Solar Desalination of Water Collected from River Niger for Domestic Purposes

Ugwoke Emmanuel Eze[1]; Audu Ibrahim Ali[2]; E.C. Ugwuoke[3]; Okoh Promise Emeka[4]; and I. Ofili[3]

[1]Weather Forecasting Services, Nigerian Meteorological Agency, Nigeria
[2]Department of Mechanical Engineering, The Federal Polytechnic, Idah, Nigeria.
[3]Projects Development Institute (PRODA), Enugu, Nigeria.
[4] Institute of Management and Technology (IMT), Enugu, Nigeria.

E-mail: emmychyugwuoke@yahoo.com

ABSTRACT

Desalination is one of the oldest technologies used by people for water purification in the world. Desalination uses a large amount of energy to remove a portion of pure water from a saltwater source. Saltwater is fed into the process, and the result is one output stream of pure water and another of wastewater with a high salt concentration. Solar energy can directly or indirectly be harnessed for desalination. Collection systems that use solar energy to produce distillate directly in the solar collector are called direct collection systems.

The study was done with 30 liters of water producing average of 2.79 liters per day. The production of distillate was not steady at the period of the experiment due to fluctuating nature of solar radiation. The distillate yield from the results indicated that the higher the temperature the higher the distillate produced each day, for example the maximum atmospheric temperature during the experiment was at day 2 and day 3, respectively, which corresponded to the maximum distillate yield of 3.4 liters and 3.3 liters, respectively. The atmospheric temperature during the experiment varied from 26 – 31ºC.

(Keywords: desalination, river water, purification, solar energy, distillate)

INTRODUCTION

Many human diseases are due to polluted or non-purified water resources. Even today, underdeveloped and developing countries alike face a huge water scarcity problem because of unplanned mechanisms and pollution created by man-made activities [1]. Desalination is one of the oldest technologies used by people for water purification in the world. In this context, many conventional and non-conventional techniques have been developed for purification of saline water [2].

The main problems with the use of solar thermal energy in large scale desalination plants are the relatively low productivity rate, the low thermal efficiency, and the considerable land area required. Since solar desalination plants are characterized by free energy and insignificant operation cost, this technology is suitable for small-scale production, especially in remote arid areas and islands, where the supply of conventional energy is scarce [3,4].

Desalination uses a large amount of energy to remove a portion of pure water from a saltwater source. Saltwater is fed into the process, and the result is one output stream of pure water and another of wastewater with a high salt concentration. Solar energy can directly or indirectly be harnessed for desalination.

Collection systems that use solar energy to produce distillate directly in the solar collector are called direct collection systems whereas systems that combine solar energy collection systems with conventional desalination systems are called indirect systems [1]. In indirect systems, solar energy is used either to generate the heat required for desalination and/or to generate electricity that is used to provide the required electric power for conventional desalination plants such as multi-effect (ME), multi-stage flash (MSF) or reverse osmosis (RO) systems [5].

Desalination is increasingly being used to provide drinking-water under conditions of freshwater scarcity [6]. Water scarcity is estimated to affect one in three people on every continent of the globe, and almost one fifth of the world's population live in areas where water is physically scarce. This situation is expected to worsen as competing needs for water intensify along with population growth, urbanization, climate change impacts and increases in household and industrial uses. Desalination of available brackish water has been considered as an alternative approach [7].

Desalination may be applied to waters of varying levels of salinity, such as brackish groundwater, estuarine water, or seawater; in some regions, it forms the primary source of drinking-water. At its origins, desalination technology was primarily thermal, by flash distillation, but as a result of technological advances, membranes have become a more cost-effective alternative that is increasingly being selected for new systems. Many thermal plants remain in use.

Saline sources are different from freshwater sources in that they always require a substantive treatment step [6]. However, while the desalination process usually provides a significant barrier to both pathogens and chemical contaminants, this barrier is not necessarily absolute, and a number of issues could potentially have an impact on public health. Some of these are similar to the challenges encountered in most piped water systems, but others, such as those related to stabilizing and remineralizing the water to prevent it from being excessively aggressive, are different and therefore must be addressed within the context of a site-specific health risk management plan.

