

Honeycomb Encapsulated Atmospheric Solar Collector Along with Single Basin Solar Still in Highly Energy Absorbing Weather Condition

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Abstract

Background/Objectives: Solar-still based desalination technique is applied for converting saline water into potable one. In this work have been developed a single slope single basin solar still integrators with honeycomb encapsulated collector to enhance the efficiency of the system. **Methods/Statistical analysis:** Thermal model of expressions for natural circulation of water between the collector and the still, summer and winter, hourly variation of temperature of glass cover, water mass, and basin liner have been derived. A numerical calculation has been made for one of the typical days at Chennai in Tamil Nadu, India which is highly energy absorbing weather condition produced in the still. **Application/Improvements:** It has been used in the system to compare with and without collector energy absorbing weather condition. The summer and winter average efficiency of the still with collector is 48.34%, 49.40% which is 19.04% summer and winter 13.82% higher than the still without collector.

Keywords: Atmospheric Solar Collector, High Efficiency, Honeycomb Structure, Single Basin Solar Still

1. Introduction

Water is life in all its forms. Free energy has been used to get drinkable water from saline water or kitchen water. Solar-based distillation technique is one such model to get quality water. The single slope single basin type solar still has also been developed to increase the thermal efficiency.

Transient analysis of double-basin solar still integrated with collector has been performed¹. The still integrated with solar collector has shown good result of distillate yield compared with the still without integration with collector. Another report has undergone transient analysis of double basin solar still coupled to a flat-plate collector

in the thermosiphon mode and forced circulation mode. It has been concluded that the performance of the system operated with forced circulation is slightly better than that of the system using thermo siphon mode². Further report³ based on the transient analysis of a single basin solar still coupled to a flat-plate collector using thermo siphon and forced circulation mode of operation inferred that the thermo siphon mode should be preferred as it did not need electrical power to run the pump for circulation of water. The formulations for beam and diffuse radiation transmittance of honeycomb array have been proposed report inferred that the utilization of honeycomb arrays have improved the performance of the solar thermal systems significantly⁴.

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In ⁵ concluded that the coupling a flat-plate collector and mirrors fixed to interior sides of a solar still increased the productivity by 36%. In ⁶ analyzed a solar collector equipped with different arrangements of square-celled honeycomb and found that air gaps below and above the honeycomb suppresses the convection losses significantly. In ⁷ fabricated a new hybrid desalination system constituting a Wind Turbine (WT) and Inclined Solar Water Distillation (ISWD) integrated with Main Solar Still (MSS). The system was tested at different water depths (0.01, 0.02, and 0.03m), different water flow rates (25.0, 41.7, and 58.3 ml/min). It is found that the amount of fresh water per square meter from the ISWD is higher than the MSS with about 26.55 to 29.17%. The system is due south could be high as 27.1 to 32.93% when system is tracking the sun.

The influence of the presence of salt on the thermodynamic characteristics of salt water solutions of triple effect desalination system coupled to plane solar collector has been found and concluded that the regulation of feed flow-rate control the salinity significantly⁸. In ⁹ proposed a thermal modeling of a double slope active solar still and thermal efficiency of double slope active solar still is lower than the thermal efficiency of double slope passive solar still. The exergy efficiency of double slope active solar still is higher than the double slope passive solar still. In ¹⁰ studied in both natural and forced convection collector and found that the collector provided the high efficiency that the average air speed in the forced convection was about 21% higher than the natural convection in solar dryers.

In this paper, thermal model of a single slope single basin solar still coupled to a honeycomb encapsulated solar collector has been tested experimentally and analyzed theoretically. The performance of the system has been tested with natural circulation of water between the collector and the solar still. Analytical expressions for summer and winter hourly variation of temperature of glass cover, water mass, and basin liner of the proposed system have been derived. Analytical results are presented and comparison of the performance of still coupled with and without collector has been done.

2. Materials and Methods

2.1 Design of the System

The experimental analysis of solar still in coupled to a honeycomb encapsulated solar collector is shown in the Figure 1.



