Production of Drinking Water by Solar Distillation Process.

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ABSTRACT

The world demand for potable water is increasing steadily with the growing global population. Water desalination using solar energy is suitable for potable water production from brackish and seawater. In this study, a solar distillation in a single basin is studied theoretically and experimentally at National Centre for Energy Research and Development, University of Nigeria, Nsukka. The still was constructed using a 500 mm x 500 mm base area and the glass cover of still inclined at 45°C. Temperatures of glass cover, seawater inside the still, seawater interface and ambient air and humidity were recorded continuously and distilled water production was measured each hour. The distillate collected for a period of 3 days indicated a maximum value of 1.9 liters for time period of 3 hours. The maximum temperature recorded during the experiment was 33°C.

(Keywords: distillation, brackish water, seawater, distillate, solar energy)

INTRODUCTION

The most important substance for human in their surrounding material world is natural water [2]. Water is a renewable natural resource and is extremely essential for the survival of all living organisms [2]. Today, freshwater demand is increasing continuously, because of industrial development, intensified agriculture, improvements in standards of living, and increases of the world population. Only about 3 % of the world water is potable and this amount is not evenly distributed on the Earth [3]. On deserts and islands where underground water is not readily obtainable and the cost of shipping the places is high, it is worthwhile to take into consideration the production of potable water from saline water, using solar energy that is in abundance in desert environments.

Large quantities of fresh water are required in many parts of the world for agricultural, industrial, and domestic uses. Lack of fresh water is a prime factor in inhibiting regional economic development. Only 1% of Earth's water is in a fresh, liquid state, and nearly all of this is polluted by both diseases and toxic chemicals [4]. The oceans constitute an inexhaustible source of water but are unfit for human consumption due to their salt content, in the range of 3 % to 5 %.

Seawater and sometimes brackish water desalination constitute an important option for satisfying current and future demands for fresh water in arid regions. The transportation of drinking water from far-off regions is usually not economically feasible/desirable [5]. Naturally, solar energy heats water in the seas and lakes, and then evaporation takes place [6]. Desalination is now successfully practiced in numerous countries in the Middle East, North Africa, southern and western US, and southern Europe to meet industrial and domestic water requirements.

The supply of drinking water is a growing problem for most parts of the world. More than 80 countries, which between then have 40 % of the world's population are being suffered from this problem [7]. In order to solve this problem, new drinking water sources should be discovered and new water desalination techniques be developed. In many countries, fossil fuel burning water desalination systems are currently used. These systems can range up to 10 ton/day in capacity.

The main water desalination or purification methods are distillation, reverse osmosis and electrodialysis. Desalination processes require significant amount of energy [8]. For bigger systems, reverse osmosis and electrodialysis are more economical, but for smaller ones, simple solar stills could be preferred because of their low costs. These days, in a number of countries including West-Indian Islands, Kuwait, Saudi Arabia, Mexico and Australia, these type of distillation units exist. The efficiency of a still is based on the amount of useful energy that the still converts as a function of the incoming total radiation [9].

Single-basin stills have been much studied and their behavior is well understood [10]. Desalination has become increasingly important in providing an economically viable solution to the problem of decreasing fresh water resources. There are many factors to take into consideration to make a new technology .sustainable. As we begin the 21st century, we must look towards cleaner sources of energy. Fossil fuel resources will soon be expired due to our rate of consumption. Cleaner energies such as natural gas, solar power, and photovoltaic technology must be integrated into desalination technology.

Solar desalination is a process where solar energy is used to distill fresh water from saline, brackish water for drinking purposes, charging of the batteries and medical appliances, etc. Solar energy warms the absorber surface and some of the water evaporates and condenses on the glass roof [11]. In recent years desalination of water has been one of the most important technological work undertaken in many countries.

