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Development of a Solar Water Distiller and Laboratory Analysis of the Product

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Abstract: *In spite of the significance and availability of water, only an approximate value of about 1% is portable. Distillation processes which comprise evaporation and condensation in a box like machine called Solar Water Distiller was adopted for distilling unsafe to safe drinkable water in our homes. The design method adopted for the machine was energy method/balancing equation. The developed machine is a single stage distiller which is fabricated using local available materials. The heat energy required for powering the solar water distiller was 337.2 W/m^2. This was the quantity of energy per unit time and area required for distilling the water based on average room temperature of 28.6 ^{o}C. The machine has capacity of average daily capacity of 28 litres as distillate water volume within 6.68 hours. It has design capacity of producing 4.2 litres per hour at minimum wind speed of 5.75m/s. The results show that produced machine has 75% efficiency with quality drinkable water that satisfied condition of Nigerian Standard for Drinking Water Quality NSDWQ (2007) rating.*

Keywords: *Distillate, Distillation, Microbiological, Physico-chemical, Solar.*

1. INTRODUCTION

Energy and water are two vital issues from the environmental point of view; both play a significant role in the improvement of the economy over the entire world. Potable water is a basic human need, and pollutants made by human beings have adversely affected it [1]. Distillation however is one of many processes available for water purification, of which sunlight can be used to power that process taking into account the advantage of zero fuel cost associated with direct use of solar energy.

The term of Distillation refers to a combination of two separate processes, namely Evaporation and Condensation, which in conjunction serve to purify substances. Distillation is always taking place in a closed system especially in a box for preventing losses. Different researches have been conducted on the conventional solar still by modifying it in order to increase the efficiency of this kind of system [2]. The efficiency of a conventional solar still depends on solar irradiation, ambient temperature, weather conditions, heat loss and glazing material [2]

Solar distillers work by mimicking the natural water cycle: the sun provides energy to warm the water, the water evaporates (forms clouds) and condenses (makes rain) when it meets a cooler surface [3]. Unlike the electric distillation, boiling is not required for solar distillation. Vigorous boiling “can force unwanted residue into the distillate (distilled water), defeating purification”. Distillation and reverse-osmosis (RO) filtering are the two best methods for purifying water. Both approaches remove more contaminants than activated carbon filters do. The U. S. Environmental Protection Agency for example says only reverse-osmosis systems and distillers may be called water "purifiers." All other systems are water "treatment" devices, in spite of the performance claims many manufacturers make.

1.1 The Solar Still

Solar still distillation is one of the different processes that can be applied to remove the impurities from water [4]. Solar irradiation is the source of heat energy needed for this kind of work. In this process, the sun radiation provides heat to evaporate water and to separate the vapour from impurities that exist in the water, after that condense it as portable water under the glazing [5]. Distillation processes simulate water evaporation and raining cycle on the earth. The sun’s radiation or solar radiation heats the water in the oceans, seas and rivers. It evaporates and condenses and forms clouds, which fall on the earth as rainwater. Solar still can be classified basically in two types; active and passive solar still systems [6].

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2. MATERIALS AND METHODS

The materials and methods adopted in this work are listed below.

2.1 Materials

The following materials were selected for the development of the solar distiller:

i. Mild steel and stainless-steel pipe
ii. MBF plywood and fibre glass/glass plate

iii. Mild steel pipe and zinc alloy sheet
iv. Reflective plate
v. Paint and flex seal
vi. Bolt and nut, epoxy resin and nails

The research materials/equipment used for water laboratory test includes:

a. Conical flask with distilled water and river water
b. Pipettes and Petri dishes
c. Culture media
d. Trioxonitrate (iv) acid (HNO_3) and tetraoxosulphate (vi) acid (H_2SO4)
e. Detergent (phosphate)
f. Digital pH meter (330iwTw) and conductivity meter
g. Dissolved oxygen meter and colorimeter
h. Florescent lamp and magnifying lens

2.2 Methods

The optimised design was considered in the design process that was affordable and reliable cost of production. The water distiller was fabricated by bending a sheet of aluminium sheet into required designed because it was available at low cost. The basin part of the distiller was covered by epoxy resin for absorbing incoming radiation from the sun and prevention of corrosion in the designed basin. The basin was designed in a cuboid shape. The cuboid shape was fabricated using aluminium sheet. The glass was mounted at inclined desired angle of 11^o taking into account the very close angle of solar radiation in Nigeria by polar system at latitude 10^o 00' North of Equator. The angle was chosen as experimental angle for this design. This choice ensures that the sun's rays will be closest to normal incidence averaged over one year. The maximum volume of required water inlet in distiller was designed to be the volume of designed cuboid shape. The performance evaluation of the solar water distiller was carried out for ten days using one litre (1 dm^3) of water per day.

