Brine Evaporation Speed Enhancement by Solar Energy for Optimization of Salt Production of Lake Merouane El Oued Southeastern of Algeria

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Abstract

In this present paper we will study an assembly of two systems for collecting solar energy at the unit of SME (Salins Merouane El Meghaier) located in southeastern Algeria, by the development of a black grid floating in the brine and a reflection mirror of the solar radiation directed towards the evaporating surface in the test pan P4 and also a witness pan P0 which helps us to illustrate the influence of these two systems, results will be obtained suggest an increase in the evaporation-crystallization rate of P4 compared to that of P0 which is due to the improvement of the annual production of SME unit.

Keywords: *Algeria, lake, solar energy, mirror, black body, optimization, evaporation-crystallization, salts*

Introduction

The brine represents an important source of mineral salts suitable for domestic and industrial uses. The salts are composed of mainly halite mixed with other impurities such as carbonates, bicarbonates, and sulfates of sodium and potassium respectively. Thermodynamic calculations based on Pitzer's ion interaction model indicate that the lake brine is under-saturated with respect to the major dissolved mineral salts (Kasedde and al., 2014).

Algeria has considerable salt potential thanks to the very favorable climate conditions for the production of solar salt in chotts or lakes of the North, chotts or lakes of the highlands and high plains and chotts or vast depressions of the Saharan platform. These latter environments (chott, lake and depression) in Algeria have been the subject of rare detailed studies (Haddane Abdennour and al 2015). Among the lagoon areas of North Africa, chott Melghir and Merouane constitute with all the Tunisian chotts the largest closed depression (Gueddari.M; 1980). The regions of chott Merouane and Melghir are characterized on the surface by consolidated dunes of very fine sand (about 10 m thick), cemented at depth by gypsums, and the thickness of the sand is very important where the vegetation favors the stabilization of desert winds. Underlying we find these fine sands about 70m of clays which in turn rest on about 35m of sand and sandstone, forming part of the most important aquifer (Cornet, A, 1964).

This region has a Saharan climate with very high temperatures in summer (50°C in July and less than 5°C in January), a real evaporation exceeding 480mm/year where winds are very frequent in the region (Maximum speed of about 4.20 m/s). Precipitation is very rare and does not exceed 30 mm/year (Messaoud HACINI and al, 2004).

Solar energy is an important energy resource for salt precipitation from lake (KASEDD H. and al, 2015), it is one source of free energy that is inexhaustible in supply and use. Many processes in the mining and mineral processing industry, such as fractional crystallization and leaching lend themselves to solar applications. These operations constitute a major portion of the chemical processing employed in the purification and concentration of salts from brine. Enhancing brine evaporation in the solar ponds can be used not only as a means to offset energy costs to improve efficiency, but also to provide a suitable processing environment (Lesino and al., 1991; Folchitto 1991; Guijt and al, 1999). A number of experimental and modeling investigations directed towards the utilization of solar energy to enhance brine evaporation have been reported in literature. Abdel-Aal and Al-Naafa, 1993 investigated the enhanced evaporation of saline water in multi-purpose solar desalination units using flat-plat solar collectors. Their results showed that the concentrated solar energy input was estimated to be 3.5 times than that of direct solar flux allowing separation of soluble mineral salts such as NaCl, MgCl2 and others. Zhang and al, 1993 presented a simulation model of evaporating brine by solar radiation for salt production where the different parameters involved in the behavior of the salt pan were studied. Huang and al., 1999 investigated the effect of a black insulation sheet on the evaporation rate from a shallow salt pan. Results showed that the evaporation rate of the salt pan increased by 10%. In another attempt, Tamimi and Rawajfeh, 2007 modeled the thermal performance of solar evaporative ponds charged from Dead Sea water. The model results showed that the efficiency of any solar evaporator is limited by the optical absorptivity of the saline water as an upper limit. Zeng and al, 2011 demonstrated a strategy for solar evaporation enhancement using floating light-absorbing magnetic particles. In their investigation, evaporation was enhanced by a factor of 2.3 in the solar evaporation of 3.5% water. Horri and al., 2014 modeled the solar evaporation process assisted by floating light porous materials. The model results showed that the evaporation rate can be enhanced by approximate factors of 2.3, 2, and 1.8 when using 0.045, 0.023, and 0.015 g of light absorbing material respectively.