Source Water and Potential Hazards

Source water for desalination can be marine or brackish surface water or highly mineralized groundwater. By definition, this water has a significant content of naturally occurring inorganic ions, and the objective of treatment is to reduce the concentration of, or remove, these substances [6]. These naturally occurring substances include some that would be of potential concern if present in sufficient concentrations after treatment. Like all surface water sources and some groundwater sources, there can be contamination by pathogenic viruses, bacteria and parasites and by a variety of chemical contaminants from human activities.

There are notable differences between freshwater sources and brackish or saline sources. In particular, the survival of many microbial pathogens is significantly reduced in saline waters, especially in combination with a high level of solar radiation. However, some pathogens, such as *Vibrio cholerae*, do survive well in saline waters. There are also many marine algae that can produce toxins of concern to human health. These issues are covered in detail in Desalination technology: health and environmental impacts [8]. Chemical constituents of interest include boron (borate), bromide, iodide, sodium and potassium; they may require additional actions for removal (boron) or are present in such concentrations as to leave significant residues.

While natural organic matter (NOM) varies significantly, there are a number of organic substances, coming from both natural and anthropogenic sources, which are of particular interest. Individual and groups of chemicals that are of concern for desalination processes are considered in more detail in a large-scale desalination process.

Understanding the hazards that are likely to be present in the source water is a critical condition for the proper design of the desalination process; it highlights the need for pre-treatment steps and the removal of contaminants in treatment or the need for additional treatment barriers. In the case of potential problems from contaminants, either chemical or microbial, the first step in reducing the associated risks is to try to prevent or reduce inputs at source. In some cases, this may be possible; in other cases, siting of the raw water intake may help to minimize the intake of contaminants into the desalination plant. However, thermal plants, in particular, are often co-located with power plants, and there may be limited options in terms of suitable locations for the intake [6].

Where source water quality is highly variable, some form of monitoring will help to provide information in managing water abstraction to minimize the intake of constituents or contaminants. For example, some estuarine-based desalination plants abstract water only at a particular tide level to reduce the salinity in the source water and the concentrations of possible anthropogenic contaminants. In addition, knowledge of potential contaminants is important in preparing emergency plans to protect source water quality (e.g., to deal with oil spills in oil-producing regions).

Overseas Use of Desalination Technologies

In predominantly arid regions of the world, and especially in the Middle East, where conventional sources of fresh water (e.g., rivers, lakes, reservoirs or groundwater) are not readily available, seawater desalination will continue to supply drinking water [9]. In some countries, desalinated water may also be used for government subsidized agricultural operations where self-sufficiency and national security are primary objectives. However, desalinating irrigation water for traditional open-field agriculture will probably not be economically competitive in the foreseeable future anywhere in the world. In the absence of free market constraints (e.g., government subsidies), it is usually more cost-effective to import crops from water-rich agricultural regions [9].

In most lower-tier developing countries the vast majority of water will continue to come from essentially salt-free surface and groundwater supplies. It is estimated that about half of the people in these countries do not have adequate (e.g., disinfected) drinking water supplies; about 70 percent have inadequate sanitation facilities.

Water treatment, if there is any, generally involves the use of more conventional technologies, such as sedimentation, filtration, and disinfection. However, relatively small desalination plants may be of particular value for tourist hotels, construction sites, and certain isolated communities that have no other readily available sources of freshwater. In very remote areas small solar stills or solar-powered desalting units may be an appropriate desalting alternative. The majority of industrialized countries are located in temperate zones where supplies of freshwater are adequate. Therefore, desalination technologies will be used in these countries primarily for industrial purposes, and secondarily for treating drinking water.

