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Improving the Productivity of Water by Coupling a Solar Still with Flat Plate Collector

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***Abstract*— The last statistics show that within the next fifty years, the world population will increase by 40 to 50 %. This population growth, coupled with industrialization and urbanization will result in an increasing demand for water and will have serious consequences on the environment. To confront these problems, several techniques of desalination of brackish or waste water have been developed around the world.**

Among the techniques used especially for arid and deserted area, solar distillation is characterized by being simple and easy. Moreover, solar still does not require an expensive and complex installations unlike other techniques used for the desalination of water, because the solar distillation depends entirely on solar energy to raise the water temperature.

Unfortunately, the solar distillation remains limited to the individual use. Where the experiments have shown that the productivity of traditional solar still estimated at about 3 liters per day this result is not satisfactory, and in order to improve the production of the solar still, our work focuses on the coupling of a still with a flat plate collector. This study was conducted various types of solar stills: single slope, double slope and spherical solar still.

After having established the thermal balances of the various solar stills at instationary regime, the equations are solved by using 4th order Runge–Kutta method. The numerical results obtained show clearly the effect of coupling a solar still with a flat plate collector. The improvement of production resulting by preheating water for all types of solar stills studied was estimated.

Index Terms— ***solar still, flat plate collector, preheat, productivity.***

NOMENCLATURE

A	area (m^2)
C	heat capacity per unit (j/kg.K)
I	absorbed solar radiation (W)
L_v	latent heat of vaporization (j/kg)
m	mass (kg)
m_{ev}	distillate rate (kg/s)
P	partial pressure (Pa)
Q	heat flux (W)
t	time (s)
T	absolute temperature (K)
Subscripts	
a	ambient
b	basin linear
c	convection
cd	conduction
ev	evaporation
g	glass cover
gi	inner glass cover
go	outer glass cover
g1	glass oriented to the east
g2	glass oriented to the west
is	insolent
ii	inner insolent
io	outer insolent
r	radiation
w	water

I. Introduction

Algeria is a country of 2.4 million square kilometers and 85% of this area is the Algerian Sahara rich of solar energy, however this area sulfur of severe water shortage. Solar distillation and for relatively low needs, can eases this deficit where several types of solar stills are appear around the worlds.

But the major drawback of this type of process is the low yield where the daily production of conventional solar still is about 3 liters per m^2.

Coupling of a solar still with a flat plate collector intended to improve the production of drinking water. In this work a comparison between the daily productions of a solar still that work alone and that of coupled system solar still-collector for different types of solar stills.

II. THEORITICAL ANALYSIS

A. Systeme description

The theoretical study of three systems, single slope still-collector, hot box- collector and spherical solar still-collector is taken successively in the transient regime. For this, we established the heat balance at each of these systems.

In the first system (Fig.1) the simple solar still is essentially consisting of a capacitor sealed surmounted by a glass. The bottom is covered with water (brackish water or seawater). Under the action of the solar flux G, transmitted through the transparent cover, the water is heated and a portion thereof evaporates. The steam produced is condensed on the inner face of the glass cover and the condensate is collected by a receiver. A water make-up compensates the flow of distillate. To reduce heat loss to the outside, the side walls and bottom are isolated. The solar still is connected by tubes to a flat plate collector circulating liquid coolant (water) consisting of an absorber with a copper tube coil-shaped.

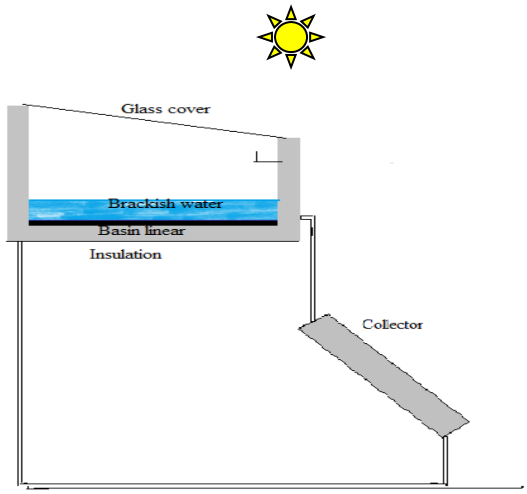

Figure 1. Schematic view of single slope solar still coupled with flat plate collector.

