ISSN (Online) : 2319 - 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

Volume 3, Special Issue 3, March 2014

2014 International Conference on Innovations in Engineering and Technology (ICIET'14)
On 21st&22ndMarch Organized by

K.L.N. College of Engineering and Technology, Madurai, Tamil Nadu, India

Performance Enhancement Study on Single Basin Double Slope Solar Still Using Flat Plate Collector

Suresh babu.k, S.Chinnathambi, M.Sridharan

Department of Mechanical Engineering, Saranathan College of Engineering, Panjapur, Tiruchirapalli, India

ABSTRACT— The major source of water in the earth is ocean, which is of high salinity.To desalinate the saline water large amount of energy have to employed, a renewable energy like solar energy is utilized it will be a promising source for desalination. The main objective of this research is to utilize the FPC solar water heater effectively for solar still productivity enhancement at an optimal cost.Probably its performance will be one of the best for water production in remote, arid to semi-arid, small communities, where fresh water is unavailable. The experiment is carried out in a typical day in a melded climatic condition at Trichy (10°8050'N, 78°6856' E), Tamilnadu, India. The basin water depth is maintained in 0.02m throughout the study. The performance of the setup is studied theoretically and experimentally. It proves that 77% higher yield when compared to the single basin double slope passive solar still.

KEYWORDS— FPC, Solar Still, Desalination, Optimal Cost, Efficient etc...

I. INTRODUCTION

Basic need for all living beings is clean water but man-made products are affecting it adversely through pollution. The global water resource is classified into two: sea water and fresh water (in the form of deep wells and natural aqueducts). Sea water covers the major part of the resource ie. 97.5% and 2.5% of fresh water is available in which human can use only 1% for the purpose of drinking and agriculture due to reachability. By 2025, Due to the scarcity of fresh water, two thirds of the human population in the world will have shortage of drinking water. Supply of the fresh water is decreasing whereas the demand is increasing rapidly. Now our technology has an important role to match the supply of the fresh water with the demand. In the present scenario, people accept the technology created by the scientist when it is ecologically friendly and economically viable. Most of the desalination technologies does not satisfy the above considerations.

In rural areas, nowadays solar distillation has become very popular. Comparing with the other available method, it is very simple and more economical. The method incorporated in solar still is similar to the natural hydrological cycle of evaporation and condensation but the process is carried out in a very small closed system. There is an inclined transparent cover through which the solar energy reaches the basin water. In the inner surface of the transparent cover, water will be condensed before which the water is heated and evaporated. Microbes and contaminates in the water stays on the basis during evaporation and the water is collected in a separate container. Single-basin type solar still has a simple construction and operation. It is also termed as Passive solar still (PSS). Due to the season, region and intensity of solar radiation, it has Low yield of about 2 kg/dm^2 (winter) to 5.5 kg/d m^2(summer) which is main drawback of PSS[3]. For Productivity enhancement, various designs like weir type, concave type and tube type were also reported. An active mode of operation is developed through considerable research to enhance the yield of solar still[2]. An additional thermal energy like solar collectors or another heat source is supplied to increase the temperature of the water in Active solar still (ASS). Modification in design includes the increase in cost and difficulty in operation. It is reported that solar still integrated with flat plate collector type solar water heater is not done through experimental work in any of the literatures.

II. AIM OF THE WORK

The aim of the work is to increase the basin water temperature economically. By utilizing the solar water heater, the basin water temperature is increased. The passive solar distillation system is a slow process for purification of saline/brackish water in solar desalination. To enhance the daily yield many options such as use of various materials for condensing covers, hybrid solar still with parabolic concentrator and evacuated tubeand flat plate collector hadbeen tried by researchers. Due to low maintenance cost and simple design flat plat collector is widely used[1]. When flat plate collector solar water heater is integrated with solar still, extra thermal energy is supplied to the basin water from the storage tank and hence rise in water temperature is more when compared to passive solar still. The objectives of the present studies are

1. Thermal modelling of double slope active solar still under natural circulation mode without considering the heat capacity of condensing cover and thermal insulation.
2. To do experimental study of the flat plate solar water heater integrated with the double slope solar still.

