Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.807042

52 (2014) 1761–1769
February

Taylor & Francis
Taylor & Francis Group

Optimization and modeling of a solar still with heat storage

Nafila Smakdji[a,*], Abdennacer Kaabi[a], Bernard Lips[b]

[a]*Department of Climatic Engineering, Mentouri University, Constantine, Algeria*
Email: smakdji_nafila@yahoo.fr
[b]*Thermal Center of Lyon, CETHIL, UMR CNRS 5008/INSA Lyon/UCB Lyon1, Villeurbanne, France*

Received 30 January 2012; Accepted 2 May 2013

ABSTRACT

In order to improve the performance of a solar still to a simple greenhouse, several experimental works have carried out from which we can enumerate the active distiller which represents a simple-effect solar still coupled with a solar collector and where the brine to be distilled is preheated. In order to increase the amount of distilled water, we set up an active solar still with a storage balloon of sensitive heat. Our prototype consists of a solar still with a simple greenhouse effect, having a metal cover which is considered as a condenser. A heat exchanger "tube type" is set up inside the basin to heat the distilled and where a good insulation is provided at the posterior side of the solar still. The aim of this work is to enrich the already available data by a mathematical modeling of the proposed prototype, which is based on the thermal balances and by using appropriate heat and mass coefficients aided by some simplifying assumptions. The aim of the simulation is also the optimization certain parameters that affect the production of distilled water and, as a result, having a certain appreciation about how will thermal storage contribute to a better performance of a solar still with a simple effect.

Keywords: Thermal storage; Solar energy; Brackish water (brine); Solar distillation

1. Introduction

Water is necessary for all living species. Its use by humanity has increased substantially with the demography evolution [1] and with the way of life (technological way). In the poor and developed countries, the water becomes, actually, a more and more important challenge. The problem of water in the world is a problem of its quality added to its availability (quantity). From eight billion of humanity, four billion people suffer from water deficiency [2]:

(a) 2.3 billion live with a water stress.
(b) 1.7 billion live with a water shortage.

One of the first rights of human beings is the guaranteed access to fresh water, essential to its survival, to cover its needs on irrigation, farming, and industrial purpose [3].

---

*Corresponding author.

Presented at the Third Maghreb Conference on Desalination and Water Treatment (CMTDE 2011)
Hammamet, Tunisia, 18–22 December 2011

Because of the draught, freshwater is not more obtained from the precipitation; desalination of saline waters represents then an essential solution to increase the freshwater resources.

According to the degree of salinity, the saline waters are classified on:

(a) Seawaters with a salinity close to 35 g/l.
(b) Brackish water, with an average salinity between 1 and 10 g/l [4].

Several methods of desalination are currently used.

2. Principal technologies of water desalination

Current water desalination technologies are classified into two categories:

(1) Thermal processes, distillation, and freezing involving a change of phases.
(2) Membrane methods, reverse osmosis, and electrodialysis [5,6].

The use of solar power as energy source is to reproduce model miniaturized the natural cycle:

(a) Absorption of solar radiation by the oceans, lakes, etc., causes evaporation of water.
(b) The produced steam is transported as the humidity of the air to the colder regions through winds.
(c) When the steam is cooled, the condensation causes precipitation of rain and snow eventually.

Solar distiller reproduced the same cycle (Fig. 1).

There are several types of solar stills using the same principle of operation, but are different in terms of design and in terms of used materials.

Fig. 1. The single slope basin type solar still.

The physical state of the brine in the basin distinguishes two major families: static distillers and runoff distillers.

3. Origin and history of the solar distillation

Solar distillation was used during several centuries:

(a) In 1551, the first equipment to distill saltwater was designed by Arab alchemists, this information is reported by Mouchot [7].
(b) In 1862, the French chemist Lavoisier used large glass lenses to focus the Sun's rays in order to distill the water in bottles [7].
(c) In 1872, the Swedish engineer Carlos Wilson makes the first conventional solar still of a surface of 5,000 m^2 in Las Salinas, in the North of the Chile. Because of the problem of rapid accumulation of salts, the basin and the need for regular cleaning of the distiller installation, the experience was stopped in 1910 [8].
(d) In 1920, Kaush used metal reflectors to concentrate the Sun's rays [8].
(e) In the early 1930s, Trivinof had proposed a sloping still [8].
(f) In 1938, Abbot used parabolic cylindrical reflectors to concentrate the Sun's rays on tubes of water [9].
(g) 1945 was marked by the invention of a new solar still of spherical type. A large number of this model were used during the second world war.
(h) In 1952, the University of California began investigations in order to study the effects of some parameters on the performance such as geometry and various insulation materials [10].
(i) In 1953, Cyril Goméla in Algeria developed 10 types of solar stills which were then tested and marketed through North Africa, Senegal, and the Australia. To increase performance, Savornin and Le Jeune studied other types of inclined solar stills [11].
(j) In 1960, three large solar stills stations were built in Tunisia.
(k) In 1962, the Group of solar energy of the Tunisian Agency of Atomic Energy has actively studied solar distillation.
(l) Between 1963 and 1967, the CSIRO of Australia (Common Wealth Scientific and Industrial Research Organization) has built and tested more than eight distillers in order to improve the efficiency and the study of the effect of some parameters [12].

