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Contribution of Night Time Yield to The Overall Water Production Capacity of A Simple Basin Solar Still Under Makurdi Climate

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***Abstract:* -** The yield of the simple solar still is relatively very low and several research efforts are going on to improve it. In this work, 2 solar stills of aperture 0.003 m^2 inclined at 10^0 were designed and constructed along with a rock bed thermal storage unit. One, still 1, was linked to the storage unit. Hourly ambient and still water temperatures, incident insolation and volumes of water distilled were measured daily from 10:00 to 16:00 hours daily for 6 days in May 2011. The water in still 1 was drained daily at 16:00 hour and water from the storage unit introduced into it. The temperatures of the water in the storage unit were measured at 10:00 and 16:00 hours daily. The volumes of the water distilled during the night by the stills were measured daily in the morning. The efficiencies of the stills were computed. Stills 1 and 2 distilled maximum daily daytime mean volumes of 78.2 and 57.3 cm^3 respectively on the 6th day. The respective corresponding night time yields were 181 and 242 cm^3. The maximum mean daily distillation efficiencies were respectively 31.1 and 25.1%. The total night time yield was about 43% of the total. The cost of distilled water was computed to be about ₦52.50/litre/m^2. Hence, solar distillation remains a viable option for provision of potable in Makurdi metropolis and its environs.

***Keywords:* -** *Cost of distilled water, Night time yield, Potable water, Solar radiation, Solar still, Thermal storage,*

I. INTRODUCTION

In developing countries, lack of safe and reliable drinking water constitutes a major problem. Makurdi Metropolis in Benue State, Nigeria faces serious water supply issues that are comparable to those found in many parts of the developing world. There are some parts of the town where pipe borne water is not in existence. Water vendors are common place within the town thereby diverting human resource that could positively impact the economy to carrying out the duties of an ineffective/nonexistent water supply system. Some of these vendors sell water directly obtained from the River Benue which flows by the town while the more reasonable or 'hardworking' ones push their water carts for long distances in order to obtain pipe borne water. For those that have access to the pipe borne water, the quality does not meet the standards acceptable for drinking even by physical observation. Many packaged water firms have sprung up and though a package sells for between ₦5.00 and ₦10.00 depending on the volume of business, time of the year, type of water or simply the location, the general consensus is that the quality is generally very low to the point that there is a call for an act of parliament to counter this obvious health hazard [1].

On both sides of the River Benue, there are unorganized communities that have limited infrastructural development, including water supply. Several hundreds of people that live along the river bank in *North Bank*, *Wurukum*, *Wadata* and along *Gboko Road* for which safe drinking water can only be acquired by purchasing and probably hauling portable water from elsewhere. In these locations municipal water supplies do not meet drinking water standards if and when available. The unorganized nature of the water supply network and the quality of the 'treated' water leaves so much to be desired.

Solar distillation could offer a real and effective solution for families in these locations to clean their water supplies on-site. Solar still has been proven to be the best solution to solve water problem in remote arid areas. Purifying water through distillation is a simple yet effective means of providing drinking water in a reliable and cost-effective manner. Solar stills effectively eliminate all water borne pathogens, salts, and heavy metals, and produce ultrapure water that is proven to be superior to most commercial bottled water sources [2]. This device is however not popular because of its low productivity. Over the last few years, there have been efforts to develop simple solar distillation technologies that could be applied in these locations to meet drinking water needs [3-5].

Various efforts have been embarked upon to improve the production rate of this device. The methods that have been attempted to increase the productivity ranges from decrease the volumetric heat capacity of the basin, attachment of additional sub-systems and other major departures from the simple configuration. [6] designed, constructed and tested a prototype solar still having a vertical flat absorber of 0.817 m^2 outdoors. It was constructed using locally available materials as well as local technical assistance and had a total area of glass cover of 0.8769 m^2. The absorbing surface consisted of a set of a parallel black porous cloths wick plate located in an enclosure. The still was formed by a vertical absorbing surface, two transparent glass covers and a vertical back wall made of galvanized iron, darkened with black color internally and covered externally with 5 cm of glass wool as insulator.

Two solar stills (single basin and double decker) both having the same basin area (0.45m^2) were fabricated and tested by [7]. For the double-decker basin solar still, the upper glass cover and the first basin were tilted at 12^0 with respect to the horizontal, while for the single basin solar still, the glass cover was tilted at 36^0 with respect to the horizontal. Two types of measurements were performed; one with the still-sides insulated and the other without. The daily average still production for the double-basin still is around 40% higher than the production of the single-basin still. [8] carried out an experimental investigation to study the effect of coupling a flat plate solar collector on the productivity of solar stills. Other different parameters (i.e. water depth, direction of still, solar radiation) to enhance the productivity were also studied. Single slope solar still with mirrors fixed to its interior sides was coupled with a flat plate collector. It was found that coupling of a solar collector with a still increased the productivity by 36%. Also they reported that increase of water depth decreased the productivity, while the still productivity is found to be proportional to the solar radiation intensity.

A simple single basin solar still with optimum inclination of glass cover of 33.3^o for both summer and winter was designed by [9]. The average daily output of solar still based on data of 8 days in July 2004 was found to be 1.7 liters/day for basin area of 0.54 m^2 and the efficiency of the still was calculated as 30.65% with a maximum hourly output of 0.339 liters/hr at 1300 hrs. The drinking water produced had total dissolved solids (TDS), conductivity and pH of 84 ppm, 31 m S/cm and 5.74 after desalination with the values for TDS and pH agreeing with the WHO guidelines for drinking water quality. [10] fabricated and tested a stepped solar still and an effluent settling tank for desalinating the textile effluent. The effluent is purified in an effluent settling tank. For better performance, the stepped solar still consisted of 50 trays with two different depths. The first 25 trays with 10 mm height and the next 25 trays with 5 mm height were used. Fin, sponge, pebble and combination of the above are used for enhancing the productivity of the stepped solar still. A maximum increase in productivity of 98% occurred in stepped solar still when fin, sponge and pebbles are used in this basin.

