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SOLAR POWERED DISTILLATION OF LAGOS BAR BEACH WATER

Strictly as per the compliance and regulations of:

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Abstract - In this study Lagos Bar-beach water was distilled using a rectangular solar still. The solar still is a single slope type inclined 22° to the horizontal in the north-south direction. The various chemical and biological parameters of the seawater were analysed before and after distillation. The results showed a total dissolved solid value of 4,014 mg/l and total coliform count of 380 cfu/ml. Thus, Lagos bar-beach water is not suitable for human consumption due to basically high total coliform count far above acceptable maximum limit of 10 cfu/ml. However after the solar distillation zero coliform count and no dissolved solids were recorded. Data generated from the performance evaluation of the solar still over an ambient day time temperature range of between 23–31 °C, and a daily global irradiation range of between 7.5–17.1 MJ m^2 that involved physical monitoring of the temperatures of different components of the solar still to determine its efficiency, also validated this result.

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I. Introduction

Safe drinking water remains inaccessible for about 1.1 billion people in the world, and the hourly toll from biological contamination of drinking water is 400 deaths of children below age 5 (Gadgil, 1998). Availability of plentiful and safe water for domestic use has long been known to be fundamental to the development process, with benefits, such as labour productivity, spread across all sectors. Most recently, the UN General Assembly declared the period from 2005 to 2015 as the International Decade for Action, "Water for Life" (WHO, 2008**).** According to Kalogirou (2005) "Water is one of the most abundant resources on earth, covering three-fourths of the planet's surface. About 97% of the earth's water is salt water in the oceans and 3% (about 36 million km^3) is fresh water contained in the poles, ground water, lakes and rivers, which supply most of human and animal needs. Nearly, 70% from this tiny 3% of the world's fresh water is frozen in glaciers, permanent snow cover, ice and permafrost. Thirty percent of all fresh water is underground, most of it in deep, hard-to-reach aquifers. Lakes and rivers together contain just a little more than 0.25% of all fresh water". The only nearly inexhaustible sources of water are the oceans. Their main demerit is their high salinity. Thus, desalination is a major way of making ocean water (seawater) accessible to mankind. Desalination refers to the removal of salts and minerals, as in soil desalination. Water is desalinated in order to convert salt water to fresh water to make it suitable for human consumption or irrigation. Sometimes the process produces table salt as a by-product.

Large-scale desalination typically uses extremely large amounts of energy as well as specialized, expensive infrastructure, making it very costly compared to the use of fresh water from rivers or groundwater. Generally, the energy requirements of desalination processes are high (Fischetti, 2007) making it difficult in developing countries or isolated areas where electricity is erratic, unreliable, and a high percentage of the population is not on the electricity grid (UNDP, 2002). According to (García-Rodríguez, 2003), since most arid regions have high renewable energy resources, the use of renewable energies in seawater desalination exhibits an interesting chance, or even the only way to offer a secure source of fresh water.

Despite the continual technological progress in desalination methods, the conventional solar still continues to be a choice that can be made, mainly for remote areas, due to the known advantages it has, such as use of free energy without harming the environment, autonomous operation independent of conventional energy sources and need for simple technological and construction solutions that can be implemented locally (Mathioulakis and Belessiotis, 2003). Solar still uses the principle of distillation in its operation.

Solar distillation is a technique to distillate water using solar energy. Distillation is the oldest and most commonly used method of desalination. It is a phase separation method whereby saline water is heated to produce water vapour, which is then condensed to produce freshwater. Distillation units routinely use designs that conserve as much thermal energy as possible by interchanging the heat of condensation and heat of vaporization within the units. The major energy requirement in the distillation process thus becomes providing the heat for vaporization to the feed water.

In this study, Lagos bar beach water (seawater) was distilled using a locally made solar still to obtain a distilled water and the result compared to the WHO standards for drinking water.

