Desalination and Water Treatment
www.deswater.com

doi:10.5004/dwt.2019.24091

153 (2019) 54–64
June

Sensitivity analysis of N identical partially covered (50%) PVT compound parabolic concentrator collectors integrated double slope solar distiller unit

Haridwar Prasad[a], Pratap Kumar[b], Rakesh Kumar Yadav[c], Ashis Mallick[a], Navneet Kumar[b], Desh Bandhu Singh[b,*]

[a]*Department of Mechanical Engineering, Indian Institute of technology (ISM) Dhanbad, Jharkhand, India, email: guptanitjamshedpur@gmail.com (H. Prasad), mallick@iitism.ac.in (A. Mallick)*
[b]*Galgotias College of Engineering and Technology, Plot No. 1, Knowledge Park II, Greater Noida-201306, U.P., India, email: pratap.kumar@galgotiacollege.edu (P. Kumar), navneet.kumar@galgotiacollege.edu (N. Kumar), dbsingh@galgotiacollege.edu (D.B. Singh)*
[c]*KCC Institute of Technology and Management, Greater Noida-201306, U.P., India, email: er.rakeshyadava@gmail.com (R.K. Yadav)*

Received 6 March 2018; Accepted 7 March 2019

ABSTRACT

This paper deals with the sensitivity analysis of double slope solar still coupled with N identical partially covered photovoltaic thermal (PVT) compound parabolic concentrator collectors (CPCs) using one-at-a-time (OAT) technique. The proposed analysis has been executed with the help of computational program written in MATLAB for a typical day in the month of May for New Delhi climatic condition. The values of potable water and DC electric power outputs have been computed for different values of mass flow rates, number of collectors, packing factor and water depth. It is observed that the value of potable water output decreases, whereas DC electric power output increases with the increase in mass flow rate for the considered values of number of collectors, packing factor and water depth. It is also observed that the value of DC electric power increases marginally by 0.95% if water depth is increased from 0.07 m to 0.14 m for the considered values of mass flow rate, number of collectors and water depth.

Keywords: Sensitivity analysis; PVT-CPC; Doubleslope solar still; OAT

1. Introduction

The potable water and energy are two basic needs for the survival of human beings on the planet earth; however, they can access only less than 1% of water which is also getting polluted day by day due to various anthropogenic activities. It has been analyzed that 2/3rd population of the world will face a shortage of water by 2025 as reported by UN. The photovoltaic thermal (PVT) coupled active solar distillation can be one of the best alternatives to mitigate the issue of the shortage of potable water and energy.

The solar distiller unit is classified as passive and active solar distiller units. The passive solar distiller unit does not take any heat from outside source. It works on the solar flux falling on the surface of glass cover that acts as the condensing surface. However, it suffers with the problem of low distillate output. This problem of passive solar distiller unit is addressed in active solar distiller unit where external source of heat is integrated with the basin of solar still to add heat to water in the basin. It results in increased temperature of water surface in the basin and higher evaporation is obtained which gives higher distillate output. Active solar distiller unit was investigated by Rai and Tiwari [1] and Zaki et al. [2] for the first time. Since then, a lot of variation in the design of active solar distiller unit has been proposed and results have been presented. Recently, Sahota and Tiwari [3] have presented the detailed review of active solar distiller

*Corresponding author.

1944-3994 / 1944-3986

units. Active solar distiller unit becomes self-sustainable if photovoltaic module is integrated. This property of active solar distiller unit makes it suitable to work independently in remote areas where sunlight is available in abundance. Such an active solar distiller unit was investigated experimentally by Kumar and Tiwari [4] and they reported an enhancement in production of potable water by more than 3.5 times over conventional solar distiller unit. Further, Tiwari et al. [5] and Singh et al. [6] extended their work in which both series connected FPCs were partially covered with PVT. They reported that though the exergy efficiency and overall thermal efficiency values of the system in partially covered PVT-FPCs are better, the thermal efficiency is lower than the system reported by Kumar and Tiwari [4].

Singh [7] made comparative study of single slope passive solar still and single slope solar still (SS) integrated with N identical partially covered (25%) photovoltaic thermal (PVT) flat plate collectors (FPCs) and SS integrated with N identical PVT compound parabolic concentrator collectors (CPCs). He concluded that the life cycle conversion efficiency of N-PVT-FPC-SS was higher by 56.25% and 37.5% than N-PVT-CPC-SS and single slope passive solar still respectively under optimized condition. The reason was attributed to higher exergy output of N-PVT-FPC-SS under optimized condition. Issa and Chang [8] studied experimentally the performance of solar still integrated with evacuated tubes for West Texas climatic condition and reported that the capacity of producing potable water for the active system was 2.36 times higher than passive system due to increased water temperature in basin by approximately 20°C. In a study, Singh [9] reported that the life cycle conversion efficiency of evacuated tubular collector integrated solar still is higher by 75.86% than the similar passive system due to higher exergy obtained from the active system. Fathy et al. [10] studied experimentally the performance of double slope solar still by integrating with parabolic trough collector and reported that the daily efficiency of double slope solar still with tracked parabolic trough collector was 29.86%. Gnanadason et al. [11] investigated experimentally single-basin solar still for increasing the productivity and concluded that the modified copper solar still coupled with vacuum pump was suitable for getting higher amount of distillate. Singh et al. [12] studied single slope solar still coupled with N identical evacuated tubular collectors (ETCs) and reported that the daily energy efficiency for the proposed system was higher by 22.65% than single slope solar still coupled with PVT-CPCs because convection loss does not take place in ETCs.

The existing research shows that the sensitivity analysis of N identical partially covered PVT-CPCs has not been reported by any researchers. In the present work, the effect of variation of mass flow rate, number of collectors and packing factor on potable water and electric power outputs has been reported. The main objectives of the research study can be stated as follows:

To study the effect of variation of mass flow rate on the potable water and DC electric power outputs for the considered value of number of collectors, packing factor and water depth for double slope solar still coupled with N identical partially covered PVT-CPCs.

To study the effect of variation of number of collectors on the potable water and DC electric power outputs for the considered value of mass flow rate, packing factor and water depth for the proposed system.

To investigate the effect of variation of packing factor on the output of the system for the considered values of mass flow rate, number of collectors and water depth for the system under study.

To investigate the effect of variation of water depth on the output of the system for the considered values of mass flow rate, number of collectors and packing factor for the system under study.