Many areas in Middle East and elsewhere have little or no natural water supplies which can be used for human consumption and, hence, depend heavily on water produced by desalination. Several methods of solar water desalination are known. Many workers indicate that the utilization of solar energy for water desalination is becoming more attractive as the cost of energy is continuously increases. Solar desalination is particularly important for locations where solar intensity is high and there is a scarcity of fresh water. The methods of solar water desalination are classified according to the way in which solar energy is used; the best-known method is the direct use of solar energy [12].

Small production systems as solar stills can be used if fresh water demand is low and the land is available at low cost. High fresh water demands make industrial capacity systems necessary. These systems consist of a conventional seawater distillation plant coupled to a thermal solar system. Highly efficient solar capillary distillation system is the most promising to overcome all the problems of conventional solar stills [13]. This technology is known as indirect solar desalination.

Many small size systems of direct solar desalination and several pilot plants of indirect solar desalination have been designed and implemented. Nevertheless, in 1996 solar desalination was only 0.02 % of desalted water production. Solar distillation uses the heat of the sun directly in a simple piece of equipment to purify water [14].

Another advantage of desalination is that it will never run out its .raw material. Because the facility is located right next to the ocean, and the ocean is so vast. Because of this, desalination is a .drought-proof. resource that is constantly able to produce fresh water regardless of the amount of rainfall. This is a great advantage if the desalination process is located in an agricultural area.

Solar Desalinization

The use of direct solar energy for desalting saline water has been investigated and used for some time. During World War II, considerable work went into designing small solar stills for use on life rafts [15]. This work continued after the war, with a variety of devices being made and tested. These devices generally imitate a part of the natural hydrologic cycle in that the sun's rays heat the saline water so that the production of water vapor (humidification) increases. The water vapor is then condensed on a cool surface, and the condensate collected as fresh water product.

An example of this type of process is the greenhouse solar still, in which the saline water is heated in a basin on the floor, and the water vapor condenses on the sloping glass roof that covers the basin. Variations of this type of solar still have been made in an effort to increase efficiency, but they all share the following difficulties, which restrict the use of this technique for large-scale production:

- Large solar collection area requirements
- High capital cost

Vulnerability to Weather-Related Damage

A general rule of thumb for solar stills is that a solar collection area of about one square meter is needed to produce 4 liters of water per day (10 square feet/gallon). Thus, for a 4000 m^3/d facility, a minimum land area of 100 hectares would be needed (250 acres/mgd). This operation would take up a tremendous area and could thus create difficulties if located near a city where land is scarce and expensive [16].

MATERIAL AND METHOD

Determination of the Best Inclination for the Glass Cover

The angle of inclination determines the quantity of solar radiation on the glass surface which still contribute maximally to the quantity of distillate produced. Laboratory tests determined the best slope of the glass cover, by evaluating the production during 4 hours with temperature variations according to the proposed inclinations [17]. The tests had two stages: producing water vapor on contact with the glass to determine the minimum possible inclination that allows the flow of condensed water, and the other producing vapor inside the basin.

Four glass covers were built by varying their inclinations by 15, 25, 30 and 45°, and by maintaining the base area at 500mm x 500 mm for all the inclination, applying water temperatures of 60, 70 and 80°C for each inclination. The temperature inside of the basin was controlled by thermocouple sensors until it reaches 50, 60, 70 and 80ºC. The result indicated that the inclination of 45° was the best for the production of distillate water.

Production of Distillate from Untreated Water

The pilot solar purifier was designed on a glass fiber quadrangular structure, with a reservoir for treated water, with a raw water evaporation pan and a 1 cm water level. There is a glass cover, with an inclination of 15 degrees from the horizontal, with silicon at the junction interfaces above the pan. There are glass fiber troughs on the inner part of the square base perimeter, for the collection of the produced water.

For raw water supply, there is a 5-L glass bottle capsized in a support of 250 mL (bird fountain type system) internally supplying the pan for the process evaporation. The equipment was tested between the parallels 27°10’ and 27°50’ of south latitude and meridians 48°25’ and 48°35’ west longitude from Greenwich (Nsukka, Enugu), from November 2013 to December 2013 with raw sea water, brackish water and fresh contaminated water.

