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AQUASOLAR-Maroc project: Brackish Water Desalination by coupling Solar Energy with Reverse Osmosis and Membrane Distillation Process

K. Gourai[1], K. Allam[1], A. El Bouari[1], B. Belhorma[2], L. Bih[3], N. Cherai[4]

[1]*University Hassan II Casablanca, Faculty of science Ben M'sik Casablanca (LPCMA)*
[2]*National Centre for Energy, Nuclear Science and Technology, CNESTEN, B.P. 1382 R.P. 10001.*
[3]*University Moulay Ismail, Faculty of science Meknes*
[4]*LSA Industries, 125 Rue Michel de l'Hospital Roches Noires, 20290, Casablanca.*

**Corresponding Author. E.mail: gouraikhadija@yahoo.fr ; Tel: (+212645770783)*

Abstract

AquaSolar-Maroc project focuses on brackish water desalination using solar energy. This project is funded by the Institute for Research in Solar Energy and New Energies (IRESEN), and involves both scientists and engineers from CNESTEN, Moulay Ismail and Hassan II Universities, and the "LSA-Industries" and "Tube et Profil" companies, and the Plataforma Solar de Almeria (PSA-Spain).The chosen technologies consist of a combination of reverse osmosis (RO) powered by photovoltaic (PV) panels and membrane distillation (MD) powered by solar thermal panels. This station therefore uses both the heat and the light emitted by the sun to produce on average 5m3 of drinking water per hour. The solar potential of Morocco is among the most higher in the world, with a peak of the global normal irradiance up to 1100W/m2 and an average of 2.8MWh/year. The solar field of the station is composed of 57 flat photovoltaic solar panels and 18 flat thermal solar panels, producing respectively 10kWe and 14kWth necessary to supply autonomously the whole station composed of the RO and MD processes as well as the accessories (air conditioning and lighting).

Among the project work packages, we can cite:

- Study of hydrological and climatic conditions of the site
- Study of the technical performances of RO/PV and MD/thermal processes individually as well as their coupling
- Study of perspective material for low cost water treatment

This article gives an overview on the AquaSolar-Maroc project, and the main results on the hydrological and climatic conditions of the site.

Keywords: Solar Energy, Desalination, Reverse Osmosis, Membrane Distillation, Brackish Water.

Introduction

Currently freshwater resources became inadequate or non-sufficient due to the demographic and industrial growth. The shortage of freshwater resources is a major problem in arid regions of the world. More than 97% of the water on the surface of the Earth is salt water and the desalination of this water presents an alternative solution to provide water for drinking and irrigation purposes. [1, 2]

The project AquaSolar-Maroc, within its pilot station implemented in Benguerir, makes use of solar energy to supply brackish water desalination unit. The desalination technology is based on the combination of Reverse Osmosis (RO) and Membrane Distillation (MD) processes.

We initiated our work by studying the climatic and hydrological conditions in the region of Benguerir. Results of these studies are given in the following paragraphs.

2. Materials and methods

2.1 *Climate and irradiance data*

Benguerir city is situated in the center of Morocco at about 70 km north of Marrakech (latitude: 32°14'58'' Nord, longitude: 7°56'56'' Ouest).

In order to evaluate the solar energy potential, it is necessary to study the climatic conditions of the site, Benguerir in our case. The main parameters are temperature, wind speed, precipitation, hygrometry and solar irradiance:

- ✓ Hygrometry: that corresponds to the humidity of the atmosphere. A high humidity rate has negative effects on the solar potential decreasing the solar irradiance at the solar panels level, and by the corrosion effects on the metallic structure supporting the panels.
- ✓ Wind speed is an important parameter namely for technical aspects related to the dimensioning and design of the solar panels mechanical supports.
- ✓ Horizontal daily solar radiation is the sum of the direct normal irradiation and the diffuse radiation.
- ✓ The DNI (Direct Normal Irradiance): is the monthly/yearly average of the sum of the solar radiation energy that comes directly from the sun (so excluding light from sky and clouds) per one flat square meter.
- ✓ Ratio of diffuse to global irradiation: A large fraction of the radiation arriving at the ground does not come directly from the sun but results on scattering from the air (the blue sky) clouds and haze, this is known as diffuse radiation. This parameter gives the fraction of the total radiation arriving at the ground which is due to diffuse radiation.

On the other hand, since the project concerns water desalination, it was necessary to study also the water resources and its quality in the region, by study the: turbidity, TDS and conductivity.

