



Development of a Solar Distiller for the Production of Potable Water for Human Consumption

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ABSTRACT: The study is a continual quest towards the provision of affordable, health-friendly fresh potable water in rural areas; using available, affordable and durable materials for the construction of a solar distiller for freshwater production. The aim of this study was to develop a solar distiller for the production of potable water in waterborne diseases infested rural communities in northern Nigeria. Solar radiation with an intensity of 32 kcal/day was made to pass through a transparent polythene of 1039.6 cm² that covers a 6800 cm² of water collected through evaporator made with 78% refined clay constituent distilling 1.3 litres/day of pure water. An efficiency of 77% was determined after several test runs. Information from this study will serve as a guide to researchers on the production of portable water from the solar distiller. Also, it will guide the government and agencies on policy and decision making on water resources.

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The water cycle consists of four distinct stages: storage, evaporation, precipitation, and runoff. Water may be stored temporarily in the ground; in oceans, lakes, and rivers; and in ice caps and glaciers. It evaporates from the earth's surface, condenses in clouds, falls back to the earth as precipitation (rain or snow), and eventually either runs into the rivers or re-evaporates into the atmosphere. Almost all the water on the earth has passed through the process of water cycle countless times, with very little water that might have been created or lost over the past billion years. Evaporation being a process by which water changes from liquid state changes to gaseous (vapour) state before being deposited in the atmosphere. An estimate of about 1,200 cu km (about 290 cu mi) of water evaporates from the ocean, land, plants, and ice caps every day, while an equal amount of precipitation falls back on the earth. If evaporation did not replenish the water lost by precipitation, the atmosphere would dry out in ten days. All these water formation processes are being masterminded by solar energy from the sun (Encarta, 2009).

Lack of adequate potable water creates a serious danger in the developing countries such as Nigeria, where lack of it kills more children than anything else. This is because of the presence of microorganisms in the available water which causes dysentery that

eventually leads to diarrhoea and fatal dehydration (Duncan, 1998). Distilled water like rain is the purest source of drinking water, if not for aerosols in the atmosphere that contaminates it, therefore any means that will incorporate this principle without external interference by toxic element can provide safe drinking. A Solar distiller is a functional system that utilizes the energy derived from the sun to produce consumable water through distillation principle. The production of pure water has being a worldwide problem. This problem is more prominent in the rural areas of the world. The natural sources of consumable freshwater are rain and springs. Other sources include sea, ocean; and inland sources of rivers, lakes, oasis and ponds. Consumption of inland surface water without treatment has resulted to the contraction of diseases such as Guinea worm; which is a prominent case in West Africa. The commonest methods of producing consumable fresh water are; pumping of underground water from boreholes and chemical treatment of surface water. Another method commonly in use in many countries of the world is the solar distillation method. This method can be used by many countries of the world, individuals, industries, and government where there is no underground water and when the cost of chemicals for treating surface water and their transportation are extremely high (Elekalach, 1990). The solar distillation used here, is

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one by which impure water is heated by energy from the sun, the evaporated water vapour is trapped and the condensed distillate collected as fresh portable water. The principal constituents of the solar distiller where the process takes place are: transparent cover, impure water container (evaporator), and the distillate collector (Dind *et al.*, 1978). A solar still is a mechanism that purifies water of different sources; saline and contaminated. Still is referred to the trapping of water vapour in a condition that when it becomes saturated it distils without escaping to the atmosphere. Literature has revealed numerous designs and ideas related to the solar-powered distiller, such as *The Solar Collection System Design* with radiation concentrated on heat absorber vanes (Husson, 1987). This design contained a few key ideas such as the use of Fresnel lenses to increase the efficiency and overall production of the distiller by focusing the incoming radiation onto a trough of water. The second idea that this design introduced was the use of individual water troughs instead of a large water basin in the distiller. At the base of the troughs were tightly spaced vanes that utilize the capillary action of water to increase the surface area of the water that is exposed to the incoming solar radiation, further increasing the overall efficiency of the distiller. By using troughs, the distiller is able to maximize available surface area and minimize water volume in the distiller (Anwarul and Milon, 2015).

The *Complex Solar Water Distillation System Design*, this design utilize electrical power generation to aid in increasing the fresh water output. Using heat exchangers and a complicated water plumbing system. The phase changes from water to water vapor can be completed and maintained at a constant rate. Although this design tends to increase the overall water output of the system, the construction of heat exchangers, complicated plumbing, and electrical power generation lead to a device that is simply too expensive and impractical to be utilized in the areas that would require such a device (David, 1991).

