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# Performance analysis and simulation of a double basin glass solar still under Indian summer climate

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***Abstract:*** Groundwater and reservoirs are the largest available sources of freshwater to fulfill mankind needs. However, these sources do not always prove to be useful due to the excessive salinity in the water. In this paper, simple solar still system is constructed and tested for converting saline water into potable water. The double basin glass solar still system is installed at Periyanaickenpalayam, Coimbatore, Tamil Nadu, India. Water quality parameters such as dissolved solids, pH and electrical conductivity (dSm-1) in the saline water were measured on a daily basis from April 2010 to May 2010. Concurrently, theoretical calculations were performed on the basis of summer climatic condition prevailed at the Coimbatore district. Experimental results have shown that average daily output of the glass solar still is 1.64 l/0.27 m2/ day and the maximum efficiency is 66.9% whereas total dissolved solids (TDS) of fresh water is 40 ppm. Theoretical results are comparable with experimental results suggesting that robustness of the solar still system. The present approach is more appropriate for small scale production of drinking water in and around coastal regions and groundwater contaminated areas.

***Keywords:*** *Solar still, solar radiation, double basin, humid condition, water quality and India.*

## 1. INTRODUCTION

Water demand has increased rapidly in all kind of manmade activities such as domestic, commercial, industrial and agriculture purpose. Our earth is made up of 71% water bodies and 29% of land surface. However, about 97% of earth's water is contaminated by saline and 2% is frozen in glaciers and polar ice caps; remaining 1% is suitable for drinking and domestic utilities [1]. Solar energy is a suitable resource for seawater desalination either by thermal process or by electricity process. In general, solar desalination systems are classified into two categories namely direct collection systems and indirect collection systems. Direct collection systems use solar energy to produce distillate directly in the solar collector, whereas indirect collection systems processed by two sub-systems. Conventional desalination systems are similar to solar desalination systems because of them equipped with same techniques. In the earlier case, conventional boiler or electricity is used to provide the required heat for water desalination; whereas solar energy is applied in the recent days [1]. The studies related to include double basin solar still [2-7], double exposure single basin solar still [8], triple basin solar still [9], multiple basin solar still [10-11], double slope active solar still [12], inverted absorber solar still [13-17], tubular solar stills [18-22], and characteristic equation of the inverted absorber solar still [23] have provided an insight to technical and experimental setup of the solar still system. The metallic components are rapidly corroded by salinity in the water. Therefore, we used the glass material to construct the solar still system. This paper provides experimental analysis on double basin glass solar still for producing potable water from saline water. The still system is tested during the Indian summer climatic condition.

## 2. EXPERIMENTAL SETUP AND PROCEDURE

A double basin experimental solar still was fabricated as shown in Figure. 1. The overall size of the inner basin is 590 mm x 440 mm x 440 mm and the outer basin is 600 mm x 460 mm x 460 mm. The solar still has a 3 mm thick top cover, inclined at 17° on all the sides and supported by steel frames. The upper basin is partitioned into three segments to avoid the dry spots on the higher portion of inner glass cover. Silicone rubber sealants have been used to seal off and prevent the water leakage between the boxes of the still. A hole in the basin's side wall allows saline or wastewater filling, as well as collecting the condensed water.

