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Electric-Solar Horizontal Patternator for Laboratory and Field Nozzle Spray Pattern Determination

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Abstract: *Plant protection operations are generally done using hydraulic energy sprayers, gaseous energy sprayers, centrifugal energy sprayers and kinetic energy sprayer. Nozzle selection is one of the most important decisions to be made related to pesticide applications. In pesticide application, accuracy and uniformity of application is most important to avoid adverse effects of pesticides on environment and crop injury, and reduced pest management. A poor choice in spray nozzles selection, or use of under-performing nozzles, can lead to re-spraying and reduced performance, so one should be very particular regarding use of nozzles. Mechanical Patternator is the most direct method to evaluate the liquid distribution provided by a nozzle, or array of nozzles. Typical mechanical patternator collects the sprayed material at many locations across the spray plume and the level of each collection bin is recorded. These instruments are very useful for quickly and accurately assessing the spray distribution pattern with different nozzle types/capacities; operating conditions, spray distances, and nozzle spacing. The use of a mechanical patternator offers a very direct and accurate method for assessing the liquid volume distribution across a spray plume. It is also employed in determining nozzle flow rate, droplet size, droplet density and swath at various pumping pressure and heights of nozzles above target. Hitherto Mechanical patternators are housed in the laboratory and powered by electricity. There has been the problem of accommodating field effects in the patternator experiments inside in the laboratory. Simulations using blowers offer estimations that are sometimes largely different from the field conditions. Thus, results obtained in the lab are often vitiated by drift occasioned by the wind in the field during spray. The invention of Electric Solar Patternator offers the opportunity of conducting patternator experiments both in the laboratory and in the field where exact field conditions integrate.*

Keywords: *Pesticide, Nozzle, Spray, Pattern, Uniformity, Drift, Field.*

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I. Introduction

Estimates of potential global losses in agricultural production due to insect and vertebrate pests, diseases and weeds vary from crop to crop. It has been estimated that these pests possibly cost up to 40% of the world's production of food by reducing crop yield and causing losses in storage. Crop yield is reduced mainly due to attack of pests, diseases and weeds. Chemical control is the popular method adopted for controlling most insects, weeds and diseases. They are applied in varying amounts, depending upon the type and concentration of active ingredients. At present in Nigeria the farmers are mostly using hydraulic energy sprayers in their field. Hydraulic energy sprayers are sprayers that use hydraulic pressure energy to break spray liquid into droplets of a wide range of sizes. In the hydraulic sprayer, a pump supplies energy that carries spray material to the target. Understanding how to use these sprayers is essential for the successful application of agricultural chemicals, especially selective post emergence herbicides. In order to successfully use herbicides, their application must be accurate and uniform. The spray characteristics of agricultural spray nozzles are important criteria in the application of pesticides because of their ultimate effect on the efficiency of the pesticide application process. The uniformity of the spray distribution across the boom or within the spray swath is essential to achieve maximum chemical effectiveness with minimal cost and minimal non-target contamination.

Droplet size and velocity affect the structure of the spray deposits and the drifting level of the droplets. Furthermore, droplet size may influence the biological efficacy of the applied pesticide as well as environmental hazards. Hence, the ideal nozzle–pressure combination will maximize spray efficiency for depositing and transferring a lethal dose to the target, whilst minimizing off-target losses such as spray drift and user exposure. The spray characteristics influencing the efficiency of the pesticide application process are the droplet size and velocity distribution, the volume distribution pattern, the entrained air characteristics, the spray structure and the structure of individual droplets (Nuyttensa *et al.,* 2007). It has been estimated that only 55% of the spray from an air blast sprayer actually reaches the intended target. The remaining 45% either hits the ground or becomes airborne as spray drift. An adequate adjustment of spray liquid distribution to the canopy structure can reduce spray drift up to 90% and reduce pesticide use up to 20%. The negative consequences following inefficient pesticide applications are both economic and environmental due to up to 80% of product being lost during application An adequate adaptation of liquid distribution to canopy structure is fundamental in order to achieve an homogeneous pesticide distribution throughout the whole canopy reducing at the same time the risk of environmental contamination as a consequence of better control of pesticide losses into the soil and, most importantly, through a better control of the droplets passing over the canopy at the top part of the plants, trees or vines (Gil *et al.,* 2013).