The outer surface of the cuboid shape was constructed with MBF plywood. Between the aluminium sheet and the MBF plywood was fibre glass to create insulating property to maximise energy usage. The fibre glass serves as insulator that conserves heat within distiller system. Rectangular surface reflective glass was mounted vertically erect and in contact with inclined glass in order to concentrate heat energy as well as buffer to the glass. This was screwed onto the surface of the standalone MBF plywood that seals one of the sides of the cuboid shape or water distiller container. The reflective glass serves as mirror for creating solar incidence on the water distiller inclined glass surface. Flex seal was fixed on the inner edges of the cuboid/water distiller container for easy fixing and removal of inclination glass when desired. Water inlet pipe was made of PVC while that of the water outlet was fabricated using stainless steel pipe. The stainless steel was adopted for prevention of contamination of the water through corrosion process. The stand support for the water distiller was fabricated using mild steel. The solar water distiller is designed to be powered by a renewable energy source which was the sun. It was suited to be operated between the times of sunrise to sunset

The performance of a solar water distiller (SWD) is designed and analysed based on energy and mass balance equations and generally expressed as the average volume of water distilled per day [7].

However, effective protection of public health against water related diseases requires a preventive integrated management approach, this includes:

i. The protection of drinking water from catchments and source to its use by consumers
ii. The development of procedures and requirements that ensure good water quality management in order to meet the maximum allowable limits.

This work used insulators as composite materials and they include epoxy resin, fibre glass and MBF plywood. This was used for conserving heat in solar water distiller basin. Computer Aided Design programme called Pro-engineering was used for modelling the design water distiller as a prototype before fabrication and assembly process. Study considers the use of insulated composite for improving heat conservation in the water basin at an average room temperature of 28.6 ^oC as heat sources from solar under atmospheric pressure. This will help in producing a quantified volume of distil water. The quality of the condensed water is extremely good with a chloride content of about 24-40 ppm and a pH value between 6.70 and 7.05 and a critical examination of physico-chemical and microbiological parameters of distilled water obtained from the machine was compared with existing acceptable drinking water standard.

2.3 Experimental Procedures and Laboratory Analysis

2.3.1 Laboratory Test

The culture media required for indicator bacteria analysis was prepared according to standard manual. However, experimental analysis was carried based on physico-chemical and microbiological constituents of both distilled and river water.

2.3.1.1 Physical and Chemical Parameters

i. pH: This was measured using pH meter (330iwTw) by dipping the terminals into the water samples. The reading displayed and recorded.
ii. Total Suspended Solids (TSS): Direct Reading Spectrophotometer (DR/2000) from HACH Company as used. The program number (630) for suspended solids was entered and the wavelength adjusted to 810nm and the mg/l was displayed. A blank of 25ml of deionised water was measured into the sample cell and placed in the cell holder. The light shield was closed. The zero key was pressed, and the reading displayed 0.00 mg/l. The blank was then removed, 25ml of water sample was measured using the sample cell bottle and placed into the light shield then closed. The enter key was pressed and the reading displayed in mg/l and recorded. This procedure was repeated for two replicates.

iii. Total Dissolved Solids (TDS): The Total Dissolved Solid meter (Model 50150 from HACH Company) Direct Reading Spectrophotometer (DR/2000) was switched on and the probe immersed into distilled water and agitated. The reading displayed 0.00mg/l. The probe was removed and then immersed into the water sample, the result displayed recorded. This procedure was repeated for two replicates.

iv. Dissolved Oxygen: The Dissolved oxygen meter (Model 9071 HACH Company) was used. The probe immersed into distilled water and adjusted the value to zero reading. The reading displayed 0.00mg/l. The probe was removed and then immersed into the water sample, the result displayed recorded. This procedure was repeated for two replicates.

