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SINGLE EFFECT GREEN HOUSE TYPE SOLAR STILL FOR PORTABLE WATER SUPPLY

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ABSTRACT

A Single Effect Symmetrical Green House Type Solar Still which can be used as a model for the supply of portable water in rural communities was constructed from locally available materials. Water quality profile tests performed on a brackish water sample before and after purification in the still indicate that the Total Dissolved Solid (TDS) decreased from 1268 to 487 ppm while the Biochemical Oxygen Demand (BOD) decreased from $2.5x10^{-3}$ to $15.1x10^{-3}$g/l. The Hydrogen ion concentration (pH) increased from 5.79 to 6.93 while the electrolytic conductivity decreased from $1.38x10^{-8}$ to $7.16x10^{-8}\Omega m^{-1}$ and resistivity increased from $7.03x10^{8}$ to $8.87x10^{8}$ Ωm. A comparison of the values of these parameters for the purified water from the solar still with that expected for standard pure water shows that the values are very comparable. For example, water in its purest form has TDS and BOD less than 500ppm and $8x10^{-3}$ g/l respectively with a pH of 7, conductivity of $1.0x10^{-9}$ Ωm^{-1} and resistivity of $1.0x10^{9}$ Ωm. The values obtained for the purified water from the still for these parameters are 478ppm, $15.1x10^{-3}$g/l, 7, $7.16x10^{-8}\Omega m^{-1}$ and $8.87x10^{8}\Omega m$ for TDS, BOD, pH, Conductivity and Resistivity respectively. This level of purity profile for the water purified by the still is close enough to that of standard pure water. The still is also found to be capable of producing enough quantity of water to meet the consumption need of small rural families. Community water supply can be achieved by constructing several stills and coupling them together. Therefore THE SINGLE EFFECT SOLAR STILL can be used to purify water for portable water supply for the communities in the Riverine areas of the Niger Delta Region of Nigeria where there is abundance of brackish water with no safe water for drinking, and also in semi urban and urban centres where utility is non-existent or not functional.

INTRODUCTION

The most important determinants in rural development are the provision of good portable water for drinking and other uses and the establishment of enabling infrastructure for the support of small-scale industries (Okujagu 1998; Duffy 2005; Johnson 1997). Lack of these amenities poses a threat to the development of most rural communities (Okujagu 1996; Hoffman 2005; Foster et al 2005). Infact it has been said that adequate supply of safe water is the pre-requisite for significant socio-economic development (Gordes and Perlin 2005; Hinkebein 2005; Litter and Blessa 2005). This is because safe water reduces the incidence of disease and promotes good health and hence contributes to development as well because as it is usually said; “Health is Wealth”. (Johnson 1997; Roddick and Biggs 2004). Again, good source of water supply in rural communities in combination with complementary health and economic development programmes would reduce migration from the rural areas to the cities (Johnson 1997; Rae 2005; Hoffman 2005). Therefore safe water supply system can be used to encourage the grouping of dispersed population into community units of some size (Roddick and Biggs 2004; Müler-Holst et al 2005). The more concentrated the population to be served with safe water, the more likely it is that financially viable and properly maintained water supply system should be provided (Linsey et al, 1990; Yoklic and Bautz 2005; Sagie 2005; Hinkebein 2005).

While it might be difficult to present a rigorous justification for small community water projects on financial ground (Duffy 2005; Hoffman 2005), justification for such can be safely based on improving the quality of water for better hygiene, health, improved economic activities and greater convenience (Hinkebein 2005; Shukla 2005). The need for safe water by purification is predicated on the fact that in most rural communities, safe water do not occur naturally, rather most rural drinking sources are from streams and ponds which are mostly contaminated or naturally hard due to dissolved salts and organic matter (Rae 2005; Ribeiro and Bidoia 2005; Delyannis 2003; Okujagu 1998; Gordes and Perlin 2005; Alarcon 2005; Hoffman 2005; Roddick and Biggs 2004).

