DEVELOPMENT OF A WATER DESALINATOR LOW COST SOLAR HEATING

DESENVOLVIMENTO DE UM DESSALINIZADOR DE ÁGUA DE BAIXO CUSTO COM AQUECIMENTO SOLAR

Leandro Ferreira-Pinto¹
Diogo Italo Segalen da Silva²
Daniel Mantovani³
Marcos Antônio Lima Moura⁴
João Inácio Soletti⁵
Sandra Helena Vieira de Carvalho

Abstract. Approximately two thirds of the land surface is covered with water, with 97% salt, the remainder, only 1% can be used for human consumption. An alternative to the use of drinking water is desalination of salt water using solar energy. Desalination can be applied to seawater (total dissolved solids ≥ 30,000 mg.L⁻¹) as brackish water from wells, (total dissolved solids between 500 and 30,000 mg.L⁻¹). This study investigated the effect of operating variables and design of a desalination unit for brackish water, low cost, for family use, that meets the communities of the semi-arid areas. The variables studied and related to climatic conditions: high water level, watersalinity and solar radiation. The experiments were performed at latitude 9°3' South and longitude 35°35' west, in Maceió, Alagoas. Production was obtained from 2.5 litres.m⁻² of distilled water per day.

Keywords: Desalination. Solar Energy. Purification.

Resumo. Aproximadamente 2/3 da superfície terrestre está coberta com água, sendo 97% salgada, do restante, apenas 1% pode ser utilizada para consumo humano. Uma alternativa para o uso de água potável é a dessalinização de águas salgadas utilizando energia solar. A dessalinização pode ser aplicada tanto à água do mar (total de sólidos dissolvidos ≥ 30,000 mg.L⁻¹), como à água salobra, proveniente de poços, (total de sólidos dissolvidos entre 500 e 30,000 mg.L⁻¹). Neste trabalho foi estudado o efeito das variáveis de operação e de projeto de um dessalinizador para água salobra, de baixo custo, para uso familiar, que atenda comunidades do semi-árido brasileiro. As variáveis estudadas e relacionadas às condições climáticas foram: altura da lâmina d’água, salinidade da água e radiação solar. Os experimentos foram realizados a uma latitude de 9°3’ sul e longitude de 35°35’ oeste, em Maceió, Alagoas. Foi obtida uma produção de 2,5 litros.m⁻² de água destilada dia⁻¹.


1 INTRODUCTION

The ability to handle salt water, so as to make it fit for consumption, has been sought by mankind for a long time, since more than three quarters of the earth’s surface is covered by salt water and this, although it is important for some means of transport and for fishing, contains a high amount of salt which makes the maintenance of human life through its consumption, as well as rural activities (AKILI et al., 2008). According to Soares (2004), factors such as climate, geological features, soil types and distance from the sea will determine the salinity of natural

¹ Department of Chemical Engineering, Universidade Estadual de Maringá, 87020-900, Maringá, Paraná, Brazil. Corresponding author: leandropinto@gmail.com
² Institute Federal of Mato Grosso, Campus Rondonópolis, 78721-520, Rondonópolis, Mato Grosso, Brazil.
³ Department of Chemical Engineering, Universidade Estadual de Maringá, 87020-900, Maringá, Paraná, Brazil.
⁴ Institute of Atmospheric Sciences, Universidade Federal de Alagoas, 57072-970, Maceió, Alagoas, Brazil.
⁵ Department of Chemical Engineering, Technology Center-CTEC, Universidade Federal de Alagoas, 57072-970, Maceió, Alagoas, Brazil.

waters. Indeed, in arid or semi-arid regions, it is common to see water becoming saline due to its own constitution. It is worth noting that the inadequate management of soil can also cause an increase in salinity (MATHIOULAKIS et al., 2007).

Regarding irrigation water, Soares (2004) states that irrigated areas become unproductive due to poor quality of water used. For this type of water, the salinity limits are determined according to the types of crops, soil and climate, and that water containing dissolved salts at concentrations exceeding 2,000 mg L\(^{-1}\) cause significant declines in agricultural production. Water containing dissolved salts concentration equal to or greater than 1,000 mg L\(^{-1}\) are harmful to health and unfit for human consumption (BUROS, 1990; DANTAS, 1998).