Figure 1. SExperimental analysis of coupled solar still with FPC.

2.2 Schematic Diagram

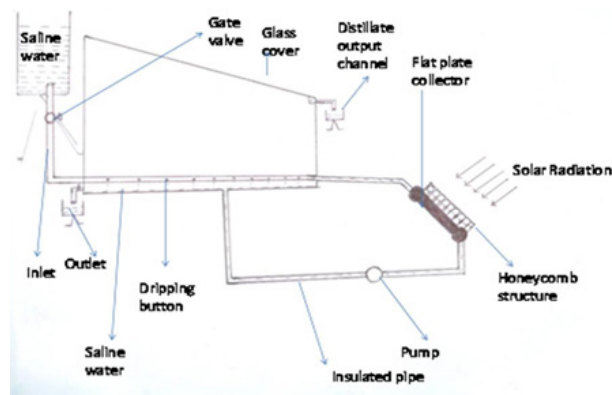


Figure 2. Schematic diagram of coupled solar still with FPC.

The experimental analysis of solar still is shown in the Figures 1 and 2. The still consists of plywood with dimension of 130 x 130 cm and 125 x 125 cm. The inner and outer side in between gap is filled with thermal conductivity of 5 cm. The back wall height is 30 cm and front wall height is 10 cm. The glass plate of thickness 4 mm is used as the glass cover surface is fixed as 11°. The system is made vapor tight with the help of metal putty. The drainage channel is fixed near the front wall to collect the output trickled down to the measuring jar. The still is used in copper sheet in black painted to absorb more solar radiation in the basin. Saline water through the basin area is drop by drop in the basin and special arrangement of heat resistant pipes area fixed to drip button at regular intervals of 10 cm horizontally in the basin. A saline water is allowed to inlet of the

honeycomb encapsulated collector and the output of the collector is coupled to the dripping arrangement of solar still by means of gate valve. The solar collector has the dimension of 110 cm x 110 cm and copper is used as the absorber plate. Copper tubes are painted black and welded on the copper plate in lengthwise manner with a regular interval of 10 cm and output is taken out from the final copper tube. The arrangement has been covered with the honeycomb encapsulated between two transparent glass covers. Saline water from the tank is allowed to flow through the copper tube of the collector and hot saline water is taken out from the output of the collector. Hot saline water is taken out as continuous mode and is given to the inlet of the solar still. Figure 3 and Figure 4 shows the photograph of the honeycomb encapsulated solar collector, encapsulated honeycomb structure in the proposed system. The basin, saline water, glass cover temperature of the still and inlet, outlet water temperature of the collector has been measured by fixing thermocouples wire in calibrated initially. Solar radiation intensity and ambient temperature was measured with solar radiation monitor and digital thermometer.

Experiment analysis was measured out from 6 am to 6 am of 24h duration with compare with and without drip button use in the still for during winter and summer days at Research centre of Physics, *Vel Tech Multitech* Dr. Rangarajan Dr. Sakunthala Engineering College at Chennai in Tamil Nadu, India.

2.3 Solar Still used in Honeycombs Encapsulated Coupled with FPC

Figure 3 is data collection of the honeycombs encapsulated coupled with collector.



Figure 3. Photograph of honeycomb encapsulated coupled with FPC and solar still.

2.4 Group of Honeycomb Structure

Figure 4 is data collection of the group of honeycombs structure.



Figure 4. Photograph of honeycomb structure.

3. Methodology of the Solar Still

3.1 Analysis of the System

The still is using in the energy balance equations follow the assumption:

It is no temperature gradient through the outside in glass cover areas.

- The honeycomb structure used in the still is made full vapor tight.
- The condensing plate and saline water surface are equal in this area.
- The honeycomb structure used the flat plate collector is coupled in natural circulation mode to the still.
- The heat transfer coefficients in honeycomb structure used the flat plate collector of the still are temperature relend.