v. Biochemical Oxygen demand (BOD): The dissolved Oxygen meter (Model 9071, HACH) was used. The probe of the meter was immersed into distilled water and adjusted to zero value. 5ml of the water sample was then isolated and using the same meter, dissolved oxygen was measured in three replicates and their mean recorded as D1 in mg/l. The sample was then incubated for 5 days at 200C and dissolved oxygen after incubation usually referred to as residual oxygen was measured in three replicates and their mean recorded as D2 in mg/l. The difference between the two readings which is the oxygen used for oxidizing the organic matter present in the water sample was calculated using the relation:

$$BOD_5 = (D1 - D2)\, f_d \quad (1)$$

f_d = Dilution factor (Volume of sample/300)

vi. Chemical Oxygen Demand (COD): The programme number (432) for COD was entered and the wavelength adjusted to 512nm and the mg/l was displayed. A blank of 25ml of deionised water was measured into the sample cell and placed in the cell holder. The light shield was closed. The zero key was pressed, and the reading displayed 0.00 mg/l. The blank was then removed, 25ml of water sample was measured using the sample cell bottle and 2.0 ml of Manganese (III) solution was mixed and allow to two minutes reaction time, after which it was placed into the cell holder. The enter key was pressed and the reading displayed in mg/l and recorded. This procedure was repeated for two replicates.

2.3.1.2 Microbiological Analysis

i. Total Coliform (TC): in the analysis MPN Method was used with 25 fermentation tubes each containing lauryl tryptose broth. It was diluted in three replicates (100ml, 10.0ml, 1.oml, 0.1ml, 0.01ml). Incubation process was carried out at 350C for 48hrs. They were shaken and observed for turbidity and gas. Those that exhibited both were recorded as been presumptively positive. The remaining was left for another 48hrs, and those that showed both were also marked as positive. Using a sterile wooden applicator, organisms from the positive tubes were transferred in to fermentation tubes containing Brilliant green lactose bile (BGLB) broth. This was incubated at 35^0C for 48±3hrs for turbidity and gas. Tubes exhibiting both were confirmed positive for total coliforms. The number of positives for each dilution, the MPN index was calculated at 95% confidence interval. The average per dilution was determined and multiplied by the reciprocal of the dilution ratio. It was expressed as colony-forming units per millilitre (cfu/ml) of the sample.

ii. Faecal Streptococci: Membrane filtration was also used for the analysis. 20ml of the sample was suspended. It was then diluted in saline buffer (8.5g of NaCl, 0.3g, and 0.6g of Na_2HPO4 per litre at pH 7.3). And also filtered with a 47 mm diameter sterile. This was gridded with filter membrane of pore size 0.45µm (type GN-6; Gelman Sciences). The filter was transferred to a Petri dish containing m-Enterococcus agar (BBL) and incubated for 24 hrs at 37 ^{0}C. The individual red-pigmented colonies were picked with sterile toothpicks. The red pigment is transferred into micro oven plates containing 0.2ml of Enterococcosel broth (BBL). This was incubated for 24 hrs at 37^0C. The colonies that exhibited growth and form black colour after incubation in enterococcosel were counted. The counting is noted as faecal streptococci using fluorescent light and a magnifying lens.

3. DESIGN CONSIDERATIONS

Three heat processes that include conduction, convection and radiation were considered.

3.1 Mode of Heat Transfer in the Distiller

The conductive heat flow analysis of Fourier's law is adopted by this study and mathematically written as follow [8]:

$$q \propto A\left(\frac{dT}{L}\right) \quad (2)$$

$$q_{cond} = -\lambda A\left(\frac{dT}{L}\right) \quad (3)$$

where:

q_{cond} = heat flow through a body per unit time (watt)

A = surface area of the material in m^2

dT = temperature difference in direction heat flows,^{0}C

L = thickness of body in the direction of flow, m

λ = thermal conductivity of the workpiece (W/mK)

Convection heat flow analysis adopted in this study as stated by Newton's law of cooling and mathematically stated as [8]:

$$q_{conv} = h_{conv}\, A\,(t_s - t_f) \quad (4)$$

Where:

q_{conv} = heat flow through a surface fluid per unit time (w)

h_{conv} = convective heat transfer coefficient in W/m^{2}K

t_s = surface temperature of the material in ^{o}C

t_f = fluid temperature in ^{o}C

The radiation heat flow analysis is based on analysis of solar energy consumed by the water distiller through reflective surfaces and it is given by [8]:

$$q_{rad} = \varepsilon\sigma A\,(T_s^4 - T_{sur}^4) \quad (5)$$

Where:
ε = Emissivity (effects of surface properties and geometry
σ = Stefan-Boltzmann constant for good emitter, 5.67×10^{-8} W/m^{2}K^4
T_s = Surface temperature in ^{o}C
T_{sur} = Surrounding temperature in ^{o}C