With regard to water for industrial use, salinity tolerated depends on the type of product. The water used in the manufacture of textiles, chemicals, paper and food, for example, require low salinity. According to Tlemat (1979), thermal desalination processes is one of the oldest, water purification. However, in Brazil, the use of water desalination is still little known, although the Northeast is applied the process of reverse osmosis desalinationbrackish water coming from wells for the supply of small communities.

Bouchekima (2002) highlights the advantages of solar distillation for desalination of water, stressing the fact that this technology uses a clean energy source, free and does not harm the environment. He said the solar distillation seems to be a promising method and an alternative way to the water supply of small communities in remote areas as wilderness (MATHIOULAKIS et al., 2007).

In order to satisfy different audiences, there are several types of solar stills, from the conventional, also called distillers simple effect that can be covered like one or two waters, to more elaborate models which were developed from those with the goal of optimizing and increasing income by reducing costs (QIBLAWEY and BANAT, 2008; EL-GHONEMY, 2012).

The solar distillation is used in hot areas, with the construction of large tanks covered with glass or other transparent material having a surface sunlight passes through the tanks are filled with brackish or salty water of the liquid evaporates, the vapors condense inside the glass, turning it into drinking water, which flows into a collection system, as shown in Figure 1 and thus separate the water from all the salts and impurities (KHAWAJI et al., 2008; ETTOUNEY et al., 2001; AL-KARAGHOULI and ALNASER, 2004\(^{ab}\)). According to Esteban et al. (2000) the glass cover of the device is transparent to incoming solar radiation, allowing their passage, but is opaque to infrared radiation emitted by hot water. Fuentes and Roth (1997) show that in solar distillation heat transfer by convection is not desired, the process is useless.

![Figure 1. Principle of a desalination unit.](image)

Walls and bottom of wood, covered with black paint, black FVC and canvas.
According to Esteban et al. (2000), the glass cover of the device is transparent to incoming solar radiation, allowing their passage, but is opaque to infrared radiation emitted by hot water. Fuentes and Roth (1997) show that in solar distillation heat transfer by convection is not desired, the process is useless. It should be noted that the efficiency of solar distillation is directly related to climatic conditions (such as humidity, wind, sunshine, cloud cover) and the equipment capacity to absorb the incident energy (ETTOUNEY et al., 2001; QIBLAWEY and BANAT, 2008). Bezerra (2001) recommends a minimum slope possible to increase efficiency, in that the slope is around 20° here in Brazil, because the absorption is maximum when the incidence angle is 90 degrees. It is known that the efficiency suffers a variation with latitude and longitude.

Al-Hinaiet al. (2002) and Cappelletti, (2002) consider that solar distillation is a promising technology, particularly in areas of high insolation and arid desert areas, but they are necessary studies and research intended to improve yields and increase the feasibility of this technique. This process can be applied both to sea water (total dissolved solids ≥ 30,000 mg L\(^{-1}\)) as well as brackish groundwater from wells (total dissolved solids between 500 and 30,000 mg L\(^{-1}\)) (ELTAWIL et al., 2004; KALOGIROU, 2005), which despite providing lower salinity water from the sea, is still above the limits for drinking and domestic use (CONAMA357, 2005).

This paper inter-relates the following variables: temperature, water depth, and the steam produced in the external environment, when the water depth, the influence of water salinity in relation to the distillation volume of distilled water and solar radiation.

2 EXPERIMENTAL

2.1 STUDY AREA

This study was conducted in the city of Maceió, capital of Alagoas State, northeastern Brazil, with an area of approximately 513.55 km\(^2\). Situated between the geographical coordinates 9°39′57″ latitude and 35°44′07″ longitude WGr. The temperature in the region varies between a minimum of 19°C and an absolute maximum of 31°C. The study period occurred between the months of November and June. During this period, two desalination plants were sized, constructed, and operated simultaneously in the solar month of highest incidence.

