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Solar Distiller Study for Freshwater Production by Seawater Desalination

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ABSTRACT

Water covers 70% of the planet Earth. Of the total volume of water on the planet, 2/3 (two-thirds) is in the form of ice or underground water. On the other hand, fresh water is an increasingly scarce resource in the world, with only 3% of the world's water being drinkable. Data from the United Nations (UN), indicate that approximately 1.1 billion inhabitants on planet Earth do not have access to fresh water. The same data also reveal that 2.7 billion inhabitants suffer from water scarcity for approximately one month a year. According to these data, water scarcity currently affects more than 40% of the world's population. This condition has driven the proposition of technological solutions to minimize the impact of difficulties in accessing this good [1].

Allied to all these aspects, in recent decades, industrial development and the growth of the world population have demanded a greater need for fresh water. At the same time, pollution and the reduction of surface water sources limit access to available freshwater resources [2].

Thus, there is a need for alternative water sources, leading to a focus on using previously technologies, with an emphasis on saltwater desalination. Many areas affected by freshwater scarcity are close to the sea, favoring implementing these technologies.

1. Introduction

Water covers 70% of the planet Earth. Of the total volume of water on the planet, 2/3 (two-thirds) is in the form of ice or underground water. On the other hand, fresh water is an increasingly scarce resource in the world, with only 3% of the world's water being drinkable. Data from the United Nations (UN), indicate that approximately 1.1 billion inhabitants on planet Earth do not have access to fresh water. The same data also reveal that 2.7 billion inhabitants suffer from water scarcity for approximately one month a year. According to these data, water scarcity currently affects more than 40% of the world's population. This condition has driven the proposition of technological solutions to minimize the impact of difficulties in accessing this good [1].

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Thus, there is a need for alternative water sources, leading to a focus on using previously technologies, with an emphasis on saltwater desalination. Many areas affected by freshwater scarcity are close to the sea, favoring implementing these technologies.

1.1. Water Characteristics

International legislation classifies fresh water as water that contains salinity equal to or inferior to 0.5%, while salted water presents salinity greater than 0.5% and inferior to 30%. Finally, saline water is that water with salinity equal to or greater than 30% [2]. This description can be better framed by analyzing the data in Table **1**.

Table 1: Water salinity levels.

Salinity	Classification of Water
Less than or equal to 0.5%	Potable
Greater than 0.5% and smaller than 30%	Brackish
Greater than or equal to 30%	Saline

It can be emphasized that sodium chloride is not the only component present in marine waters, but its percentage is an average of 68.5% among dissolved inorganic substances. Table **2** describes the main components present in marine water.

Table 2: Main salts dissolved in saline water [3].

Components	Concentration (g/l)	Components	Concentration (g/l)
$NaCl$	24.53	$NaHCO_3$	0.201
$MgCl_2$	5.20	KBr	0.101
Na_2SO_4	4.09	H_3BO	0.027
$CaCl_2$	1.16	$SrCl_2$	0.025
KCl	0.695	NaF	0.003

Even with lower percentages, water treatment processes focus on eliminating these substances up to the minimum threshold for consumption established by the current legislation.

1.2. Water Desalination

The study of membrane water desalination (DM) began in the 1960s. At the time, it was commercially unfeasible given the lack of membranes with the necessary characteristics and affordable costs. These characteristics include reduced permeability for liquids and non-volatile components, high vapor permeability, high resistance to heat flow by conduction, adequate wall thickness, structurally reduced humidity absorption rates, and long service life when in contact with saline solutions [4, 5].

The desalination process requires energy and different types of technologies to effect separation. Fig. (**1**) shows a block diagram describing the working principle of the desalination process.