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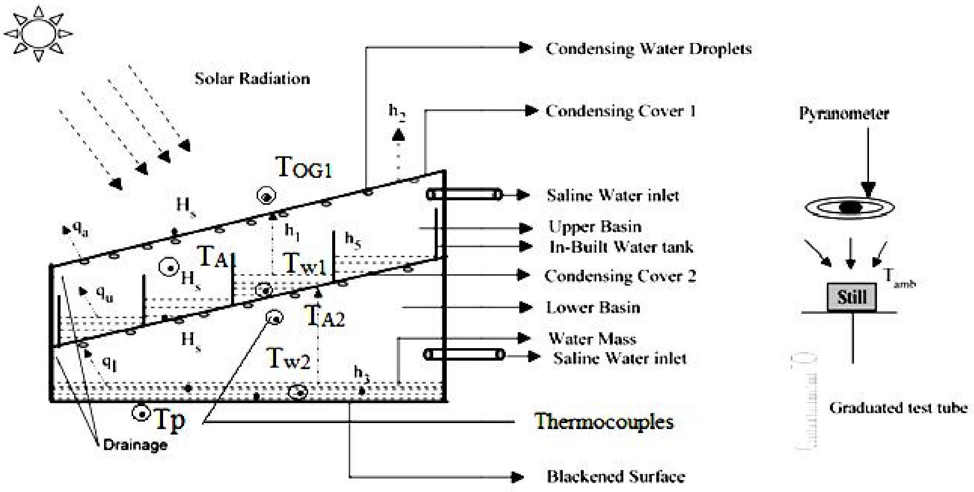

Figure 1. Cross sectional view and temperature measuring points of the double basin glass solar still

Moreover, thermocouple wires were inserted to the temperature with respect to the time period. When the still is in operation, the hole is closed with an insulating material to avoid heat and vapor losses. The experimental work is carried out during the summer of the year 2010, at the Solar Energy Laboratory, in the campus of Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore, Tamil Nadu, India. The setup is located at 11°08'30.79"N and 76°56'43.91"E geo-coordinates with 443m elevation above the mean seal level. Figure 2 illustrates the front view of the solar still and the temperature measurement system whereas Figure 3 shows the still's side view. To reduce the water vapor leakage, the solar still is hermetically sealed. A 4 mm solar absorber made from a blackened copper sheet was put in the lower basin of the solar still. The collected condensate was constantly drained through a flexible hose and stored in a measuring graduated test tube.

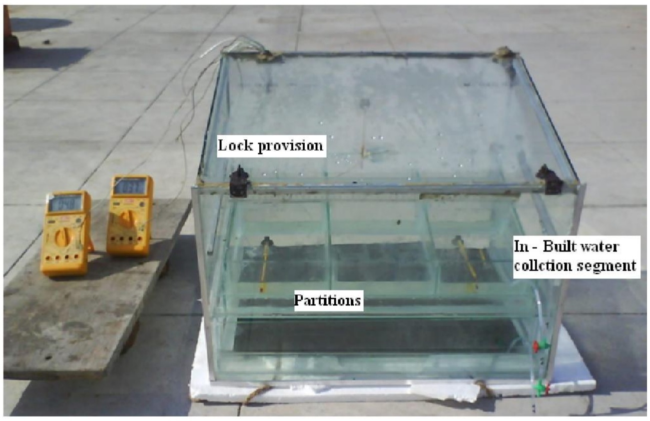

Figure 2. Photographic view of the double basin glass solar still (front view)

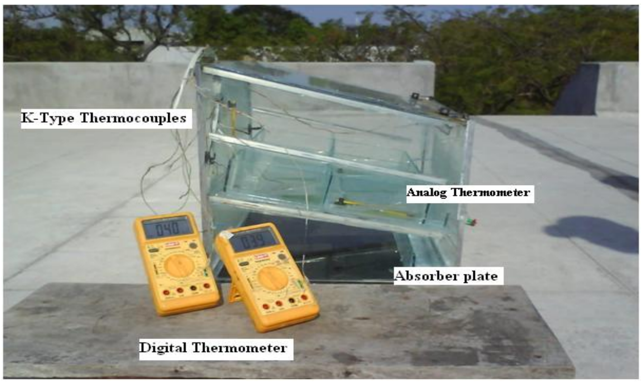

Figure 3. Photographic view of the double basin glass solar still (side view)

After each scheduled time interval, raw water is added in the still so that the water mass from the basin is nearly constant. An isolating sheet is placed under the solar still to reduce the heat losses to the ground. Several thermocouples and a Pyranometer are connected to a digital multimeter. The monitored parameters are: solar radiation, ambient air temperature, water temperature, inner and outer glass temperatures and the quantity of distilled water produced by the still. The data are collected each half an hour. The accuracies, range and error for various measuring instruments are shown in Table 1.