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II. Theory of the Passive Solar Still

The solar still operation is governed by various heat and mass transfer modes occurring in the system. Within the solar still the convection heat and mass transfer from water surface to the inner glass cover surface can be observed (Fig. 1). The trapped long wave radiation from incident solar radiation heats up the water by way of "green house effect". The hot water evaporates and condenses on the transparent cover. Energy considerations in a passive solar still yield the following equations (Kurmar et al., 2000; Azi and Iyoha, 2007):

Glass cover;

$$\alpha_g I(t)A_g + h_{wg}(T_w - T_g)A_w = h_{ga}(T_g - T_a)A_g \qquad (1)$$

Water;

$$\alpha_w(1-\alpha_g)I(t)A_w + h_w(T_b - T_w)A_b = (m_w C_w)\frac{dT_w}{dt} + h_{wg}(T_w - T_g)A_w \qquad (2)$$

Basin;

$$\alpha_w(1-\alpha_g)(1-\alpha_w)I(t)A_b = [h_{bw}(T_b - T_w) + h_{ba}(T_b - T_a)]A_b \qquad (3)$$

Given T_g and T_w, the hourly production of the still is calculated as

$$\dot{m}_{ew} = \frac{h_{ew}(T_w - T_g)\times 3600}{L_w} Kg/m^2 - h \qquad (4)$$

Where T_o, T_g, T_w and T_a are outer surface cover, inside surface cover, basin saline water and ambient temperatures respectively while h_{ew} and L_w are evaporative heat transfer coefficient from the water surface to the glass cover and latent heat of vapourisation of water respectively. The above equations were derived based on the assumptions that; the unit is in the quasi-steady state, airtight and perfectly insulated. Absorption coefficients and heat capacities of the transparent cover and water are deemed negligible.

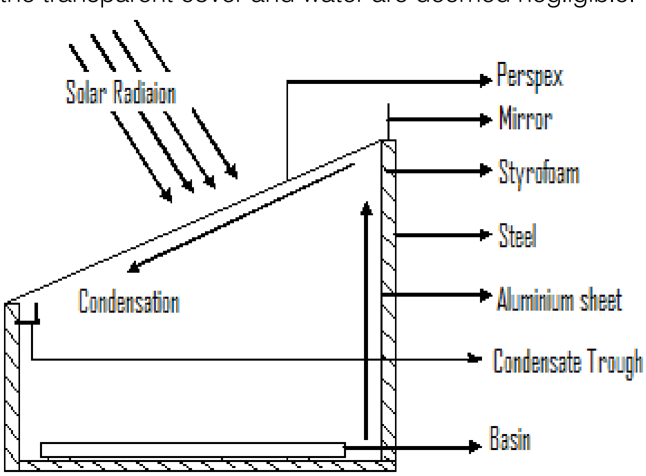

Fig. 1 : Schematic diagram of a solar still

Still Efficiency Determination: the experimental steady state efficiency (η) of the solar still is given as (Hamdan et al., 1999)

$$\eta = \frac{mL_w}{GA_g\Delta t} \qquad (5)$$

where m, L_w, G, A_g and Δt are the mass condensate collected in a time interval, water latent heat of evaporation, hourly solar radiation flux, the glass collecting area and the time interval, respectively. Also, the daily efficiency (η_d) of the solar still is given as (Swelam, 2005):

$$\eta_d = \frac{\sum mL_w}{\sum AGt} \qquad (6)$$

Equation was used to determine the still daily efficiency, as it is summing up the hourly condensate production (m) multiplied by the latent heat of evaporation (L_w), divided by the summation of the average daily solar radiation (G), the whole still area (A) and time of (t).

III. Materials and Methods

The solar still used is shown in Fig. 2 and developed at the National Centre for energy research and development, University of Nigeria Nsukka. It is a rectangular box with a transparent slanted Perspex cover. The perspex cover is inclined at an angle of 22^0 to the horizontal. The solar still is oriented facing south as recommended by Duffie and Beckman (1991).

