Performance and economic evaluation of a single basin and single slope solar still

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***Abstract*— Water scarcity is a major problem in many parts of the world. The problem of unavailable and contaminated water can be solved by the solar still using solar energy. A single basin single slope solar still with a basin area of 1 m x 1 m and slope of 13° has been used. Both the inner and outer walls are painted black, in order to improve the heat transfer rate. Water used for the solar still process should be free from toxins and other radioactive materials. Water depth is an important parameter that affects the performance of the solar still. In this work, the minimum water depth of 1cm is maintained in the solar still basin, in-order to avoid dry spots. The solar still has a simple construction, and is economic in operation. Galvanized Iron is chosen as the basin material, as it is cheap and readily available in the market compared to other materials.**

***Index Terms*— Ambient, Basin, Desalination, Design, Passive solar still, Glass, , Solar radiation, Solar energy, Water depth.**

I. INTRODUCTION

The solar still basin material reflects 11% of the received solar radiation, without using it in the process of condensation and evaporation [1]. Three different basin materials like coated metallic wiry sponges, uncoated metallic wiry sponges and volcanic rock, increase the water collection gain by about 28%, 43% and 60% respectively [2]. Aluminium integrated basin material has the highest gain compared to the leather material [3].The increases in the daily water productivity of various basin materials coupled with the still, are black rubber mat by 38%, black ink by 45% and black dye by 60% [4].The solar still integrated with a black rubber mat increases the amount of solar radiation in the still, and enhances the yield rate [5-6].

II. EXPERIMENTAL SETUP

I In this work, Galvanized Iron as the basin material has been designed and fabricated, to study the performance of the solar desalination systems, as shown in Fig. 1.Experiments were conducted at the Faculty of Mechanical Engineering, Institute for Energy Studies, Anna University, Chennai, from 6 a.m. to 6 a.m. the following clear day during September 2013. The whole basin surface is coated with black paint inside to increase the absorption. The basin is covered with a glass sheet 5mm thick, inclined at nearly 13° horizontally, which is the latitude of Chennai city, Tamil Nadu, to maximize the amount of incident solar radiation. The whole experimental setup is kept in the south direction to receive the maximum solar radiation throughout the year. The solar radiation, atmospheric temperature, basin temperature, glass temperature and distilled water yield rate were measured every 30 minutes. The water vapor formed is condensed at the inner glass surface and the water droplets glide along the glass. The condensed water is collected in a measuring jar. The depth of the saline water in the solar stills is maintained constant manually, using the feed water tank and control valves.

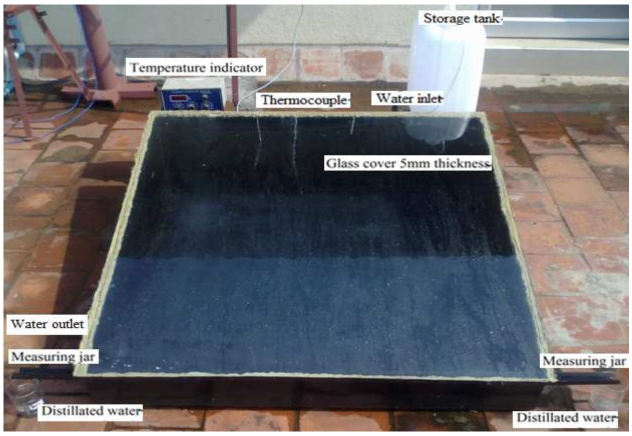

Fig. 1. Photograph of the experimental setup

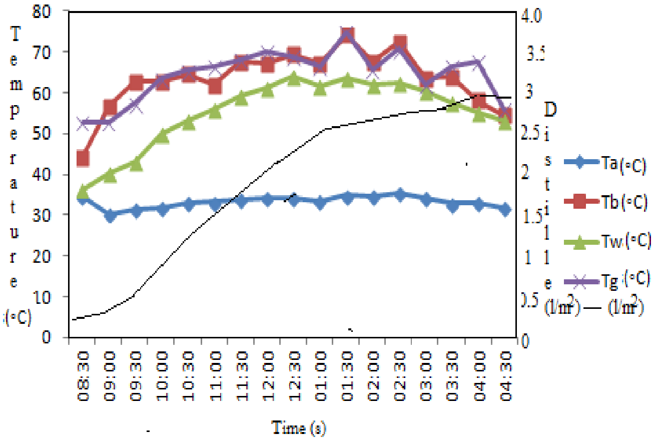

Fig. 2.Time variation of the ambient (Tatm), basin (Tb), water (Tw) and glass (Tg) temperatures and distillate for the still with a brine depth of 1 cm.