Solar-Powered Water Desalination

Solar energy is the oldest energy source used by human beings [10]. The first known practical application was in drying for food preservation. Scientists have long looked at solar radiation as a source of energy, trying to convert it into a useful form for direct utilization. Archimedes, the Greek mathematician and philosopher (287–212 BC), used the sun's reflected heat to burn the Roman fleet in the Bay of Syracuse [11]. During the eighteenth century, the French naturalist Boufon experimented with various solar energy devices which he called 'hot mirrors burning at long distance' [12].

Most forms of energy are solar in origin. Oil, coal, natural gas and wood were originally produced by photosynthetic processes [13]. Even wind and tide energy have a solar origin, since they are caused by differences in temperature in various regions of the earth. The great advantages of solar energy, compared with other forms of energy, are that it is clean, sustainable and can be used without any environmental pollution.

Solar energy is used to heat and cool buildings, to heat water for domestic and industrial uses, to heat swimming pools, to power refrigerators, to operate engines and pumps, to desalinate water for drinking purposes, to generate electricity, in chemistry applications and for many more functions. The decision about which source of energy to use should be made on the basis of economic, environmental and safety considerations. Because of its desirable environmental and safety advantages, it is widely believed that, where possible, solar energy should be utilized instead of energy derived from fossil fuels, even when the costs involved are slightly higher [14]. This section focuses on the desalination of saline water by using solar energy.

Water Desalination using Solar Power

Solar water desalination has a long history. The first documented use of solar stills was in the sixteenth century and, in 1872, the Swedish engineer, Carlos Wilson, built a large-scale solar still to supply a mining community in Chile with drinking water [15]. Solar desalination using humidification and dehumidification is a promising technique for producing fresh water, especially in remote and sunny regions. It has the potential to make a significant contribution to providing humans with fresh water using a renewable, free and environmentally friendly energy source [16].

Solar energy can be used to convert saline water into fresh water with simple, low cost and economical technology and thus it is suitable for small communities, rural areas and areas where the income level is very low [17]. Recent developments have demonstrated that solar powered desalination processes are better than the alternatives, including ED, RO and freezing, for freshwater provision in remote rural areas [18]. Solar-powered desalination processes are generally divided into two categories, direct and indirect systems.

Direct systems: The direct systems are those where the heat gaining and desalination processes take place naturally in the same device. The basin solar still represents its simplest application, the still working as a trap for solar radiation that passes through a transparent cover.

Solar Still: Solar still distillation represents a natural hydrologic cycle on a small scale. The basic design of a solar still, which is similar to a greenhouse, is shown in Figure 1. Solar energy enters the device through a sloping transparent glass or plastic panel and heats a basin of saltwater [10]. The basin is generally black to absorb energy more efficiently. The heated water evaporates and then condenses on the cooler glass panels. The condensed droplets run down the panels and are collected for use as fresh water. Experience proves that 1 m^2 of ground will produce 3–4 l/day of freshwater. Because of this low production, it is important to minimize capital costs by using very inexpensive construction materials. Efforts have been made by various researchers to increase the efficiency of solar stills by changing the design, by using additional effects such as multistage evacuated stills and by adding wicking material, etc. And these modifications have increased production per unit area [19]. In the simple solar still shown in Figure 1, the latent heat of condensation is dissipated to the environment. However, the latent heat of condensation can be used to preheat the feed water, and this obviously leads to an improvement in the still efficiency.

Advantages and disadvantages of the solar still: Solar still technology requires a large area for solar collection, so it is not viable for large-scale production, especially near a city where land is scarce and expensive. The comparative installation costs tend to be considerably higher than those for other systems.

They are also vulnerable to damage by weather. Labor costs are likely to be high for routine maintenance to prevent scale formation and to repair vapor leaks and damage to the still's glass [19, 20]. However, they can be economically viable for small-scale production for households and small communities, especially where solar energy and low-cost labor are abundant [19, 21].