The efficiency of the equipment was measured by the production and quality of the treated water. The main analyzed physical-chemical and bacteriological characteristics were: conductivity, apparent color, true color, odor, pH, taste, salinity, total dissolved solids, turbidity, total and fecal coliforms. Analyses were performed according to APHA - Standard Methods for Examination of Water and Wastewater. (APHA/AWWA/WPCF, 2005).

Experimental Method

Solar energy warms the absorber surface and some of the water evaporates and condenses on the glass roof [18]. The condensate flows into the condensate channel and is taken out through a hose pipe. The volume of distilled water produced hourly was measured for ten consecutive days. The water sample was obtained from Adada River. Adada is one of the popular rivers located in the Nsukka, Eastern part of Nigeria. Hourly measurement of volume and temperature wascarried out at University of Nigeria, Nsukka in Enugu State, Nigeria. The atmospheric temperature was measured using a thermometer.

RESULT AND DISCUSIONS

With an 8 hour-time interval, the best inclination tested as a function of the internal atmosphere temperature and water production was 45º. For every 2pm when the cover increased in temperature, there was a greater production with 45º slope, and productions were similar at 3pm due to constant sun intensity between the time. Similar results were found in studies dealing with 10, 20, 35, and 45º for one face and two faces structures (Capelletti; Probert) [19]. Use rates of solar insolation are directly related to the ease of drainage of the condensate (Cerda et al.) [20]. However, we found that under suitable sunshine availability, there might be a loss of condensate by re-evaporation, if it is not rapidly taken to an adequate reservoir (Al-ismaily) [21]. We also observed that the period between 11 a.m. and 14 p.m. has the greatest production of distillate (Rosa; Filho, 2007) [22]. This fact also opposes on the orthogonality of the surface being the best at 90% and with a 20º of inclination there is almost no direct radiation that passes through the glass (Al-ismaily; Probert) [23].

Table 1 indicates distillate production for a period of 3 days at interval of 3-hours. It was observed the production of distillate was irregular due to variation of solar radiation. Similar result was also observed by Ugwuoke et al. [24]. Atmospheric temperature in Figure 2 varied from 27°C at 6pm to 33°C at 3pm.this also shows that the atmospheric temperature of the day was irregular during the time of the experiment. The total daily production of distillate varied from 3.7 L on day 1 to 4.8L on day 9.

CONCLUSION

Water and energy are two inseparable items that govern our lives and promote civilization. Looking into the history of mankind one finds that water and civilization were also two inseparable entities. It is not a coincidence that all great civilizations were developed and flourished near large bodies of water. Rivers, seas, oases and oceans have attracted mankind to their coasts because water is the source of life. The transportation of drinking water from far-off regions is usually not economically feasible/desirable, desalination of available brackish water has been considered as an alternative approach. Conventional desalination processes based on distillation involve phase change. The experiment conducted gave a maximum distillate production of 4.8 liters. The maximum observed atmospheric temperature was 33°C.

Table 1: Distillate Production for Four Days at 3 hour Period.

Day	10am-1pm	12pm-3pm	2pm-5pm
1	1.1	1.4	1.2
2	0.9	1.5	1.6
3	1.3	1.1	1.3
4	0.8	1.9	2.1

