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Effect of absorber coating on the performance of a solar still in the region of Ouargla (Algeria)

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ABSTRACT

As the world's population grows in number and riches, the demands for water and energy are increasing faster than ever. Reports on the availability of potable water have listed Algeria among top countries affected by water shortage. This work provides a study dealing with distillation for isolated low-density population areas using solar energy. The utmost objective of the present investigation is to enhance the yield of a solar still by improving the performance of its absorber. This was achieved by laminating the surface of the absorber by layers of treated alluvial sand. Small-scale solar-powered distillation pilot units have been set up and operated. The tests were conducted in Ouargla, south of Algeria. Two series of experiments were performed. The first consisted of studying the effect of the sand diameter on the daily output of the still. The influence of the sand surface density was investigated in the second series. The experimental results showed that: For a fixed mass of sand (given surface density), the yield improvement of the still was inversely proportional to the sand particle diameters. The output in distilled water for a fixed particle diameter increases with the increase in the sand surface density.

Keywords: Desert climatic conditions; Solar still; Absorbers; Desalination; Solar energy; Arid zones

1. Introduction

Water and energy are closely associated with evolution and civilization of mankind. As the world's population grows in number and riches, the demands for both resources are increasing faster than ever. Lately, global water consumption levels increased dramatically, reaching or exceeding the limits of renewable water resources in some areas, especially in the Middle East and North African countries. In these places, the existing freshwater resources are under heavy threat from overexploitation, pollution and global warming [1].

The physical evidence of water scarcity can be found in increasing magnitude around the world. Nowadays, say 40% of the world's population lives in water menace conditions, and this situation could deteriorate if the current consumption trends continue [2].

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In an attempt to overcome the continuous rising demand for fresh water worldwide, many desalination techniques have been used. Thermal desalination [3,4] and membrane desalination [5–8] are the technologies predominantly used for easing the problem of water scarcity. Usually, these desalination plants require significant amounts of thermal and/or electrical energy. Consequently, they have been seen as energy intensive, pollutant, and expensive processes.

Due to the geographical situation, Algeria disposes of an important potential of renewable energies. However it is lacking in one very essential resource: water. The water deficits are increasing from year to year due to the increase of the demand. Like other North African countries, a great part of the population is rural. Currently, some 55% of the populace lives in rural area, about 1.5 million nomads live in the Saharan area.

Most of the locations in many geographic remote areas in Algeria are isolated and are thinly populated. The inhabitants of such areas have limited access to grid electricity and are in need of drinking water. The little water they obtain is from borehole wells by traditional means. Unfortunately, this underground water is not always considered to be apt for drinking.

Recent reports on the availability of potable water in the world have listed Algeria among the 14 countries worldwide most affected by water shortage, and might jump to the sixth place by the year 2025 [1]. The water availability per capita is diminishing at an alarming rate. In theory, the current water availability in Algeria is about 500 m^3/capita, down from 1,500 m^3 in 1962. It is projected that it will further plunge to 430 m^3 in 2020. When Algeria's water deficiency is projected forward in relation to the growing demand from an increasing population, Algeria can be seen to be already in a category of serious water scarcity in the very near future [2].

Located within the solar stripe of the world, Algeria has substantial solar energy throughout its territories which constitutes a considerable asset for arid and semi-arid localities. The mean solar irradiance period in the town of Ouargla (south of Algeria)—(latitude 31.95 north, longitude 5.40 east, and altitude 141 m) is around 3,500 h per year, delivering some 2,650 kWh/(m^2year) of solar irradiance on the horizontal surface [9,10]. In fact, the total solar potential of Algeria is estimated to 1,69,440 TW h per year, which represents 5,000 times the national annual power consumption in electricity [11].

Although this region has an abundance of year-round solar irradiance, most existing desalination plants currently use conventional nonrenewable energy sources with associated carbon dioxide emissions contributing to the global climatic change. To reduce the CO_2 production, renewable energy sources, such as solar-generated power, could be used. Solar energy is available when demand for water is high (day time during summer), which is advantageous. The use of this free, abundant, and nonpollutant form of energy in this area could be an attractive alternative and can be used for many applications like drying, heating, distilling water, etc.