India has an abundance of solar energy, many people realized that andadopted solar water heaters. The climatic conditions of the area where the solar water heater [5] is used and the user requirement will decide the FPC solar water heater usage. A survey was taken in solar water heater users in Trichy, Tamilnadu, India over 80% people did not prefer hot water bathing during the summer. In this condition storage tank water will be in higher temperature for a long time, eventually heat losses will be in there. Our present study makes this unusable time of solar water heater for enhancement of productivity in single basin double slope solar still. Eventually the flat plate collector has been made to utilize the solar energy for further heating of the water in natural circulation.

By this work the FPC solar water heater and single basin double slope solar still is integrated to work in a hybrid mode. The hybrid system leads to enhancement in productivity with utilization of hot water. The performance of the hybrid active solar still is tested in various methods and also the theoretical and experimental results are validated.

A.Experimental setup and observations

The schematic diagram of the hybrid single basin double slope solar still is shown in the *Figure1*. The basin area of single basin double slope solar still is $1m^2$and $2m^2$area of flat plate collector is used. The single basin double slope solar still is connected with storage tank of the flat plate collector solar water heater i.e. hot water from the storage tank enters into the solar still under natural circulation. The circulation of water through solar still basin is controlled by a gate valve which is provided in the inlet pipe. A 4mm thick plane glass[14]is used as the condensing cover inclined at an angle 11° to the basin of solar still. The thermocol is used as insulation for the still basin [11].To receive the maximum possible solar radiation, the collector plate is placed in south and inclined at 25° whereas the double slope solar still faces the east-west direction.The solar energy is absorbed by the collector plate and the energy is transferred to the water flowing through the tubes which is then collected in the storage tank. To attain a high absorptivity, black paint is used in the bottom of the solar still surface [3]. For both active and passive mode, the depth of the water should be of 0.02m. At morning 7, experiment should be started. The parameters like solar intensity on the glass cover[9], ambient temperature, distillate yield, temperature of the water and outer condensing cover are measured for continuous 24hours as hourly basis[6].

III. THERMAL MODELING

Energy balance equations for modelling double slope solar still:

Tiwari et al. [2] developed the thermal models for flat plate collectors and for various collectors. The following assumptions were taken into consideration for writing energy balance equations for different components of a double slope active solar still:

1. Thermal capacity of insulating material of wall of solar still andglass covers are neglected.
2. The water inside the basinhas no temperature gradient.
3. The condition of the system is under quasi-steady state.
4. The average temperature of water in upper and lower header of flat plate collectoris equal to the average temperature of water column in the basin.
5. The connecting pipe between the flat plate collector andsolar stillare perfectly insulated

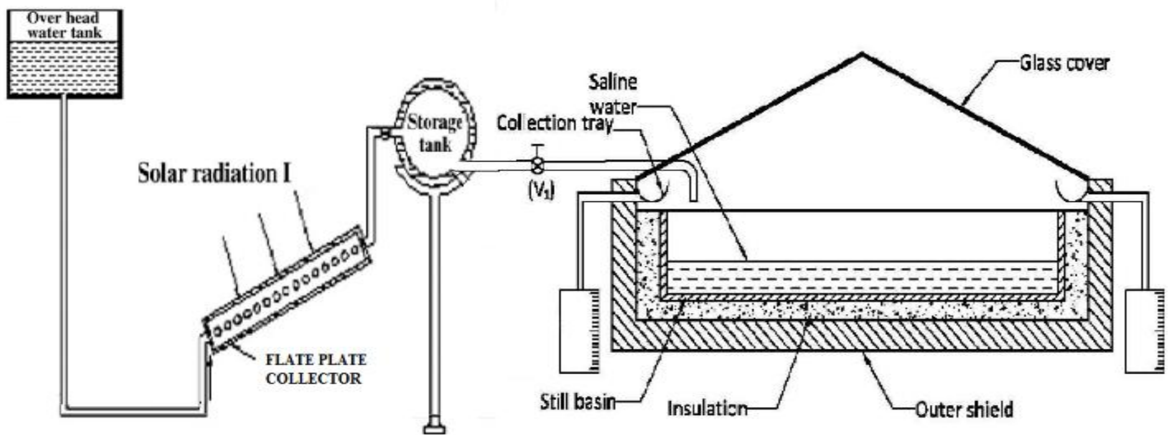

Figure 1 Schematic Diagram of a Double Slope Active Solar Still

Energy balances on east condensing cover:

The energy balance for inner and outer surfaces of east condensing cover are as follows

Inner condensing cover

$$\alpha'_g I_E + h_{tE}(T_w - T_{ciE}) - U_{Ew}(T_{ciE} - T_{ciW}) = \frac{K_g}{L_g}(T_{ciE} - T_{coE}) \quad \ldots..(1)$$

Outercondensing cover

$$h_{aE}(T_{coE} - T_a) = \frac{K_g}{L_g}(T_{ciE} - T_{coE}) \quad \ldots..(2)$$

Where,

$$h_{tE} = h_{cwE} + h_{ewE} + h_{rwE} \quad \ldots..(2a)$$

Energy balances on west condensing cover:

The energy balance for inner and outer surfaces of west condensing covers is as follows

Inner condensing cover

$$\alpha'_g I_W + h_{tW}(T_w - T_{ciW}) + U_{Ew}(T_{ciE} - T_{ciW}) = \frac{K_g}{L_g}(T_{ciW} - T_{coW}) \quad \ldots\ldots (3)$$

Outer condensing cover

$$h_{aW}(T_{coW} - T_a) = \frac{K_g}{L_g}(T_{aw} - T_{coW}) \quad \ldots\ldots (4)$$

Where,

$$h_{tW} = h_{cwW} + h_{ewW} + h_{rwW} \quad \ldots.. (4a)$$

Energy balance for water mass:

The energy balance for basin water is

$$(MC_w)\frac{dT_w}{dt} = (I_E + I_W)\alpha'_W + 2U_{bw}(T_b - T_w) - h_{tE}(T_W - T_{ciE}) - h_{tw}(T_w - T_{ciw}) + \dot{Q}_u \quad \ldots\ldots (5)$$

Where, the rate of thermal energy available from flat plate collector is given by

$$\dot{Q}_u = A_c F'[(\alpha\tau)I_c - U_L(T_w - T_a)] \quad \ldots. (6)$$

With the help of above equations [1–6], one can get the following first order differential equation as,

$$\frac{dT_w}{dt} + aT_w = f(t) \quad \ldots\ldots (7)$$

Where,

$$a = \frac{1}{(MC)_w}\left[\left[\frac{2U_{bw}U_{ba}}{U_{bw} + U_{ba}}\right] + \frac{(p - A_2)h_{tE}}{P} + \frac{(p - B_2)h_{tW}}{p} + A_c F' U_L\right] \quad \ldots\ldots (7a)$$

$$f(t) = \frac{1}{(MC)_w}\left[\left[\alpha'_W + \frac{\alpha'_b U_{bw}}{U_{bw} + U_{ba}}\right] + (I_E + I_W) + A_c F'(\alpha\tau)I_c + \frac{(h_{tE}A_1 + h_{tW}B_1)}{P} + \left(A_c F' U_L T_a + \frac{2U_{bw}U_{ba}}{U_{bw} + U_{ba}}T_a\right)\right] \quad \ldots..(7b)$$

In order to obtain an approximate solution of Eq. ***(7)*** *the following assumptions have been made:*

1. The time interval Δt ($0<t<\Delta t$) is small.
2. The function f (t) is constant, i.e. $f(t) = \overline{f(t)}$ for the time interval Δt, and 'a' is constant during the time interval Δt.
3. The internal convective (h_{cw}), evaporative (h_{ew}) and radiative(h_{rw}) heat transfer coefficients for east and west condensing cover have been evaluated at initial (t=0) water (T_{w0}) and inner condensing cover (T_{ci0}) temperature and assumed tobe constant over 0-t time interval. Hence, $h_{te}$and h_{tw} have been considered constant over 0-t time interval.