2. System descriptions

The schematic diagram of series connected N identical partially covered (50%) photovoltaic thermal (PVT) compound parabolic concentrator collectors (CPCs) integrated double slope solar distiller unit is presented in Fig. 1. The cross sectional side view of partially covered PVT-CPC first collector is presented in Fig. 2. Fig. 3 represents cut section XX′ front view of partially covered PVT-CPC collector. The values of various parameters for the proposed system are presented in Table 1. The value of average wind velocity for the month of May is 4.02 m/s. Here, collectors have been connected in series for getting higher temperature of water in basin which will result in higher potable water output. Due to heat gain in collectors, hot water is obtained at the outlet of Nth collector which is allowed to flow to the basin with an objective of transferring heat to water kept in the basin. The inlet of 1st collector gets water coming from basin with the help of DC motor pump resulting in the formation of closed loop.

3. Thermal modeling

The thermal modeling of the proposed solar distiller unit involves writing energy balance equations for various components of the system and consequently solving these equations to get water and condensing cover/glass cover temperatures in terms of some known parameters such as solar flux, ambient air temperature, heat transfer coefficients (HTCs) and various constants. The assumptions for writing energy balance equations are as follows:

(i) The proposed active distillation system is in quasi steady state condition.
(ii) The ohmic losses between two solar cells are neglected.
(iii) There is no temperature gradient across thickness of solar cell, insulating and glass materials.
(iv) The heat capacity of solar cell, glass covers, absorbing and insulation materials is neglected.
(v) Heat flow has been considered as one dimensional.
(vi) The solar still is vapor leakage proof.
(vii) The level of water in the basin is constant.
(viii) There is no stratification of water in the basin of the solar still and
(ix) The film type condensation occurs on inner surface of the glass cover.

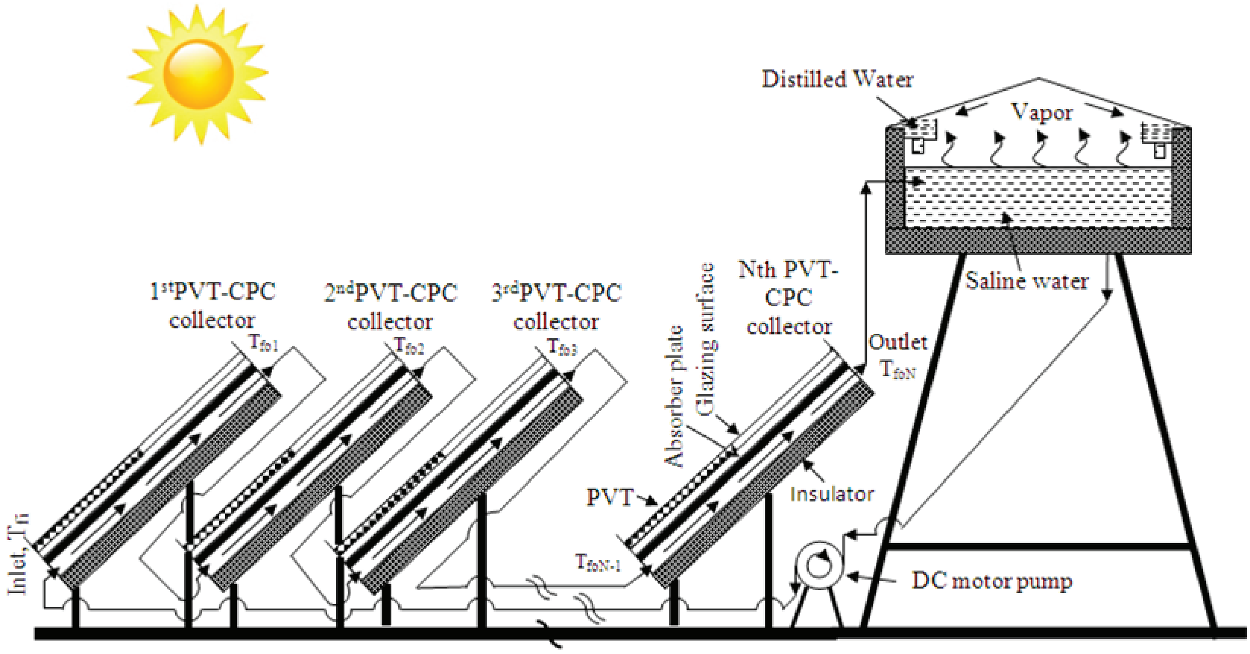


Fig. 1. Double slope solar still integrated with N identical partially covered PVT-CPC collectors.

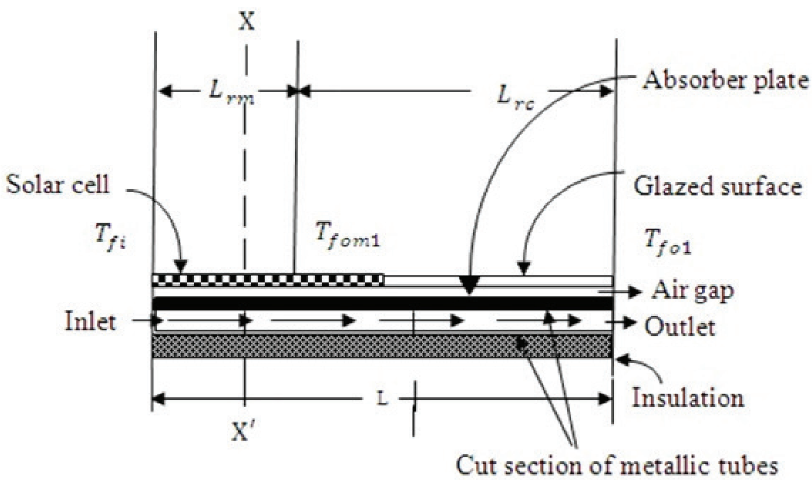


Fig. 2. Cross sectional side view of partially covered (50%) PVT-CPC first collector.