(m) In 1969, Cooper suggested a simulation to study the performance of a solar still with a greenhouse effect [13].

4. Parameters affecting the solar-still performance

The parameters affecting the solar-still performance are classified as follows:

The construction parameters including:

1. *Cover*: It is a condensation surface, where it must be non-hydrophobic, able to be wet, resistant to wind and solid particles attacks [14]. Baum and Bairamov [15] showed that the distance between the cover and the brine must not be great in order to avoid the increase in the buffer layer which has no role in the heat transfer inside the solar still. Satcunanathan and Phansen [16] found that the thickness of this layer affects the performance.
2. *Absorber*: It is generally made of metal, black painted and is characterized primarily by absorptivity close to the unity, good thermal inertia, and good chemical resistance to the oxidation by mineral deposits of the brine.
3. *Insulation*: A good insulator should be placed on the rear part of the solar still.

There are many types of insulation:

(a) *Mineral insulation* such as glass wool, rock, cellular glass, perlite, vermiculite, and expanded clay.
(b) *Natural insulation* such as cork, hemp, flax fiber, wool sheep, feathers duck, coconut fibers, panels of reeds, cellulose wadding, wool cotton.
(c) *Synthetic insulation* such as expanded polystyrene, extruded polystyrene, polyurethane, phenolic foam [17].

4.1. Meteorological parameters

Two main parameters affect the solar-still performance [18]:

1. the global incident radiation;
2. the wind.

4.2. Thickness brine

The thickness of the brine represents a very important factor during the hourly production. Low thickness means a low quantity of water to be heated. It is heated quickly, at a high temperature giving a good hourly performance.

5. Main characteristics of a solar still

A solar still is characterized by:

1. The performance which represents the amount of distilled water, produced by m^2 of the evaporation surface per day [19].
2. Efficiency and according to Cooper [20], efficiency is represented by:

(a) The overall efficiency which represents the ratio of the amount of energy used by evaporation by m^2 of the amount of incident global energy:

$$\eta g = \frac{qevap}{Pg}$$

(b) Internal efficiency which represents the ratio of the amount of energy used for evaporation by m^2 of the amount of energy actually absorbed by the brine by m^2 of the incident surface:

$$\eta i = \frac{qevap}{\alpha w.Pg}$$

3. The performance.

Satcunathan and Hansen [16] have defined raw performance (F.P.B) factor and factor of hourly performance (F.P.H) as follows:

$$\text{F.P.B} = \frac{\text{Amount of water input within 24 hours}}{\text{Amount of energy input within 24 hours}}$$

$$\text{F.P.H} = \frac{\text{Amount of water input after one hour}}{\text{Amount of energy input after one hour}}$$

6. Bibliographic research

The solar still with simple greenhouse effect is the most simple and economical solar distiller. It is characterized by low performance and the lack of production of fresh water during the night [21]. Because of the absence of solar radiation, temperatures at the glass and in the brine decreases; this is desired for the glass but not for the brine.

Reaching hot brine and a cold glass was the concern of several researchers, where several works involving a solar still coupled to a solar collector were carried out [22].

Experiments have shown the improvement of the performance of 30% [23,25] and a night production of 0,941 (l/h) during the night [24].

Works focused also on the study of the optimum inclination of the glass [26], of the optimum thickness of the brine and the flow rate [27].

Many experimental studies were carried out by changing the design of the system:

(a) A double-glazed solar still with separate condenser, directed by El-Bah and Inan [28].

(b) Solar still with separate glass reflector. A tray filled with brine is surmounted by a metal condenser. Such a design has been tested by Yadv, Eams, and Norton [29].

(c) Aboula-Enein, El-Sebaii, and El-Bialy studied the effect of the depth of the brine. The results showed that performance is proportional to the depth of the brine during the night and inversely proportional to it during the day [30]. Voropoulos, Mathioulakis, and Belessiotis studied a joint energy system. They placed a heat exchanger in the brine above the absorber; the heat-transfer fluid is heated by an electrical resistance to get a good night production [31].

(d) The best production is obtained by tilting the glass of an angle equals to the latitude of the place [21,32].

(e) Toure and Meukam found that the variation in the glass thickness does not affect the production of distilled water [33].

(f) The realization of a simple solar still with a greenhouse effect having a floating absorber, which can take different positions, increases the performance of 15 to 20% [34].