[11] designed and fabricated a simple transportable hemispherical solar still and was evaluated its performance under outdoors of Dhahran climatic conditions. He reported that the daily distilled water output from the still ranged from 2.8 to 5.7 l/m^2 day with the daily average efficiency of the still reaching 33% and the corresponding conversion ratio near 50%. He also reported that the average efficiency of the still decreased by 8% when the saline water depth increased by 50%. An experimental investigation on the effect of internal and external reflectors inclined at angles 0° (vertical), 10°, 20° and 30° on the output of simple-basin solar stills in summer, autumn and winter was presented by [12]. The increase in the productivity of the still with reflector(s) compared to the still with no reflectors (increase ratio) is averaged at 19.9% and 34.5%, 34.4%, 34.8% and 24.7% for still with internal reflector only, still with internal and an inclined external reflector tilted at 0°, 10°, 20°, and 30° respectively. They also projected a comparable yearly productivity for external reflector angle ranging from vertical to 20°.

[13] presented a theoretical analysis of a tilted wick solar still with an external flat plate reflector. He found the optimum inclination angle of the still as well as the optimum inclination angle of the reflector for each month at 30°N latitude. He reported that the daily amount of distillate of the still can be increased by adjusting the inclination of both the still and reflector for any season, thus producing an average of about 21% more than a conventional tilted wick still throughout the year. A theoretical analysis of a basin type solar still with internal and external reflectors was presented by [14]. The external reflector is a flat plate that extends from the back wall of the still, and can presumably be inclined forwards or backwards according to the month. He found the optimum external reflector inclination for each month for a still with a glass cover inclination of 10–50. The increase in the average daily amount of distillate throughout the year of a still with inclined external reflector with optimum inclination in addition to an internal reflector, compared to a conventional basin type still was predicted to be 29%, 43% or 67% when the glass cover inclination is 10, 30 or 50 and the length of external

reflector is half the still's length.

[15] theoretically studied a basin solar still with internal and external reflectors. A theoretical analysis of a one step azimuth tracking tilted-wick solar still with a vertical flat plate reflector was presented by [16]. They found that the increase in the daily amount of distillate of a tilted-wick still would average about 41% for four days, and can be achieved by the simple modification of using a flat plate reflector, setting the still at proper tilt angle according to seasons and rotating the still just once a day. Based on a theoretical analysis of a tilted-wick solar still with an inclined flat plate external reflector on a winter solstice day at 30^0 N latitude and the daily amount of distillate [17] predicted for a still with an inclined reflector was about 15% or 27% greater than that with a vertical reflector when the reflector's length is a half of or the same as the still's length.

[18] considered the integration of energy utilization system and seawater desalination as an innovative technology enabling efficient simultaneous use of middle or low temperature thermal energy and supply freshwater. Three feasible approaches were considered and the findings indicate that combining seawater desalination with industrial processes is a feasible and promising way to solve the problems of the lack of freshwater and low efficient use of low temperature thermal energy in coastland areas. A new approach to improve the efficiency of a solar still by introducing a medium to provide large evaporation surface and utilize the latent heat of condensation was presented by [19]. They modified the conventional still by integrating an energy storage medium in the form of a jute cloth which is kept vertically in the middle of basin saline water and also attached with the rear wall of the still. It was found that the cumulative still yield in the regenerative still with jute cloth increases approximately by 20% and efficiency increases by 8% with low cost for this modification as the jute cloth is very cheap and easily available.

[20] produced a portable solar still and integrated a solar collector, a wall covered with black wool, and water sprinkling system to increase evaporation rate, and a thermoelectric cooling device to enhance water condensation due to the small size and low productivity in order to enhance and improve the performance. The performance of the still was tested under the climate condition of Semnan (35° 33′ N, 53° 23′ E), Iran. The experiments were carried out in nine winter days and the results were measured in the same manner for each day. The results show that ambient temperature and solar radiation have direct effect on still performance but water productivity decreases when the wind speed increases. By comparing the results for summer and winter, they concluded that the efficiency in summer is higher than in winter. Their results also show that the cost per litre of distilled water is comparable with that for other types of solar stills. The enhancement of solar still performance using a reciprocating spray feeding system was investigated by [21] while [22] carried out a study using a hybrid photovoltaic thermal double slope active solar still. [23] presented a study on a still with modification for enhanced condensation while [24] investigated a tilted wick still with an external flat plate reflector considering optimum still and reflector inclination.

The enhancement of the productivity of the solar desalination system, in a certain location, could be attained by a proper modification in the system design. However, the increase in the system productivity with high system cost may increase also the average annual cost of the distillate. [25] undertook a cost analysis of 17 design configurations of solar desalination units in order to evaluate the benefit of modification from the economical point of view using a simplified model. Their results show that, the best average and maximum daily productivity are obtained from solar stills of single-slope and pyramid-shaped. The higher average annual productivity for a solar still is about 1533l/m^2 using pyramid-shaped while the lower average annual productivity is about of 250l/m^2 using modified solar stills with sun tracking. The lowest cost of distilled water obtained from the pyramid-shaped solar still was estimated as 0.0135$/l while highest cost from the modified solar stills with sun tracking is estimated as 0.23$/l.

The Energy Systems Research Group of the Department of Mechanical Engineering at University of Agriculture, Makurdi has been working to further develop the technology and demonstrate its practicality as an innovative, effective, simple, and decentralized on-site water treatment system that can provide safe water in a cost effective and reliable manner. This effort began in earnest a few years ago and is still ongoing. This is because the abundant solar distillation feedstock (water) provided by the River Benue and the immense solar radiation that Makurdi is reputed for almost all year round can be harnessed to positively impact the availability of drinking water. Makurdi on latitude 7.7^0N and longitude 8.73^0E receives an average insolation of 35430 kJ/m^2/day from an average 6.13 hours of sunshine with the highest and lowest in August and December respectively [26].

Specific work has been done by [27] in investigating the effect of coupling a pre-heat tank and a reflector to a simple basin still at Makurdi. Also, [28] investigated the effect of a pebble thermal storage on the performance of a basin still. These and other unpublished works are aimed at making this simple technology to impact on provision of save drinking water in Makurdi Metropolis and its environs. The present study in which the contribution of night time distillation is investigated is also part of this effort. It is a deliberate attempt to incorporate the distillation process that definitely occurs during the night as a result of the temperature change imposed on the water in the still during the day time. The usually cooler ambient temperatures at night should play a vital role in achieving a reasonable yield.