The integration of renewable resources such as solar in desalination and purification of available brackish water seems to be a logical and attractive answer for supplying these small remote agglomerations with fresh water. This is especially true for Sahara Algerian sites, where both salty underground water and solar radiation are abundant.

The significant groundwater resources of Algeria are located in the south. In fact about 76% of the underground water resources are situated in the Sahara [12]. The salinity levels in these parts are variable and some sources have salinity levels of up to 8 g/L; and this is well beyond the allowed 550 ppm salt levels for human consumption [13]. Distillation method using solar energy can be economical, environment-friendly, and renewable energy-based technology [14].

Small-scale brackish water solar distillation can make a considerable contribution to secure some freshwater supplies for these rural communities. More importantly, it will help in keeping these inhabitants in place and therefore, prevent/reduce unplanned immigration floods to the already densely-populated large cities.

Nomads, for example, are constantly on the move following the graze for their flocks. Solar distillation stills are characterized by their small size. Probably their greatest advantage is that they can easily be transported by the moving nomads.

Within this framework outline, a research group on small-scale solar distillation destined especially for isolated locations was established in the laboratory of new and renewable energies in arid zones (LENREZA) at Ouargla University, Algeria, as a possible solution for converting brackish water into soft water. For this purpose, basin-type solar stills were constructed and experimentally tested under climatic conditions of the arid zone of Southern Algeria. These types have the advantage of being simple devices in terms of construction, operation and maintenance. They are cost-free energy, easy to transport, environment-friendly, usually more targeted towards poor communities, and more importantly, they can run untended for long periods of time in remote isolated sites in the desert.

Various investigations concerning solar still yield improvement have been reported by many researchers. For example, Al Hayek et al. and Mahdi et al. [15,13] proposed designs and construction of solar stills. Patel et al. [16] studied the influence of different photocatalysts on the overall efficiency of the still. They showed that the rate of production of distillate water was increased to a remarkable extent. The effect of refractors on a single basin was studied theoretically and experimentally by Ayav and Atagunduz [17]. This paper provides a study dealing with distillation for isolated low-density population areas using solar energy. The utmost objective of the present investigation has been to enhance the yield of a solar still by improving the performance of its absorber. This was achieved by laminating the surface of the absorber by the blackened layers of treated alluvial sand.

Dune and alluvial sands are abundant in this region. They contain large percentage of silicium oxide (SiO_2) and traces of other metal oxides. Due to their photocatalytic properties, these sands have received special attention by our laboratory LENREZA. Moreover, they have been used in other water treatment applications in this region as biological filters [18].

2. Experimental

2.1. Construction of solar stills

Two identical solar still prototypes were constructed, one of which was used as a reference unit (witness unit) while the parameters under investigation were applied to the other (test unit). The two units were used to overcome the variation in meteorological parameters ambient temperature, solar irradiance, and wind velocity from one day to the other. Fig. 1, shows a sketch of the single-basin solar still used in this study. The solar still was made of wood 40 mm thick. Its basin (absorber) is a tray ($480 \times 370 \times 30$ mm) made of galvanized metal 3 mm thick. The absorbers of both stills were blackened on the surface to ensure maximum absorption of solar irradiance for effective heating of the water. The base of each assembly was further lagged with a 30 mm thick polystyrene insulation. The 3 mm thick removable glass cover of the stills was placed such that it makes an angle of 13° with the horizontal which is recommended for Ouargla region [10]. The slopping glass cover was sealed tightly by silicone sealant to prevent any vapor leakage. Local brackish water (3 g/L concentration) was supplied to each still via an adjustable float to provide and maintain the desired water level in the still. A distillate trough runs along the lower edge of the glass to collect the distillate and carry it out of the enclosure through plastic tubing.

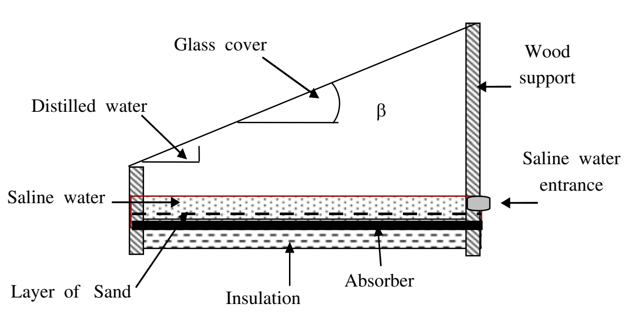

Fig. 1. Cross-section of solar still.

