DESIGN AND FABRICATION OF A PHOTOTYPE AUTOMATED SOLAR POWERED COCOA SEED DRYER

BY:

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ND/23/ABE/FT/0027

BEING A RESEARCH PROJECT SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL AND BIO-ENVIRONMENTAL ENGINEERING TECHNOLOGY, INSTITUTE OF TECHNOLOG Y, KWARA STATE POLYTECHNIC, ILORIN.

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF NATIONAL D IPLOMA (ND) IN AGRICULTURAL AND BIO-ENVIRONMENTAL ENGINEERING TECHNOL OGY

2024/2025 SESSION

CERTIFICATION

This is to certify that this project title, Design and Fabrication of a Prototype Automated Solar Powered Cocoa Seed Dryer Submitted by Daramola Temidayo Stephen with Matric number **ND/23/ABE/FT/0027** was carried out under my Supervision at the Department o f Agricultural and Bio-environmental Engineering Technology, Institute of Technology, Kw ara State Polytechnic, Ilorin. This Project report has been read and approved having met the requirement for the award of National Diploma (ND) in Agricultural and Bio-environm ental Engineering Technology.

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DEDICATION

This project is dedicated to Almighty the most Beneficient, the Most merciful.

ACKNOWLEDGEMENT

All praise and gratitude belong to Almighty God ,the Most Gracious, the Most Merciful, for granting me life, strength, wisdom, and perseverance throughout the period of this project and my academic journey. His mercy and guidance have been my anchor, and without His favor, this achievement would not have been possible.

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Special thanks to my coursemates and colleagues who directly or indirectly contributed to the success of this project. The discussions, shared resources, and teamwork during practicals and lectures were invaluable.

ABSTRACT

This research focused on the development and evaluation of a prototype solar automated cocoa seed dryer designed to enhance the drying process of Theobroma cacao seeds. The study aimed to fabricate a solar-powered drying system integrating key components such as a collector, fan, monitoring equipment, solar panel, drying chamber, frame, and trays, with structural elements welded using an electric arc welding machine for durability and integrity. Experimental trials were conducted varying sample mass (1000–3000 g) and air flow rate (0.4–0.6 kg/h) to assess the drying rate and drying efficiency of cocoa seeds under controlled solar drying conditions. Results demonstrated significant effects of both mass of sample and air flow rate on drying performance, with drying rates ranging from 0.024 to 0.042 kg/h and drying efficiencies between 78.3% and 96.3%. Statistical analysis using ANOVA highlighted the significance of the model ($p < 0.0001$) in influencing drying rate and efficiency, with no significant lack of fit, confirming the reliability of the experimental design. The optimized conditions suggested that lower mass and moderate air flow improved drying efficiency, thereby expediting the drying process while preserving seed quality. This prototype offers a sustainable alternative to conventional drying methods by harnessing solar energy, potentially reducing post-harvest losses and enhancing cocoa production efficiency in regions with abundant solar resources.

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CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Cocoa (Theobroma cacao) is a vital cash crop in Nigeria and many other tropical countries, contributing significantly to income generation, employment, and export earnings. After harvesting, cocoa beans must be properly dried to reduce their moisture content and improve their storage stability, flavor development, and resistance to mold (FAO, 2017). Traditionally, cocoa beans are sun-dried, a process that is highly dependent on weather conditions and time-consuming, often leading to poor-quality beans due to contamination, uneven drying, or fermentation issues (UNIDO, 2015).

The integration of technology into post-harvest processing has brought new solutions to age-old challenges. One such innovation is the development of solar-powered dryers. These systems utilize solar energy—a clean, renewable, and cost-effective source—to facilitate the drying of agricultural products (Tiwari & Jain, 2007). When combined with automation, solar dryers can become more efficient, reliable, and user-friendly (Mohammed et al., 2021).

This project focuses on the design and fabrication of a prototype automated solar-powered cocoa seed dryer to enhance the drying process by minimizing human intervention, improving drying efficiency, ensuring consistent moisture reduction, and preserving the quality of the cocoa beans.

1.2 Problem Statement

Traditional cocoa drying methods are fraught with several challenges:

- Inconsistency in drying due to weather fluctuations
- High labor input and time consumption
- Risk of contamination from dust, insects, and animals
- Over-drying or under-drying leading to quality degradation (FAO, 2017)

There is a pressing need for an improved drying system that addresses these issues using sustainable and energy-efficient methods. An automated solar-powered dryer provides a promising solution (Ogunlade et al., 2020).

1.3 Aim and Objectives of the Study

Aim:

To design and fabricate a prototype of an automated solar-powered dryer for cocoa seeds that improves drying efficiency and maintains product quality.

Objectives:

- To design a solar-powered drying chamber suitable for cocoa seeds
- To incorporate an automated temperature and humidity control system
- To fabricate the prototype using locally available materials

- To evaluate the performance of the prototype in terms of drying time and moisture content reduction

1.4 Justification of the Study

This study is justified by the increasing need for effective post-harvest technology in agricultural production. By providing a reliable and eco-friendly alternative to traditional drying methods, this project aims to:

- Improve cocoa quality and market value
- Reduce post-harvest losses (UNIDO, 2015)
- Promote the use of renewable energy in agriculture (Tiwari & Jain, 2007)
- Support smallholder farmers with low-cost drying solutions

1.5 Scope of the Study

The scope of this project is limited to the design and fabrication of a prototype dryer using solar energy with an automated control system for cocoa seeds. It includes design analysis, material selection, construction, and preliminary performance testing.

CHAPTER TWO: LITERATURE REVIEW

2.1 Cocoa Production and Post-Harvest Processing

Cocoa is a major cash crop in tropical regions, especially in West Africa, accounting for over 70% of global production. Post-harvest processing of cocoa involves fermentation, drying, and storage. Drying is crucial for reducing the moisture content of beans from about 60% to 6-7%, which is optimal for storage and further processing. Improper drying can lead to mold growth, poor flavor, and decreased market value (FAO, 2017).