3.1. Useful heat gain $(\dot{Q}_{uN})$ *for series connected N identical partially covered PVT- CPCs*

Following Singh and Tiwar [13] and Tripathi et al. [14], the rate of useful heat gain from series connected N identical partially covered PVT-CPCs and temperature at the outlet of Nth collector can be written as:

$$\dot{Q}_{uN} = N\left(A_m F_{Rm}\right)\left[\left(PF\right)_2\left(\alpha\tau\right)_{meff} I_b\left(t\right) - U_{Lm}\left(T_{fi} - T_a\right)\right] \quad (1)$$

$$T_{foN} = \left[\frac{(PF)_2(\alpha\tau)_{meff}}{U_{Lm}} I_b + T_a\right]\left[\frac{N(A_m F_{Rm})U_{Lm}}{\dot{m}_f C_f}\right] + T_{fi}\left[1 - \frac{N(A_m F_{Rm})U_{Lm}}{\dot{m}_f C_f}\right] \quad (2)$$

The various unknown terms used in Eq. (2) are given in the appendix of Singh and Tiwari (2016). The analytical expression for the temperature dependent electrical efficiency of solar cells (η_{cN}) of a number of fully covered PVT-CPC water collectors is given by Evans [15] and Schott [16] as:

$$\eta_{cN} = \eta_o\left[1 - \beta_o\left(\overline{T}_{cN} - T_o\right)\right] \quad (3)$$

where η_o stands for efficiency at standard test condition and $\overline{T}_{cN}$ stands for the average solar cell temperature of Nth PVT-CPC water collector. The value of $\overline{T}_{cN}$ can be computed following the expression reported by Tripathi et al. [14] in which $T_{fi} = T_w$. The value of hourly electrical energy can be computed as:

$$\dot{E}_{elec} = A_m I_b(t) \sum_1^N (\beta_c \tau_g \eta_{cN}) \quad (4)$$

Here, A_m stands for area of module, $I_b(t)$ stands for hourly beam solar intensity β_c stands for packing factor and τ_g stands for transmissivity of glass. The daily electrical power can be computed by adding hourly electric power for 10 h because solar intensity exists for 10 h only.

3.2. Energy balance equations for double slope solar still

Following Singh and Tiwari [13], the fundamental energy balance equations for various components of double slope solar still can be written. Further, these equations can be solved using Eq. (1) to get water temperature (T_w), east oriented glass cover temperature at the inner surface (T_{giE}) and west oriented glass cover temperature at the inner surface (T_{giW}) as follows:

$$T_w = \frac{\overline{f}(t)}{a}\left(1 - e^{-at}\right) + T_{w0}e^{-at} \quad (5)$$

$$T_{giE} = \frac{A_1 + A_2 T_w}{P} \quad (6)$$

$$T_{giW} = \frac{B_1 + B_2 T_w}{P} \quad (7)$$

Here, t is time and T_{wo} is the temperature of water in basin at time, $t = 0$. The various unknown terms used in Eqs. (3)–(7) are given in the appendix of Singh and Tiwari [13].

After evaluating the values of, T_w, T_{giE} and T_{giW} from Eqs. (5), (6) and (7) respectively, one can evaluate the value of hourly potable water output as:

$$\dot{m}_{ew} = \frac{\frac{A_b}{2}\left[h_{ewgE}\left(T_w - T_{giE}\right) + h_{ewgW}\left(T_w - T_{giW}\right)\right]}{L'} \times 3600 \quad (8)$$

where L' represents the latent heat of evaporation. Its value has been taken as 2400 kJ/kg. The term h_{ewgE}, h_{ewgW} stand for the evaporative heat transfer coefficient from the surface of water to the inner surface of east oriented glass cover and the evaporative heat transfer coefficient from the surface of water to the inner surface of west oriented glass cover. Their values can be computed as:

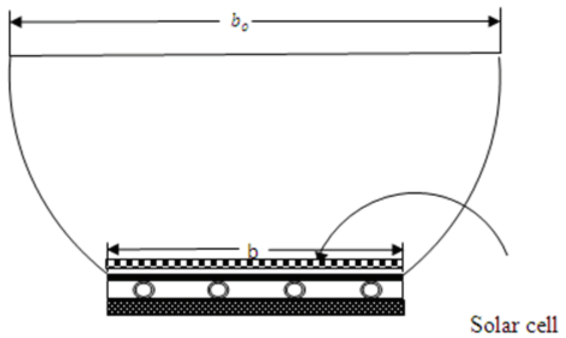


Fig. 3. Cut section XX′ front view of partially covered PVT-CPC collector.

Table 1
Specifications of double slope solar still coupled with N identical partially covered PVT-CPCs

Double slope active solar still			
Component	Specification	Component	Specification
Length	2 m	Material of body	GRP
Width	1 m	Material of stand	GI
Inclination of glass cover	15°	Cover material	Glass
Height of smaller side	0.2 m	Orientation	East-West
PVT-CPC collector			
Component	Specification	Component	Specification
Type and no of collectors	Tube in plate type, N	Aperture area	2 m^2
Receiver area of solar water collector	1.0 m × 1.0 m	Aperture area of module	0.5 m × 2.0 m
Collector plate thickness	0.002	Aperture area of receiver	0.5 m × 2.0 m
Thickness of Copper tubes	0.00056 m	Receiver area of module	0.5 m × 1.0 m
Length of each Copper tubes	1.0 m	Receiver area of collector	0.5 m × 1.0 m
K_i ($W\,m^{-1}\,K^{-1}$)	0.166	F′	0.968
Pipe diameter	0.0125 m	ρ	0.84
Thickness of insulation	0.1 m	τ_g	0.95
Angle of CPC with horizontal	30°	α_c	0.9
Thickness of toughen glass on CPC	0.004 m	β_c	0.89
Effective area of collector under glass	0.5 m^2	α_p	0.8
Effective area of collector under PV module	0.5 m^2	FF	0.8
DC motor rating	12 *V*, 24 *W*		

$$h_{ewgE} = 16.273 \times 10^{-3} h_{cwgE} \left[\frac{P_w - P_{giE}}{T_w - T_{giE}} \right] \tag{9}$$

Here, $$h_{cwgE} = 0.884 \left[\left(T_w - T_{giE}\right) + \frac{\left(P_w - P_{giE}\right)\left(T_w + 273\right)}{(268.9 \times 10^3 - P_{w})} \right] \tag{10}$$

$$P_w = \exp\left[25.317 - \frac{5144}{\left(T_w + 273\right)} \right] \tag{11}$$

$$P_{giE} = \exp\left[25.317 - \frac{5144}{(T_{giE} + 273)} \right] \tag{12}$$

$$h_{ewgW} = 16.273 \times 10^{-3} h_{cwgW} \left[\frac{P_w - P_{giW}}{T_w - T_{giW}} \right] \tag{13}$$