2.2. Sand preparation

Prior to any experimentation, the used alluvial sand has to be cleaned of all impurities and classified into different sizes. This was achieved following the processing steps:

Local alluvial sand was brought from nearby sites. Using different size sieves, the sand was classified according to its size into three categories. The average sand grain diameters of the sand varieties used were 0.315, 0.16, and 0.08 mm, respectively. Each sand category was then treated separately as follows:

(1) washed with distilled water, then
(2) with hydrochloric acid (HCl 10%),
(3) afterwards, it is washed again with distilled water to remove all traces of HCl,
(4) later on, put in an electric oven set to a temperature of 900℃ to eliminate remaining impurities,
(5) finally, the pure sand is painted with black mat paint and let to dry in the shade.

2.3. Experimental procedure

The stills were installed and tested at the LENREZA laboratory, Ouargla University, south of Algeria, with long axes of the stills facing south-north direction in order to take in utmost solar irradiance.

All runs started at 8.00 am and terminated at 5.00 pm local time. During operations, measurements of solar irradiance, temperatures of inner surface of the glass cover and water in the basin were made regularly. The ambient temperature, wind velocity, and distillate were also monitored. The values of the different raw data were recorded at regular intervals throughout the duration of the tests.

Two experimental series were performed. The objective of which was to ameliorate the output of the solar still by improving the performance of its absorber. This was realized by laminating the surface of the absorber by layers of treated local alluvial sand. The black painted sand was homogeneously overspread over the entire surface of the absorber of the test still (under study), whereas the other still (witness unit) remains without sand.

The first series consisted of studying the effect of the sand diameter on the average daily output of the still. Therefore, the mass of the sand layer on the absorber was maintained at 200 g, i.e. at a surface density of 1.134 kg of sand/m^2 absorber, whereas, the sand category was varied. The used sand diameters were 0.315, 0.16, and 0.08 mm, respectively.

In the second series of runs, the grain size was fixed and the chosen one had a diameter of 0.16 mm. The sand surface density on the absorber was varied by adding 100 g of sand after each set of experiment. The respective masses of sand in these sets of experiments were 200, 300, and 400 g, that is to say, with sand surface densities of 1.134, 1.70, and 2.268 kg of sand/m^2 absorber, respectively.

The reproducibility of the results in all tests was ascertained by repeating each experiment three times in three subsequent days. The results of each experimental series were normalized, in a form of productivity factor which is simply the yield comparison between the witness and the test units. This experimental practice was carried out on the two units throughout the entire run, thus giving a better indication of the units' output and overcoming the problem of fluctuations/nonsymmetry of the day as well.

3. Results and discussion

3.1. First series (fixed mass ($m = 200$ g), variable size)

Fig. 2 displays typical measured temperature–time history curves of still in the first series of tests. As shown, the temperatures follow the same trend as the solar irradiance. They increase in the first half of the day to maximum values at around 13.00 h, before they start to decrease in the afternoon. The water temperature in the basin was highest, since the solar energy is absorbed in the absorber, followed by the glass temperature and then the ambient temperature.

It can be easily ascertained from the results of the first series that the output of the test still was improved by coating the absorber by a thin layer of

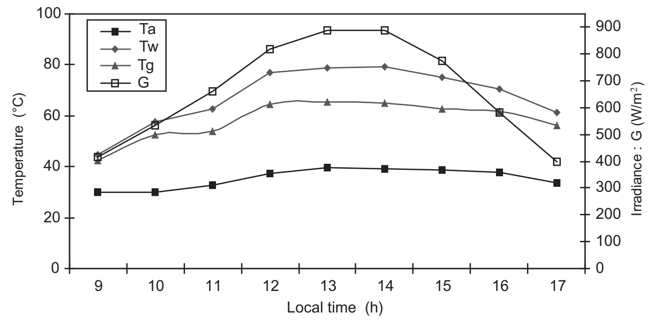

Fig. 2. Typical solar irradiance and difference temperature curves for still with layer of sand ($D = 0.16$ mm, $m = 200$ g).

sand (1.134 kg of sand/m^2). It can also be noticed that the percentage of the yield enhancement was inversely proportional to the sand particle diameter.