From the foregoing, it is obvious that the relative advantages of the simple basin solar still are being investigated in order to make it relevant in the potable water production mix especially in developing regions of the world. This becomes very appropriate because in most of these places, the political will to address the drinking water needs of the majority of the citizenry does not simply exist. This technology can however be developed to confer some level of control to the end user as far as the issue is concerned.

II. MATERIALS AND METHODS

The construction of the solar still was done using a procedure similar to those used by [28]. The design specifications are given in Table 1. Fig. 1 shows the orthographic representation of the solar still. The thermal storage unit has the following design specifications shown in the Table 2. Fig. 2 shows a sectional view of the storage medium.

Table 2: Design Specifications for the Solar Stills.

Parameters	Dimensions
Width of glass cover	607 mm
Length of glass cover	707 mm
Area of glass cover	429149 mm^2
Length of tank	600 mm
Width of tank	501 mm
Height of tank	200 mm
Volume of tank	60120000 mm^3
Height of distillate collector	11.5 mm
Length of distillate collector	4140 mm
Width of distillate collector	10 mm
Thickness of wood	1.875 mm & 1.25 mm (¾ & ½ in)
Insulation thickness for the sides	10 mm
Insulation for the base	5 mm
Diameter for PVC pipe	2.5 mm (1 in)
Angle of inclination	10^0
Diameter of water drainage	2.5 mm (1 in)

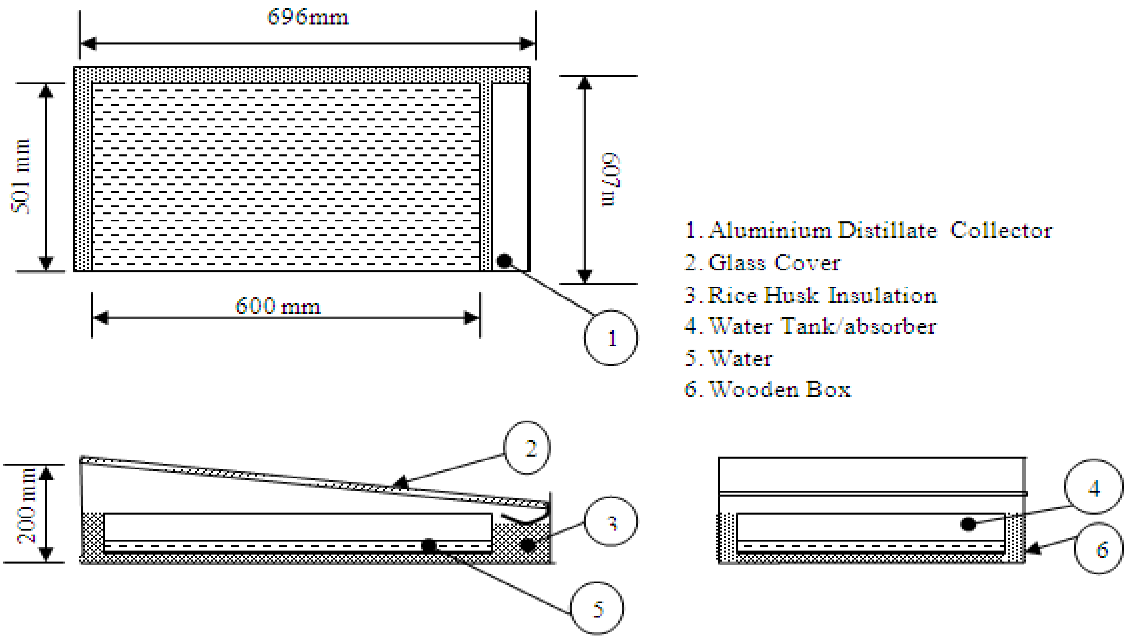

Fig.1: orthographic representation of the solar still

Table 3: Design Specifications for the Storage Medium

Parameters	Dimensions
Length of glass cover	703.5 mm
Width of glass cover	703.5 mm
Area of glass cover	494912.25 mm^2
Length of metal tank	355 mm
Width of metal tank	355 mm
Height of metal tank	150 mm
Volume of metal tank	18903750 mm^3
Width of wooden box	705 mm
Height of wooden box	39 mm
Volume of wooden box	27495 mm^2
Thickness of pebbles gap (base, sides and top)	10 cm

