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Purification of brackish water by solar water distillation process

Ugwuoke EC, Eneh Joy, Edeh HI, Ochu RC, Onyia BI

Projects Development Institute (PRODA), Enugu, Nigeria

Abstract

There is always a scarcity of clean and pure drinking water in many developing countries. Water from various sources is often brackish (i.e. contain dissolved salts) and/or contains harmful bacteria and therefore, cannot be used for drinking purpose 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 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. In many countries, fossil fuel burning water desalination systems are currently used. This experiment was performed at National Centre for Energy Research and Development, University of Nigeria Nsukka. The experiment recorded a maximum distillate of 1.1litres yield on day 4 between the hours of 2-4pm. The solar radiation affected the result of the experiment and maximum atmospheric temperature recorded was 31 °C.The boiling point of the distillate water tested is 100 °C and the melting point of the water is 0 °C which correspond to World Health Organization (WHO) standard. The average solar Insolation at the centre is 450W/m^2.

Keywords: Brackish Water, Distillate, Desalination, Dissolve salt, solar still

1. Introduction

Water is the basic necessity for human along with food and air. There is almost no water left on Earth that is safe to drink without purification [1]. Contaminated drinking water is one of the reasons of major health hazards.

Responsible for almost 90 % of the health problems in rural areas [2]. 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. For this reason, purification of water supplies is extremely important. Distillation is one of many processes that can be used for water purification [3]. Moreover, typical purification systems are easily damaged or compromised by disasters, natural or otherwise. This results in a very challenging situation for individuals trying to prepare for such situations, and keep themselves and their families safe from the myriad diseases and toxic chemicals present in untreated water [4]. Everyone wants to find out the solution of above problem with the available sources of energy in order to achieve pure water. Fortunately there is a solution to these problems. It is a technology that is not only capable of removing a very wide variety of contaminants in just one step, but is simple, cost-effective, and environmentally friendly. That is use of solar energy.

Solar Stills

Single-basin stills have been much studied and their behaviour is well understood [5]. The solar distillation is presented as a simple system consisting of a shallow tank with a transparent glass cover, with a stable volume [6]. The efficiency of solar stills which are well-constructed and maintained is about 50% although typical efficiencies can be 25%. Daily output as a function of solar irradiation is greatest in the early evening when the feed water is still hot but when outside temperatures are falling. At very high air temperatures such as over 45 ºC, the plate can become too warm and condensation on it can become problematic, leading to loss of efficiency.

Some problems with solar stills which would reduce their efficiency include:-

- Poor fitting and joints, which increase colder air flow from outside into the still
- Cracking, breakage or scratches on glass, which reduce solar transmission or let in air
- Growth of algae and deposition of dust, bird droppings, etc. To avoid this the stills need to be cleaned regularly every few days
- Damage over time to the blackened absorbing surface.
- Accumulation of salt on the bottom, which needs to be removed periodically

The saline water in the still is too deep, or dries out. The depth needs to be maintained at around 20mm

The cover can be either glass or plastic. Glass is preferable to plastic because most plastic degrades in the long term due to ultra violet light from sunlight and because it is more difficult for water to condense onto it [7]. Tempered low-iron glass is the best material to use because it is highly transparent and not easily damaged (Scharl & Harrs, 1993) [8]. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the blackened base [9]. However, if this is too expensive or unavailable, normal window glass can be used. This has to be 4mm think or more to reduce breakages. Plastic (such as polyethylene) can be used for short-term use. Stills with a single sloping cover with the back made from an insulating material do not suffer from a very low angle cover plate at the back reflecting sunlight and thus reducing efficiency. This interior surface uses a blackened material to improve absorption of the sunrays [10]. It is important for greater efficiency that the water condenses on the plate as a film rather than as droplets, which tend to drop back into the saline water. For this reason the plate is set at an angle of 10 to 20º. The condensate film is then likely to run down the plate and into the run off channel.

Brick, sand concrete or waterproofed concrete can be used for the basin of a long-life still if it is to be manufactured on-site, but for factory-manufactured stills, prefabricated ferro-concrete can be used. Moulding of stills from fibreglass was tried in Botswana (Yates, Woto & Tlhage, 1990) [11] but in this case was more expensive than a brick still and more difficult to insulate sufficiently, but has the advantage of the stills being transportable. By placing a fan in the still it is possible to increase evaporation rates. However, the increase is not large and there is also the extra cost and complication of including and powering a fan in what is essentially quite a simple piece of equipment. Fan assisted solar desalination would only really be useful if a particular level of output is needed but the area occupied by the stills is restricted, as fan assistance can enable the area occupied by a still to be reduced for a given output.