(g) Yadav [35] coupled a simple solar still to a solar collector. He concluded that the evaporation coefficient changes with the temperature of the brine and improvements were noticed when this last gets higher values.

(h) Harmim and Boukar [36] confirmed the usefulness of coupling of a solar still type hotbox with a solar sensor, which is characterized by separating the uptake surface from the surface of vapor condensation.

(i) Due to a series of experiments, in 1995, Belessiotis et al. proved that the behavior of a solar still can be described by an empirical mathematical method based on the input parameters (the mean daily room temperature, the initial temperature of the brine, the global solar incident radiation on the solar still) and the output parameters (daily performance). This method is called "input-output method." This method was validated in 1999 by Mathioulakis et al.

(j) Voropoulos et al. in 1996 coupled a solar still with a storage tank and a solar collector. They tested the results in 2001 on an installation consisting of a storage tank having a capacity of $3.75\,m^3$ of water, heated by $48\,m^2$ of surface of sensor with 5 cm as a thickness of the brine. They found a significant increase in the performance and a remarkable night production.

(k) To validate the method of "input-output," Voropoulos, Mathioulakis, and Belessiotis [37] studied the performance of the installation by varying the thickness of the brine. A good concordance of the theoretical results with those of the ones was obtained. They concluded that this method can be a useful tool for the optimization of the already existing installations.

7. Description of the prototype and performance of the installation

The prototype includes a water solar collector. A mass flow "mc" with a water temperature "Tco" transfers heat generated in the flask of water mass storage "Mst."

A flow of hot and mass water "ms" with a temperature "Ted" feeds a tube type heat exchanger immersed in the basin of the solar still with a greenhouse effect filled with a quantity of brine of mass "miws" surmounted of a metal cover that serves as a condensation surface. Brine will heat up till the boiling with the heat exchanged through the tube. It will evaporate and will condense on the cover. The water drops runoff till a gutter used to fresh water recovery. The system operates in a closed circuit by thermosiphon, where the amount of water "ms" will get out of the tube at a temperature "Tos" and then get into the storage tank (Fig. 2).

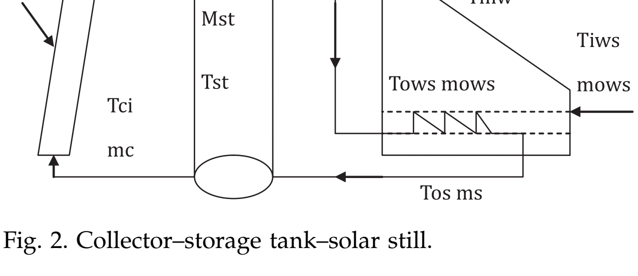

Fig. 2. Collector–storage tank–solar still.

8. Simplifying hypotheses

Simplifying assumptions for the formulation of the model have been used:

(a) Heat losses in different pipelines are considered negligible.
(b) The system (collector–storage tank–still) is fully insulated.
(c) The thermal and mass exchanges between the free surface of the water and the cover are described by considering that the temperature and the partial pressure of water vapor are constant.
(d) The temperature gradient between the internal side and external coverage is negligible.
(e) The water temperature in the storage tank is uniform; a selective coating is applied on the outside.
(f) The physical properties of various materials are considered constant.

9. Formulation of the model

The mathematical formulation of the model has been established from the heat balance.

(1) Solar still

The Kirchhoff law allows to establish the energy balance and the resolution was approached by a digital approach based on the method of Gauss Seidel iterations.

(a) At the level of the metal wall:

$$\frac{\text{Mmw.Cpmw}}{\text{Smw}} \cdot \frac{\text{dTmw}}{dt} + \text{hce.Smw.(Tmw} - \text{Tamb)} + \text{hrmw.(Tmw} - \text{Ts)} = \text{hgbmw.(Tows} - \text{Tmw)}$$

(b) At the level of the brine:

$$\frac{\text{Mows.Cpw}}{\text{Sows}} \cdot \frac{\text{dTows}}{\text{d}t} + \text{hgzbmw.(Tows} - \text{Tmw)} = \text{ms.Cpw.(Tis} - \text{tos)}$$

(c) Tube type heat exchanger

efficiency is calculated by the following equation

$$\varepsilon = \frac{\text{Tows} - \text{Tiws}}{\text{Tis} - \text{Tiws}}$$

(2) Solar collector

$$^{*}\text{Q captured} = f(\text{Tc}, \text{Tamb}, \text{Po}, \text{mc})$$

$$\text{mc.Cpw.(Tco} - \text{Tci)} = F_{\text{R.}}(\tau.\alpha)\text{Po} - F_{\text{R.ul}}(\text{Tci} - \text{Tamb})$$

$$F_{\text{R.}}\ (\tau.\alpha) = 0.68 F_{\text{R.}}.U_{\text{L.}} = 4.90\ (\text{W/m}^2)$$

These relationships are valid for solar collector with water glass and correspond to the results tested on the collectors by the Thermodynamics Company (Chandra sekhar and Thevenard, 1995).