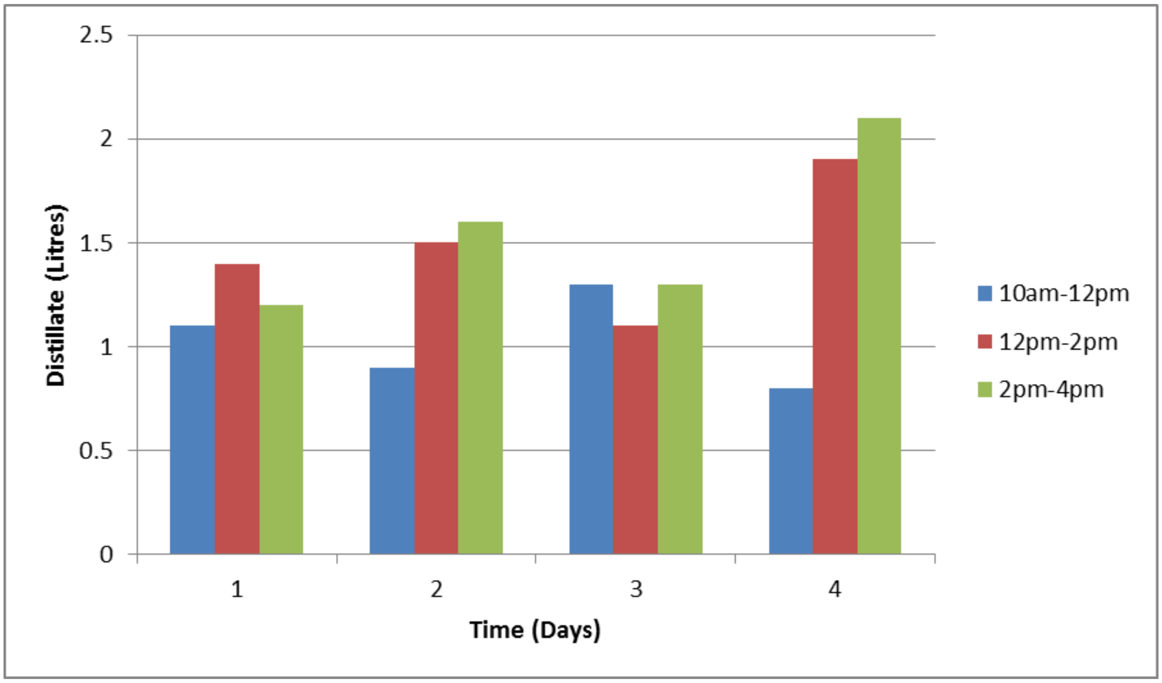

Figure 1: Distillate production for four days at 3 hour period.

Time (hr)	8	9	10	11	12	1	2	3	4	5	6
Atm Temp (°C)	28	29	31	33	29	34	32	33	31	30	27