As displayed in Fig. 3, the amount of distilled water in the test still was improved by 27.43% when using the largest sand grain ($D = 0.315$ mm). Fig. 4 Shows, that the water productivity was enhanced by about 30.67% by utilizing the intermediate sand size ($D = 0.16$ mm). Interestingly, the employment of the finest sand grains ($D = 0.08$ mm) resulted in a further rise in the daily distillate production which reached 43.51% (Fig. 5).

A comparison of the cumulative yield for the different sizes of the sand grains (first series) is presented in Fig. 6. The amelioration in performance can be readily seen from the curves. These curves show clearly that the daily cumulus in distilled water is inversely proportional to the diameters of grains.

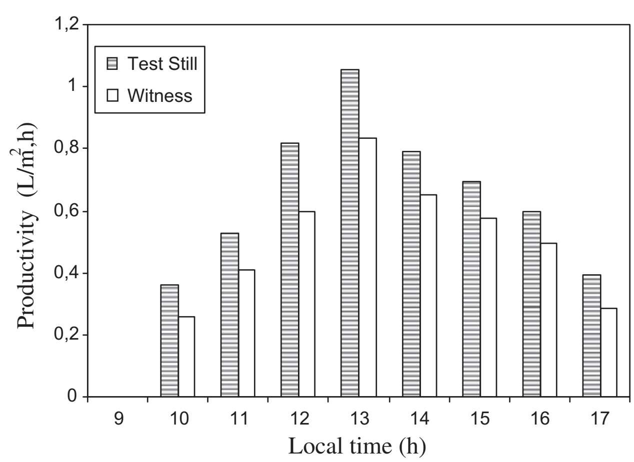

Fig. 3. Volumetric productivity of the two stills in the first series ($D = 0.315$ mm, $m = 200$ g).

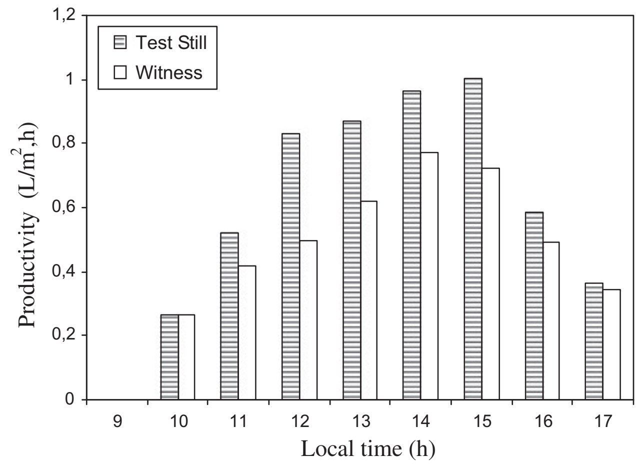

Fig. 4. Volumetric productivity of the two stills in the first series ($D = 0.16$ mm, $m = 200$ g).

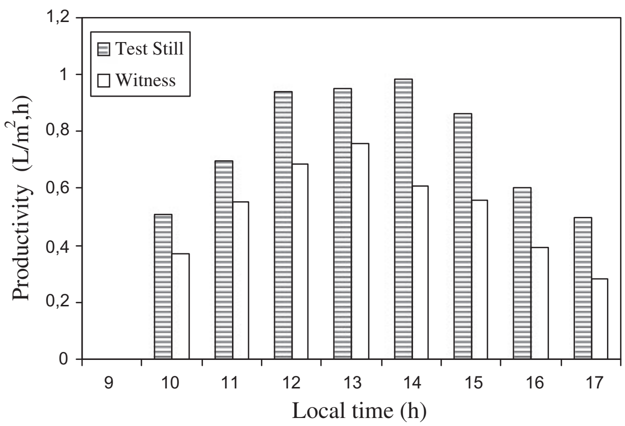

Fig. 5. Volumetric productivity of the two stills in the first series ($D = 0.08$ mm, $m = 200$ g).