3.2 The Honeycomb Structure is Transmittance in Form

The honeycomb structure is glass tube of thickness 0.003m, height of 0.07m and diameter of 0.03m with an aspect ratio $H/D < 3$. The honeycomb structure in the flat plate collector helps to natural convection, infrared radiation heat loss and conduction heat loss through the walls. The honeycomb structure is total radiation inside the flat plate collector. To analyze of the honeycomb structures are following the assumption in the Figure 4 shows the corresponding optical path in the structure.

- The solar radiation waves into the glass tube will be

considered as parallel lines entering through the top of the glass tube and reflecting between the two side walls.

- The source entering the glass tube to transmitting will be total converted into the reflected light within the glass tube.

Figure 4 shows glass tubes light transmitted through the honeycomb structure, each every time the solar radiation decays by a fraction τ . The light source from to one glass tube in to another, its intensity decay by a fraction τ_e , which is effective transmittance. The light transmitted through the total fraction of reflected light inside the flat plate collector, or high performance of reflectivity will be

$$\rho_e = \tau_e + \rho = 0.64 + 0.05 = 0.69 \quad (1)$$

3.3 Single Glass Tube in Honeycomb Structure of the System

Figure 5 is data collection of the single glass tube of honeycombs structure.

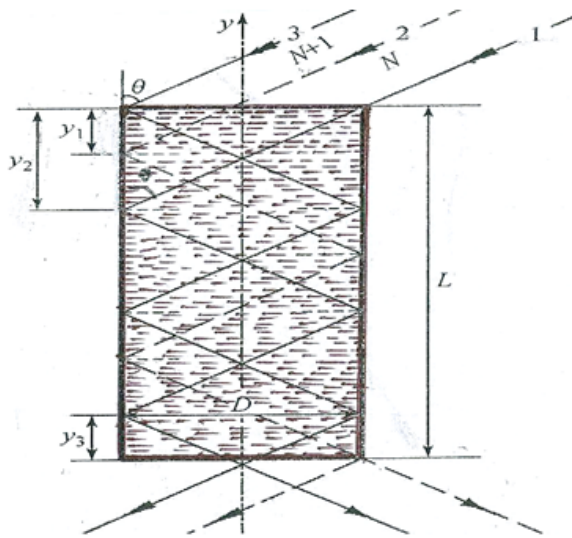


Figure 5. The diagram of Single glass tube in honeycomb structure.

The rays of the glass tube are at angle ' θ ' to be represented by line 1 is incident on a point in the wall after transmitted through the glass tube with distance ' Y_α ' from the opening of the glass tube. It can be derived that

$$Y_\alpha = \frac{D}{\tan \theta} \quad (2)$$

If the height of the honeycomb is ' N ' time the distance ' Y_α ' thus length of the glass tube will be $L = NY_\alpha$ an incident angle of the sunlight changes with time. Thus we have $\frac{L}{Y_\alpha} = \frac{L}{D} \tan \theta$, which is cannot an integer. The light lines coming out of the glass tube, small fraction of lines experience one more reflection through the bottom wall section Y_3 . Since $Y_1 = Y_2$, the ray 2 and 3 must experience $N+1$ times reflection before emerging out of the tube. The fractions of rays are which under goes $N+1$ time reflection can be obtains as $X_1 = \frac{Y_1}{Y_2} = \frac{L - NY_2}{Y_2} = \frac{L}{D} \tan \theta - N$. The fraction of rays having N times reflection can be written as $X_2 = 1 - X_1 = 1 + N - \frac{L}{D} \tan \theta$. Therefore, the effective transmittance through the honeycomb structure can be expressed as a simple formula as

$$\begin{aligned} \tau_e &= (X_1 \rho_e^{N+1} + X_2 \rho_e^N) = \left(\frac{L}{D} \tan \theta - N \right) \rho_e^{N+1} + \left(1 + N - \frac{L}{D} \tan \theta \right) \rho_e^N \\ &= \left(1 + \left(N - \frac{L}{D} \tan \theta \right) (1 - \rho_e) \right) \rho_e^N \end{aligned} \quad (3)$$

