Desalting of Brackish Water

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ABSTRACT

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. 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. 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.

This work examined the rate of distillate water produced for a period of 14 days with different variations in atmospheric temperature. A total volume of 25 liters salt water was used to perform this experiment. The initial volume of 3.1 liters of distillate water was produced for the first day. The volume increased gradually to 3.5 liters on the second day, then decreased to 2.8 liters on the third day. The variation in the volume of the distillate produced from day 1 to day 14 was due to variation in the amount of solar radiation. The atmospheric temperature during the experiment also varied recording a maximum value of 31°C on day 4 and minimum value of 26°C on day 13.

(Keywords: desalting, desalinization, brackish water, solar radiation, temperature, distillate)

INTRODUCTION

Desalting refers to a water treatment process that removes salts from water. It is also called desalination or desalinization, but meanings are synonymous. Desalting can be done in a number of ways, but the result are fresh water is produced from brackish water or seawater [1].

Throughout history, people have continually tried to treat salty water so that it could be used for drinking and agriculture. Also desalination of sea and/or brackish water is an important alternative, since the only inexhaustible source of water is the ocean [2]. Of all of the globe's water, 94 percent is salt water from the oceans and only 6 percent is fresh. Of the latter, about 27 percent is in glaciers and 72 percent is underground.

While seawater is important for transportation and fisheries, it is too salty to sustain human life or farming. Desalting techniques have increased the range of water resources available for use by a community. Until recently, only water with a dissolved solids (salt) content generally below about 1000 milligrams per liter (mg/l) was considered acceptable for a community water supply. This limitation sometimes restricted the size and location of communities around the world and often led to hardship to many that could not afford to live near a ready supply of fresh water. The application of desalting technologies over the past 50 years has changed this in many places. Villages, cities, and industries have now developed or grown in many of the arid and water-short areas of the world where sea or brackish waters are available and have been treated with desalting techniques.

Different methods of desalination have also been used in several countries to resolve the crisis of drinking water [3]. This change has been very noticeable in parts of the arid Middle East, North Africa, and some of the islands of the Caribbean, where the lack of fresh water severely limited development. Now, modern cities and major industries have developed in some of those areas thanks to the availability of fresh water produced by desalting brackish water and seawater [4].

The Development of Desalting

Desalting is a natural, continual process and an essential part of the water cycle. Rain falls to the ground and once on the ground, it flows to the sea, and people use the water for various purposes as it makes this journey. As it moves over and through the Earth, the water dissolves minerals and other materials, becoming increasingly salty [5]. While in transit and upon arrival in the world's oceans or other natural low spots like the Dead Sea or the Great Salt Lake, a part of the water is evaporated water leaves the salt behind, and the resulting water vapor forms clouds that produce rain, continuing the cycle. It is shown in Figure 1.

A major step in development came in the 1940s, during World War II, when various military establishments in arid areas needed water to supply their troops. The potential that desalting offered was recognized more widely after the war and work was continued in various countries. A desalting device essentially separates saline water into two streams: one with a low concentration of dissolved salts (the fresh water stream) and the other containing the remaining dissolved salts (the concentrate or brine stream). The device requires energy to operate and can use a number of different technologies for the separation. This process is shown in Figure 2 [6].

