COMPARISON OF LOCALLY CONSTRUCTED BASIN-TYPE SOLAR STILL AND STANDARD ELECTRONIC DISTILLER FOR EFFECTIVE WELL WATER DISTILLATION

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ABSTRACT: This paper discusses the comparative performance of a locally constructed basin-type and a standard electronic distiller for effective well water distillation. The working principle of the still utilizes the solar energy and some environmental factors like wind speed and ambient temperature. A well water sample was collected in sterile jerry can and fed into the locally constructed distiller as well as a standard electronic distiller. Enumerations of aerobic contaminants and coliform bacteria were carried out. Also, the pH value and Fe^{2+} were measured both before and after the distillation. The sample was heavily contaminated with an average microbial load of 3.00 x 10^4cfu/ml, 100% distribution of coliform bacteria and 260mg/l of Calcium Carbonate, $CaCO_3$. The results revealed that heavy contaminats such as aerobic contaminants, coliform bacteria and $CaCO_3$ were completely removed. The total distillate collected in a day was 3.6 litres. A maximum thermal efficiency of 26% was obtained. The result showed that the locally constructed distiller performs just as the standard electronic distiller does and the distillate is of high quality and portable.

INTRODUCTION

The need for portable water cannot be over emphasized. Providing adequate supply of freshwater becomes the most serious problem facing the whole world. The most likely sources of freshwater are the great oceans, seas and in some remote areas the wells that need to be desalinated and or distilled before it can be used. Most of the convectional distillation plants use electricity as their source of energy (Vanfrassen 2004; Alkasim *et al.*, 2011). The three most popular ways by which people distil drinking water in tropical countries are: (i) Filteration: using sieve (ii) Decantaion: the water is allowed to settle naturally and then decant it carefully into a clean basin, and (iii) Chemically: using alum despite the rudimentary nature of the process involved, these techniques still remain in common use (Howe, 1992).

The simplest way to tackle this problem is through the direct use of solar energy (using the solar still). The use of solar energy will become increasingly attractive with time on account of the rapid increase in price of crude oil and its possibility of extinction (Garba *et al.*, 1996).

A solar still essentially consists of a mass of water in a container, which is covered by a transparent cover and the interior surface of this enclosure is coated black to absorb solar radiation entering through the condensation of water vapour. The cover is sloped on one side to enable the condensation to trickle into a channel. The whole enclosure is insulated to minimise heat losses from the sides and the bottom surface (Garg and Prakash, 1997).

Solar distillation (Mona *et al.*, 2002, Kaabi and Smakdji, 2007) represents a most attractive and simple technique among other distillation processes and is especially suited to small-scale units, environmentally friendly, simple maintenance and technology and it is appropriate to developing countries with abundant solar radiation. It is necessary therefore to search for solar stills which could provide us with the necessary daily amount of freshwater, not forgetting the drought that has been prevailing in several areas of Africa for the last two decades (Bachir, 2002).

Distilled water is required for a number of uses such as in institutions for laboratory experiment, health care centres, car batteries, industrial and commercial organisations. Equally important, it is required for drinking, for domestic animal and human beings.

Study Area

Girei is a town 10 km from Yola, the State Capital. The Local Government is located between Latitude 9.22°N and 9.23°N and longitude 12.9°E and 13°E. It hosts the Modibbo Adama University of Technology, Yola.

Girei town lies within the tropical region, hence, it has tropical climate marked by wet and dry seasons. The average minimum temperature is 18.5^0C and the average maximum temperature is 40.7^0C. Hottest months are March and April and coldest are November and December (Tukur 1999). Rainfall is about 958.99 mm per year with highest records in August and September. Thunderstorms are occasional (Tukur 1999).

Solar Still

A conventional solar still is an air tight basin made of galvanized iron sheet in a 1.0 m^2 base rectangular shape. The top cover is made of glass sloped at an angle and the interior surface painted black for the maximum absorption of solar energy. Saline water was poured into the still to fill it partially and then exposed to the Sun. A typical solar still is shown in Figure 1.