## 2. THEORETICAL ANALYSIS

The performance of a double basin glass solar still is generally expressed as the quantity of water evaporated per unit basin area per day. Solar still performance is evaluated by the mass and energy balance empirical equations.

TABLE 1
Accuracies, range and error for various measuring instruments

| S.no | Instrument | Accuracy | Range | % Error |
|---|---|---|---|---|
| 1 | Pyranometer | ±30W/m$^2$ | 0-1750 W/m$^2$ | 3 |
| 2 | Digital thermometer | ±1 ºC | 0-100 ºC | 1 |
| 3 | Thermocouple | ±1ºC | 0-100 ºC | 1 |
| 4 | Graduated test tube | ±10ml | 0-1000ml | 1 |

### 2.1. *Energy balance equation*

The solar radiation trapped by the still is continuously transformed into heat, which is then absorbed by the water from the basin. This results in an increase in water temperature and also in the heat transfer rate from the water to the glass cover. A part of this heat transfer is due to convection and radiation, and the rest due to evaporation caused by the temperature difference between the saline water surface and the lower surface of the lower glass cover. The vapor condenses at the bottom surface of the cover, transferring the heat to the glass. Despite all precautions taken, still a small part of the available heat is lost to the atmosphere through the bottom surface and the side walls due to conduction and convection. Modeling of the system is based on energy balance equations for each component of the distillation unit, namely, the glass covers and the basin. This system considers the design and climatic parameters. The following basic assumptions are made for the simulation:

a. The surface areas of the top cover, the water surface and the base of the still are equal.
b. The wind velocity is constant.
c. The initial water temperature equals the ambient air temperature.
d. The heat capacities of condensing covers, basin liner, walls and frame are neglected.
e. The side losses are neglected.The still is vapor tight.
f. There are no temperature gradients through the upper and lower water masses.

The energy balance equation for the various components of the system can be written as follows:

Upper condensing cover:

$$I\alpha_g + h_1(T_{wu} - T_{gu}) = h_{rwg}(T_{gu} - T_s) + h_w(T_{gu} - T_a) \quad \text{---} \quad 1$$

Upper water mass:

$$I\tau_g\alpha_{wu} + h_5(T_{gl} - T_{wu}) = (m_{wu}c_w / A_b)(dT_{wu} / dt) + h_1(T_{wu} - T_{gu}) \quad \text{---} \quad 2$$

Lower condensing cover:

$$I\tau_{gu}\alpha_{gl} + h_3(T_{wl} - T_{gl}) = h_5(T_{gl} - T_{gu}) \quad \text{---} \quad 3$$

Lower water mass:

$$I\tau_{gu}\tau_{wu}\tau_{gl}\alpha_{wu} + h_b(T_b - T_{wl}) = (m_{wl}c_{wl} / A_b)(dT_{wl} / dt) + h_{wl}(T_{wl} - T_{gl}) \quad \text{---} \quad 4$$

Basin liner (blackened surface):

$$I\tau_{gu}\tau_{wu}\tau_{gl}\tau_{wu}\alpha_b = h_b(T_b - T_{wl}) + U_b(T_b - T_a) \quad \text{---} \quad 5$$

Formulae of heat transfer coefficients in Equations 1-5 are given in Appendix I. The system efficiency (η) is defined as the ratio of the heat used for water evaporation to the total heat input. The efficiency of the conventional still is usually defined as follows:

$$\eta = \frac{m_e h_{fg}}{I A D t} \quad \text{---} \quad 6$$

## 3. WATER CHARACTERIZATION

Water quality analyses were conducted at the Soil Science and Agricultural Chemistry Department, Tamil Nadu Agricultural University, Coimbatore. Before and after desalination of water samples for two months (totally 122 samples) were pretreated at the laboratory and water quality parameters such as total dissolved solids (TDS), pH and the electrical conductivity were measured for each sample. The results obtained are presented in Table 2. The initial salinity level is rather high (1 dSm$^{-1}$). However, it decreased to 0.10 dSm$^{-1}$ after desalination. The optimum pH varies in the range of 6.5 to 8.