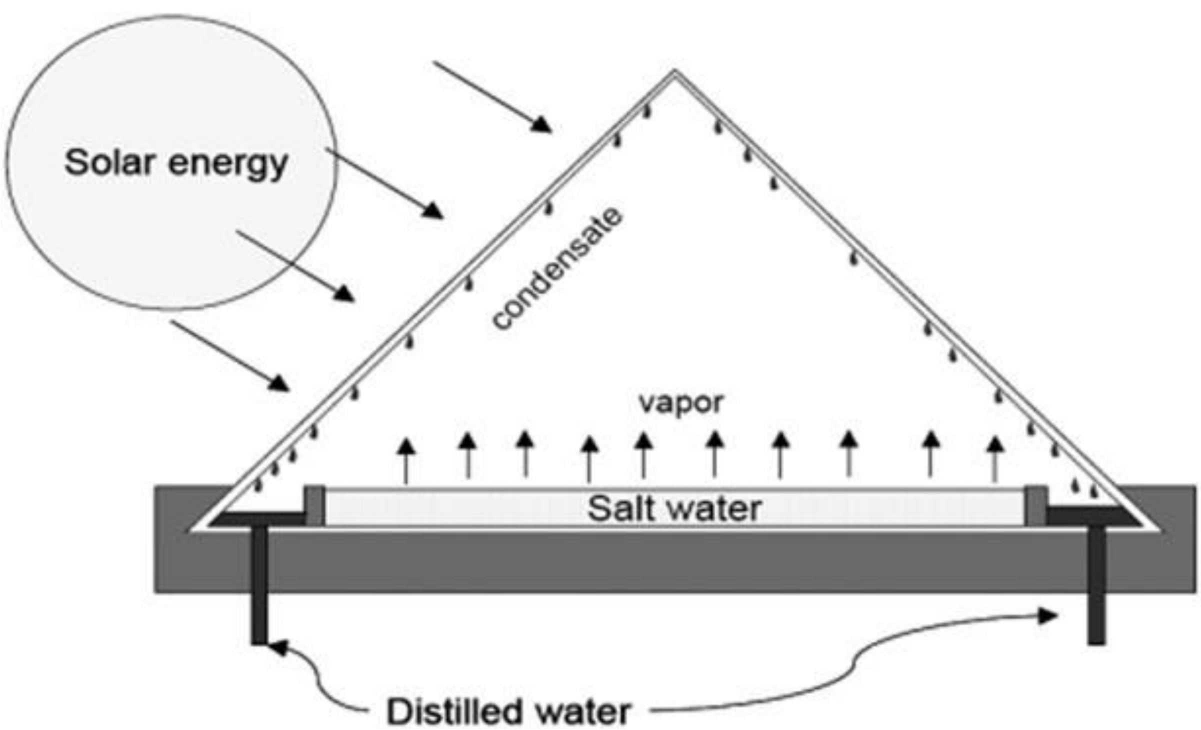

Figure 1: Solar Still Unit [20].

