g}}$, are computed by solving eqs. (1), (4), and (11), respectively. For evaluating, the previous mentioned temperatures in the simulation, the experimentally measured values of solar radiation and ambient temperature of the corresponding day and hour are used.

The total condensation rate is:

$$\left(\frac{\mathrm{d}m_{\mathrm{c}}}{\mathrm{d}t}\right) = h_{\mathrm{e,w\text{-}g}} \frac{T_{\mathrm{w}} - T_{\mathrm{g}}}{h_{\mathrm{fg}}} \tag{16}$$

For the next time step, the parameter is redefined:

$$T_{\mathrm{w}} = T_{\mathrm{w}} + \mathrm{d}T_{\mathrm{w}} \tag{17}$$

$$T_{\mathrm{g}} = T_{\mathrm{g}} + \mathrm{d}T_{\mathrm{g}} \tag{18}$$

$$T_{\mathrm{b}} = T_{\mathrm{b}} + \mathrm{d}T_{\mathrm{b}} \tag{19}$$

The iteration is continued for 24 hours duration from 6 a. m. to 6 p. m. using the actual metrological and operational data.

Results and discussions

Comparison between experimental and theoretical results

The variation in productivity for still with wicks and with wicks and pebbles is shown in figs. 2(a) and 2(b), respectively. The comparison between the experimental and theoretical values is shown in figs. 3(a) and 3(b), respectively. The experimental results were identical to that of the theoretical values. The maximum deviation between the experimental and theoretical results was 8.8%. The productivity of the still with wicks and pebbles is higher than that of the still with wicks.

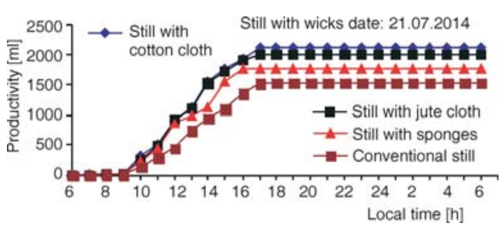

Figure 2(a). Variation of productivity rate for still with wicks

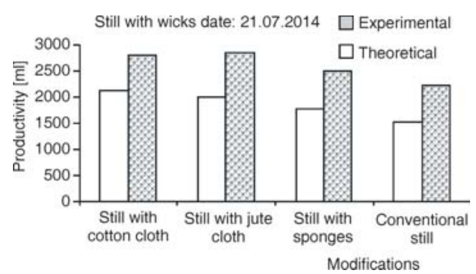

Figure 3(a). Comparison between experimental and theoretical values for still with wicks

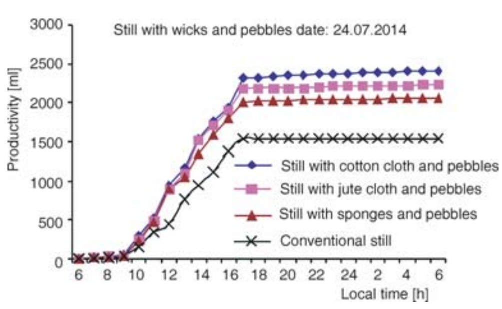

Figure 2(b). Variation of the productivity rate for still with wicks and pebbles

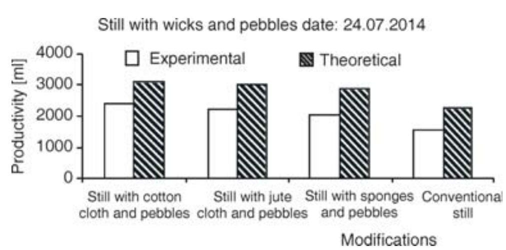

Figure 3(b). Comparison between experimental and theoretical values for still with wicks and pebbles

Effect of different mass of water

The variation of the different mass of water (4 kg, 5 kg, and 6 kg) in the basin is discussed in this section. Figure 4 shows the variation of productivity in different mass of water. Still with a minimum mass of water has higher productivity and for the same mass of water the productivity of still with wicks and pebbles is higher than that of the productivity of still with wicks.

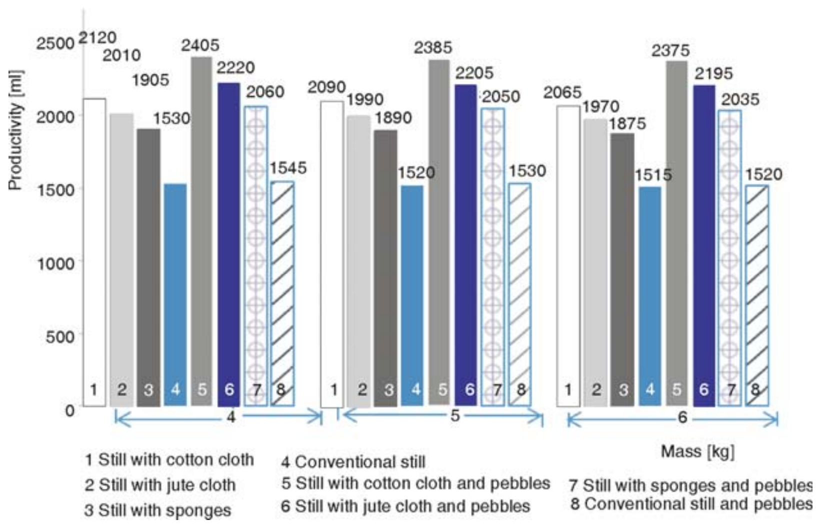

Figure 4. Variation in productivity for different wicks of different mass of water

Effect of using wicks and pebbles

Cotton has a high absorbency rate than the jute cloth and sponges. Hence, the productivity of the still with cotton cloth has higher productivity compared to stills with jute cloth and sponges. The sensible heat storage of pebbles is very high and hence the evaporation rate is increased. The increase in the evaporation rate leads to increase in the productivity. Thus, the productivity of stills with wicks and pebbles is higher than that of stills with wicks. The productivity of still with black cotton cloth and pebbles is also higher than that of the conventional still.

Conclusions

Four SBSS have been fabricated and their performances were compared to various basin conditions. The following conclusions are drawn:

- Providing different wicks in the inner sides of the basin increases the productivity.
- The productivity of the still with cotton cloth, jute cloth, and sponges are 38.56%, 31.37%, and 24.50%, respectively, more than the conventional still.
- The productivity of the still with cotton cloth with pebbles, jute cloth with pebbles, and sponge with pebbles are 55.66%, 43.68%, and 33.33%, respectively, more than the conventional still.
- The use of pebbles in the basin with wicks increased the productivity by 17%.
- Maximum water production is 2405 ml/m^2 per day for the still with black cotton cloth and pebbles.
- The stills with a minimum mass of water yielded higher productivity.

Nomenclature

A – area, [m^2]
c_p – specific heat, [Jkg^{-1}K^{-1}]
$I(t)$ – solar flux on the collector, [Wm^{-2}]
P – partial pressure, [Nm^{-2}]
Q – Heat transfer, [W]
T – temperature, [°C]
dt – time interval, [s]
h – heat transfer coefficient, [Wm^{-2}K^{-1}]
h_{fg} – enthalpy of evaporation at T_w, [Jkg^{-1}]
m_c – condensate, [kgm^{-2}]
m – mass, [kg]
U – side heat loss coefficient from basin to ambient, [Wm^{-2}K^{-1}]

Greek symbols

ε – emissivity
α – absorptivity
σ – Stefan-Boltzmann constant, [Wm^{-2}K^{-4}]

Subscripts

a – ambient
b – basin
c – convective
e – evaporative
g – glass
r – radiative
w – water
eff – equivalent
loss – side loss

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