STUDY OF THE OPTICAL PERFORMANCE OF A SOLAR STILL WITH A DOUBLE SLOPE AND A GREEN HOUSE EFFECT

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1. ABSTRACT

This study is mainly based on the observation of a solar still with a double slope, set up in the area of Constantine (east of Algeria).

A theoretical approach is used to simulate the behaviour of some thermo physical parameters related to the solar-still and as well as the temperature difference between the evaporation surface and that of the condensation and their change in time as well as their effects on the system performance during a sun shining period (selected period).

The mathematical resolution of the system allows describing energetic balance of each component of the solar still. This leads to the following conclusions (observations):

The daily production of the distilled water increases with the wind velocity, where it can reach a critical value of 10 m/s, giving a maximum production.

Hourly and daily productions are related to the inclination angle of the collector. An optimum angle of 10° enhances the evaporation-condensation phenomenon, where better productions can be obtained.

A large temperature difference between the glass and the water surface (the absorber) improves the daily production; this is related to the importance of solar radiation during the day.

The system gives higher productions and higher efficiencies in the case of shallow waters.

A solar still with a double slope is characterised by its better collection of solar radiation, giving a high performance of the system (system production).

Finally, optimised thermo physical parameters as well as a better conception lead to a good comprehension of the main factors and parameters that are in relation with the system performance (solar-still performance).

Key words: solar still, optimisation, performance.

2. INTRODUCTION

In order to overcome the low productivity from conventional distillers, many techniques (processes) have been developed such as systems using external condensers as well as systems performing with a good insulation, in order to minimise heat losses. Whereas, there are other systems using pre-heated and saline water prior to its introduction into the solar still [1].

This study proposes a theoretical model of a solar still with a double slope (double exposure) and having a green house effect. The aim of this study is to increase the system production (distilled-water production) through a better exposure of the collectors in order to intercept a maximum solar radiation. One of the characteristics of this model (novelty of this work) is to increase the evaporation rate by increasing the temperature difference till the obtention of optimised values between the saline water in the basin (absorber) and the glazing cover (collector), leading to an increase of distilled water.

All these associated phenomena take place as a result of the influence of certain thermo physical parameters related to the climate as well as to the system design: inclination angle, type of insulation, water depth in the basin, wind velocity, global solar radiation and of course the temperature.

3. THEORETICAL STUDY AND MODELLING SYSTEM

A system of equations governing the solar-still performance is set up having a maximum contribution of internal and external heat, by radiation, convection, conduction and evaporation respectively.

This system of equations brings out the variation of the thermo physical parameters as well as their effect on each component of the solar still.

The proposed model consists of a simple solar still with a double exposure (slope) and with a green-house effect (figure 1). This considered system is experienced in the area of Constantine (north-east of Algeria), which is characterised by the following geometric and geographical phenomena [2]: a latitude of 36° 22 to the north, a longitude of 6° 37 to the east, a maximum temperature of 41° c and a maximum wind velocity of 28 km/h corresponding to 22nd July which is selected as a pseudo representative day for our simulation, as it is considered as the hottest day during the last decade (the meteorological journal : underground). The aim of this study consists also to show the different temperatures related to the solar-still components, in a considered time of the day (from 7.00 hours to 19.00 hours). The solar still is cut up into fictive slices (grids). This cut is realised in the direction of the incident solar radiation (I), as from the high to the low position. We set up then the overall global heat transfers which take place at each component of the system (node) (figure 2).