Water Pollution Parameters:

Water pollution parameters can be described as the contamination of any water resource or drinking water source with substances that make it unsuitable for the purpose for which the water is meant to fulfill. For instance a navigable water resource can be contaminated with weeds or solid materials to such an extent that navigation becomes impossible in the water body. Similarly, a drinking water source can be made non-drinkable or non-portable when it is contaminated with varying degrees of dissolved substances which are dangerous to human health. Pollution of drinking water sources can be described by the following parameters;

(i) Physical pollutant parameters are; Taste, Odour, Colour, Turbidity and Colloids.
(ii) Electro-Chemical pollutant parameters are; Electrolytic conductivity/resistivity, Hydrogen ion concentration or alkalinity/acidity measure known as pH and water hardness caused by the presence of soluble salt of Ca or Mg.
(iii) Biological pollutant parameters are; Carbon-chloroform Extract-CCE (Metcaff 2005; Sagawe et al 2005), Biochemical Oxygen Demand - BOD, Chemical Oxygen Demand – COD and Bacteriological scale (Metcaff 2005).
(iv) Radiological Parameters (Saayigh 1998; Wang et al 2005; Ribeiro & Bidoia 2005).

For the purpose of defining water quality, these pollution parameters can be grouped together into some important measurable parameters. These are;

(a.) Total Dissolved Solids (TDS)
(b.) Biochemical Oxygen Demand (BOD)
(c.) Concentration of Hydrogen ion (pH)
(d.) Electrolytic Conductivity
(e.) Electrolytic Resistivty.

(Sagawe et al 2005; Metcaff 2005).

Water Treatment Processes:

The process used for treatment of water is usually related to the type of contaminant in a given water sample which is in turn related to the nature of the phenomenon for bringing about the observed change in the water quality. Two broad methods exist, namely;

(a) Chemical/Biochemical Unit processes in which change is brought about by Chemical and Biochemical reaction such as screening, micro screening, mixing, flocculation, filtration and membrane filtration, (Salter et al 2005; Koshikowski et al 2005; Kullab 2005).

(b) Physical Unit Operation processes in which changes in water quality are brought about by application of physical forces such as gravity, gyroscoping (setting), distillation (evaporation/ cooling) and solar distillation (evaporation/condensation) (Ribeiro and Bidoia 2005; Metcaff 2005; Sagawe et al 2005; Wang et al, 2005; and Kiastirim et al 1987).

Most Effective Treatment Process

Of these purification methods, the most effective way of providing portable water as well as establishing simple industrial projects for the rural populace seem to be that of Solar Distillation Scheme. This is because in addition to providing portable water, this scheme will help operators to embark on development projects such as the establishment of small cottage industries for the production of salt from the residue of the sea water. This scheme which can also provide viable source of income for the rural people can be made to be cost effective if it is installed to achieve direct on-the-spot purification, conversion, storage and distribution of the produced water, thus eliminating the transportation of finished products as is the case with public water utility projects or the installation of complicated machinery parts and the side effects of corrosion and clogging (Okujagu 1998; Duffy 2005; and Johnson 1997). Such a scheme can be achieved through a simple solar energy flat collector called "Solar Still", whose technology and device fabrication are simple, cheap and environmentally friendly (Rae 2005). Solar Still are simple solar desalination or distillation units which are capable of desalinating brackish (saline) water or distilling dirty (impure) water to yield fresh pure water (as distillate) and salt (as the residue if saline water is used) Okujagu (1998); Zhu (2005); Bassuoni (1986); Litter and Blessa (2005); Abakr, Ismail and Mahmoud (2005); Ahatov et al (2005); Alarcon (2005); Foster, Amos and Eby (2005); Hay (1996); Foster and Comier (1999); Hay (2005); Salter et al (2005) and Roddick and Biggs (2004).

THE EXPERIMENTAL SOLAR STILL

The evaporation basin (about 2cm deep) of the experimental Single Effect Green House Type Solar Still was constructed with a 1mm thick galvanized iron sheet. The inside of the basin was painted black with two rubber hoses attached to two pipes by the side of the basin. One of these serves as the inlet for the brine (sea water) and the other, outlet for pure water after evaporation – condensation process within the still system.