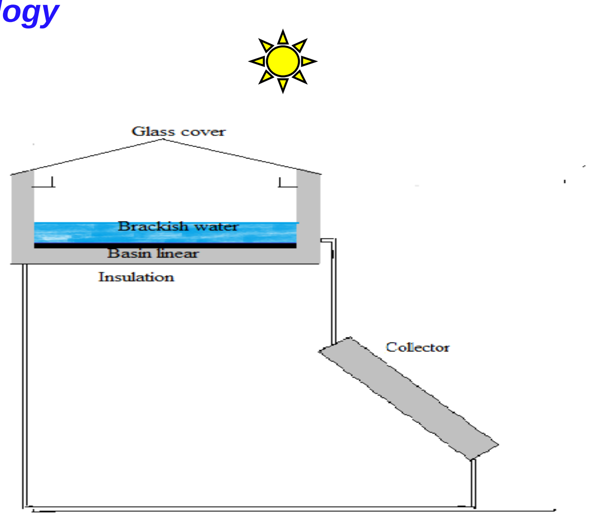

Figure 2. Schematic view of double slope solar still coupled with flat plate collector.

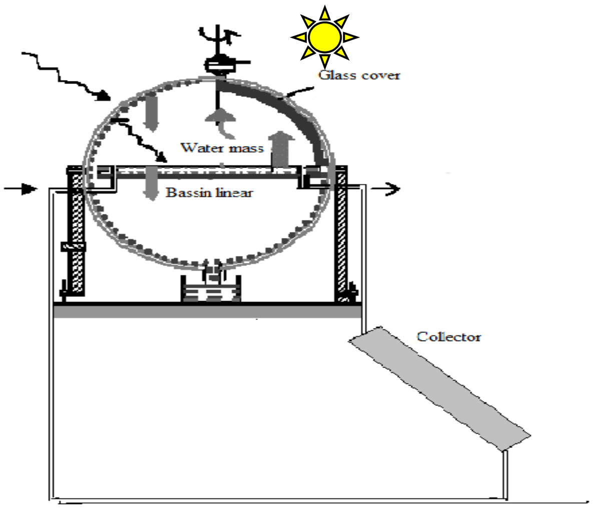

Figure 3. Schematic view of spherical solar still coupled with flat plate collector.

In second installation (fig.2), The conventional double slope basin solar still (hot box) consist of an uninsulated shallow basin painted with black paint holding shallow depth of brackish water and covered with double glass cover of the inverted V type, with long axis of the still facing east-west direction. To improve distillate collection process and increase the quantity of distilled water.

Finally, a schematic diagram of the spherical solar still is shown in Fig. 3. The still mainly consists of the circular basin and absorber plate carrying the saline water and a the spherical cover. The distillate output from the still was frequently collected using a container placed under the solar still. Due to spherical geometry of the glass cover, this still have not a preferred orientation.

B. Thermal modeling

The heat exchange, inside and outside of the solar still, is realized by means of four modes of heat transfer, convection, radiation, conduction and evaporation.

- Outer and inner glass cover

$$\frac{m_g \cdot C_g}{2} \cdot \frac{dT_{go}}{dt} + Q_{rgc} + Q_{cga} = Q_{cdg} + I_g \quad (1)$$

$$\frac{m_g \cdot C_g}{2} \cdot \frac{dT_{gi}}{dt} + Q_{cdg} = Q_{rgw} + Q_{cgw} + Q_e + I_g \quad (2)$$

- Water mass

$$m_w \cdot C_w \cdot \frac{dT_w}{dt} + Q_{rgw} + Q_{cgw} + Q_e + m_d \cdot C_w \cdot (T_w - T_a) = Q_{cap} + Q_{cwb} + I_w \quad (3)$$

- Basin linear

$$m_{ab} \cdot C_{ab} \cdot \frac{dT_{ab}}{dt} + Q_{cwb} + Q_{bis} = I_{ab} \quad (4)$$

- Outer and inner insolent

$$\frac{m_{is} \cdot C_{is}}{2} \cdot \frac{T_{ii}}{dt} + Q_{cdi} = Q_{bis} \quad (5)$$

$$\frac{m_{is} \cdot C_{is}}{2} \cdot \frac{dT_{io}}{dt} + Q_{ris} + Q_{cis} = Q_{cdi} \quad (6)$$