Fig. 1. Photography of the Merouane Chott, salt pans and the salt production unit
Rys. 1. Fotografia Merouane Chott, solarów i wytwórni soli

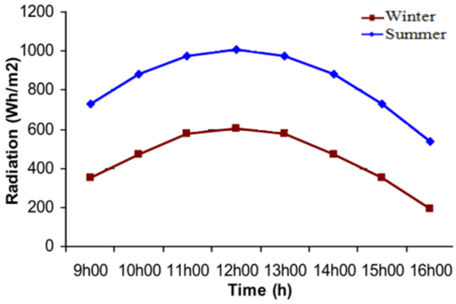

Fig. 2. Solar radiation Evolution of El Oued region
Rys. 2. Promieniowanie słoneczne. Zmiany w regionie El Oued

This work aims to assemble the concentration of two systems of solar radiation in the brine by the development of a black grid and a reflection mirror, and this for object to optimize the process of NaCl crystallization at SME unit figure.01 in order to master the quantitative and qualitative plan according to the needs of the market. So a test is done during the months of December and January on pans near the lake Merouane gave us more encouraging results.

Materials and methods

Solar Radiation and Sun Position of Lake Merouane

Figure.02 shows the solar radiation evolution in Wh/m² during the day time (in hours), one in winter and the other in summer. The radiation increases gradually in both cases until reaching a maximum value between noon and 2:00 pm with the only difference that the solar radiation in winter has not exceeded the value of 600 Wh/m² but in summer it has reached the value of 1000 Wh/m² (A. Khechekhouche2017).

Sun Height and Azimuth

Using Sun Earth Tools software online, the azimuth and elevation (see annex table N°01) of the day 27/12/2016 was determined to know the sun position as it traveled around the test point figure.03.

Figure 04 illustrates that the sun position in the south side is between the interval of sunrise time at 6:40 (where the elevation at - 0.833° and the azimuth at 117.18°) and almost at noon 11:35, after this last, the sun position is in the south west where the sunset at 16:34 of the evening where the elevation to - 0.833° and the azimuth to 242.14°. The curve of sun trajectory figure.05 illustrates also a more and more increase of elevation and azimuth angles from - 0.833° up to 32.5° and from 117.88° up to 180° successively, and that between the interval Cited above, then the azimuth angle stay to increase up to 242.14° while the elevation decreases to - 0.833° which is the sunset.

The estimation of evaporation from weather data

Two requirements must be met to permit continued evaporation H. L. Penman (1948). There must be a supply of energy to provide the latent heat of vaporization, and there must be some mechanism for removing the vapour, i.e. there must be a sink for vapour. Analytical attacks on the problem start from one of these two points and it is convenient to consider the latter first as it has been the more popular.

Empirical equations

Until recent years the approach was empirical, a hundred years' work since Dalton having produced little improvement in the form of equation he gave. In essentials it is

$$E=(e_s-e_d)\,f(_u) \quad (1)$$

where E is the evaporation in unit time, e, is the vapour pressure at the evaporating surface, e_d is the vapour pressure in the atmosphere above, and $f(_u)$ is a function of the horizontal wind velocity. For water, e_s is known if the surface temperature is known. Of the many empirical formulae cast into this form, one due to Rohwer (193I) summarizes results of very intensive work at Fort Collins, Colorado, at 5000 ft. above sea-level. Other things being equal, Rohwer found a small variation of evaporation rates with atmo-

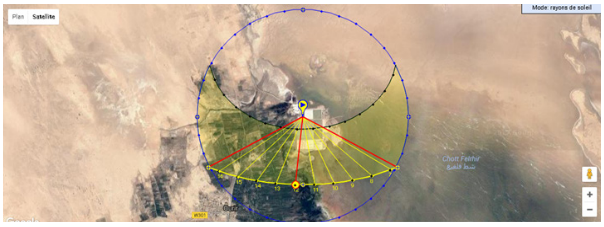

Fig. 3. The hourly position of the sun in relation to the test point
Rys. 3. Godzinowe położenie słońca w stosunku do punktu testowego

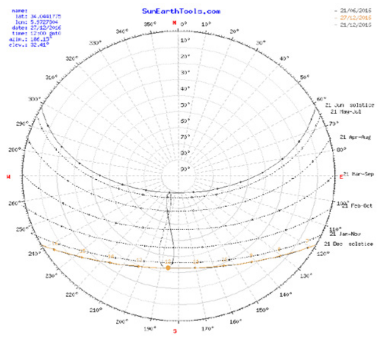

Fig. 4. Position of the sun each hour for sunshine to sunrise
Rys. 4. Położenie słońca w każdej godzinie do wschodu słońca