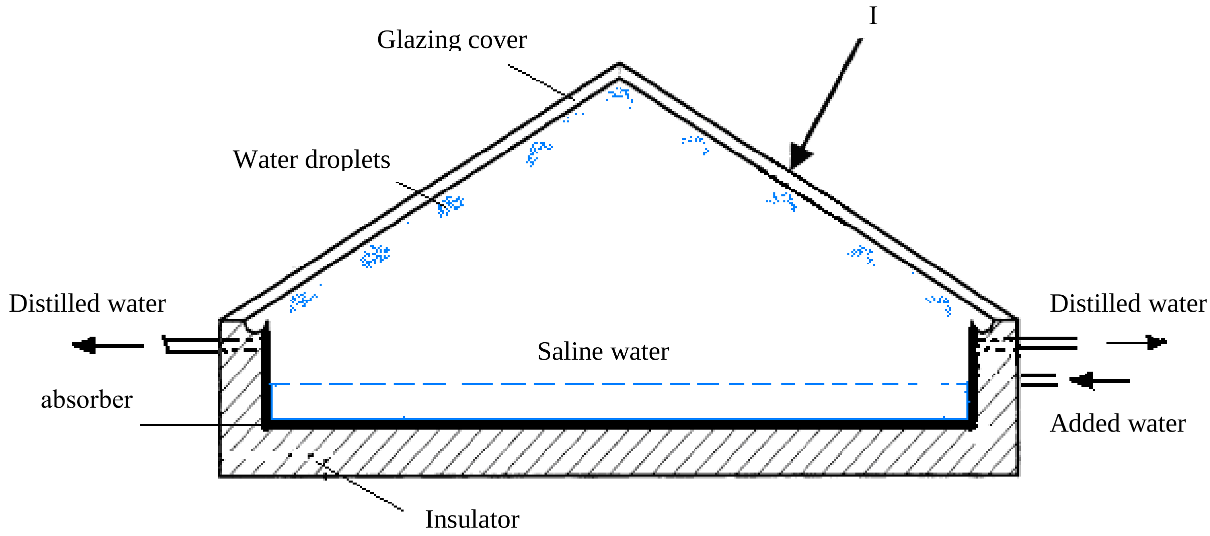

Figure1. Solar still with double exposure and a green-house effect

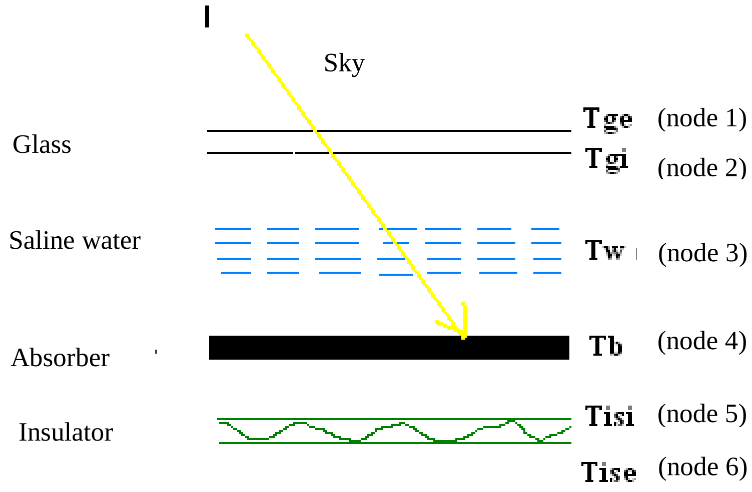

Figure 2. Different nodes considered in the grid of a simple solar still with a double exposure and a green-house effect

The simulation is carried out from an initial time “t_0” and affecting an initial temperature to each component of the solar still with a considered step time of one hour.

The overall global heat transfers of any solar still can be established through different coefficients of heat exchange, during internal and external heat transfer of the solar still, where we find mainly coefficients related to heat exchanges by conduction, convection, radiation and evaporation respectively.

Dunkle correlations [3] are applied in order to simulate the global coefficient of internal heat exchange (h_1) and external heat exchange (h_2):

$$h_1 = h^r_{wg} + h^c_{wg} + h^{év}_{wg} \tag{1}$$

$$h_2 = h^r_{gc} + h^c_{ga} \tag{2}$$

Where:

h^r_{wg}, h^c_{wg} and $h^{év}_{wg}$ represent the coefficients of heat exchange between the glass (collector) and the water (absorber) by radiation, convection and evaporation respectively.

h^r_{gc} and h^c_{ga} represent the coefficients of heat exchange between the glass and the external environment by radiation and convection respectively.