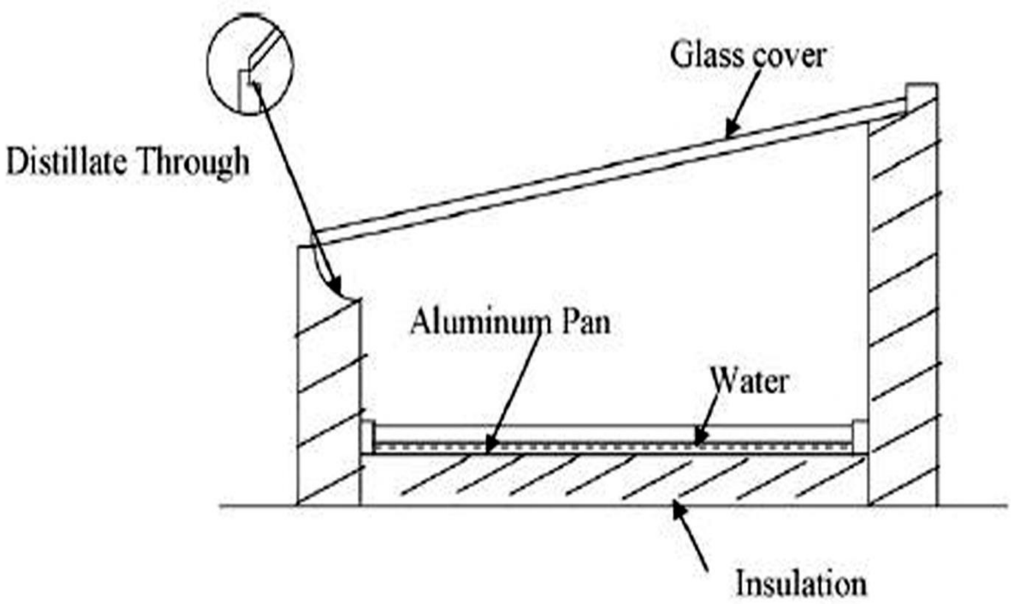

Figure 2: Schematic Diagram of a Simple Solar Still [22, 23]

MATERIALS AND METHODS

Collection of Water

The water used in this experiment was collected from the River Niger close to Onitsha Anambra State, Nigeria. The water was tested and found out that it is contained salt and some mineral element such as calcium, sodium and other minute element. Some of the mineral element causes hardness of water. They require some treatment before it will be used for drinking and domestic purposes.

Apparatus

The solar still is possibly the oldest method of desalination of water. Its principle of operation is the greenhouse effect; the radiation from the sun evaporates water inside a closed glass covered chamber at a temperature higher than the ambient [22]. A schematic diagram of typical basin type solar still is shown in Figure 2.

Experimental Method

The 30 liters of saline water was fed on a black plate in the lower portion of the solar distiller. The heat of the sun caused the water to evaporate and water vapor condensed to form purely distilled droplets of water when it reaches the cool transparent leaning surface made of glass or plastic. The droplets slide down along the leaning surface and are collected through special channels located under the leaning surface.

Determination of Chemical Properties of the Water

Color of Water: The method adopted by Ofili and Ugwuoke, et al. [7] was used. The water color was determined by measurement of optical density (absorbance) on a spectrometer which has various wavelength of light passage. This works with the principle that the wavelength that was maximally absorbed by water is the characteristic of its colors. The water that was used for the investigation was first filtered to eliminate possible turbidity. The value of the optical density is a measure of color intensity. In this experiment the 575-590 wavelength was maximally absorbed by the water.

pH Determination: The method adopted by Ofili and Ugwuoke et al. [7] was also used. Water reaction is usually expressed as concentration of hydrogen ion. When pH =7, water reaction is neutral; if pH is > or < 7 then the reaction change in the alkaline or acid direction, respectively. In natural waters, the concentration of hydrogen ions depends on the dissociation and hydrolysis of the combination occurring in it. The pH meter was used for the determination of hydrogen ion and the value of pH of the water obtained was 6.9.

RESULT AND DISCUSSION

The result obtained indicated that the desalination of 30 liters of water from River Niger collected from Onitsha, Anambra State gave a maximum yield of 3.4 liters at day 3. This was as result of high solar radiation during the day which resulted to evaporation of the clean water from the basin of the solar still and consequently collection of the distillate. The fresh water collected was not steady for the 10 days period of the experiment. This was as a result of unsteady nature of solar intensity. Also, poor weather condition such as high humidity also affects the desalination of the brackish water. The minimum yield of 1.8 liters was recorded on the 9th day. The range of the distillate water produced was 1.8 -3.4 liters.

Table 1: Volume of the Distillate Produced.