2.2 *Hydrological resources of Benguerir*

The main underground water resources of the city belong to the Bahira in Tensift El Haouz basin (Figure 2), and the main surface water source is the river of Oued Gaino, with an estimated flow of 50 l/sec. Superficial intakes of this river crus are most likely low, around 5 Mm^3/year. [3]

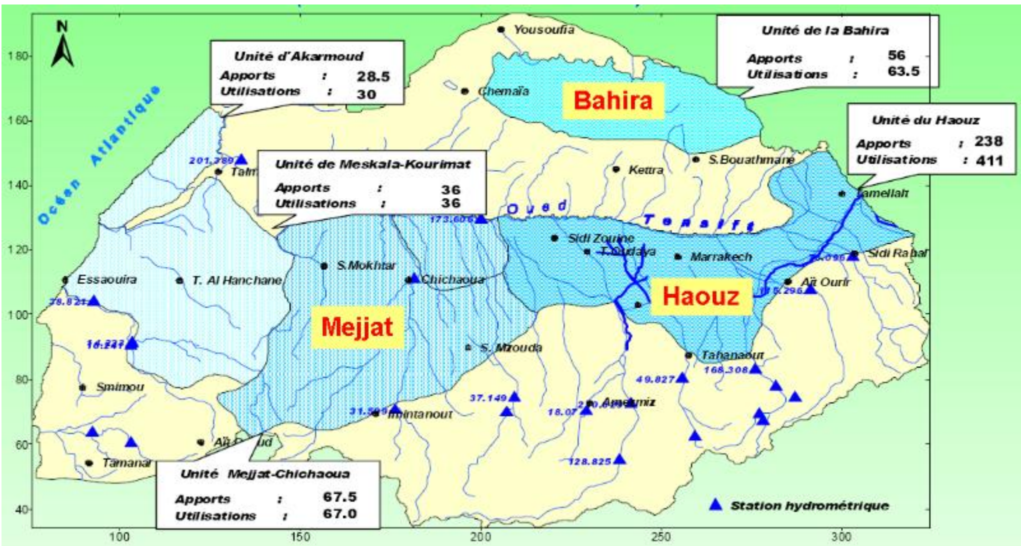

Figure 1: The water sheet of Bahira

Direct infiltration of rainwater and infiltration of runoff from the Jbilet are of the order of 56 million m^3 and are the main component of the natural recharge of the aquifer system of Bahira. The general flow is toward the Oued Tessaout. A portion of this flow accumulates in lake Sed El Majnoun where it evaporates. In the western part of the plain, very little flow occurs to the Zima lake where water also evaporates.

2.3 *General description of the project*

The project involves studying solar energy and its use for the desalination of brackish water. The photovoltaic panels produce 10 kWe for supplying RO process and other devices (namely lights, pumps and air conditioning). The flat thermal panels produce 15 kWth to provide thermal energy for membrane distillation process. This combination is represented as follows:

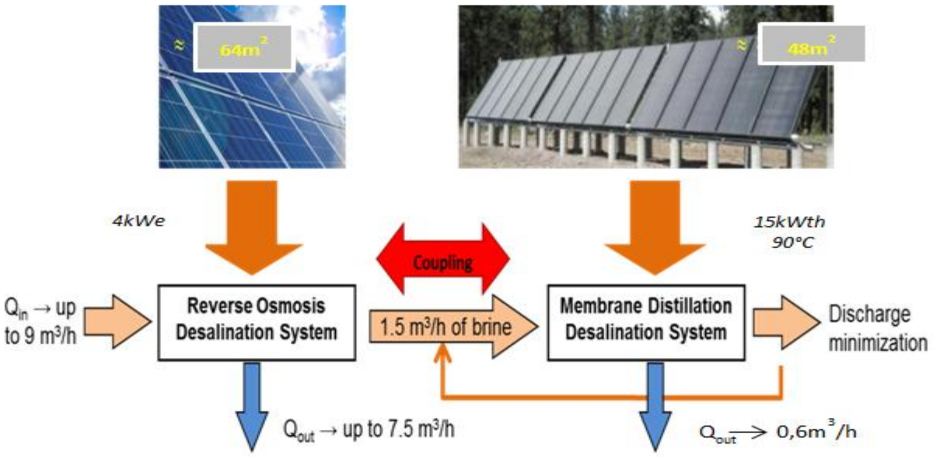

Figure 2: General description of the project.

The processes used in this project are:

- Reverse osmosis (RO): Reverse osmosis is a process used in the brackish water treatment plant; before tackling the process water is initially subjected to a pretreatment with multi-media filtration and cartridge filtration to be after subjected to post treatment. [4, 5]. Reverse osmosis is a tangential filtration process which allows the extraction of water, by selective permeation through a dense membrane under the action of a pressure gradient. (Fell 1995). Water produced by RO has always very high quality. Treatment of neutralization is necessary when the water is destined for drinking, by adding an amount of calcium and magnesium to improve taste of the produced water. [6]
- Membrane Distillation: Membrane distillation is a thermal process using a hydrophobic membrane impermeable to liquid water, to distillate seawater at a temperature of 70 to 90°C. When heating salt water on the surface of the membrane, the hydrophobic nature of the membrane allows water vapor crossing through the membrane, but the salty liquid cannot penetrate. Water vapor which accumulates on the other side of the membrane is then condensed to provide distilled water. [7, 8].