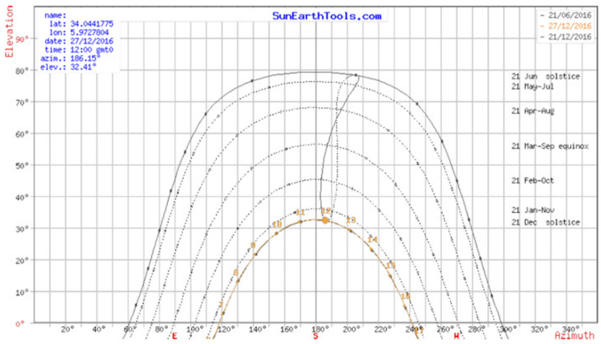

Fig. 5. Trajectory of the sun each hour for sunshine to sunrise
Rys. 5. Trajektoria słońca w każdej godzinie od wschodu do zachodu słońca

spheric pressure, and reduced to conditions at sea-level, his equation for the daily rate from an open water surface 3 ft. square is

$$E=0.40(e_s-e_d)(1+0.27u_0), \text{ mm/day} \quad (2)$$

Where vapour pressures are in mm. mercury, and wind speed at ground level is in m.p.h. Examining the effect of size of surface on evaporation rates, over a period of 485 days, he compared the observed values of evaporation from a large surface 86 ft. diameter with the estimates based on (2), and found the mean value of observed/ estimated to be 0.77. There is some bias here, however, for the average wind speed over the whole period was only 1.50 m.p.h, and examination of the individual daily records shows that on the rare occasions of a wind speed in excess of 3 m.p.h. the correction factor is nearly unity. The ground wind velocity u0, is an extrapolated value estimated from a number of readings at various heights, and if from Rohwer's u, z curve we interpolate at 2 m., the relation becomes

$$E=0.4(e_s-e_d)(1+0.17u_2) \text{ mm/day} \quad (3)$$

And except at very low wind speeds might be expected to apply to large open water surfaces.

Experimentation

In this study, we did a test next to the salt pans of the unit SME during the months of December and January, therefore the pans dimensioned in the table No 01,02 are made of plastic, and implanted on the ground to avoid the heating of its outer walls by solar radiation figure.06, They are filled by brine of lake Merouane with a density of 23.6 B°, the volume of this last is 22.44 dm^3 in each pan, a black grid floating BB2 on the surface of brine in P4 figure.07 thanks to a fixed balloon on which. The orifices of the grid gives way to passage of air towards the brine surface for its agitation (formation of the salt crystals) and releases the evaporated particles of water to the air, the pan P4 is also equipped with a standard mirror (simple) for the reflection of solar radiation towards the evaporating surface of the brine. Thus, the results obtained are in

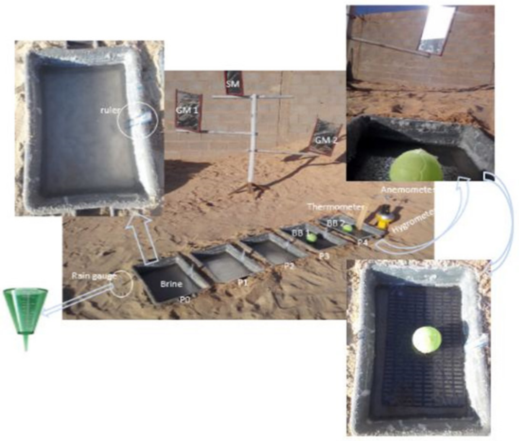

Fig. 6. Photograph of the pans during the test
Rys. 6. Zdjęcie panelu podczas testu

comparison with the witness pan P0 in order to know the difference in the crystallization rates between them. A follow-up of the evaporation measures every morning at 9.00 am thanks to the rules fixed in each pan.

In this paper, we just did a study for the pans P0 and P4. The other results of P1, P2 and P3 will be studied later.

Pans equipments

Sizing of the equipments used

Equipments of measure:

Densimeter: The accuracy of measure is ± 0.001 g/ml.

Weather station (anemometer, hygrometer, rain gauge and thermometer)

The accuracy of the integrated sensor suite of the weather station for measuring each climatic variable was ± 6% for wind speed, ± 4% for relative humidity, ± 4% for rainfall, and 0.5oC for ambient temperature.

Results and discussion

Statistical analysis of the evaporation results

The Statistica software is used to compare the evaporation of brine in the two pans P0 and P4 (see annex Table N°02) table, hence the results obtained in annex Table N°03.

The test used is that of the normal law N (0, 1) useful for the comparison of the two u, so we propose the hypotheses H0 and H1.

To compare the effect of the reflection mirror and the black grid on the volume of evaporated water for the two pans P0 and P4.