4. SOLAR STILL PERFORMANCE

The performance of any solar still is characterised by its global and internal efficiencies [4]:

- Global efficiency:

$$\eta g(\%) = \frac{Q^{év}{wg}}{I_G \times Ag} = \frac{m_d \times Lv}{I_G \times Ag} \tag{3}$$

- Internal efficiency:

$$\eta i(\%) = \frac{Qévwg}{qwater} = \frac{md \times Lv}{qwater} \tag{4}$$

Where:

md- is distilled water-flow;

Lv- is the latent heat of water vaporisation;

Ag- is the glass surface (collector surface);

I_G- is the intensity of global solar radiation;

Q- is the heat flow used for water evaporation;

q_{water}- is the quantity of heat absorbed by water.

5. RESULTS AND DISCUSSION

Among the climatic factors that have a direct effect on the solar-still production (performance), there is wind velocity, where, in our case, its values are taken according to the recorded day (reference day) corresponding to 22nd July 2005. As the wind velocity is considered as a cooling fluid for the condenser, its increase leads then to the increase of the coefficient of heat exchange by convection which, in its turn, lowers the temperature of the external face of the glass (Tge) and then increases the distiller production (figure 3).

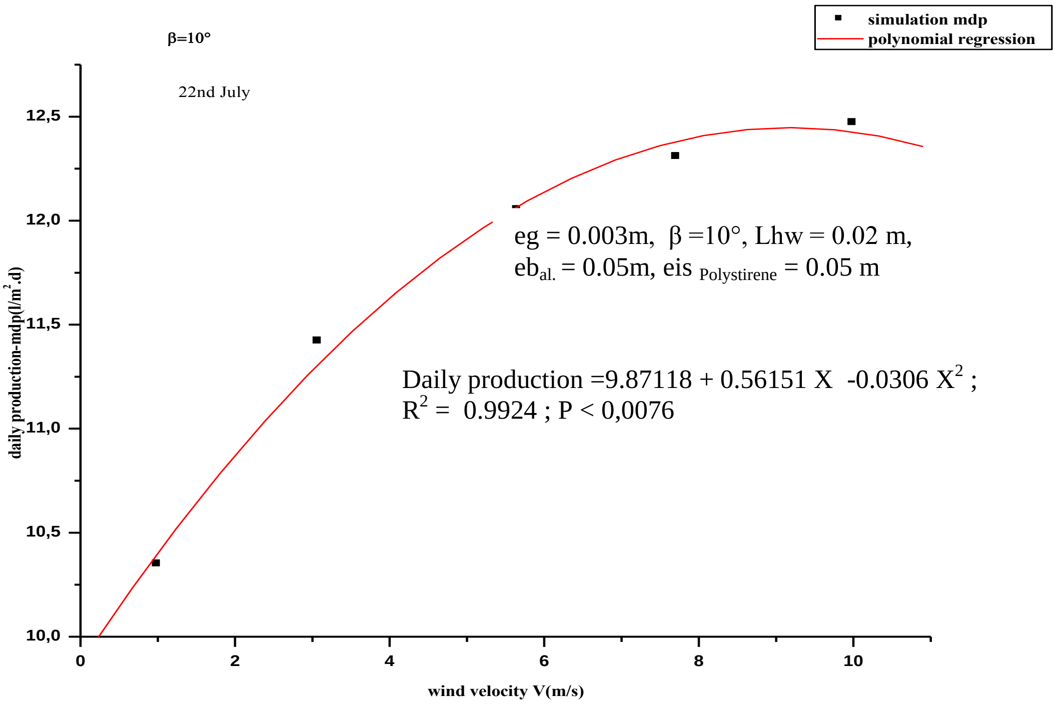

Figure 3. Daily production change with wind velocity

The daily production of the distilled water reaches its maximum when the inclination angle of the collector (β) is at 10°, with a wind velocity of 10 m/s (figure 4). The obtained results seem in agreement with other results carried out before [5, 6, 7, 8, and 9]. It is noticed then that production of distilled water becomes insignificant for higher values of wind velocity.