(3) Storage tank

$$\frac{\text{Mst.Cpw}}{\text{Ast}} \cdot \frac{\text{dTst}}{dt} = \text{A.}[F_{\text{R.}}(\tau.\alpha)\text{Po} - F_{\text{R.}}U_{\text{L.}}(\text{Tci} - \text{Tamb})]\text{-ms.Cpw.(Tsi} - \text{Tso)} - k_{\text{s.}}(\text{Tst} - T_{\text{o}})$$

k_{s}: the conductance between the storage and the external ambience;

T_{o}: the temperature in the space surrounding the storage tank;

For a 1 h time step, the storage temperature was obtained by the Euler method.

10. Interpretation and discussion of the results

The resolution of different equations describing our model is made by considering the weather parameters of the day of the 15 July. The calculations are performed, for each component of the system at an initial time "t_{in}, and initial temperature" T_{in}, taking into consideration the geographical coordinates corresponding the region of Ouargla (south of Algeria).

From the minimum and the maximum daily temperatures, a sinusoidal profile of the ambient temperature and the temperature of the sky is generated.

The temperature of the sky is a function of the ambient temperature $Ts = (0.0552 \times \text{Tamb}^{3/2})$, the change in the overall incident energy, which reaches its maximum values, between 11 and 15 h is also sinusoidal (Figs. 3 and 5).

Fig. 11 shows the change of the water-storage temperature and that of the solar-collector output. This change is similar to that of the overall incident energy, which seems logical. The difference between the two values (Tco and Tst) is not high because this change is a function of the water flow out coming from the solar collector and directly feeding the storage tank. At 16 h, the two temperatures are equalized

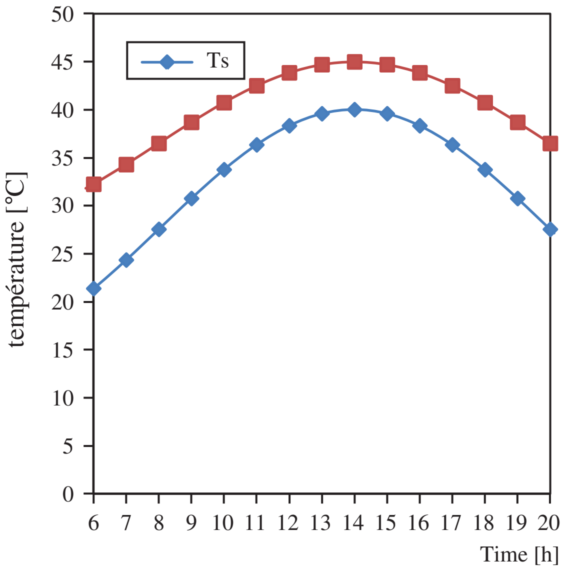

Fig. 3. Temporal change of ambient temperature and the temperature of the sky.

and reach the value of 89.65˚C. Then, the temperature of the storage tank (Tst) exceeds that of the output collector (Tco). This can be explained by the cooling of the heat-transfer fluid due to the attenuation of the overall incident solar radiation. The storage tank keeps the heat at a high temperature for more than 10 h which was proven by an experimental study on the sensitive storage [37]. We notice that the maximum temperature is obtained at 14 h for a 60 kg mass of storage, which requires a valve to stop the water from the solar collector and which can cool the water of the storage.

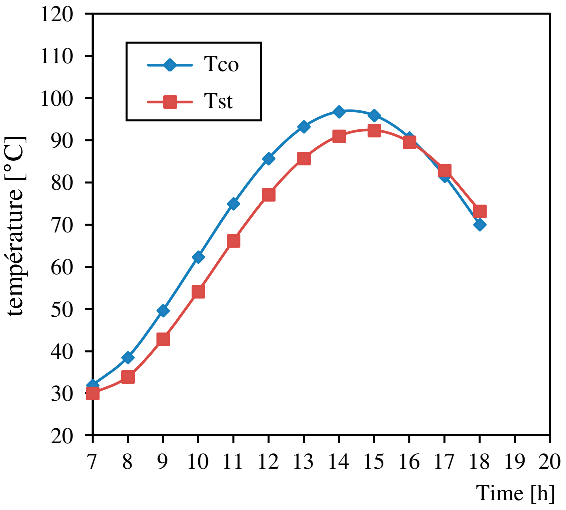

Fig. 4. Temporal variation of temperature "collector output" and the storage mc = 50 kg/h, Mst = 60 kg.