Here, $$h_{cwgW} = 0.884 \left[\left(T_w - T_{giW}\right) + \frac{\left(P_w - P_{giW}\right)\left(T_w + 273\right)}{(268.9 \times 10^3 - P_{w})} \right] \tag{14}$$

$$P_{giW} = \exp\left[25.317 - \frac{5144}{(T_{giW} + 273)} \right] \tag{15}$$

4. Sensitivity analysis

Sensitivity analysis represents how the variation in different input variables of the model affects the variability of the output. It aims at increased understanding of the relationships between input and output variables in a system or model. There are many techniques for conducting the sensitivity analysis; however, one of the simplest and most common approaches involves changing the value of variable/factor one-at-a-time (OAT) to see what effect this produces on the output [17]. It should be noted here that other variables are kept constant while changing one variable. This method of sensitivity analysis is preferred because the modeler immediately knows which input factor is responsible for the failure in the case of model failure [18]. Fig. 4 presents the purification of saline/brackish water to potable water using active solar still. The output and input variables have been shown. Out of the input variables, solar flux and ambient air temperature cannot be monitored as they are highly dependent on weather. Other variables can be monitored. So, the change in output with the change in one input (say mass flow rate) while keeping all other inputs constant can be computed. Similarly, change in output by changing other variables one by one can be computed and the result obtained can be plotted.

5. Methodology

The following methodology has been employed for the sensitivity analysis of double slope solar still coupled with series connected N identical partially covered PVT-CPCs:

Step I

The input data namely solar flux and ambient air temperature for New Delhi climatic condition have been obtained from Indian Meteorological Department, Pune, India. The value of solar intensity for inclined surface at 30° north latitude has been computed using Liu and Jordon formula with the help of computational program in MATLAB.

Step II

The values of T_w, T_{giE} and T_{giW} have been evaluated using Eqs. (5)–(7) respectively. Then the value of hourly potable water output has been computed using Eq. (8).

Step III

The value of hourly electric power output has been computed using Eq. (4). Then, the value of daily electric power output has been evaluated by adding hourly electric power output for 10 h.

Step IV

The values of hourly potable water and daily electric power outputs have been computed for different values of one input parameter while keeping all other parameters constant. The results obtained have been plotted.

Step V

Step IV has been repeated for all input parameters except solar intensity and ambient air temperature.

The flow chart for better understanding the methodology has been drawn as follows:

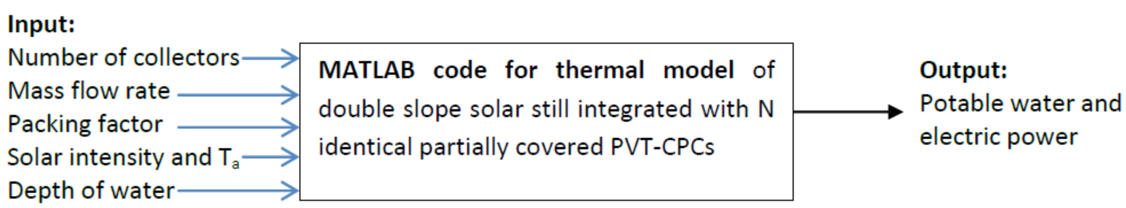
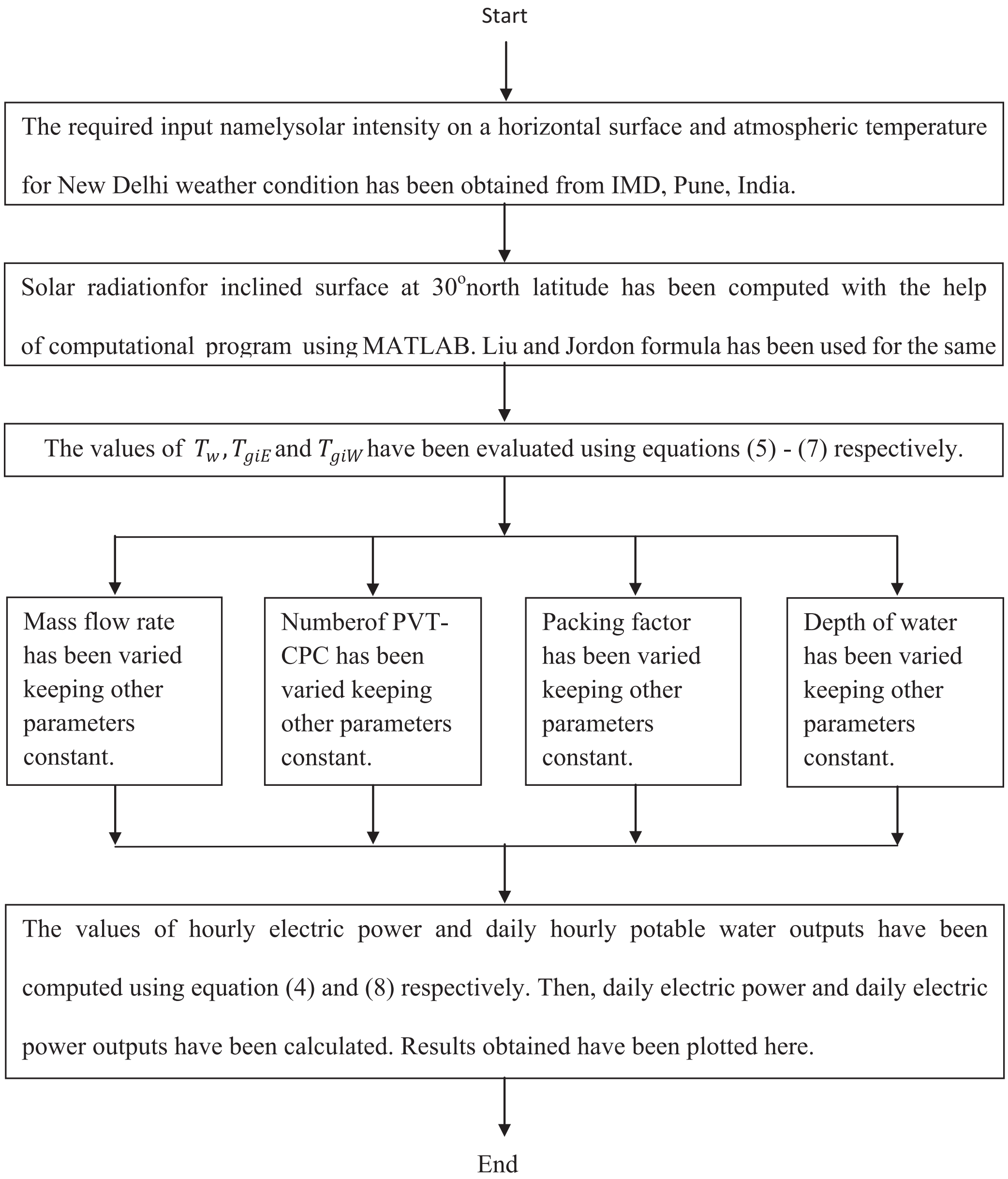