2.2 PARAMETERS EVALUATED

We analyzed the following parameters: height of the water depth (corresponding to 10 L and 20 L), salinity (0 mg L\(^{-1}\), 800 mg L\(^{-1}\), and 1600 mg L\(^{-1}\)), volume of desalinated water (mL) and solar radiation (W m\(^{-2}\)). As shown in Table 1, the first column represents the number of the experiment and \(V_i\) is the initial volume of solution to be distilled. (DI) the desalination without salt (CI) and desalination (DII) with salt concentration (CII).

<table>
<thead>
<tr>
<th>Table 1. Experimental variables.</th>
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<tbody>
<tr>
<td>Experiment</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
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</table>

The data of temperature, solar radiation, and volume of distilled water were obtained from a weather station for 24 hours a day and stored in a data logger connected to desalination plants.
shown in Figure 2.

Figure 2. Schematic of the desalination unit connected to the datalogger.

2.3 EXPERIMENTAL ASSEMBLY

The desalination plants were built in the Laboratory of Separation Systems and Process Optimization - LASSOP, Universidade Federal de Alagoas - UFAL, with the following dimensions: 0.5 m long; 1.25 m wide; heights of 0.1 m and 0.4 m, corresponding to the side, which is supported on the glass cover, with an area of 0.8375 m² and a thickness of 0.005 m, forming an angle of 26.6° with the horizontal. The walls were lined and insulated with PVC and a black canvas, Figure 3. These desalination plants were built from low-cost materials such as wood, PVC, glass, and black plastic.

Figure 3. Desalinator built solar.

For the experiments, the saline solutions were produced in the laboratory. We also conducted other experiments with water coming from wells in the region of Alagoas. With the physical-chemical analysis performed to measure salinity in desalinated water through a digital conductivity meter.
3 RESULTS AND DISCUSSION

The experiments were performed at different operating conditions: height of water depth, solar radiation, salinity, temperature and water depth in the external environment. The desalination plants operated simultaneously, with equal volumes of water, but different concentrations of salts. The equipment I refers to the one operated with unsalted water and equipment II refers to the one operated with concentrations of 800 or 1,600 mg L\(^{-1}\) of salt, depending on the experiment.

As shown in Table 2, four experiments were performed considering two initial heights of water, corresponding to the volume of 10 L and 20 L. In this table, the concentrations I and II refer, respectively, to the concentrations of salt water in desalination plants in operation simultaneously, i.e., subjected to the same environmental conditions. VolumeDesal. I and II refer to the daily volume of distilled water produced in each desalination. The yield of water desalination using saline water was calculated as the ratio of the total volume of distilled water desalination and brackish water desalination to the total volume distilled without salt.

### Table 2. Summary of experiments.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial volume (L)</th>
<th>Concentration I (mg L(^{-1}))</th>
<th>Desal. I volume (L/day)</th>
<th>Concentration II (mg L(^{-1}))</th>
<th>Desal. II volume (L/day)</th>
<th>Relative performance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>0</td>
<td>2.3</td>
<td>800</td>
<td>1.95</td>
<td>85</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>0</td>
<td>1.3</td>
<td>1,600</td>
<td>1.00</td>
<td>71</td>
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<tr>
<td>3</td>
<td>20</td>
<td>0</td>
<td>2.3</td>
<td>800</td>
<td>1.50</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>0</td>
<td>2.6</td>
<td>1,600</td>
<td>1.50</td>
<td>59</td>
</tr>
</tbody>
</table>

*Experiment 1*: (Initial volume of 10 L of water and salt concentration from 0 and 800 mg L\(^{-1}\)). The Figure 4 shows that the distillation desalination I begins before distillation desalination II. Moreover, the peaks of distillation are greater than I to II, characterizing their influence, directly, the salt concentration in the distillation. One can also observe a similar route between the curves of solar radiation and the volume distilled for both devices (with and without salt), showing the interrelationship between these variables, that is, the higher the rate of radiation, the greater the volume of distilled water.
Figure 4. Graph of solar radiation (W.m$^{-2}$) and the volume of distilled water distillers in I and II, for an initial volume of 10 L of water and salt concentration of 800 mg.L$^{-1}$.