2.2 Traditional Methods of Cocoa Drying

Traditional drying methods involve spreading the cocoa beans under the sun on mats, tarpaulins, or raised platforms. Although low-cost, this method is labor-intensive and weather-dependent, often resulting in uneven drying and contamination (UNIDO, 2015). During the rainy season, drying is especially problematic, leading to delays and spoilage.

2.3 Solar Drying Technology

Solar dryers use solar energy to heat air, which is then circulated through a drying chamber containing the agricultural product. Types of solar dryers include:

- Direct solar dryers (where sunlight directly heats the product)
- Indirect solar dryers (where sunlight heats air, which then dries the product)
- Mixed-mode dryers (combining both approaches)

Solar drying has proven effective in reducing drying time, protecting products from contamination, and improving product quality (Tiwari & Jain, 2007). It is especially suitable for rural areas with abundant sunlight.

2.4 Automation in Drying Systems

Automated drying systems use sensors and microcontrollers to monitor and regulate key drying parameters such as temperature and humidity. Automation:

- Reduces labor requirements
- Prevents over-drying
- Enhances drying uniformity
- Improves energy efficiency (Mohammed et al., 2021)

In this project, automation will involve using temperature and humidity sensors connected to a microcontroller (e.g., Arduino) that controls fans or vents accordingly.

2.5 Related Works

Several studies have been conducted on the development of solar dryers for agricultural products:

- Adeyemi et al. (2018) developed a mixed-mode solar dryer for cassava chips and reported a 40% reduction in drying time compared to open sun drying.
- Ogunlade et al. (2020) implemented a hybrid solar-electric dryer for cocoa beans,

showing improved drying consistency and reduced mold incidence.

- Mohammed et al. (2021) designed an automated solar dryer using Arduino with promising results for tomato drying.

These studies support the feasibility and benefits of solar drying and automation in agricultural processing.

2.6 Gaps in the Literature

While there is extensive work on solar dryers and automation in agriculture, few designs are specifically optimized for cocoa seeds, and even fewer prototypes are automated and affordable for local farmers (Ogunlade et al., 2020). This project aims to bridge that gap by providing a low-cost, efficient, and scalable solution.

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CHAPTER THREE

Materials and Methods

3.1 Design Considerations

The Hybrid dryer design was influenced by the following factors:

- The quantity of moisture that needs to be taken out of a specific amount of cocoa bean.
- The period of time during which the drying is needed.
- The number of hours of sunlight per day for determining the total drying time.
- The amount of air required for drying.
- The daily solar radiation to determine the energy received by the dryer per day.

3.2 Description of the Hybrid Dryer

The dryer is composed of a solar collector (triangular prism) and a solar drying chamber constraining rack of drying trays both being integrated. The air allowed in through the air inlet is heated up in the solar collector and channeled through the drying chamber where it is utilized in drying the cocoa bean. The dimensions of the drying chamber so designed were 62cm x 50cm (length x width), the solar collector so designed were 40cm x 50cm x 25cm (height x base x width). The locally available materials that was used for the construction were glass collectors, mild steel sheets, fiberglass, square pipe, angle iron, silicon gum, hinges & locks, and consumables.

3.2.1 Collector

Collector captures solar energy and convert it into heat. The transparent top of the dryer which was made of glass, acts as the collector. It allows sunlight to pass through and heat the air inside the dryer.

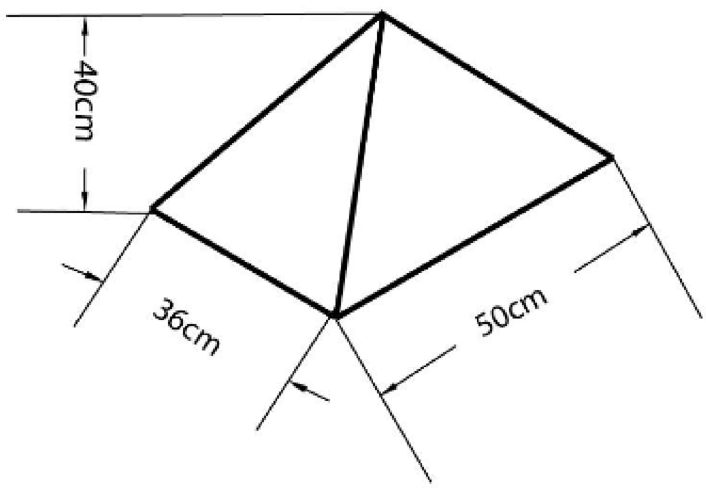


Figure 3.1 Collector

3.2.2 Drying chamber

Drying chamber houses the cocoa bean to be dried. This is the enclosed space where the cocoa bean is placed on trays. It’s designed to retain heat and provide a controlled environment for drying. The dark colour of the interior enhances heat absorption.

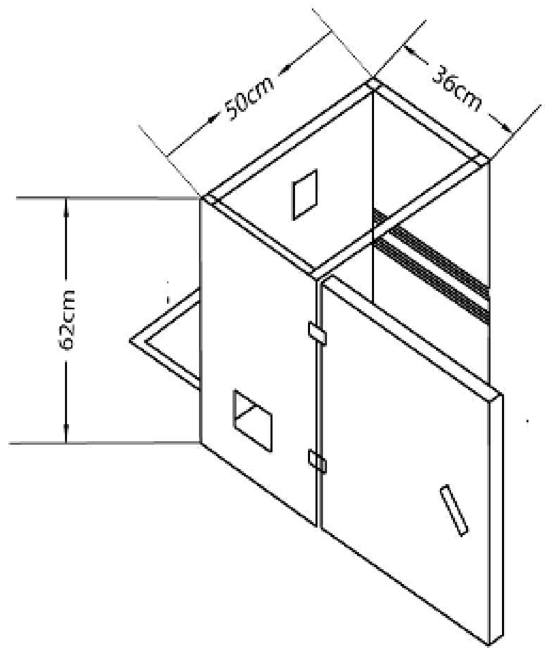


Figure 3.2 Drying chamber

3.2.3 Trays

Trays holds the cocoa bean to be dried. These trays were made of metal mesh to allow for good airflow and even drying. The cocoa bean was spread out on the trays to maximize exposure to the hot air.