Four sheets of glass (3mm thick) were used to cover the top of the basin in a V roof shaped manner (Tiwari & Tiwari 2005; Trinipathy and Tiwari 2005). The glasses are fitted into the margin at the top of the water basin forming the groove for the collection of the distilled water. Brine (sea water) was introduced into the basin through the inlet pipe and the still was placed in an open field and exposed to sunlight. As the water is being heated up by the absorbed solar radiation, bulk evaporation began to take place and the humid air ascends above the water surface to the glazing, (Shukla 2005; Tianju 2005). It cools down and may reach an over saturation condition where the moisture in it becomes drops of water (dew) (Inaba, 1984). Thus condensation takes place on the inside surface of the glass cover, giving off heat of condensation, (Zhu 2005; Wang et al 2005).

The released heat rises the temperature of the glazing, but the heat is quickly conducted through the glass cover and finally conveyed away into the atmosphere by the surrounding wind/air (Inaba 1984; Hay 2005; Kiastirim et al 1987; Koshikowski, et al 2005). **Fig 1a** shows the schematic lateral diagram of the still, while **Fig 1b** shows the cross sectional diagram of the still.

ANALYSIS OF THE SOLAR STILL SYSTEM

Generally, the quantity and quality of the water produced by the solar still are determined by the still basin and water temperatures, glass surface temperature, ambient temperature, water depth and variations in water conditions (Kiastirim, Bhattachaya and Wibulwos 1987; Kim et al 2006; Inaba 1984; Trinipathi and Tiwari 2005). Three types of analysis were carried out on the solar still system, namely: Analysis of the Evaporation Profile; Water Quality Profile and Temperature Profile;

Evaporation Profile:

Table.1. Shows the cumulative volume of water evaporated and condensed in the still in the first 10days, 20 and then 30days over which the experiment was performed.

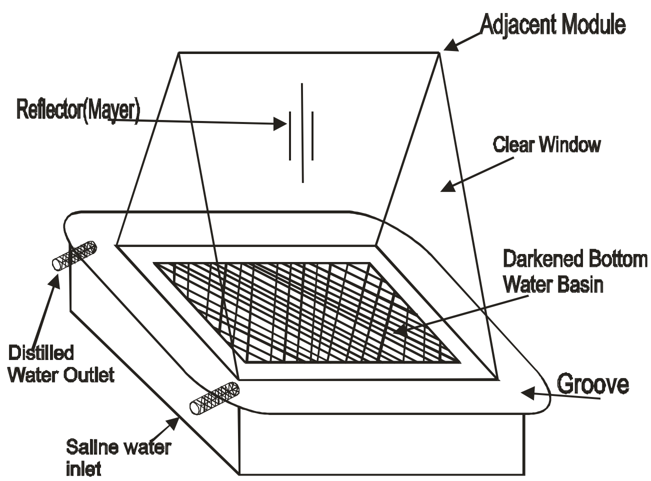

Fig. 1a. Schematic Diagram of Green House Type Solar Still

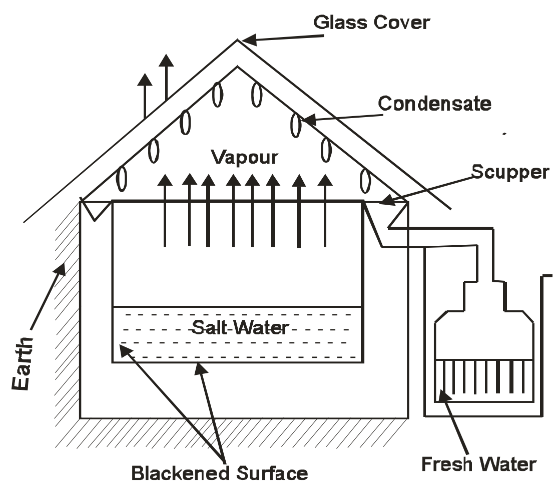

Fig 1b. A cross Section of the Green House Solar Still

Table.1. 30 Days Evaporation Profile.