Fig. 4. Purification of saline/brackish water to potable water using active solar still.



6. Results and discussion

The input data namely solar flux, ambient air temperature and air velocity have been fed to the computational program written in MATLAB for carrying out the sensitivity analysis of the proposed system. The values of solar flux and ambient air temperature have been presented in Fig. 5. The output obtained from the computational program is presented in Figs. 6–15.

The hourly variation of potable water output with mass flow rate for the considered values of number of collectors (N = 4), packing factor (β_c = 0.89) and water depth (d = 0.14 m) for double slope solar still coupled with N identical partially covered PVT-CPCs has been represented by Fig. 6. It is observed that the value of hourly potable water output decreases as the value of mass flow rate is increased. It occurs because increased mass flow rate results in higher quantity of water for the given time and hence increase in temperature is lower at the outlet of Nth collector. It results in less increase in temperature of basin water and hence potable water output is less with the increase in mass flow rate. It is also observed that the gap between two consecutive curves of potable water output decreases if mass flow rate is increased and these curves will overlap if mass flow rate continues to increase. It occurs because fluid flowing through the tubes of collectors will get less time to absorb heat from absorber plate with increased mass flow rate and after certain value of mass flow rate a steady state will be achieved. At this state heat absorbed by water is approximately equal to heat gained by absorber plate. Here, it should be noted that increase in mass flow rate has negative effect on potable water output; however, it has positive effect on the daily DC electric power output as shown in Fig. 7.

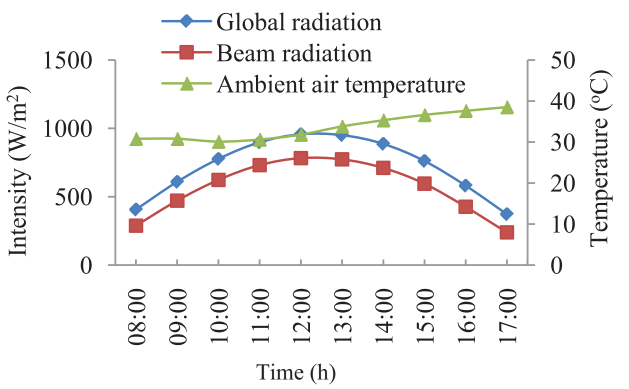


Fig. 5. Hourly variation of intensity and ambient air temperature for a typical day in the month of May.

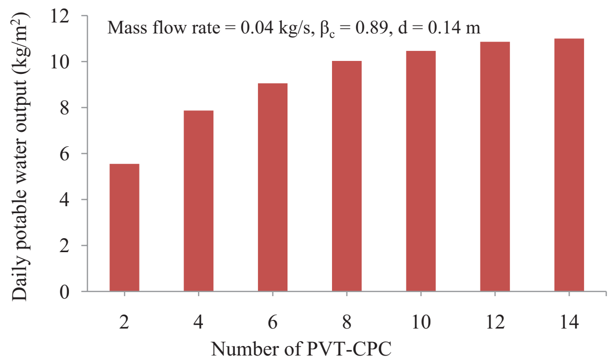


Fig. 8. Variation of daily potable water output with N for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

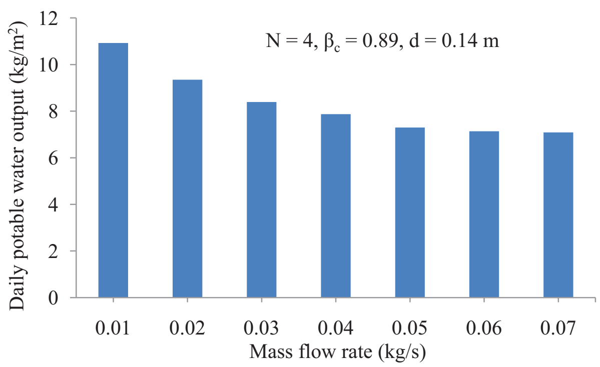


Fig. 6. Variation of daily potable water output with mass flow rate for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

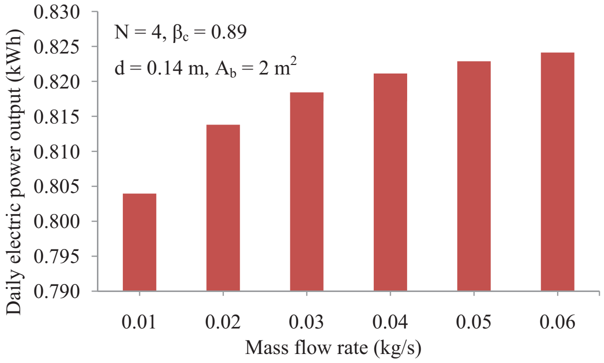


Fig. 7. Variation of daily electric power output with mass flow rate for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

Fig. 7 represents the variation of daily DC electric power output with the variation in mass flow rate for the considered values of number of collectors (N = 4), packing factor a (β_c = 0.89) and water depth (d = 0.14 m) for N identical partially covered PVT-CPCs integrated double slope solar distiller unit. It is observed that the value of DC electric power output increases as the value of mass flow rate is increased. It happens because of the decreased temperature of solar cell with higher mass flow rate. Higher mass flow rate means higher velocity of flow of fluid flowing below PVT which results in increased rate of heat transfer from solar cell to fluid. It is also observed that the increase in DC electric power output is less at higher values of mass flow rate. So, one will have to compromise between potable water output and DC electric power output while selecting the value of mass flow rate of fluid. If main aim is to get potable water, lower value should be preferred. At the same time, if the main aim is to get DC electric power output, higher value of mass flow rate should be preferred.