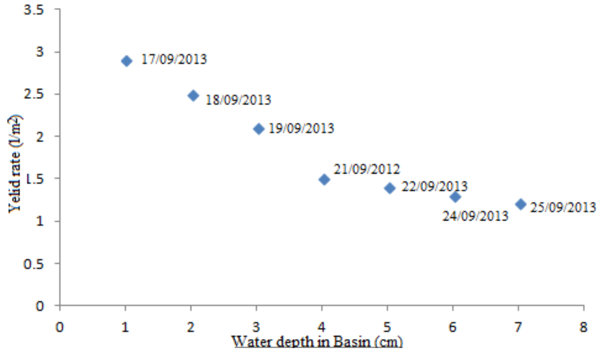

Fig. 3. Water depth in Basin (cm) and Yield rate (l/m^2) with respect to the date.

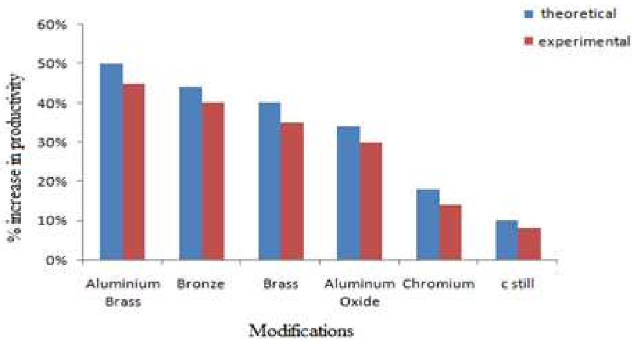

Fig. 4. % increase in productivity and modifications compared with the theoretical and the experimental results.

Table 1

Effect of modifications in conventional solar stills on productivity

Modification	**Solar still**
Aluminium brass	50%
Bronze	44%
Brass	40%
Aluminium oxide	34%
Chromium	18%

III. ENERGY BALANCE EQUATION

The energy balance equation for the conventional solar still basin material can be written as follows [7-9],

$$SR(t)A_b\alpha_b = m_b C_{pb}\left[\frac{dT_b}{dt}\right] + Q_{c,b-w} + Q_{loss} \quad (1)$$

The energy balance equation for the conventional solar still water temperature can be written as follows [7-9],

$$SR(t)\alpha_w A_w + Q_{c,b-w} = Q_{c,w-g} + Q_{r,w-g+}Q_{e,w-g} + m_w C_{p,w}\left(\frac{dT_w}{dt}\right) \quad (2)$$

The energy balance equation for the conventional solar still glass temperature can be written as follows [7-9],

$$SR(t)\alpha_g A_g + Q_{c,w-g} + Q_{r,w-g} + Q_{e,w-g} = Q_{r,g-sky} + Q_{c,g-sky} + m_g C_{pg}\left(\frac{dT_g}{dt}\right) \quad (3)$$

IV. MODIFIED MODEL:

The energy balance equation for the modified solar still, basin material integrated with the aluminium brass sheet of 0.7mm thickness can be written as follows, with the area taken as 0.92 m^2.

$$SR(t)A_b\alpha_b = \left[\left(m_b C_{pb} + m_{albr\,albr} C_{p\,albr}\right)\left(\frac{dT_b}{dt}\right) + Q_{c,b-w} + Q_{loss}\right] \quad (4)$$

The energy balance equation for the modified solar still, basin material integrated with the bronze sheet of 0.7mm thickness can be written as follows, with the area taken as 0.92 m^2.

$$SR(t)A_b\alpha_b = \left[\left(m_b C_{pb} + m_{brz} C_{p\,brz}\right)\left(\frac{dT_b}{dt}\right) + Q_{c,b-w} + Q_{loss}\right] \quad (5)$$

The energy balance equation for the modified solar still, basin material integrated with the aluminium oxide can be written as follows, area taken as 0.92 m^2.

$$SR(t)A_b\alpha_b = \left[\left(m_b C_{pb} + m_{brs} C_{p\,brs}\right)\left(\frac{dT_b}{dt}\right) + Q_{c,b-w} + Q_{loss}\right] \quad (6)$$

The energy balance equation for the modified solar still, basin material integrated with the aluminium oxide can be written as follows [7-9], area taken as 0.92 m^2.

$$SR(t)A_b\alpha_b = \left[\left(m_b C_{pb} + m_{alox} C_{alox}\right)\left(\frac{dT_b}{dt}\right) + Q_{c,b-w} + Q_{loss}\right] \quad (7)$$

The energy balance equation for the modified solar still, basin material integrated with the chromium of 0.7mm thickness can be written as follows, area taken as 0.92 m^2.

$$SR(t)A_b\alpha_b = \left[\left(m_b C_{pb} + m_{chr} C_{pchr}\right)\left(\frac{dT_b}{dt}\right) + Q_{c,b-w} + Q_{loss}\right] \quad (8)$$

The total yield rate can be written as follows [7-9],

$$\left[\frac{dm_d}{dt}\right] = \frac{h_d\left(T_w - T_g\right)}{h_{gh}} \quad (9)$$