After making the above assumptions, Eq. **(7)** becomes first order simple differential equation. The solution of Eq**. (7)** with initial condition, Tw = Tw_0 at t=0, becomes

$$T_w = \frac{\overline{f(t)}}{a}[1 - \exp(-a\Delta t)] + T_{w0}\exp(-a\Delta t) \quad \ldots..(8)$$

And inner and outer glass cover temperatures obtained from Eqs. **(1) – (6)** are:

$$T_{ciE} = \frac{(A_1 + T_W A_2)}{p} \quad \ldots... (9a)$$

$$T_{ciW} = \frac{(B_1 + T_W B_2)}{p} \quad \ldots... (9b)$$

$$T_{coE} = \frac{\frac{K_g}{L_g}T_{ciE} + h_{aE}T_a}{\frac{K_g}{L_g} + h_{aE}} \quad \ldots\ldots(10a)$$

$$T_{coW} = \frac{\frac{K_g}{L_g}T_{ciW} + h_{aW}T_a}{\frac{K_g}{L_g} + h_{aW}} \quad \ldots\ldots(10b)$$

The obtained values of water and inner condensing cover temperature become initial temperature for next set of calculations. Similarly this procedure has been adopted for other set of time interval.

The constants of Eqs. (10a) and (10b) and (11a) and (11b) are given in the appendix. The evaporative heat transfer rate from east and west side of a double slope solar still is given by

$$\dot{q}_{ewE} = h_{ewE}(T_w - T_{ciE}) \quad \ldots\ldots(11a)$$

$$\dot{q}_{ewW} = h_{ewW}(T_w - T_{ciW}) \quad \ldots\ldots(11b)$$

Then the hourly yield can be found as

$$\dot{m}_E = \frac{\dot{q}_{ewE} \times 3600}{L} \quad \ldots\ldots \quad \textbf{(12a)}$$

$$\dot{m}_W = \frac{\dot{q}_{ewW} \times 3600}{L} \quad \ldots\ldots \quad \textbf{(12b)}$$

The total hourly yield of double slope solar still is

$$m_{ew} = \dot{m}_E + \dot{m}_W \quad \ldots\ldots \quad \textbf{(12c)}$$

Table 1: Design Parameters used in Thermal Modelling

Parameters	Value
Design parameters for solar still	
α_b	0.8
α_g	0.05
α_w	0.6
ε_W	0.95
Eg	0.95
A_S	1 m^2
L_b	0.005 m
L_g	0.004 m
K_b	0.035 W/m°C
K_g	0.78 0 W/m°C
C_W	4188 J/kg°C
M	20 kg
σ	5.67×10^{-8} W/m^2 °C
Design parameters for flat plate collector	
A_c	2 m^2
F′	0.8
U_L	6 W/m^2 °C
$(\alpha\tau)_c$	0.6