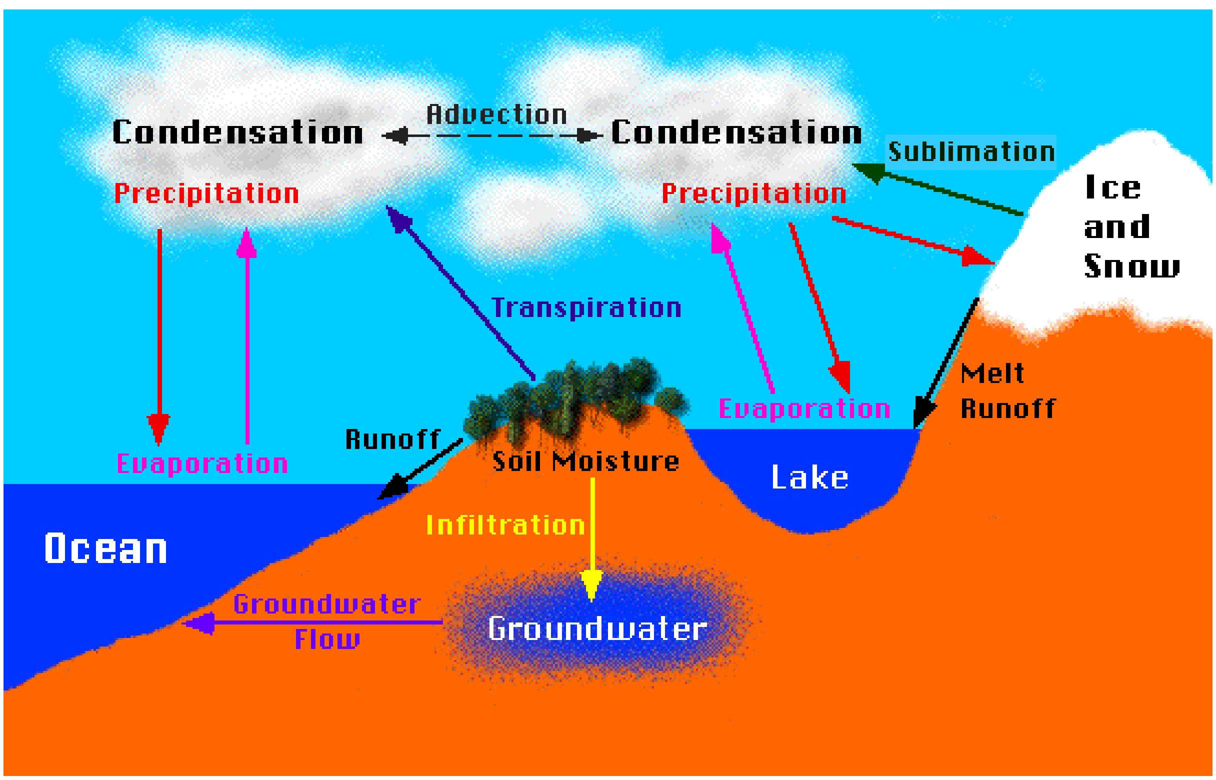

Figure 1: Natural Water Cycle [4].

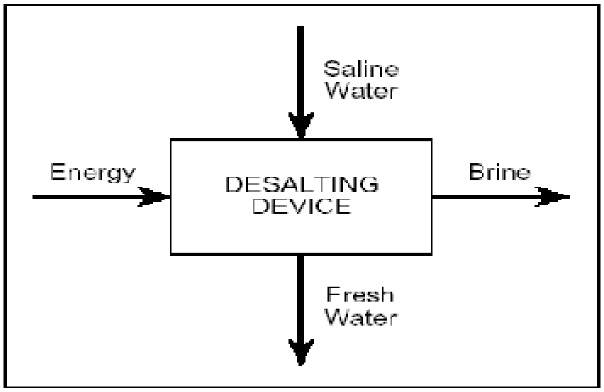

Figure 2: Diagram of Desalinization Process [6].

Desalinization can be achieved by using a number of techniques. These may be classified into the following categories:

- Phase change or thermal processes
- Membrane or single-phase processes

In Table 1, the most important technologies in use are listed. In phase change or thermal processes, the distillation of seawater is achieved by utilizing a thermal energy source. The thermal energy may be obtained from a conventional fossil-fuel source, nuclear energy or from a non-conventional solar energy source. In the membrane processes, electricity is used either for driving high-pressure pumps or for ionization of salts contained in seawater [7].

Table 1: Desalination Processes [7].

Thermal Processes	Membrane Processes
Multistage flash(MSF	Reverse osmosis (RO)
Multiple effect boiling (MEB)	RO without energy recovery
Vapor Compression(VC)	RO with energy recovery (ER-RO)
Freezing	Electrodialysis (ED)
Solar stills	Ion exchange
Conventional solar stills	---
Special stills	---
Wick-type stills	---
Multiple wick type stills	---

Thermal Processes

About half of the world desalted water is produced with heat to distill fresh water from seawater. The distillation process mimics the natural water cycle in that salt water is heated, producing water vapor that is in turn condensed to form fresh water. In a laboratory or industrial plant, water is heated to the boiling point to produce the maximum amount of water vapor [8]. To do this economically in a desalination plant, the applied pressure of the water being boiled is adjusted to control the boiling point because of the reduced atmospheric pressure on the water, the temperature required to boil water decreases as one moves from sea level to a higher elevation. Thus, water can be boiled on top of Mt. McKinley, in Alaska [elevation 6,200 meters (20,300 feet)], at a temperature about 16 °C (60.8 °F) lower than it would boil at sea level. This reduction of the boiling point is important in the desalination process for two major reasons: multiple boiling and scale control.