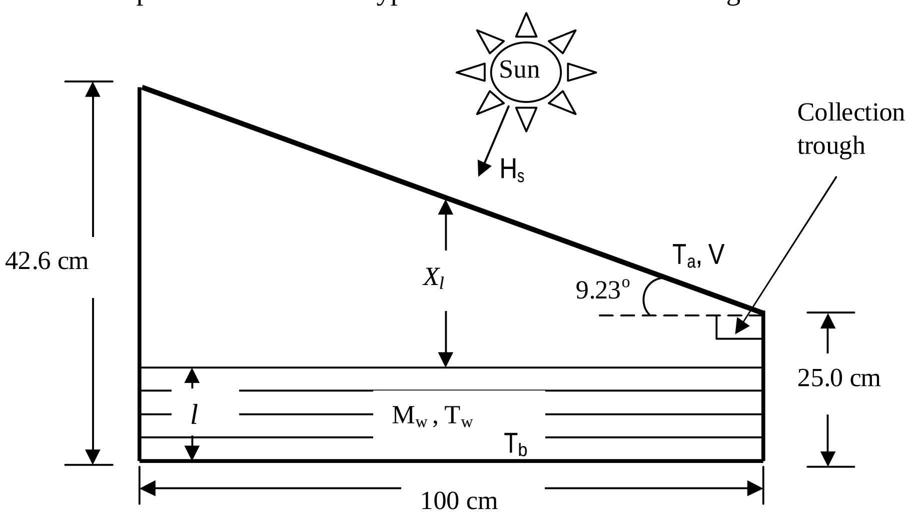

Figure 1: A typical Single-basin solar still.

The glass cover permits solar radiation to get into the still, which is absorbed predominantly by the black base. Consequently, the water gets heated up and hence the moisture content of the air trapped between the water surface and the glass cover increases. The base also radiates energy in the infrared region which is mainly absorbed by water in the basin. Thus, the glass cover traps the solar energy inside the still; it also reduces the convective heat losses. The glass cover is usually sloped to enable the water vapour which condenses on the interior surface to trickle in to a collecting trough.

The Energy Balance Equations and Efficiency Determination The energy balance for the glass cover and the water content in the basin can be expressed as follows:

$$h_1(T_w - T_g) = h_2 F_1 (T_g - T_a) \quad (1)$$

and

$$\rho_w l c_w \frac{dT}{dt} = \tau_1 H_s - h_1(T_w - T_g) - h_3 F_2 (T_w - T_b) \quad (2)$$

where ρ_w is the water density; l the water length; c_w the specific heat capacity of the water and T is the temperature, the subscripts w, g, a and b are for the water, glass, ambient and base respectively; F_1 and F_2 are the top loss and side wall correction factors respectively; h_1, h_2 and h_3 are the heat transfer coefficients from the water surface to the glass (evaporative heat transfer coefficient), from the glass cover to the ambient (external convection heat transfer coefficient) and from the water to the basin liner (internal convection heat transfer coefficient), respectively, given by Tiwari (2002) and Garba *et al* ,(1996) as:

$$h_1 = 8.71 + h_{ew} \quad (3)$$

where h_{ew} is the evaporative heat transfer coefficient. It is related to the pressure, P

$$h_{ew} = 4.0 \frac{P_w - P_g}{T_w - T_g} \quad (4)$$

It is important to mention here that the value of h_{ew} can be more realistic for larger value of (T_w - T_g). The values of P_w and P_g (for the range of temperature 10°C – 90°C) can be obtained from the expression (Fernandez and Chargoy 1990).