Days	Volume (cl)	Cumulative (cl)average	Difference in Volume (cl)
1st 10 days average	1,800	1,800	1,800
2nd 10 days average	2,700	4,500	900
3rd 10 days average	3,200	7,700	500

The variation in the water yield is linked to the process of optimization of water quantity, namely; (depth) of the still, still temperature, prevailing environmental factors and heat transfer within the still as the days progressed. From the values of the water yields, the evaporation rate can be obtained using the equation below:

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$$\text{Evaporation Rate} = \frac{\text{Quantity of Distilled Water (Qd)}}{\text{Time interval (t)}}$$

For the 1st 10 days, the evaporation Rate is therefore $\frac{1,800}{10\text{days}}$ =180cl per day.

For the 2nd 10 days, the evaporation Rate is $\frac{2,700}{10\text{days}}$ = 270cl per day.

In the last 10 days, the evaporation Rate is $\frac{3,200}{10\text{days}}$ = 320cl per day.

Therefore the cumulative evaporation Rate is $\frac{7,700}{30\text{days}}$ = 256.6cl per day.

This gives an average of 2.56 liters of water per day for this size of Solar Still. This water yield may satisfy an individual's water in take for the day.

This rate of water yield obtained from this size of solar still can serve as a good model for small scale water production to serve a small family if the size of the still is expanded commensurately for the number of persons in the family. For a community, several stills can be constructed and joined in series to increase water yield (Richards et al 2005; Tiwari & Tiwari 2005; Müler-Holst et al 2005; Kumurarel, Kannan and Golapaswamy 2005). It was found that the productivity of the still was highest in the afternoon between 1 and 2pm. This is as expected for equatorial locations and for the time of the year when sun is over head at about that time of the day.
Also, at that time of the day when the sky is less cloudy, the sun is effective in heating the brine in the still thereby causing higher rate of evaporation-condensation process. It was also observed that between the beginning of evaporation on the first day and the tenth day, the difference in productivity was 1,800cl. That between the 10th and the 20th day was 2,700-1,800 = 900cl, while that between the twentieth and the thirtieth day was 3,200-270 = 500cl.

This shows that the differences in yields between each 10day average decreases from 1,800cl to 900cl and to 500cl. This is as expected from a single filling of the still due to the fact that as the days go by, the bulk of the water would have been evaporated and condensed to form pure water. As the volume of water reduces in the still, bulk yield difference reduces due to the fact that the small volumes of water can no longer support large yield difference. This result therefore requires that to achieve continuously large yield and yield difference, the still should be replenished with appropriate quantity of fresh water to replace that which has been evaporated. This will also ensure adequate and continuous water yield through the life time of the Still.

Water Quality Parameters Profile:

A sample of brackish water was taken and analysed to ascertain the water quality before the evaporation processes began. At the end of the experiment, a sample of the evaporated/condensed water from the out let container was also analysed to ascertain the quality of the resulting distilled water. This was done with the aim of comparing the quality of the distilled water to that of the brackish water and standard pure (portable) water. Table 2 shows the different methods used in the analysis.

Table 2: Different methods for the analysis of water quality parameters.

	Parameters	**Instrument for Measurement**	**Significance**
1.	TDS	"Tyndall effect apparatus" which indicates the amount of dissolved salt by the scattering of light beam that is shone into the solution.	Indicates the sum total of organic solutes and all soluble materials in the water.
2.	BOD	Biochemical Analyzer	Determines the amount of Oxygen absorbed by a given water sample.
3.	pH	pH meter/monitors and multispectrometer.	Measures the acidity or alkalinity of the water and is represented by the concentration of hydrogen ion present in the water.
4.	Conductivity and Resistivity	"Conductivity/Resistivity meter (multispectrometer)	Measures the total ionizable material present in the water which is directly reflected either as conductivity or resistivity parameters of the electrolyte (water sample).

The result of these analyses and that of the parameters for standard pure water quality are as shown in table 3.

Table 3: Water Quality Profile for Brackish Water, Purified Water and Standard Pure Water.