Daily efficiency can be written as follows [7-9],

$$\eta = \sum \frac{m_d h_{gh}}{ASR} \quad (10)$$

% increase in productivity can be written as follows [7-9],

$$\%\text{increase in productivity} = \left[\left(\frac{m_{d,with} - m_{d,without}}{m_{d,without}}\right)\right] \times 100\% \quad (11)$$

V. RESULTS AND DISCUSSION

Based on the results obtained from the experimental work, the following can be concluded. Fig. 3 shows the variation of the hourly temperature for an experiment conducted in the month of September, using a passive solar still with a tilt angle of 13°.The annual yield of the solar still was found to be the maximum when the condensing glass cover inclination is equal to the latitude of the place [11].The maximum water temperature occurred between the hours of 12.30 and 3.30 p.m. It ranged between 50°C and 55°C. The ambient temperature for all the experiments was in the range of 31-35°C.A higher variation in the atmospheric condition on any day is not considered for the analysis. The theoretical performance of the still was evaluated, by solving the energy balance equation (Eqs. (1) - (8)). Eq (9) was used to calculate the total condensation rate. Eqs. (10) and (11) were used to calculate the daily efficiency and increase in the productivity of the still. The theoretical and the experimental results were compared with those of the modified still and the conventional solar still, shown in Fig 4. The conventional solar still with modifications was done on a clear day of (04/04, 22/04, 25/04, 27/04, 30/04, 01/04/2014) with the average solar radiation of 600 W/m^2. The maximum water temperature was between the hours of 01.30 and 2.30 p.m. It ranged between 50°C and 69°C.The ambient temperature for all the experiments was in the range of 28-37°C.Initially the basin, water, ambient, and glass temperatures were assumed as constants, and equal to 31°C. Using these temperatures and the actual measured metrological data, calculations were performed at intervals of 30 minutes. The experiment was conducted at different water depths of 1,2,4,6,8,10,12cm, and it was found, that 1cm has the highest yield rate compared to the other water depths (2,4,6,8,10,12cm) shown in Fig.3 with respect to date. An increase in the depth of water in the basin decreases the productivity of the solar still. The pure water yield depends onthe water depth. A decrease of 14% in productivity as a result of an increase in depth from 2 cm to 7 cm was experimentally proved [10].The total heat capacity of the water and the basin material, is indirectly proportional to the maximum glass and water temperature.

VI. ECONOMIC ANALYSIS

A model economic analysis calculation and single basin solar still is given below [5].The modification costs of the solar still material include the following: the aluminium brass, bronze, brass, aluminium oxide and chromium cost for the area of 0.92 m^2 is Rs. 3000. The investment cost for the still and modification is Rs. 3000.Maintenance cost= Rs. 1/day. Daily average productivity of the solar still = 1.21 l/m^2/day. Cost of water produced=cost of water per litre × productivity= 5×3.0=Rs. 6.05, Cost of mineral per litre=Rs. 0.3, Cost of minerals for 3.0 =Rs. 0.9.Net earnings=

Cost of water produced − Maintenance cost − Cost of minerals= Rs. 4.15. Payback period=Investment/Net earning=6000/4.15= 1445.7 days

VII. CONCLUSION

The raw water feed inside the solar still with a salinity of 700 mg/l reduced to 10 - 20 mg/l during the process of film condensation and evaporation for all the basin materials used. The distillate obtained from the experiment is best suitable for drinking purpose. A single basin and single slope solar still was fabricated and tested for different water depths. An increase in the productivity of the passive solar still by decreasing the water depth in the basin was observed. For 1cm water depth, the productivity is 1.21 l/m^2/day; it was only 0.25 l/m^2/day for 12 cm water depth.The theoretical and the experimental results for the modified still and the conventional solar still were compared. The theoretical results had 5-9% deviation from the experimental result for the basin materials. The aluminium brass integrated basin material has 50% increase in productivity compared with the bronze, brass, aluminium oxide and chromium materials for 2 cm water depth in the basin.

NOMENCLATURES

A	Area, m^2
C_p	Specific heat, J kg^{-1} K^{-1}
h_{gh}	Latent heat of evaporation, J kg^{-1}
SR	Solar radiation on a collector, W m^{-2}
m	Mass, kg
m_b	Mass of basin, kg
m_d	Mass of yield, kg
m_{albr}	Mass of aluminium brass, kg
m_{brz}	Mass of bronze, kg
m_{brs}	Mass of brass, kg
m_{alox}	Mass of Aluminium oxide, kg
m_{chr}	Mass of Chromium, kg
t	Time, s
ΔT	Temperature difference, °C
dT_g	Change in glass temperature, °C
dT_b	Change in basin temperature, °C
Q_{loss}	Convective heat transfer side losses , W m^{-2}
$Q_{c,w-g}$	Convective heat transfer between water and glass ,W m^{-2}

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