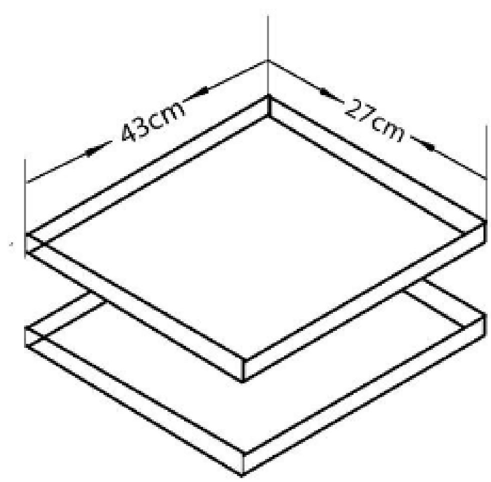


Figure 3.3 Trays

3.2.4 Fans

The fan circulate air within the dryer. The capacity of the fan is 0.44A(amps) and 12V. There was three fans in this design;

Side fans: These two fans draws in fresh, outside air into the dryer, helping to maintain humidity levels and prevent moisture buildup.

Top fan: This fan extracts moisture-laden air from the drying chamber, accelerating the drying process and creating negative pressure to pull in more air.

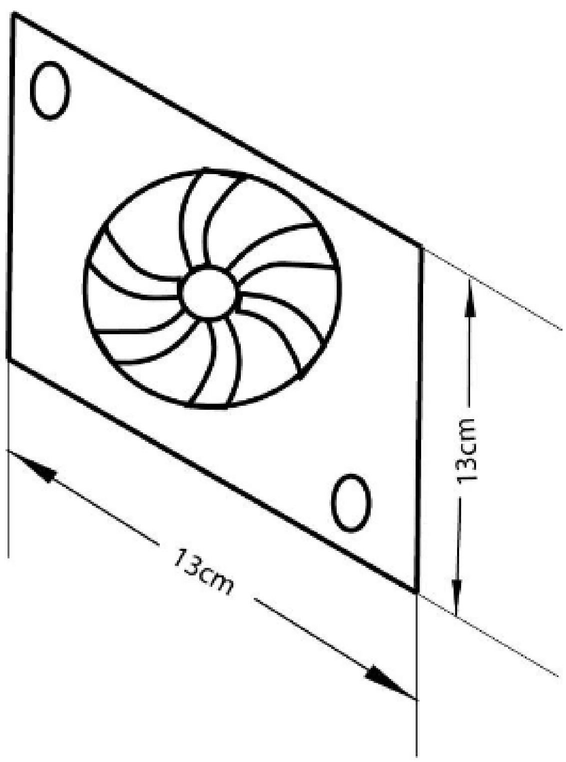


Figure 3.4 Fan

3.2.5 Frame

The frame provides structural support for the dryer. It was made of metal and gives the dryer its shape and stability.

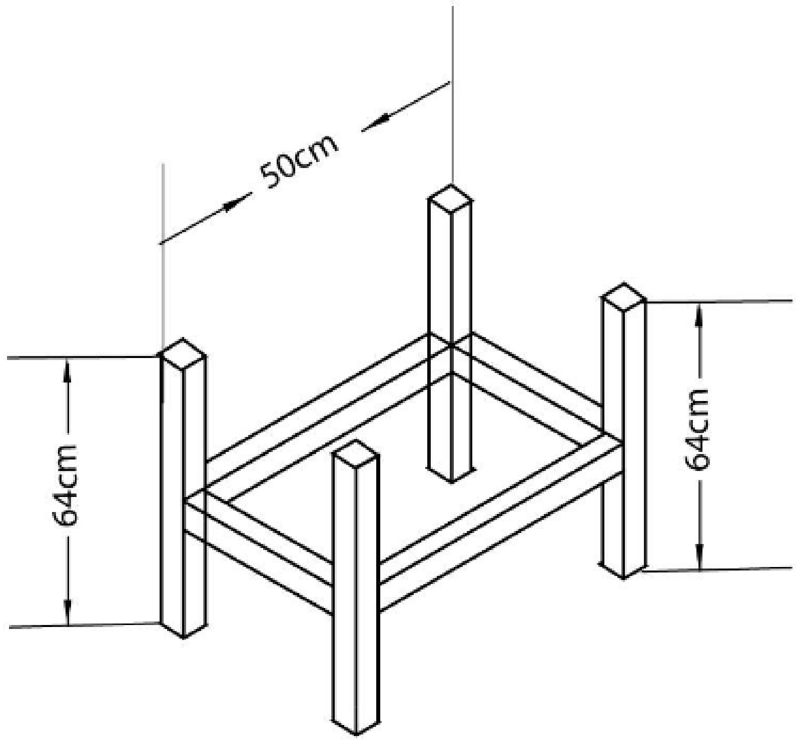


Figure 3.5 Frame

3.2.6 Monitoring equipment

It monitors conditions of the environment. It includes instruments to measure temperature and relative humidity of the environment. The monitoring equipment houses charge controller, solar battery, hygrometer and thermometer.

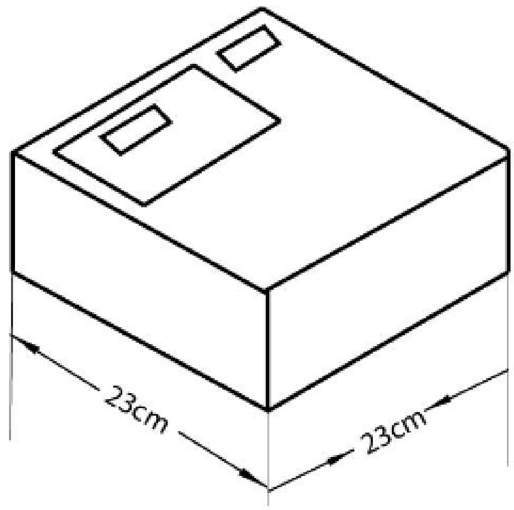


Figure 3.6 Monitoring equipment

3.2.7 Hinges and locks

Hinges are used to attach the door of the hybrid dryer together. It allows the panels to open and close smoothly, making it easy to access the contents of the dryer. Locks were used to secure the door of the hybrid dryer when it is closed. This helps to protect the products inside the dryer from the elements and theft.

