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Design Construction and Performance Evaluation of a Quadro-Outlet Solar Distiller for Use under Biu Climatic Condition

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ABSTRACT

A Quadro-outlet solar distiller unit is a simple solar still with four collection points each for a side of the rectangular box covered with glass. Clean water is a key to human healthy life and thus providing clean water that is free of microbial contaminants and heavy ions is very necessary. The alarming increase in human population in the developing countries of Western Sahara including Nigeria coupled with the lack social amenities like electricity which could be used for pipe borne water production makes it very hard for the local communities to access clean water. Solar distillation process is highly recommended for its simplicity and that it requires only solar radiation which is readily available in these countries most especially the Northern Nigeria. In this paper, a Quadro-outlet type passive solar still was designed and fabricated using the available local materials in Biu (9.6117°N, 12.1919°E), North-Eastern Nigeria. Its performance was evaluated at different initial water depths ranging from 1.0 cm, to 2.5 cm at the interval of 0.5 cm. The daily cumulative yield was maximum, 2926 ml (≈ 3.0 L) at 1.0 cm initial depth and minimum, 1988 ml (≈ 2.0 L) at 2.5 cm initial water depth. The maximum computed instantaneous thermal efficiency (η_{th}) is 68 % at 1.0 cm initial water depth. The yield (both instantaneous and cumulative) for the Southern, Eastern slopes was averagely higher than that of the Northern, Western slopes.

Keywords:
Quadro-outlet solar still,
Solar Energy,
Thermal Efficiency,
Cumulative Yield.

INTRODUCTION

The increase in the world population translates to the increase in the need for food and water in general and a clean drinking water in particular at the minimal cost. This prove to be very difficult with high cost of living as well as that of the electricity which was mainly used for the production of a distill or clean water. The solution to this is solar still which does not depend on electricity. Various designs of solar stills have been made over the years (Tiwari, 2004; Abu-Qudais *et al*.,1996; Tiwari & Suneja, 1998; Sudha *et al*., 1981 and Alkasim et al., 2024). Generally, the design factors that affects the productivity of solar still includes: thickness of glass cover, basin height, shape, inner surface area, initial water depth and angle of inclination (Alkasim, 2013). A conventional solar still consists of: (i) a basin, (ii) support structures, (iii) glazing, (iv) a distillate trough (channel), and (v) insulation. In addition to these, other components may include: (a) Sealants, (b) pipes and valves, (c) tank for storage and (d) an external cover to protect the other components from the weather (Alkasim, 2013; Alkasim et al., 2012). The optimum inclination of the glazing inner surface mainly depends on the location, glazing material and the season. It has been observed experimentally by various investigators that the minimum inclination of the glass cover should be at least 10°, to avoid the drop back of the condensate (Tiwari, 2004).

The use of copper or aluminum for the panel work prevents corrosion which was observable with galvanized iron. The life span of solar still built with aluminum or copper sheets are estimated to be above twelve years. Aluminum has hindrance in its use due to welding difficulty (relative to iron) of the metal sheet. Argon welding set, however, offers solution to this problem. Copper is very expensive and is not easily obtained in most parts of the country. This situation makes the use of copper for the fabrication of solar still is very expensive.

A single and double slope solar still of the same surface areas made from galvanized iron sheet painted black was designed and fabricated (Alkasim et al., 2017 and Alkasim et al., 2024). Both of the single and double sloping consist of 3mm plain glass that covers the panels.

The glass was tilted to angle of 12.5° which correspond to the latitude of Birnin Kebbi for both designs. Inlets and out let were available on the panel body for the introduction of brackish water and for collection of the distillate respectively.

The insulating material used by (Alkasim et al., 2017) to prevent heat loss from the solar still particularly during the off – sunshine hours was a moisture free saw dust. Glass wool saw dust and groundnut husk can also be used as insulator; glass wool is a relatively more expensive than others. Hard wood was also used to construct the outer jacket of the still which was framed with some wood and rubber gasket.