We have:

$$\begin{cases} H_0: u1 = u2 : \text{the reflection mirror and the black grid have no effect on the volume of evaporated water.} \\ H_1: u1 \neq u2 : \text{the reflection mirror and the black grid have an effect on the volume of evaporated water} \end{cases}$$

$$\text{So; to be } U_{calculated} = \frac{\bar{x}1 - \bar{x}2}{\sqrt{\frac{s1^2}{n1} + \frac{s2^2}{n2}}} = \frac{0{,}561 - 0{,}748}{\sqrt{\frac{(0{,}16)^2}{52} + \frac{(0{,}22)^2}{37}}} = -4{,}4104$$

The value of u_2 for α = 5% read on the table of the normal law N (0, 1) is $u_{theoretical\ (0,05)} = 1{,}96$

We have $U_{calculated} = -4{,}4104 \notin]-1{,}96;1{,}96[$ therefore, we reject H0 and we accept H1, which says: there is a significant difference between the two pans P0 and P4 so the reflection mirror and the black grid have an effect on volume of the evaporated water.

The climate during this test appeared favorable for the natural evaporation of the brine (average wind speed 1.13 m/s and average humidity 36%). So from figure.08, the daily average of the evaporated water volume of the pan P4 is 0.425 ± 0.207 dm^3 against this one of the P0 is 0.300 ± 0.154 dm^3 which due to a spacing between the curves of a value average of 0.125 dm^3, this difference explains the significant influence of the solar radiation concentration thanks to the reflection mirror (S. Remli., and al., 2018) and the floating black grid in the brine of P4, which due to the evaporation reinforcement of the water amount in it which took 37 days (12/12/2016, 17/01/2017) for total evaporation in comparison with the brine of pan P0 which also took 52 days (12/12/2016, 01/02/2017) as a result we have a profit of 15 days, so an optimization of the salt crystallization process up to 41%. As the study of the average evaporation flux from the traditional system (KASEDD H. and al., 2015) is about 0.02 kg/m^2-hr while that of the enhanced system is about 1.68 kg/m^2-hr, corresponding to a brine temperature increment from 30°C to 50°C. The results show that the evaporation of the brine is increased with the implementation of parabolic solar concentrator as compared to the natural process. The increment in the evaporation flux implies a decrease in the number of days for the crystallization process thus improved productivity. Also, the simulation analysis of Diaz R.B.F and al 2012, they used a Concentrated Solar Thermal Energy to Enhance Sea Salt Production in Southern Spain, so the evaporation rate is drastically increased with the enhanced system compared to the evaporation rate through the natural process. It is estimated that the enhanced system evaporates water six to ten times faster than the natural process.

We have also in figure.09 the curves of the brine and crystallized salt volume in the pans P0 and P4 initiate by the same amount (22.44 dm^3), then they known a spacing more and more between them until the end of salt crystallization where its volume is 7.48 dm^3. There is also a remarkable growth of volume curves due to the precipitation of 2.5 mm in the day (11/01/2017).

To know the difference in temperatures between the pans P0 and P4 generated by the use of the reflection mirror and the black grid, we made hourly measurements of them compared to that ambient during the day 27/12/2016. So the re-

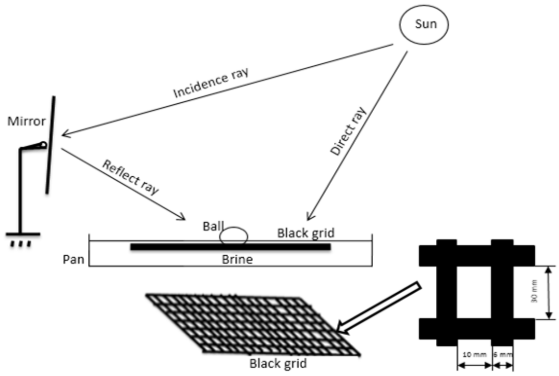

Fig. 7. Assembly of solar radiation concentration systems of the pan P4
Rys. 7. Montaż układów koncentracji promieniowania słonecznego P4

Tab. 1. The equipment of each pan
Tab. 1. Wyposażenie każdego panelu

Brine Pan	with Grand Mirror GM1	With Small Mirror SM	With Black Body BB1	With black body + Grand mirror BB2 + GM2
P0 (Witness)				
P1	■			
P2		■		
P3			■	
P4				■