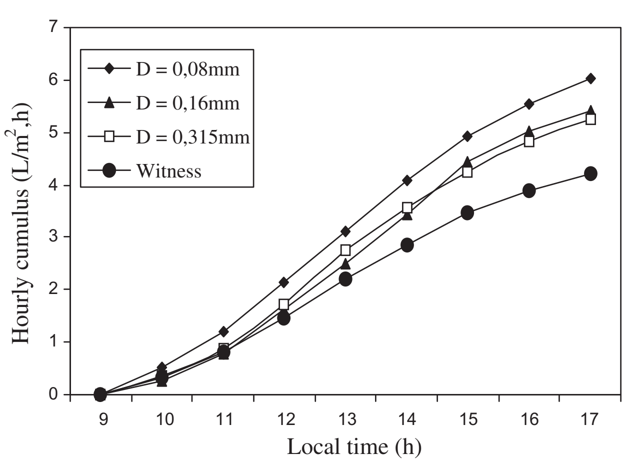

Fig. 6. Hourly cumulus for different grains size in the first series ($m = 200$ g).

3.2. Second series (fixed grain size ($D = 0.16$ mm), variable mass)

From the results of the second series, it can be seen that the output of the distiller increases with the increase of the mass of sand on the absorber (surface density).

In this series of runs, the grain size was fixed and the chosen sand had a diameter of 0.16 mm; the sand surface density on the absorber varied by adding 100 g of sand after each set of experiments. The respective masses of sand in these test sets were 200, 300, and 400 g, that is to say, with surface densities of 1.134, 1.70 and 2.268 kg of sand/m^2 absorber.

The enhancement in performance can be facilely observed from Figs. 7–9. The average daily gain in distilled water was 30.67% (for a mass of 200 g of sand, or a surface density of 1.134 kg of sand/m^2. absorber) (Fig. 7).

When the surface density of sand on the absorber was raised to 1.70 kg of sand/m^2.absorber (i.e. 300 g of sand); the average daily clear profit in distilled water followed suit and reached 37.44%.

It was remarked here that between 8.00 and 10.00 am local time (Fig. 8) the witness still has cumulated some 320.76 mL while the test still (under study) has gathered only 315.5 mL. This could be explained by the fact that with an additional mass of 300 g of blackened sand, the capacity of the absorber to store more energy starts to become important. It is of interest, to notice that after 10.00 am this phenomenon was reversed and the production of the test distiller becomes significant and exceeds that of the witness still.

For a mass of 400 g of sand (surface density 2.268 kg of sand/m^2 absorber); here again the test still between 8.00 and 11.00 am begins to store the solar energy within the additional 400 g of blackened sand

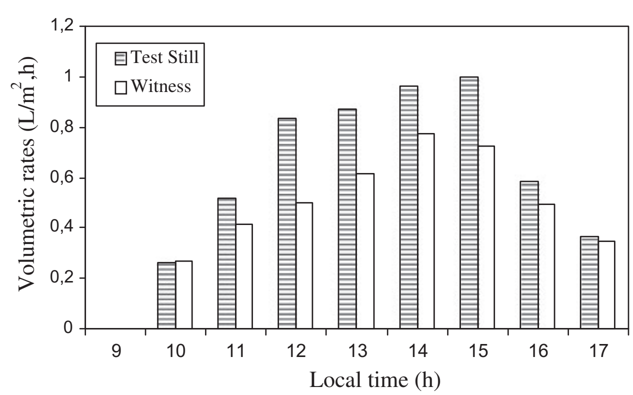

Fig. 7. Volumetric rates of distilled water for the two stills in the second series ($D = 0.16$ mm, $m = 200$ g).

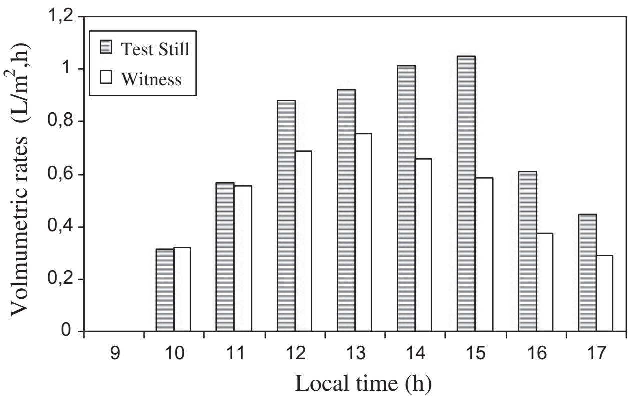

Fig. 8. Volumetric rates of distilled water for the two stills in the second series ($D = 0.16$ mm, $m = 300$ g).