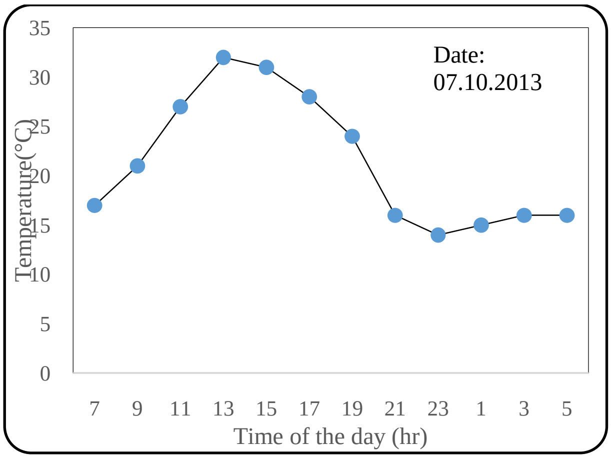

Figure 2 : Hourly variation of ambient air temperature for a day of experiment

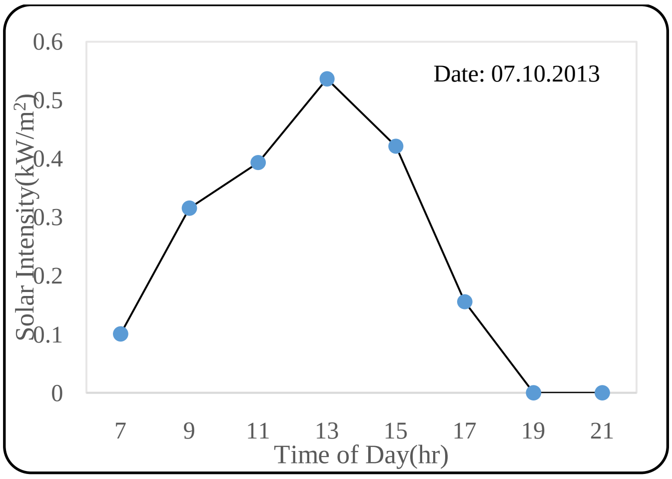

Figure 3 : Hourly variation of solar Intensity for a day of experiment.

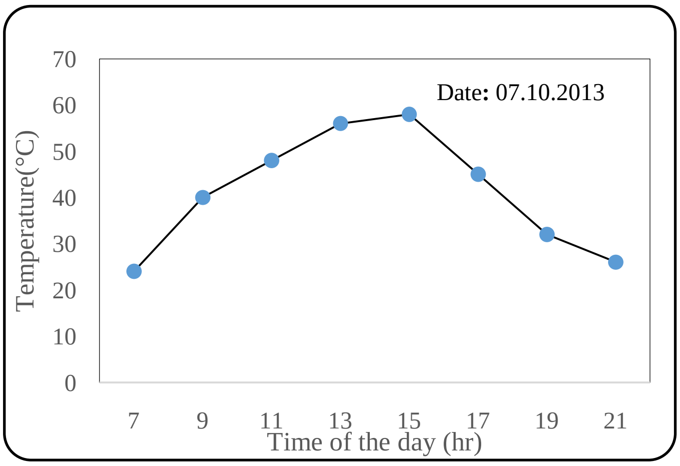

Figure 4 : Variation of water temperature for a day of experiment.

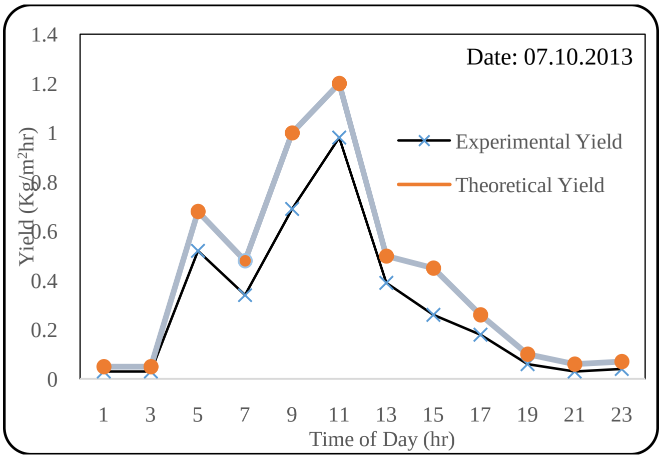

Figure 5 : Hourly variations of theoretical and experimental yield for 0.02 m water depth of a double slope active solar still.

A. Experimental uncertainty

A solarimeter, thermocouples and a measuring jar were used to measure the intensity of the solar radiation, the temperatures at various locations and the distillate output, respectively. The errors that occurred in the measuringinstruments were calculated and are shown in

Table 2.The minimum error that occurred in any instrument was equal to the ratio between its minimum gradation and the minimum value of the output measured.

Table 2 : Specification of the measuring instruments.

Sl. No	Instrument	Range	Accuracy	%Error
1	Solarimeter	0–1200W/m^2	±5 W/m^2	5%
2	Thermocouple	0 °C–700 °C	±1 °C	4%
3	Thermometer	0 °C–100 °C	±0.1 °C	0.4%
4	Measuring jar	0–1000 ml	±10 ml	10%

B. Results and discussion

By energy balance on east and west condensing covers water mass and basin the thermal model of the single basin double slope active solar still was developed. The parameter used such as solar radiation intensity, ambient air temperature used in thermal modelling shown in *Fig. 2&3*also the thermal modelling design parameters shown in *Table 1*. In appendix the expressions for heat transfer coefficient given which is used in the modeling. The hourly yield is evaluated by using the temperature of inner and outer condensing covers and the hourly temperature variation of water also by design and climatic parameters. The data obtained from the theoretical modeling is validated with the experimental results.