Tab. 2. The dimensions of the test equipment
Tab. 2. Wymiary sprzętu badawczego

Designation	Dimension, m	area, m^2
P0, P1, P2, P3, P4	0.55 * 0.34	0.187
SM	0.31 * 0.19	0.0589
GM1, GM2	0.48 * 0.30	0.144
BB1, BB2	0.46 * 0.26	0.119

sults obtained are recorded in table N°04 and represented by curves in figure.10. From these last, the temperatures averages of the pans P0 and P4 from 09:00 to 16:00 are 16 ± 2.82°C and 20 ± 3.93°C successively, they initiate by 11°C and 13°C at 09:00 and then they are accompanied by a growth of the values with a spacing more and more between them up to 5°C during 13:00, this hour represents the temperature threshold during this day, it keeps its value until 14:00 then they knew a slight decrease in its values of 17.5°C for the pan P0 and 22°C for that P4. The ambient air temperature is almost symmetrical with respect to the curves of the pans and its average value is 34.18 ± 2.82°C.

Lake Merouane characterized by an arid region. The exploitation of salt at the unit SME is done by the traditional method with an annual production of 150 000 T/year. The harvesting companion begins with the pumping and ends with the rehabilitation of infrastructure and harvesting means from December to July, which is the life of the lake during the year. The process involves pumping the brine from the lake to 22 Be°, this operation will commence on month of December. The pumped volume decreases appreciably with the evaporation, it is necessary to make additions to maintain the height of the brine in the salt pans, also it is customary to pump 30 to 50 cm of brine layer, once the pumping from the last table is finished the feeding of the first one is repeated until the end of the filling of the lake. After the crystallization of salt, harvesters (harvesting machinery) harvest this crystallized layer from the end of June but they encounter enormous difficulties due at their stops because the rapid hardening of this layer (very high temperature in the summer period), the harvesting continues thanks to the loaders but unfortunately they provoke the layer salt against which generates alterations in the salt pans and a bad quality of the salt. The product is transported by trucks to the washing station for washing and storage in camels and sometimes screening before washing (ENASEL 2011).

In addition, the lake knows variations in the percentage of chemical elements in the brine according to time (temperature, wind… etc) which have a negative influence on the quality of the salt especially the concentration of NaCl.

These last years, the SME unit is known a strong demand for salt products in the market, such as long-term contracts for orders from countries, France, Spain, Niger… etc which leads to an increase in production by realization other salt pans, which poses a problem for the unit: reservations of agricultural area in this region (date palms) currently occupied.

To solve all these problems mentioned above, we propose to install the systems of solar radiation concentration in the salt pans (after an economic study shows the profitability of this investment) which serve to mastery the quality of the salt by the concentration of these systems when the lake becomes rich in percentage of NaCl and low in that of Mg (undesirable salts) and by deconcentration in the opposite case. Also this installation has given us an early crystallization of the salt layer where the climate is favorable for the harvest (a soft salt layer for harvesters), on the other hand there is a possibility

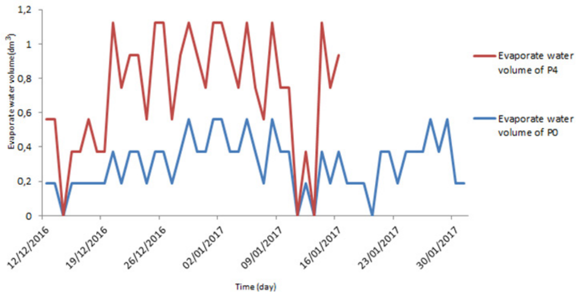

Fig. 8. Curve of evaporated water volume of the pans P0 and P4
Rys. 8. Krzywa objętości odparowanej wody w panwiach P0 i P4

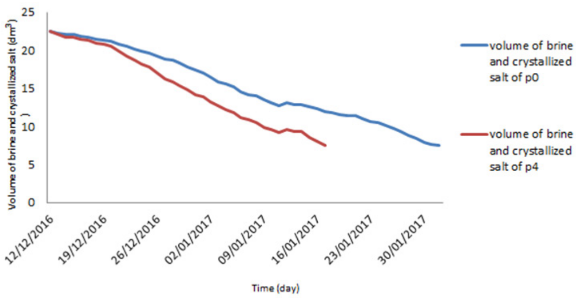

Fig. 9. Curve of the brines and crystallized salt volumes of the pans P0 and P4
Rys. 9. Krzywa solanek i objętości skrystalizowanych soli w panwiach P0 i P4

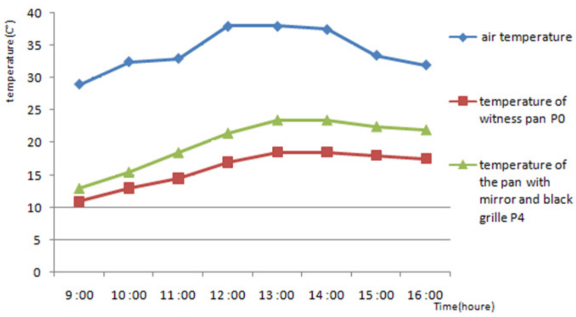

Fig. 10. Curves of air temperature, P0 and P4
Rys. 10. Krzywe temperatury powietrza, P0 i P4

of multiplying the production by another operation (pumping until harvest) and this all depends on the capacity we want to install it.