3.2.8 Solar battery

A Panasonic 12V 7Ah lead- acid battery was used because of its affordability and reliability. It stores the energy generated by the solar panel for use when there is no sunlight.

3.2.9 Solar panel

It collects energy from the sun in form of sunlight which will help power the monitoring instrument.

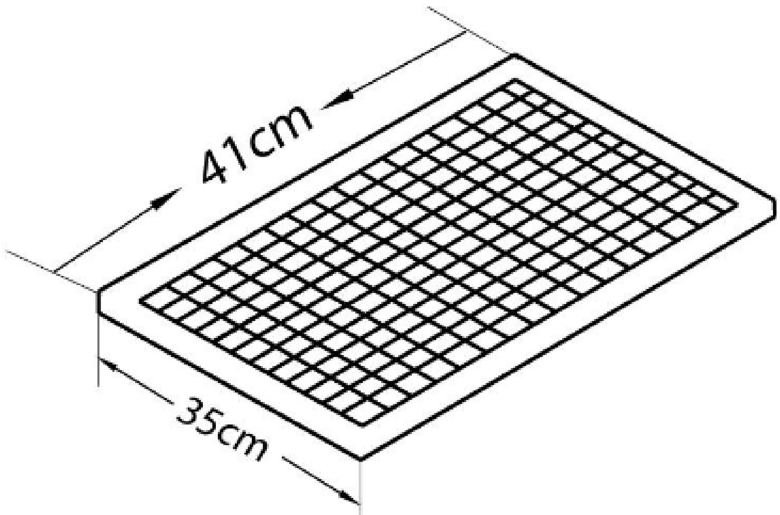


Figure 3.7 Solar panel

3.2.10 Charge controller

The charge controller maintains batteries at their highest state of charge without overcharging them to avoid gassing and battery damage.

3.3. Hybrid Dryer Parts Design

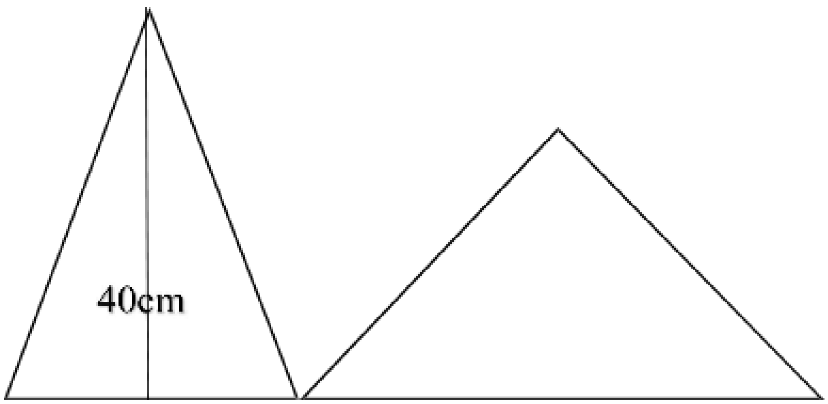
(a) Solar collector area

The solar collector is a triangular prism and it is an isosceles triangle. The solar collector area is given by;

Total surface area = 2 x (area of triangular base) + 3 x (area of rectangular side)

(3.01) Area of the isosceles triangle base = (√3/4) x side2(3.02)

Area of the rectangular sides = length x width(3.03)



25cm50cm

Side view of the collectorfront view of the collector Where;

Base of the isosceles triangle = 50cm

Height of the isosceles triangle = 40cm

Width = 25cm

Area of the rectangular sides = 25cm x 40cm = 1000cm2

Area of the isosceles triangle base = (√3/4) x $(50cm)^2$

=1082.53 Total surface area = 2 x (1082.53) + 3 x (1000) =

5165.06cm2

(b) Absorber Surface Area,

The surface area of the absorber Aab is approximately equal to the area of the collector surface area, Ac; this is related to the length, Lc and width, W of the solar collector as follows:

$A_{ab} = L_c \times W$ (3.04)

L_c = height of prism + height of drying chamber

= 40cm + 62cm = 102cm

$A_{ab} = 102 \times 50$

$= 5100cm^2$

A_{ab} = Absorber surface area of the

collector L_c = Length of the collector

W = Width

(c) **The total area of the dryer,**

Area of the dryer (rectangle) = $L \times H$ (3.05)

$= 62 \times 50$

$= 3100cm^2$

L = length of the

dryer H = Height

3.4 Moisture Content (M.C.):

The moisture content is given as:

$$MC(\%) = \frac{Mi - Mf}{Mi} \times 100\%; \text{ wet basis} \quad (3.06)$$

Where;

Mi = mass of sample before drying

and Mf = mass of sample after

drying.

3.5 The mass of water evaporated or moisture loss

Moisture loss is given as;

$$mw = mi \left[\frac{Mi - Me}{100 - Me} \right] \quad (3.07)$$

Where:

mi= initial mass of the food item (kg);

Me = equilibrium moisture content (% dry basis); Mi= initial moisture content (% dry basis).

Also this can still be obtained by using equation 3.05

$$mw = (mi - mf) \quad (3.08)$$

Where;

mi is the mass of the sample before

drying mf is the mass of the sample

after drying

3.6 Average drying rate

Mdr, would be determined from the mass of moisture to be removed by the solar heater and drying time by the following equation:

Mdr = Mw

td

(3.09)

Where:

Mdr = average drying rate, kg/hour;

Mw = mass of wet products

and td = overall drying time

3.7 Principle of Operation of the Hybrid Dryer

Solar energy is captured by the collector in form of sunlight which heats the air inside the dryer. The side fans bring in fresh air while the top fan extracts moist air, creating a continuous airflow. The hot air then circulates around the products, removing moisture and drying it. A humidity sensor and temperature sensor is used to monitor the environment temperature and relative humidity and controls the drying process.