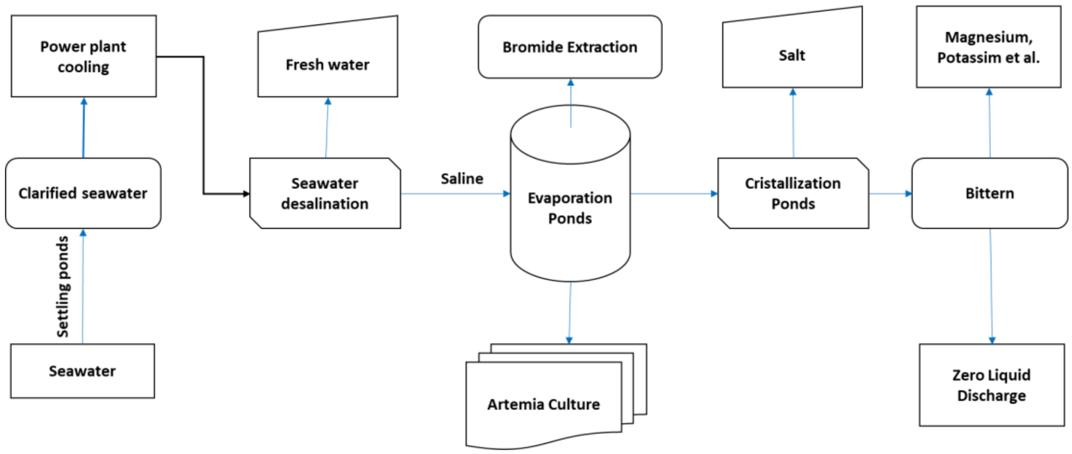

Figure 1: Diagram of seawater or brackish water desalination blocks adapted by [6].

Desalination methods are classified according to the energy source used or the saltwater separation process. According to the energy source used, desalination processes can be a) thermal or b) non-thermal. A desalination method commonly used for freshwater production is solar distillation. This desalination process uses solar radiation to promote water evaporation [6, 7].

1.3. Solar Distiller

1.3.1. Process

In this process of solar distillation, the radiation incident on the surface of the distiller is converted into thermal energy, resulting in the evaporation of the water from the saline solution contained inside the distiller. The water vapor produced under saturation rises and condenses when it comes into contact with the inner part of the distiller's covering surface, which is kept at a lower temperature. The cover is tilted to ensure that the condensate drains by gravity to the lower end of the cover, where there is a condensate collection channel. Fig. (**2**) shows the operating principle of a solar distiller used to produce fresh water from saline or saline water.

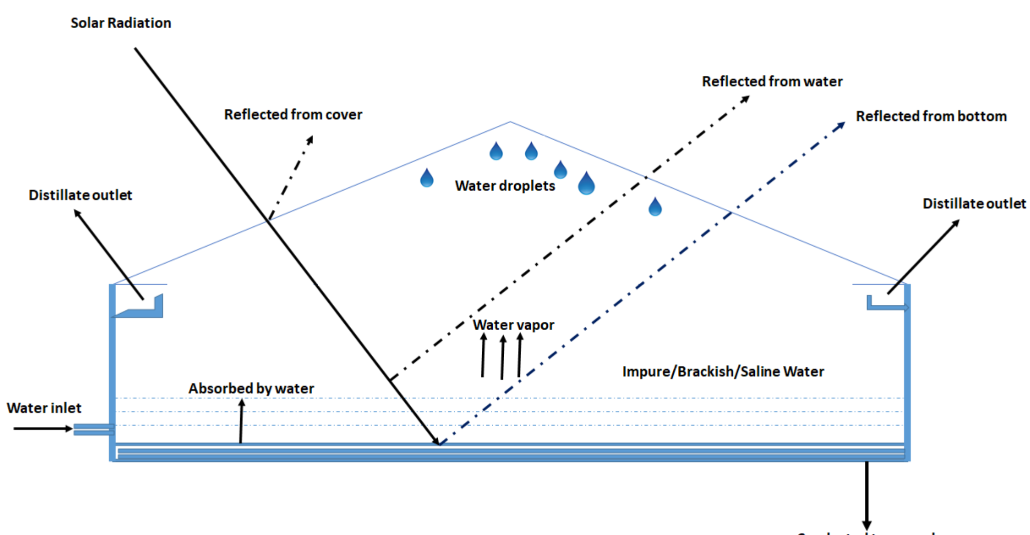

Figure 2: Principle of a solar distiller adapted by Singh *et al*. [8].

Solar distillation is a promising technological alternative to saltwater desalination. It can partially supply the needs of humanity with freshwater production based on the use of relatively affordable technological resources. The operation and maintenance of this process do not require fruitful engineering knowledge but require permanent analyses of the water produced to ensure the quality of the process for its intended purposes.

Solar distillation is classified as a process with reduced production capacity. On the other hand, it is considered the most conducive to water desalination in arid and remote regions with high sunshine. The reduced efficiency of this process restricts the installation of units to areas with a higher incidence of solar radiation and larger surface coverage. However, the development of solar distillation technologies has been adequate for desalination processes when weather conditions are favorable and the demand for freshwater is not very high.

Studies indicate that the rate of freshwater production by solar distillation depends on the coverage area of the distillation system. A solar distiller includes a roof, feeding position, condensate collection channel, drainage circuit, basin, coating, and a support structure that ensures the fixation of the evaporation unit.