3.2 Energy Balance Equation

The design and fabrication of water distiller depends on the assumption of following steady state energy balance principle:

i. The distiller is in a quasi-steady state
ii. The distiller's water temperature at the middle equals sum of one quarter of four edge temperature of the assumed surface container
iii. The energy input equals at energy output
iv. The wind speed of the atmosphere is constant during experimental period

Energy balance equation can be derived as:

Total of Energy in System (E_t) = *Input of Energy into System* (E_i) – *Output of Energy from System* (E_o) (6)

These energies can be transferred into or out of the system by flow of mass through stream processes that bring the various forms of energy with them. Flow work in solar water distiller occurs at areas of a system's boundary across which there is material flowing. Let rate of energy in the water distiller system expressed in terms of kinetic, potential and internal energy expressed as:

$$\frac{dE_t}{dt} = \frac{dE_k}{dt} + \frac{dE_p}{dt} + \frac{U}{dt} \quad (7)$$

$$\frac{dE_k}{dt} = \frac{1}{2}\dot{m}u^2 \quad (8)$$

$$\frac{dE_p}{dt} = \dot{m}gz \quad (8b)$$

$$\frac{U}{dt} = \dot{m}\widehat{U} \quad (8c)$$

The expression of equation (7) in terms of (6) becomes:

$$\frac{dE_k}{dt} + \frac{dE_p}{dt} + \frac{U}{dt} = \dot{m}\left(\frac{1}{2}u^2 + gz + \widehat{U}\right) \quad (9)$$

$$\sum_{input} \dot{m}_j \left(\frac{1}{2}u^2 + gz + \widehat{U}\right) - \sum_{output} \dot{m}_j \left(\frac{1}{2}u^2 + gz + \widehat{U}\right) + \dot{Q} = 0$$

This is the required energy balance equation for the designed solar water distiller. Thus, heat flux is the rate of heat energy transfer through a surface of the material used in the distiller per time ($\dot{Q}$)and unit is Joule/s (J/s) or Watt (W). Heat flux density (q) is the heat flow rate per unit area and measured in terms of W/m^2. The additional heat flow into the system ($\dot{Q}$) is expressed as:

If, $E = \dot{Q}t$ (11)

$q = \dot{Q}/A$ (12)

However, $\sum \dot{Q} = q_1A_1 + q_2A_2 \ldots + q_nA_n$ (13)

Thus, $E = (q_1A_1 + q_2A_2 \ldots + q_nA_n)t$ (14)

Where:
E = Added System energy in J
A = Area of the surface in heat flow direction in m^2
t = Time obtained during operation in s
q = Heat flux density in W/m^2
$\dot{Q}$ = Additional heat flow rate or heat flux in W

The complete heat flux density in the system is expressed generally as in terms of both heat flow entering and leaving must be equal at steady state

$$\sum_{entering} q_1A_1 + q_2A_2 + q_3A_3 + q_4A_4 + q_5A_5 + q_6A_6 + q_7A_7 + q_8A_8 = \sum_{leaving} q_1A_1 + q_2A_2 + q_3A_3 + q_4A_4 + q_5A_5 + q_6A_6 + q_7A_7 + q_8A_8 \quad (15)$$

Where:
The of unit of all heat flux density is W/m^2
q_1 = Radiative heat flux density from reflector to glass surface
q_2 = Radiative heat flux density from sun to glass surface
q_3 = Convective heat flux density from atmosphere through air leakage onto water surface
q_4 = Convective heat flux density from water surface to surface of epoxy resin
q_5 = Conductive heat flux density from epoxy resin to zinc alloy sheet
q_6 = Conductive heat flux density from zinc alloy sheet to fibre glass
q_7 = Conductive heat flux density from fibre glass to MBF plywood
q_8 = Conductive heat flux density from MBF plywood to the ground
$A_1, A_2, \ldots A_9$ = Respective surface area in heat flow direction