Water Quality Parameter	***Value for Brackish Water, Before Solar Distillation***	***Value for Solar Distilled Water***	***Value for Standard Pure Water***
TDS (ppm)	1269	487	Not exceeding 500
BOD g/l	$2.5x10^{-3}$	$15.1x10^{-3}$	Not exceeding $8x10^{-3}$
pH	5.79	6.93	7.0
Conductivity Ωm^{-1}	$1.38x10^{-8}$	$7.16x10^{-8}$	$1.0x10^{-9}$
Resistivity Ωm	$7.03x10^{8}$	$8.37x10^{8}$	$1.0x10^{9}$

This result shows that the distilled water quality has improved greatly and is highly comparable to those of pure portable water standards, (Hinkebein 2005). For example the TDS value decreased from 1269 ppm to 480ppm. The US geological survey report states that water is safe for consumption when TDS level does not exceed 500ppm and BOD level does not exceed $8x10^{-3}$ g/l (Linsley et al 1990). Also the BOD level for the water sample decreased from $2.5x10^{-3}$ to $15.1x10^{-3}$ g/l. It can therefore be said that solar distillation is an effective method of purifying water to obtain acceptable TDS and BOD values. Hence solar distilled water is safe for consumption. This is in keeping with the findings of (Kulab, Liu and Martin 2005 and Kumaravel, Kannaon and Gopalaswami

2005). Similarly, the pH of the water increased from the brackish acidic state of 5.79 to 6.93 which is very close to that of pure water value of 7.0. Also, the electrolytic conductivity reduced from 1.38×10^{-8} to $7.16 \times 10^{-8} \Omega\ m^{-1}$, a value close to the standard value of $1.0 \times 10^{-9} \Omega m^{-1}$, while the resistivity increased from 7.03×10^{8} to 8.3×10^{8} which is close to a standard value of $1.0 \times 10^{9}\ \Omega m$ the prescribed values for pure water (Henkebien 2005; Read and Cooper, 1974; Richards et al 2005; Tiangu 2005; Tiwari and Tiwari 2005).

Temperature Profiles of the Various Components of the Still:

Figures 2, 3 and 4 show the mean temperature variation for the still components (basin, water and glass) and the ambient temperature for the 1st 10days, 2nd 10days and 3rd 10days respectively, while (Figure 5) shows the 30days-mean temperature for the parameters.

The following facts were observed from the temperature profiles.

(i) Temperatures of all the still components (water, basin, glass) were higher than the ambient temperatures. This shows that the components have the ability of intercepting and converting solar radiation to thermal radiation (heat).

(ii) Water temperatures are higher than the basin temperatures. This shows that when the black basin surface intercepts and converts solar radiation into heat, the heat is quickly transferred to the water body which traps the heat in itself because the brine (salt water) acts as a halocline (salt gradient solution), leaving the basin at a lower temperature than the water.

(iii) The ambient temperature and the glass temperature follow the same pattern because they are directly affected by the incoming solar radiation and atmospheric condition around the still. On the other hand, the water and the basin temperatures follow the same pattern because they are both affected by the absorbed and reradiated thermal radiation in the still system.

(iv) The behaviours of the ambient and glass temperatures were a bit erratic for the first 10days average (Figure 2). These parameter begin to streamline in the next 10days (Figure3) and then in the last 10days (Figure 4). Finally, the parameters follow the day time temperature pattern in these latitudes in the 30days mean profiles of (Figure 5).

It is also noted that the level of water temperature above that of the ambient show how much heat is trapped by the water to cause evaporation to take place within the water and from the water surface. Since the glass temperature is cooler, water vapor reaching it then cools down and condenses to form water droplets which coalesces together to form liquid (water) that flow down the slope into the groove (trough) or channel at the top of the water basin.