In the case of double slope and spherical solar still the equation (1), (2) and (3) will be replaced with four equations:

$$\frac{m_{g1} \cdot C_{g1}}{2} \cdot \frac{dT_{go1}}{dt} + Q_{rgc1} + Q_{cga1} = Q_{cdg1} + I_{g1} \quad (7)$$

$$\frac{m_{g1} \cdot C_{g1}}{2} \cdot \frac{dT_{gi1}}{dt} + Q_{cdg1} = Q_{rgw1} + Q_{cgw1} + Q_{e1} + Q_{r12} + I_{g1} \quad (8)$$

$$\frac{m_{g2} \cdot C_{g2}}{2} \cdot \frac{dT_{go2}}{dt} + Q_{rgc2} + Q_{cga2} = Q_{cdg2} + I_{g2} \quad (9)$$

$$\frac{m_{g2} \cdot C_{v2}}{2} \cdot \frac{dT_{gi2}}{dt} + Q_{cdg2} = Q_{rgw2} + Q_{cgw2} + Q_{e2} + Q_{r12} + I_{g2} \quad (10)$$

$$m_w C_w \cdot \frac{dT_w}{dt} + m_d C_w (T_w - T_a) + Q_{rgw1} + Q_{cgw1} + Q_{e1} + Q_{rgw2} + Q_{cgw2} + Q_{e2} = Q_{cap} + Q_{cwb} + I_w \quad (11)$$

I_g: solar flux absorbed by glass cover.

I_{g1}: solar flux absorbed by east glass cover.

I_{g2}: solar flux absorbed by west glass cover.

I_w: solar flux absorbed by water mass.

I_b: solar flux absorbed by the basin liner.

The evaporation heat transfer from basin water to condensing cover is described by the relation [1]:

$$Q_{ev} = h_{ev} \cdot (T_w - T_{gi}) \cdot A_w \quad (12)$$

Where h_{ev} is the evaporative heat transfer coefficient and it given by [2]:

$$h_{ev} = 16273 \cdot 10^{-3} \cdot h_{cgw} \cdot \frac{(P_w - P_{gi})}{(T_w - T_{gi})} \quad (13)$$

Where A_w is the surface of water and h_{cgw} is the convective heat transfer coefficient and it given by [3] [4]:

$$h_{cgw} = 0.884 \cdot \left[(T_w - T_{gi}) + \frac{(P_w - P_{gi}) \cdot (T_w + 273)}{268.9 \cdot 10^3 - P_w} \right]^{1/3} \quad (14)$$

P_w, P_{gi}, are the partial pressures of the vapor of water respectively, in water temperature T_w and the inner glass cover temperature T_{gi} [5].

$$P_w = exp\left[25.317 - \left(\frac{5144}{273 + T_w}\right)\right] \quad (15)$$

$$P_{gi} = exp\left[25.317 - \left(\frac{5144}{273 + T_{gi}}\right)\right] \quad (16)$$

The hourly yield per unit area can be evaluated from known values of water and glass temperatures, and is given by [6]:

$$\dot{m}_{ev} = \frac{h_{ev} \cdot (T_w - T_{gi}) \cdot 3600}{L_v} \quad (17)$$

Where L_v is the latent heat of vaporization, dependent of temperature [7], [8]:

$$L_v(T) = 3408 - 5.21 \cdot T + 0.01 \cdot T^2 - 1.194 \cdot T^3 \quad (18)$$

III. NUMERICAL RESOLUTION

Equations are solved by using 4th order Runge-Kutta method. The computer programs have been developed in 'fortan' language to predict the hourly variations of water temperature, glass temperature, distillate output and the various heat transfer coefficients of solar still.

IV. RESULTATS AND DISCUTION

First of all, makes a comparison between the numerical and experimental results. Fig.4 illustrated the temporal variation of the hourly production of a single solar still works alone, Theoretical results obtained in this work are compared with experimental results of S. Abdallah et al [9], while Fig.5 compared the theoretical results of the hourly production of two systems: single slope still-collector and double slope-collector with the experimental results of O. Badran et al [10] and that A. Badran et al [11], we can note that there is a good agreement between numerical and experimental results.

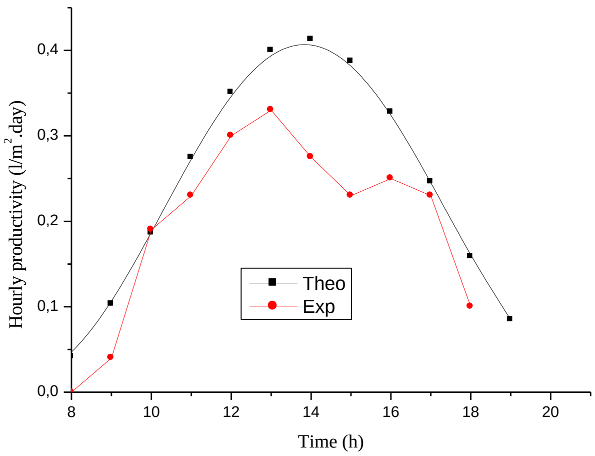

Figure 4. hourly production of a passiv single solar still.

