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

BY:

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ND/22/ABE/FT/0036

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

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CERTIFICATION

This is to certify that this project title, Design and Fabrication of a Prototype Automated Solar Powered Cocoa Seed Dryer Submitted by AWILAGBARA EMMANUEL SEGUN with Matric number **ND/22/ABE/FT/0036** was carried out under my Supervision at the Depart ment of Agricultural and Bio-environmental Engineering Technology, Institute of Technol ogy, Kwara State Polytechnic, Ilorin. This Project report has been read and approved havi ng met the requirement for the award of National Diploma (ND) in Agricultural and Bio-e nvironmental 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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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.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Cocoa beans are a vital agricultural commodity, serving as the raw material for chocolate production. Ensuring the quality and safety of cocoa beans during drying and storage is crucial to meet the demands of both local and international markets (Hii et al., 2012)

Traditional drying methods, such as sun drying, have several limitations, including weather dependence, labor intensity, and difficulty in controlling quality (Kalogirou, 2014) .Drying is a critical step in cocoa production, reducing moisture content and preventing mold growth. Proper drying techniques are essential to maintain bean quality and meet international standards. Traditional drying methods, such as sun drying, have several limitations, including weather dependence, labor intensity, and difficulty in controlling quality (Kalogirou, 2014).

Cocoa beans are a vital commodity for many countries, particularly in West Africa, where they are a major source of income for farmers. However, the drying process of cocoa beans is a critical step in preserving their quality and preventing spoilage. Traditional drying methods, such as sun drying, are often labor-intensive and weather-dependent, making them less reliable (Hii et al., 2012)

Automated solar dryers offer a promising solution to these challenges by providing a controlled drying environment that can optimize the drying process and improve product quality. However, traditional drying methods often result in inconsistent product quality and can be time-consuming. Automated solar dryers can provide several benefits over traditional drying methods, including improved efficiency, reduced labor requirements, and enhanced product quality (Kumar et al., 2016).

Automated solar drying systems offer a potential solution to these challenges. These systems can provide consistent drying conditions, reduce labor requirements, and improve drying efficiency.

By leveraging solar energy, these systems can also reduce energy costs and environmental impact [3].solar drying systems can significantly improve drying efficiency and reduce drying times. For example, a study on the optimization of direct solar drying for cocoa beans using artificial intelligence found that the system can improve efficiency compared to conventional methods [1].These dryers can also reduce the risk of contamination and spoilage, resulting in higher-quality products.

1.2 Problem statement of the study

Cocoa seed drying, a critical step in cocoa processing, is often hindered by unreliable and inefficient traditional drying methods, resulting in poor quality cocoa beans, reduced yields, and economic losses for small-scale cocoa farmers, thereby necessitating the development of a sustainable and energy-efficient drying solution."

1.3 Aim and objectives of the study

The main aim the project is to design and develop an innovative solar –powered cocoa seed with automated temperature control and battery backup While:

Specific Objective

This study objectives are to evaluate the quality of cocoa beans after continuous drying, investigate the effects of continuous drying on cocoa's physical, chemical, and sensory properties, and identify the optimal continuous drying conditions for maintaining high-quality cocoa beans.

1.4 Scope of the study

The scope of this study is to design and develop a solar-powered cocoa seed dryer with temperature control and battery backup, and to evaluate its performance in terms of drying time, energy efficiency, and cocoa seed quality. The study will focus on small-scale cocoa farmers and will investigate the economic viability of the solar-powered dryer.

1.5 Justification of the study

The justification for this study is multifaceted, driven by the need to improve cocoa quality, address energy poverty, enhance sustainability, support small-scale farmers, and fill a knowledge gap in the use of solar-powered dryers in cocoa production, ultimately contributing to the development of a reliable and efficient solar-powered cocoa seed dryer with temperature control and battery backup.