We can obtain the effective transmittance of the honeycomb unit in the flat plate collector. The total solar radiation through the collector has been estimated by using the thermal effective transmittance of honeycomb with flat plate collector. Hence the equation can be written as

$$I_{Tot} = I_H - \tau_8 \quad (4)$$

3.4 Energy Balance Equation of the Single Slope Single Basin Still

Heat observe energy balance equation for the still in Glass cover

$$\alpha_g I(t) A_g + h_{11} (T_w - T_g) A_b = h_{21} (T_g - T_a) A_g \quad (5)$$

Heat balance for the still Basin liner

$$\alpha_g \alpha_w I(t) A_b = h_3 (T_b - T_w) A_b + h_b (T_b - T_a) A_b \quad (6)$$

Heat balance for the still Water mass

$$M_w \frac{dT_w}{dt} \alpha_w \alpha_g I(t) A_w + h_3 (T_b - T_w) A_b + h_{11} (T_w - T_g) A_b + \dot{Q}_u \quad (7)$$

$\dot{Q}_u$ is the rate of useful energy transfer into collector values,

$$\dot{Q}_u = F_R A_c [(\alpha \tau)_g I_{Tot} - U_L (T_{wc} - T_a)] \quad (8)$$

Solving the Equations (5) and (6), the equation for T_g and T_b can be written as

$$T_g = \frac{\alpha_g I(t) A_g + h_{11} A_b T_w + h_{21} A_g T_a}{h_{11} A_g + h_{21} A_b} \quad (9)$$

and

$$\frac{dT_w}{dt} + a T_w = f(t) \quad (10)$$

Substituting the equation for T_g , T_b and $\dot{Q}_u$ in Equation (7) and rearranging of this equation can be written in this method

$$\frac{dT_w}{dt} + a T_w = f(t) \quad (11)$$

Where

$$f(t) = \frac{1}{M_w} \left[\alpha_w I(t) A_b + \frac{\alpha_w I(t) h_3 A_b}{h_3 + h_b} + \frac{\alpha_g I(t) A_g h_{11} A_b}{h_{11} A_g + h_{21} A_b} + F_R A_c U_L (T_a - T_w) + \left(\frac{h_b h_3 A_b}{h_3 + h_b} + \frac{h_{11} h_{21} A_g A_b}{h_{11} A_g + h_{21} A_b} + F_R A_c U_L \right) T_a \right]$$

and

$$a = \frac{1}{M_w} \left[h_3 A_b + h_{11} A_b + F_R A_c U_L - \frac{h_3^2 A_b^2}{h_3 + h_b} - \frac{h_{11}^2 A_b^2}{h_{11} A_g + h_{21} A_b} \right]$$

The general solution used in this equation (11) can be written form

$$T_w = \frac{f(t)}{a} + C e^{-at} \quad (12)$$

Initial conditions are used solution of Equation (12)

$$T_w(t=0) = T_{w0} \quad (13)$$

Substituting c in Equation (12), we get

$$T_w = \frac{f(t)}{a} + [1 - e^{-at}] T_{w0} e^{-at} \quad (14)$$

Equation (14), Equation (9), Equation (10) are expression for the temperatures of the water, glass cover and basin temperature of the still respectively.

The instantaneous hourly distillate output in the still is calculated by

$$m_e = \frac{h_{ewg} (T_w - T_g)}{L} \times 3600 \quad (15)$$

The efficiency of the still is expressed as

$$\eta\% = \frac{M_e L}{A_b \int I(t) \Delta t} \times 100 \quad (16)$$

Where

Δt Refers to the time interval and solar intensity is measured.

