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Experimental study of a distillation unit by the use of a Sheffler solar Parabola

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ABSTRACT/RESUME

Abstract:*The present work is an experimental study of a solar desalination unit which operates on the principle of humidification-dehumidification using a Scheffler solar parabola. This unit is installed in the National Centre for Studies and Research on Water and Energy, University Cadi Ayyad Marrakesh, Morocco. The system comprises a primary reflector (10 m2 area), secondary reflector, distillation still, condenser and Florentine flasks. In order to describe the studied system, The variations of the debit condensate, the solar radiation and the characteristic temperatures of the system are measured during the day. The gotten results show that this system is very profitable since that it permits to get a mass output of 97%. The average power and efficiency of the solar distillation system were found to be 2.39 kW and 29.67% respectively for an average beam radiation of 987 W/m2.*

I. Introduction

The resources in soft water in the world, facing the demographic growth of the human being and the increase of the needs, are more and more insufficient and are more threatened by all sorts of pollution [1]. The crisis of the drinking water throws back the interest strongly to develop techniques of less expensive desalination, simpler, more robust, more reliable, if possible less energy consuming and respecting the environment. The desalination of water by classic units of treatment requires a lot of electric energy and / or calorific. The solar distillation represents a method of desalination less consumer of energy because it uses a source of free energy.

Works on the conventional solar distillers where the evaporation and the condensation take place in a same container show that the output is weak [2, 3]. Works are oriented then toward the separation of the two phenomena where the output of this type of distillers is increased. These distillers are called solar distillers by humidification-dehumidification. These types of distillers were the subject of numerous studies to improve the output as the used solar sensors are plane sensors [4, 5, 6]. In this work we used a Scheffler solar parabola; this parabola rotates along an axis parallel to the earth's axis of rotation with the help of a precise photovoltaic tracking device and keeps the reflected beam aligned with the fixed secondary reflector as the sun moves. The secondary reflector further reflects the beam to target the bottom of the distillation still. The advantage of the concentration of radiation is to work at high temperatures which increase the evaporation rate.

II. Materials and methods

II.1. Solar distillation system

The solar desalination system essentially consists of a Scheffler reflector and a secondary reflector and a distillation unit (Fig.1).

This solar system that allows the evaporation of the water is constituted by a primary reflector (Scheffler solar parabola) and a secondary reflector.

II.2. Scheffler solar parabola

The Scheffler reflector used is having an area of 10 m2, It is essentially composed of Reflecting mirrors incorporated in the elliptical shape of the parabola. and they are well secured with seven cross-bars.

The primary reflector rotates along an axis parallel to the earth’s axis of rotation with the help of a precise photovoltaic tracking device and keeps the reflected beam aligned with the fixed secondary reflector as the sun moves. Hereafter, they converge to a fixed focus to produce the heat required for evaporation of water (Fig.1).

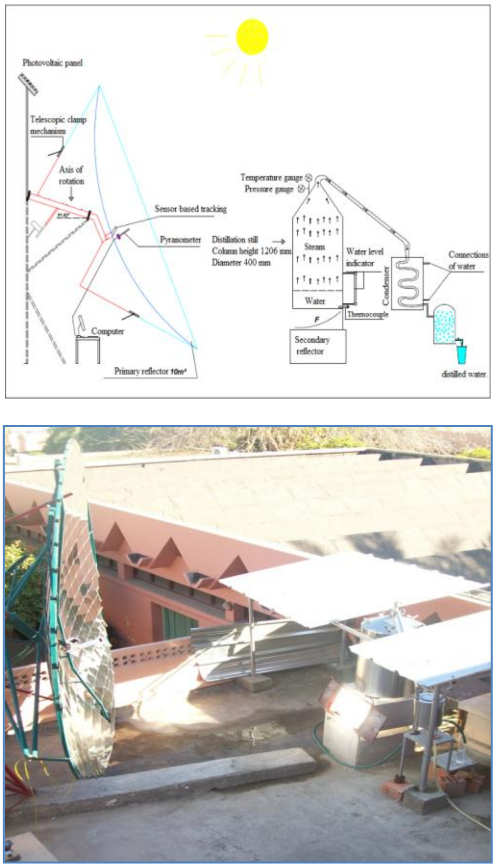

Figure 1. *Solar distillation system*

The secondary reflector is designed to converge all the radiations onto the bottom of distillation still (400 mm diameter) for distillation experiments.