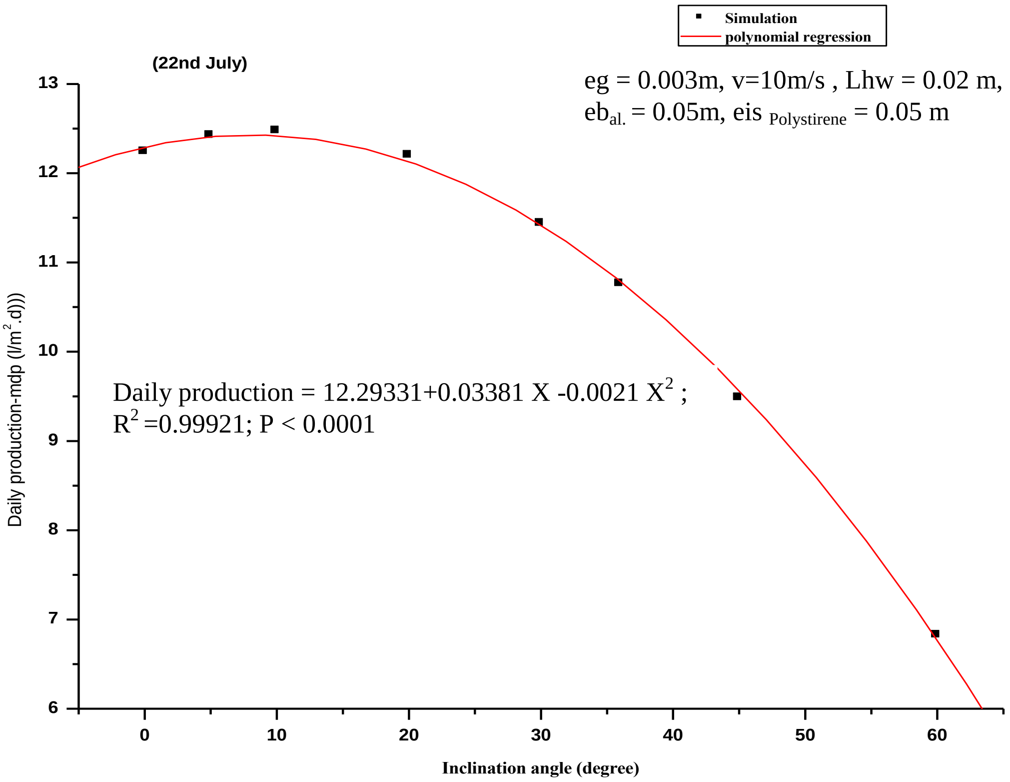

Figure 4. Daily production change with the inclination angle

Tests were carried out for different water depths in the basin, where we observed that the daily water production starts to increase till reaching its maximum at minimum water depths. In others words, at a minimum depth of the basin water (Lwh = 0.02 m) and an optimum inclination angle (β = 10°), the solar-radiation intensity reaches its maximum value between 11.00 hours and 15.00 hours. In this case, heat transfers by radiation, convection and evaporation can be accomplished in the same time. All these factors, when combined together, and added to the increase of the temperature difference (ΔT) between the basin water (condenser) and the inner face of the glass, may render the increase of the hourly production of the distilled water (md) possible. We notice also that this production increases gradually with the increase of ΔT (figure 5). It seems lower at the beginning of the solar still performance (during the morning) and from then reaches its high levels. The system can then improve its performance in terms of distilled water, followed by an important production of the energy by evaporation. These results seem in agreement with other studies carried out previously [5, 6, 7, 8 and 9].