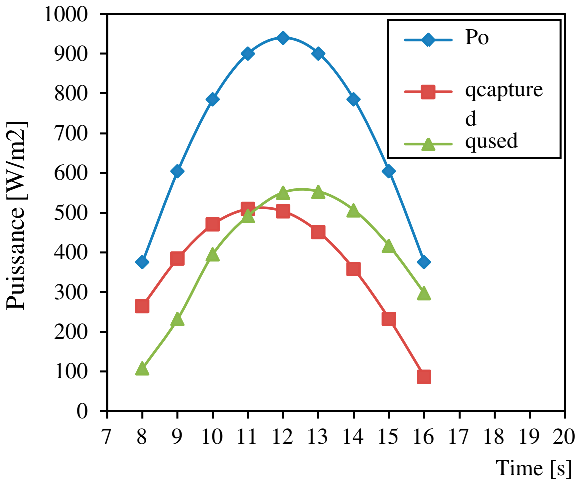

Fig. 5. Temporal changeof the global powers, captured and used.

Fig. 12 shows a parametric change of the temperature of the heat-transfer fluid at the outer of the solar collector. The maximum temperature is obtained for a flow rate of 50 kg after 9 h. The temperature is identical to mc = 100 and 150 kg. An increase in the flow is therefore unnecessary.

Fig. 5 shows that captured and used powers are lower than the overall incident power. Before 11 h, the useful power for heating the brine is lower than that captured but it is higher to it after 11 h, which means that solar still receives heat directly from the energy stored in the tank of water. Before 11 h, the system (installation) works to capture and store solar energy in order to reuse it in the solar still.

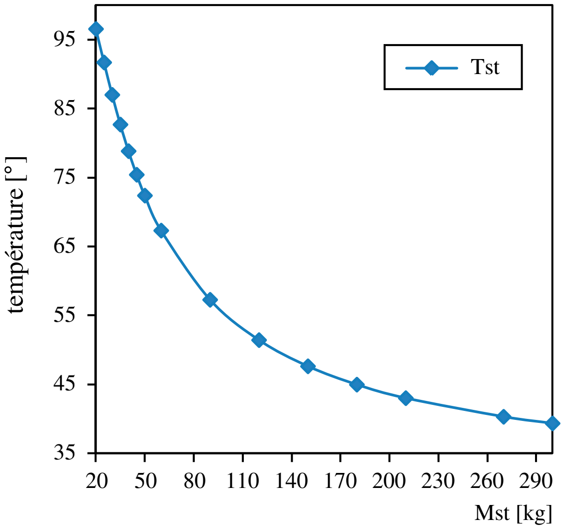

Fig. 6. Temperature change of storage with its mass, mc = 50 kg.

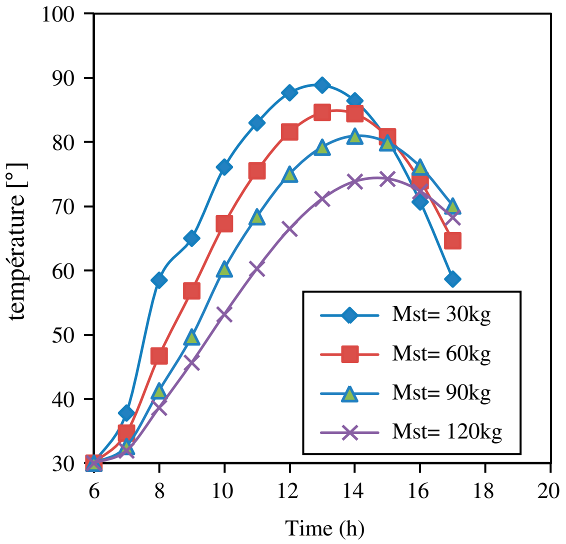

Fig. 7. Temporal change of the storage temperature, mc = 150 kg.

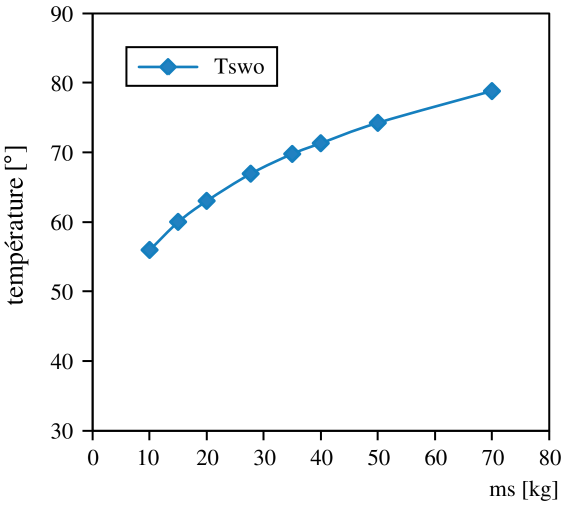

Fig. 9. Change of Tswo with the flow.