3.8 Experimental procedure

The apparatus used in this experiment were stopwatch, which was used for taking more accurate timing, weighing scale, cocoa bean, grain moisture-meter and the solar dryer.

The solar dryer consists of two trays, two fans for blowing air into the dryer, a fan for sucking the air out of the machine.

The machine was firstly test run with small quantity of cocoa before the main drying to know if there was any fault or any adjustment to be made.

The dryer was placed to face the direction of the sun. The three fans were switched on, the speed of the fans blowing air inside the solar dryer was regulated to be at an average.

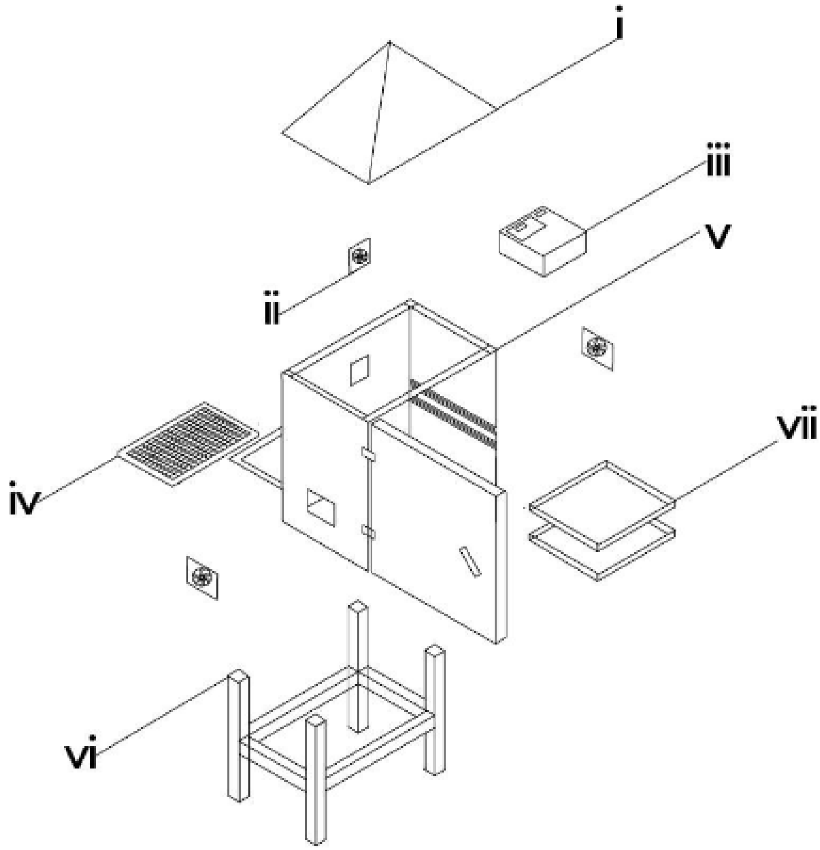
The wet cocoa bean was weighed and the moisture content was known and recorded. The two trays were brought out and the weight of the trays were known and recorded. Tray 1and tray 2 were filled with an equal amount of wet cocoa bean and the weight of the trays filled with wet cocoa bean was recorded, the trays were then placed in the solar dryer. The temperature and relative humidity was recorded as well. The stopwatch was set at an interval of one hour.

After an hour, the trays were brought out to be weighed, and they were placed back after weighing. Then, the temperature and relative humidity was recorded. The stopwatch was set to an interval of an hour again.

This procedure was repeated till the wet cocoa bean was dried to a constant weight three times.

3.9 Material used for construction of solar dryer

- Mild steel sheet
- Square pipe
- Glass collector
- Angle iron
- Fibre glass
- Silicon gum
- Hinges & locks
- Consumables
- 12V 7ah battery
- Dc fan
- 20w solar panel
- Temperature and humidity sensor
- Box
- Wires and clips
- Charge controller



MACHINE PARTS' LIST		
S/N	KEY S	PARTS' NAME
1	I	COLLECTOR
2	II	FAN
3	III	MONITORING EQUIPMENT
4	IV	SOLAR PANEL
5	V	DRYING CHAMBER
6	VI	FRAME
7	VII	TRAYS

Figure 3.8 Exploded view and labeling of components of the hybrid

dryer.