In short, a solar distiller consists of a basin containing the solution to be distilled (saline water). In this case, the core of the distiller operation is the space between the basin and the cover. Solar radiation hits the surface of the cover and suffers the effects of reflection, absorption, and transmission. Once reflected and absorbed by the cover, a remaining portion of solar radiation passes through the cover into the water. The radiation that passes through the cover is reflected, absorbed, and transmitted. Finally, the radiation absorbed by the water is on the lower surface of the bottom of the basin, where it is reflected.

The angle of incidence of solar radiation on the cover influences the amount of incident solar radiation that enters the solar distiller. So, the higher the perpendicular to the surface, the lower the transmissibility and the higher the reflection coefficient. The impacts of the angle of incidence directly affect the phenomena of reflection, absorption, and transmission of energy, resulting in the increase or reduction of the evaporation rates in the separation processes present in solar distillation.

1.3.2. Specifications of a Distiller

The solar distiller is delimited at the top by a transparent radiation cover. The sun's rays are absorbed and transmitted to the equipment's internal surface, resulting in the greenhouse effect inside the distiller.

Distillers must ensure the condensation of the water vapor, which involves: a) resistance to climatic conditions; b) transmissibility of solar radiation equal to or above 85%; (c) they must be opaque to radiation with a wavelength of more than 3μm, emitted from the black surface of the bottom of the basin, to store more heat inside the distiller; d) reflection coefficient of solar radiation, at a normal angle of incidence, shall not exceed 10%; e) absorption coefficient of solar radiation should be reduced, primarily when the cover is used as a condensing surface; f) reduced water absorbability, both as a rain catchment surface on the outer surface, and condenser on the inner surface; g) high thermal capacity to efficiently dissipate heat, thus keeping temperatures reduced; (h) the properties of the material should not change over time; (i) the material must not have electrostatic properties that concentrate dust particles on the outer surface; j) it must withstand wind speeds of up to 45 m/s.

1.3.3. Distiller Cover

The literature shows that most solar distillers' roofs are made of glass. Glass materials have a longer lifetime than other materials; their main disadvantage is that they are breakable. Typically, tempered or not thin glass with reduced iron content (0.01% Fe_2O_3) is the most recommended glass for water production processes by solar distillation [9].

The plastic cover has lower efficiency and a shorter lifetime (<15 years) than the glass cover. With its higher flexibility, plastic allows the selection of more comprehensive geometries for the configuration of the distiller. Its coefficient of expansion is also higher than that of glass. Phadatare and Verma [9] carried out comparative studies of distillers covered with glass and plastic, and they found that the glass cover provides 30 - 35% more productivity than distillers with plastic covers.

1.3.4. Distiller Base Structure

The basin or the base structure of solar distillers is where the solution to be distilled is inserted. The material used in constructing the distiller structure must be resistant to salt water. It can be made of materials such as brick; concrete mounted on the installation site using prefabricated molds; wood impregnated in epoxy resin; hard, UV-resistant plastic; fiber-reinforced plastic; aluminum; magnesium alloy; stainless steel and galvanized iron [10].

The bottom of the basin should absorb as much solar radiation as possible. For that, a coating with selective behavior, black, similar to a black body, should be applied. The materials used in the construction of the bottom of the basin are: a) for cheaper constructions, its background should be painted with black paint; b) a plastic plate, resistant to high temperatures and sunlight, embedded in the bottom of the basin (black polyethylene); c) butyl rubber; and d) asphalt [10, 11].

However, a black absorber surface can be used when the basin functions as a single element. Any black material can be used in the construction of the bottom of the basin, provided that it has the following properties: a) must be waterproof; b) must withstand high operating temperatures (≈90°C); c) must have high absorption coefficients of solar radiation (≥ 0.95); d) should not be toxic; e) the surface should be smooth, so as not to provide ideal surfaces for the deposition of solid particles and make the cleaning process of the equipment easier; f) as the coating, is sometimes placed directly on the soil, the material should not deteriorate in this situation [12].

The insulating material placed at the bottom of the basin aims to reduce thermal losses to the external environment by dissipation. The side walls of the basin should also be insulated. For thermal insulation, the materials used should be light and mechanically resistant, with reduced thermal conductivity, reduced water absorption rates, and high-temperature resistance [12].