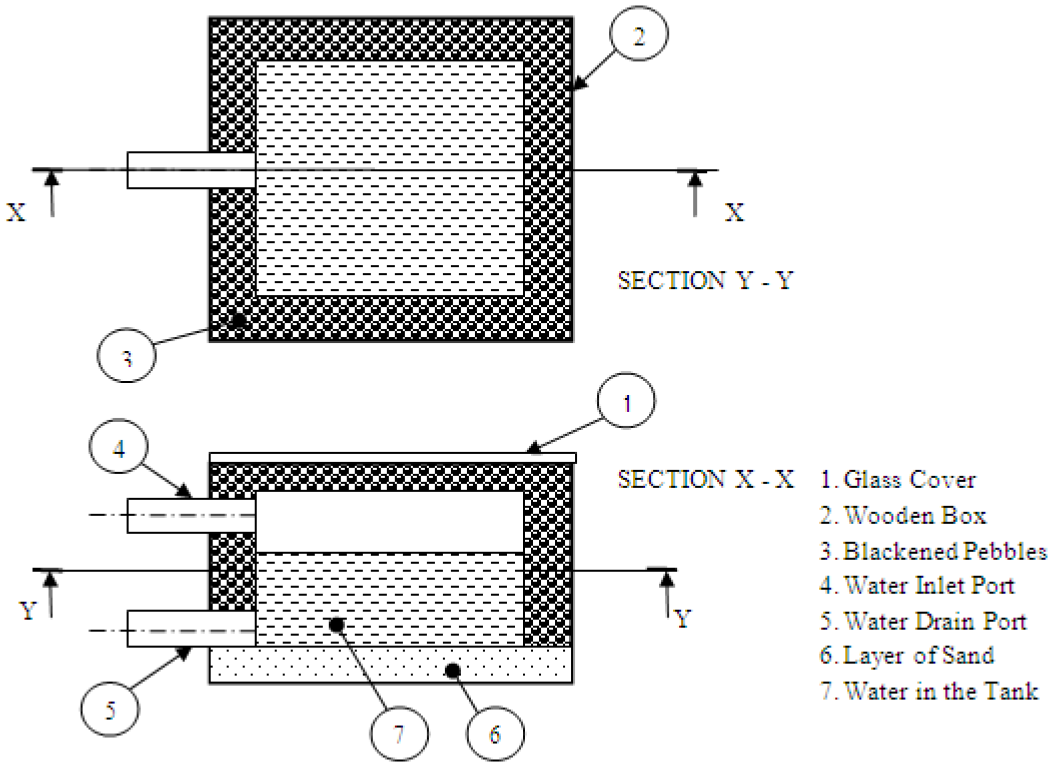

Fig.2: sections through the rock bed storage unit

The set up for the study was at the Engineering Complex at University of Agriculture, Makurdi. One of the solar still (still 1) and the solar storage medium were joined using a flexible hose linking the outlet tap from below the tank of the storage medium to the inlet pipe of the solar still while the other one (still 2) was mounted independently beside the first one. A flexible hose was used so that slight changes in elevation or orientation of the individual components (i.e. the still or the storage medium) could be made without affecting the position of the other component. The solar still was mounted above ground level. The pebbles storage medium was mounted on a higher level than the still so that water was able to flow freely as a result of the hydrostatic pressure head set up between the components by virtue of difference in the elevation when the tap is opened. A plastic container was place below the discharge pipe of the stills to collect the liquid distillate from them. Plate 1 shows the storage medium and the two solar stills.

Water was first of all poured into the solar storage medium through the inlet pipe after which water was added into the stills to an appropriate depth through the still inlet pipe and the pipe was closed. This was done in the morning at about 09.00 hours daily for the period of study. The water in the solar still was then left to distill using direct solar radiation from in the morning, while the water in the solar storage medium was left to absorb heat from the surrounded black coated pebbles across the metal tank walls.

The temperatures of the water fed into the storage medium and the stills as well as the temperature of the water in the storage medium in the evening (after 16.00 hours) were recorded daily. The hourly ambient and still water temperatures as well as the available insolation were also recorded from 10.00 -16.00 hours daily during the period of study. The temperatures were measured using mercury in glass thermometers calibrated for accuracy with a thermocouple. The corresponding volumes of water distilled and collected were measured using a measuring cylinder and recorded. The available insolation was measured with a solarimeter (sun meter).

The water remaining in the still 1 was drained off after recording the final set of readings for each day. Water from the storage medium was the released into the still 1 through the flexible hose such that the distillation could occur during the night by making use of the stored thermal energy from the sun. In the morning the distillate volume was noted for both stills 1 and 2, and the water in both stills made the same before the commencement of another round of operation. The water used for the study was source around the University. The solar still efficiency, total output as well as other associated ratios were computed using (1) and (2):

Solar still production is given as

$$M_e = \frac{Q_e}{L} \quad (1)$$

The solar still efficiency is given as

$$\eta = \frac{Q_e}{Q_t} \quad (2)$$

$M_e =$ daily distilled water output (kg/m^2 day), $Q_e =$ quantity energy utilized in vaporizing water in the still (J/m^2 day), $L =$ latent heat of vaporization of water (J/kg), $\eta =$ Solar still efficiency and $Q_t =$ quantity of incident solar energy on the still (J/m^2/day) [29].

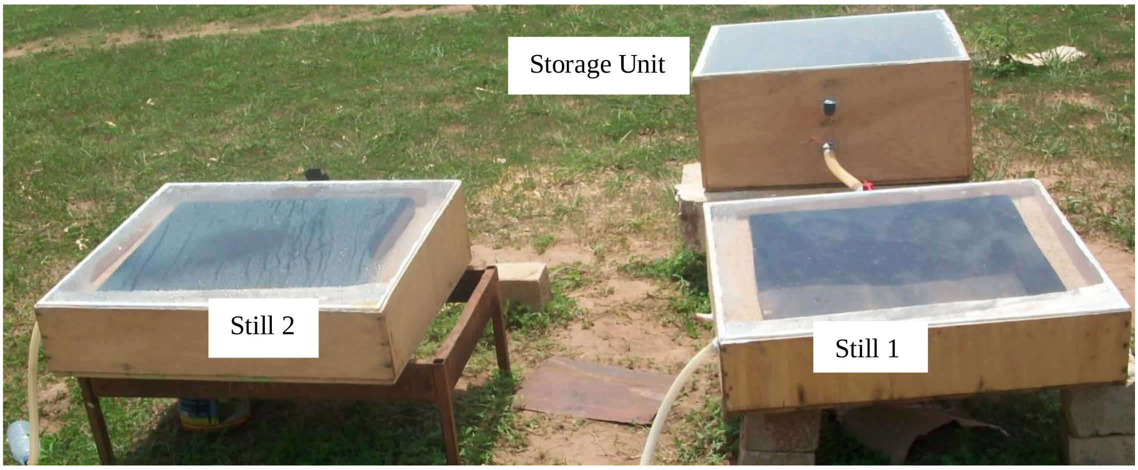

Plate 1: picture of the components of the set up for the study

III. RESULTS

Table 3 shows the temperatures associated with the operation of the storage medium used for this study and the measured volumes of water produced during the night time operation of the stills. Table 5 shows the mean daily measured and computed parameters for the two stills for day time operation. Table 6 shows the corresponding mean hourly values of the parameters.