Experiment2- (Initial volume of 10 L of water and salt concentration from 0 and 1,600 mg.L$^{-1}$). The Figure 5, the radiation peaks presented only in the first part of the experiment. The volumes of distilled desalination plants exhibited similar behavior to that of Figure 4, that is, desalinator I (no salt) a larger volume of distilled water compared to desalination II.

Figure 5. Graph of solar radiation (W.m$^{-2}$) and the volume of distilled water distillers in I and II, for an initial volume of 10 L of water and salt concentration of 1,600 mg.L$^{-1}$.

Experiment3- (Initial volume of 20 L of water and salt concentration of 0 mg.L$^{-1}$ and 800 mg.L$^{-1}$).
The Figure 6 shows the dependence of the volume distilled and radiation, peaking around distilled volume of 300 mL and 200 mL for the desalination I (0 mg L\(^{-1}\)) and II (800 mg L\(^{-1}\)), respectively. For the salt concentration of 800 mg L\(^{-1}\) (desalination II) was obtained from a volume of distilled water (8.7 L), which represents an efficiency of 65% over the desalinator I, with 0 mg L\(^{-1}\) of NaCl concentration in which we obtained a volume of 13.6 L. Again it was evident that the higher the rate of radiation, the greater the volume of distilled water.

![Figure 6. Graph of solar radiation (W m\(^{-2}\)) and the volume of distilled water distillers in I and II, for an initial volume of 20 L of water and salt concentration of 800 mg L\(^{-1}\).](image)

Experiment 4 - (initial volume of 20 L of water and salt concentration of 0 mg L\(^{-1}\) and 1,600 mg L\(^{-1}\)). The Figure 7 shows the influence of salt concentration in the volume distilled. In this experiment the volume of water was 20 L, necessitating a greater amount of energy to heat water, which justifies a greater delay in beginning the distillation compared to Experiments 1 and 2.
Figure 7. Chart radiation (W/m²) and the volume of distilled water in distillers I and II for an initial volume of 20 L water and salt concentration of 1,600 mg.L⁻¹.

Figure 8 refers to Experiment 1 and demonstrates both the volume of water produced and the temperature profile of the following: environment, water vapor, water desalination and glass I (D₁). There was concordance between the profiles of the temperature of steam, water, and glass and the volume of distillate. There is also the response time between the start of the heating and production of distilled water.

Figure 8. Performance of temperatures within the desalination unit (D₁), for Experiment 1.
In addition to our experiments, experiments were performed with brackish water from wells in some regions of Alagoas, which showed similar behaviors. Figure 9 shows the visual aspect of artesian well water before and after desalination.

![Figure 9. Comparison between the incoming water (left) and output (right) of the desalinator.](image)

The water produced in desalination plants showed characteristics of drinking water: odorless, tasteless and colorless, and a salt concentration in the range of 200 mg L\(^{-1}\), below the maximum allowed (500 mg L\(^{-1}\)) by CONAMA Resolution 357, 2005, for water drinking.

### 4 CONCLUSIONS

Regardless of the salinity of the water and the height of the water depth used in the experiments, the profiles of the curves of volume of distilled water by solar radiation show a similar behavior, since the variation of solar irradiation has a daily cycle, with a maximum peak water production in the schedule of noon to one o'clock. After this period, despite the reduction in the incidence solar desalination unit maintains the temperature, showing a significant production until around 16:00 hours. From this time there is a drop in water production representative, which is gradually reduced.

Moreover, it was observed that the height variation of water depth changed the system performance, with regard to the volume of distilled water, compared with the same system without using water salinity. For a more conclusive, there is need to evaluate the solar incidence for each period of the experiments. Regarding the influence of saline solution, increasing salinity reduced the volume of produced water, which can be explained by the Dühring diagram, Perry and Green (1984).

These desalination plants showed a low initial investment, low maintenance and high reliability. The solar desalination have great ability to solve problems of small scale water treatment in Brazil, provided that the conditions necessary for the choice of this technology to be present, such as a place endowed with high levels of insolation, brackish water and abundant impossibilityphysical or economic to use other energy sources.
ACKNOWLEDGMENT

The authors would like to thank CNPq and FAPEAL (Fundação de Pesquisado Estado de Alagoas) for financial support and for scholarships awarded.

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