1.3.5. Solar Distillation Technologies

Solar distillation technology has gained ground since its implementation in the 16th century; it was used by the US shortly after World War II, with the demographic explosion of the urban population and the industry's enormous growth. In this context, research and development projects were funded to find solutions to the water scarcity problem. Five demonstration facilities of solar distillation were built in Daytona Beach, where several typologies and configurations of solar distillers were tested [13, 14].

In Australia, the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Melbourne has conducted several studies on solar distillation. In 1963, a prototype was produced with a glass cover coated with a black polyethylene sheet. Based on this prototype, solar distillation facilities were built in the Australian desert, which aimed to produce water to meet human and animal needs and was the largest solar distillation facility built in Coober Pedy [15].

In the USSR, several studies and experiments were carried out with solar distillers, especially in Ashgabat (Turkmenistan), where a solar distillation unit was built to produce fresh water for sheep. The facility was fed with salted wells, using an experimental photovoltaic generator that produced electricity to pump the water to the distillers [16-18].

Between 1965 and 1970, solar distillation facilities were built on the Greek islands, aiming to produce fresh water to meet the needs of small communities [19-22].

Several studies have been conducted to increase the efficiency of solar distillers, but no large capacity installation built in recent years has been identified. On the other hand, recent literature on renewable energy has associated conventional desalination units of small capacity with the production of drinking water for small communities, especially during the summer. These are related to desalination facilities by reverse osmosis, with capacities above 1.0 m^3/day. Many of these pilot-scale facilities are used for experimental purposes.

1.4. Potential Solar Radiation in Angola

Angola has a privileged incidence of solar energy since its territory is in a tropical region. This condition enables suitable irradiation throughout the year, mainly in the provinces of Benguela, Huíla, Namibe, Cunene, and Kuando Kubango. According to data from the Ministry of Energy and Water of the Republic of Angola, the solar potential varies between 1.92 and 3.12 W/m^2/year, with greater intensity in the country's southern provinces. To better understand this distribution, Fig. (**3**) presents a scale that shows the inclusion of Namibe, Huíla, and Cunene provinces as those with more significant potential for solar radiation. They can support the implementation of solar distillers, which aims to produce drinking water to meet the needs of the population of these regions that have experienced squeamish situations resulting from the absence of drinking water for human and animal consumption.

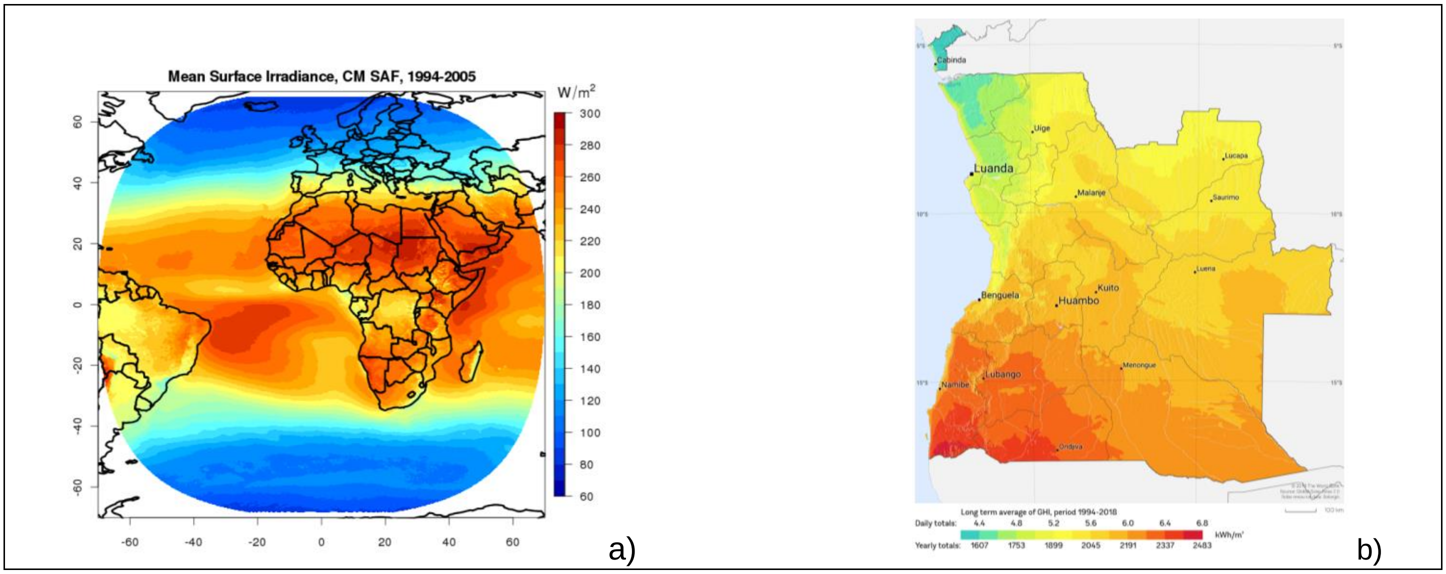

Figure 3. a) Impact power of solar radiation in Africa; b) Photovoltaic power in Angola [23].