Alkasim *et al.* (2017) studied the performances of the two stills between the months of February to April in Yola Nigeria. The results indicate that the performance of the single sloping type is higher than the double sloping arrangement under the same conditions.

In this work a four slope (Quadro-slope) passive basin type solar still was designed, constructed in Biu, Borno Nigeria and its performance was evaluated using the available materials in the town. The distillate both instantaneous and cumulative as well as the instantaneous thermal efficiency were calculated at various initial water depths.

MATERIALS AND METHODS

The sequence in achieving the desired result of this research was divided into Design, construction and Evaluation based on the logicity of the fabrication. A conventional solar still is an air tight basin made of galvanized iron sheet in a (1 x 1) m^2 base rectangular shape. The top cover is made of glass sloped at an angle approximately that of Yola and the interior surface is painted black for the maximum absorption of solar energy. Saline water is poured into the still to fill it partially and then exposed to the Sun. A typical solar still is shown in figure 3. 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 vapor which condenses on the interior surface to trickle in to a collecting trough.

Design and fabrication

In this model, a conventional solar still of $1m^2$ base was curved out a of galvanized iron sheet in a rectangular based shape that has four collection point one at each side of the basin through was considered. The high of the basin was 25.0 cm as in (Malik and Van-Tran, 1973) The top cover is made of glass Quadro-sloped at each of the four sides the rectangular box at an angle (9.61°) equal to the latitude of the point of research (NAU Biu) as suggested by (Alkasim, 2013). The interior surface was painted black for the maximum absorption of solar energy. The basin was covered with the glass as ridge roof. At the base of the glass was a cylindrical through which the dripped water will be conducted to the collection point. Hard water from Biu town was assumed to fill the solar still partially and then exposed to the Sun.

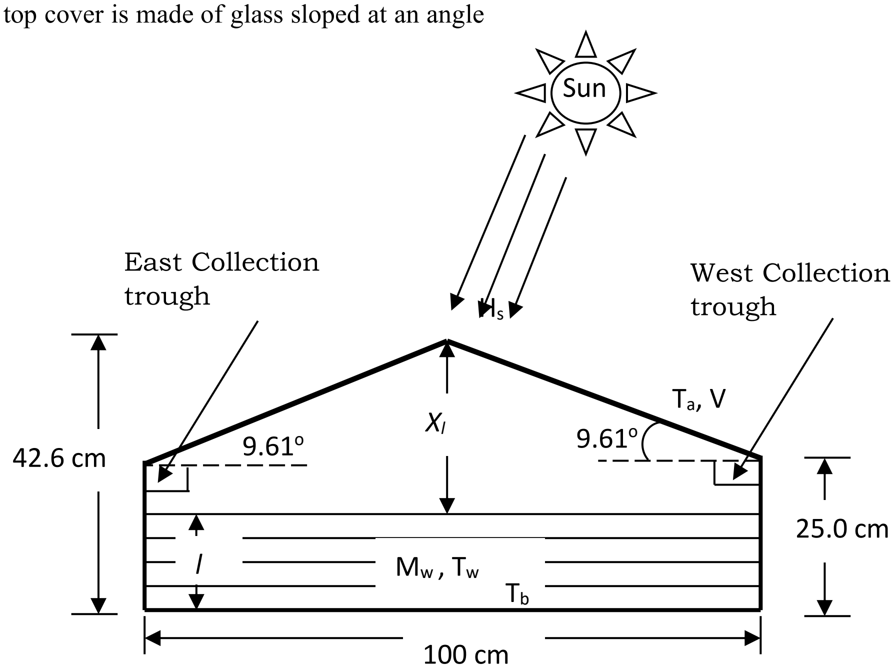

Figure 1: Schematic cross-section of the distiller unit

Materials and Construction procedure

The materials used for this research work especially for the fabrication of the solar still were obtained from Biu, markets as well as from the Department of Physics, Nigerian Army University, Biu. As for the construction they include: Aluminum sheet, Plywood, marker pen, Cotton wool, Top bond gum, Top bond glue, Black paint, Leather fore maker, Iron rod, Soldering sticks, Flank wood Plastic water pipes, Plastic water tap, Plastic bucket, Silver plated ruler, Flash band Thermocouples probes, Digital multi-meters, Glass sheet and Measuring cylinder.