Fig. 8 represents the variation of daily potable water output with the number of collectors (N) for the considered value of mass flow rate $\left(\dot{m}_f = 0.04kg/s\right)$, packing factor ($\beta_c$ = 0.89) and water depth (d = 0.14 m) for N identical partially covered PVT-CPCs coupled double slope solar distiller unit. It is observed that the value of daily potable water output increases with the increase in the value of N. It occurs because heat added to the water kept in basin increases with increased value of N which results in increased evaporation of water and hence higher potable water output is obtained. It is also observed that the gap between two consecutive hourly potable water output curves decreases as value of N is increased. For example, the gap between potable water output curves corresponding to N = 8 and N = 9 is very less than the gap between potable water output curves corresponding to N = 1 and N = 2. The percentage increase in the value of daily potable water outputs when N increases from 8 to 9 is 5.14%; whereas, the percentage increase in the value of daily potable water outputs when N increases from 1 to 2 is 46.20%. If the value of N is continued to increase, the curves of potable water output either overlaps or the increase in output is not significant. Also, the cost of system will increase as CPC collector is costly and value of water temperature may become higher than 100°C. If the water temperature is higher than 100°C, the thermal model will not be valid. So, N should be selected such that water temperature is less than 100°C which is the boiling point of water. While selecting the value of N, one should also check whether the increase in potable water output is significant and economical or not.

Fig. 9 represents the variation of hourly DC electric power output with N for the considered value of mass

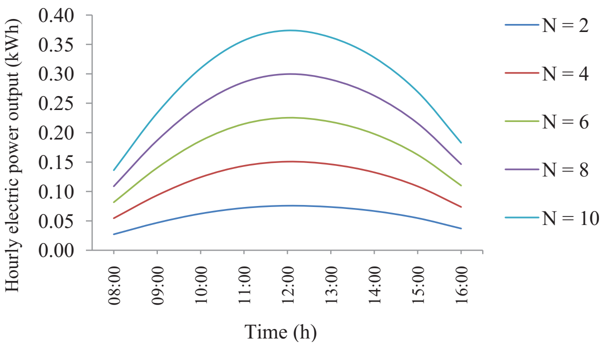


Fig. 9. Variation of hourly electric power output with N for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

flow rate $\left(\dot{m}_f = 0.04 kg/s\right)$, packing factor ($\beta_c$ = 0.89) and water depth (*d* = 0.14 m) for N identical partially covered PVT-CPCs integrated double slope solar distiller unit. It is observed that the value of DC electric power output increases as the value of N is increased. It occurs because the area of photovoltaic module increases with the increase in the value of N and higher amount of solar flux is converted into electric power. It should be noted here that water temperature increases with the increase in the value of N and it may become higher than the boiling point of water (100°C). So, the value of N should be selected in such a way that the temperature of water is less than the boiling point of water as the thermal model is not valid for the value of T_w higher than the boiling point of water.

Figs. 10 and 11 represent the variation of hourly potable water output and daily potable water output respectively with packing factor of PVT for the considered value of mass flow rate $\left(\dot{m}_f = 0.04 kg/s\right)$, number of collectors (N = 4) and water depth (*d* = 0.14 m) for N identical partially covered PVT-CPCs integrated double slope solar distiller unit. It is observed that the value of potable water output decreases as the value of packing factor is increased. It happens because distance between solar cells decreases with the increase in packing factor as more number of solar cells will be there for the given area. Due to decreased distance between solar cells, the amount of solar flux reaching to the water flowing through tubes of collector is less which results in less increase in the value of temperature of water at the outlet of Nth collector and ultimately less increase in temperature of water in the basin. It results in lower evaporation and hence lower potable water output. Fig. 12 represents the variation of hourly DC electric power output for the considered value of mass flow rate $\left(\dot{m}_f = 0.04 kg/s\right)$, number of collectors (N = 4) and water depth (*d* = 0.14 m). It is observed that the value of DC electric power output increases with the increase in the value of packing factor because of increased number of solar cells for the given area and hence higher amount of solar flux is converted into electric power. It should be noted here that increase in the value of packing factor has negative effect on potable water output as shown in Figs. 10, 11 and positive effect on the electric power output as shown in Fig. 12. Hence, one will have to make a compromise between potable water output and DC electric power output while selecting the value of packing factor. If potable water output is the main product and DC electric power output is by product, lower value of packing factor should be preferred and vice-versa.

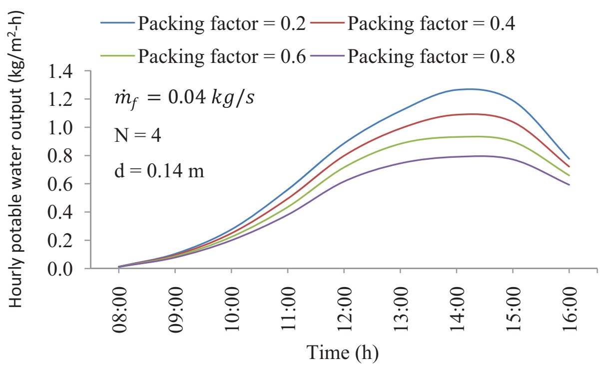


Fig. 10. Variation of hourly potable water output with packing factor for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

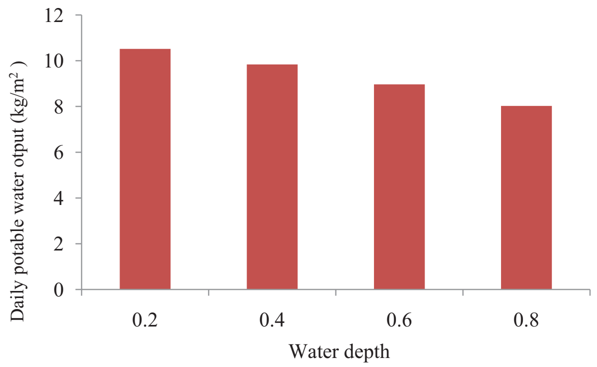


Fig. 11. Variation of daily potable water output with packing factor for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