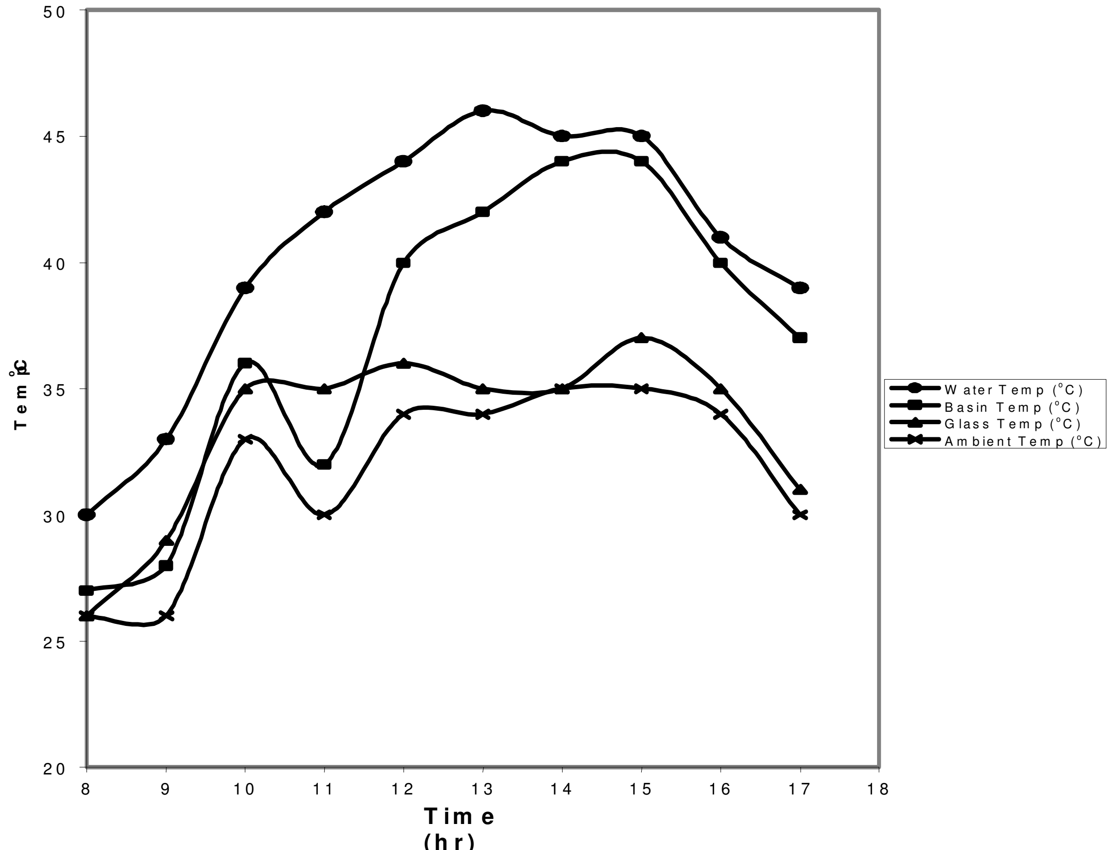

Fig.2. Mean (Water, Basin, Glass and Ambient) Temperature for the 1st 10 days
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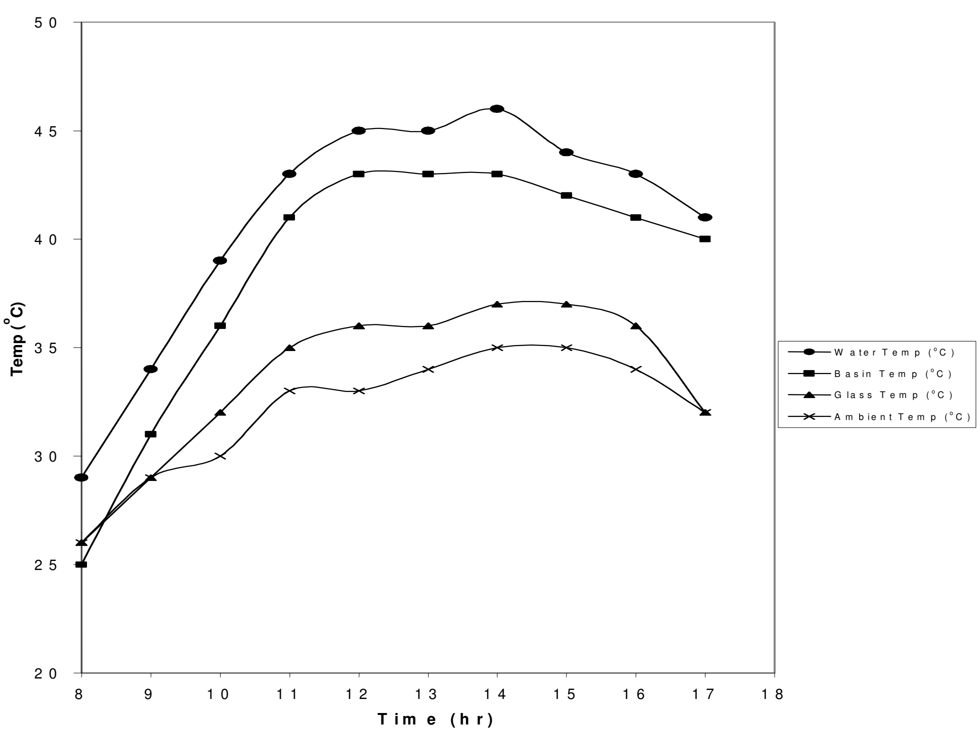