TABLE 2
Tested water quality results

| Parameter | Average rate of 122 samples | |
|---|---|---|
| | Before desalination | After desalination |
| TDS (mg/l) | 1320 | 40 |
| pH | 7.60 | 7.32 |
| Conductivity(dSm$^{-1}$) | 1 (High saline) | 0.10 (Low saline) |

## 4. RESULTS AND DISCUSSION

The double basin glass solar still (DBGSS) thermal performance was investigated from April to May 2010. The ambient temperatures, inner and outer cover temperatures, water film temperatures, air temperatures were measured daily from 8 to 18:30. The heat transfer coefficients, instantaneous efficiency and hourly outputs were estimated from the collected data. The water was fed to the two basins of the solar still up to the desired level at 7:30 daily. The distilled water output was measured the next day, at the same time. After that, non potable water was filled into the basin of the still again. Figure. 4 depicts the variations in the hourly temperatures for an experiment conducted on April 28, 2010 using a tilt angle of 17°. Similar trends were noticed in other experiments too. Consequently, it was observed that the water temperature in the base of the still always remained the highest, due to the better absorption of solar energy there. The maximum water temperature monthly occurred between 13:00 to 14:30. It ranged from 30 °C to 53 °C in the upper basin and 30 °C to 59 °C in the lower basin of the still. Ambient temperatures throughout the experiment are changed from 29 °C to 35 °C.

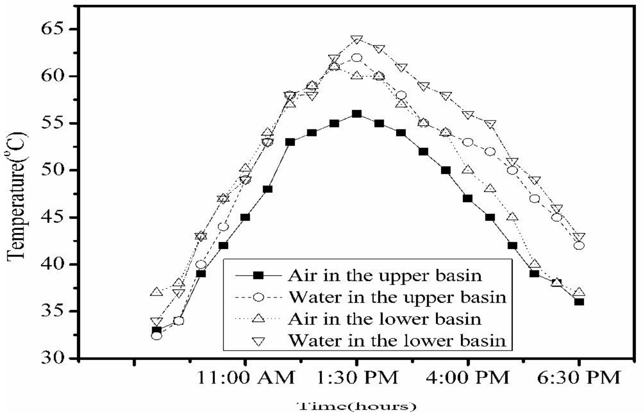

Figure 4. Average temperature variation in DBGSS per day

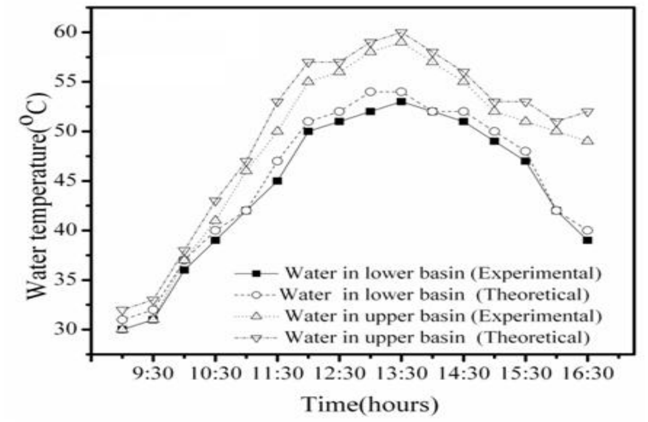

Figure 5. Hourly variation of theoretical and experimental water temperature in DBGSS