Fig. 2: The Solar Still

The effective total absorber area is $0.6m^2$. The body of the box is made of prefabricated fibre reinforce plastic 0.005m thick. The interior of the rectangular basin is painted black. Inside the solar still is a rectangular black steel basin of area 0.5m2 and height 0.06m. The basin serves as the container for the seawater. A mirror of $0.18m^2$ was fitted on the still side walls. During the study, four litres of Lagos Bar-beach water was poured into the solar still basin for distillation. The water evaporates only to condense on the underside of the transparent cover, leaving other constituents of the seawater behind. The gentle slope of the glass directs the condensate to a condensate trough from where the water runs out to a storage vessel. Periodically, the temperatures of the seawater, the base of solar still, transparent cover and the ambient were measured using I-Bk thermocouples. At sunset each day the volume of water distilled in the container is measured. Some samples of the sea water and distilled water were analysed to determine their chemical and biological components. Water pH, Turbidity and Total dissolved solid, Total viable cell count and Total coliform count were determined using the method of Franson (1976), Total hardness, calcium, magnesium, sulphate and chloride were determined by AOAC (1990) method. The evaluation was done between 24th May and 4th June, 2011.

IV. Results and Discussion

Results presented in figures 3 to 5 are typical hourly averages as usual in a work of this nature where Amb, Basin, Perspex, and water represent ambient, still interior base, transparent cover and saline water temperature respectively while Solar Rad represents solar radiation.