4. Results and Discussion

Experiments were carried out with the solar still integrated

to with and without collector in the during on March 2014 to June 2015. The measure to one of the four typical days in the month of October and May was used to predict the thermal performance of the system with and without collector on summer and winter days. Hourly variation of the still to a solar radiation and ambient temperature for four experimental days has been depicted in Figure 6. Solar radiation intensity and ambient temperature is same trend and found to be maximum at noon and then decreases gradually till 5pm.

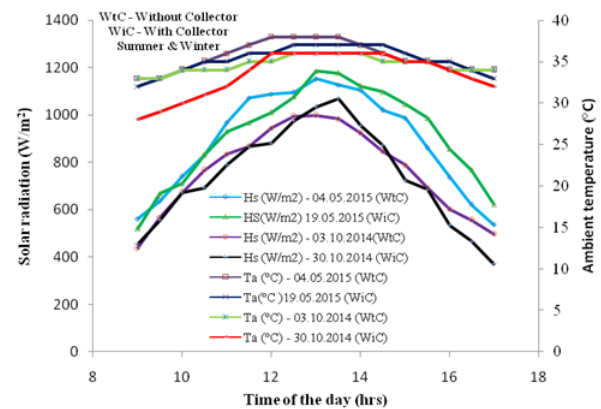


Figure 6. Time variations of solar radiation and ambient temperature with summer and winter.

Figure 7 in the hourly various of the still is coupled to the collector in summer and winter days had shown a maximum distillate yield of 0.430, 0.330 kg/m²hr during 13.00 pm to 13.30 pm and without collector is 0.262, 0.233 kg/m²hr during 13.00 pm to 13.30 pm. The natural circulation mode between the solar still and solar collector had enhanced the performance of the still with auxiliary heat by the collector in addition to the energy received directly. In this during 9 am to 5 pm of the still when coupled with summer and winter the collector is 5.655, 4.7305 kg/m², during 5 pm to 8 am the yield is 1.773, 1.4832 kg/m² and total of 7.4288, 6.2137 kg/m²day is obtained. For the solar still use for without collector alone, summer and winter day-time collection during 9 am to 5 pm is 3.346, 3.2017 kg/m², night-time collection during 5 pm to 8 am is 0.9234, 0.8123 kg/m² and total of 4.2703, 4.014 kg/m² is obtained. The still couple with collector in natural circulation mode has shown a good performance throughout the summer and winter days because of the auxiliary heat provided by the collector during day-time.

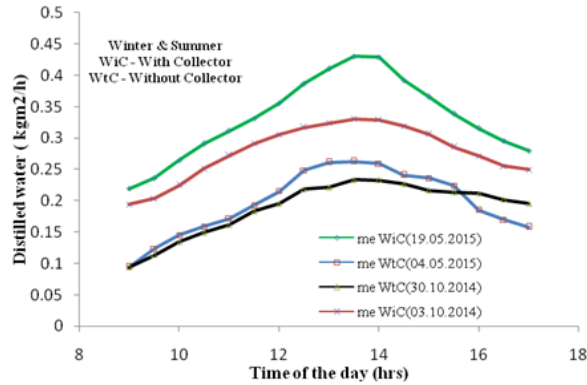


Figure 7. Hourly variation of distillate yield of the still with and without collector.

Figure 8 has shown the hourly variation of summer and winter in efficiency of the still with and without collector. It is a still coupled with collector in higher efficiency during 9 am to 5 pm than the solar still without collector. The average efficiency of the still coupled with the collector summer and winter during 9 am to 5 pm is 48.3306%, 49.4052% and 29.2948%, 35.5787% for solar still without collector alone. It is average efficiency of the still in summer and winter days found to be 19.04%, 13.82%.

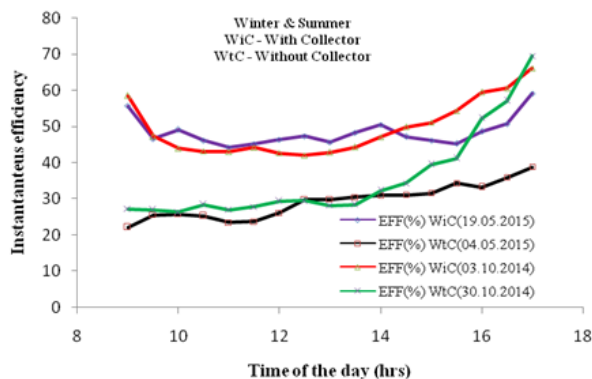


Figure 8. Summers and winter day's hourly variation of efficiency a still with and without collector.