The rational choice of such a technology requires a technical and economic comparison, which depends essentially on the cost price of a ton of salt extracted, the latter is determined by the knowledge of a bank of information such as: the prices of investments, the wage bill of labor, the energy consumed... etc.

Conclusion

the test done in the company of Salins Merouane El Meghaier (SME) suggests that the systems of solar radiation concentration in the pan P4 filled by the brine have a significant influence on the rate of evaporation-crystallization compared to the witness pan P0, this influence due to an acceleration of the process of the solar salt crystallization thanks to a free energy respectful to the environment, thus an optimization of the stay time until 41% if the surfaces of the black grid and the mirror of reflection represent 63 % and 77% respectively, and those compared to the evaporation surface of the brine.

This work in comparison with other works like Diaz R.B.F and al 2012, KASEDD H. et al. 2015…etc depends mainly on the production yield and the investment costs of these systems, and to choose the adequate system it is necessary to make a detailed technical and economic study which decides the rational choice.

The optimization by solar energy and the presence of a biodiversity favorable environment represent assets of sustainable development of the solar salt industry as well as the development of a region rich in fauna and flora and geotouristic.

Annex: Tab. 1. The angles of elevation and azimuth every hour of the day 27/12/2016
Załącznik: Tab. 1. Kąty wzniesienia i azymut o każdej godzinie dnia 27.12.2016

Date	27/12/2016/GMT0	
Coordinates	34,0441775 - 5,9727804	
Location	El Meghaier Algeria	
Houre	Elevation	Azimut
06:40:24	-0,833°	117,88°
07:00:00	2,71°	120,66°
08:00:00	12,84°	130,07°
09:00:00	21,54°	141,25°
10:00:00	28,16°	154,57°
11:00:00	31,98°	169,87°
12:00:00	32,41°	186,15°
13:00:00	29,4°	201,82°
14:00:00	23,4°	215,67°
15:00:00	15,15°	227,37°
16:00:00	5,32°	237,17°
16:34:27	-0,833°	242,14°

Annex: Tab. 2. Results of evaporation and precipitation of the witness pan P0 and that equipped by the mirror and black grid P4
Załącznik: Tab. 2. Wyniki parowania i wytrącania z szalki obserwacyjnej P0 i tej wyposażonej w lustro i czarną kratkę P4

Number of Day	Day	volume of brine and crystallized salt dm³		volume of evaporated water dm³		precipitation (mm)	Meteorological observation
		Witness pan P0	pan with mirror + black grill P4	Witness pan P0	pan with mirror + black grill P4		
1	12/12/2016	22,44	22,44	-	-	0	
2	13/12/2016	22,253	22,066	0,187	0,374	0	Clear sky
3	14/12/2016	22,066	21,692	0,187	0,374	0	Clear sky
4	15/12/2016	22,066	21,692	0	0	0	cloudy
5	16/12/2016	21,879	21,505	0,187	0,187	0	cloudy
6	17/12/2016	21,692	21,318	0,187	0,187	0	Clear sky
7	18/12/2016	21,505	20,944	0,187	0,374	0	cloudy
8	19/12/2016	21,318	20,757	0,187	0,187	0	cloudy
9	20/12/2016	21,131	20,57	0,187	0,187	0	Clear sky
10	21/12/2016	20,757	19,822	0,374	0,748	0	Clear sky
11	22/12/2016	20,57	19,261	0,187	0,561	0	Clear sky
12	23/12/2016	20,196	18,7	0,374	0,561	0	Clear sky
13	24/12/2016	19,822	18,139	0,374	0,561	0	Clear sky
14	25/12/2016	19,635	17,765	0,187	0,374	0	Clear sky
15	26/12/2016	19,261	17,017	0,374	0,748	0	Clear sky
16	27/12/2016	18,887	16,269	0,374	0,748	0	Clear sky
17	28/12/2016	18,7	15,895	0,187	0,374	0	Clear sky
18	29/12/2016	18,326	15,334	0,374	0,561	0	Clear sky
19	30/12/2016	17,765	14,773	0,561	0,561	0	Clear sky
20	31/12/2016	17,391	14,212	0,374	0,561	0	Clear sky
21	01/01/2017	17,017	13,838	0,374	0,374	0	Clear sky
22	02/01/2017	16,456	13,277	0,561	0,561	0	Clear sky
23	03/01/2017	15,895	12,716	0,561	0,561	0	Clear sky
24	04/01/2017	15,521	12,155	0,374	0,561	0	Clear sky
25	05/01/2017	15,147	11,781	0,374	0,374	0	Clear sky
26	06/01/2017	14,586	11,22	0,561	0,561	0	Clear sky
27	07/01/2017	14,212	10,846	0,374	0,374	0	Clear sky
28	08/01/2017	14,025	10,472	0,187	0,374	0	Clear sky
29	09/01/2017	13,464	9,911	0,561	0,561	0	Clear sky
30	10/01/2017	13,09	9,537	0,374	0,374	0	Clear sky
31	11/01/2017	12,716	9,163	0,374	0,374	2,5	rainy
32	12/01/2017	13,09	9,537	0	0	0	Clear sky
33	13/01/2017	12,903	9,35	0,187	0,187	0	cloudy
34	14/01/2017	12,903	9,35	0	0	0	Clear sky
35	15/01/2017	12,529	8,602	0,374	0,748	0	Clear sky