Time (Days)	1	2	3	4	5	6	7	8	9	10
Vol.(Litres)	1.9	3.1	3.4	2.7	2.9	3.3	2.5	3.1	1.8	3.2

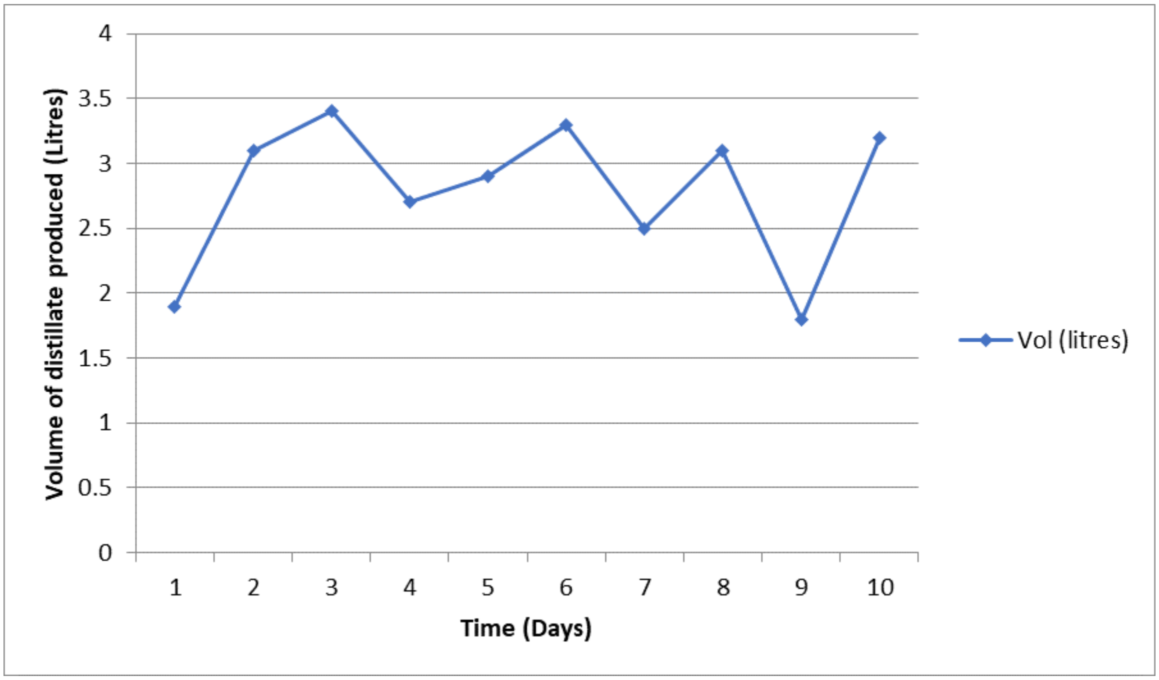

Figure 3: Volume of Distillate Produced (Liters) versus Time (Days).

Table 2: Maximum Atmospheric Temperature.