For an 10 m2 reflector design, seven pieces of aluminium profiles are prepared to the specific radius and are fixed on the secondary reflector frame. The length of each aluminium piece is 700 mm and width is 100 mm.

The secondary reflector is designed to receive all the solar radiations reflected from the primary reflector and then further reflect it to the bottom of the distillation still.

Figure 2 . *Secondary reflector*

II.3. Distillation unit

The distillation unit is fabricated of a food grade stainless steel material that is 2 mm thickness, in a column 1210 mm high and 400 mm in diameter (this is the designed diameter of the receiver for 10 m2 Scheffler reflector). Three I-bolts are used for quick opening and closing of the top dome of the distillation still. The distillation unit was insulated with 60 mm rock wool covered by galvanised iron sheets (1 mm thickness) to minimize heat losses.

The still is also provided with safety mountings and fittings such as safety valve, pressure gauge and water level indicator.

The distillation unit has provision to operate for water and steam distillation. A stainless steel pipe connects the top end of the distillation still to the steel condenser. The condenser is provided with a steel coil, a cold water inlet

Figure 3: *Distillation unit with secondary reflector*

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II.4. Testing procedure and experimentation

The Scheffler reflector used is having an area of 10 m2. The sunlight that falls on this reflector is reflected sideways to the focus located at some distance of the reflector. The axis of daily rotation is located exactly in north-south-direction, parallel to earth axis and runs through the centre of gravity of the reflector. That way the reflector always maintains its gravitational equilibrium and the electronic daily tracking system doesn't need to be driven by much force to rotate it synchronous with the Sun. The focus is located on the axis of rotation to prevent it from moving when the reflector rotates. During the day the concentrated light rotated around its own centre but not move sideways in any direction. That way the focus stays fixed. At the focus it has a still to hold water. The advantage of the concentration of the solar radiation is to have an elevated temperature that increases the rate of water evaporation inside the still, this steam passes in a pipe that connects the top of the still to a condenser, then we open the system of cooling, as soon as the apparition of the first soft water drop we begin taking the measures. The parameters measured were water temperature (K-Type thermocouple), solar radiation (Pyranometer), and condensed water (Graduated cylinder).

III. Results

III.1 Effect of the variation of the initial water volume introduces in the still

To study the influence of the initial volume of the water supply introduced in the still on the capacity of production of the system, we made the experience during three days for three different volumes (15l, 30l and 60l).
The result of the influence of the initial volume on the time of evaporation and the capacity of production of the system that is the quantity of water produced in one minute is given in the table1.

Table 1. *Influence of the variation of the initial volume of the tap water*

Initial volume (l)	Day	Time of evaporation (min)	Capacity of system (ml/min)
15	27-12-2012	44	**88**
30	03-01-2013	66	**90**
60	04-01-2013	123	**89**

III.2 Variation of the debit condensate during the day

After having studied the capacity of the production system that is nearly constant of the order of 90ml/min. For this experience, we introduced 35l of water supply in the still.
We studied the evolution of the debit of condensate during the day, as well as the variation of the received beam radiation by the Scheffler solar parabola; the results are represented by the figure 4.