2. Experimental Procedures

2.1. Experimental Equipment Design and Construction

2.1.1. Project Design

For the development of this work, the project of a solar distillation desalination unit was first designed, Fig. (**4**).

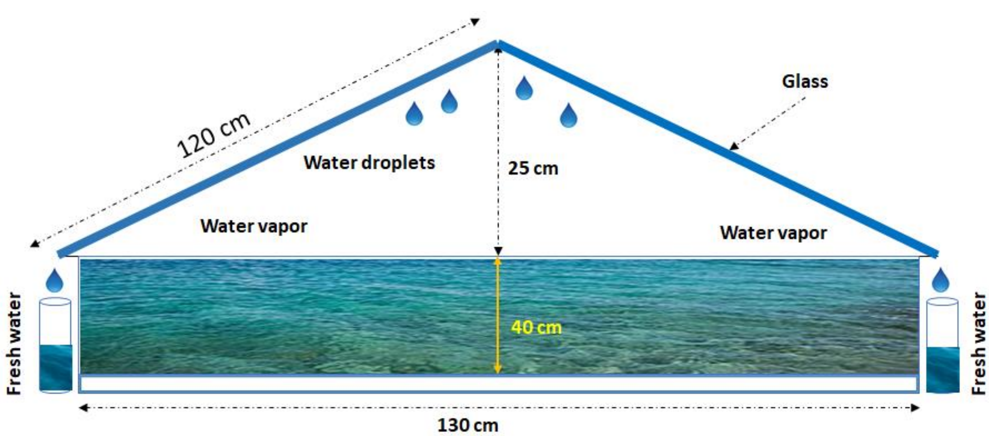

Figure 4: Desalination unit designed, built, and used in this project.

2.1.2. Laboratory Scale Equipment

With the dimensions in Fig. (**4**), the unit was designed using the AutoCAD® tool, with the appropriate geometry description for a laboratory scale. After preparing the blueprints, those were printed using a 3D printer, as shown in Fig. (**5**), using a density of 100%. To analyze absorption, two prototypes with different colors were printed, a white and a black one, considering that the bottom surfaces with higher absorption in the wavelength range of the sun reach higher equilibrium temperatures. On the other hand, the black color absorbs between 95-98% of the incident solar radiation, while the white color absorbs between 18 and 20%.

Figure 5: Solar seawater distiller 3D printing.

2.2. Experimental Procedure

The unit was designed to operate on a laboratory scale, with an initial liquid volume of 500 cm^3, with progressive control of evaporation rates that ensure the description of the evaporation curve to recover up to 40% of the liquid initially fed. The process dynamics are controlled, characterized by the evolution of the rate of fluid accumulation over time and the increase in the concentration of sodium chloride in the remaining water in the container. The execution of the experiments consisted, first, of the physicochemical characterization of the seawater sample, when the specific masses, viscosity, thermal conductivity, and pH were determined, parameters commonly used in the measurement of water portability. A seawater mass of approximately 450 grams was then measured and placed in the container through the top of the unit. The glasses were placed at the top of the device, and the device was sealed to avoid external interference. Subsequently, the device was placed in the sun to ensure the incidence of solar radiation, a phenomenon that results in water evaporation, which is recovered as drinking water collected by the channel of the experimental device.

After understanding the unit's operation principles, on a laboratory scale, linearization and the appropriate adjustments were made and build the solar seawater distiller on a pilot scale (Fig. **6**).

Figure 6: Solar seawater distiller on a pilot scale.

To collate the samples used to characterization, the desalter was fill with seawater and 2 liters this liquid were collected and placed in a PET bottle and sent it to laboratory to analysis. The desalination seawater was carried out for 4 days, when the fresh water is produced and two samples collected for day and evaluated in terms of quality and potability. The samples collected were placed in a PET bottle and forwarded it to the laboratory to determine the quality. The desalinated water parameters related in Table **3** are the averages measurements of each parameter. After completing the desalination, a sample of the remaining water or residual water is collected and placed in a PET bottle and submitted it to laboratory analyses

The water collected was characterized in terms of dissolved solid contents of the evaporated water samples were measured (ABNT NBR 14363), as well as specific mass (ABNT NBR 6457) and pH, using a Digimed pHmetro, series 24177.