IV. CONCLUSIONS

The following conclusions have been attained

1. The double slope active solar still under natural modes gives 77% higher yield when compared to the double slope passive solar still.
2. The climatic, design parameters and heat transfer coefficient, the hourly variation of water, inner and outer condensing cover temperature are used and hourly yield have been evaluated theoretically and compared with the experimental results.
3. The theoretical yield calculated is 4.76 kg/m^{2}and the experimental yield is 3.55kg/m^2.

A. Appendix A

The constants of equations **(9a), (9b), (10a),**& **(10b)** are as follows

$$p = U_1 U_2 - (U_{EW})^2$$
$$U_1 = U_{aE} + h_{te} + U_{Ew}$$
$$U_2 = U_{aW} + h_{tW} + U_{Ew}$$
$$U_{aE} = \frac{K_g h_{aE}}{K_g + h_{aE} L_g}$$
$$U_{aW} = \frac{K_g h_{aW}}{K_g + h_{aW} L_g}$$
$$A_1 = R_1 U_2 + R_2 U_{EW}$$
$$A_2 = h_{tE} U_2 + h_{tW} U_{EW}$$
$$B_1 = R_1 U_{EW} + R_2 U_1$$
$$B_2 = h_{tE} U_{EW} + h_{tW} U_1$$
$$R_1 = \alpha'_g I_E + U_{aE} T_a$$
$$R_2 = \alpha'_g I_W + U_{aW} T_a$$

Heat transfer relationship used:

External heat transfer coefficient

Heat transfer from glass cover to ambient air takes place by convection and radiation. The total heat transfer coefficient from glass cover to ambient is given by

$$h_{aE} = h_{aW} = 5.7 + 3.8V$$

The overall heat transfer coefficient from basin to ambient is given by the equation

$$U_{ba} = \frac{1}{\frac{L_b}{K_b} + \frac{1}{h_b}}$$

The convection, evaporation and radiation are the mode of heat transfer from water mass to inner glass cover. Dunkle's equation for convective heat transfer coefficient is

$$h_{CW} = 0.884 \left[T_w - T_{ciE} + \frac{(P_W - P_{ciE}) T_W}{268.9 \times 10^3 - P_W} \right]^{\frac{1}{3}}$$

and, evaporative heat transfer coefficient is given by

$$h_{ew} = 16.276 \times 10^{-3} h_{cwE} \frac{P_W - P_{ciE}}{T_w - T_{ciE}}$$

Radiative heat transfer coefficient is calculated by

$$h_{rw} = \frac{\sigma (T_w{}^2 + T_{ciE}{}^2)(T_w + T_{ciE})}{\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_w} - 1}$$

Radiative heat transfer between east and west surfaces has also been considered. The Radiative heat transfer coefficient between two glass surfaces is given by

$$U_{EW} = 0.034\sigma \left[(T_{ciE} + 273)^2 + (T_{ciW} + 273)^2 \right] [T_{ciE} + T_{ciW} + 546]$$

B. Glossary

A_s : Surface area of condensing cover (m^2)
A_c : Surface area of flat plate collector (m)
F' : Flat plat collector efficiency factor
h_t: Total internal heat transfer coefficient (W/m^2°C)
h_{cw}:Internal convective heat transfer coefficient (W/m^2°C)
h_{ew}: Internal evaporative heat transfer coefficient (W/m^2°C)
h_{rw}:Internal radiative heat transfer coefficient (W/m^2°C)
h_a: Heat transfer coefficient between outer condensing cover and ambient air (W/m^2°C)
I: Solar intensity on the condensing cover (W/m^2°C)
K_g: Thermal conductivity of condensing cover (W/m°C)
L_g: Thickness of condensing cover (m)
L: Latent heat of vaporization (J/kg)
M: Mass of water in the basin of solar still (kg)
m: Hourly distillate yield (kg/m^2)
P: Partial saturated vapour pressure (N/m^2)
Q_U: Useful thermal energy gain from the collector (W/m^2)
q_{ew}: Evaporate heat transfer rate (W/m^2)
T: Temperature (°C)
U_L: Overall heat transfer coefficient for flat plate collector (W/m^2°C)