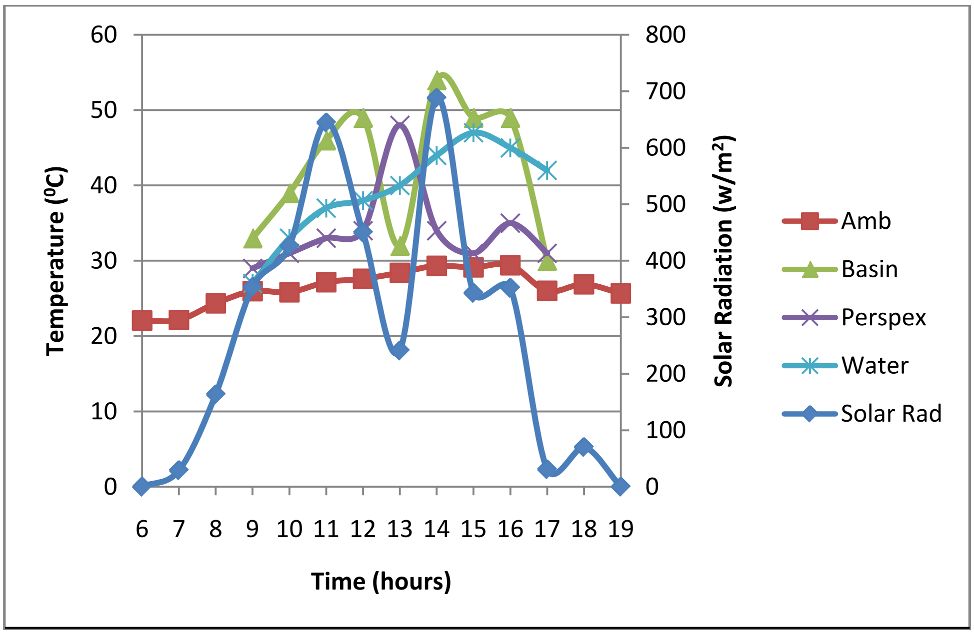

Fig. 3 : Temperature and Solar radiation of 24th May, 2011 Vs Time

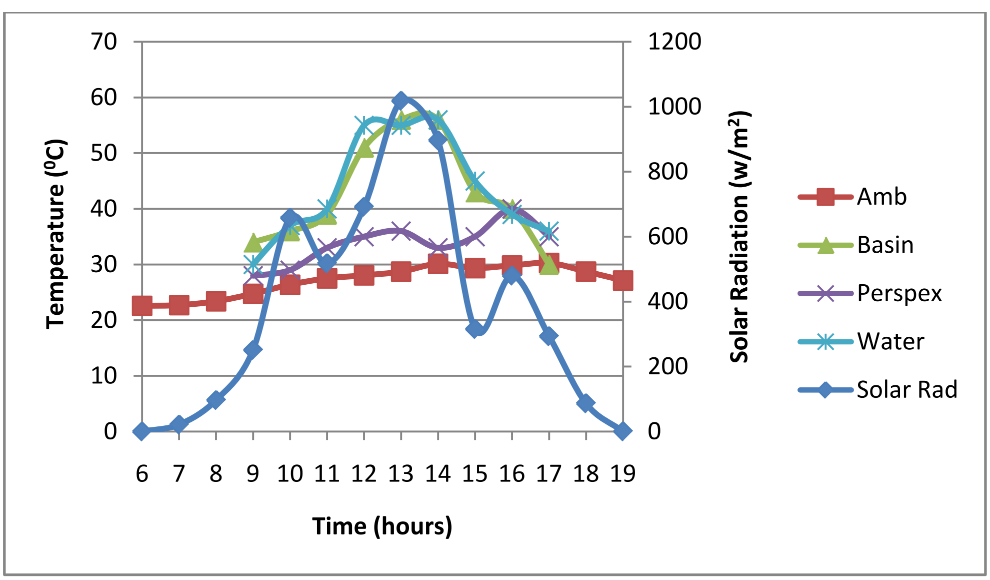

Fig. 4 : Temperature and Solar radiation of 25th May, 2011 Vs Time

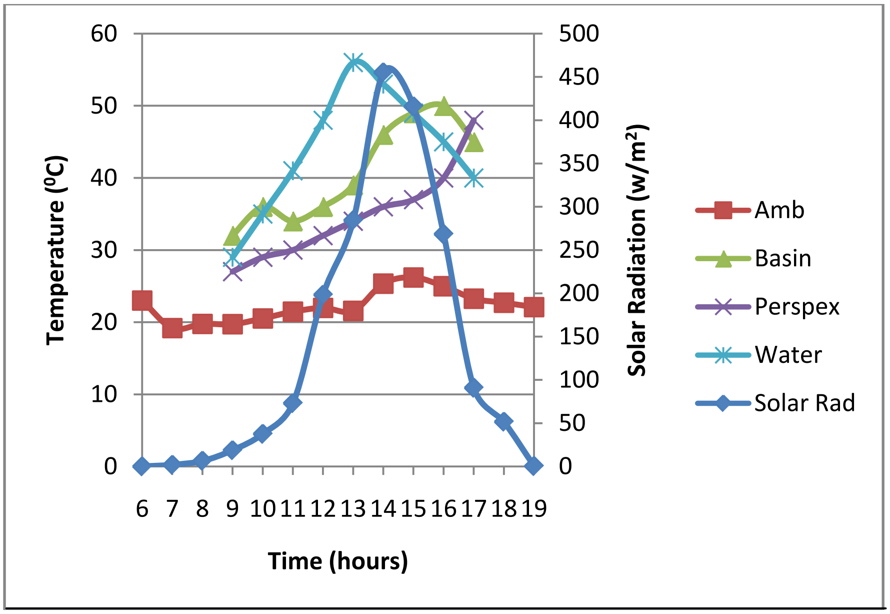

Fig. 5 : Temperature and Solar radiation of 26th May, 2011 vs Time

It is observed that as sun begin to rise from 06:00 hours, solar radiation value started increasing till it reached its peak period between the hours of 13:00 and 14:00 when the sun is vertically overhead (Duffie and Bechman, 1991). After this, radiation value started decreasing till sunset at about 18:00 hour. Among the three days selected, May 26th recorded lowest radiation values. This low values were as a result of the cloudiness of the weather on that day. It was also noticed that all the temperatures measure varied in sympathy with the solar radiation. Also, it is observed that, still interior components temperatures were higher than ambient temperature due to existence of the transparent cover which traps the solar energy inside the solar still (greenhouse effect). The transparent cover which is opaque to the infrared rays from the absorber interior (Badran, and Al-Hayek, 2004) resulted in a higher temperatures inside solar still (Radwan et al., 2009).