Spray drift, defined as the quantity of plant protection product that is carried out of the sprayed area by the action of air currents during the application process, continues to be a major problem when applying agricultural pesticides. Drift can cause crop protection chemicals to be deposited in undesirable areas with serious consequences. Most of the negative consequences can cause: (a) damage to sensitive adjoining crops and other susceptible off-target areas; (b) environmental contamination such as water contamination and illegal pesticide residues; (c) health risks to animals and people and (d) lower dose than intended on the target field, which can reduce the effectiveness of the pesticide, wasting both pesticide and money. In order to improve the liquid distribution and to adapt it to the plant characteristics, it is important to have available a device which can easily show and measure the spray distribution under field conditions. Good liquid distribution has been shown as one of the main aspects related to drift reduction in pesticide applications (Gil *et al.,* 2013).

The ultimate goal of agricultural spraying application system is to put the correct amount of pesticides, in the correct place, at the correct time to reduce the pest to a level below the economic threshold in order to improve agricultural production. Spraying application nozzle is designed to achieve good spray distribution and uniformity. Uniformity of spray volumetric distribution is the most important indicator of nozzle performance. Measuring the volumetric distributions of liquid from individual nozzle or group of nozzles have been investigated and identified by researchers using patternator under laboratory conditions. Typical mechanical patternators which are sometimes referred to as Patternation tables, collect sprayed material at many locations across the spray plume, and the level of each collection bin is recorded. These instruments are useful for quickly and accurately assessing the spray distribution change with different nozzle types / capacities, operating conditions, spray distances and nozzle spacing. A spray patternator measurement would probably be sufficient to accurately evaluate the static spray volumetric distribution (Hassen *et al.,* 2013), if field conditions especially with regard to drift are integrated in the measurements. This can be possible when experimentations can be executed in the field during the times and seasons when routine pesticide applications are planned. Spray volume distribution pattern under field conditions can only be made possible when a Patternator is built to use portable source of power other than electricity. The essence of a hybrid Electric/Solar Patternator which can employ solar power for on the field experiments is thus underscored by this need. Even in the laboratory, power availability is not assured. The epileptic power supply in Nigeria is widely acknowledged fact since it is a major problem of economic and industrial development in the country. With the abundant human and natural resources the country is blessed with, it becomes self-contradictory that after more than one hundred years of existence and more than sixty years of independence, Nigeria is still not getting it right in terms of energy sufficiency. If the problem is only that the power is insufficient or epileptic, it would have been a better situation but the major setback is that the power supply is erratic. Being erratic means that the power supply is not regular and the residents and companies requiring electricity cannot predict when it will be available for consumption (Jimah *et al*., 2009). Thus apart from field experiments this innovation also cures national grid power inconsistency as the solar power sustains its operation every time it is needed.

Hitherto, nozzle spray pattern determination has always been done in the laboratory rather than the farm where actual field conditions can manifest. This is typically due to lack of power source in the field. Simulations using blowers have not offered satisfactory field characteristics especially with respect to drifts at varying wind speeds. Hence the creation of this invention which incorporates Solar energy for on the field evaluations and both Solar and Electric energy for laboratory work as desired. Spray parameters characteristics which can be obtained employing the patternator include: i). Flow rate, ii). Spray volume distribution pattern. iii). Droplet size, iv). Droplet density and v). Swath. The procedure for the determination of these parameters are as follows:

i. Flow rate: The flow rate offers idea of the volume of pesticide to be consumed per time. It is used to calculate the Application rate which is the volume of pesticide deposited per hectare. Polythene sacks are tied to each nozzle on a boom of nozzles positioned above a patternator such that liquid discharge from the nozzles collect in the sacks. After timed flow at the chosen pressure, the volumes are each measured using the graduated measuring cylinder. The flow rates are determined using expression given below.