2.0 CHAPTER TWO

2.1 Introduction to Automated Solar Cocoa Seed Dryers

Automated solar cocoa seed dryers represent a significant advancement in the post-harvest processing of cocoa beans, offering a sustainable and efficient solution for drying cocoa seeds. These dryers utilize solar energy to reduce moisture content, thereby preserving the quality and extending the shelf life of the cocoa beans (Adebayo & Adeyemi, 2017). The integration of automation technologies further enhances the drying process by ensuring optimal conditions are maintained, reducing labor requirements, and improving overall efficiency.

2.1.1 Importance of Efficient Drying

Efficient drying is crucial for maintaining the quality of cocoa beans. Moisture content must be reduced to safe levels to prevent mold growth and spoilage, which can lead to significant economic losses for farmers and processors (Hii et al., 2012) .Traditional drying methods, such as sun drying, are often labor-intensive and weather-dependent, making them less reliable. Automated solar dryers address these challenges by providing a controlled drying environment that can be optimized for specific conditions.

2.1.2 Benefits of Automated Solar Dryers

Automated solar dryers offer several benefits over traditional drying methods. They reduce the dependency on fossil fuels, lower operational costs, and minimize environmental impact (Kalogirou, 2014)]. Additionally, these dryers can improve the quality of the dried product by maintaining consistent temperatures and airflow, which is critical for preserving the flavor and nutritional value of cocoa beans.

2.1.3 Challenges in Cocoa Drying

Despite the benefits, there are challenges associated with drying cocoa beans, including the risk of over-drying or under-drying, which can affect the quality of the final product (Shanmugam & Natarajan, 2007).

Automated solar dryers can mitigate these risks by providing precise control over the drying process, ensuring that the cocoa beans are dried to the optimal moisture level.

2.1.4 Future Directions

The development of automated solar cocoa seed dryers is an area of ongoing research and innovation. Future directions may include the integration of advanced sensors and artificial intelligence to further optimize the drying process and improve energy efficiency (Kumar et al., 2016). Additionally, there is potential for these dryers to be adapted for use with other agricultural products, expanding their applicability and impact.

2.2 Design Considerations for Automated Solar Cocoa Seed Dryers

The design of automated solar cocoa seed dryers involves several critical considerations to ensure efficient and effective drying. These considerations include the type of solar collector, drying chamber design, automation and control systems, and energy storage options.

2.2.1 Solar Collector Design

The solar collector is a crucial component of a solar dryer, responsible for capturing solar radiation and converting it into heat energy. There are several types of solar collectors that can be used in solar dryers, including flat plate collectors, evacuated tube collectors, and concentrating collectors (Kalogirou, 2014). The choice of solar collector depends on the specific requirements of the drying application and the climate conditions.

- Flat Plate Collectors: Flat plate collectors are commonly used in solar dryers due to their simplicity and effectiveness (Duffie & Beckman, 2013). They consist of a flat plate absorber that absorbs solar radiation and transfers the heat to a fluid, which is then used to heat the drying air.

- Evacuated Tube Collectors: Evacuated tube collectors are more efficient and can operate at higher temperatures, making them suitable for applications that require higher drying temperatures (Kumar et al., 2016).

2.2.2 Drying Chamber Design

The drying chamber is another critical component of a solar dryer, responsible for holding the cocoa beans and allowing them to dry. The design of the drying chamber should ensure uniform airflow and temperature distribution, as well as adequate ventilation to remove moisture (Hii et al., 2012).

- Size and Shape: The size and shape of the drying chamber can impact the performance of the solar dryer, with larger chambers accommodating more cocoa beans but requiring more energy to heat.

- Materials: The materials used in the construction of the drying chamber should be durable, corrosion-resistant, and able to withstand the operating temperatures (Adebayo & Adeyemi, 2017).

2.2.3 Automation and Control Systems

Automation and control systems are essential components of an automated solar cocoa seed dryer, responsible for monitoring and controlling the drying process. These systems can include sensors to monitor temperature, humidity, and airflow, as well as actuators to control the drying conditions (Kumar et al., 2016).