3. Results and Discussion

3.1. Laboratory Scale Operation

The construction of distillers on a laboratory scale made it possible to know the operational principles, especially about the evaporation and condensation phenomena, all related to heat resulting from the incidence of solar radiation on the glass surface. In addition, the intensity of vapors inside the distiller, the phenomena of droplet formation, surface tension, and the relationship of the forces involved in the recovery of condensed water was observed.

3.2. Scale Expansion and Construction of the Pilot Unit

The design and construction of the unit on a 3x4 meters scale, was built in Buraco Neighbourhood, district of Mussulo, Municipality of Talatona in Luanda. Four solar distillers were constructed, Fig. (**6**).

The pilot unit proposed to produce drinking water contains the structure shown in Fig. (**6**), with square-based geometry, in the shape of a house with glass tile, which receives the solar radiation that passes through the upper glass and focuses on the salt water of the sea contained inside this parade. With the action of solar radiation, water vaporization occurs, which rises to the lower surface of the glass when condensation occurs. As a function of surface tension, water adheres to the lower surface of the glass and descends superficially to the collection channel.

3.3. Pilot Scale Distillers

With the unit's data on a laboratory scale, based on the initial tests, the unit was designed and built on a pilot scale, which allowed a better knowledge of the phenomena of these operations and specific rates of drinking water production. For this, the first sample of water produced was analyzed, and the results are presented in Table **3**.

Table 3: Properties of desalinated water.

Parameters	Seawater	Desalinated water	Reference potability
Temperature (°C)	25.00	25.00	25
pH	8.35	9.32	6.0-9.0
Conductivity (mS/cm)	40.82	20.38	0,61-10.0
Salinity (g/Kg)	26.45	0.09	0.05
SDT (ppt)	19.99	35.12	Less than 100.0
Calcium ($mgCa^{-2}$)	781.56	68.12	0.7 - 50.0
Magnesium ($mgMg^{-2}$)	9325.10	77.00	Less than 50.0
Total hardness ($mCaCO_2$)	1798.10	2.16	1
Total alkalinity ($mgCaCO_2$)	175.00	80.00	120.0 - 150.0
Chlorides (mgCl)	1242.50	17.60	13

The data in Table **3** show the various parameters of the quality of the water produced and the impacts of desalination. The water produced is characterized by a significant change in its variables, such as salinity, calcium contents, total hardness, magnesium contents, and total alkalinity. Comparing these data shows that, with the implementation of desalination, the water produced approximately meets the main parameters mentioned above. Table **4** describes water quality at the beginning (Seawater before desalination), during (desalination water), and at the end (Residual seawater) of the process, and it is important to highlight the resulting significant differences. In this case, the desalination water parameters were measured during the processes until the end and the results referenced in Table **4** for "Desalinated water" were related to the average of the physical and chemical parameters carried out during desalination.

Table 4: Water characteristics before, during, and after desalination.

Parameters	Seawater before Desalination	Desalinated Water	Residual Seawater	Reference Potability
Temperature (°C)	25.00	22.60	23.30	25.00
pH	8.35	7.32	9.08	6.0-9.0
Conductivity (mS/cm)	40.82	17.35	48.57	0,61-1.0
Salinity (g/Kg)	26.45	0.10	31.65	0.05
SDT (ppt)	19.99	38.01	23.80	Less than 100.0
Calcium (mgCa-2)	781.56	76.15	300.60	0.7 - 50.0
Total hardness (mgCaCO2)	9325.10	28.80	403.30	Less than 50.0
Magnesium (mgMg-2)	1798.10	23.82	9099.70	1.00
Total alkalinity (mgCaCO2)	275.00	75.00	335.00	120.0 - 150.0
Chlorides (mgCl)	1242.50	0.21	150.88	13.00

Therefore, the data on the desalinated freshwater shown in Table **4** reveals that it complies with the principles of potability commonly used in water treatment stations, requiring adjustments in chloride, alkalinity and hardness, with the exception for calcium. These adjustments must involve mixing or dosing operations of the required chemicals. On the other hand, wastewater concentrates significant amounts of salts that can be used, by natural evaporation and crystallization, to produce crystal salt for commercial purposes. In addition, the desalination operations carried out along these studies have required quantifying the mass or volume of water produced using this parameter as a function of time.