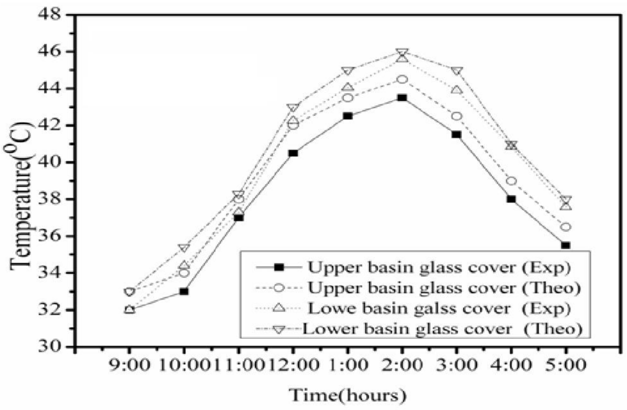

Figure 6. Result showing variation of theoretical and experimental glass cover temperatures in DBGSS on 28th

The experimental and theoretical water and glass temperatures for the DBGSS are represented in Figure. 5-6. The difference between the theoretical values and the experimental is relatively small (8%). The experimental water temperature was maximum 59 °C while the theoretical value was maximum 60 °C. Similarly, the maximum cover temperature was observed at 43.5 °C and was expected theoretically to be 46 °C. Figure. 7 shows the variation of the performance ratio depending on the irradiation intensity. The performance ratio is increasing with the solar radiation intensity. The performance ratio observed during the study ranged between 14% to 34% in the upper basin and 24% to 40% in the lower basin of the solar still. When the temperature reached the maximum value, it did not affect the performance ratio of the still, which remained constant. The warm-up period caused a change in the performance ratio as the temperature rose. This effect could be due to the differences in the solar energy radiation.

The variations in the hourly output of purified water are presented in Figure. 8. It can be observed from the measured data that the upper basin (1.64 l/0.27 $m^2$/day) gives a higher yield compared to the lower one (0.630 l/0.27$m^2$/day). The water evaporation in the lower basin is caused mainly by heat produced during condensation at the glass cover of the upper basin. As a result the upper basin continues to produce an appreciable amount of distillate during the night. This clearly proves that the performance of the double basin glass solar still is much better as compared to the single slope solar still.

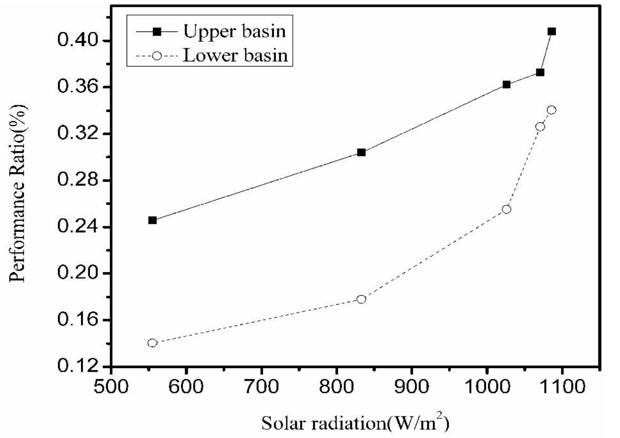

Figure 7. Variation of performance ratio with respect to the solar radiation under summer climate