To boil, water needs two important conditions: the proper temperature relative to its ambient pressure and enough energy for vaporization. When water is heated to its boiling point and then the heat is turned off, the water will continue to boil only for a short time because the water needs additional energy (the heat of vaporization) to permit boiling. Once the water stops boiling, boiling can be renewed by either adding more heat or by reducing the ambient pressure above the water. If the ambient pressure were reduced, the water would be at a temperature above its boiling point (because of the reduced pressure) and would flash to produce vapor (steam), the temperature of the water will fall to the new boiling point. If more vapors can be produced and then condensed into fresh water with the same amount of heat, the process tends to be more efficient.

To significantly reduce the amount of energy needed for vaporization, the distillation desalting process usually uses multiple boiling in successive vessels, each operating at a lower temperature and pressure. Typically 8 tons of distillate can be produced from 1 ton of steam. This process of reducing the ambient pressure to promote additional boiling can continue downward and, if carried to the extreme with the pressure reduced enough, the point at which water would be boiling and freezing at the same time would be reached.

Aside from multiple boiling, the other important factor is scale control. Although most substances dissolve more readily in warmer water, some dissolve more readily in cooler water. Unfortunately, some of these substances, like carbonates and sulfates, are found in seawater. One of the most important is calcium sulfate ($CaSO_4$), which begins to leave solution when seawater approaches about 115 °C (203 °F). This material forms a hard scale that coats any tubes or surfaces present. Scale creates thermal and mechanical problems and, once formed, is difficult to remove. One way to avoid the formation of this scale is to control the concentration level of seawater and to control the top temperature of the process.

Another way is to add special chemicals to the seawater that reduce scale precipitation and permit the top temperature to reach 110ºC. These two concepts have made various forms of distillation successful in locations around the world. The process that accounts for the most desalting capacity for seawater is multi-stage flash distillation, commonly referred to as the MSF process [9].

Membrane Processes

In nature, membranes play an important role in the separation of salts, including both the process of dialysis and osmosis, occurs in the body. Membranes are used in two commercially important desalting processes: electrodialysis (ED) and reverse osmosis (RO). Each process uses the ability of the membranes to differentiate and selectively separate salts and water. However, membranes are used differently in each of these processes. ED is a voltage driven process and uses an electrical potential to move salts selectively through a membrane, leaving fresh water behind as product water. RO is a pressure-driven process, with the pressure used for separation by allowing fresh water to move through a membrane, leaving the salts behind.

Figure 3 shows the diagram of membrane process. Scientists have explored both of these concepts since the turn of the century, but their commercialization for desalting water for municipal purposes has occurred in only the last 30 to 40 years [10].

Membrane processes constitute a well-established technology for the desalination of brackish water. Recently, the use of membrane systems has increased substantially and is rapidly expanding its share of the desalination market for brackish water, wastewater reuse, and seawater [11].

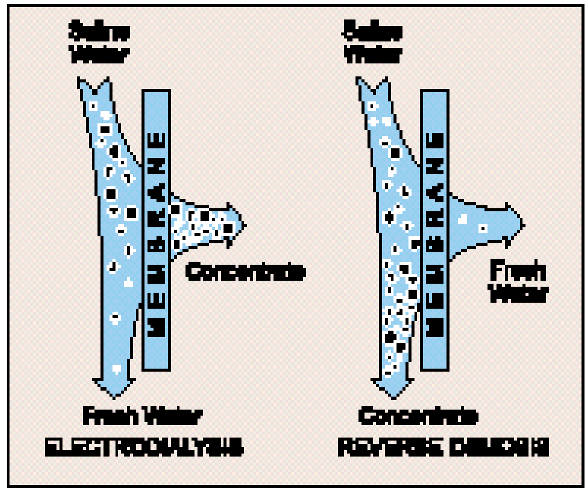

Figure 3. Diagram of Membrane Processes [6].

Solar Desalination

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. 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. 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. Figure 4 shows diagram of a solar still.

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).