The *High Output Solar Distillation System design*, this design describes a useful multiple effect system. The term “multiple effects” refers to a system designed in such a way that evaporated water from one surface condenses on the bottom of another surface and subsequently transfers thermal energy to the second surface, which also contains evaporating water. The design uses an inclined wicking system in an enclosed area, similar to a basic distiller, to supply a constant feed of water through the still. The saturated wick allows for some of the feed water to vaporize for condensate and the rest of the feed water run out of the distiller as hot water (Weinstein, 2002). The lapses

created by the above mentioned solar distiller designs was the incorporation of sophisticated technologies on them which has made their use, operation and maintenance at local or rural areas difficult. Also the spare parts for maintenance and repair are scarce and difficult to get as their parts comes from abroad, their production countries.

The Single Basin Wicking Design, this was the design employed in this study. This design uses a more traditional single basin design, but again uses a water-wicking system. One of the advantages of this system designs was that it maintains a constant feed rate that can be predetermined based on the wick size. It also introduces the idea of preheating the feed water to increase efficiency, and creating a vapor circulation system inside the distiller to further increase efficiency. However, as with all wicking systems, the ability to clean the still effectively is compromised because each of the wicks would have to be cleaned with water at the end of each day of use (Anwarul and Milon, 2015).

However, this design closes the gap on using less sophisticated technology yet very efficient unlike the case of the *solar collection system design* which uses Fresnel lenses to increase the output, the *complex solar water distillation system design* which uses electrical power generation to aid in increasing the fresh water output and the *high output solar distillation system design* which uses multiple effect system to increase the fresh water output respectively. Also, the design utilized in this study enjoyed the use of locally available resources which infers availability spare parts and low maintenance cost.

Information from this study will serve as a guide to researchers on the production of portable water from the solar distiller. Also, it will guide the government and agencies on policy and decision making on water resources.

The objective of this study was to design and construct solar distiller that will harness our abundant regional solar energy for the production of fresh portable water that will be free of water-borne diseases; using locally sourced available, affordable and durable material.

MATERIALS AND METHODS

Study Area: The solar data for the research was collected at Anguwan Alhaji Sule Bororo, a Fulani settlement close to Falokun village in Ifelodun Local Government Area of Kwara State. The study area is 370m above sea level and lies on lies between Latitude 9°50' and 8°24' North and Longitudes 4°38' and 4°03' East (Awu *et al.*, 2017). The climate is influenced by

the Inter-tropical Convergence Zone (TCZ), which results in wet and dry seasons. The rain usually starts in April and lasts till late October, with the peak rainfall occurring both in June and September and the dry season lasts between November and March. The mean annual rainfall of the area is 1700mm, while the mean monthly maximum and minimum temperatures within the basin are 31°C and 29°C, respectively, with the highest temperatures recorded in the months of February, March and April. The potential evapotranspiration of the area is between 1500 –

1700mm per annum with mean solar radiation of 32kcal/day (Met. Report, 2009). The materials used for the construction of the solar distiller were locally sourced. Clay, being abundant is processed through a series of stages reported in the works Williams (1997).

Material Cost Analysis: Table 1 shows the cost of the materials used in the manufacture of the Solar Distiller, labour and transportation. The table revealed that the cost of development of a Solar Still (prototype) is ₦6,300.00.

Table 1: Cost of the materials used in the manufacture of the solar distiller

S/N	Material	Quantity	Rate ₦	Amount ₦
1	Polythene	160 x 130mm	300.00	300.00
2	P.V.C pipe Ø18 mm	2 yards	100.00	200.00
3	Filler	½ Tin	1600.00	800.00
4	Adhesive binder	5 pcs	100.00	500.00
5	Paint	1 lt	600.00	600.00
6	Sand paper (rough)	2 cards	100.00	200.00
7	Technician (Labour)	1 person	lump	2,200.00
8	Firing (Clay Treatment)	1 pcs	1,000.00	1,000.00
9	Transportation of Materials	-	lump	500.00
Total				₦6,300.00

Source: Author's compilation

Design Methodology: In the design of the solar distiller, the following parts were considered; the evaporator (made from locally available raw materials), the collector, the reservoir and the transparent cover.

Design for thermal circuit: The first step in the design process was to develop and analyze the thermal circuit for the *Single Basin Wicking* asymmetrical solar distiller is shown in Figure 1 (Coffrin *et al.*, 2007).

The simplified thermal circuit models the convection, conduction, and radiation of energy as well as the evaporation and condensation processes throughout the developed solar distiller device. However, the energy balance in the solar distiller assumes that the temperature difference between one side of the glass to the other is negligible and the temperature difference between T_w and the basin is negligible, there is no heat loss through the sidewalls, T_w is uniform, no vapor leakage, and R_{evap} is equal to R_{cond} , respectively.