$$P(T) = \exp\left(25.317 - \frac{5144}{T + 273}\right) \quad (5)$$

The heat transfer coefficient, h_2 from the glass cover to the ambient is a function of wind velocity, V and is given by (Mowla and Karimi 1995) as:

$$h_2 = 5.7 + 3.8V \quad (6)$$

The internal convective heat transfer coefficient, h_3 from heat flow from the horizontal basin (hottest region in the still) to water mass in the basin and vice-versa is determined from the following relations (Sodah *et al* 1980, Malik *et al* 1982 and Egarievwe 1989):

$$Nu = Co(Gr \cdot \Pr)^n \quad (7)$$

where Nu is the Nusselt number, Gr is the Grashof number, Pr is the Prandtl number while the rest are constants. They have the following relations

$$Nu = \frac{h_3 X_l}{k_w} \quad (8)$$

$$Gr = \frac{X_l^3 \rho_w^2 g \beta \Delta T'}{\mu_w^2} \quad (9)$$

$$\Pr = \frac{C_{pw} \mu_w}{k_w} \quad (10)$$

here k_w is the thermal conductivity of water in the basin; X_l is the water-glass distance, g the acceleration due to gravity; β is the glass inclination from horizontal and $\Delta T'$ is given as

$$\Delta T' = \left[\Delta T + \frac{(P_W - P_g)(T_W + 273)}{268.9 \times 10^3 - P_W}\right] \quad (11)$$

$$\Delta T = T_w - T_g \quad (12)$$

For a normal operating temperature range, ~ 50 °C and $\Delta T' = 17$ °C, the expression for *Gr* reduces to (Tiwari, 2002)

$$Gr = 2.81 \times 10 X_1^3 \tag{13}$$

For the normal operating temperature range and at a spacing, $X_1 = 0.25$ m; the value of the constants are:- $Co = 0.075$ and $n = 1/3$.

After substituting the values of *Nu*, *Gr* and *Pr* in equation (7) the convective heat transfer coefficient h_3 can be written as

$$h_3 = \frac{Cok_w}{X_1}\left[\frac{X_1^3 \rho_w g \beta \Delta T'}{\mu_w^2} \cdot \frac{C_{pw}\mu_w}{k_w}\right]^{\frac{1}{3}} \tag{14}$$

Dunkle (1961) also derived the following expression for h_3 as thus:

$$h_3 = 0.884\left[T_w - T_g + \frac{(P_w - P_g)(T_w + 273)}{268.9 \times 10^3 - P_w}\right]^{\frac{1}{3}} \tag{15}$$

The energy balance for the basin liner may be written as:

$$\tau_2 H_s = h_3 F_2 (T_b - T_w) + U_{sw} F_3 (T_b - T_a) + U_{bw}(T_b - T_a) \tag{16}$$

The factors *F* in equations (1), (2) and (16) are used to correct for the heat transfer areas while U_{sw} and U_{bw} are the side wall and the bottom wall overall heat transfer to the ambient.

Substituting the values of T_g and T_b from equations (1) and (16) into (2), will result in

$$M_w C_w \frac{dT_w}{dt} = aT_w + bT_a + cH_s \tag{17}$$

where

$$a = \frac{h_3^2 F_2^2}{h_3 F_2 + U_{sw} F_3 + U_{bw}} + \frac{h_1^2}{h_1 + h_2 F_1} - h_1 - h_2 F_2 \tag{18}$$

$$b = \frac{h_1 h_2 F_1}{h_3 + h_2 F_1} + \frac{h_3 F_2 U_{sw} F_3 + h_3 F_2 U_{bw}}{h_3 F_2 + U_{sw} F_3 + U_{bw}} \tag{19}$$

$$c = \tau_1 + \frac{h_3 F_2 \tau_2}{h_3 F_2 + U_{sw} F_3 + U_{bw}} \tag{20}$$

And from equation (17), T_w can be calculated as a function of time. The heat flux at any time due to evaporation can be written as:

$$Q_{ew} = h_{ew}(T_w - T_g) \text{ or } Q_{ew} = \frac{h_{ew} F_1 h_2}{F_1 h_2 + h_1}(T_w - T_a) \tag{21}$$

The rate of water evaporation, *m* at any time is given by

$$m = \frac{Q_{ew}}{\lambda} = \frac{h_{ew}(T_w - T_g)}{\lambda} \tag{22}$$

where λ is the latent heat of vaporisation.