The Brace Research Institute still

This is essentially a still designed by the research institute. However the stills are placed next to each other over the width of say 10 metres of the distillation plant. Lengthwise, the unit such as shown is built over a considerable distance, such as 15 metres. Glass plates are placed along the length of the still and simply joined with sealant. Units of this size also have two small weirs lengthwise to encourage saline water to flow along the full length of the still. A project of this type was set up by the Brace Research Institute, McGill University, Canada in Haiti [12]. The scale of the unit requires caretakers to be trained in the maintenance of it, and maintenance requirements are quite considerable.

Multiple-effect basin stills

Have two or more compartments. The condensing surface of the lower compartment is the floor of the upper compartment. The heat given off by the condensing vapour provides energy to vaporize the feed water above. Efficiency is therefore greater than for a single-basin still typically being 35% or more but the cost and complexity are correspondingly higher.

Wick stills

In a wick still, the feed water flows slowly through a porous, radiation-absorbing pad (the wick). Two advantages are claimed over basin stills. First, the wick can be tilted so that the feed water presents a better angle to the sun (reducing reflection and presenting a large effective area). Second, less feed water is in the still at any time and so the water is heated more quickly and to a higher temperature. Simple wick stills are more efficient than basin stills and some designs are claimed to cost less than a basin still of the same output.

Some designs have been developed which incorporate absorbent or film-type materials to increase the surface area of evaporation – e.g. an article on the design developed by G.N. Tiwari of the Indian Institute of Technology, New Delhi, was published in the New Scientist.

Use of reflector

The inside wall of the still can incorporate a reflective coating, such as aluminium foil, to increase the reflection of heat energy onto the evaporating water. It is not known how far this has helped to improve the efficiency of the still [12].

Inverted Absorber Solar Stills

Heat is absorbed from the underside of the still to improve efficiency. This allows that condenser plate and the collector plate to be separate. There are several designs of inverted absorber from the fairly simple to more complex absorber.

Spherical Still

In a design developed by the Thermal and Solar Laboratory at Claude Bernard University, Lyons, France, a trough, where the saline water is placed, is positioned in the centre of a hollow transparent plastic sphere. Distillate water condenses on the inside surface of the sphere and is collected by a mechanical windscreen type wiper blade which forces the condensed water to fall to the bottom of the sphere to be collected. There seems to be a small improvement in efficiency compared with a conventional solar still, but the greater cost of this still might cancel out this advantage.

Inclined Stills

The aim of inclining a still is to increase the solar radiation, by catching it head on, rather than at an angle as with stills which lie flat. To do this constantly, as the sun rises and sets, would need someone to monitor the sun and turn the unit regularly, or a sophisticated automatic tracking and turning mechanism.

Condensate Heat Recovery

Heat recovery from the energy given out when water vapour condenses has generally not been attempted with small-scale solar distillation, unlike with larger-scale systems. It is known that the Ben Gurion Institute, and more latterly the Technion Institute in Israel has undertaken some experiments with heat recovery. In the simplest system, saline water is made to flow over the outside of the condensation plate before entering the still, but then this would reduce the amount of solar radiation passing through the plate. There may be scope for further research to overcome current difficulties with attempting heat recovery from solar distillation.

Basin Type

It consist of shallow, bracken basin of saline/impure water covered with a sloping transparent roof solar radiation that passes through the transparent roof heats the water in blackened basin [13]. Thus evaporating water which gets condensed on the cooler under side of the glass and gets collected as distillate attached to the glass [14].

Emergency still

To provide emergency drinking water on land, a very simple still can be made. It makes use of the moisture in the earth. All that is required is a plastic cover, a bowl or bucket, and a pebble.

Hybrid designs

There are a number of ways in which solar stills can usefully be combined with another function of technology. Three examples are given:

Rainwater collection. By adding an external gutter, the still cover can be used for rainwater collection to supplement the solar still output.

Greenhouse-solar still

The roof of a greenhouse can be used as the cover of a still.

Supplementary heating. Waste heat from an engine or the condenser of a refrigerator can be used as an additional energy input.