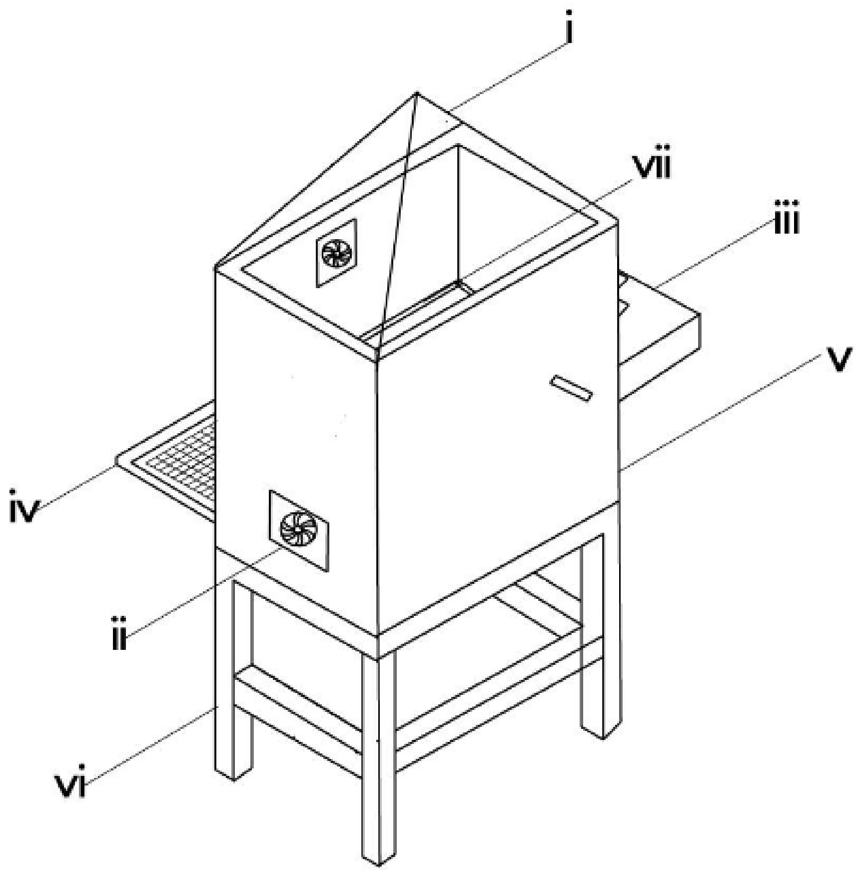


Figure 3.9 Isometric view of hybrid dryer

MACHINE PARTS' LIST		
S/N	KEYS	PARTS' NAME
1	I	COLLECTOR
2	II	FAN
3	III	MONITORING EQUIPMENT
4	IV	SOLAR PANEL

5	V	DRYING CHAMBER
6	VI	FRAME
7	VII	TRAYS

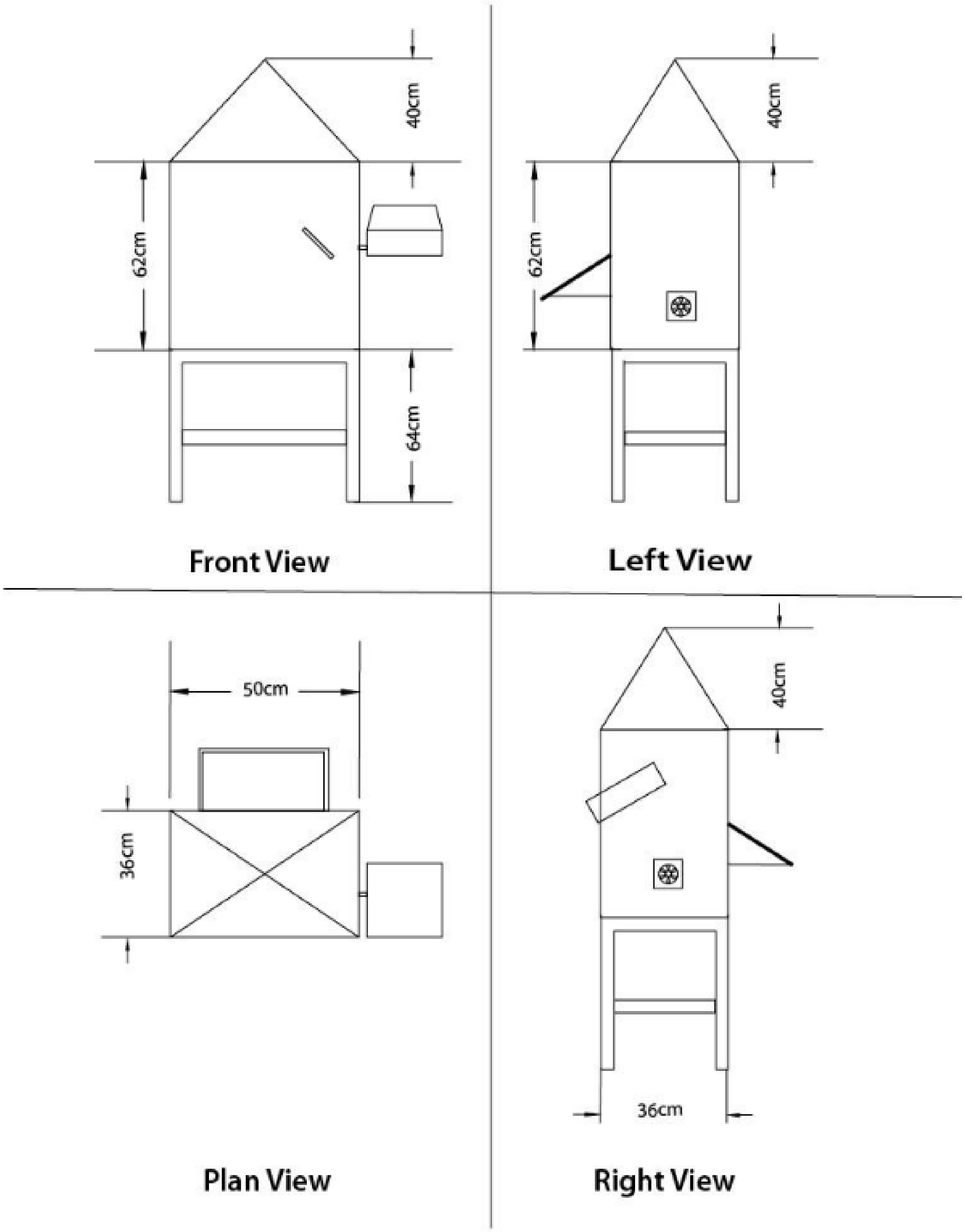


Figure 3.10 Views of The Machine Drawing

3.10Tools and Equipment

1. Electric Arc Welding Machine: it was employed during the fabrication of the drying chamber, supporting frame and tray assembly. It was used to join metal components with high strength and durability ensuring structural integrity of the dryer.

2. Grinder/Cutting Machine: It is a power tool with a rotating abrasive disc or blade which was used for cutting and smoothing metal.It is used to cut metal sheets, pipes, or rods to required sizes and for grinding welds to smooth finishes.

3. Drilling Machine: It is a machine tool which was used for used to drill holes into materials (metal, wood, etc.). It is used to create holes for bolts, screws, or other fittings in your project components.

4. Screwdriver Set: It is a set of hand tools with different tips (flat, Phillips, etc.) which was used for driving screws. It is used for tightening or loosening screws during assembly or adjustments of electrical and mechanical parts.

5. Spanner Set: It is a set of tools which was used for for tightening or loosening nuts and bolts. It is essential for assembling and disassembling mechanical parts such as frames, joints, or supports.