The total distilled water produced for a period of time *t* can be obtained by:

$$m_t = \int_0^t m\,dt = \int_0^t \frac{h_{ew} F_1 h_2}{\lambda(F_1 h_2 + h_1)}(T_w - T_a)\,dt \tag{23}$$

The efficiency, η of the solar still, defined as the ratio of the energy used for water production to the total solar radiation rate is given by:

$$\eta = \frac{Q_{ew}}{H_s} \tag{24}$$

As it is seen, the efficiency, η, is also a function of time.

Materials and Construction

The materials used for still construction are: aluminium sheet, black paint, transparent glass, headlamp gum and selotape, hard wood, ply wood and cooton wool. The coupled solar still is as shown in Fig 2.

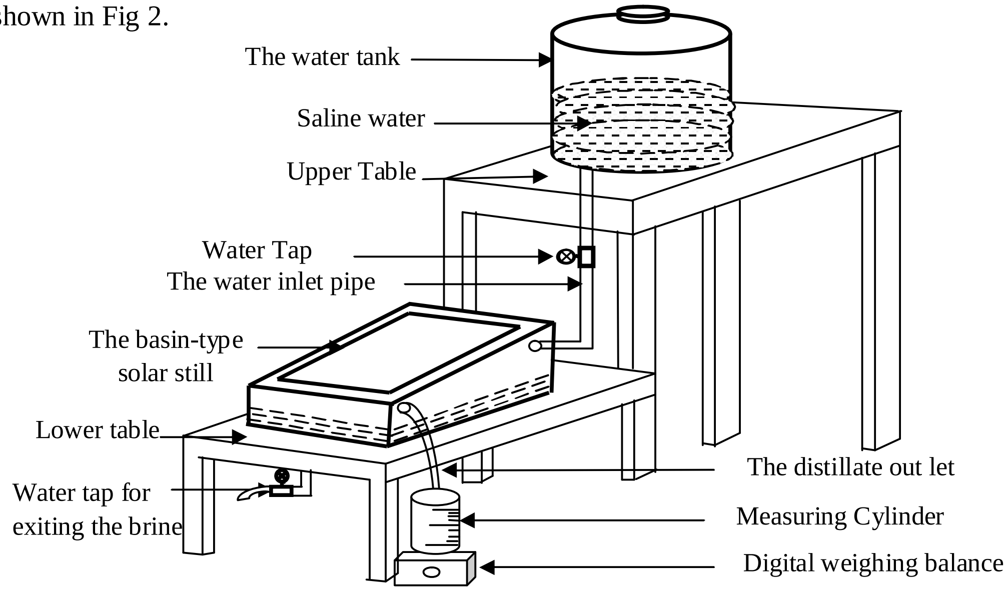

Figure 2: Sketch diagram of the experimental set up.

Figure 3: Life picture of the experimental set up.

The records of the monthly mean daily sunshine data for Yola, Adamawa state in the year 2010 is presented in Table 1. Data used in this work were obtained from the Nigerian Environmental Climatic Observing Program (NECOP) station located in the Department of Physics Modibbo Adama University of Technology, Yola. The record was also used to comfirm the availability of continuos sunshine in the study area necessary for the supply of the solar energy to the constructed solar still.

A sample of the well water obtained from Girei was divided into two parts. The first part was fed into the constructed distiller outside in a shadow less environment while the other part was fed into the electronic distiller. The water sample’s properties were tested both before and after the distillation process.