$$V = Q/t \text{ l/min (Matthews 1979)} \qquad (1)$$

Where
V = Flow rate (l/min.)
Q = Average discharge in liters
T = Average time for discharge in minutes

ii. Spray volume distribution pattern: The spray pattern of most agricultural nozzles is tapered and the nozzles built to deposit uniformly across its swath. To achieve uniform distribution on a boom of multiple nozzles, a degree of overlap of the spray patterns is required because spray distribution from a nozzle is generally more in the central region, reducing towards the outer edges, following a normal distribution. The patternator test at various heights enables the determination of the height that gives the most uniform spray volume distribution. The position corresponding to minimum coefficient of variation is selected as the best placement for the nozzles on the boom at the particular height of the nozzles from the target and at the given working pressure (Khurana *et al.,* 2007). The nozzle spray volumes are collected across the collection glass tubes. The averages, standard deviation and coefficient of variations of the experiments are then calculated and used to indicate the pressure and height of nozzles above target which gives the most uniform pattern. This setting serves as the recommended spraying pressure and nozzle height. Ensuring a uniform placement of the applied materials (pesticide) to the target (pest) is an important task for the sprayer operator and requires careful setting for the sprayer.

Spray distribution expressed by the coefficient of variation (CV, %) defines the required (maximum) efficiency of chemical crop protection with minimum costs and environmental contamination. Sayinci and Bastaban, (2011) reports that uniformity of volumetric distribution is the most important indicator of the nozzle performance and that the measurements made by Prairie Agricultural Machinery Institute (PAMI, Canada) under laboratory conditions at stationary patternator rendered spray distribution as acceptable for 15% of the variation. Similarly, Subr *et al.* (2017) states that the coefficient of variation is a measure of the process uniformity expressed (usually in percentages) as the ratio of the standard deviation to the arithmetic mean of the sample. CV% refers to variation in volume or mass of spray liquid or granular deposited over the treated area transverse to the direction of travel, while the spray angle is the angle formed close to a spray nozzle by the edges of the spray. The work further reports that the measured CV% value from the field deposit must be 15% or less when applying pesticide on soil, grass, or weed surfaces.

iii. Droplet size: An accurate knowledge of droplet size distribution as a function of the conditions of the system is a prerequisite for setting a sprayer for pesticide application. The size range of droplets produced by the system must be known in order to assess spraying efficiency and other performance of the system. Hipkins and Grisso, (2014) reports that Nozzle type and application pressure govern droplet size which in turn affects system output (application rate), target deposition, uniformity, efficacy, and the risk of drift. Table 1 and Table 2 depict the Droplet range for various application and the Droplet size classification respectively.

Hipkins and Grisso, (2014) further states that very fine droplets (VMD less than 145 microns) are collected efficiently by flying insects or needles on coniferous plants, but they tend to remain in the air stream, which carries them around the stems and leaves of weeds. Fine and medium-size droplets (VMD between 145 and 325 microns) will deposit efficiently on stems and narrow vertical leaves such as grasses if applied when there is some air movement. Coarse (or larger) droplets (VMD more than 325 microns) deposit efficiently on large, flat surfaces such as the leaves of broad-leaved weeds. Insecticides, fungicides, and contact herbicides generally require smaller droplets than systemic herbicides to obtain adequate coverage of the target. Essentially, the intended application will inform the nozzle type and pumping pressure required.

For the measurements, glass slides are uniformly coated with magnesium oxide by burning two 10 cm strips of magnesium ribbon. Droplet samples are collected on the coated slides, at the various test pressures. The samples collected are then observed under a microscope fitted with a field Graticule eyepiece for precise droplet size measurement (Matthews, 1979). With the aid of mechanical stage of the microscope, the craters are lined in series on Graticule in which droplets are classified as 50 microns, 100 microns 200 microns and 400 microns.