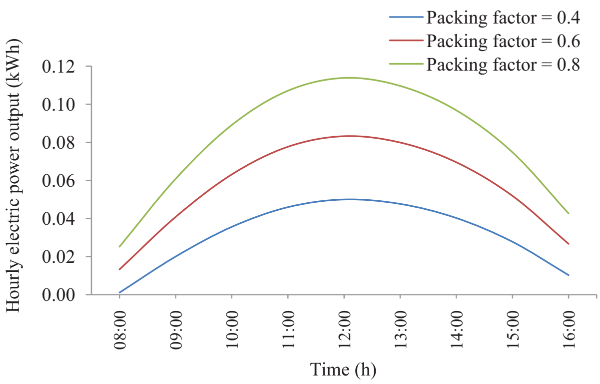


Fig. 12. Variation of hourly electric power output with packing factor for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

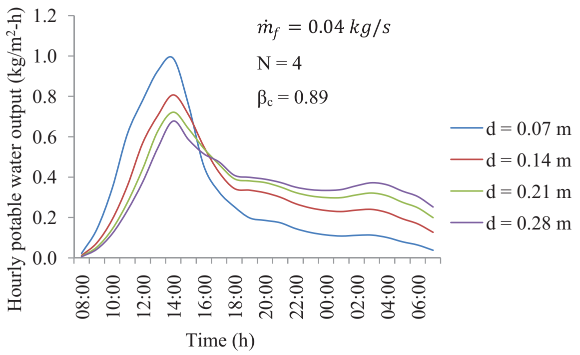


Fig. 13. Variation of hourly potable water output with water depth for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

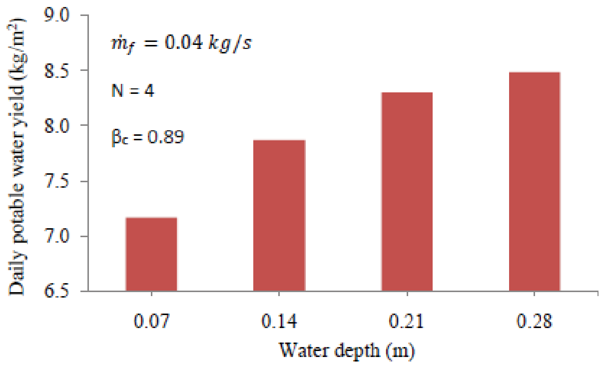


Fig. 14. Variation of daily potable water output with water depth for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

Figs. 13 and 14 represent the variation of hourly potable water output daily potable water output with water depth for the considered values of number of collector (N = 4), mass flow rate $\left(\dot{m}_f = 0.04 kg/s\right)$, and packing factor ($\beta_c$ = 0.89). The value of potable water output has been found to decrease during sunshine hours and to increase during off-sunshine hours as the value of water depth is increased. The value of hourly potable water decreases with the increase in water depth during sunshine hours because the amount of heat added is same but the quantity of water is higher. So, increase in temperature of water in the basin is lower and hence lower evaporation which results in lower distillate output. During off-sunshine hours, the value of hourly potable water output increases with the increase in water depth because of higher sensible heat contained by larger water mass at higher water depth. It has also been observed that the daily potable water output increases with the increase in water depth because increase in distillate output during off-shine hours is higher than the decrease in distillate output during sunshine hours. Hence, higher water depth is advisable.

Fig. 15 represents the variation in daily DC electric power output with water depth for the considered values of number of collector (N = 4), mass flow rate $\left(\dot{m}_f = 0.04 kg/s\right)$ and packing factor (β_c = 0.89). It is observed that the value of daily DC electric power output increases with the increase in water depth because water temperature in the basin is lower which is allowed to pass through tube kept below PVT resulting in increased heat transfer rate due to higher temperature difference between solar cell and water passing through tubes of collectors. Hence, higher depth should be preferred.

Table 2
Values of various input parameters that affect the output of double slope solar still integrated with N identical PVT-CPCs

Variable	Range	Remarks
Number of PVT-CPC (N)	2–14	With the increase in values of N, production of potable water as well as electric power output increase. However, cost of set up and temperature of water also increases. So, one should keep in mind the boiling point of water as well as cost of set-up while selecting value of N. Temperature of water should be less than the boiling point of water. Also, the revenue obtained by selling potable water as well as electric power should justify the cost of set-up. The recommended value of N is 7.
Mass flow rate $(\dot{m}_f)$	0.01 kg/s–0.07 kg/s	With the increase in value of mass flow rate, value of electric power increase but the production of potable water decreases. So, one will have to compromise between electric power output and production of potable water while selecting the value of mass flow rate. Also, one should keep in mind that the temperature of water should not rise above its boiling point. The recommended value of mass flow rate is 0.04 kg/s.
Packing factor (β_c)	0.2–0.8	With the increase in the value of packing factor, the electric power output increases but the production of potable water decreases because less heat will be added to water flowing through copper tubes at increased value of packing factor. The recommended value of packing factor is 0.8.
Depth of water in the basin (d)	0.07 m–0.28 m	With the increase in the value of depth of water, both electric power output and production of potable water increase. So, higher values of depth of water are recommended.

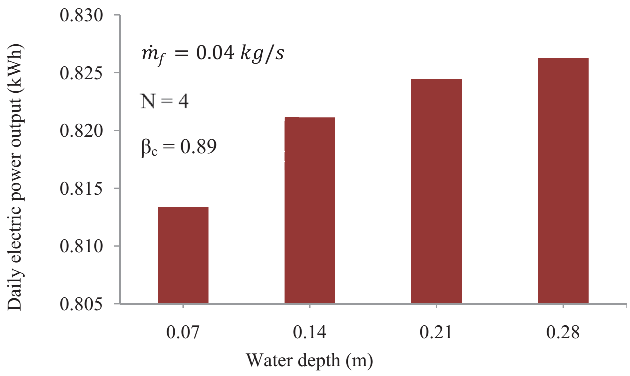


Fig. 15. Variation of daily electric power output with water depth for double slope solar still integrated with N identical partially covered PVT-CPCs for a typical day in the month of May.

7. Conclusions

The sensitivity analysis of double slope solar still coupled with N identical partially covered PVT-CPCs has been carried out using one at-a-time (OAT) method. On the basis of the current research study, the following conclusions have been drawn:

(i) The value of potable water output decreases, but the value of DC electric power output increases with the increase in the value of mass flow rate for the considered values of number of collectors, packing factor and water depth.