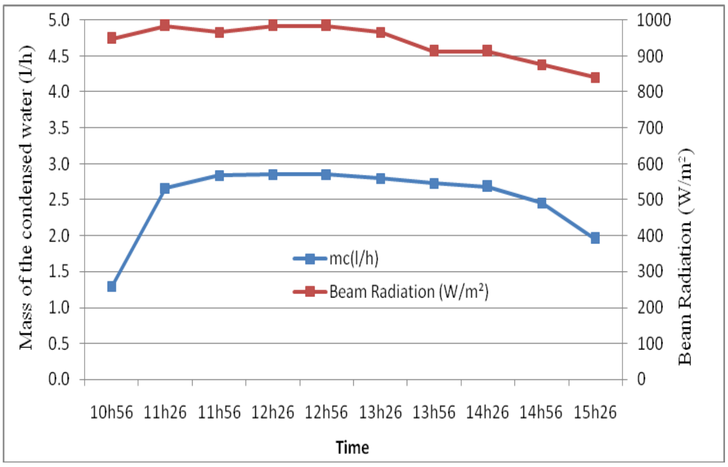

Figure 4. *Evolution of the condensate debit during the time 07-01-2013:*

III.3 Performance evaluation of solar distillation system

III.3.1 Calculating the efficiency of the system

The thermal efficiency of the solar distillation system is given below [7]:

$$(\eta\%) = \frac{10^3 E_p}{\int_{t=0}^{tp} Gb\ S_p\ dt} 100 \qquad (1)$$

The calculation of the surface of opening of the parabola is given by the following formula [8] :

$$S_0 = S_p \cos(43,23^\circ \pm \delta/2) \qquad (2)$$

The calculation of the solar declension is given by Cooper formula (1969) [9]:

$$\delta = 23,25 \times \sin\left(\frac{284+n}{365}\right) \qquad (3)$$

The solar declension varies from -23,5° to 23,5° December 21 to June 21. The variation of the solar declension and the surface of opening (for the northern hemispheres and south) during is shown all year round in the Fig.5

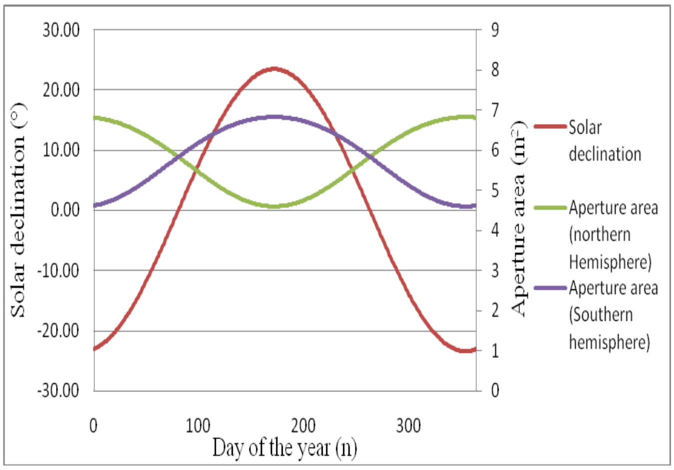

Figure 5. *Variation of solar declination and aperture area of Scheffler reflector for the whole year (n=1 for January 1)*

The total thermal energy Ep en KWh during the process of distillation is calculated by the following expression [7]:

$$E_p = \frac{m_e\, C_p \Delta T}{3600} \qquad (9)$$

And the average power (W) during the experience of distillation is:

$$P = \frac{E_p}{t_p} \qquad (10)$$

The results during the test of assessment of the performances of the system with 15 liter of initial volume of water and an average beam radiation of 987 W/m2s are shown below (Table 2).

Table 2*. Calculation results of the system efficiency*

Experience Date	Ep (Wh)	P(KW)	η(%)
15-01-2013	1,4	2,39	29,67

III.3.2 Calculation of the mass output of the system

The mass output of the system is defined by the following relation:

$$R_m = \frac{m_c}{m_v} \qquad (11)$$

The mass of water evaporated is calculated by the following formula:

$$m_v = m_e - m_{res} \qquad (12)$$

And $R_m = \frac{26{,}1}{26{,}9} = 97\%$ (13)

III.4 Analysis of condensed water

To guarantee the found results, it is necessary to analyze the condensed water and to insure that it is distilled water. This is why we measured the electric conductivity of the brackish water introduced in the still, the condensed water and the remaining water inside the still at the end of the experience (table 3).