Therefore, the solar energy entering the system was calculated using equation 1

$$R_{solar} = R_{evap} + K_{ins} A \frac{(T_w - T_{\infty})}{l_{ins}} + P_w A (T_w - T_{air}) + A \epsilon \sigma (T_w^4 - T_g^4) \quad 1$$

Hence, solar energy entering at node T_{air} is given in equation 2

$$P_w A (T_w - T_{air}) = P_g A (T_{air} - T_g) \quad 2$$

Whereas the energy at the node T_g is given in equation 3

$$A_g \epsilon \sigma (T_g^4 - T_{air}^4) A_g (T_{\infty} - T_g) = R_{cond} + P_g A_g (T_{air} - T_g) + A_g \epsilon \sigma (T_g^4 - T_{\infty}^4) \quad 3$$

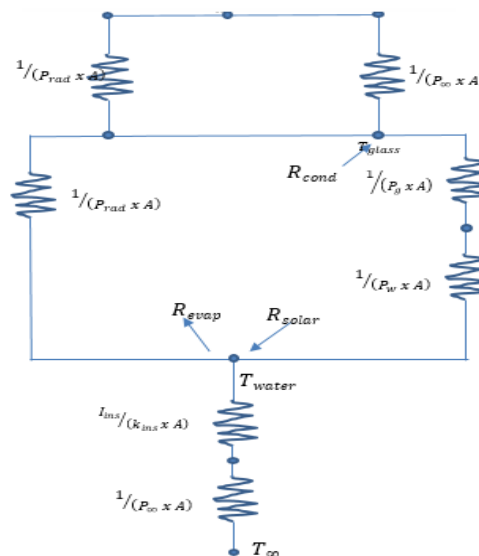


Fig 1: the Simple thermal circuit (Modified from Coffrin *et al.*, 2007)

The angle of solar declination was calculated using equation 4

$$\delta = \Phi \sin[0.9863(284 + n)] \quad 4$$

Also, the direction of the solar distiller was calculated using equation 5

$$\beta = (\Phi - \delta) \quad 5$$

Therefore, the angle of incident was calculated using equation 6

$$\begin{aligned} \cos \theta = & \sin \delta \cdot \sin \Phi \cdot \cos \beta - \sin \delta \cdot \cos \Phi \cdot \sin \beta \cdot \cos \omega \\ & + \cos \delta \cdot \cos \Phi \cdot \cos \beta \cdot \cos \omega \\ & + \cos \delta \cdot \sin \Phi \cdot \sin \beta \cdot \sin \omega \\ & + \cos \delta \cdot \sin \beta \cdot \sin \omega \quad 6 \end{aligned}$$

The Intensity of insolation on collector surface, I_c , was determined using equation 7

$$I_c = IR \times \cos \theta \quad 7$$

For the horizontal surface, since $\beta = 0$ and hence, $\cos \beta = 1$ and $\sin \beta = 0$.

Therefore,

$$\cos \theta R = \sin \delta \cdot \sin \Phi + \cos \delta \cdot \cos \Phi \cdot \cos \omega \quad 8$$

Where, $\cos \theta R =$ cosine of angle of beam radiation on horizontal surface.

The Distillation efficiency was calculated using Equation 9 while the internal efficiency was calculated using equation 10 (Igbenedion, 1999).

$$\eta_i = \frac{q_e}{\alpha \omega \tau \lambda H_z} \quad 9 \quad (\text{Kumar, 1996})$$

$$\eta_{disy} = \frac{Q_e}{Q_t} \quad 10$$

where, Q_e is the heat required, Q_t is the heat available, T_{water} (K) is the temperature of the water in the basin, T_{glass} (K) is the temperature of the glass surface above the basin, T_{air} (K) is the temperature of the air between the water and glass, T_{∞} (K) is the ambient temperature around the solar still, R_{solar} (W) is the solar energy entering into the system R_{evap} (W) is the energy required to evaporate a given amount of water, R_{cond} (W) is the energy required to condense a given amount of water, A (m^2) is the Area of the basin, A_g (m^2) is the Area of the glass, k_{ins} is the thermal conductivity of insulation, l_{ins} (m) is the length of insulation, h_{∞} ($\text{W}/(\text{m}^2 \text{K})$) heat transfer coefficient for convection

from T_g to T_{∞} , h_g ($\text{W}/(\text{m}^2 \text{K})$) is the heat transfer coefficient for convection from T_{air} to T_g , h_w ($\text{W}/(\text{m}^2 \text{K})$) is the heat transfer coefficient for convection from T_w to T_{air} , σ ($\text{W}/(\text{m}^2 \text{K}^4)$) is the Stefan-Boltzmann Constant, ε is the emissivity of glass, δ ($^{\circ}$) is the solar declination Angle, β ($^{\circ}$) is the Slope of collector, Φ ($^{\circ}$) is the latitude, ω ($^{\circ}$) is the hour Angle ($^{\circ}$) Degree, Q_e (kWh) is the Heat required, Q_t (kW-hr) is the heat available and η is the Overall Efficiency of Solar (Brenidorfer, 1985)