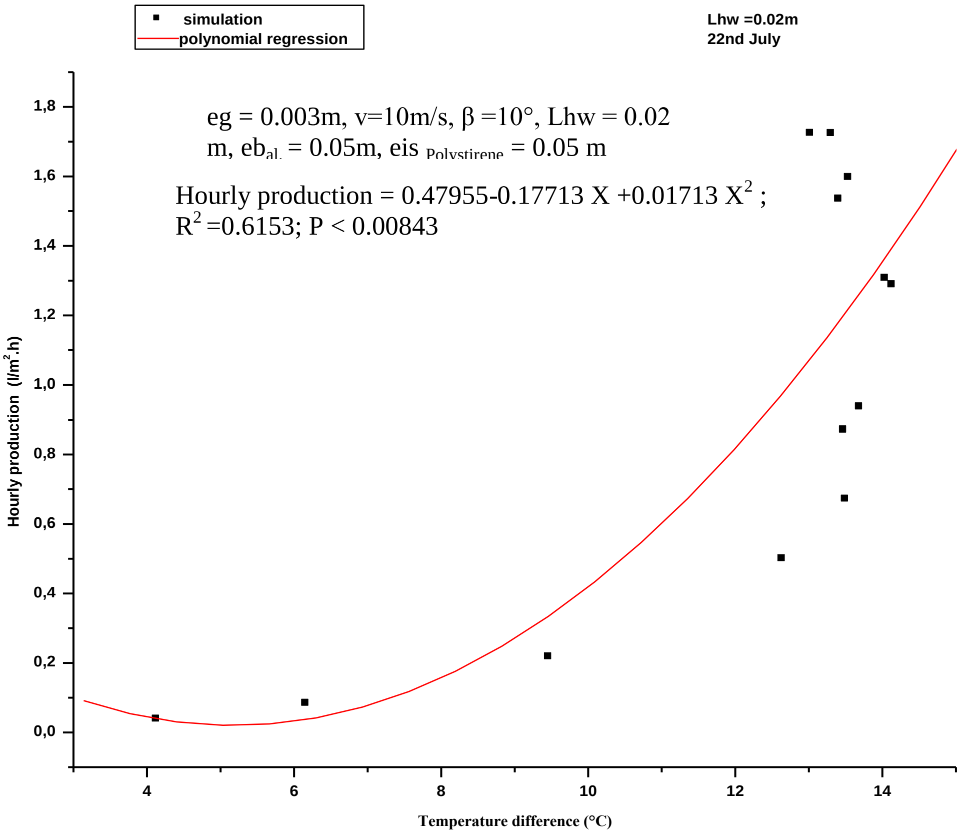

Figure 5. Hourly production change with temperature difference ΔT

The thermal inertia becomes higher when water depth in the basin is important. In this case and in order to decrease this inertia, we have to lower the water depth (Lhw), which lead to the increase of the temperature difference (ΔT).As a result, we can have a better evaporation and of course a better production of distilled water. We notice also that the temperature difference (ΔT) decreases when the water depth (Lhw) increases (figure 6). It is also noticed that ΔT increases with the increase of wind velocity. This result agrees with different studies carried out before [5, 10].

Finally, we find that global and internal efficiencies (η_g and η_i) are high only at the beginning and at the end of the day, where they reach, in the case of global efficiency, 2.56 and 10.63 % respectively and in the case of internal efficiency 3 and 12.48 % respectively, whereas they are low during the rest of the day (table 1). This can be explained that solar radiation intensity reaches its maximum because of the conserved heat by the basin water, in other words, there is an effect of thermal inertia.

The internal efficiency is also found higher than the global one, due to the amount of the absorption of the global-radiation intensity by the glass and the brine.