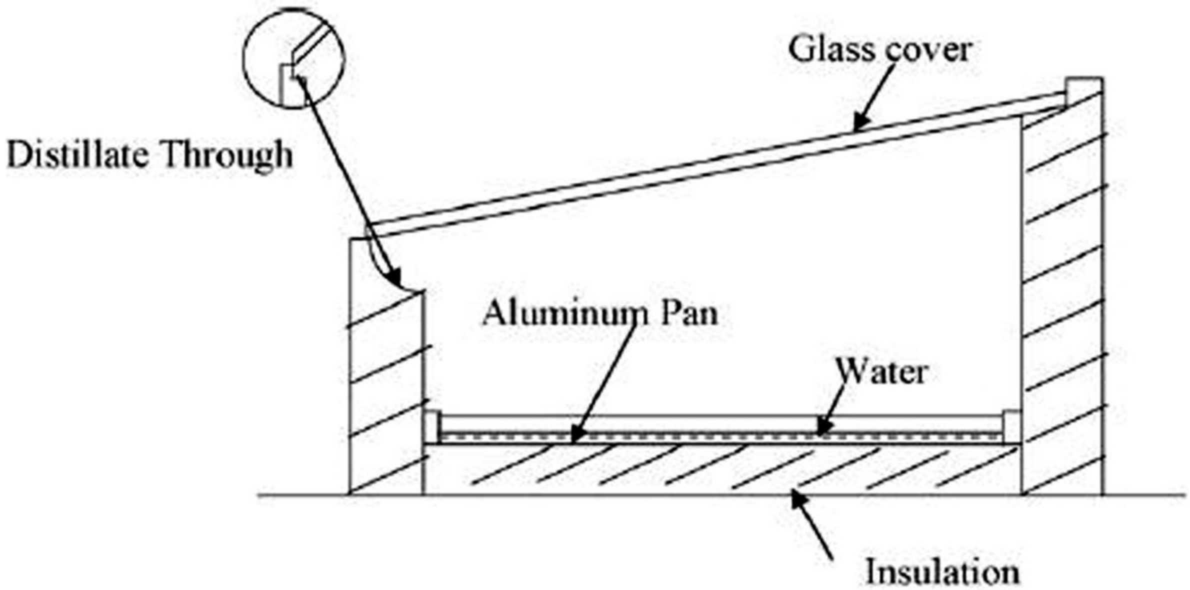

Figure 4: Schematic Diagram of a Simple Solar Still (Kaushal and Varun, 2010).

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 [12].

Solar Desalination Systems

A representative example of direct collection systems is the conventional solar still, which uses the greenhouse effect to evaporate salty water. It consists of a basin, in which a constant amount of seawater is enclosed in a v-shaped glass envelope. There are different types of solar stills built in different countries on the world, which in common have a saline water basin with a black bottom, a transparent cover and collecting pipes, which give the condensed water as end product. Sunlight heats the water in the basin. This heated water evaporates and re-condenses on the underside of the sloping transparent cover and runs down into collecting through along the inside lower edges of the transparent cover (Figure 5).

Usually the transparent cover is made of glass or plastic such as polyvinyl chloride or polyvinyl fluoride. The basin is covered with a thin black plastic film, like butyl caoutchouc and insulated against the heat losses into the ground.

A typical still efficiency, defined as the ratio of the energy utilized in vaporizing the water in the still to the solar energy incident on the glass cover, is 35%(maximum) and daily still production is about 3-4 l/m^2.

Several attempts have been made to use cheaper materials such as plastics. These are less breakable, lighter in weight for transportation, and easier to set up and mount. Their main disadvantage is their shorter life. Many variations of the basic shape have been developed to increase the production rates of solar stills. Some of the most popular are shown in Figure 6.

On the islands where underground natural sources are not available and the cost of shipping water to the islands is high, plastic rooftop solar stills are convenient to use, Figure 6.

This type of a solar still usually consists of a plastic cover, a black plastic solar still basin and a fixed insulation. The water depth should be no more than 2 cm, because of the weight, which brings an additional load to the roof of the building Figure 7 shows a lightweight collapsible solar still for only few gallons per day of fresh water production. These types of solar stills usually are used for emergency cases on islands, which are used as navy bases.

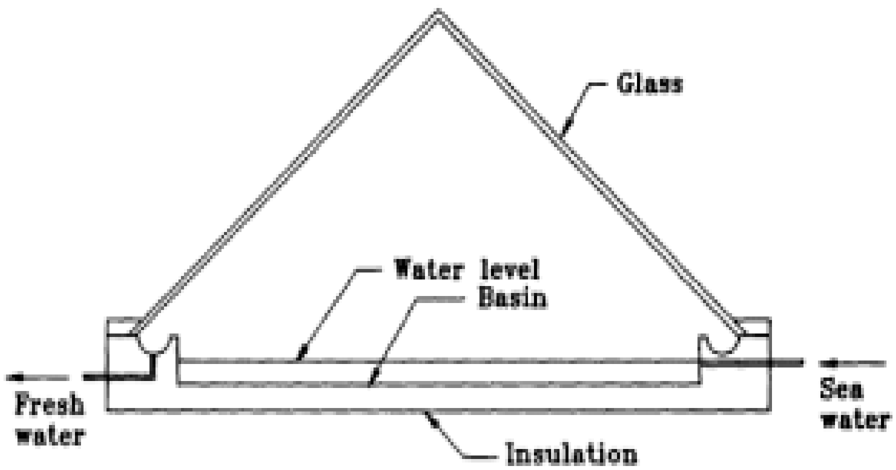

Figure 5: Schematic of a Solar Still [13].