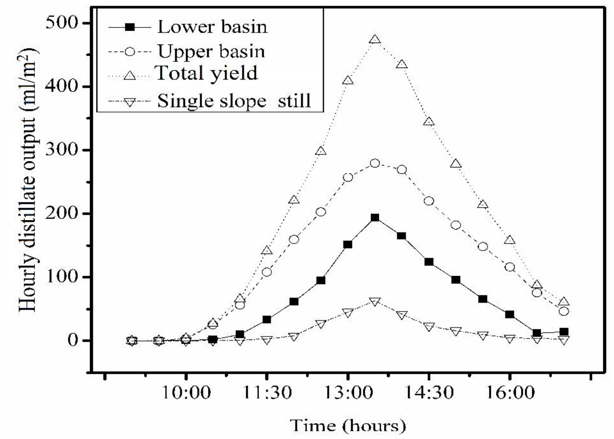

Figure 8. Hourly variation of distillate output under summer climate

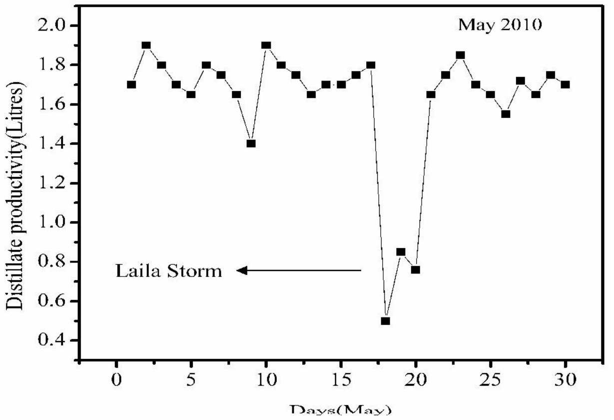

Figure 9. Variation of distillate water yield in May 2010

The daily distillate water production is shown in Figure. 9. A near steady yield of ~5.66 l/m$^2$/day of the distilled was recorded. However, this yield decreased on May 18, 19 and 20 when a marine storm named 'Laila' struck the coastal areas of Tamil Nadu, changing the normal climatic conditions. Figure 10 show the evaporative heat transfer with respect to time. The yield is higher in the lower basin than in the upper basin of the system. The values for the radiation and convection heat transfer coefficients did not change significantly throughout the experiment, thus they are not very temperature dependent. However, the values of the evaporative heat transfer coefficients changed due to their direct dependence on the partial pressure as they are very sensitive to changes in the temperatures.

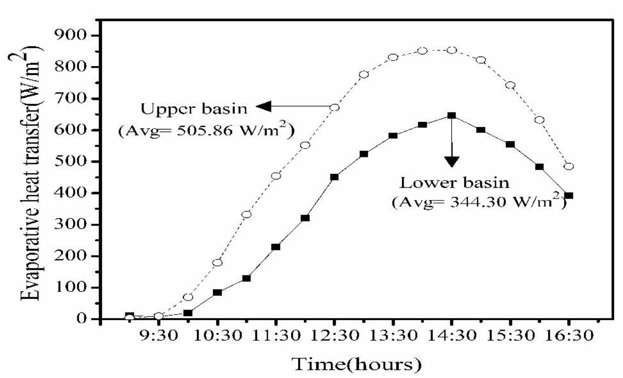

Figure 10. Hourly variation of evaporation heat transfer on summer climate

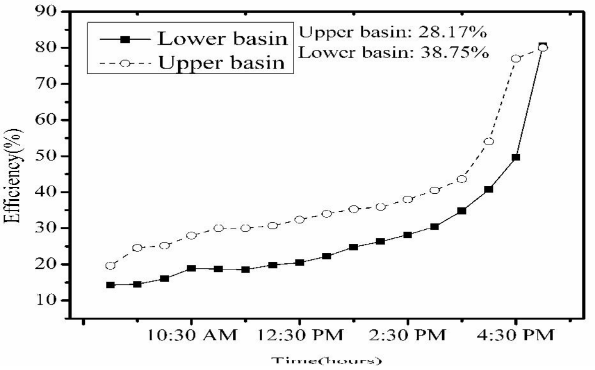

Figure 11. Efficiency of upper and lower basin on summer climate

The evaporative heat transfer was found to range from 2.9 W/m$^2$ to 854 W/m$^2$ in the upper basin and 11.52 W/m$^2$ to 645 W/m$^2$ in the lower basin. Variations in instantaneous efficiency of the still, Eq (10), are presented in Figure.11. The system's efficiency ranged between 14.3% to 80.6% in the upper basin and 32.4% to 86% in the lower basin. The average efficiency of the system is 66.9% (because water is produced from both the lower and upper layers).