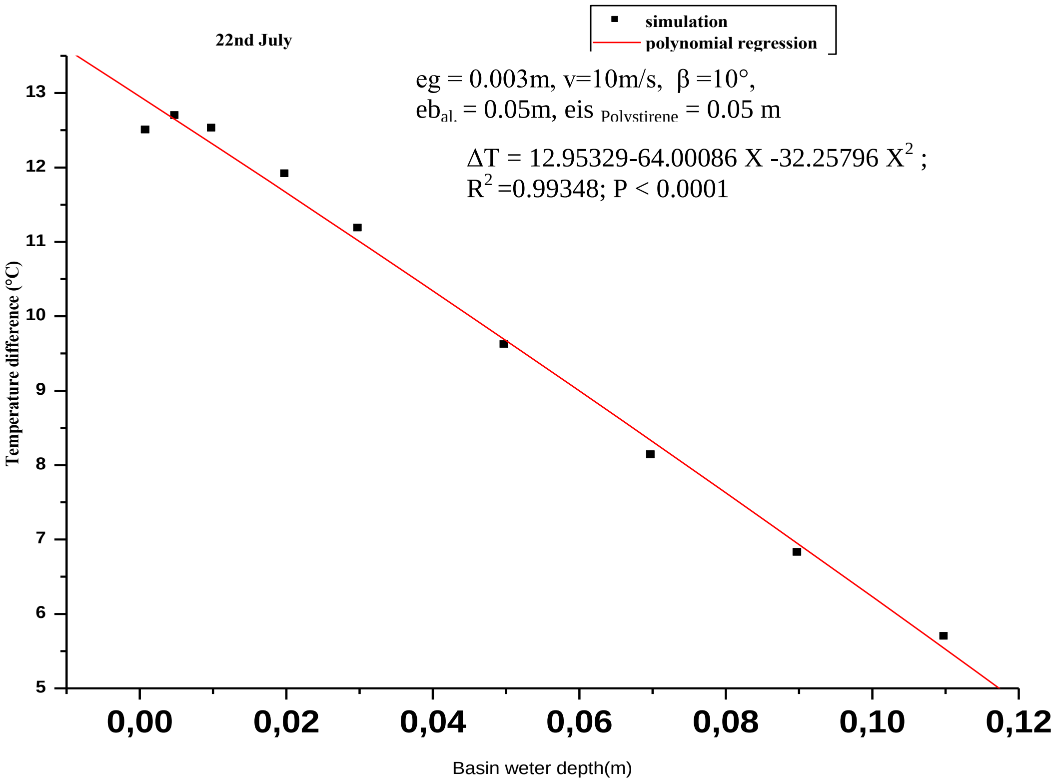

Figure 6. Temperature difference change with basin water depth

Table 1. Variation of global and internal efficiencies (in percent) with time

TL (h)	Ta (°c)	I_G (w/m2)	**ng (%)**	**ηi (%)**
7	28	171.341	2.56	3.00
8	31	380.4752	1.15	1.35
9	34	588.2839	0.74	0.87
10	36	765.4906	0.57	0.67
11	39	894.5992	0.49	0.57
12	39	964.5296	0.45	0.53
13	40	969.6103	0.45	0.53
14	41	909.4358	0.48	0.57
15	40	788.8642	0.56	0.65
16	40	618.1145	0.71	0.83
17	38	413.5361	1.06	1.24
18	38	201.7622	2.17	2.55
19	36	41.20965	10.63	12.48

6. CONCLUSIONS

The use of solar energy for water desalination becomes necessary in the case of Algeria, as there is a lack of water for domestic and industrial purpose in one hand and the existence of a large period of solar radiation during almost all the year in another hand. In this case, we propose in this study a model of a solar still with a collector having two slopes (double exposure). The system collects a maximum of solar radiation if, of course, it is well directed, allowing the obtention of a better production of distilled water.