The equation (2.14) is used in this study as follow:

$$q_1 = \varepsilon\sigma(T_a^4 - T_s^4) \quad (15b)$$

where:
ε = Emissivity of the stainless steel reflector
σ = *Stefan-Boltzmann constant for good emitter, 5.67 ×10–8 W/m²K⁴*
T_s = Surface temperature of stainless steel reflector in ^{o}C
T_a = Atmospheric temperature in ^{o}C

$$q_2 = \varepsilon\sigma(T_a^4 - T_1^4) \quad (15c)$$

Where:
$\mathcal{E}$ = Emissivity of the glass
T_1 = Surface temperature of glass in ^{o}C
T_a = Atmospheric temperature in ^{o}C

$$q_3 = h_1\,(T_a - T_2) \quad (15d)$$

Where:

$$h_1 = 5.7 + 3.8u \quad (16)$$

This is force convective heat transfer coefficient in W/m^{2}K between atmosphere and air within distiller that depends on wind velocity (u) in m/s [7].
T_2 = surface temperature of the water in ^{o}C

The equation (15) is the required heat flux entering the system while the equation (17) is the required heat flow in the system as a result of entering heat flux:

$$q_4 = h_2\,(T_2 - T_3 \quad (17)$$

Where:
h_2 = convective heat transfer coefficient between water surface and surface of the epoxy resin W/m^{2}K
T_3 = surface temperature of the epoxy resin in ^{o}C

The next flows in equations (2.17b to 2.17e) are conductive heat flux density within the layer of material used in the design.

$$q_5 = \lambda_1\,(\frac{(T_3 - T_4)}{L_1}) \quad (17b)$$

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$$q_6 = \lambda_2 \left(\frac{(T_4 - T_5)}{L_2}\right) \quad (17c)$$

$$q_7 = \lambda_3 \left(\frac{(T_5 - T_6)}{L_3}\right) \quad (17d)$$

$$q_8 = \lambda_4 \left(\frac{(T_6 - T_7)}{L_4}\right) \quad (17e)$$

Where:

T_4, T_5, T_6, T_7 = Surface Temperature in zinc alloy sheet, fiber glass, plywood and ground /ambient temperature in ^{0}C

L_1, L_2, L_3, L_4 = thickness of surface in contact in the direction of flow in m

$\lambda_1, \lambda_2, \lambda_3, \lambda_4$ = thermal conductivity of epoxy resin, zinc alloy sheet, fiber glass and MBF plywood respectively (W/mK).

By considering equation (12) again, in terms of enthalpy, $h = U + PV = U + P/\rho$

Where:

V = Volume in m^3

U = Internal energy in J/kg

P = Pressure in N/m^2

ρ = Density in kg/ m^3

$$\sum_{input} \dot{m}_j \left(\frac{1}{2}u^2 + gz + h\right) - \sum_{output} \dot{m}_j \left(\frac{1}{2}u^2 + gz + h\right) + \dot{Q} = 0 \quad (18)$$

Let entering components denoted by (1) and leaving components denoted (2) in this system, thus

$$\dot{Q} = \dot{m}_2 \left(\frac{1}{2}u_2^2 + gz_2 + h_2\right) - \dot{m}_1 \left(\frac{1}{2}u_1^2 + gz_1 + h_1\right)$$

If, mass flow rate, $\dot{m}_1 = \dot{m}_2 = \dot{m}_j$

$$\dot{Q} = \dot{m}_j \left(\frac{u_2^2 - u_1^2}{2} + g(z_2 - z_1) + h_2 - h_1\right) \quad (19)$$

The energy balance equation on a unit mass basis is obtained by dividing equation (19) with mass flow rate ($\dot{m}$)

$$\frac{\dot{Q}}{\dot{m}_j} = \frac{u_2^2 - u_1^2}{2} + g(z_2 - z_1) + h_2 - h_1$$

$$\dot{q} = \frac{u_2^2 - u_1^2}{2} + g(z_2 - z_1) + h_2 - h_1 \quad (20)$$

Equation (20) is the heat transfer to the fluid per unit mass, J/kg

By substituting for enthalpy,

$$\dot{q} = \frac{u_2^2 - u_1^2}{2} + g(z_2 - z_1) + U_2 + (P/\rho)_2 - U_1 - (P/\rho)_1$$

$$\frac{u_1^2}{2} + g(z_1) + (P/\rho)_1 = \frac{u_2^2}{2} + g(z_2) + (P/\rho)_2 + (U_2 - U_1 - \dot{q}) \quad (21)$$