Basin Design of Impure Water (Evaporator): Designs were made for the area and volume of the basin slab using equation 11 and 12;

$$\text{Area for slab, } A = l \times b \quad 11$$

$$\text{Volume of slabs, } V = A \times T \quad 12$$

Where l is the length, b is the breadth and T is the height

Therefore, the total volume of four (4) number of slabs equals the volume of a slab multiplied by four ($4 \times V$). However, the outer slab is constructed to allow passage of distilled water to the reservoir.

Design for the Collector: The area and volume of the collector was calculated using equation 13 and 14.

$$\text{Area, } A = l \times b \quad 13$$

$$\text{Volume, } V = A \times T \quad 14$$

Fire treated clay was used for the construction of the collector for its availability and permeability.

The isometric drawing of the developed Single Basin Wicking solar distiller in this study is shown in Figure 2

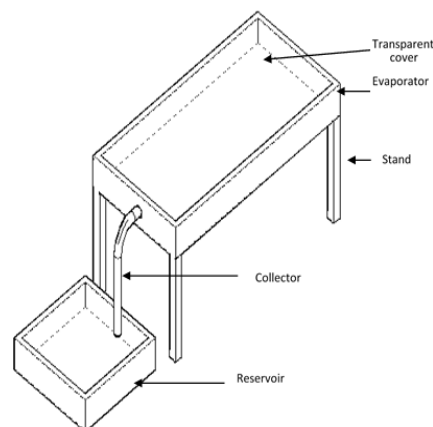


Fig 2: The isometric drawing of the solar distiller (Source: Author's Drawing drawing)

RESULTS AND DISCUSSION

In this study, a *Single Basin Wicking* solar distiller was developed. The principle of operation and maintenance of distillation was employed in the developed solar distiller, it is very important to note that the effective operation of the system depends on the amount of vapour that can be condensed in the still, and maximum vapour condensation will only be achieved if there exists little or no vapour escape from the system. In the design, there was a balance between maintenance and effective operation of the system. The collector and the reservoir need frequent washing, as the basin itself contains impure water. The rubber hose connecting these two parts can be detached during maintenance.

It was observed that the water production from the developed solar distiller is a function of the level of water in the basin and the solar radiation. Also, there is an inverse relationship between the water level of the basin and solar radiation. As the radiation increases the production rate also increases, this agrees to the study of Abdullah *et al.*, (2015). The ratio of water vaporization energy and the latent heat of vaporization were the major determinant of the daily production of the distilled water. The solar still developed was tested and water production output was determined using equation 15 (Donald and Isam, 1995).

$$M_{out} = \frac{\eta_{overall} \times G \times A}{\Delta P_v} \quad 15$$

Where ΔP_v is the enthalpy of vaporization, $\eta_{overall}$ is the efficiency of Solar Still, G is the global Radiation and M_{out} is the water output.

From the design of the developed solar distiller, the area of the basin was 0.6 m²; the enthalpy of vaporization of water was 2.257MJ/Kg. So, from equation 15 the distil output was calculated to be 1.3 liters per day. The distil output obtained in this study was very close to the output of 1.5 liters per day obtained by Anwarul and Milon (2015).

The distiller efficiency was carried out in this study. The typical overall efficiency of solar still was calculated according to Mink (1998). The solar radiation with an intensity of 32 kcal/day was made to pass through a transparent polythene of 1039.6 cm² that covers a 6800 cm³ of water collected through evaporator made with 78% refined clay constituent.

Thus, the distiller efficiency was calculated using equation 9 as described in section 2.0,

$$\eta_i = \frac{19kcal/kg^{-1} \times 1.3kg}{32kcal/day}$$

$$\eta_i = 0.772 = 77\%$$

Hence, solar distil efficiency of 77% was recorded in this study.

Conclusion: In his work a water distiller was designed, constructed and evaluated. This will serve as an alternative to producing potable water for rural areas who lack access to portable water. Information from this study will serve as a guide to researchers on the production of potable water from solar distiller as well to the government and agencies on policy and decision making on water resources.

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