6. Multimeter (for testing connections): it is an electronic measuring instrument that combines several functions (voltage, current, resistance testing). It was used to check electrical circuits, test battery voltage, or ensure proper connections in the solar-powered system

7. Pliers: It is a hand tool with gripping jaws, sometimes with cutting edges.it was used for holding objects firmly, bending wires, or cutting small materials.

8. Measuring Tape: It is a flexible ruler used to measure distances or dimensions. It is used to take accurate measurements of components during fabrication or assembly.

9. File (for finishing edges):It is a hand tool with a roughened surface used for smoothing or shaping metal.It is used to smoothen sharp edges after cutting or welding metal parts.

10. Paintbrush/Spray Gun: it is a tool used to apply paint or protective coatings. It is used for finishing touches to protect metal surfaces from rust and improve aesthetics.

11. Soldering Iron (for electronic parts): It is a hand tool that heats up to melt solder (a metal alloy) for joining electronic components. It is used in assembling or repairing the electronic parts of your project like sensors, circuits, or connections.

Plate 3.1a:Electric Arc Weldingplate 3.1b: Grinding

Plate 3.1c: Thong   plate 3.1d Electrodes

Small GrinderHammer

3.11Design Layout

The experimental design for this study was structured using a two factor factorial design to evaluate the effect of the drying parameters on the drying rate and drying efficiency of cocoa seeds. The factors and responses are presented as follows:

i. Mass of Sample (g)

ii. Air flow rate (m^3/s)

2. Experimental Responses (Dependent Variables)

Two performance indicators were monitored during the drying process:

i. Drying Rate (kg/h): measured as the rate at which moisture was removed from the cocoa seeds.

ii. Drying efficiency (%): calculated as the ratio of useful energy utilized for moisture removal to the total energy supplied.

3. Experimental Runs

A total of 13 experimental runs were carrid out as presented in Table 3.1. The runs were randomized to minimize the experimental bias and ensure the independence of observations. The experimental matrix includes various combinations of the two factors and their respective levels.

Table 3.1shows the experimental design matrix with the factors and responses for the cocoa seed drying process

		Factor 1	Factor 2	Response 1	Response 2
Std	Run	A:Mass of Sample	B:Air Flow Rate	Drying Rate	Drying Efficiency
		g		Kg/h	%
3	1	1000	0.6		
9	2	2000	0.5		
12	3	2000	0.5		
7	4	2000	0.4		
4	5	3000	0.6		
2	6	3000	0.4		
13	7	2000	0.5		
1	8	1000	0.4		
11	9	2000	0.5		
5	10	1000	0.5		
10	11	2000	0.5		

6	1 2	3000	0.5		
8	1 3	2000	0.6		

CHAPTER FOUR

Results and Discussion

4.1 Result

The result obtained from the testing of the fabricated hybrid dryer for cocoa bean were presented in table 4.1 below.

Table 4.1: Summary of Result of Cocoa Drying Using the Fabricated Hybrid Solar Dryer

Run	Mass of Sample (g)	Air Flow Rate (kg/h)	Drying Rate (kg/h)	Drying Efficiency (%)
1	1000	0.6	0.042	78.3
2	2000	0.5	0.033	87.6
3	2000	0.5	0.033	87.6
4	2000	0.4	0.029	91.2
5	3000	0.6	0.031	89.2
6	3000	0.4	0.024	96.3
7	2000	0.5	0.034	86.1
8	1000	0.4	0.035	85.4
9	2000	0.5	0.031	89.2
10	1000	0.5	0.037	83.9
11	2000	0.5	0.033	87.6
12	3000	0.5	0.027	92.8
13	2000	0.6	0.036	84.1

4.2 Discussion

The results obtained from testing the hybrid dryer were presented in table 4.1 above. From the table, it was observed that different mass of sample and airflow rate gave different drying rate and drying efficiency respectively. It was also observed that an increase in mass of sample at the same air flow rate gave a decrease in the drying rate and drying efficiency while an increase in the air flow rate at the same mass of sample gave an increase in drying rate and drying efficiency. This could be attributed to the ease of moisture migration within the sample at higher air flow rate. The analysis of variance (ANOVA) for the drying rate and drying efficiency of cocoa bean is presented in table 4.2 and 4.3 below respectively.

Table 4.2: Analysis of Variance (ANOVA) for the Drying Rate of Cocoa Bean

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0002	2	0.0001	184.90	< 0.0001	significant
A-Mass of Sample	0.0002	1	0.0002	258.49	< 0.0001	
B-Air Flow Rate	0.0001	1	0.0001	111.32	< 0.0001	
Residual	6.603E-06	10	6.603E-07			
Lack of Fit	1.803E-06	6	3.004E-07	0.2504	0.9353	not significant
Pure Error	4.800E-06	4	1.200E-06			

Cor Total	0.0003	12				

***Significant @P≤0.05**

From table 4.2 above, the p value < 0.0001 shows that the model is significant being far below 0.05. this indicates that the selected factors of mass of sample and air flow rates have a great effect on the drying rate of cocoa bean. The graphical representation is shown in figure 4.1 below.