The system expressions for the basin, water and glass cover temperature was measured climatic and design parameters of the still same trend and compared with values are experimental and thermal model. Figures 9 and 10 both modes were measured and calculated value of the basin, water and glass cover temperature with and without coupling of solar collector. The observed values in theoretical and experimental have same

trend throughout the working hours of the system in both modes of operations. Moreover, thermal capacity coupled with honeycomb encapsulated solar collector has significantly enhanced to provide higher production rate by utilizing the energy output of the collector. The continuous through the water of the still was higher differences between water and glass cover temperatures to summer and winter during night-time of honeycomb encapsulated solar collector performance of the solar still.

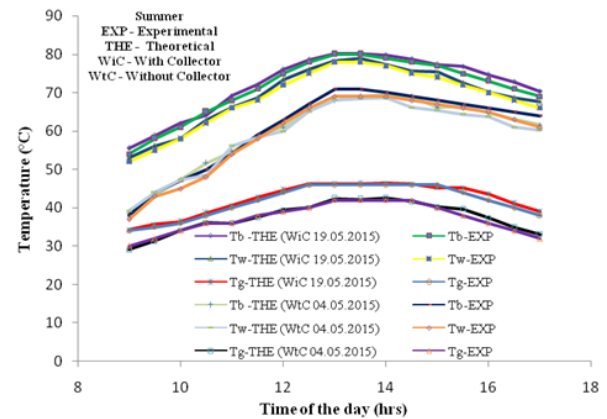


Figure 9. The values of basin, water and glass cover temperature with and without collector in summer days.

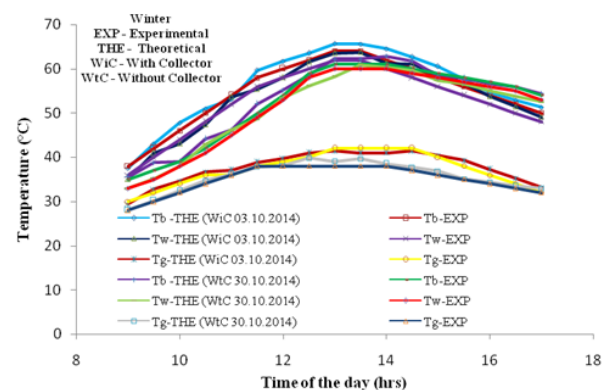


Figure 10. The values of basin, water and glass cover temperature with and without collector in winter Days.

5. Application and Improvements of the Still

The productivity of the FPC coupled solar still in summer and winter days over 24hr cycle for with and without

collector in the basin has been shown in the Figure 11. The experimental and theoretical results of basin liner, water, glass, distillate yield and efficiency have been considered. Figure 11 in the still 24hours used in the whether condition in energy absorber in saline water converted into drinking water produced in the system.

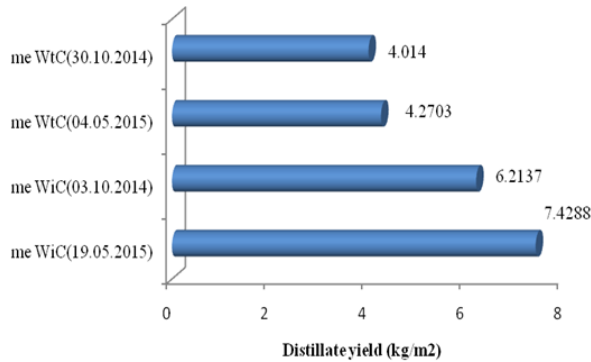


Figure 11. Distillate yield for FPC coupled with solar still.