36	**16/01/2017**	**12,342**	**8,041**	0,187	0,561	0	Clear sky
37	**17/01/2017**	**11,968**	**7,48**	0,374	0,561	0	Clear sky
38	**18/01/2017**	**11,781**		0,187		0	Clear sky
39	**19/01/2017**	**11,594**		0,187		0	Clear sky
40	**20/01/2017**	**11,407**		0,187		0	Clear sky
41	**21/01/2017**	**11,407**		0		0	Clear sky
42	**22/01/2017**	**11,033**		0,374		0	Clear sky
43	**23/01/2017**	**10,659**		0,374		0	Clear sky
44	**24/01/2017**	**10,472**		0,187		0	Clear sky
45	**25/01/2017**	**10,098**		0,374		0	**cloudy**
46	**26/01/2017**	**9,724**		0,374		0	Clear sky
47	**27/01/2017**	**9,35**		0,374		0	Clear sky
48	**28/01/2017**	**8,789**		0,561		0	Clear sky
49	**29/01/2017**	**8,415**		0,374			
50	**30/01/2017**	**7,854**		0,561			
51	**31/01/2017**	**7,667**		0,187			
52	**01/02/2017**	**7,48**		0,187			

Annex: Tab. 3. Obtained results by Statistica software
Załącznik: Tab. 3. Wyniki uzyskane przez program Statistica

after	N° of actives	Average	Median	Minimum	Maximum	1st Quartile	3rd Quartile	Extended Quartile	standard deviation
P0	52	0,294885	0,374000	0,00	0,561000	0,187000	0,374000	0,187000	0,158615
P4	37	0,414432	0,374000	0,00	0.748000	0,374000	0,561000	0,187000	0,216536

Annex: Tab. 4. The hourly monitoring of air and brines temperatures P0 and P4
Załącznik: Tab. 4. Cogodzinne monitorowanie temperatur powietrza i solanek P0 i P4

time (hour)	Air temperature C °	Temperature of the witness pan P0 C °	Temperature of the pan with mirror and black grill P4 C °	Meteorological observation
9 :00	29	11	13	Clear sky
10 :00	32,5	13	15,5	Clear sky
11 :00	33	14,5	18,5	Clear sky
12 :00	38	17	21,5	Clear sky
13 :00	38	18.5	23,5	Clear sky
14 :00	37,5	18,5	23,5	Clear sky
15 :00	33,5	18	22,5	Clear sky
16 :00	32	18	22	Clear sky