The construction procedure consists of a basin ($1m^2$ basin area) of 25 cm height made of the Aluminum metal which was coated with a black paint. It was then inserted into a 5 mm lag (cotton wool), larger plywood box. The top was covered with a transparent glass sloped at the four sides as designed. The whole assembly was covered externally with a leather fore-maker for protection against the influence of rain and external moisture. The slopping pane of glass, supported an iron frame covers the upper part of the basin and was sealed tightly with a water proof cello-tape to minimize the vapor leakage. The frame was supported by four trolley rollers and it supports the refill bucket as in the sketch (Figure 2).

The whole assembly was mounted on a metal frame (1m above the ground level) in an open area at the back of the FNAS building, NAUB. The refilling bucket (tank) was placed on top of the upper table frame 1.5 m above the ground. The slopping glass cover slants towards the collection through at an angle of 9.61^o equal to the latitude of Biu for maximum solar radiation. The schematic diagram of the assembly is shown in Figure 2.

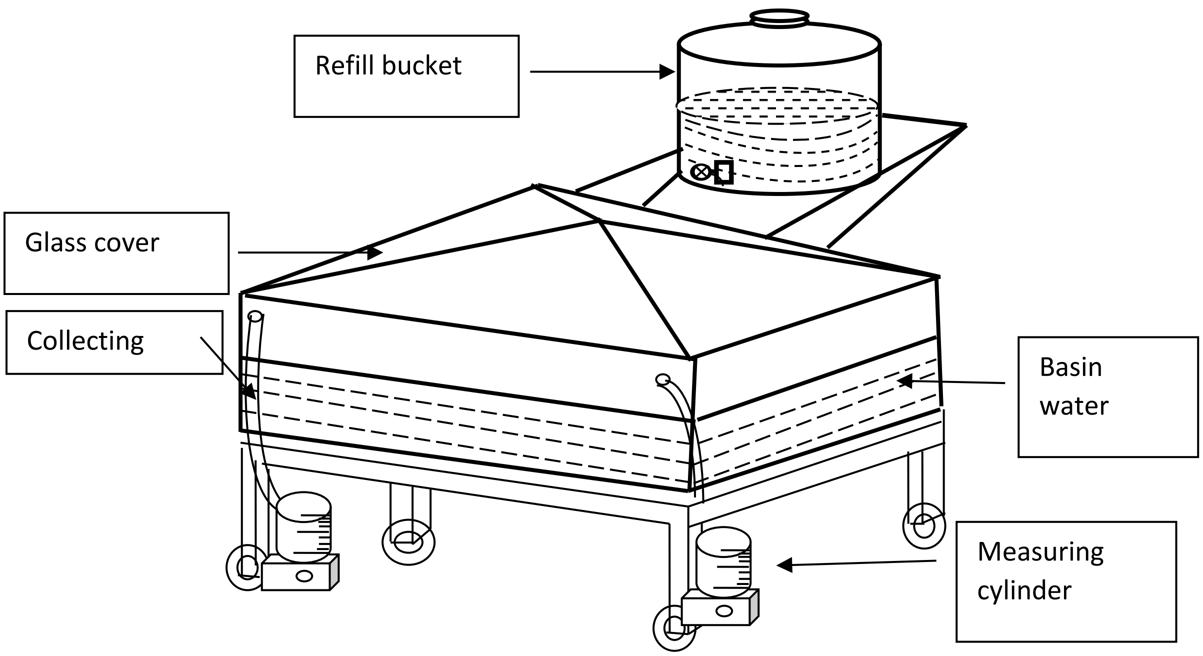

Figure 2: The Fabricated Quatro-outlet solar still

Figure 3: The life picture of a multi outlet passive solar still *source* (Alkasim et al., 2024)