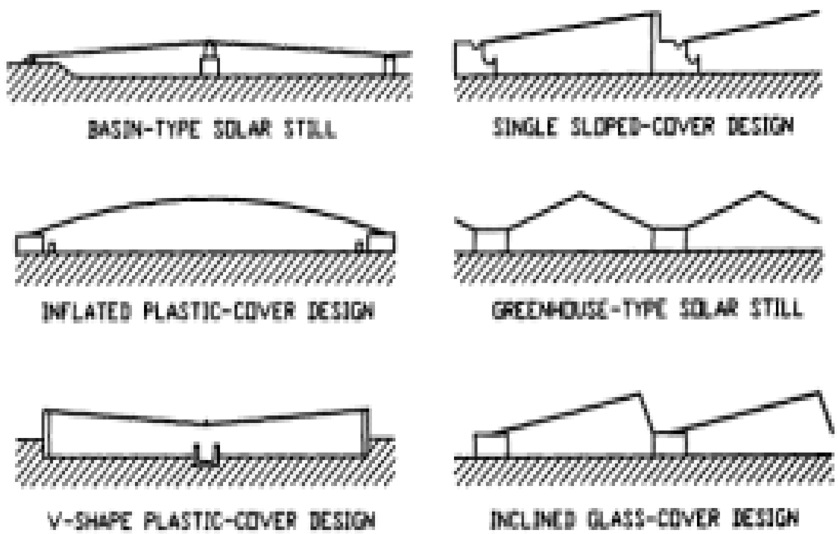

Figure 6: Common Designs of Solar Stills.

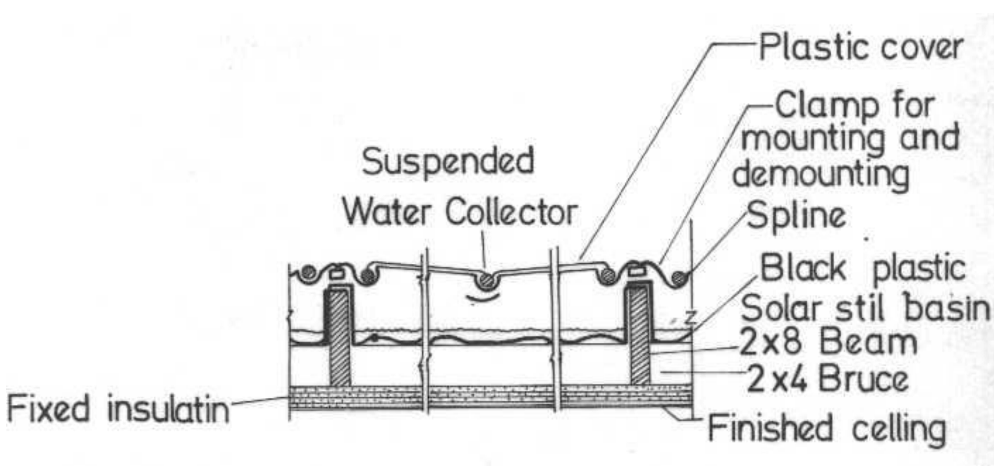

Figure 7: Plastic Rooftop Solar Still [9].