(ii) With the increase in the value of the number of collector, the values of both potable water and DC electric power outputs have been found to increase for the considered values of mass flow rate, packing factor and water depth. However, one needs to keep the value of water temperature in the basin as well as in tubes of water collectors below the boiling point of fluid (water) while selecting the value of N during design and installation phases.

(iii) As the value of packing factor increases, the value of potable water output decreases, but the value of DC electric power output increases for the considered values of number of collectors, mass flow rate and water depth. So, a compromise between potable water output and electric power output has to be made while selecting the value of packing factor during design stage.

(iv) Both potable water and DC electric power outputs have been found to increase with the increase in water depth for the considered values of number of collector, mass flow rate and packing factor. Hence, higher water depth should be preferred.

Symbols

A_{gE} — Area of east oriented glass cover
A_{gW} — Area of west oriented glass cover
A_b — Area of basin
A_m — Receiver area of module
b — Width of receiver surface
b_o — Width of aperture surface
CPC — Compound parabolic concentrator
C_f — Specific heat capacity of fluid/water
DC — Direct current
d — Water depth
$\dot{E}_{elec}$ — Hourly DC electric power
HTC — Heat transfer coefficient
h_{ewgE} — Evaporative HTC from water surface to inner surface of east oriented glass cover
h_{ewgW} — Evaporative HTC from water surface to inner surface of West oriented glass cover
h_{cwgW} — Convective HTC from water surface to inner surface of east oriented glass cover
h_{cwgE} — Convective HTC from water surface to inner surface of west oriented glass cover
h — Hour
$I_{b(t)}$ — Beam radiation/solar flux
L' — Latent heat
L — Length of collector
L_{rc} — Length of receiver surface of collector
L_{rm} — Length of receiver surface of module
$\dot{m}_f$ — Mass flow rate
N — Number of collectors
OAT — One at-a-time
PVT — Photovoltaic thermal
$\dot{Q}_{uN}$ — Heat gain by series connected N identical partially covered PVT-CPCs
DS — Double slope solar still
FF — Fill factor
T_{foN} — Temperature at the outlet of Nth PVT-CPC
T_w — Temperature of water in the basin
T_{fi} — Temperature at the inlet of 1st PVT-CPC
T_a — Ambient air temperature
T_{wo} — Temperature of water in the basin at time, t = 0
T_{gi} — Temperature at the inner surface of glass cover
T_{go} — Temperature at the outer surface of glass cover
$\bar{T}_{cN}$ — Average solar cell temperature
T_o — Reference temperature, 25°C
U_{cga} — Overall heat transfer coefficient from cell to ambient through glass
t — Time
β_c — Packing factor
η_{cN} — Temperature dependant electrical efficiency of solar cell
η_o — Efficiency at standard test condition
β_o — Temperature coefficient
τ_g — Transmissivity of glass

References

[1] S.N. Rai, G.N. Tiwari, Single basin solar still coupled with flat plate collector, Energy Convers. Manage., 23(3) (1983) 145–149.
[2] G.M. Zaki, T. El Dali, H. El. Shafie, Improved performance of solar still, Proc. First Arab Int. Solar Energy Conf., Kuwait, 1983, pp. 331–335.

[3] G.N. Tiwari, L. Sahota, Advanced Solar-Distillation Systems: Basic Principles, Thermal Modeling, and Its Application, Springer, Singapore, 2017.
[4] S. Kumar, A. Tiwari, Design, fabrication and performance of a hybrid photovoltaic/thermal (PVT) active solar still, Energy Convers. Manage., 51 (2010) 1219–1229.
[5] G.N. Tiwari, J.K. Yadav, D.B. Singh, I.M. Al-Helal, A.M. Abdel-Ghany, Exergoeconomic and enviroeconomic analyses of partially covered photovoltaic flat plate collector active solar distillation system, Desalination, 367 (2015) 186–196.
[6] D.B. Singh, J.K. Yadav, V.K. Dwivedi, S. Kumar, G.N. Tiwari, I.M. Al-Helal, Experimental studies of active solar still integrated with two hybrid PVT collectors, Solar Energy, 30 (2016) 207–223.
[7] D.B. Singh, Improving the performance of single slope solar still by including N identical PVT collectors, Appl. Thermal Eng., 131 (2018) 167–179.
[8] R.J. Issa, B. Chang, Performance study on evacuated tubular collector coupled solar still in West Texas climate, Int. J. Green Energy, 14 (2017) 793–800.
[9] D.B. Singh, Energy metrics analysis of N identical evacuated tubular collectors integrated single slope solar still, Energy, 148 (2018a) 546–560.
[10] M. Fathy, H. Hassan, M.S. Ahmed, Experimental study on the effect of coupling parabolic trough collector with double slope solar still on its performance, Solar Energy, 163 (2018) 54–61.
[11] M.K. Gnanadason, P.S. Kumar, V.H. Wilson, A. Kumarave, Productivity enhancement of a-single basin solar still, Desal. Water Treat., 55(8) (2014) 1998–2008.
[12] D.B. Singh, V.K. Dwivedi, G.N. Tiwari, N. Kumar, Analytical characteristic equation of N identical evacuated tubular collectors integrated single slope solar still, Desal. Water Treat., 88 (2017) 41–51.
[13] D.B. Singh, G.N. Tiwari, Effect of energy matrices on life cycle cost analysis of partially covered photovoltaic compound parabolic concentrator collector active solar distillation system, Desalination, 397 (2016) 75–91.
[14] R. Tripathi, G.N. Tiwari, I.M. Al-Helal, Thermal modeling of N partially covered photovoltaic thermal (PVT)−Compound parabolic concentrator (CPC) collectors connected in series, Solar Energy, 123 (2016) 174–184.
[15] D.L. Evans, Simplified method for predicting PV array output, Solar Energy, 27 (1981) 555–560.
[16] T. Schott, Operational temperatures of PV modules, Proc. 6th PV Solar Energy Conference, 1985, pp. 392–396.
[17] D.M. Hamby, A review of techniques for parameter sensitivity analysis of environmental model, Environ. Monit. Assess., 32 (1994) 135–154.
[18] A. Saltelli, P. Annoni, How to avoid a perfunctory sensitivity analysis, Environ. Model. Software, 25 (2010) 1508–1517.