The Experimental procedure

The Constructed still was fed with a saline/ dirty / unclean water through the refill bucket at a shallow depth through the back upper tap. A distillate trough ran along the four sides of the glass pane (East, South, North and West) to collect the distillate and channel it out through the outlet pipes to the measuring cylinders which measured the volume of the distillate. The refilling tube was located near the upper edge of the still, with its level controller. To serve as a drain, an outlet pipe was located near the bottom of the still to carry away the brine/ brackish water.

The data collection was done using a meteorological observing equipment's form as set up for the research. The set up was linked to a computer Data logger through a wireless network. The following materials were used: (i) The locally constructed Quadro-outlet solar still (ii) A computer set with a workable Excel program and a printer for the data generation/analysis. (iii) A data logger which was linked with the computer PC using a USB data cable directly for downloading, analyses, and comparison. This method has become the established means of configuring laboratory-scale data collection system (Egarievwe, 1989).

The designed model theoretically examined different aspects of solar still developed by many researchers as well as their different models with the aim of improving the thermal efficiency and the yield (Howe,1992; Malik &Van-Tran, 1973; El-Nashar, 1992; Ghandhidasan & Abdulhumaydi, 1994; Porta *et al*., 1997; Fedalis & Bougriou, 2010 and Tiwari,2002). A common approach to modelling solar stills is the use of energy balance equations in which the input solar energy is balanced against the useful output energy and various losses from the system. It should be noted that the law of conservation of energy is vital in the analysis of heat transfer to and from a system. Tiwari, (2002) reported that correlations for the internal heat and mass transfer in a conventional solar still developed by Dunkle (1961) were still in use in most studies on solar still modelling.

The Model Equations used

The modelled equations used for the yield as well as the thermal efficiency of the still as in (Seithi & Dwived, (2013); Alkasim, (2013) and Alkasim et al., (2011) are:

$$m_W = \sum(m_{wE} + m_{wW} + mwN + mwS) \quad (1)$$

$$\eta_{th} = \frac{m_W\lambda}{3600[(A_b \times \sum H_S) + (A_C \times \sum I_C)]} \quad (2)$$

$$\lambda = 2.4935 \times 10^6[1 - (9.4779 \times 10^{-4}T_W + 1.3132 \times 10^{-7}T_W^2 - 4.7974 \times 10^{-9}T_W^3)] \quad (3)$$

Observation/Data Collection

The observations from the data collected were presented in the figure 4 and 5 for the different initial water depths in the distiller unit. The weather conditions of Biu (the Collection Area) at the specific dates of collection were clear and sunny in most parts of the day. Table 1 was the record of the compared results of the instantaneous yield and the respective thermal efficiencies at the four different initial water depths. This was done to determine the perfect initial depth for optimum distillate production.

Table 1: Cumulative Yield and instantaneous Thermal efficiency recorded at 30 minutes interval as from 7:00 am to 7:00 pm local day time at various initial water depths