Table 1: Average climatic conditions of Yola (Latitude 9.23 ^{0}N; Longitude 13 ^{0}E) for 2010

Month	Sun-shine (hrs)	Monthly mean daily sun shine (hrs)	T_{mean} (^{0}C)	R.H. (%)	R'fall (mm)
Jan	234	7.80	26.1	30	0
Feb	217	7.23	28.7	27	0
March	205	6.83	29.3	33	4.8
April	224	7.47	33.3	44	40.3
May	238	7.93	31.0	58	138.8
June	222	7.40	29.1	69	127.2
July	184	6.13	27.4	79	192.5
Aug	187	6.23	27.2	79	215.2
Sept	202	6.73	27.2	77	147.4
Oct	248	8.27	28.5	66	42.1
Nov	263	8.77	27.6	44	2.7
Dec	255	8.50	26.2	34	0

Source: NECOP Data Station, Department of Physics MAUTECH, Yola (2010)

The constructed solar still is as shown in Fig. 2. The features consist of a basin (1.0 m^2 basin area) made of aluminium metal with a transparent glass cover sloped at one side at an angle of 9.23^0 to the horizontal. The basin is made up of steel and the basin liner is coated with a black paint. The whole apparatus is insulated with a 3 cm thick cotton wool and covered externally with plywood.

The still was filled with the well water obtained at a shallow depth. A slopping pane of glass, supported by an appropriate frame, covers the upper part of the basin and is sealed tightly to minimise the vapour leakage. A distillate trough runs along the lower edge of the glass pane to collect the distillate and channel it out to the measuring cylinder or the rain gauge. The refilling tube for refilling the basin is located near the upper edge of the still, and a level controller also serves as a drain to carry away the brine. This is located near the bottom of the still.

The whole assembly is mounted on a table in a shadowless area. It is then oriented so that the slope of the still runs in east-west direction. The slopping glass cover slants towards the equator for maximum solar radiation.

Procedure for Purity Test of the Output Water

The pH Test

A buffer solution of known pH (9.0 ± 0.01) was used to calibrate the pH meter electrode. It was rinsed with distilled water and then dipped into the sample. The result indicates the pH of the sample.

The Total Water Hardness Test ($CaCO_3$ Enumeration)

Precisely 50 ml of the sample was added to 1ml of ammonia buffer and then 4 to 5 drops of eriochrome black T indicator was added. The prepared solution was titrated against EDTA solution (EDTA Preparation: 3.723g of Sodium was dissolved in 1 litre of distilled water) untill the wine color of the solution turns blue. The total hardness is calculated as

$$Total\,hardness(mg/l) = \left(\frac{Titre\ value}{Volume\,of\ the\,sample}\right) \times 1000\ in\,mg/l \qquad (25)$$

Enumeration of Aerobic bacteria

The sample was mixed well by shaking. 1ml of the sample was pipetted into a clean glass tube containing 9 ml of the buffered peptone water. 1 ml of the first diluted mixture was transfered to a second dilution tube containing 9 ml of the buffered peptone water, then 1 ml of the second diluted mixture was transfered into the third dilution tube containing 9 ml buffered peptone water. 1 ml of the three-fold diluted samples was inoculated into appropriately marked duplicate nutrient agar plates. The plates were incubated at 30 ^oC for 36 hrs. The resulting bacterial colonies were observed followed by variable microbial count done using colony counter thus;-

$$Microbial\,Count = No.\ of\ \ colonies \times\ Dilution\ \ factor\ (in\ cfu) \qquad (26)$$

Enumeration of coliform (Multiple-tube Fermentation Technique)

(i) Presumtive Test

Three tubes of the single-strength lactose broth were inoculated with 0.1 ml, 1 ml and 5 ml water samples. These were then incubated at 35 ^oC for 36 hrs. The lactose broth tubes were observed for gas production after 24 hrs.

(ii) Confirmatory Test

Tubes showing positive presumptive test were used to streak eosine methylene blue agar plate. The plates were incubated at 35 ^oC for 24 hrs. The plates were observed for coli form colonies.

(iii) Completed Test

The comfirmed coliform colonies were used to inoculate a tube of lactose broth with Durham tube. The tubes were incubated at 35 ^oC for 36 hrs. The lactose broth culture was observed for gas production.