- Sensors and Actuators: The use of sensors and actuators can improve the efficiency and effectiveness of the drying process, reducing labor requirements and improving product quality.

2.2.4 Energy Storage Options

Energy storage options are important considerations in the design of automated solar cocoa seed dryers, as they can provide backup power during periods of low sunlight or at night. Batteries are a common energy storage option, but other options such as thermal energy storage and phase change materials can also be used (Duffie & Beckman, 2013)

2.3 System Components of Automated Solar Cocoa Seed Dryers

Automated solar cocoa seed dryers consist of several key components that work together to dry cocoa beans efficiently. These components include:

1. Solar Collector

The solar collector is a critical component of a solar dryer, responsible for capturing solar radiation and converting it into heat energy. There are several types of solar collectors that can be used in solar dryers, including flat plate collectors, evacuated tube collectors, and concentrating collectors (Kalogirou, 2014)

2. Drying Chamber

The drying chamber is designed to hold the cocoa beans and allow them to dry. It should be well-insulated to minimize heat losses and ensure uniform airflow. The drying chamber can be designed with multiple trays to increase the drying capacity (Hii et al., 2012).

3. Fans and Airflow System

Fans and airflow systems are used to circulate hot air through the drying chamber, ensuring that the cocoa beans dry evenly. DC-powered fans are often used in solar dryers due to their energy efficiency (Kumar et al., 2016).

4. Control and Monitoring System

The control and monitoring system is responsible for regulating the drying process and ensuring that the cocoa beans are dried to the optimal moisture level. This system can include sensors to monitor temperature, humidity, and airflow, as well as actuators to control the drying conditions (Shanmugam & Natarajan, 2007).

5. Energy Storage System

An energy storage system, such as batteries, can be used to provide backup power during periods of low sunlight or at night. This ensures that the drying process can continue uninterrupted (Duffie & Beckman, 2013)

2.3.1 Design Considerations

When designing an automated solar cocoa seed dryer, several factors should be considered, including:

- Climate and Weather Conditions: The design should take into account the local climate and weather conditions, including temperature, humidity, and solar radiation.

- Drying Capacity: The drying capacity of the dryer should be sufficient to meet the needs of the user.

- Energy Efficiency: The dryer should be designed to maximize energy efficiency and minimize energy losses.

2.3.2 Benefits of Automated Solar Cocoa Seed Dryers

Automated solar cocoa seed dryers offer several benefits, including:

- Improved Drying Efficiency: Automated solar dryers can dry cocoa beans more efficiently than traditional drying methods.

- Reduced Labor Requirements: Automated solar dryers can reduce labor requirements and improve productivity.

- Improved Product Quality: Automated solar dryers can improve the quality of the dried product by maintaining consistent drying conditions.

2.4 Automation and Control Strategies in Solar Dryers

Automation and control strategies play a crucial role in optimizing the performance of solar dryers. By integrating sensors, microcontrollers, and other automation technologies, solar dryers can maintain optimal drying conditions, reduce energy consumption, and improve product quality.

2.4.1 Types of Automation and Control Strategies

There are several types of automation and control strategies that can be used in solar dryers, including:

- Temperature Control: Temperature control is critical in solar dryers, as it directly affects the drying rate and product quality. Sensors can be used to monitor temperature levels, and microcontrollers can adjust the heating element or airflow to maintain optimal temperatures (Kalogirou, 2014)

- Humidity Control: Humidity control is also important in solar dryers, as high humidity levels can lead to mold growth and spoilage. Sensors can be used to monitor humidity levels, and microcontrollers can adjust the airflow or heating element to maintain optimal humidity levels (Hii et al., 2012)

- Airflow Control: Airflow control is essential in solar dryers, as it affects the drying rate and product quality. Sensors can be used to monitor airflow rates, and microcontrollers can adjust the fan speed to maintain optimal airflow rates (Kumar et al., 2016)

2.4.2 Benefits of Automation and Control Strategies

The benefits of automation and control strategies in solar dryers include:

- Improved Product Quality: Automation and control strategies can help maintain optimal drying conditions, resulting in higher-quality products.