6. Conclusion

The summer and winter production rate of the still coupled with the honeycomb encapsulated solar collector is higher than the still without collector for all typical working days in the year. The summer and winter average efficiency of the still with collector is 48.34%, 49.40% which is 19.04% summer and winter 13.82% higher than the still without collector. The end of the solar still results is method well suited for pollution free environment.

Nomenclature

A_b Area of the basin in still (m^2)
 A_c Area of the collector (m^2)
 A_a Area of the glass cover (m^2)
 A_w Area of the water surface in the basin (m^2)
 F_R Heat removal factor of the collector
 h_b Bottom heat loss coefficient of solar still $\frac{W}{m^2 \cdot ^\circ C}$
 h_{11} Total heat transfer coefficient from the water surface to the glass cover $\left(\frac{W}{m^2 \cdot ^\circ C}\right)$
 h_{22} Total heat transfer coefficient from the glass cover to ambient $\left(\frac{W}{m^2 \cdot ^\circ C}\right)$
 h_3 Heat transfer coefficient from the basin liner to water $\left(\frac{W}{m^2 \cdot ^\circ C}\right)$
 $I(t)$ solar radiation incident on still $\left(\frac{W}{m^2}\right)$
 I_{Tot} Solar radiation transmitted through honeycomb and reaching the collector $\left(\frac{W}{m^2}\right)$

m_e Hourly distillate output $\left(\frac{kg}{m^2}\right)$

M_w Mass of hot saline water from collector to the basin of the still (kg)

T_a Ambient temperature ($^\circ C$)

T_g Glass covers temperature of still ($^\circ C$)

T_w Water temperature of still ($^\circ C$)

T_{wc} Temperature of collector and water within it $\left(\frac{^\circ C}{m^2}\right)$

U_L Overall heat loss coefficient of the collector $\left(\frac{W}{m^2 \cdot ^\circ C}\right)$

Greek symbols

$(\alpha\tau)_g$ Transmittance-absorptance product

α_g Absorptivity of glass cover

η Thermal efficiency

α_w Absorptivity of water

ρ Reflectance

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8. References

1. Yadav YP. Transient analysis of double basin solar still integrated with collector. Desalination. 1989; 71(2):151–64.
2. Yadav YP, Jha LK. A double-basin solar still coupled to a collector and operating in the thermo siphon mode. Energy. 1989; 14(10):653–9.
3. Yadav YP. Analytical performance of a solar still integrated with a flat plate solar collector Thermosiphon mode. Energy conversion and management. 1991; 31(3):255–63.
4. Kaushika ND, Reddy KS. Thermal design and field experimental of transparent honeycomb insulated integrated-collector-storage solar water heater. Applied Thermal Engineering. 1991; 19(2):145–61.
5. Badran OO, AL-Tahaineh HA. The effect of coupling a flat-plate collector on the solar still productivity. Desalination. 2005; 183(1–3):137–42.
6. Ghoneim AA. Performance optimization of solar collector equipped with different arrangements of square-celled honeycomb. International Journal of Thermal Science. 2005; 44(1):95–105.
7. Eltawil MA, Zhengming Z. Wind turbine-inclined still collector integration with solar still for brackish water desalination. Desalination. 2009; 249(2):490–7.
8. Sow O, Maré T, Orfi J, Adj M. Modeling, simulation in dy-

- namic mode of a triple effect desalination system coupled to a plane solar collector. *Desalination and water Treatment*. 2010; 22(1-3):91-9.
9. Tiwari GK, Dwivedi VK. Experimental validation of thermal model of a double slope active solar still under natural circulation mode. *Desalination*. 2010; 250(1):49-55.
 10. Hematian A, Ajabshirchi Y, Bakhtiari AA. Experimental analysis of flat plate solar air collector efficiency. *Indian Journal of Science and Technology*. 2012; 5(8):3183-7. DOI: 10.17485/ijst/2012/v5i8/30537