Figs. 6 and 7 show that the temperature of water storage is inversely proportional to the mass of the tank (Mst).This value reaches its maximum at 13 h for a low mass of water. This does not mean that there is a good performance of the system because the storage is likely to be saturated. Good performance can be obtained with the increase in the size "Mst.Cpw.ΔT," this last is being proportional to "Mst."

Fig. 8 gives the brine temperature (Tswo), the metal wall temperature (Tmw), and water temperature at the outer of the heat exchanger (Tso), this latter coincides with (Tswo) because of thermal equilibrium between the brine and the heat exchanger. A temperature difference between the brine and the wall leads to a production of distilled water, represented by Fig. 10 and changes with time. Solar still continues to produce distilled water during the night period.

Fig. 9 shows the change of the brine temperature on the water flow "ms" in the heat exchanger. A maximum of temperature is obtained for a large amount of water, but this does not mean that we can have this value which is directly linked to the size of the exchanger type "tube" and of the amount of the existing brine in the basin, because a large flow "ms" causes dysfunction of the installation due to the decrease in the surface of evaporation. Fig. 10 shows the schedule the performance. The production of distilled water reaches its minimum value at 16 h, which seems consistent according the information available

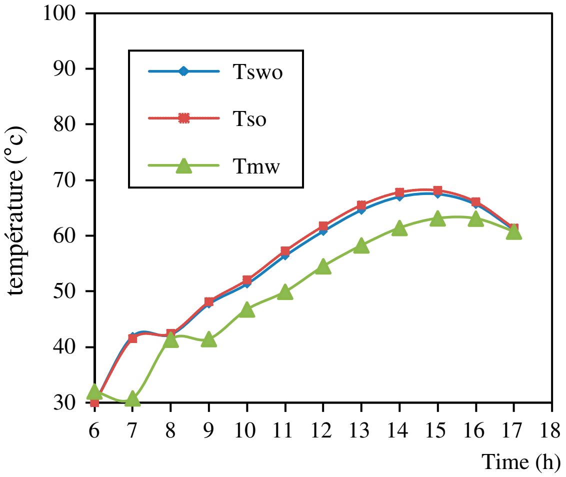

Fig. 8. Temporal change of Tswo, Tso and Tmw, mc = 50 kg/h, Mst = 60 kg, ms = 28 kg/h, Thw = 0.02 m.

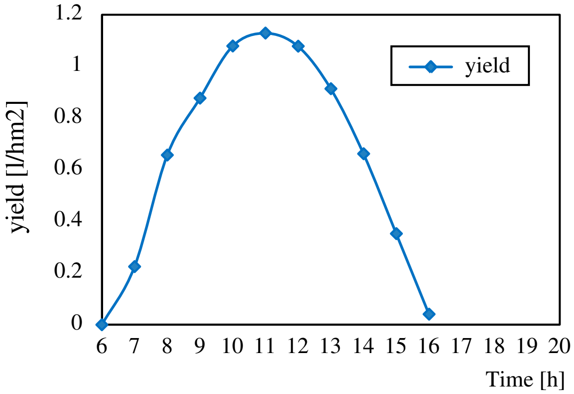

Fig. 10. Time change with the performance mc = 50 kg/h, Mst = 60 kg, ms = 28 kg/h, Ths = 0.02 m.

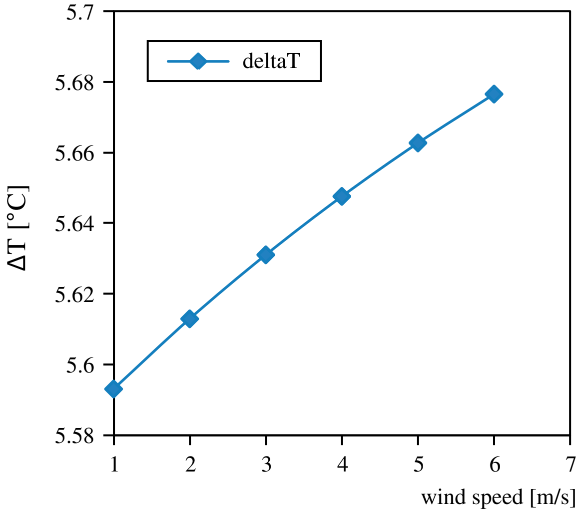

Fig. 11. Change of temperature difference with wind speed Mst = 60 kg, Thw = 0.03 m.

in the Figs. 4 and 5, but in reality the solar still continues to produce water by the heat stored and transferred by the heat exchanger tube. According to previous works, we notice that the amount of produced water is a double of that produced by only a simple solar still with a greenhouse effect. The performance is then proportional to the temperature difference (ΔT) and where this temperature difference increases with the heat transfer by convection between the metal wall and the external environment, therefore, with the speed of the wind according to the relationship: 5.7 + 3.8 × V (Fig. 11).