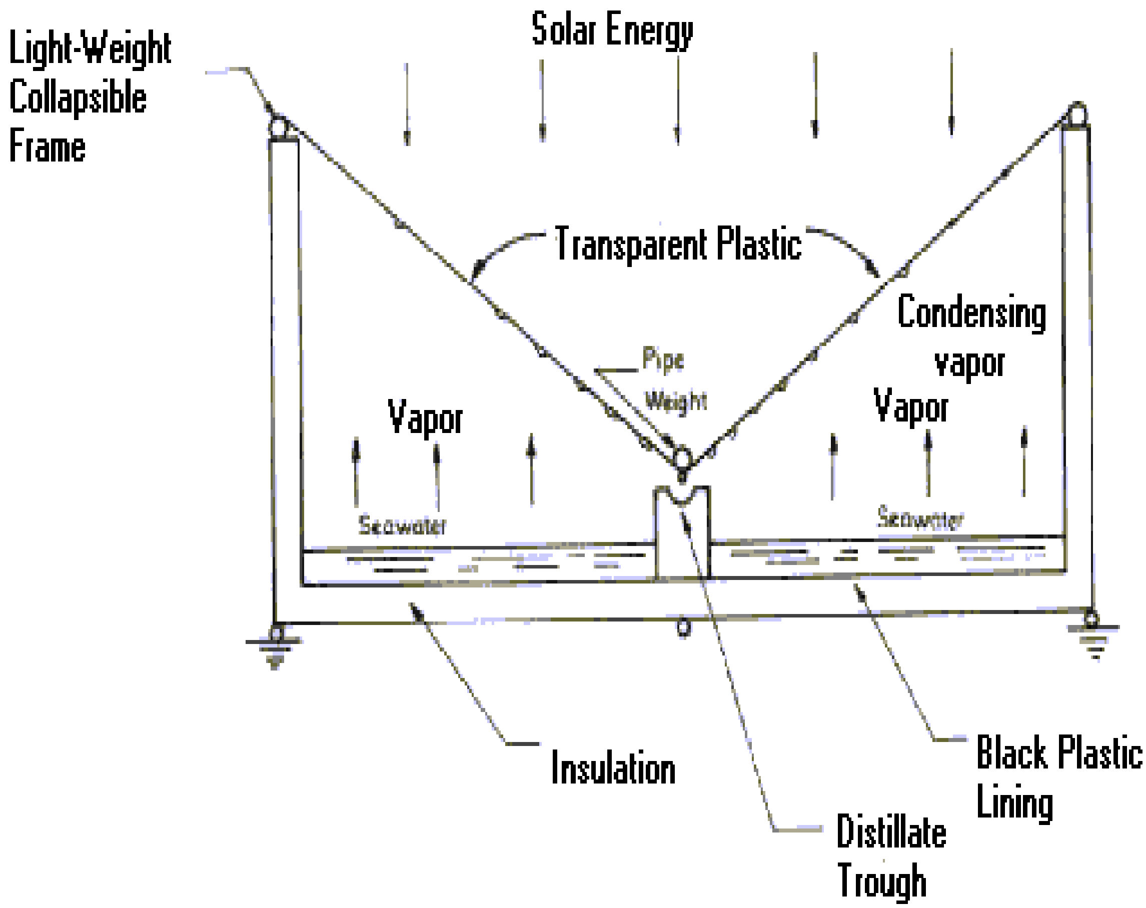

Figure 8: Light-Weight Collapsible Solar Still [14].

Figure 8 gives the basic concept of a horizontal concentric tube solar still. This solar still utilizes air as working medium. Air carries the water vapor from the annular space between the clear outer and the inner tube through the inside of the inner tube where the water vapor condenses and gives up its heat of condensation directly to the seawater being sprayed on the outer surface of the inner tube. The water vapor will have the preferential tendency to condense on the inside surface of the clear outer tube.

Figure 9 shows high performance solar still. In this type of solar still the heat of condensation of water vapor is received by a working fluid (e.g., water can be used as a working fluid).

As shown in Figure 9, the working fluid circulates around the solar still. Its temperature is minimum at point 1 and maximum at point 2, from where it flows down on an insulated inclined plane back to the heat exchanger. The heat exchanger is either a double plate or a double pipe type. In the latter case, the outer pipe has perforations on it. The seawater enters the annular space and evaporates on receiving heat from working fluid.

The issuing vapor then rises and condenses on a glass plate as it gives up its heat to the working fluid.