Table 4: Storage Medium Temperatures and Volume of Water produced during the Night by the Stills

Day	T_1 (^{0}C)	T_2 (^{0}C)	ΔT (^{0}C)	V_1 (cm^3)	V_2 (cm^3)
1	30.0	38.0	8.0	68.0	150.0
2	32.0	40.0	8.0	190.0	302.0
3	30.0	38.0	8.0	160.0	175.0
4	31.0	45.0	14.0	251.0	175.0
5	31.0	38.0	7.0	157.0	300.0
6	30.0	45.0	15.0	260.0	350.0
Mean	**30.8**	**40.7**	**10.0**	**181.0**	**242.0**

Table 5: Daily Mean Values of Measured and Computed Still Parameters

Day	T_a (^0C)	T_{s1} (^0C)	T_{s2} (^0C)	V_{s1} (cm^3)	V_{s2} (cm^3)	$\square_{s1}$	$\square_{s1}$	I(W/m^2)
1	32.7	42.7	42.7	20.2	20.3	0.147	0.139	133.2
2	35.7	43.5	43.5	66.3	49.8	0.262	0.203	148.5
3	31.3	40.0	40.0	31.2	27.0	0.147	0.106	132.8
4	34.5	42.8	42.8	58.8	43.8	0.236	0.176	154.0
5	36.7	45.7	45.7	56.5	48.8	0.311	0.251	122.2
6	35.7	46.0	46.0	78.2	57.3	0.299	0.216	169.7

Table 6: Hourly Mean Values of Measured and Computed Still Parameters

Time	T_a (^0C)	T_{s1} (^0C)	T_{s2} (^0C)	V_{s1} (cm^3)	V_{s2} (cm^3)	$\square_{s1}$	$\square_{s1}$	I(W/m^2)
10-11	33.3	40.3	40.3	11.5	12.3	0.054	0.062	146.3
11-12	34.5	42.6	42.6	34.3	22.6	0.186	0.124	114.3
12-1	36.0	44.2	44.2	55.5	36.2	0.273	0.187	121.5
1-2	34.5	44.5	44.5	69.7	53.8	0.337	0.245	135.8
2-3	34.7	44.8	44.8	77.8	66.8	0.263	0.229	174.8
3-4	33.5	44.2	44.2	62.3	55.3	0.238	0.219	171.8

Figs. 3 to 5 show line graphs of the volume of water produced by the stills for night time operation, the daily mean volumes of water produced during the daytime and the corresponding hourly values. Figs. 6 and 7 show the relationship between the hourly mean efficiencies of the stills to the corresponding mean volumes of water produced. Figs. 8 and 9 show the corresponding relationships based on the hourly mean efficiencies and volumes. Figs. 10 and 11 show the relationships between the daily mean ambient temperature during the period of the study and the volume of water produced by the stills. Figs. 12 and 13 show the relationship of the mean available insolation to the volume of water produced.