In the analyses performed, it was observed that for the dimensions of the solar distillers built, the water flow varies between 140 and 195 liters per day, corresponding to 35 and 48.75 liters per day for each solar distiller. Considering that the total area of the four solar distillers is 48 m^2, it can be affirmed that the daily fresh water production per square meter per day is 2.92 to 4.06 liters. These values are like those presented in the literature, which show that water production is between 2-5 liters/m^2 [24-26].

To achieve the maximum production condition defined in the literature, the optimization of the operating parameters should be performed, with emphasis on increasing the temperature of the system or establishing a vacuum that can increase the relative humidity of the system and, therefore, the evaporation rates. Therefore, with the results presented in this work, it can be affirmed that the desalination enhances the production of water in serving regions with a scarcity of this good, especially in coastal regions and desert regions that extract groundwater from artesian wells but with high salt content (brackish) that requires the implementation of the technology described in this work.

For reality of Buraco Neighbourhood, district of Mussulo, Municipality of Talatona in Luanda with lacking access of fresh water share access to saline water resources, high levels of solar radiation and a precarious economic situation. If appropriate technologies are defined as decentralized, labor-intensive, energy-efficient, environmentally friendly and locally autonomous solutions developed for a given context, there is a strong need to develop and promote appropriate technologies that are adapted to these conditions. That are the same conclusion obtained by Romero *et al*. [27] that write a critical review of existing technology under the appropriate technology paradigm.

For other hand, while the productivity of solar desalination is limited, their simple construction and low maintenance requirements makes them an attractive and feasible option for community-scale desalination, as Buraco Neighbourhood that have only approximately 1.700 people. This recommendation is the same proposed by Hota *et al*. [28] that develop the study about the feasibility of desalination by solar stills for small community scale freshwater demand and shows that low-cost solar stills are capable of producing sufficient freshwater for small disadvantaged communities at costs lower than competing technologies.

4. Conclusion

The results presented throughout this work make it possible to conclude that:

1) The quality and performance of the distiller presented in this work are due to previous dimensional studies, choice of more suitable materials, and parametric evaluation of operation;
2) The volume of salt water initially inserted in the distiller is directly related to the production capacity of fresh water; that is, the higher the volume of initial water, the smaller the volumes of fresh water produced;
3) Solar radiation does not affect process efficiency when the volume of salted water is high. However, when the volume of water in the tank is reduced, solar radiation promotes the increase in water temperature, thereby boosting the rates of freshwater production;
4) Water desalination is an efficient and inexpensive procedure for the production of drinking water, which can be used to meet the needs of this well for populations with access limitations;
5) It is necessary to carry out studies of the incidence of solar radiation in the country to define more appropriate sites for the installation and implementation of this type of project in Angola. However, the southern region is the most appropriate for this purpose;
6) regarding the production rates, it was confirmed that the volumes produced are similar to the data contained in the literature, and optimization studies can be performed to increase these parameters;
7) The quality of water produced meets the international parameters of the quality of drinking water consumed in the world. However, final adjustments to water parameters should be made to better suit international quality.

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

References

[1] Rieu-Clarke A, Moynihan A, Magsig BO, UNESCO World Water Assessment Programme. Transboundary water governance and climate change adaptation: international law, policy guidelines and best practice application. Paris, France: UNESCO; 2015.

[2] Resolução CONAMA N° 430. Ministério do Meio Ambiente. Conselho Nacional do Meio Ambiente, CONAMA. 2011. Brasil.

[3] Singh S, Singh R, Sharma NR, Singh A. Ethanolic extract of cockroach wing powder as corrosion inhibitor for N80 steel in an ASTM D1141-98(2013) standard artificial seawater solution. Int J Electrochem Sci. 2021; 16: Article ID: 210841. https//doi.org/10.20964/2021.08.43

[4] Alklaibi AM, Lior N. Membrane-distillation desalination: status and potential. Desalination. 2004; 171(2): 111-31. https://doi.org/10.1016/j.desal.2004.03.024

[5] Duffie JA, Beckman WA. Solar engineering of thermal processes. 4th ed. Hoboken, New Jersey: John Wiley & Sons, Inc.; pp. 1-796.