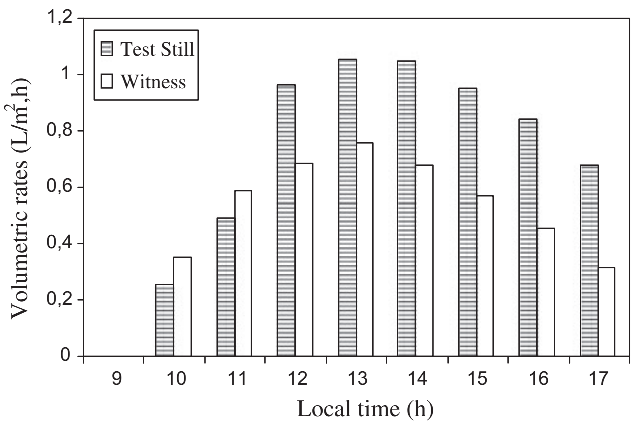

Fig. 9. Volumetric rates of distilled water for the two stills in the second series ($D = 0.16$ mm, $m = 400$ g).

which became much higher. During this period, the witness distiller had cumulated 935.7 mL compared to 745.28 mL collected by the test still (negative gain percentage). After 11.00 am the percentage becomes positive and the overall daily gain in distilled water attained 43.28%. It is also observed that the (study) still in this case (with 400 g of sand) continues to distill even after sunset because of the energy stored previously in the sand bed (Fig. 9).

Fig. 10 represents, the hourly cumulus of distilled water (L/m^2 h) for the different sand surface densities with the same sand variety ($D = 0.16$ mm, second series). It is clear that the amelioration in the cumulative output is directly proportional to the surface density of sand layers.

The productiveness of the still in terms of yield per square meter could be augmented by several ways. Evaporation rate can be increased if the temperature difference between the absorber and the condenser is increased. This can be brought off by either increasing the basin temperature or decreasing the glass cover temperature or both.

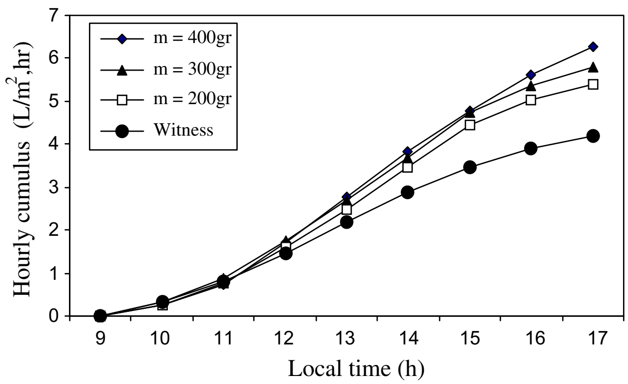

Fig. 10. Cumulative yields for different sand masses in the second series ($D = 0.16$ mm).

According to Fig. 10 we can notice:

The production of distiller with 400 g of sand does not exceed that of with 300 g until 16.00 h. We speculate that the output of a probable distiller with 500 g of sand becomes important only when sunset nears. At that time, the temperature decreases and losses of the heat stored by the absorber to the outside becomes important. So we concluded that a probable distiller with 500 g of sand would not be beneficial.

Fig. 11, displays the temperature difference ($\Delta T = T_w - T_g$) between glass cover and basin water of stills in the second series with different surface densities of sand layers.