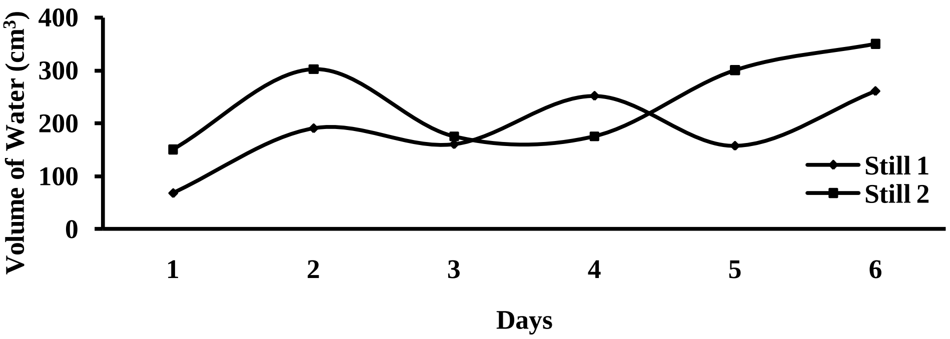

Fig. 3: volume of water produced by the water stills during the night

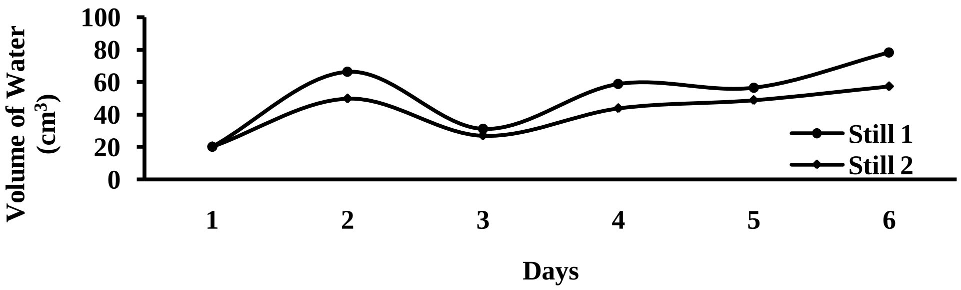

Fig. 4: daily mean volumes of water produced by the stills

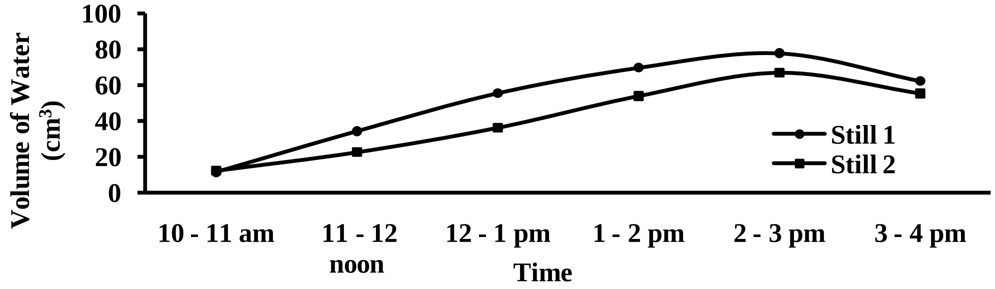

Fig. 5: hourly mean volumes of water produced by the stills

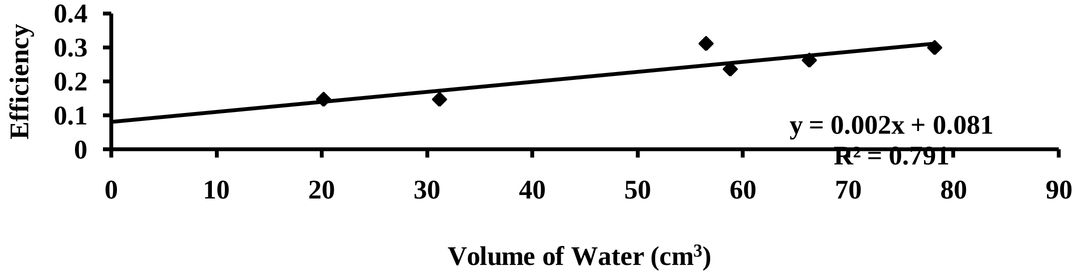

Fig. 6: daily mean efficiencies against volumes of water produced by still 1

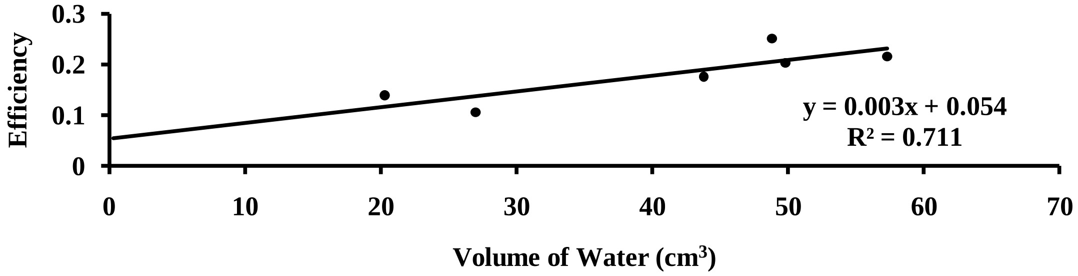

Fig. 7: daily mean efficiencies against volumes of water produced by still 2

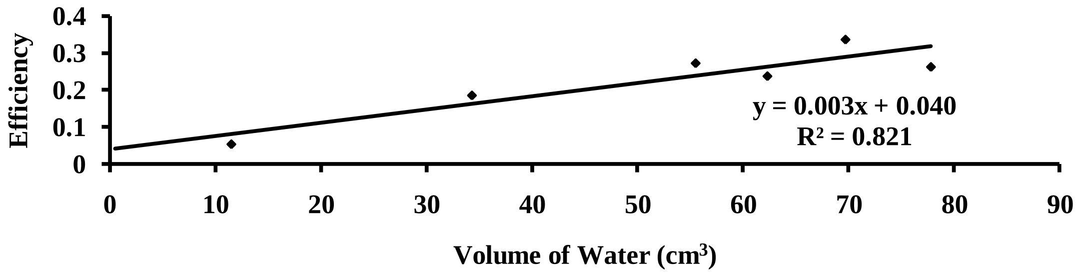

Fig. 8: hourly mean efficiencies against volumes of water produced by still 1

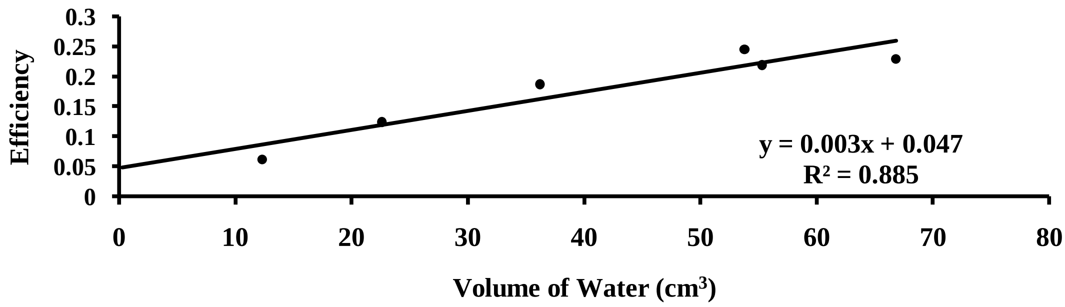

Fig. 9: hourly mean efficiencies against volumes of water produced by still

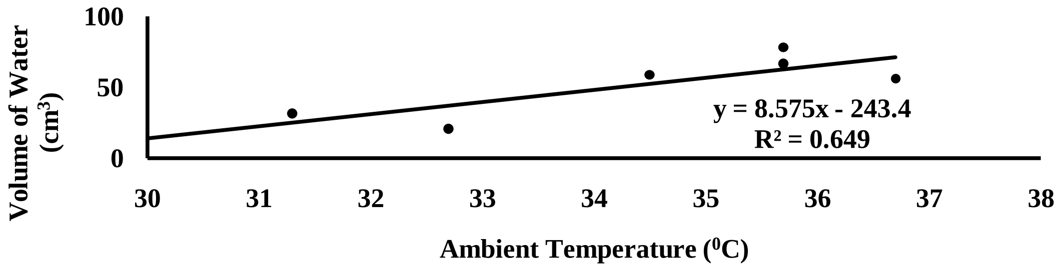

Fig. 10: variation of daily mean ambient temperatures with volume of water for still 1

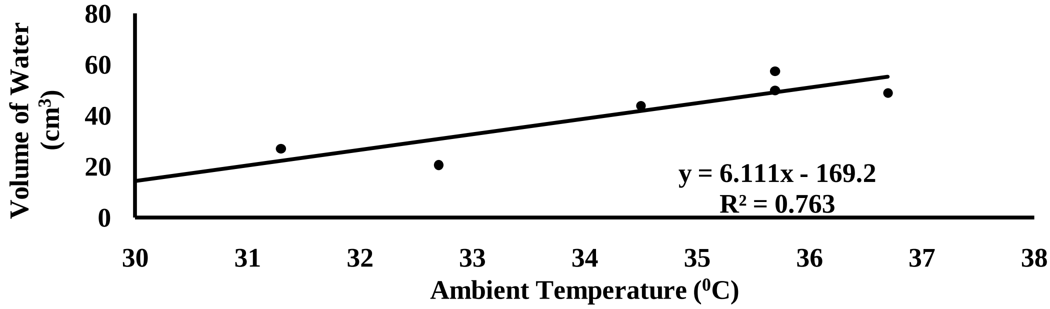

Fig. 11: variation of daily mean ambient temperatures with volume of water for still 2