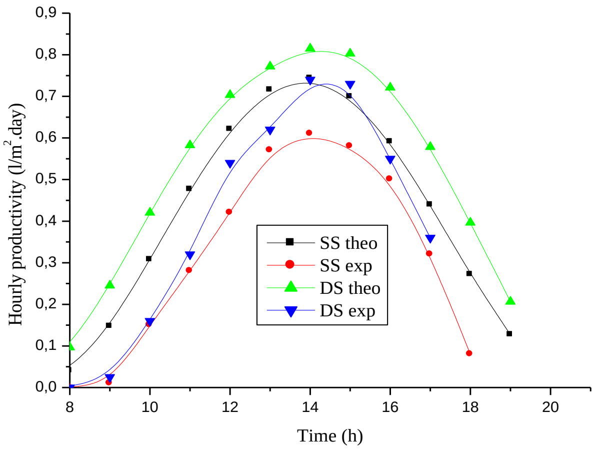

Figure 5. hourly production of two systems: single slope still-collector and double slope still-collector.

The fig.6 chow that single slope solar still that was oriented in the south absorbed the major of solar energy between 11^h-15^h. however the double slope solar still absorbed the major of incoming radiation in the morning and in the evening, we can explain this result by the orientation east-west of the double slope solar still, where one side of the glass cover is extended to the sun end the other side is under shadow, who keeping a low temperature of the glass cover and arising the rate of evaporation, this results are confirmed by the experimental works of V.K. Dwivedi et al [12].

When the sun was in the south, The problem of orientation do not exist in the case of the spherical solar still, because the spherical geometry of the glass cover allow the admission of the incoming radiation whatever the position of the sun in the sky.

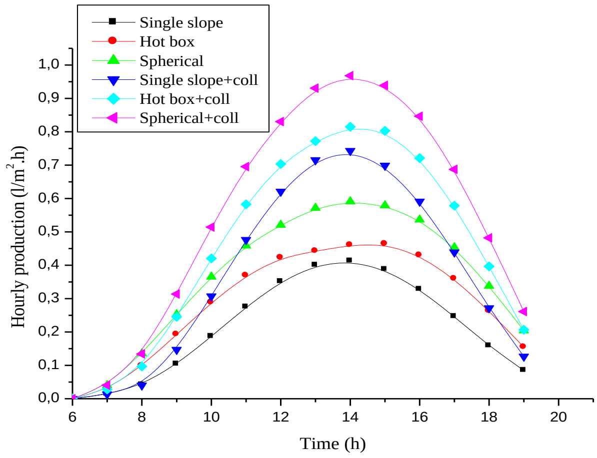

Figure 6. hourly production of single slope, double slope, spherical, single slope -collector, double slope -collector and spherical-collector.

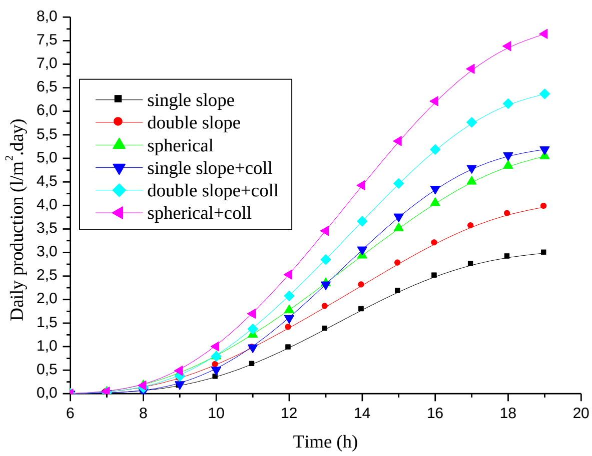

Figure 7. Hourly variation of daily production of different systems studied.

The daily production of different systems studied is shown in fig.7. Table 1 includes the daily production of all systems and the resulting improvement of water preheating:

Solar still type	Production (l/m^2.day)	enhancement %
Single slope	2,99	42.39
Single slope+	5. 19	

collector		
Double slope	3.96	37.83
Double slope+collector	6.37	
Spherical	5.05	33.73
Spherical+collector	7.62	

TABLE I. DAILY PRODUCTION OF SOLAR STILLS.