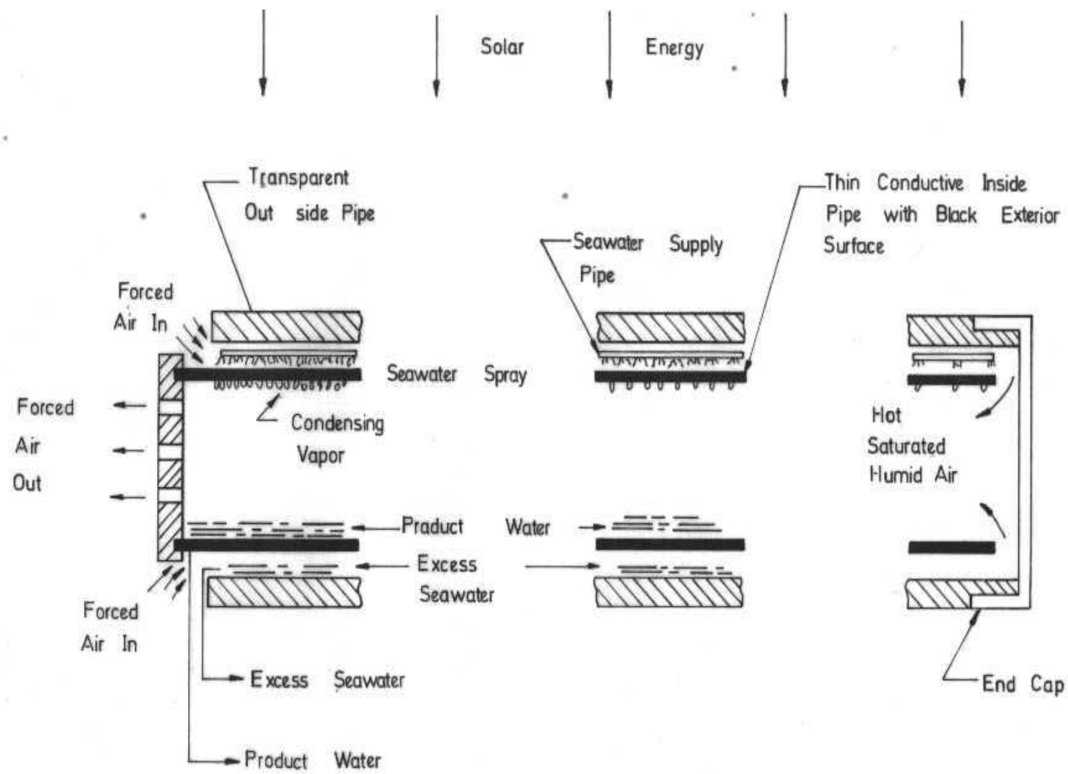

Figure 9: Horizontal Concentric Tube Solar Still [15].

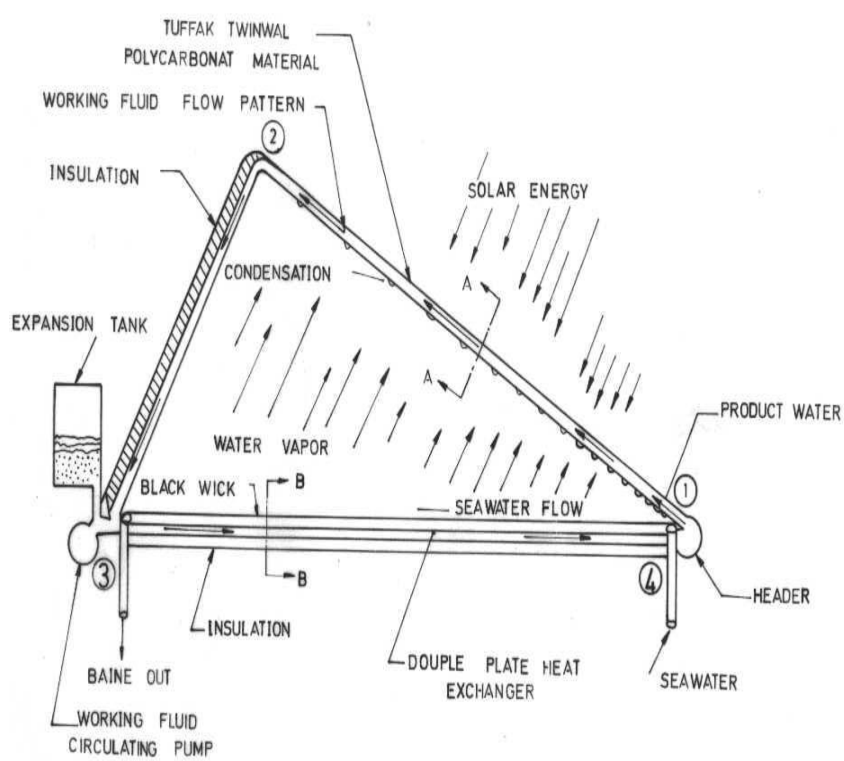

Figure 10: High Performance Solar Still.

MATERIALS AND METHODS

Material

The water used in this experiment was obtained from Uzo-Uwani River. Uzo-Uwani is in Uzo – Uwani Local Government Area of Enugu State. The water is salty water which needs to be treated before using it domestically or industrially. The water also contains other minerals which cause either temporal or permanent hardness of water. These minerals are sodium, calcium and magnesium. There compounds responsible for these hardness are $NaCO_3$, $CaCO_3$, $MgCO_3$ and there hydrogen carbonate. The best way of treating this kind of water is either by desalting or by desalinization. These are two ways of removal of salt or other impurities from water to make it hygienically safe for drinking or use for other purposes. These two processes are economical because they require only direct radiation from the sun.