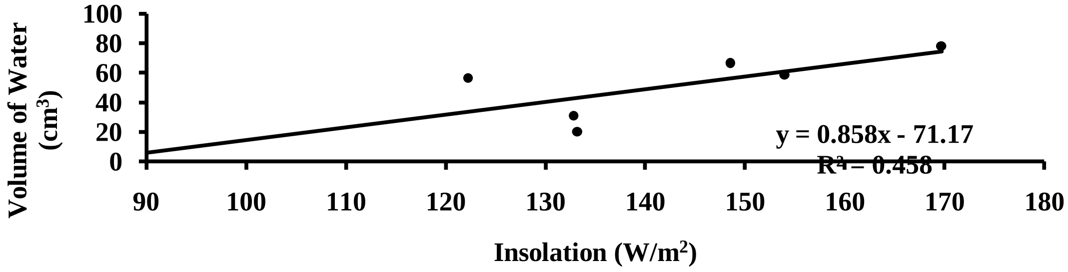

Fig. 12: daily means of available insolation against volume of water for still 1

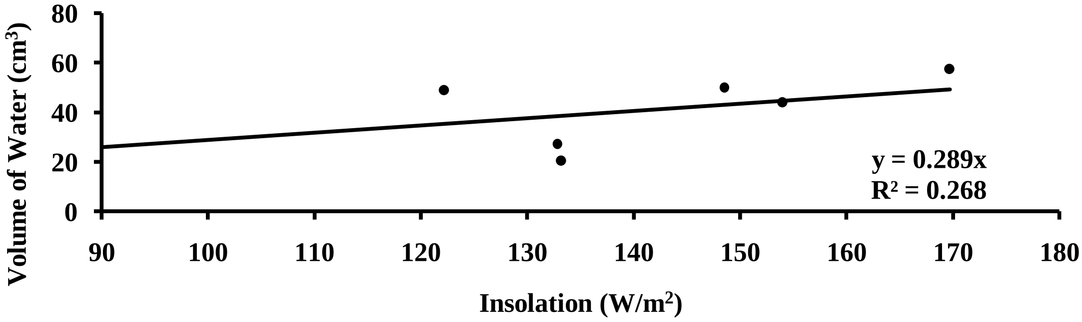

Fig. 13: Daily Means of Available Insolation against Volume of Water for Still 2

IV. DISCUSSION

Fig. 3 shows the volumes of water produced by the solar stills during the night for the period of the study. Still 1 was emptied in the evening daily and water from the thermal storage unit introduced into it while the water in still 2 was not changed. The figure shows that except on the fourth day still 2 had a better yield than still 2 which seems to contradict the claim of [28] that by using a separate thermal storage unit to supply water at a reasonably high temperature to a still in the evening it is possible to increase the cumulative yield of a simple basin still. Their assertion was based on the fact that the driving force for still operation depends largely on the difference in temperature between the still glass cover surface and the water. They maintained that the usually colder night temperatures will likely lower the cover surface temperature below what was obtained in the day time thereby imposing a higher difference in temperature for the purpose of producing water. However, it appears on the other hand than their assertion could be valid as justified by the yield of still 1 on the fourth day. This is further strengthened by the fact that the mean final temperature of the water from the storage medium throughout the period was 40.7 ^{0}C as shown in Table 4. This was below the daily mean final temperatures for the normal day time operation of the two stills for all the days which ranged between 42 to 46 ^{0}C except on the third day (40 ^{0}C) as shown in Table 5. Also, it was below the mean hourly final temperature of 44.2 ^{0}C as shown in Table 6. The discrepancy could have resulted from an error in the design of the storage medium with respect to some unchecked heat losses or improper selection and/or proportion of the storage medium material which could be attended to in further work. This does not however invalidate the idea of using night time operation to supplement day time yield as a means of increasing the cumulative daily water yield of a simple basin solar still.

The mean temperature difference between the initial and final temperatures of the water in the storage medium was 10 ^{0}C as shown in Table 4. This translates to stored heat energy in the region of 42,000 kJ/kg of water. The quantity of energy stored could also have been affected drastically by the weather fluctuations during the period of the study with the change in temperature of the water reaching 14 ^{0}C and 15 ^{0}C only on the fourth and sixth day respectively. Only the initial and final temperatures of the water were recorded as the transfer of water from the medium into still 1 was done at the end of each day's work. The quantity of heat stored could have been more substantial if the period of the study was longer in terms of the number of hours per day. However, this advantage can be better harnessed during the period of the year with clearer sky conditions.

The mean volumes of water produced during the night operation as shown in Table 1 were 181 cm^3 and 242 cm^3 for stills 1 and 2 respectively. These translate to about 60,333.33 cm^3 and 80,666.67 cm^3 of water per square metre of still aperture. The total volume of water produced by the stills for night operation for the period of the study were 1086 cm^3 and 1452 cm^3 respectively for still 1 and still 2. These translate to 362,000 cm^3 and 484,000 cm^3 per square metre of still aperture. Hence, the potential estimate of the total water that can be produced for night operation by the two stills for the period of the study is 846,000 cm^3 which shows the existence of the capacity to supplement day time still operation in generating drinking water for residents in some locations like *North Bank*, *Wurukum* and *Wadata* in Makurdi Metropolis. An array of several simple basin stills carefully laid out can therefore go a long way in producing portable water very close to or at the point of use.

Figs. 4 and 5 show the daily and hourly means of volumes of water produced by the two stills for day time operation for the period of the study. For both categorizations of the data, still 1 produced a higher volume of water on all the days except on the first day. It produced the largest volume of water of 78.2 cm^3 on the sixth day against 57.3 cm^3 produced by still 2. This translates to 26,066.7 cm^3 and 19,100 cm^3 per square metre of still aperture. This difference is unexpected since the dimensions, orientations and angles of tilt of the stills were the same. It could have been as a result of some undetected fault in the assembly of still 2. However, the respective yields on the sixth day indicate that the available insolation affects the quantity of water produced by a solar still because the highest mean insolation for the study period of 169.7 W/m^2 was recorded that day. This value is much lower than the average value for Makurdi location [26]. This is indicated by the highest total daily volume of 469 cm^3 of water produced. Figs. 12 and 13 however, show that there was significant fluctuation in weather clearness during the period of the study. The mean insolation recorded on the fifth day was the lowest though the volume of water produced was not the least. Hence, other factors like relative humidity could have possibly played a role by affecting the ambient temperature but were not taken into account in this study. Further work may be carried out in which the effect of relative humidity in particular may be studied since humidity is exceptionally high in Makurdi for most part of a year.