Local Time	Initial Water Depth							
	1.0 cm		1.5 cm		2.0 cm		2.5 cm	
	mW	ηth	mW	ηth	mW	Hth	mW	ηth
7:00 am	0	0.0000	0	0.0000	0	0.0000	0	0.0000
7:30 am	0	0.0000	0	0.0000	1	0.3980	0	0.0000
8:00 am	4	0.0000	0	0.0000	6	1.9582	0	0.0000
8:30 am	5	0.8813	0	0.0000	5	0.7486	0	0.0000
9:00 am	4	0.7176	6	0.9403	10	1.1508	0	0.0000
9:30 am	6	0.7436	12	1.3848	7	0.7443	0	0.0000
10:00 am	6	0.6852	23	2.2708	9	0.7146	30	2.5526
10:30 am	20	2.0350	50	3.8644	40	3.0005	11	1.9838
11:00 am	80	7.3636	54	6.8643	30	2.0415	20	1.8346
11:30 am	90	6.7080	40	2.9807	30	2.5719	30	2.2421
12 Noon	210	15.9348	90	6.4963	50	11.2450	80	9.4321
12:30 pm	230	27.6271	200	14.6632	150	18.9095	40	2.8069
1:00 pm	238	28.9849	150	12.6320	140	12.9184	42	3.2263
1:30 pm	240	37.3154	170	14.3875	186	11.4356	230	34.6085
2:00 pm	160	22.5651	120	8.4706	110	7.2284	220	50.4665
2:30 pm	215	20.8818	130	33.7704	190	13.7380	210	34.6114
3:00 pm	250	29.8269	132	12.2335	170	70.6387	80	9.4264
3:30 pm	240	30.9336	120	15.8184	50	15.8729	80	15.2603
4:00 pm	90	14.4442	124	21.5534	70	28.3684	106	14.0101
4:30 pm	110	20.7093	127	27.1815	80	42.3476	120	21.8366
5:00 pm	180	50.2758	105	32.1665	80	75.0703	90	24.9874
5:30 pm	130	50.0381	78	49.2187	56	61.9686	60	46.6790
6:00 pm	90	0.0000	70	0.0000	70	22.4412	50	0
6:30 pm	72	0.0000	60	0.0000	62	0	50	0
7:00 pm	38	0.0000	60	0.0000	35	0	40	0

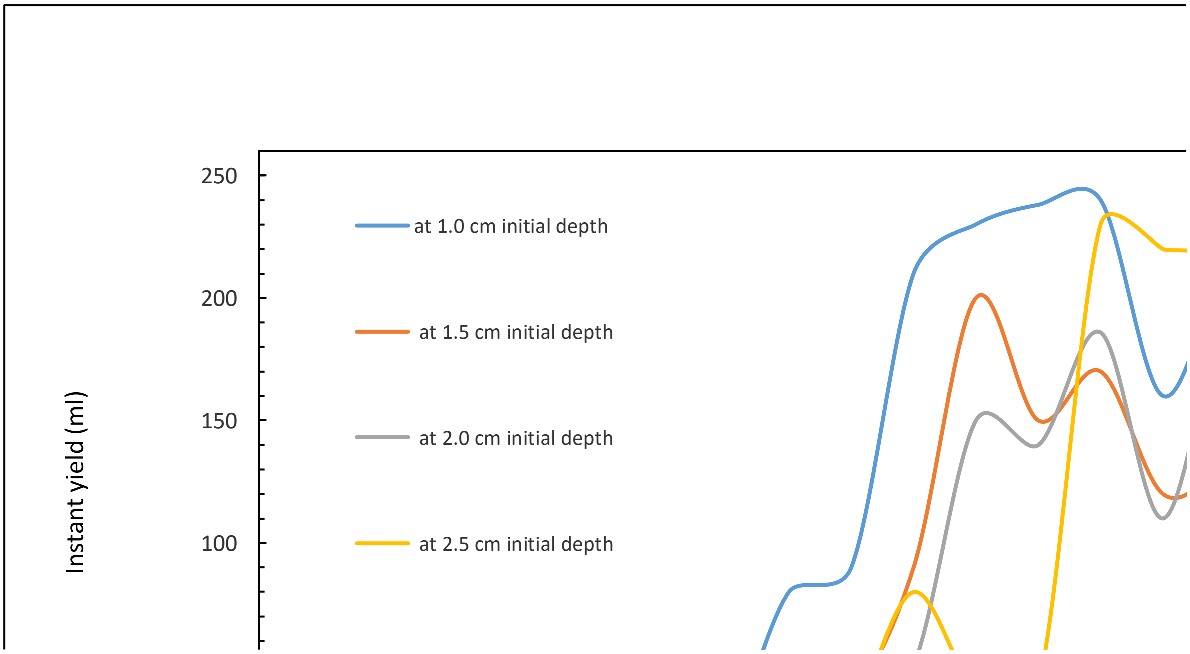

Figure 4: Variation of Instantaneous Yield with Local Time at different initial water depths