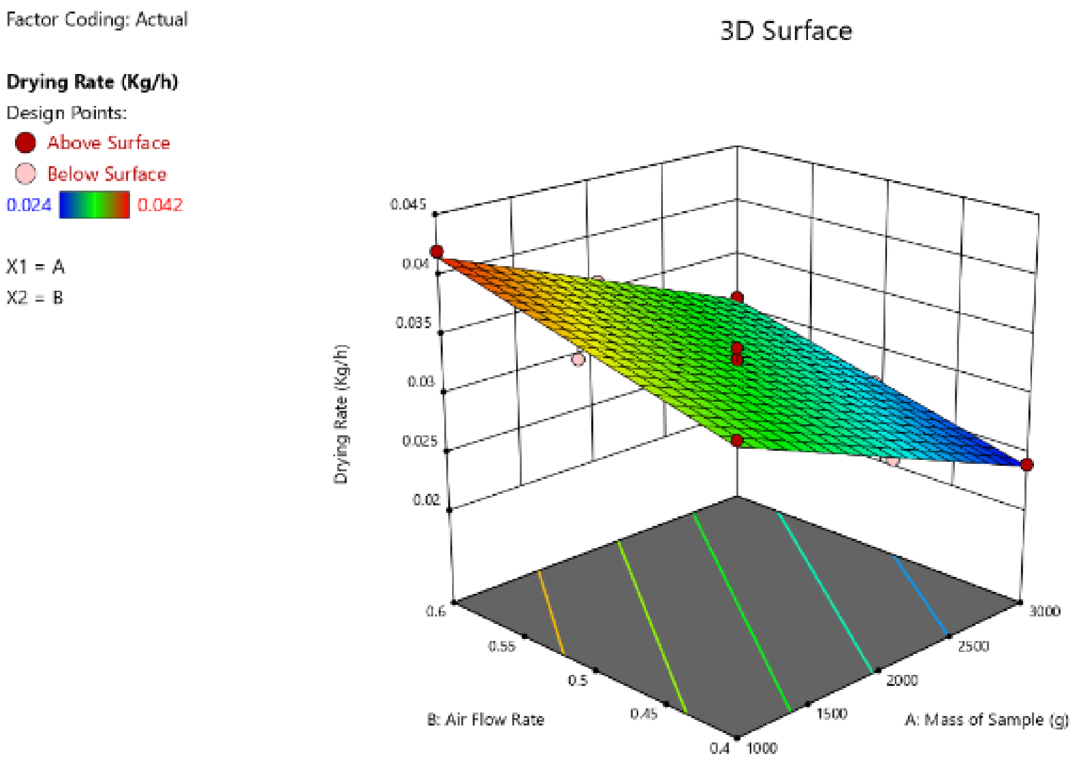


Fig 4.1: Effect of Air Flow Rate and Mass of Sample on the Drying Rate of Cocoa

Table 4.3: Analysis of Variance (ANOVA) for the Drying Efficiency of Cocoa Bean

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	232.70	2	116.35	152.81	< 0.0001	Significant
A-Mass of Sample	157.08	1	157.08	206.30	< 0.0001	
B-Air Flow Rate	75.62	1	75.62	99.31	< 0.0001	
Residual	7.61	10	0.7614			
Lack of Fit	2.81	6	0.4677	0.3891	0.8551	not significant
Pure Error	4.81	4	1.20			
Cor Total	240.31	12				

***Significant @P≤0.05**

From table 4.3 above, the p value < 0.0001 shows that the model is significant being far below 0.05. this indicates that the selected factors of mass of sample and air flow rates have a great effect on the drying efficiency of cocoa bean. The graphical representation is shown in figure 4.2 below.

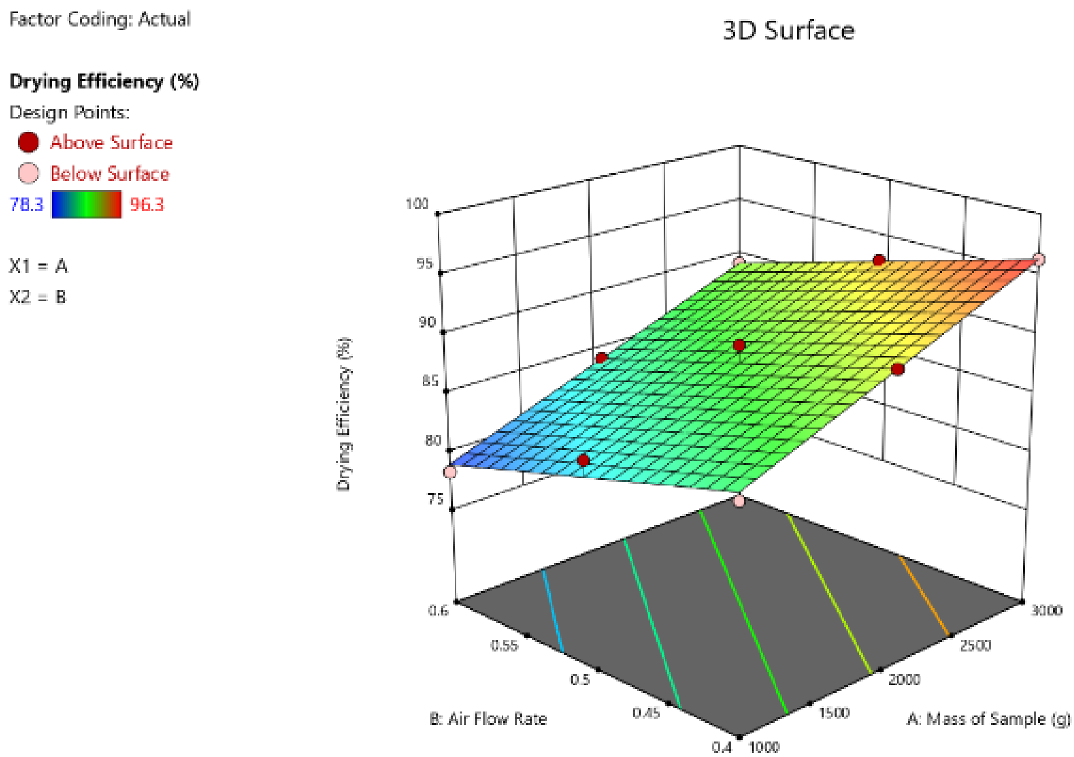


Fig 4.2: Effect of Air Flow Rate and Mass of Sample on the Drying Efficiency of Cocoa

Chapter Five

Conclusion and Recommendation

5.1Conclusion

A hybrid dryer which combines direct solar drying for drying with solar panel powered system for air flow was designed and fabricated in the department of agricultural and bio-environmental engineering technology, institute of technology, kwara state polytechnic, Ilorin. The dryer was able to dry wet cocoa bean effectively.

5.2Recommendation

The following recommendations were drawn from the study

1. It is recommended that a load cell with Personal Computer interface should be incorporated into the drying chamber to know the weight of products in the dryer at every time interval.
2. It is recommended that a wheel (Tyre) should be at the stand of the dryer for easy movement.
3. The size of the drying chamber should increase for large scale drying, as well as the size of solar panel and capacity of the battery.

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