Table 1: Droplet range for application/pest control

Application	Droplet Category[2]	Approximate VMD Range[3] (in microns)
Fungicide		
foliar protective or curative	Medium (M)	226-325
Insecticide		
foliar contact or stomach poison	Medium (M)	226-325
foliar systemic	Coarse (C)	326-400
soil-applied systemic	Coarse (C) Very Coarse (VC) Extremely Coarse (XC) Ultra Coarse (UC)	326-400 401-500 500-650 >650
Herbicide		
foliar/post-emergent contact	Medium (M)	226-325
foliar/post-emergent systemic	Coarse (C)	326-400
soil-applied/pre-emergent systemic	Coarse (C) Very Coarse (VC) Extremely Coarse (XC) Ultra Coarse (UC)	326-400 401-500 501-650 >650

(Source: Hipkins and Grisso, 2014).

Table 2: Droplet size classification

Category	Symbol and color code	Approximate VMD (μm)*
Extremely fine	XF	<60
Very fine	VF	61-144
Fine	F	145-235
Medium	M	236-340
Coarse	C	341-403
Very coarse	VC	404-502
Extremely coarse	XC	203-665
Ultra coarse	UC	>665
*Estimated from sample reference graph provided for ASABE S572.1 nozzle design		

(Source: McGinty *et al.*, 2014).

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iv. Droplet Density: The droplet density of a sprayer nozzle is defined as the number of droplet per unit target area. The test fluid is dyed and droplet samples are collected on a white photographic paper. The number of drops per square centimeter is a useful measure of the effectiveness of the spray and should be between about 10 and a 1000 depending on the target. The three main influences on the drop size spectrum are the design of the spray nozzle, the exit velocity of the spray and the physical properties of the spray liquid (Kateley et al., 2016). On the spot measurement of the number of droplet per square centimeter deposited on the photographic paper surface is counted at random under a magnifier with the aid of a droplet counting aid with 2 square window ($1cm^2$) opening. The procedure is also repeated for various heights and operating pressures. The droplet density analysis, ordinary counting method is used and compared with the theoretical empirical relation. Theoretically expected number, n of droplets per centimeter square is given by (Mathews, 1992)

$$n = \frac{60 \times (100)^3}{\pi d} \times Q \qquad (2)$$

Where,

π	=	Constant and taken 3.14
d	=	Droplet diameter
Q	=	Application Rate (L/ha)

v. Swath: Figure 1 depicts the spray pattern from overlapping multiple nozzles. The red, blue and green lines show that at any horizontal position along the Nozzle Height above target, the Spray volume distribution pattern and Swath must vary. Laboratory test is required to determine effect of variations in height on swath, thereby determine the height and swath which offers the optimum uniform deposition of herbicide. At the test height and pressure, the horizontal width covered by the spray during experiments are measured using a meter tape. The average gives the swath for the particular pressure and height.

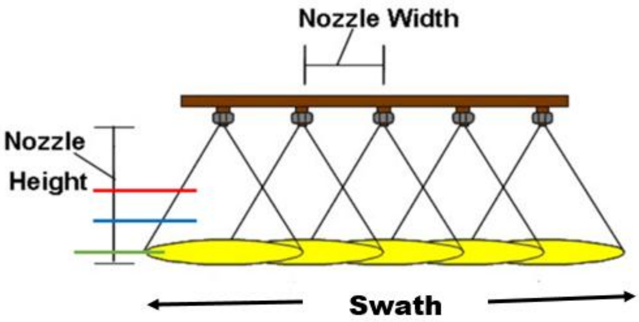

Figure 1: Spray pattern from multiple nozzles

II. Materials And Methods

Selection of appropriate spraying components is very important as they are to be used successfully and economically. The various factors responsible for uniform spray distribution of chemical across the field such as pumping pressure, height of nozzles above target, spray angle, discharge rate were taken into account. The effects of operating pressure and nozzle height on uniformity of spray distribution pattern in laboratory using different types of nozzles operated at different heights and pressure were also observed. Major components include one water tank, solar panel and table, the patternator made of corrugated plastic sheets spanning 240 cm with collection tubes across the entire length. Nozzles attachment is stationed on top of the patternator while electrical inverter and switch for harnessing and actuating solar electricity are also provided. The power consumption of hydraulic energy pumps were employed to determine the power capacity of the installed solar panel.