Output of a solar still

An approximate method of estimating the output of a solar still is given by [12]:

$$Q = \frac{E \times G \times A}{2.3}$$

Where;

Q = daily output of distilled water (litres/day)
E = overall efficiency
G = daily global solar irradiation (MJ/m²)
A = aperture area of the still ie, the plan areas for a simple basin still (²)

In a typical country the average, daily, global solar irradiation is typically 18.0 MJ/m² (5 kWh/m²). A simple basin still operates at an overall efficiency of about 30%. Hence the output per square metre of area is:

$$\text{Daily output} = \frac{0.30 \times 18.0 \times 1}{2.3}$$

= 2.347 litres (per square metre) [12]

Performance varies between tropical locations but not significantly. An average output of 2.3 to 3.0 litres/m²/day is typical, the yearly output of a solar still is often therefore referred to as approximately one cubic metre per square metre, 1m³/m²/year.

Despite a proliferation of more sophisticated designs such as TERI's solar desalination unit with offset collectors, the single-basin still has the best track record in the field. Hundreds of smaller stills are operating, in Africa and India.

The cost of pure water produced depends on:

1. The cost of making the still
2. The cost of the land
3. The life of the still
4. Operating costs
5. Cost of the feed water
6. The discount rate adopted
7. The amount of water produced.

An example of costs of a solar still in India is Rs. 28000 for 15 m² approximately $575.00 for 15m², or $38.3 per m² [12]

The price of land will normally be a small proportion of this in rural areas, but may be prohibitive in towns and cities.

The life of a glass still is usually taken as 20 to 30 years but operating costs can be large especially to replace broken glass.

It is important that stills are regularly inspected and maintained to retain their efficiency and reduce deterioration. Damage, such as breakage of the collector plate, needs to be rectified.

Some companies, e.g. in the United States, Russia, India and South Africa, sell solar stills, largely for household use to produce up to about 50 litres per day.

People need 1 or 2 litres of drinking water a day to live. The minimum requirement for normal life in developing countries (which includes cooking, cleaning and washing clothes) is 20 litres per day (in the industrialised countries 200 to 400 litres per day is typical). Yet some functions can be performed with salty water and a typical requirement for distilled water is 5 litres per person per day. Therefore 2m² of still are needed for each person.

Solar stills should normally only be considered for removing dissolved salts from water. If there is a choice between brackish ground water and polluted surface water, it will usually be cheaper to use a slow sand filter or other treatment device. If there is no fresh water then the main alternatives are desalination, transportation and rainwater collection.

Unlike other techniques of desalination, solar stills are more attractive, the smaller the required output. The initial capital cost of stills is roughly proportional to capacity, whereas other methods have significant economies of scale. For the individual household, therefore, the solar still is most economic.

For outputs of 1m³/day or more, reverse osmosis or electro dialysis should be considered as an alternative to solar stills. Much will depend on the availability and price of electrical power.

For outputs of 200m³/day or more, vapour compression or flash evaporation will normally be least cost. The latter technology can have part of its energy requirement met by solar water heaters.

In many parts of the world, fresh water is transported from another region or location by boat, train, truck or pipeline. The cost of water transported by vehicles is typically of the same order of magnitude as that produced by solar stills. A pipeline may be less expensive for very large quantities.

Rainwater collection is an even simpler technique than solar distillation and is preferable in areas with 400mm of rain annually, but requires a greater area and usually a larger storage tank. If ready-made collection surfaces exist (such as house roofs) these may provide a less expensive source for obtaining clean water.

Which solar still?

The single-basin still is the only design proven in the field. Multi-effect stills have the potential to be more economic but it would be as well to gain experience first with a single-basin still.

2. Materials and Method

Production of distillate from untreated water

The pilot solar purifier was designed on a glass fiber 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 and turbidity. 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 [9]. 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 four consecutive days. The water sample was obtained from Adada River. Adada River is one of the popular rivers located in the Nsukka, Eastern part of Nigeria. Hourly measurement of volume and temperature was carried out at University of Nigeria, Nsukka in Enugu State, Nigeria. The atmospheric temperature was measured using a thermometer.