[6] Wang H, Xu X, Zhu G. Landscape changes and a salt production sustainable approach in the state of salt pan area decreasing on the coast of Tianjin, China. Sustainability. 2015; 7(8): 10078-97. https://doi:10.3390/su70810078

[7] Bhattacharyya A. Solar stills for desalination of water in rural households. Int J Environ Sustain. 2013; 2(1): 21-30. https://doi:10.24102/ijes.v2i1.326

[8] Singh G, Kumar S, Tiwari GN. Design, fabrication and performance evaluation of a hybrid photovoltaic thermal (PVT) double slope active solar still. Desalination. 2011; 277(1-3): 399-406. https://doi.org/10.1016/j.desal.2011.04.064

[9] Phadatare, MK, Verma SK. Influence of water depth on internal heat and mass transfer in a plastic solar still. Desalination. 2007; 217: 267-75. https://doi.10.1016/j.desal.2007.03.006

[10] Talbert SG, Eibling JA, Lof̈, GOG. Manual on solar distillation of saline water. Washington: U.S. Dept. of the Interior; 1970.

[11] Cooper PI, Read WRW. Design philosophy and operating experience for Australian solar stills. Solar Energy. 1974; 16: 1-8. https://doi.org/10.1016/0038-092X(74)90037-1

[12] Lawand TA. Systems for solar distillation. In: Freyh B, Fritz G, Eds. International Conference Appropriate Technologies for Semiarid Areas: Wind and Solar Energy for Water Supply, Berlin (West), 15 to 20 September 1975, pp. 201-50.

[13] Buros OK. A history of desalting water in the Virgin Islands. Desalination. 1984; 50: 87-101. https://doi.org/10.1016/0011-9164(84)85020-1

[14] Ho-Ming Y, Lin-Wen T, Lie-Chaing C. Basin-type solar distillers with operating pressure reduced for improved performance. Energy. 1985; 10(6): 683-8. https://doi.org/10.1016/0360-5442(85)90101-X

[15] Mekhilef S, Saidur R, Safari A.A review on solar energy use in industries. Renewable Sustainable Energy Rev. 2011; 15(4): 1777-90. https://doi.org/10.1016/j.rser.2010.12.018

[16] Kalogirou SA. Seawater desalination using renewable energy sources. Prog Energy Combus Sci. 2005; 31(3): 242-81. https://doi.org/10.1016/j.pecs.2005.03.001

[17] Baum VA, Bairamov R. Prospects of solar stills in Turkmenia. Solar Energy. 1966; 10(1): 38-40. https://doi.org/10.1016/0038-092X(66)90070-3

[18] Baum VA, Bairamov R. Heat and mass transfer processes in solar stills of hotbox type. Solor Energy. 1964; 8(3): 78-82. https://doi.org/10.1016/0038-092X(64)90081-7

[19] Delyannis EE. Status of solar assisted desalination: A review. Desalination. 1987; 67: 3-19. https://doi.org/10.1016/0011-9164(87)90227-X

[20] Delyannis A. Delyannis E. Recent solar distillation developments. Desalination. 1983; 45 (1-3): 361-9. https://doi.org/10.1016/0011-9164(83)87239-7

[21] Monteiro J, Baptista A, Pinto G, Ribeiro L, Mariano H.Assessment of the use of solar desalination distillers to produce fresh water in arid areas. Sustainability. 2020; 12(1): 53-62. https://doi.org/10.3390/su12010053

[22] Eckstrom R. Design and construction of the Symi still. Sun at Work. 1965; 10(1): 7.

[23] Constantino EDG, Teixeira SFCF, Teixeira JCF, Barbosa FV. Innovative solar concentration systems and its potential application in Angola. Energies. 2022; 15(9): 7124-34. https://doi.org/10.3390/en15197124

[24] Velmurugan V, Srithar K. Performance analysis of solar stills based on various factors affecting the productivity: A review. Renewable Sustainable Energy Rev. 2011; 15(2): 1294-1304. https://doi.org/10.1016/j.rser.2010.10.012

[25] Mariano HQS. Estudo de sistema de produção de água potável através do processo de destilação solar. Departamento de Engenharia Mecânica, Instituto Superior de Engenharia do Porto, Portugal, 2019.

[26] Belessiotis V, Kalogirou S, Delyannis E. Thermal solar desalination: methods and systems. Academic Press; Elsevier Ltd. 2016.

[27] Tarazona-Romero BE, Campos-Celador A, Maldonado-Muñoz YA. Can solar desalination be small and beautiful? A critical review of existing technology under the appropriate technology paradigm. Energy Res Soc Sci. 2022; 88: 102510. https://doi.org/10.1016/j.erss.2022.102510

[28] Hota SK, Hada SS, Keske C, Diaz G. Feasibility of desalination by solar stills for small community scale freshwater demand. J Clean Prod. 2022; 379(1): 134595. https://doi.org/10.1016/j.jclepro.2022.134595