Time (Days)	1	2	3	4	5	6	7	8	9	10
Max. Atm temp(°C)	27	29	30	28	29	31	26	29	27	30

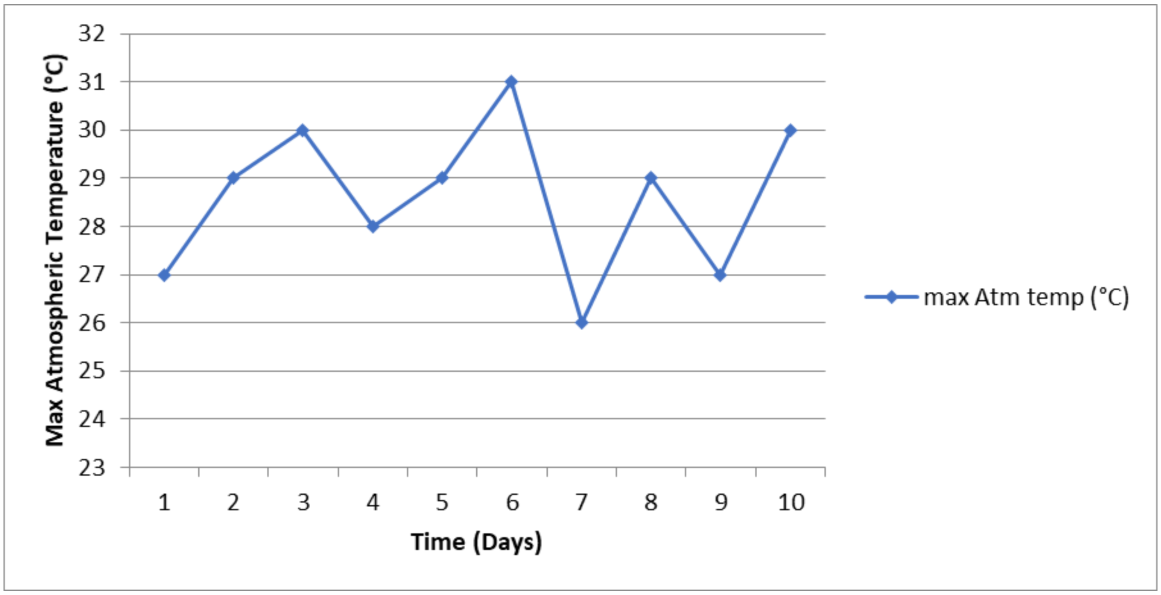

Figure 4: Atmospheric Temperature versus Time (Days).

The atmospheric temperature during the experiment varied from 26 – 31ºC. The variation of the temperature of the atmosphere has a very important effect on the result of the experiment especially the distillate output. The increase in temperature of the atmosphere will increase the basin temperature thereby making more clean water to escape to the roof of the solar still, which will later trickle down to the collection trough.

The average Insolation at the place of the experiment was 450w/m^2. The distillate yield from the tables indicated that the more the temperature the higher the distillate produced each day, for example the maximum atmospheric temperature during the experiment was at day 2 and day 3, respectively, which correspond to the maximum distillate yield of 3.4 liters and 3.3 liters, respectively.

CONCLUSION

Solar energy may be employed to produce fresh water from the sea. This may be accomplished in a large system or in a simple basin type desalination unit. Energy transfer from basin to cover occurs by evaporation and condensation, in addition to convection and radiation. The processes of energy transfer will consequently give rise to distillate water. The losses from the back of the still are to the ground. The depth of the water in the still is usually such that its capacitance must be taken into account.

The maximum distillate produced during the experiment was 3.4 liters which correspond to maximum atmospheric temperature of 30ºC. The average distillate produced for the period of the study was 2.79 liters.

REFERENCES

1. Gorjian, S., B. Ghobadian, and T.T. Hashjin. 2011. “Seawater Desalination using Solar Thermal Technologies: State of the Art”. International Conference on Sustainable Energy Technologies, Istanbul, Turkey.

2. Sampathkumar, K., T.V. Arjunan, P. Pitchandi, and P. Senthilkumar. 2010. “Active Solar Distillation - A Detailed Review”. *Renewable and Sustainable Energy Reviews*. 14: 1503-1526.

3. Naim, M. and M.A. Abd El Kawi. 2002. “Non-Conventional Solar Stills Part 1: Non-Conventional Solar Stills with Charcoal Particles as Absorber Medium”. *Desalination*.153:55-64.

4. Naim, M. and M.A. Abd El Kawi. 2002. “Non-Conventional Solar Stills Part 2: Non-Conventional Solar Stills with Energy Storage Medium”. *Desalination*. 153:71-80.

5. Garzia-Rodriguez, L. and C. Gomez-Camacho. 2000. “Perspectives of Solar-Assisted Seawater Distillation”. *Desalination*. 136: 213-218.

6. World Health Organization (WHO). 2011. *Safe Drinking-water from Desalination*. WHO Press: New York, NY.

7. Ofili, I., E.C. Ugwuoke, N.N. Eze, S.T. Ukwuani, and S.A. Ogunjobi. 2016. “Water Purification by Solar Distillation Process”. *Pacific Journal of Science and Technology*. 17(1):12-16.

8. Cotruvo, J. et al. 2010. “Desalination Technology—Health and Environmental Impacts. IWA Publishing and CRC Press: Boca Raton, FL,.