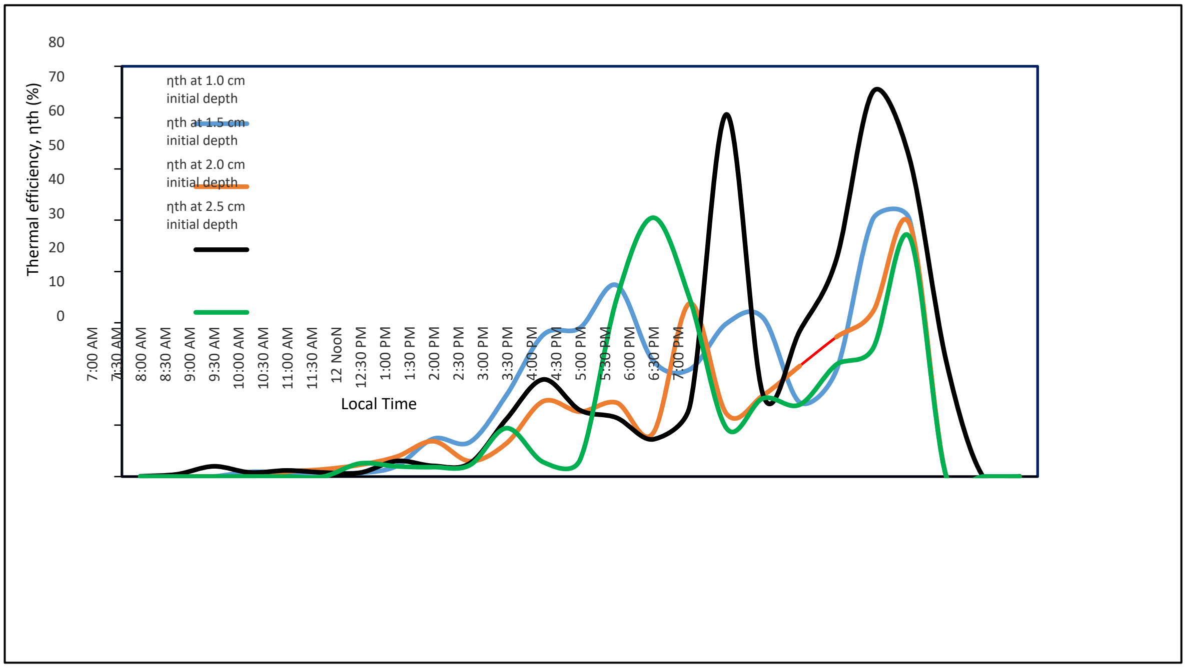

Figure 5: Variation of Thermal efficiency with local time at various initial water depths