RESULTS AND DISCUSSIONS

The minimum and maximum monthly average daily sunshine hours are 6.13 and 8.77 hrs respectively (Fig. 3). This result shows that the condition is favourable to effective usage of a solar still.

Although almost all the residents of Yola and environs rely on the borehole waters through local water vendors, the results obtained show that the waters from the research area are contaminated with at least 2.1×10^4 mg/l of microbial load, 100% distribution of coli bacteria with an average of 260 mg/l of $CaCO_3$ and a pH value of over 7.8.

The efficiency of the constructed solar still was obtained by the equation (24). It can be observed from Table 2 that the locally constructed distiller unit is capable of removing the hardness and the microbial contaminants just as the electronic distiller. The overall thermal efficincy of the constructed distiller was 26% and it is capable of of producing 3.6 litres per day of a portable water at an initial water depth of 1.0 cm. The still construction is cost effective as well since it was constructed from the locally available materials.

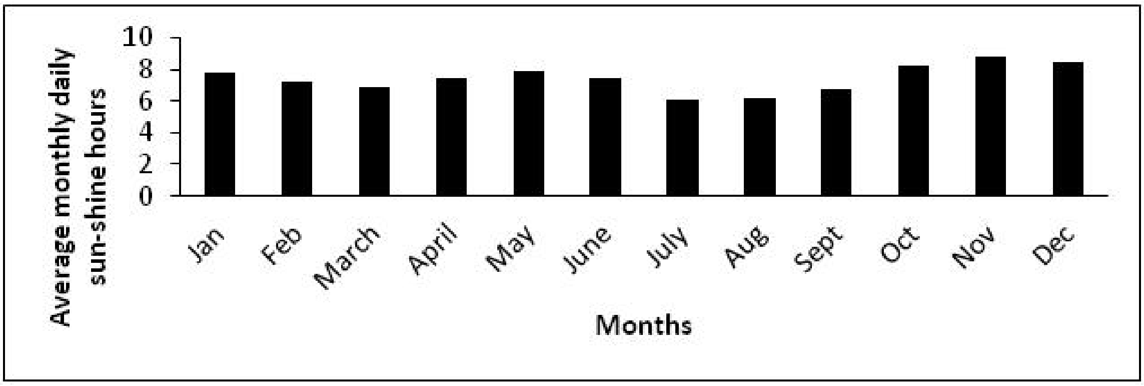

Figure 3 : Averagy Daily Monthly Sunshine hours for Yola for year 2010

Table 2: Comparison between the Results of the Water Quality Test of the Constructed Distiller Unit and that of the Standard Electronic Distiller.

Parameter Tested	Units	Sample before distillation	Distillate from the Constructed Distiller	Distillate from the Electronic Distiller	Max. WHO Standard
pH	-	7.5	7.1	7.0	6.5-8.5
Taste	-	Tasteless	Tasteless	Tasteless	No value
Turbidity	NTU	3.0	2.8	2.7	0-5.0
Temperature	^oC	31.5	31.5	31.5	Ambient
Odour	-	Unobjectionable	Unobjectionable	Unobjectionable	No value
Electrical Conductivity	HS/cm	88	0	0	90-120
Total Hardness ($CaCO_3$)	mg/l	260	0	0	150
Total Iron (Fe^{2+}) content	mg/l	1.04	0	0	0.3
Aerobic Bacterial Count	cfu/ml	2.1×10^4	0	0	0
Distribution of coli form bacteria	(%)	100%	0	0	0-10

Note NTU = Nephelometric Turbidity Unit

CONCLUSION

More than a billion people in the world today do not have portable drinking water. Mubi, a big town and Yola the state capital of Adamawa State Nigeria have most of their bore hole waters being contaminated with 100% distribution of coliform bacteria and over 3.3×10^4 cfu/ml of Aerobic bacterial count as revealed by a research done by (Madugu and Malgwi, 2006; Alkasim *et al* 2011). Almost all the resident of Adamawa depend on borehole and or well water for their daily needs. This research revealed that there is a serious health risk in the direct use of the well waters due to its contamination. The contamination may be as a result of the filthy nature of the wells' environments which are mostly contaminated by the people. The distillate from the solar stills which was cleaner than the rain water (Table 2) is higly recommended for use, especially for drinking. Obviously, one advantage of the solar distillers is that, most people would not be able to buy the electronic distiller even if supply of electricity improves.