U_{EW}: Internal radiative heat transfer coefficient between east and west condensing cover ($W/m^2 °C$)
U_{bw}: Heat transfer coefficient between basin liner and water ($W/m^2 °C$)
U_{ba}: Heat transfer coefficient between basin liner and ambient air ($W/m^2 °C$)
U_a: Overall heat transfer coefficient between outer condensing cover and ambient air ($W/m^2 °C$)

Subscripts

E : East side
W : West side
C : Collector plate
W : Water
Ci : Inner condensing cover
Co : Outer condensing cover
A : Ambient
b : Basin liner

Greek Letters

α_g': Fraction of solar energy absorbed by glass cover
α_b': Fraction of solar energy absorbed by basin water
ε_g: Emissivity of glass cover
ε_W: Emissivity of water
$(\alpha\tau)$: Effective absorptance – transmittance product

REFERENCES

[1] Hepbalsi, A key review on exegetic analysis and assessment of renewable energy sources for a sustainable future, Renewable and Sustainable Energy Reviews 12 (3) (2008) 593–661.
[2] Tiwari.G.N, VimalDimri, Usha Singh, ArvindChel, Bikash Sarkar, Comparative thermal performance evaluation of an active solar distillation system, IJER 31 (2007) 1465–1482.
[3] M. Sakthivel, S. Shanmugasundaram, Effect of energy storage medium (black granite gravel) on the performance of a solar still, Int. J. Energy Res. 32 (2008)
[4] S.A. Lawrence, G.N. Tiwari, Theoretical evaluation of solar distillation under natural circulation with heat exchanger, Energy Convers. Manage. 30 (1990) 205–213.
[5] H.N. Singh, G.N. Tiwari, Monthly performance of passive and active solar stills for different Indian climatic condition, Desalination 168 (2004) 145–150.
[6] V Velmurugan, K Srithar,Performance analysis of solar stills based on various factors affecting the productivity A review Renewable and Sustainable Energy Reviews 15 (2), 1294-1304,2011
[7] V.K. Dwivedi, G.N. Tiwari.Experimental, validation of thermal model of a double slope active solar still under natural circulation mode Desalination 250 (2010) 49–55.
[8] T. Rajaseenivasan, K.KalidasaMurugavel , T.Elango , R.SamuelHansenA review of different methods to enhance the productivity of the multi-effect solar still,Renewable and Sustainable Energy Reviews 17 (2013) 248–259.
[9] Eduardo Rubio-Cerda, Miguel A. Porta-Ga´ndara, Jose´ L. Ferna´ndez-Zayas. Thermal performance of the condensing covers in a triangular solar still, Renewable Energy 27 (2002) 301–308.
[10] FarshadFarahbod et al. Investigation of Solar Desalination Pond Performance Experimentally and Mathematically, Journal of Energy Resources Technology, December 2012, Vol. 134 / 041201-5, ASME.
[11] B.B. Sahooa, N. Sahoob, P. Mahantab, L. Borboraa, P. Kalitaa, U.K. Sahab, Performance assessment of a solar still using blackened surface and thermocol insulation, Renewable Energy 33 (2008) 1703–1708.
[12] Kandasamy et al. Performance correlation for single basin double-slope solar still. International Journal of Energy and Environmental Engineering 2013.
[13] M.R. Rajamanickam et al. Enhanced Performance of a Single Basin Double Slope Solar Still with Thin Film of Water Flowing over the Cover Plate. Journal of Energy Technologies and Policy ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)Vol.3, No.1, 2013.
[14] VimalDimri, BikashSarkara, Usha Singh, G.N. Tiwari.Effect of condensing cover material on yield of an active solar still: an experimental validation, Desalination 227 (2008) 178–189.