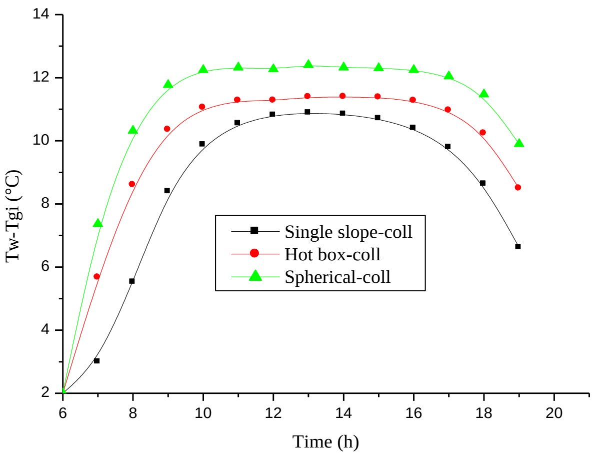

Figure 8. Hourly variation of temperaters different between water mass and inner glass cover.

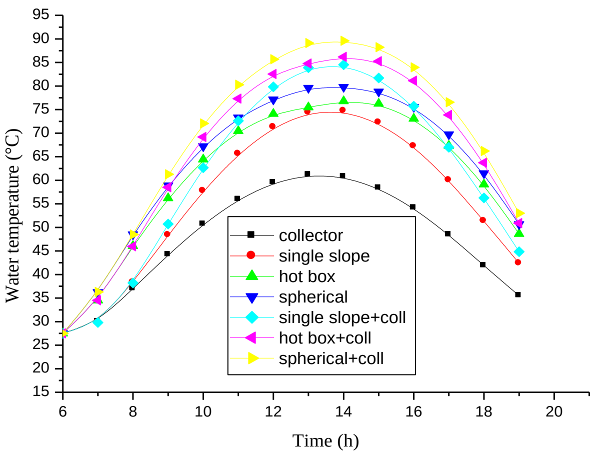

Figure 9. Hourly variation of water temperater of different systems studied.

As expected, the single slope solar still provides a daily production of nearly 3 l/day, however the double slope solar still give 4 l/m^2. These results show unambiguously that the spherical solar still give us the best production among the three types of solar stills by 5 l/day. The preheating of water improved sensibly the production of the three solar stills; we reached up to 7.62 l/day. in the case of the spherical solar still coupled with flat plate collector. T. Rajaseenivasan et al [13] in their experimental studies have found that the double slope solar still gives 3.58 l/day, while B.I. Ismail [14] concluded the daily distillate produced from the hemispherical solar still ranged from approximately 2.8 to 5.7 l/day.

O.O. Badran et al [10] were found that the productivity of the coupled still is found to be 36% higher than the still alone.

Fig.8 show that the production of the still depends on the temperature gradient between water mass and the inner side of the glass cover, this difference is greater in the case of spherical still with preheating.

More, the geometry of the glass cover in the case of double slope and spherical solar still has the advantage of conserved one side of the glass cover in the shade, which has a favorable effect on the lowering of the glass cover temperature.

Preheating significantly increases the temperature of the water in the basin for the three types of solar stills (fig.9), the water temperature of active single slope solar still above 85,59 °C and that of active double slope solar still is 87.35°C. In the case of spherical still with preheating, water temperature reaches 90.85 °C, so it is only 73.21°C in the case of single slope solar still without preheating. Coupled single slope solar still with flat plate collector augmented water temperature with 12.38 °C, experiments show that water temperature in active solar still is 10 °C higher in comparison with water temperature of passive solar still [12].

V. CONCLUSION

The solar radiations are the main factors affecting the productivity of the solar still.

The daily yield of single slope solar still is about 2.99 l/m^2, however the yield of double solar still is 3.96 l/m^2, and that of spherical solar still is about 5.05 l/m^2.

Daily production of active single slope solar still is 5.19 l/m^2 with an improvement of 42.39 %. while the production of active double slope solar still is about 6.37 l/m^2 with an improvement of the order of 37.83%.

In our case, a better production has been obtained by using spherical solar still coupled with collector with average 7.62 l/m^2.

Preheating increased temperature of water more than 12 °C.

These results show that the coupling of solar still with solar collector we give very satisfactory results, which opened the door for the use of solar collectors in water desalination on a large scale.

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