Where:

$\frac{u^2}{2}$ = Kinetic energy

gz = Potential energy

P/ρ = Flow energy

U = Internal energy

The thermal resistance of contact body is given by:

Conductive resistance in K/W,

$$R_{cond} = L/\lambda \quad (22)$$

Convective resistance in K/W,

$$R_{conv} = 1/hA \quad (22b)$$

Where:

L = thickness layer

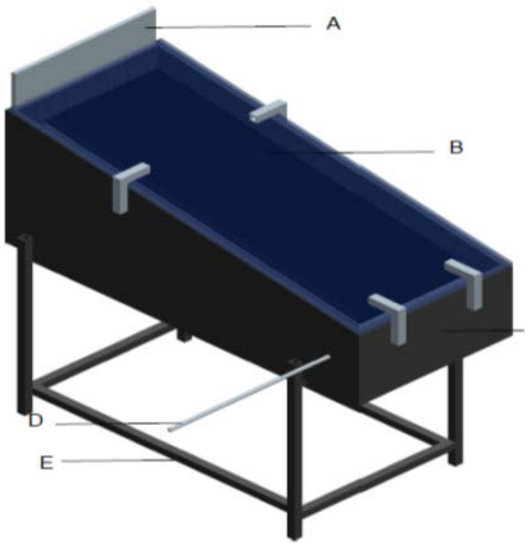
λ = thermal conductivity

A = Area

h = heat transfer coefficient

Heat flux density,

$$q = \Delta T / \Sigma R_t \quad (23)$$



A – Reflective stainless steel
B – Glass
C – Water container
D – Stainless steel pipe
E - Standing

Figure 1: The Solar water distiller

4. RESULTS AND DISCUSSIONS

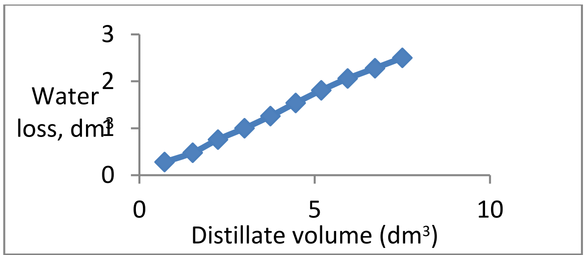


Figure 2: The distillate water volume

The distillate water experiment was conducted for 10 different days in which average time taken was 6.68 hours (400 minutes and 48seconds or 24048 seconds) with constant inlet water volume of 0.001m^3. The distillate water volume obtained was at average of 0.00075 m^3 per day. The distillate water was obtained at 75% efficiency.

The experimental temperature 'room temperature' was at average value of 28.6 ^{o}C. Figure 2 shows that the obtainable accumulated volume of water loss, 2.5 dm^3 was obtained in the experimental original water volume of 10 dm^3. The accumulated or combined volume of distillate water was 7.5 dm^3 at average daily temperature of 28.6 ^{o}C. Figure 2 illustrates the rate of water loss in the produced solar water distiller during experimental procedure. The result shows that distillate water volume of 4 and 1 dm^3 will produce water volume loss of 0.72 and 0.28 dm^3 respectively. Thus, the accumulative loss of water volume in distiller reduces with higher volume of raw water in-take. This means the higher the volume of raw water the lesser the water loss.

TABLE 1: The physico-chemical test result

Parameter	Method	Raw water	Distillate water	NSDWQ 2007
Total Dissolve Solid (mg/L)	Calculation	84.4	70.4	500
Conductivity (µS/cm)	Electrometric	126	105	1000
Dissolved Oxygen (mg/L)	Electrometric	6.40	6.68	5.0
pH	Electrometric	7.20	7.00	6.5 – 8.5
Turbidity (NTU)	Electrometric	6.02	1.51	5
Total Suspended Solid (mg/L)	Colorimetric	11.0	3.00	500
Total Hardness (mg/L)	Titrimetric	41.8	35.2	150
Sulphate (mg/L)	Electrometric	11	4.00	100
Nitrate (mg/L)	Colorimetric	5.89	2.11	50
Phosphate (mg/L)	Electrometric	2.13	1.05	
Sodium (mg/L)	Flame Photometric	4.0	2.0	200
Potassium (mg/L)	Flame Photometric	5.0	1.00	-