III. Equipment Description

A patternator normally consists of number of slanting channels aligned perpendicular to the nozzle spray and can be of any convenient length provided that it encompasses the area of the spray. The number of channels may be increased or decreased so that the whole of the spray falls within the patternator. A pump giving a steady output is used. A constant pressure regulator and a pressure gauge is placed as close to the nozzles as possible to maintain uniform pressure. Adjustments are provided to hold the nozzles at a various height during spraying. Collecting tubes are provided to collect the water from the channels during spraying. Nozzles are given a preliminary run until a constant flow rate from the patternator has been achieved and then the readings are taken. A patternator gives swath uniformity of a nozzle or boom which can be known just through visual observation.

Figure 1 depicts the assembly of the novel Electric-Solar Patternator. Water for the tests are stored in the water tank. Energy from the Sun is collected by the Solar Panels and converted to electricity by the Inverter (shown). The Switch actuates the pump which supplies the nozzles at set pressures. The volumes of the flows at various points are collected by the Collection tubes. These volumes are plotted on the y-axis against their positions on the x-axis to ascertain the Volume flow distribution Pattern. The height of the nozzles above the Patternator table are adjustable to enable the determination of the optimum height above target. The orthographic and isometric drawings are shown in Figures 2 and 3. For accuracy, experiments are usually replicated three times while the mean is the value used.