3. Results and discussion

To determine the general climate data of the regions of our study, we used RetScreen softwar, which provides climate information. For more details of solar irradiance which is an important feature, we used the PVGS online software that allows also calculating the photovoltaic. Table 1 shows the mean values of maximal and minimal temperature and the average precipitation in Benguerir recorded during the year 2013. Data of the irradiance which is a pretty important coefficient are given in table 2.

Table 1: Climate data of Benguerir (2013)

Month	Maximal Temperature (°C)	Minimal Temperature (°C)	Precipitation (mm)
January	26	15	8.55
February	20	13	0.46
March	28	17	3.06
April	27	18	1.3
May	28	18	16.87
June	30	21	0
July	32	22	0
August	38	24	0
September	29	22	5.73
October	27	22	0.39
November	24	16	1.5
December	22	15	0.87

According to the table 1, we see that the daily mean temperature reaches its maximum on August and its minimum on February. For the precipitation we see that it's low with an average maximum value less that 20 mm. We note that there is a dry period from July to August, and a wet period from October to December. So the region can be classified as semi-arid.

Table 2: Irradiance data of Benguerir

Month	Hygrometry (%)	Wind speed (m\s)	Horizontal daily solar radiation (kWh/m2/day)	DNI (kWh/m^2/day)	Ratio of diffuse to global radiation
January	53.2	3.7	5.39	5.32	0.32
February	51.1	3.9	6.01	5.76	0.31
March	48.0	4.1	6.98	6.26	0.37
April	49.1	4.3	6.93	7.02	0.28
May	48.1	3.9	6.89	7.42	0.28
June	46.4	3.8	7.17	8.44	0.23
July	42.1	4.0	7.30	8.44	0.23
August	44.9	3.7	7.29	7.73	0.24
September	49.6	3.5	6.80	6.59	0.28
October	52.0	3.4	6.40	6.01	0.3
November	54.2	3.8	5.55	5.43	0.3
December	54.5	4.0	6.49	5.12	0.32
Yearly	**49.43**	**4.3**	**6.6**	**6.63**	**0.29**

From the table 2 we note that the humidity of the atmosphere is maximum in December with a mean value of 54.5%. The wind speed is average, with a maximum value in April. These values correspond to the monthly average, but the absolute wind speed can exceed 60 km/h during some days or some hours namely on autumn. So the dimensioning of the mechanical support structures takes these maxima into account.

In order to estimate the solar potential, the Global Normal Irradiance (GNI) and the Direct Normal Irradiance (DNI) per month are among the most relevant parameters. Figure 1 gives the monthly DNI and the GNI measured during the year 2014.

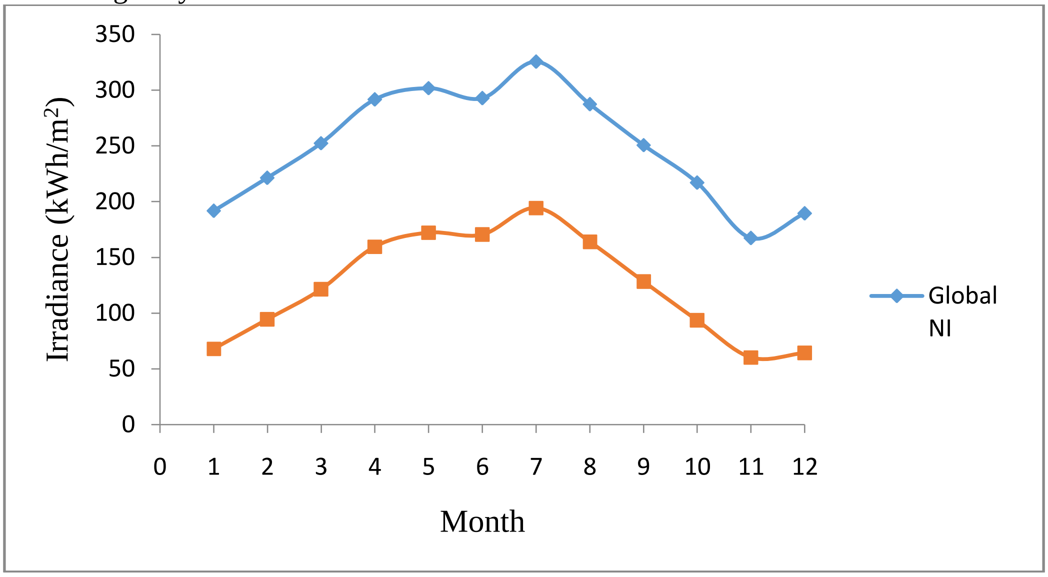

Figure 3: Global Normal Irradiance (GNI) and the Direct Normal Irradiance (DNI) per month of Benguerir (2014)

The DNI and the Horizontal daily solar radiation have the maximum in July, when the hygrometry, wind speed and the Ratio of diffuse to global radiation are minimum.