In order to render the system well performed, we optimise in this study some thermo physical parameters which have a direct effect on its performance. The obtained results allow concluding that:

A wind velocity going up to 10 m/s, affects directly the production of distilled water and beyond this value (10 m/s), this production becomes insignificant.

Taking into consideration the angle of the inclination of the collector (β) seems to be justified, where an optimum angle of 10° will give a better production of distilled water, where In this case, a supposed horizontal collector is rejected.

An increase of the temperature difference (ΔT) between the collector and the basin water will bring the production of distilled water (solar-still performance) at its maximum.

The ideal depth of the basin water is at its minimum value, where in our case a water depth of 0.02 m will give a better production of distilled water.

An absorber made of aluminium covered by a black and thick layer in order to give a better absorption of the solar radiation, leads to a better production of distilled water.

- An insulator made of polystyrene and reinforced by a metallic or a wooden support will limit heat losses.

7. REFERNCES

1. R**.N. Morse, W.R.W. Read (1968),** "A rational basis for the engineering development of a solar still", Sol. Energy 12, pp. 5.

2. **Michel Capderon, (1985),** "Atlas solaire de l'Algérie", OPU, Algiers (Algeria).

3. **R.V. Dunkle, (1961),** "Solar water distillation: the roof type still and a multiple effect diffusion still", International developments in heat transfer, A.S.M.E, part V, section A, pp. 895.

4. **Zayouti et al, (2002),** "Amélioration de la condensation de la vapeur d'eau dans les distillateurs solaire", fier (Tétouan), Morocco.

5. **A. A. El Sebaii, (2004),** "Effect of wind speed on active and passive solar stills", Energy Conversion and Management 45, 1187–1204.

6. **P.I. Cooper, (1969),** "Digital simulation of transient solar still performance", Sol. Energy 12, 313-331.

7. **A.K. Rajvanshi, (1981),** "Effect of various dyes on solar distillation", Sol. Energy 27, 51–65.

8. **S.H. Soliman, (1972),** "Effect of wind on solar distillation", Solar Energy 13, 403–415.

9. **M.A.S. Malik, V. Tran, (1973),** "A simple mathematical model for predicting the nocturnal output of a solar still", Sol. Energy 14, 371–385.

10. **A. Kaabi, N. Smakdji, (2007),** "Impact of temperature difference (water-solar collector) on solar-still global efficiency", Journal of Desalination 209, 309-316.

NOMENCLATURE

Ag : Glass surface (collector surface) (m^2)

e_g : Glass thickness (m)

h^r_{wg} : Coefficient of heat exchange between the glass (collector) and the water (absorber) by radiation ($w/m^2.°c$).

h^c_{wg} : Coefficient of heat exchange between the glass (collector) and the water (absorber) by convection ($w/m^2.°c$).

$h^{év}_{wg}$: Coefficient of heat exchange between the glass (collector) and the water (absorber) by evaporation ($w/m^2.°c$).

h^r_{gc} : Coefficient of heat exchange between the glass and the external environment by radiation ($w/m^2.°c$).

h^c_{ga} : Coefficient of heat exchange between the glass and the external environment by convection ($w/m^2.°c$).

I_G : Intensity of global solar radiation (w/m^2)

Lhw : Thickness of the saline water (brine) (m)

Lv : Latent heat of water vaporization (j/m °c)

m_d : Distilled water flow ($l/m^2.h$).

$Q^{év}_{wg}$: Exchanged heat flow by evaporation between the glass and water (w) .

q_{water} : Heat flow absorbed by water (w)

T_b : Absorber temperature (°c)

T_{ge} : Temperature of the external side of the glass (°c)

T_{gi} : Temperature of the internal side of the glass (°c)

T_{ise} : Temperature of the external side of the insulator (°c).

T_{isi} : Temperature of the internal side of the insulator (°c).

T_w : Water temperature of the basin (°c)

β : Inclination angle of the glass (degree)

ηg : Global efficiency (%)

ηi : Internal efficiency (%)