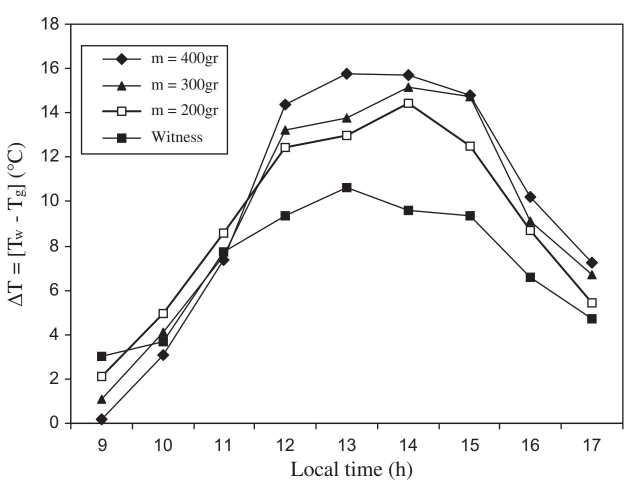

Fig. 11. Curves of temperature difference between glass cover and basin water of still with different sand masses in the second series ($D = 0.16$ mm).

As shown, the curves have the same trend, as they increase in the morning hours to their maximum values at around 13.00 h, before they start to decrease late in the morning. In general, the basin water temperature was always higher than that of the glass cover.

It is a well-known fact that the value of the temperature difference between glass cover and absorber is directly proportional to the quantity of distilled water in the still. Therefore, Fig. 11 clarifies rightly the results obtained in Fig. 10. It is noted that the results displayed in Fig. 11 could explain well those obtained in Figs. 7–9.

In the early hours of the runs (9.00 am), the witness still produces more distillate than the others, as its (ΔT) is the highest (3˚C). Whereas, the distiller with 400 g of sand layer begins between 8.00 and 11.00 am to store the radiant energy into the sand layer. And this made its production the smallest, but afterwards showed the best production. This phenomenon was observed with the two other stills with 300 and 200 g of sand, but with a lesser magnitude.

After 11.00 am local time, the yield of the still with 400 g became the highest, followed with 300 g, succeeded by 200 g and then the witness still.

Generally to increase the flow rate of distilled water, the condenser temperature must be lower than that of the absorber, or when the difference ΔT is greater. According to curves 7–11, we note that the addition of the sand mass increases the temperature difference between the absorber and the condenser and subsequently augments the cumulative amount of distilled water. We believe that this is due to:

(1) The internal overheating causes an increase in the glass cover temperature (condenser), and reduces the gap temperature between the absorber and the condenser (ΔT). Therefore, adding a mass of blackened sand will act as a reservoir of high heat capacity which absorbs suppliant energy and avoids additional internal temperature rise of the condenser (glass) keeping the gap ΔT still high, and consequently causes significant production of distilled water.
(2) To enhance the overall efficiency of conventional basin type solar still, different semiconducting metal oxides have been utilized as photocatalysts. It was observed that metal oxides not only improve the efficiency of the process but the rate of production of desalinated water was also increased to a remarkable extent [16]. In our case, the used alluvial sand which is composed mainly of SiO_2 and other lesser percentage of metal oxides (such as, FeO, Fe_2O_3, etc. …) plays the role of a photocatalyst especially when solar irradiance is low.

4. Conclusions

In these times, the lack of fresh water in remote arid and desert areas in the south-east of Algeria has reached an alarming point. The dwellers of these sites use groundwater that is abundant but often too salty for human consumption. Solar distillation using simple small-scale stills is one of the cheapest solutions given the high-intensity of solar irradiance that characterizes the region throughout the year and the simplicity of these devices.

Within this think out, a small-scale solar still system was constructed and its performance was studied. These distillers are characterized by their simplicity, ease of transportation, cleaning and maintenance, making distilled water produced by these devices cheaper.

One of the contributions to improve the daily yield of the solar stills was the use of blackened layers of alluvial sand on the absorber of the still. The experiments carried out in the LENREZA laboratory at Ouargla University, south-east of Algeria showed that:

(1) The percentage of gained distilled water increases when the sand diameter was finest (the masse of sand was maintained constant at 200 g, that is, 1.134 kg of sand/m2 absorber).

- For a sand diameter, D = 0.315 mm, the improvement in the yield was 27.47%.
- For a particle size D = 0.16 mm, the gain was 30.67%.
- For a diameter D = 0.08 mm, the percentage reached 43.51%.

(2) The amount of distilled water increased with the increase in the quantity of sand on the absorber or the surface density of sand on the absorber (the grain diameter was maintained constant D = 0.16 mm).