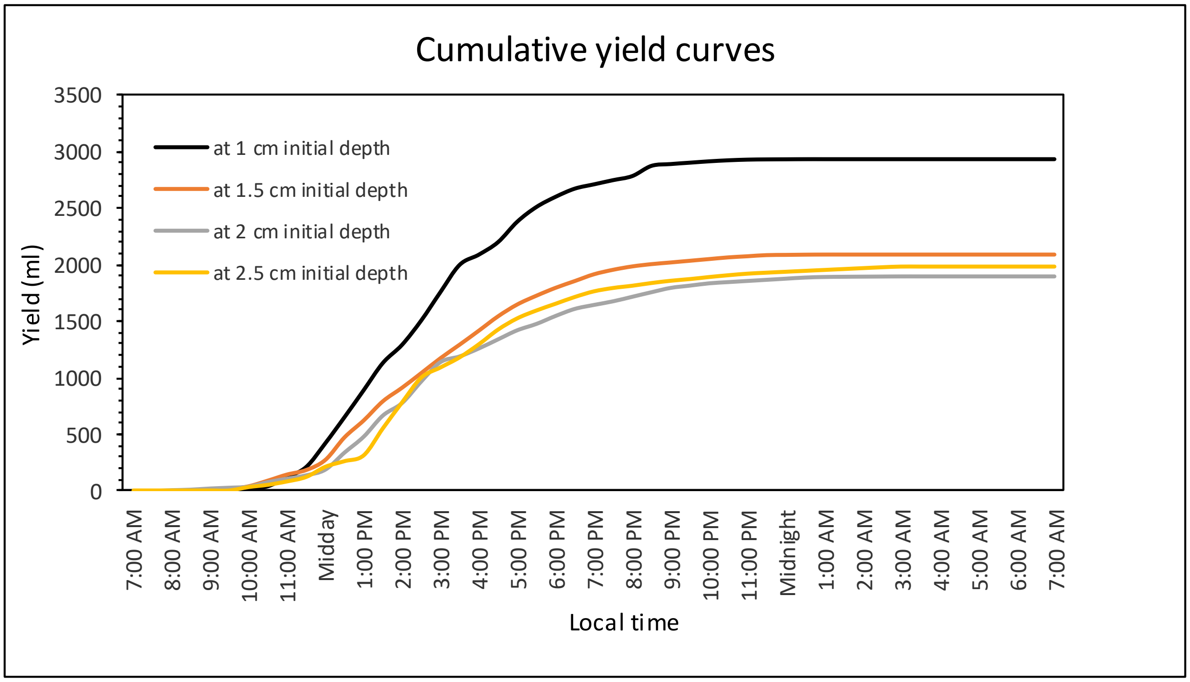

Figure 6: The Daily cumulative yield of the still for various days at various initial water depths

RESULTS AND DISCUSSION

The results were presented both in tabular as well as graphical forms to investigate the effect of initial water depth on the performance of the Quadro-outlet still so designed and constructed. The work was carried out between the months of December, 2024 to February, 2025 in Biu Borno state, Nigeria. Half-hourly measurements of the solar still characteristic temperatures (the basin water temperature, T_w, the glass temperature, T_g and the ambient temperature, T_a) as well as the solar intensities were obtained for a full day (24 hours) beginning from 7:00 am to 7:00 am the next day (Appendix: tables 1 to 4).

The instantaneous yield and thermal efficiencies were calculated during the clear days from 7 am to 7 pm for the different initial water depths (1.0 cm, 1.5 cm, 2.0 cm, and 2.5 cm) as shown in table 5. The variations of instantaneous yield and the thermal efficiencies were shown in figures 3 and 4 respectively. The highest daily cumulative yield of 2.926 L and the highest average thermal efficiency of 68% were both recorded at initial water depth of 1.0 cm (figure 5), while the lowest cumulative daily yield of 1.988 L and lowest average thermal efficiency of 50% were respectively recorded at 2.5 cm initial water depth.

The above results indicated that apart from the advantage of having four (4) different collection points from the designed still, the still can be able to distill water in Biu, Borno perfectly using the sunshine and solar radiation available in the area.

CONCLUSION

(i) The water (distillates) was collected in all the four (4) outlets of the constructed Quadro-outlet solar still. (ii) The distillate quantity varies with the initial water depth inversely (iii) The instantaneous thermal efficiency varies from 0% in the morning to about 70% in the afternoon and thus falls back to 0 in the late evening at some initial water depths 1.0 cm and 2.0 cm in the blacken distiller basin (iv) The constructed solar still can produce about 3.0 L of distilled water a day between the months of December and March as observed in Biu Borno Nigeria. This was about same as that obtained by [19]. (v) with the abundant free solar energy in Biu a locally constructed solar still can be able to distill saline water to produce fresh water which could be used by the locals in solving the hardness of the water evident in the area.

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