The temperature difference reaches its maximum at 11 and 14 h (Fig. 12).

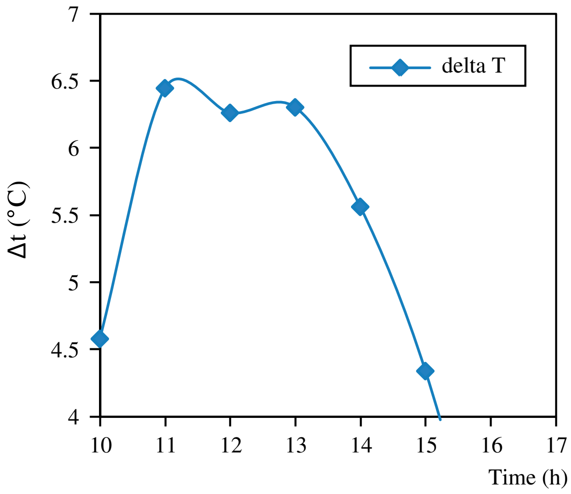

Fig. 12. Change of temperature difference with time, Mst = 60 kg, Thw = 0.02 m, ms = 27 kg/h.

11. Conclusion and recommendations

This work allowed us to acquire knowledge on the different existing energy and the different methods of desalination, especially solar desalination, and the effect of some meteorological and operating parameters on the daily performance of a simple solar still with a greenhouse effect coupled with a solar collector and a storage tank. To perform this work, we have developed a numerical model to simulate the operation of the installation (system). The resolution of the equations established to find results that corroborate the interest of a system in which brine is more heated directly by solar radiation but through a stocked water (in storage tank). The performance of the system is primarily influenced by the intensity of the hourly radiation, the temperature difference between the surface of evaporation and the condensation one, the wind speed, the inclination of the cover (collector), the volume of the of storage tank, and the size of the heat exchanger.

In order to give a continuation to, we recommend to:

(1) Realize an experimental work to validate the obtained theoretical results and measure the quantity actually produced during the night.
(2) Establish a theoretical study of the same installation with bladed walls, in order to increase the outer exchange.
(3) Study the phenomenon of stratification in the storage tank in order to check if the water temperature (Tsi) outcoming from the upper part is really equal to that outcoming from of the lower part with a temperature (Tci).
(4) Study the thermosyphon phenomenon.

Nomenclature

C — specific heat, J/kg°C
h_{gbmw} — coefficient of equivalent overall heat exchange between brine and the metal wall, W/m^2 K
m — water flow, kg/s

Index —
mw — metal wall
w — the brine
s — solar still
st — the storing
c — solar collector

References

[1] E. Delyannis, Sol. Energy 75 (2003) 357–366.
[2] C. Paton, A. Davis, The seawater greenhouse for arid lands, in: Proceedings Mediterranean Conference on Renewable Energy Sources for Water Production, Santorini, June 10–12, 1996.

[3] J.S. Perret, A.M. Al-Ismaili, S.S. Sablani, Development of Humidification-dehumidification System in a Quonset Greenhouse for Sustainable Crop rPoduction in Arid Regions, Biosystems Engineering.

[4] http://fr.wikipedia.org/wiki/Eau_de_mer# Origine_du_sel_de_l.27eau_de_mer

[5] http://www.techniques-ingenieur.fr/base-documentaire/procedes-chimie-bio-agro-th2/operations-unitaire

[6] A. Maurel, Dessalement de l'eau de mer et des eaux saumâtres et autres procédés non conventionnels d'approvisionnement en eau douce [Desalination of sea and brackish waters and other non conventional processes of freshwater supply]. Lavoisier Tec & Doc (2001).

[7] A.A.S. Malik, G.N. Tiwari, A. Kumar, M.S. Sodha, Solar Distillation, Pergamon Press, Oxford, 1982.

[8] A.A. Sfeir, G. Guarracina, Ingénierie des Systèmes Solaires, Applications à l'Habitat [Engineering of solar systems, applications to habitat], Technique and Documentation, Paris, 1981.

[9] M. Telks, Solar Distiller for Life Rafts, Office of Science, Boston, MA, 1945.

[10] E.D. Howe, B.W. Theimat, Twenty years of work on solar distillation at the University of California, Sol. Energy 16 (1974) 97–195.

[11] L.G. Savornin, Etude sur l'Evaporation et la Condensation de l'Eau dans les Distillateurs Solaires, Application Thermique de l'Energie Solaire dans le Domaine de la Recherche et de l'Industrie, Colloques Internationaux, Centre National de la Recherche Scientifique (CNRS), 1961, pp. 589–600.