## 5. CONCLUSION

The present approach is a low cost solution for creating fresh water from saline and waste waters. Performance tests attested the robustness of the present system for potable water productivity through the direct exploitation of the solar energy. The experimental results suggested that productivity of the upper basin in the solar still is higher than the productivity of its lower basin. The present system can produce maximum of 1.64 l/0.27 m$^2$ per day. The maximum efficiency of the experimental still works out to be 66.9%. Theoretical results are comparable to the experimental outcome. The present solar still system is more suitable for developments in the field of desalinate of polluted water.

## APPENDIX - I

Heat transfer coefficients can be calculated as follows:

$$h_1 = h_{cw} + h_{ew} + h_{rw} \qquad h_2 = h_{ca} + h_{ra} \qquad h_{ew} = \frac{q_{ew}}{(T_w - T_g)}$$

$$h_{cw} = \frac{q_{cw}}{(T_w - T_g)} \qquad h_{ra} = \frac{q_{ra}}{(T_w - T_g)} \qquad h_{ca} = \frac{q_{ca}}{(T_w - T_g)}$$

$$q_{ra} = \varepsilon_g \sigma \left[ \left(T_g + 273\right)^4 - \left(T_{sky} + 273\right)^4 \right]$$

$$T_{sky} = T_a - 6 \; q_{ca} = h_{ca}\left(T_g - T_a\right) \qquad h_{ca} = 5.7 + 3.8V$$

$$h_{ew} = 16.276 \times 10^{-3} h_{cw} R_1 \qquad R_1 = \frac{T_w - T_g}{P_w - P_g}$$

$$U_b = \left( \frac{1}{h_b} + \frac{L}{k_1} + \frac{1}{h_{ca}} \right)^{-1}$$

## Symbols

A - Surface area, m$^2$
$A_w$ - Area of the water in the upper basin, m$^2$
C - Specific heat, J/Kg °C
h - Convective heat transfer coefficient from the basin linear to the glass cover of the first effect, W/m$^2$ °C
$h_1$ - Convective heat transfer coefficient from water surface to glass cover, W/m$^2$ °C
$h_2$ - Total heat transfer coefficient from the water surface to the glass cover, W/m$^2$ °C
$h_3$ - Convective heat transfer coefficient from the glass cover of the upper basin to the water mass in the lower basin, W/m$^2$ °C
$h_4$ - Total heat transfer coefficient from the water surface to the glass cover in the upper basin, W/m$^2$ °C
$h_5$ - Convective heat transfer coefficient from lower glass cover to upper basin water, W/m$^2$ °C
$h_5$ - Overall heat transfer coefficient from water to atmosphere through bottom and sides of the still, W/m$^2$ °C
$h_{cga}$ - External convective from the lower basin to ambient, °C
$h_d$ - Mass transfer coefficient (kg/s m$^2$)
$h_e$ - Evaporative heat transfer from the upper and the lower basins, W/m$^2$ °C
$h_r$ - Radiation heat transfer coefficient from water to glass cover, W/m$^2$ °C
$h_{rg}$ - External heat transfer coefficients from the cover to sky, W/m$^2$ °C
$h_w$ - Convection heat transfer from water to glass, W/m$^2$ °C
I - Solar radiation intensity, W/m$^2$
L - Latent heat of vaporization, J/kg
M - Mass of the basin water, kg
P - Productivity, l
T - Initial glass temperature, °C
t - Time, s
U - Heat loss coefficient, W/m$^2$ °C
V - Wind velocity, m/s
x - Thickness, m

***Greek***

$\alpha$ - Absorptivity
$\eta$ - Efficiency, %
$\sigma$ - Stefan-Boltzmann's constant, W/m$^2$ K4
$\tau$ - Transmissivity

***Subscripts***

a - Ambient
av - Average
b - Basin linear
d - Daily
g - Glass
l - Lower basin
s - Sky
u - Upper basin
w - Water

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