Fig. 3. Mean (Water, Basin, Glass and Ambient) Temperature for the 2nd 10 days.

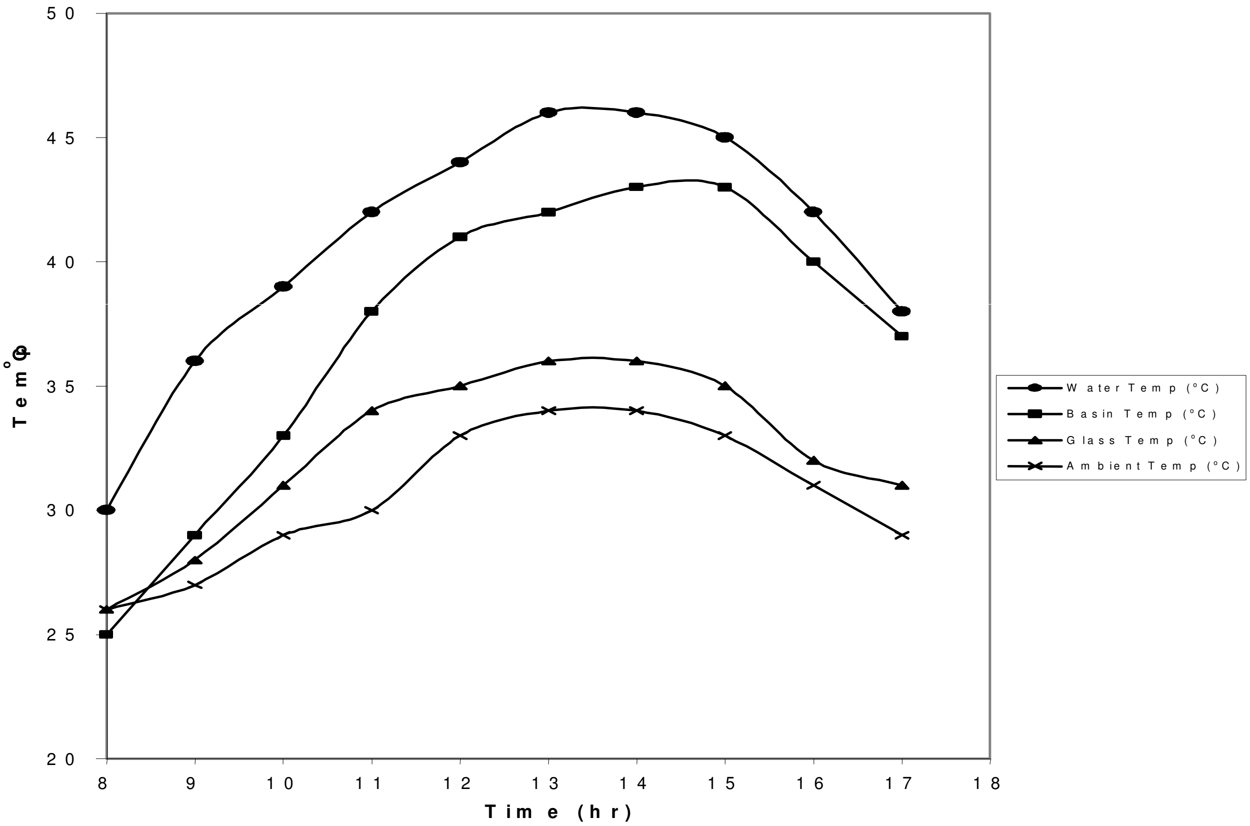

Fig. 4. Mean (Water, Basin, Glass and Ambient) Temperature for the 3rd 10 days.