[12] E. Delyannis, The patros solar distillation plant, Sol. Energy 12 (1968) 113–115.

[13] P.I. Cooper, Digital simulation of transient solar stills process, Sol. Energy 12 (1969) 313.

[14] S.D. Gomkale, S.Y. Ahmed, R.L. Data, Fresh water from sea by solar still, Paper presented at the Animal Meeting, Indian Institute of Chemical Engineers, India, December 1964.

[15] B. Baume, Heat and mass transfer process in solar still of hot box type, Krzhizhanovskey Power Institute, Moscow, Russia, 1963.

[16] S. Satcunanathan, H.P. Hansen, An Investigation of some of the parameters involved in solar distillation, Sol. Energy 14 (1973) 353–363.

[17] http://isolation.comprendrechoisir.com/comprendre/isolation_thermique

[18] H. Al-Hinai, M.S. Al-Nassri, B.A. Jubran, Effect of climatic, design and operational parameters on the yield of a simple solar still, Energy Conversion and Management 43 (2002) 1639–1650.

[19] R. Bernard, G. Menguy, M. Schwartz, 'Le Rayonnement Solaire, Conversion Thermique et Applications', Technique et Documentation, 2 ième edition, 1980.

[20] P.I. Cooper, The maximum efficiency of single effect solar still, Sol. Energy 15 (1973) 205–217.

[21] A. Kaabi, N. Smakdji, Impact of temperature difference (water-solar collector) on solar-still global efficiency, Desalination 209 (2007) 298–305.

[22] M.A.S. Malik, G.N. Tiwari, A. Kumar, M.S. Sodha, Solar Distillation, Pergamon Press lid, Oxford, 1982.

[23] A.A. Badran, A.A. Al-Hallaq, I.A. Eyal Salman, M.Z. Odat, A solar still augmented with a flat-plate collector, Desalination 172 (2005) 277–234.

[24] M.Boukar, A. Harmim, Production Nocturne d'un Distillateur Solaire Couplé à un Capteur Plan en milieu Saharien [Night production of solar still coupled with a plane collector in Saharian environment], Rev. Energ. Ren. Special Issue.: Valorization (1999) 91–96.

[25] O.O. Badran, H.A. Al-Tahaineh, The effect of coupling a flat-plate collector on the solar still productivity, Desalination 183 (2005) 137–142.

[26] S. Kumar, G.N. Tlwari, H.N. Singh, Annual performance of an active solar distillation system, Desalination 127 (2000) 79–88.

[27] A. El-Bah, D. Inan, Analysis of a parallel double glass solar still with separate condenser, Renew. Eng. 17 (1999) 509–521.

[28] Y.P. Yadv, P.C. Eams, B. Norton, Metallic condensing cover reversed absorber solar still augmented with a straightened circular reflector, World Renewable Energy Congress VI (2000).

[29] S. Aboula-Enein, A.A. El-Sebaii, E. El-Bialy, Investigation of a single-basin solar still with deep basins, Renew. Eng. 14 (1998) 299–305.

[30] K. Voropoulos, E. Mathioulakis, V. Belessiotis, Experimental investigation of the behavior of a solar still coupled with hot water storage tank, Desalination 156 (3) (2003) 15–322.

[31] M.A. Samee, U.K. Mirza, T. Majeed, N. Ahmad, Design and performance of a simple single basin solar still, Renewable Sustainable Energy Rev. 11(3) (2005) 543–549.

[32] S. Toure, P. Meukam, A numerical model and experimental investigation for a solar still in climatic condition in Abidjan (Côte d'Ivoire), Renew. Eng. 11 (1997) 319–330.

[33] S. Aboula –Enein, A. A. El-Sebaii, M.R.I Ramadan, E. El-Bialy, Year- round performance of a modified single-basin solar still with mica plate as a suspended absorber, Energy 25 (2000) 35–49.

[34] Y.P. Yadav, Transient performance of a high temperature solar distillation system, Desalination 91 (1993) 145–153.

[35] A. Harmim, M. Boukar, Simulation of operation of a hot box solar still coupled with a plane collector, Int. J. of Solar, Spring (21) (2000) 9–14.

[36] K. Voropoulos, E. Mathioulakis, V. Belessiotis, Solar stills coupled with solar collectors and storage tank—analytical simulation and experimental validation of energy behavior, Sol. Energy 75 (2003) 199–205.

[37] Gora NIANG, Mamadou ADJ, Dorothé AZILINON, Vincent SAMBOU, Atou SALL, Etude expérimentale d'un chauffe-eau solaire destiné à la récupération de l'énergie stockée dans la toiture-terrasse en béton d'un bâtiment [Experimental study of a solar water heater for recovering the energy stored in a concrete flat roof of a building], Université Cheikh Anta Diop, Dakar, Sénégal.