Table 3. *Electric conductivity measured by this experience and calculated by H. Golnabi[10]*

K_e $(\mu S/cm)$	K_c $(\mu S/cm)$	H. Golnabi K_{HG} $(\mu S/cm)$	K_s $(\mu S/cm)$
954	5.23	3.41	2240

IV. Conclusion

In this work, we presented the experimental results of a desalination system while using a Scheffler solar parabola that functions on the principle of humidification-dehumidification. The system of desalination has been submitted to exploitation on real site. We followed the working of the system then during one active period starting from the month of January 2012 till the month of May 2013. The variations of the condensate debit, of the solar radiation and the characteristic temperatures of the system are measured during the day.

When we vary the initial volume of water introduced in the still of 15l to 60l, the time of evaporation passes from 44min to 123 min whereas the capacity of production is nearly constant is the order of 90ml/min, therefore it is not necessary to introduce a great deal of water in the still in order to gain the time of evaporation (Table1).

The curve of the condensate debit and of the beam radiation by the solar parabola has been studied, one notes that they have the same pace, the temperature of water inside the still is of the order of 100°C, therefore the whole heat received by the solar parabola serves the change of water phase in steam, therefore the variation of the system production necessarily depends on the variation of the solar radiation (figure 4).

The average power and the efficiency of the system in terms of boiling point of the water supply have been calculated, are respectively in the order of 2,4 KW and 29,67% for a direct average solar radiance The middle power and the efficiency of the system in terms of boiling point of the tap water have been calculated, are respectively the order of 2,4 KW and 29,67% for an average beam radiation of the order 987 W/m2 in the month of January (Table2).

To study the feasibility of this solar distillation system us measured the electric conductivity of condensed water (5.23µS/cm) this value is close to the calculated value by H. Golnabi[10]; who is very weak compared to the electric conductivity of water introduced in the still (954µS/cm) ,therefore this water contains a number important of the ions (Na+,Cl-) who have been eliminated by use of this experience (Table3).

The gotten results show that this system is very profitable since that it permits to get a mass output close to 97% and its production is in the order of 26l during 5 hours working in the month of January.

This survey also concludes that these types of innovation of the solar concentrators can open new landmarks in the solar systems to decentralized basis. Besides, other advantages as the reduction of the consumption of fossil fuels and the climatic warming up cannot be ignored.

Nomenclature

Cp: Specific heat of water at constant pressure (4187 kJ kg-1),
Ep : Total energy to heat the water distillation process (KWh) ,
Gb: Beam radiation at time t (W/m^2),
Gbmoy: Average beam radiation (W/m^2),
hfg: Latent heat of vaporisation of water (Kj/Kg),
Ke: Electrical conductivity of the brackish water introduced into the still ($\mu S/cm$),
Kc: Electrical conductivity of the condensed water ($\mu S/cm$),
Ks: Electrical conductivity of the water remaining inside the still to the end of the experiment ($\mu S/cm$),
$\dot{m}_a$: Flow of cooling water in the condenser (Kg/s)
m_e : Mass of the initial water (Kg)
m_c : Total mass of the condensed water (Kg)
m_v : Total mass of evaporated water (Kg),
m_{res} : Mass of water remaining in the still to the end of the experiment (Kg),
n: Day number of the year,
P: Average power of the experience of the distillation (KW),
R_m : Mass yield (%)
S_o : Aperture area of the Scheffler parabola (m^2),
S_p : Area of the Scheffler parabola (m^2),
t_e : Total time of the experiment (s),
t_p : Time of the distillation process (s),
T_{ea} : Water temperature within the still (K),
T_v : Temperature of the water vapor (K),
V_{init} : Initial volume introduced into the still (l),
ΔT : Temperature variation (K)
η : System efficiency (%),
δ : Declination of the sun (°).

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