Table 1 represents the total and average daily still efficiency using equation 6. The average efficiency of 36.8% is in sympathy with the average 35% efficiency for flat plate passive solar systems (Duffie and Beckman, 1991; Okonkwo 1993

Table 1: The total and average daily still efficiency.

Days	Efficiency (%)
24th May	43.5
25th May	24.7
26th May	42.4
Average	36.8

The results of the laboratory analysis of seawater before and after distillation in comparison with acceptable WHO standards for drinking water are shown in tables 2 and 3.

Table 2 : Parameters and Maximum Allowable Limits for Drinking Water

Parameter	Maximum Permitted Level	Health Impact
pH	6.5-8.5	None
Chloride (CL)	250 mg/L	None
Calcium	75 mg/L	None
Magnesium	0.20 mg/L	Consumer acceptability
Total hardness	500 mg/L	None
Sulphate	100 mg/L	None
Total dissolved solids	500 mg/L	None
Colour	15 TCU	None
Taste	Unobjectionable	None
Odour	Unobjectionable	None
Turbidity	5 NTU	None
Total Viable cell count	0 cfu/100ml	Urinary track infections, bacteraemia ,meningities, diarrhea, acute renal failure and haemoltic
Total coliform count	10 cfu/ml	Indication of faecal contamination

Source : NIS, 2007

Table 3 : Lagos Bar beach water Analysis

Parameter	Before Distillation	After Distillation
pH	7.94	6.86
Chloride (CL)	2.84 mg/L	NIL
Calcium	53.2 mg/L	3.04 mg/L
Magnesium	2720.80 mg/L	0.76 mg/L
Total hardness	2774 mg/L	3.80 mg/L
Sulphate	19.2 mg/L	1.46 mg/L
Total dissolved solids	4014 mg/L	0.07 mg/L
Colour	Colourless	Colourless
Taste	Very salty	Tasteless
Odour	Odourless	Odourless
Turbidity	Nil	Nil
Total Viable cell count	1640 cfu/100ml	Nil
Total coliform count	380 cfu/ml	Nil

Comparing tables 2and 3, it can easily be seen that apart from the pH, chloride and calcium all other components of the bar beach water are beyond the acceptable limit for drinking water. Thus there is the need for distillation of the water especially because of the health implications of the very high values of the total viable cell count and coliform count.

It is observed that the pH of the distilled water decreased but within the acceptable range. As the solar radiation heats up the water, Co_2 reacts with water to form carbonic acid thereby reducing water pH. Equally, all the salt components of the water reduced significantly. This is as a result of the evaporation of water vapour leaving behind these components in the solar still.

Furthermore, the solar still successfully reduced the Total viable cell and coliform counts to zero which is the acceptable level for drinking water. This is as a result of the destruction of these microbes by ultraviolet rays of the solar radiation (Gadgil, 1998).

V. Conclusion

Lagos Bar beach water was distilled using a solar still developed at the National Centre for Energy Research and Development, University of Nigeria, Nsukka. Analysis of the water shows that there are very high values of the Total viable cell and coliform counts in the water which make it unsuitable for human consumption. However, after distillation of the seawater using the solar still both the total viable cell and coliform counts were reduced to zero which is the required condition for among other parameters necessary for its consumption. The solar still with an average efficiency of 36.8% performed within the acceptable range for passive solar systems. Hence the system is recommended for use to especially people living in coastal areas.

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