Integrating over the year we get the values of DNI = 1.49 MWh/m^2 and GNI = 2.98 MWh/m^2. These high values combined with the adequate climate data justify the choice of this site to implement such solar projects.

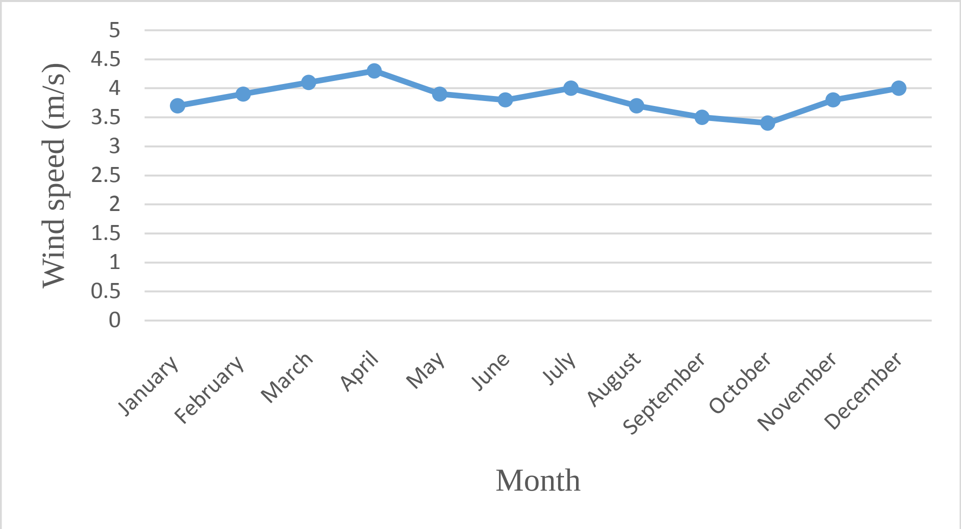

Figure 4: The wind speed per month of Benguerir (2014)

The wind speed is average; with a maximum value in April. These values correspond to the monthly average, but the absolute wind speed can exceed 60 km/h during some days or some hours namely on autumn. So the dimensioning takes these maxima into account.

In order to study the performances of the pilot desalination unit, we have studied the water quality after each treatment step of the RO process. The assessment of the water quality is made by analyzing the conductivity, turbidity and TDS of the water samples. The results obtained before and after RO treatment of brackish water pumped from nearby well are presented in the tables 3. The water quality is evaluated according to the OMS standards (table 4).

Table 3: Parameters of treated water

	Turbidity (NTU)	Conductivity (µs)	TDS (ppm)	Temperature (°C)
Feed water	2.47	2350	1170	17
The RO water	0.642	611	305	17
The neutralized water	0.166	359	197	17
Rejection	1.22	4550	2270	17

Table 4: OMS Standards of the TDS, the conductivity, and the turbidity for drinking water

TDS (ppm)	Evaluation
< 300	Excellent
300 <TDS < 600	Well
600<TDS < 900	Passable
900<TDS < 1200	Bad
>1200	Unacceptable

Conductivity (µs/cm)	Evaluation
<400	Excellent
400-1300	Good
1300-2700	Average
2700-3000	Bad
>3000	Very bad

Turbidity	Evaluation
NTU <5	Clear water
5 <NTU< 30	Slightly cloudy water
NTU > 50	Cloudy water

The brackish feed water has a bad TDS value and an average turbidity that traduces the presence of cations, anions and other non-dissociated species in water [9] as well as few organic or inorganic particles. After RO treatment, the conductivity of the desalinated and the neutralized water is excellent, whereas the rejection has a very high conductivity and TDS which confirms that the treatment works correctly and that the RO process is very efficient in removing dissolved mater and salts from the brackish water.

Conclusion

The obtained results show that the installed reverse osmosis process is well suited for brackish water desalination. On the other hand, the process is supplied by PV panels, and no anomaly was registered during all the performed tests, showing that photovoltaic energy responds well to the needs of our station.

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