Literatura – References

1. Abdel H.K. and Al-Naafa M.A. (1993), Enhanced evaporation of saline water in multi-purpose solar desalination units, Desalination, 93, 557-562.
2. A. Khechekhouche, A. Boukhari, Z. Driss, N. Benhissen(2017), Seasonal effect on solar distillation in the El-Oued region of south-east Algeria, International Journal of Energetica (IJECA), PP 42-45.
3. Cornet A ., (1964) Introduction à l'hydrogéologie saharienne. Rev. Géog. Phys. et Géol. Dyn.VI (1), 5-72
4. Diaz R.B.F., Stewart S.W. and Brownson J.R.S. (2012), Use of concentrated solar thermal energy systems to enhance sea salt production in southern Spain. World Renewable Energy Forum. Denver, Colorado. May 13-17, 2012.
5. ENASEL 2011, Rapport inédit, Entreprise d'Exploitation du sel, plan de récolte de sel, Chott Merouane El- Oued, Ministère de L'Energie et des Mines, Algérie
6. Folchiotto S. (1991), Seawater as salt and water source for solar ponds, Solar Energy, 46, 343-351.
7. Gueddari M. (1980) : Géochimie des sels et des saumures du chott El Jerid (Sud Tunisien). Thèse de doctorat 3eme cycle (131p).
8. Guijt C.M., Racz I.G, Van Heuven J.M, Reith T and de Haan A.B. (1999), Modeling of a transmembrane evaporation module for desalination of seawater, Desalination, 126, 119-125.
9. HADDANE ABDENNOUR, HACINI MASSAOUD , BELLAOUEUR ABDELAZIZ, HYDROCHIMIE ET FACIES GEOCHIMIQUES DES SAUMURES DU CHOTT BAGHDAD (SUD ALGERIEN), Troisième Colloque International sur La Géologie du Sahara Ressources minérales, Énergétiques, hydrocarbures et eaux Ouargla le 09 et 10 Décembre 2015.
10. H. L. Penman (1948), Natural Evaporation from Open Water, Bare Soil and Grass, Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences, Vol. 193, No. 1032, pp. 120-145
11. Horri B.A., Chong M.N., Chen X.D. and Wang H. (2014), Modeling of Solar Evaporation assisted by Floating Light Absorbing Porous Materials, Current Environmental Engineering, 1, 73-81.
12. Huang H., Shi M. and Ge X. (1999), The effect of a black insulation sheet on the evaporation rate from a shallow salt pond, International Journal of Energy Research, 23, 31-39.
13. Kasedde H., Kirabira J.B., Bäbler M.U., Tilliander A. and Jonsson S. (2014), Characterization of brines and evaporites of Lake Katwe, Uganda, Journal of African Earth Sciences, 91, 55-65.
14. KASEDDE H, LWANYAGA J.D, KIRABIRA J.B et BÄBLER M.U (2015), OPTIMIZATION OF SOLAR ENERGY FOR SALT EXTRACTION FROM LAKE KATWE, UGANDA, Global NEST Journal, Vol 16, No 6, pp 1152-1168
15. Lesino G., Savaria L and Galli D. (1991), Industrial Production of Sodium Sulfate using solar ponds, Solar Energy, 45, 215-219.
16. MESSAOUD HACINI, NACER KHERICI ET ERIC H. OELKERS, Evolution des saumures (Chlore et sodium) dans les chotts en zones désertiques (Cas du chott Merouane ; dans le Sahara septentrional Algérie) Colloque International « TERRE et EAU » Annaba, 21, 22 & 23 Novembre 2004
17. S. Remli., M. Bounouala., I. Rouaguia., 2018. Evaporation-Crystallization Process Of Solar Salt From Merouane Chott (South-East of Algeria). Scientific Bulletin of National Mining University VI. ISSN 2071-2227. 2018.
18. Tamimi A. and Rawajfeh K. (2007), Lumped modeling of solar-evaporative ponds from the water of the Dead Sea, Desalination, 216, 356-366.
19. Zeng Y. Yao J. and Horri B.A. (2011), Solar evaporation enhancement using floating light-absorbing magnetic particles. Energy and Environmental Science, 4, 4074-4078.
20. Zhang Y.Z., Ge X.S. and Li Y.F. (1993), Mathematical Simulation of Evaporating Brine by Solar Radiation for the production of Salt, Journal of Thermal Science, 2(2), 207.

Zwiększenie szybkości parowania solanki dzięki energii słonecznej w celu optymalizacji produkcji soli w jeziorze Merouane El Oued w południowo-wschodniej Algierii

W niniejszym artykule przeanalizowano zastosowanie dwóch systemów do wykorzystania energii słonecznej w jednostce SME (Salins Merouane El Meghaier) zlokalizowanej w południowo-wschodniej Algierii, poprzez wdrożenie czarnej siatki unoszącej się w solance i lustrzanego odbicia światła słonecznego. Promieniowanie skierowano na powierzchnię lustrzaną P4, i na powierzchnię doskonale czarną P0, co pozwoliło porównać oba rozwiązania. Uzyskane wyniki sugerują wzrost szybkości parowania i krystalizacji P4 w porównaniu z P0, który ocenioną analizując wyniki rocznej produkcji jednostek MŚP.

Słowa kluczowe: *Algieria, jezioro, energia słoneczna, lustro, ciało doskonale czarne, optymalizacja, krystalizacja przez odparowanie, sole*