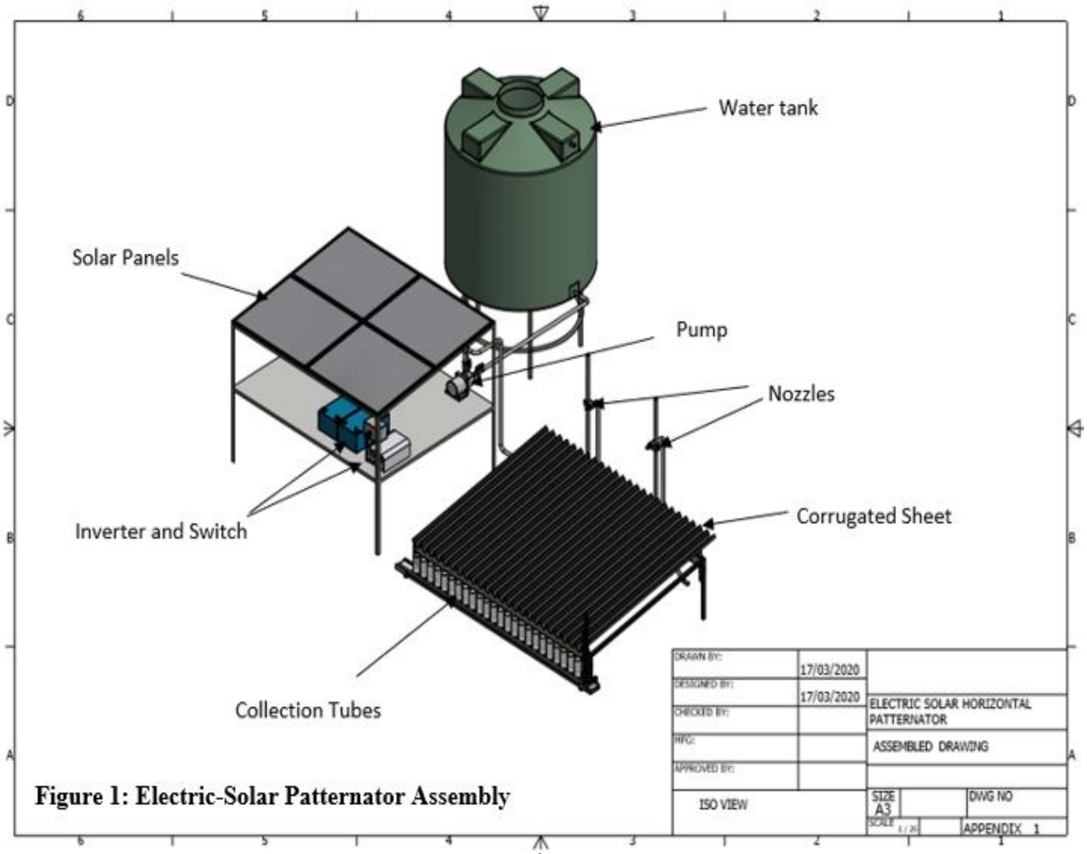

Figure 1: Electric-Solar Patternator Assembly

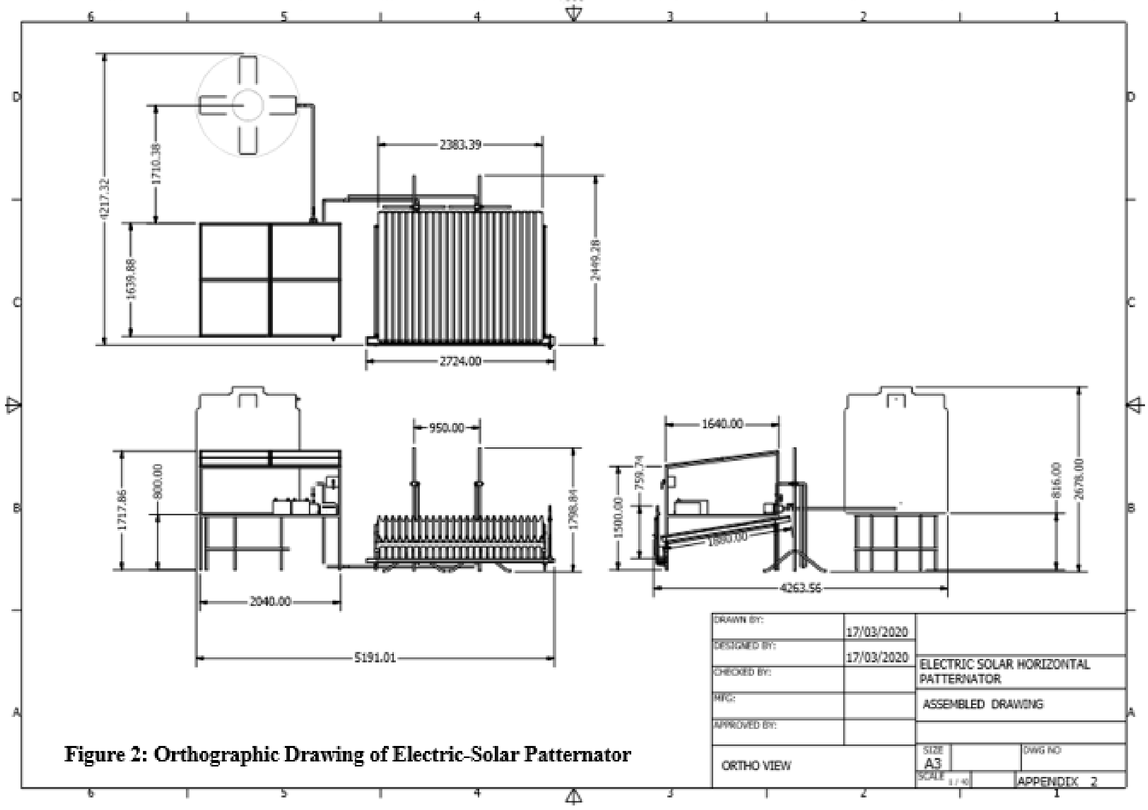

Figure 2: Orthographic Drawing of Electric-Solar Patternator

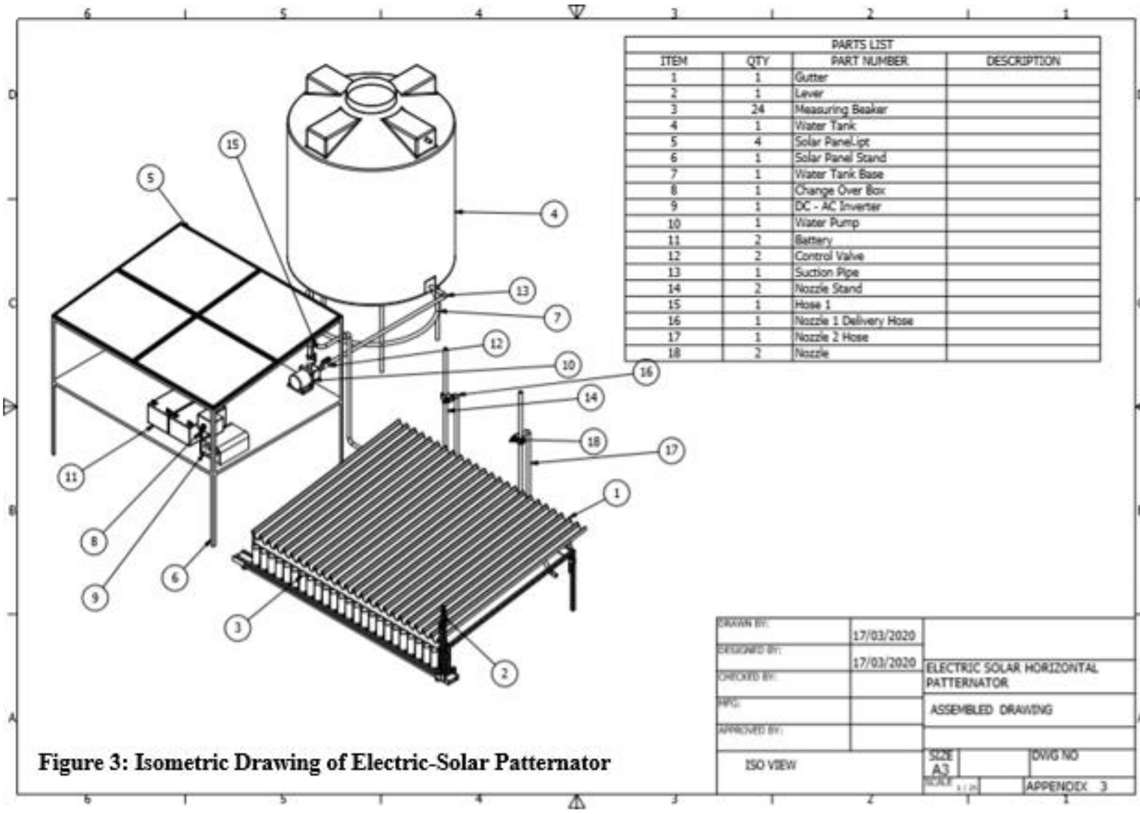

Figure 3: Isometric Drawing of Electric-Solar Patternator

The novel Electric Solar Patternator is a 240 cm x 180 cm x 100 cm frame on which is installed leak-proof corrugated plastic sheet sloped at 10^0; to allow free flow of water. The liquid flowing through the corrugations at a certain pressure and height conditions is collected in measurement cups (ml). These volumes are placed on ordinate (y-axis) and the distances of the corrugations either right or left of the nozzle center line are placed on apsis (x-axis). In this way, volumetric distribution shape (spray pattern) is obtained graphically. The main components are: 1). Power (Electric/Solar) 2). Pump 3). Water storage tank 4). Control valves 5). Frame 6). Corrugated sheet 7). Nozzle stand 8). Nozzle holder 9). Suction, delivery and overflow pipes 10). Measuring test tubes.

IV. Conclusion

The assurance of properly determining spray parameters of Flow rate, Swath, Droplet size, Droplet density and especially Spray volume distribution pattern cannot be achieved without proper nozzle flow pattern analysis on the patternator. The usual practice is to determine spray parameters of nozzles and booms of nozzles only in the laboratory setting and try to adjust to match field conditions. This study has created a dual powered patternator for spray parameters determination both in the laboratory and under field conditions. It is a product of collaboration between Hydraulic Equipment Development Institute (HEDI), Kano and Sokoto, Energy Research Centre (SERC), Sokoto with input from National Board for Technology Incubation (NBTI), Abuja and Agricultural and Bio-Resources Department, Ahmadu Bello University, Zaria. The work was patented in Nigeria in 2020.

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