Method

Procedure for the Experiment: The 25 liters brackish water was poured into a container having sieve on it to remove some material that might block solar still tap during discharge. The sieved water was then poured into distillation basin [16].

The set up was exposed to the sun to receive the sun radiation, Ofili and Ugwuoke *et al.* (2016) [17]. The essence of exposing it to sun is that the solar radiation provides the energy which will heat the absorber basin painted black. The water in the basin will receive energy and increase in temperature. As the temperature of the water rises, vapor evaporates to the glass and condenses; it then trickles down from the sliding glass cover to the storage basin, where the pure water is collected.

RESULTS AND DISCUSSION

This experiment recorded appreciable volume of distillate water as a result of high level of sun radiation during the experiment. It is expected that the more sun radiation received by the solar collector the more the volume of clean water produced. The first day of the experiment had about 3.1 liters of distillate. This volume increased up to 3.5 liters for the second day. The third day gave a volume of 2.8 liters; this decrease in volume from the first two days may be as a result of poor sun radiation. This may also be as a result of other factors. As we move down from the first day to the 14th day the volume of distillate produced fluctuated due to the factors mentioned above. The maximum volume of distillate produced was 4.6 liters and was recorded on day 4. The volume of 2.2 liters was the minimum volume of distillate produced on day 7. The ambient temperature values recorded during the experiment varied from 26°C to 31°C.

Figure 11 indicated the volume of distillate water produced for the period of 14 days which the experiment was carried out. There was variation in the plotted points of the graph which was due to the variation of the water produced. Figure 12 also followed the trend of Figure 11 due to this variation in the solar rays.

Table 2: Volume of Distillate Water Produced.

Time (Days)	Volume of Distillate (Liters)
1	3.1
2	3.5
3	2.8
4	4.6
5	3.8
6	4.4
7	2.2
8	3.3
9	4.1
10	4.3
11	4.7
12	3.9
13	2.7
14	3.5

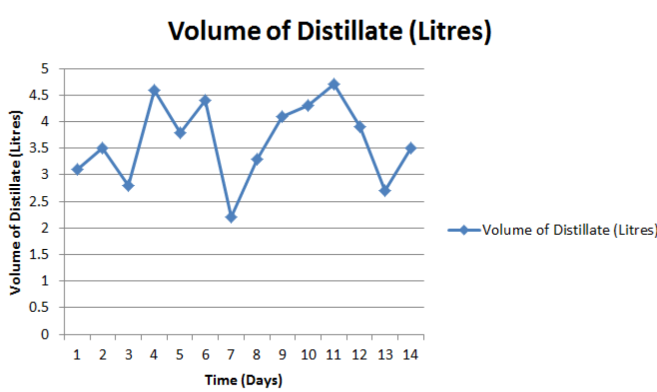

Figure 11: A Graph of Volume of Distillate (Liters) versus Time (Days).

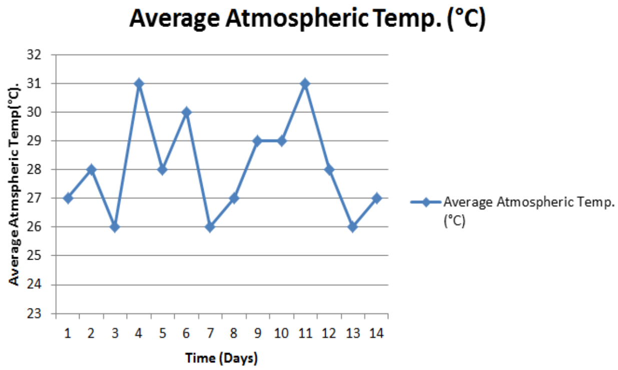

Figure 2: A Graph of Average Atmospheric Temp. (°C) versus Time (Days).

CONCLUSION

There is limited access to drinking water that meets acceptable standard levels of biological, chemical, and physical constituents. Over 97% of water available on the Earth's surface is salty, and environmental pollution caused predominantly by anthropogenic activities is also contributing to the degradation of fresh water resources.

The supply of drinking water is a growing problem for most parts of the world. More than 80 countries, which are about 40% of the world population, are being suffered from this problem. In order to solve this problem, new drinking water sources should be discovered and new water desalination techniques be developed. This work centered on purification of salty water otherwise known as desalting process of water distillation. The water obtained from this research work was found to be pure water boiling exactly at 100°C and freezing at 0°C which is the boiling and melting points of water respectively. The maximum volume of distillate water produced from this experiment was 4.6 liters while the minimum volume of water produced was 2.2 liters. Also the maximum temperature recorded from the experiment was 31°C.

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