3. Results and Discussion

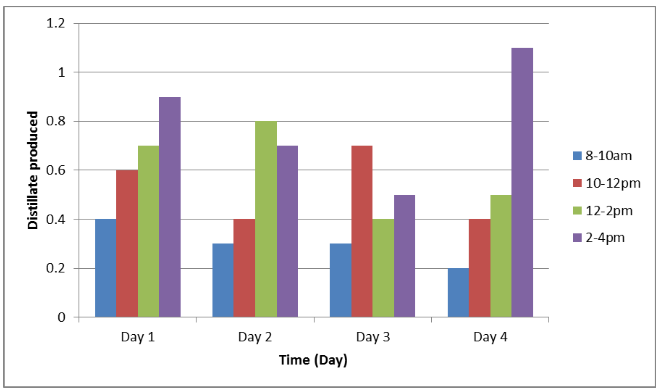


Fig 1: Daily distillate production in litres

Table 1: Daily distillate production at 2 hour period

Day	8-10am	10-12pm	12-2pm	2-4pm
Day 1	0.4	0.6	0.7	0.9
Day 2	0.3	0.4	0.8	0.7
Day 3	0.3	0.7	0.4	0.5
Day 4	0.2	0.4	0.5	1.1

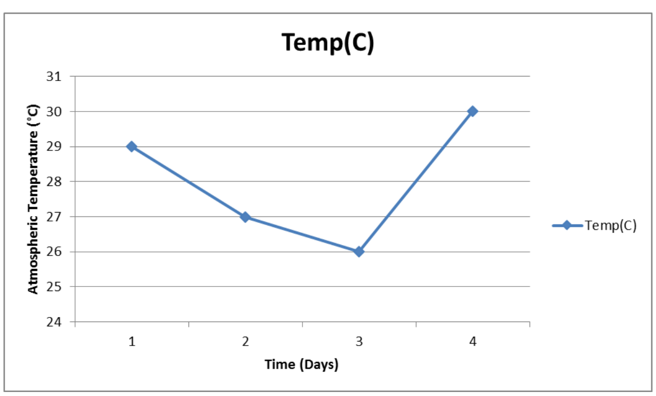
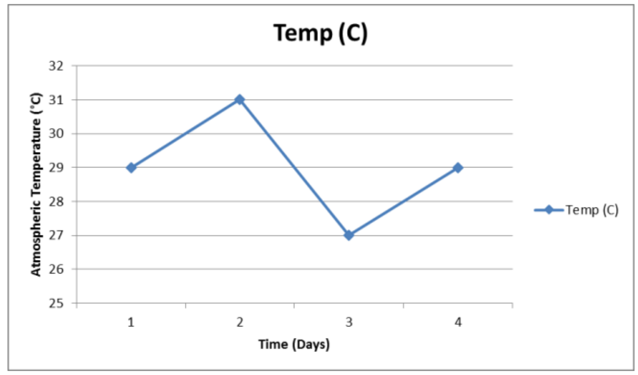


Fig 2: Atmospheric Temperature (°C) at 2-4pm from day 1-day 4.

Table 2: Atmospheric Temperature

Day	Temperature (°C) [2-4pm]
1	29
2	27
3	26
4	30



Days	Temperature (°C) [12-2pm]
1	29
2	31
3	27
4	29

The fig 1 above show daily production of distillate water from day 1- day 4 at different time of the day from 8-10am, 10-12pm, 12-2pm and 2-4pm. The maximum distillate production of 1.1 litres was recorded on day 4 at 2-4pm. Also Tenthani (2012) collected 2.549 kgm-^{2} average of distilled water daily with the improved solar still they performed experiment with in Malawi [10]. It was of noted that 0.2 litres was also recorded as the minimum distillate produced at 8-10am on day 4 as well. The value of the distillate water varied and as well fluctuate from day 1 –day 4 for different time tested due to fluctuation in solar radiation. It is expected that the more solar radiation the solar still receives on a particular day and hour the more the distillate water produced. The atmospheric temperature varied from 26 °C to30 °C during the experiment. The distillate water temperature recorded was 34 °C. Alpesh *et al.* recorded condensate temperature of 29 °C [13]. The maximum atmospheric temperature of 30 °C was recorded on day 4 at 2-4pm. The fig 3 represents the atmospheric temperature recorded from day 1- day 4 at 12 -2pm. The maximum temperature of 31 °C was recorded on day 1 while the minimum atmospheric temperature of 27 °C was recorded on day 3.The experiment was performed at National Centre for Energy Research and Development, University of Nigeria, Nsukka. The Insolation at Nsukka is 450W/m^{2} [9].

4. Conclusion

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. The experiment performed gave a maximum distillate yield of 1.1 litres on day 4 between the hours of 2-4pm. The maximum atmospheric temperature recorded during the experiment was 31 °C. The boiling point and melting point of distillate water tested correspond to World health Organization (WHO) standard.

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