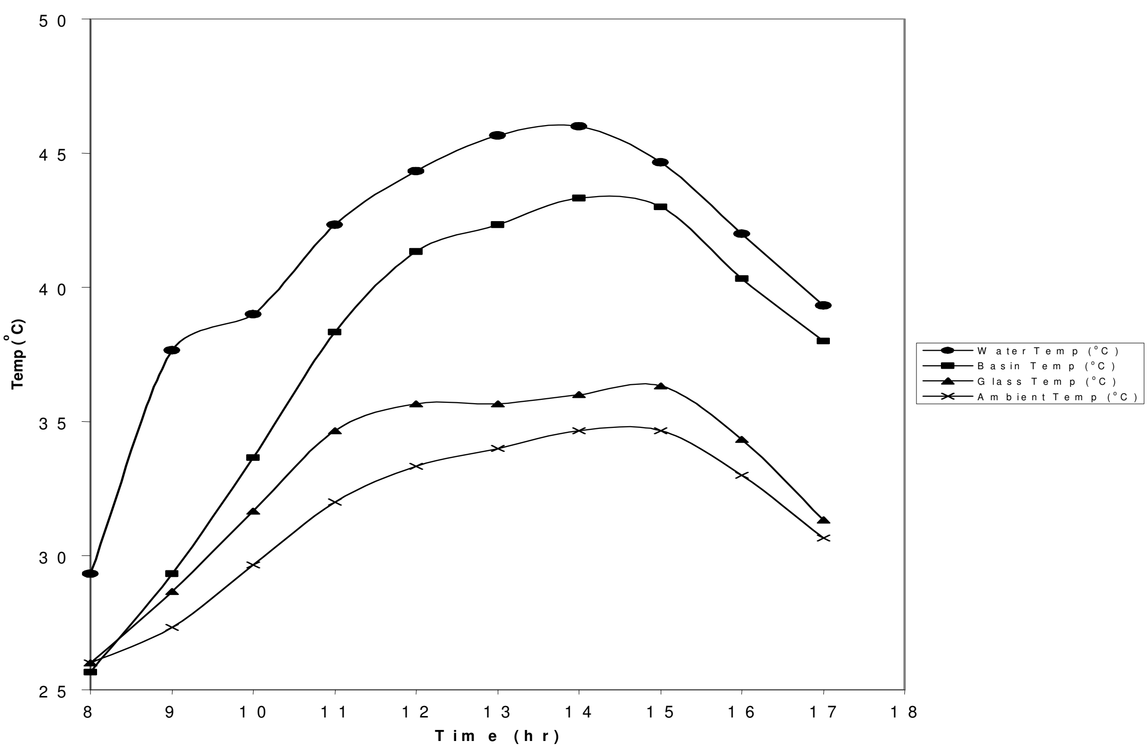

Fig. 5. 30 day Mean (Water, Basin, Glass and Ambient) Temperature for the still.

This water is then collected into a container through the outlet pipe. New brine is usually introduced through the inlet pipe to replace the evaporated water so as to continue the process. If new brine is not introduced and the water is allowed to evaporate to dryness, the salt residues will be left at the bottom of the still which can then be scrapped out to form salt. This part of the experiment and analysis will be the subject of another paper.

CONCLUSION:

The single effect solar still which was constructed from locally available materials was tested and proved to be an effective purification (desalination) unit for brackish (saline) sea water and hence for any impure pond or stream water which are prevalent in most rural areas especially those found in the Niger Delta region. The level of purification that was obtained with this system is even higher than most public utility purification systems that exist in urban areas. It is therefore recommended that both local and state governments should look into this technology with a view of adopting it for their rural and even urban water supply projects especially in the Riverine areas of Niger Delta and elsewhere where saline and brackish water are in abundance but no safe drinking water. Therefore it can be said that impure water can be purified to a very high safe consumption level for these rural populace using **"the single effect green house type solar still device technology"** or any other type of solar still technology.

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