9. U.S. Congress, Office of Technology Assessment. 1988. “Using Desalination Technologies for Water Treatment”. OTA-BP-O-46 U.S. March 1988. Government Printing Office: Washington, D.C.

10. Shatat, M. and S.B. Riffat. 2014. “Water Desalination Technologies Utilizing Conventional and Renewable Energy Sources”. *International Journal of Low-Carbon Technologies*. 9.

11. Kalogirou, S.A. 2005. “Seawater Desalination using Renewable Energy Sources”. *Prog Energy Combust Sci* 31:242–81.

12. Delyannis, E. 2003. “Historic Background of Desalination and Renewable Energies”. *Sol Energy.* 75:357–66.

13. Kreith, F. and J.F. Kreider. 1978. *Principles of Solar Engineering*. McGraw-Hill: New York, NY.

14. Kalogirou, S.A. 2004. “Solar Thermal Collectors and Applications”. *Prog Energy Combust Sci.* 30:231–95.

15. Intermediate Technology Development Group. 2007. “Solar Distillation: Technical Brief”. The Schumacher Centre for Technology & Development. 8 October 2007. http:// www.itdg.org/docs/technical_information_service.

16. Fath, H.E.S. and A. Ghazy. 2002. “Solar Desalination using Humidification–Dehumidification Technology”. *Desalination*. 142:119–33.

17. Ali Samee, M., U.K. Mirza, T. Majeed, et al. 2007. “Design and Performance of a Simple Single Basin Solar Still”. *Renew Sustain Energy Rev*. 11:543–9.

18. Abdel-Rehim, Z.S. and A. Lasheen. 2005. “Improving the Performance of Solar Desalination Systems”. *Renew Energy*. 30:1955–71.

19. Buros, O.K. 2000. *The ABCs of Desalting, 2nd edn*. ASIN: B0006S2DHY, International Desalination Association, 2000, 30.

20. Miller, J. 2008. “Review of Water Resources and Desalination Technologies”. Materials Chemistry Department, Sandia National Laboratories, 2003. (3 March 2008). http://www. prod.sandia.gov/cgi-bin/techlib/access-control.pl/2003/030800.pdf

21. Ali Samee, M., U.K. Mirza, T. Majeed, et al. 2007. “Design and Performance of a Simple Single Basin Solar Still”. *Renew Sustain Energy Rev.* 11:543–9.

22. Bhattacharyya, A. 2013. “Solar Stills for Desalination of Water in Rural Households”. *International Journal of Environment and Sustainability*.

23. Kaushal, A. and A. Varun. 2010. “Solar Stills: A Review”. *Renewable & Sustainable Energy Reviews* 14:446–453.

ABOUT THE AUTHORS

Ugwoke Emmanuel Eze, works with the Weather Forecasting Services, Nigerian Meteorological Agency, emmanugwuoke@yahoo.com, +2348037509782.

Audu Ibrahim Ali, is a Lecturer at Department of Mechanical Engineering, Federal Polytechnic, Idah. +23408033322061.

E.C. Ugwuoke, is a Master’s Degree holder in Energy and Power Technology at the University of Nigeria, Nsukka, and he also works with Projects Development Institute (PRODA), Enugu, Nigeria. His research interest is in renewable energy. He has done research on solar water distillation systems and biogas technology. emmychyugwuoke@yahoo.com, +2348039308009.

P.E Okoh, is a Lecturer in the Department of Mechanical Engineering, Institute of Management and Technology, Enugu. emekapromise25@yahoo.com, 2348166761508.

I. Ofili, is Chief Engineer at the Projects Development Institute (PRODA), Enugu, Nigeria. +2348033166479.

SUGGESTED CITATION

Eze, U.E., A.I. Ali, E.C. Ugwuoke, O.P. Emeka, and I. Ofili. 2020. “Solar Desalination of Water Collected from River Niger for Domestic Purposes”. *Pacific Journal of Science and Technology*. 21(1):5-12.

Pacific Journal of Science and Technology