- For a sand layer of 200 g (1.134 kg of sand/m2 absorber), the amelioration in distilled water was 30.67%.
- For a sand mass of 300 g (1.70 kg of sand/m2 absorber), the percentage was 37.44%.
- When the sand layer was 400 g (2.268 kg of sand/m2 absorber), the rise reached 43.28%.

Symbols

G	—	solar irradiance, W/m^2
T_a	—	ambient temperature, ℃
T_g	—	glass cover temperature, ℃
T_w	—	basin water temperature, ℃
ΔT	—	$\Delta T = T_w - T_g$, ℃

References

[1] The World Bank-Bank-Netherlands Water Partnership, seawater and brackish water desalination in the Middle East, North Africa and Central Asia, Final Report, annex 1, Algeria, DHV Water BV, Amersfoort, 2004.

[2] M. Zeroual, H. Bouguettaia, D. Bechki, S. Boughali, B. Bouchekima, H. Mahcene, Experimental investigation on a double-slope solar still with partially cooled condenser in the region of Ouargla (Algeria), Energy Procedia 6 (2011) 736–742.

[3] M.T. Myint, A. Gh Ghassemi, N. Nirmalakhandan, Modeling in desalination electro-dialysis reversal, DWT 27 (2011) 255–267 (USA).

[4] A. Neilly, V. Jegatheesan, L. Shu, Evaluating the potential for zero discharge from reverse osmosis desalination using integrated processes—A review, DWT 11 (2009) 58–65 (Australia).

[5] P. Poovanaesvaran, M.A. Alghoul, K. Sopian, N. Amin, M.I. Fadhel, M. Yahya, Design aspects of small-scale photovoltaic brackish water reverse osmosis (PV-BWRO) system, DWT 27 (2011) 210–223 (Malaysia).

[6] M. Bodzek, K. Konieczny, A. Kwiecinska, Application of membrane processes in drinking water treatment–state of art, DWT 35 (2011) 164–184 (Poland).

[7] M.A. Darwish, F.M. Al Awadhi, A.O. Bin Amer, The impact of the cogeneration power and desalting plants (CPDP) on the environment in Kuwait, DWT 12 (2009) 185–195 (Kuwait).

[8] G.N. Sashi Kumar, A.K. Mahendra, A.S.A. Sarjaland, G. Gouthaman, Generic algorithm based optimization of a multistage flash desalination plant, DWT 1 (2009) 88–106.

[9] A.W. Clarke, J.A Tinnaman, Survey of Energy Resources, World Energy Council, London, 2010.

[10] D. Bechki, H. Bouguettaia, J. Blanco-Galvez, S. Babay, B. Bouchekima, S. Boughali, H. Mahcene, Effect of partial intermittent shading on the performance of a simple basin solar still in south Algeria, Desalination 260 (2010) 65–69.

[11] Y. Himri, A.B. Stambouli, Prospects of wind farm development in Algeria, Desalination 239 (2009) 130–138.

[12] B. Bouchekima, A small solar desalination plant for the production of drinking water in remote arid areas of southern Algeria, Desalination 156 (2003) 353–354.

[13] J.T. Mahdi, B.E. Smith, A.O. Sharif, An experimental wick-up solar still system: Design and construction, Desalination 267 (2011) 233–238.

[14] R. Dev, A. Salah, Abdul-Wahab, G.N. Tiwari, Performance study of the inverted absorber solar still with water depth and total dissolved solid, Desalination 88 (2011) 252–264.

[15] I. Al-hayek, O.O. Badran, The effect of using different designs of solar stills on water distillation, Desalination 169 (2004) 121–127.

[16] S.G. Patel, S. Bhatnagar, J. Vardia, S.C. Ameta, Use of photocalysts in solar desalination, Desalination 189 (2006) 287–291.

[17] P.I. Ayav, G. Atagunduz, Theoretical and experimental investigations on solar distillation of IZTECH campus area seawater, desalination, Desalination 208 (2007) 169–180.

[18] Y. Touil, R. Issadi, S. Taha, A. Amrane, Pilot plant for wastewater treatment involving septi septic pit and biological filtration on sand sand of dunes of the Algerian Sahra, DWT 10 (2009) 148–152.