REFERENCES

Alkasim, A., Adam U. and Ododo, J.C. (2011). Performance Evaluation of a Basin-Type Solar Still for water Purification, *Nigerian Journal of Physics*, 22(1) 106-117

Adebayo, A. A. (1999), Introduction, in *Adamawa State in Maps*, Adebayo A.A. and Tukur A.L. (eds): pp. 3, Paracletes Publishers, Yola-Nigeria.

Bachir Bouchekima (2002), A Solar Desalination Plant for Domestic Water Needs in Arid Areas of South Algeria, *Desalination*,153: 65-69.

Dunkle, R.V. (1961), Solar Water Distillation, The Roof type Still and a Multiple Effect Diffusion Still, International Developments in Heat Transfer, part V, University of Colorado pp. 895

Egarievwe, S.U. (1989). Solar Stills For Fresh Water Production in Rural Areas- Design and Economic Consideration, *Nigerian Journal of Energy*, 8(8).

Fernandez, J. And Chargoy, N. (1990). Multistage, Inderectly Heated Solar Still, *Solar Energy*, 4(44): 215.

Garba, B., Atiku, A.T. and Ali, U.A. (1996). Effects of Some Meteorological Parameters On the Performance of Basin-Type Solar Still for Distilled Water Production in a Tropical Area, *Nigerian Journal of Renewable Energy*, 4(1): 30-36.

Garg, H.P. and Prakash, J. (1997). *Solar Energy Fundamentals and Applications*. Tata McGraw-Hill Publishers, New York.

Howe, E.D. (1992). Distillation of Sea Water in *Solar Energy Technology Handbook*, William, C.D. and Paul, N.C. (eds): 205-237 Publisher Marcel Dekker, inc New York.

Kaabi, P.A. and Smakdji, N. (2007). Impact of Temperature Difference (Water-Solar Collector) On Solar-Still Global Efficiency, *Desalination*, 209: 298-305

Malik, M.A.S., Tiwari, G.N., Kumar, A. and Sodha, M.S. (1982), *Solar Distillation*, Pergamon Press Ltd.

Medugu, D.W. and Malgwi, D. I. (2006). Design and Development of Solar Still for Effectiveness in Eliminating Microbial Contamination and Salt in Mubi, Adamawa State, Nigeria, *Nigerian Journal of Physics*, 18(2) 203-209

Mona, M.N., Marvat, A. Abd-El Kawi, (2002). Non-Conventional Solar Stills Part 1. Non-Conventional Solar Stills With Charcoal Particles As Absorber Medium, *Desalination*, 153: 55-64.

Mowla, D. and Karimi, G. (1995). Mathematical Modelling of Solar Stills in Iran, *Solar Energy*, 55(5): pp. 289-393.

NECOP Data Station, Department of Physics MAUTECH, Yola (2010).

Sodah, M.S., Nayak, J.K., Tiwari, G.N. and Kumar, A. (1980), Double Basin Water Still, *Energy Conversion*, 20(1) 23.

Tiwari, G.N. (2002). *Solar Energy Fundamentals, Design, Modelling and Applications*, Narosa Publishing House.

Tukur, A.L. (1999). “Landform types in Adamawa State” in Adebayo, A. A. and Tukur, A.L. (eds). *Adamawa State in Maps*. Paraclete Publishers, Nigeria.

Vanfrassen, B. C. (2004). Science as Representation: Flouting the Criteria, *Philosophy of Science* 71, Supplement, S 794-804.