Table 1 shows that only parameter called turbidity were at above requirement of Nigerian Standard for Drinking Water Quality NSDWQ (2007) rating. The turbidity of raw water was 6.02 while the treated water was 1.51 and maximum allowable was 5.0. The total dissolves solid TDS of raw and distillate water was 84.4 and 70.4 mg/l in which 500 of TDS mg/l is the maximum tolerable under NSDWQ rating condition. The pH of both water were at 7.20 and 7.00 and these are within pH condition of 6.5 to 8.5 under NSDWQ rating. The water satisfied the conductivity of 1000 µS/cm under NSDWQ condition. The total hardness required was 150 mg/l by NSDWQ and the distilled water satisfied condition as in Table 1. Total suspended solids (TSS) of 500 mg/l were satisfied by the water. However, it was understood that the raw water was purified using solar water distiller machine.

The radiative heat source obtained from steel reflector and sun were 10.88, 56.33 W/m^2 respectively and the convective heat source from air to water surface was 269.99 W/m^2. Thus, heat energy required for powering the solar water distiller was 337.2 W/m^2. The quantity of heat supplied increases due to three sources of heat applied. This was the quantity of energy per unit time and area required for distilling the water content in the basin. The average required room temperature was for machine was 28.6 ^oC “room temperature at water surface during experiment”. The present study uses combined insulator materials for conserving energy stored in the basin. However, developed water distiller by this work will store more energy in comparing to distiller machine produce by [9]. The heat loss was minimised by lagging the machine using epoxy resin, fibre glass and MBF plywood. It was also understood from the design that only 0.1924 W/m^2 was lost in the direction of flow while 337 W/m^2 was conserved. Thus, as a result 99.94% of the heat was conserved using the lagging material. The lower the temperature of the cooling agent (water in this case), the faster the rate of forming the condensate and the larger the volume of distilled water produces. To achieve a good solar radiation and source of energy for the distiller machine, however the machine requires operating only at sunrise hours during day. The radiative heat energy obtained from reflective surface and sun was 67.18 W/m^2. Thus machine can also operate with absence of solar energy but there must be presence of dry wind. The distiller machine was designed based on minimum dry wind speed of 5.75m/s recommended for powering this kind of machine.

The experiment was conducted for 10 different days with average experimental time of 6.68 hours (400 minutes and 48seconds or 24048 seconds) with average raw water volume of 0.001m^3 (1 litre). The average distillate water obtained was average of 0.00075 m^3 per day. The efficiency of the produced machine was at 75% based on distillate volume produced at room average room temperature of 28.6 ^oC. However, this present study is experimental analysis with performance evaluation. In contrast with Aybar [10] who only modelled and simulated required parameter of solar water distiller can only have estimated results.

The design capacity of the machine was to produce the distillate water volume of 28 litres. In contrast, this study also presents laboratory test result of the distillate. It was understood the produced distillate water satisfied drinkable water condition at allowable requirement of Nigerian Standard for Drinking Water Quality, NSDWQ (2007) rating [16]. The study of distillate conducted by the authors such as [9-14] do not considered laboratory test of distillate water. This is only condition that allows distillate water to be drinkable as quality water.

3. CONCLUSIONS

The water distiller was designed and fabricated using locally sourced materials. This serves as contribution to indigenous technology towards Nigerian economy. The study concludes as:

i. The distilled water helps in removing poisonous substances from drinkable water. It was also understood that continuous drinking of distilled water detoxifies the human body system.

ii. The volume of distilled water produced per hour can be increased tremendously by increasing the volume of the basin, increasing the surface area of the glass surface at which water condenses.

iii. The radiative heat source obtained from steel reflector and sun were 10.88, 56.33 W/m2 respectively and the convective heat source from air to water surface was 269.99 W/m^2. Thus, heat energy required for powering the solar water distiller was 337.2 W/m^2. The quantity of heat supplied increases due to three sources of heat applied. This was the quantity of energy per unit time and area required for distilling the water content in the basin. The average room temperature required for operating the machine was 28.6 ^{0}C.

iv. The machine can produce average daily capacity of 28 litres as distillate water volume within 6.68 hours. Thus, the machine has design capacity of producing 4.2 litres per hour at minimum wind speed of 5.75m/s.

The produced machine has 75% efficiency with quality drinkable water that satisfied condition of Nigerian Standard for Drinking Water Quality NSDWQ (2007) rating.

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