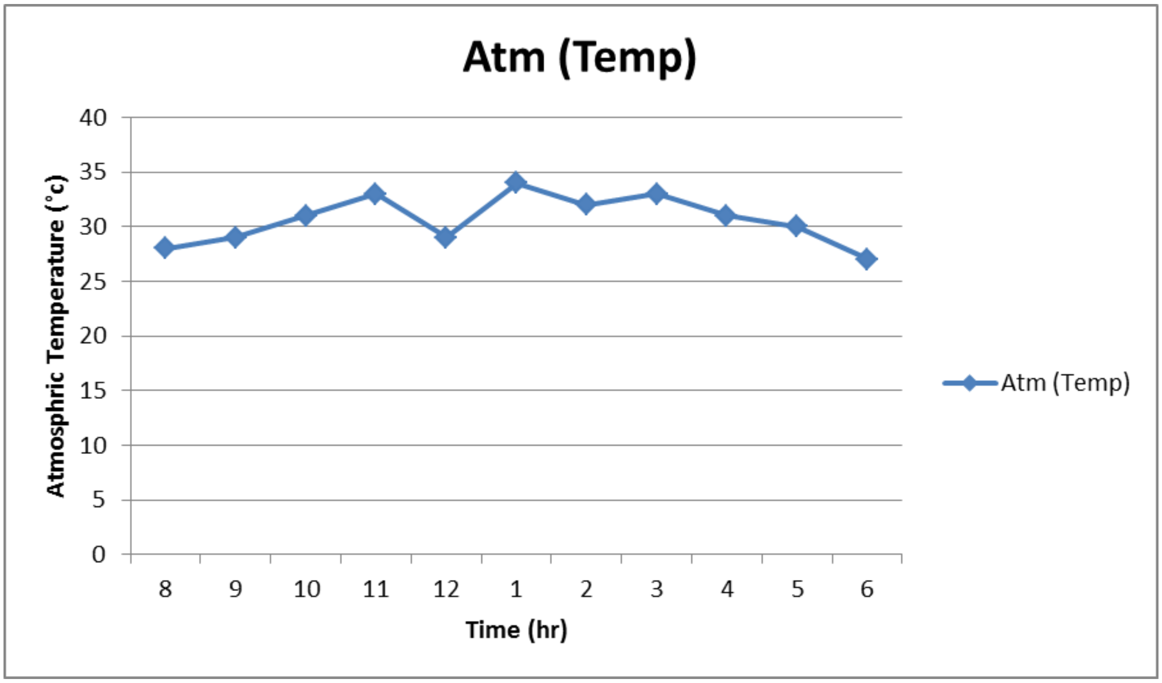

Figure 2: Hourly Variation of Temperature on 15/11/2013.

Time (Days)	1	2	3	4	5	6	7	8	9	10
Distillate (L)	3.7	4	3.7	4.8	3.5	5.1	4.6	3.9	4.8	5.3

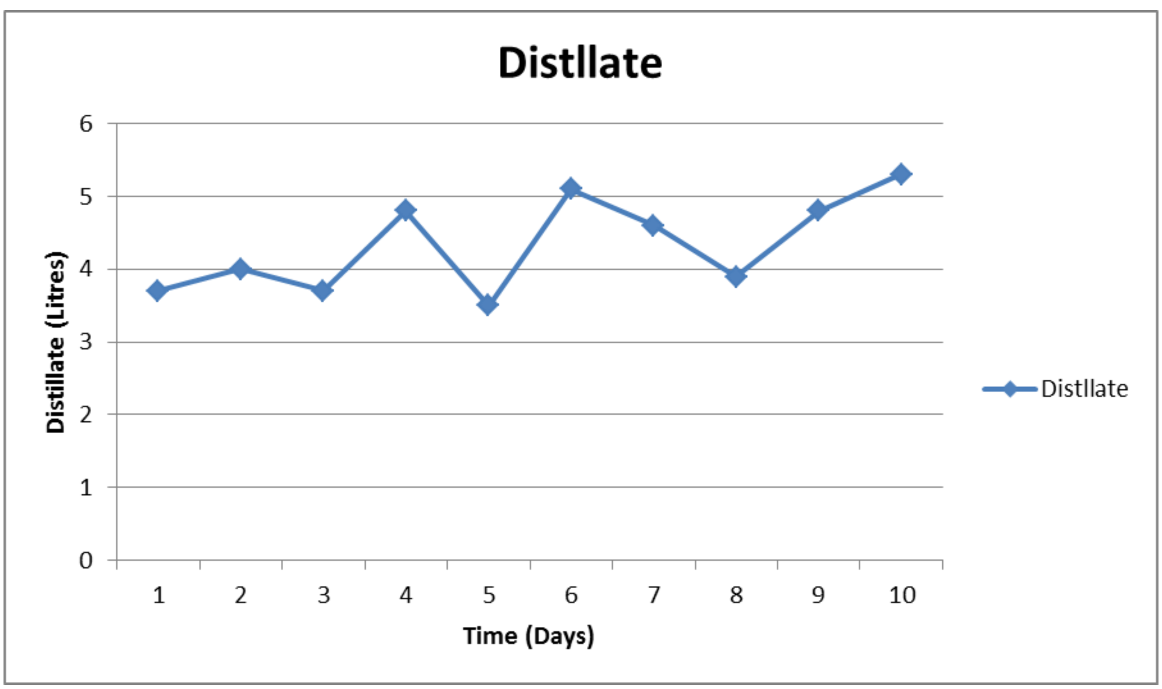

Figure 3: Daily Production of Distillate.

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