Expectedly considering at the hourly mean values presented in Table 6 and plotted in figure 5, the stills performed better as from 12.00 noon with the tempo reaching a peak between 2.00 – 3.00 pm. The decline beyond this stage is not drastic and could have increased the total daily yield if the daily study period was extended to about 6.00 pm. For this study however, the yield for the remaining two hours of daylight is included in the volume obtained for night operation of the stills. The maximum hourly volumes produced for the two stills in this study as shown in Table 3 were 77.8 cm^3 and 66.8 cm^3 for stills 1 and 2 respectively. The corresponding minimum hourly mean values were expectedly low (11.5 and 12.3 cm^3 respectively). This was because the stills were just commencing operation after the night time yields have been harvested. It can be noted here that still 2 produced a little more water than still 1 during the first hour of operation. Coupled with the fact already mentioned about the superior night operation of still 2, it appears that it was able to perform better when the insolation was little or unavailable (in the night). This could mean that still 2 had better insulation and/or was better sealed. Both stills were however able to maintain an average daily and hourly difference in temperature between feed water and the water in the stills of 13.4 ^{0}C throughout the period of the study.

The total volumes of water produced by the still 1 for the study period was 1927 cm^3 while that for still

2 was 1483 cm^3. This represents a difference of 444 cm^3 or about 23% of the expected yield assuming that the yield of still 1 is taken as a reasonable guide and becomes substantial when the cumulative yield is considered. The difference between the respective day and night time yields for the stills was more significant for still1 (841 cm^3 as against 31 cm^3 for still 2). The total yields translate to 642,333.33 cm^3 for still 1 and 494,333.33 cm^3 per square metre of still aperture. The combined day time yield for the stills per metre square of still aperture was 1,136,666.66 cm^3. The combined yield for both day and night operations of the stills for the period was 1,982,666.66 cm^3 per square metre of still aperture or 330444.44 cm^3/m^2 of still aperture/day. The estimates for monthly and yearly yield can easily be made. Hence, the yield during the night represented 42.7% of this total. This shows that the capacity for the night time operation to supplement day time yield is quite significant and could play a vital role in producing on-site portable water for both rural and many so-called urban areas in Nigeria.

Figs. 6 to 13 are attempts to relate some of the operating parameters of the stills to the volume of water produced. In figs. 6 to 9, efficiency is shown to vary approximately linearly with the volume of water as expected. However, the R^2 values obtained showed that the daily mean efficiencies showed a better relationship for still 1 (R^2 = 0.791 as against 0.711 for still 2) while the hourly mean efficiencies showed a better relationship for still 2 (R^2 = 0.885 as against 0.821 for still 1). The higher R^2 value for the relationship in still 2 seems to further affirm the fact earlier mentioned that it appeared to have better insulation or less heat loss. In comparison, the hourly values showed a better relationship probably as a consequence of the fluctuation of the available insolation during the period of the study.

Figs. 10 and 11 show that the ambient temperature has a fairly linear relationship with the volume of water produced. Again the relationship for still 2 had the better R^2 value of 0.763 compared to 0.649 for still 1. This confirms that still 2 performed better in terms of the utilization of the daily ambient temperatures for the study period. The mean hourly ambient temperatures in Table 3 shows the usual pattern of variation of time on a normal day with lower values in the mornings, peak values in the afternoon and lower ones in the evening. However, these values do not show a linear relationship with the volume of water produced due to the fluctuation of weather experienced.

Figs. 12 and 13 show that the available insolation has a poor linear relationship with the volume of water produced. This ordinarily should not be the case. The general unpredictability of the weather largely blamed on human activities and the period when this study was carried out (just before the rainy season) could be responsible for this. There were intermittent sunny and cloudy conditions experienced throughout the period of the study which was part of the reason why the time for the daily commencement of the study was not earlier than 10.00 am. The hourly mean values of the available insolation showed a poorer relationship with the water volume for both stills. Still 1 however, had a better relationship than still 2.

Purity test was not conducted on the samples that were generated in this study. It was deliberate because the objective of this study was primarily to increase yield with reference to previous work carried out. Adequate facilities are available however, for testing for total dissolved solids (TDS), pH value, salinity and other contaminants in the Department of Food Science and Technology in University of Agriculture, Makurdi as well as at Water First, Makurdi. Moreover, a New Mexico State University pilot study showed that solar stills effectively eliminate all salts, heavy metals, bacteria, and microbes from contaminated water sources as long as they are carefully design and proper material selection is done. Testing even reported successful removal of some pesticides (due to UV rays, high temperatures, and atmospheric venting), although recommendations remain to use a carbon filter with stills for guaranteed removal of all volatile organic compounds [2].

The total project cost was about seventeen thousand naira, three hundred and fifty naira only (₦17, 350.00). This translates to 5.25 kobo/cm^3/m^2 of still aperture /day. This means about ₦52.50/litre/m^2 of still aperture/day which falls within the range of costs obtained by researchers in other locations depending on the time of the year [25]. The cost will expectedly be lower in the dry season and higher in the rainy season when acute cloudy weather is common place.

V. CONCLUSIONS AND RECOMMENDATIONS

The results of the present study indicate that the night time yield has a significant contribution to the overall productivity of the simple basin solar still. This has further strengthened the position of the Energy Research Group of the Department of Mechanical Engineering at University of Agriculture, Makurdi that the system can be adopted to play a role in the potable water supply program for the people living close to the River Benue. With more focused and deliberate funding the system can be developed to operate under Makurdi climate with very positive results, Consequently, it will be a step in the right direction if this area of research is drafted into the University of Agriculture, Makurdi Strategic Plan. Better documentation and dissemination of the information already gathered is the next step in order to create awareness among the end-users, NGOs and the Government with a view of promoting acceptability and getting commitment towards realizing the immense potentials that this option provides. The Benue State Government appears to be determined to provide portable water for the citizenry as indicated by the commitment of several billions of Naira to a water project called the Greater Makurdi Water Works. A very small part of this revenue can be channeled into further development of solar still technology to make it impact on the populace.

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