- Increased Efficiency: Automation and control strategies can optimize energy consumption and reduce drying times, resulting in increased efficiency.

- Reduced Labor Requirements: Automation and control strategies can reduce the need for manual monitoring and control, resulting in reduced labor requirements.

2.4.3 Examples of Automation and Control Systems

Several automation and control systems have been developed for solar dryers, including:

- PID Controllers: PID (Proportional-Integral-Derivative) controllers are widely used in solar dryers to control temperature, humidity, and airflow rates.

- Microcontrollers: Microcontrollers, such as Arduino and ATMEGA controllers, can be used to control solar dryers and monitor drying conditions.

- IoT-based Systems: IoT-based systems can be used to remotely monitor and control solar dryers, providing real-time data and analytics.

2.5 Implementation and Testing of Automated Solar Cocoa Seed Dryers

The implementation and testing of automated solar cocoa seed dryers involve several critical steps to ensure the dryer operates efficiently and effectively. These steps include constructing a prototype, testing its performance, and optimizing its design based on the results.

2.5.1 Prototype Development

Developing a prototype of an automated solar cocoa seed dryer requires careful consideration of several factors, including the type of solar collector, drying chamber design, and automation and control systems (Kalogirou, 2014). The prototype should be designed to dry cocoa beans efficiently and effectively, while also being durable and easy to maintain.

2.5.2 Performance Testing

Performance testing is a critical step in the implementation of automated solar cocoa seed dryers. The testing should evaluate the dryer's ability to dry cocoa beans efficiently and effectively, while also assessing its durability and reliability (Hii et al., 2012). Key performance indicators may include drying time, energy efficiency, and product quality.

2.5.3 Optimization

Optimization is an essential step in the implementation of automated solar cocoa seed dryers. The dryer's design and operating parameters should be optimized to achieve maximum efficiency and effectiveness (Kumar et al., 2016). This may involve adjusting the solar collector's angle, modifying the drying chamber's design, or fine-tuning the automation and control systems.

2.5.4 Benefits of Automated Solar Dryers

Automated solar dryers offer several benefits over traditional drying methods, including improved efficiency, reduced labor requirements, and enhanced product quality (Shanmugam & Natarajan, 2007). These benefits can lead to increased productivity and profitability for cocoa farmers and processors.

2.5.6 Challenges and Limitations

Despite the benefits of automated solar dryers, there are several challenges and limitations to their implementation, including high upfront costs, technical complexity, and maintenance requirements (Adebayo & Adeyemi, 2017)

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.

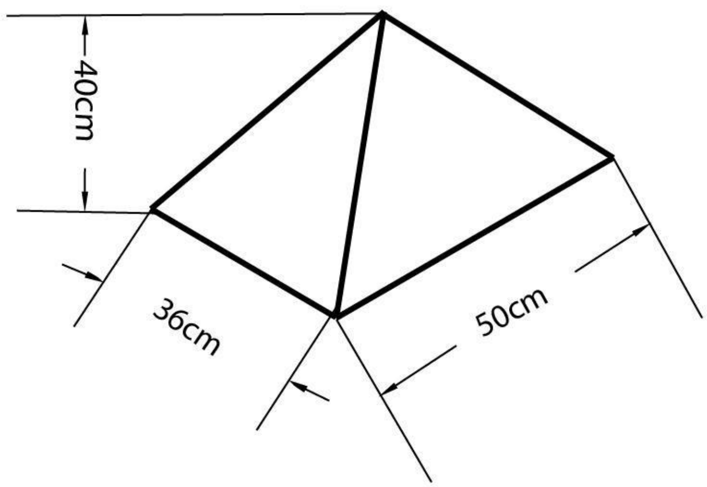


Figure 3.1 Collector

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.

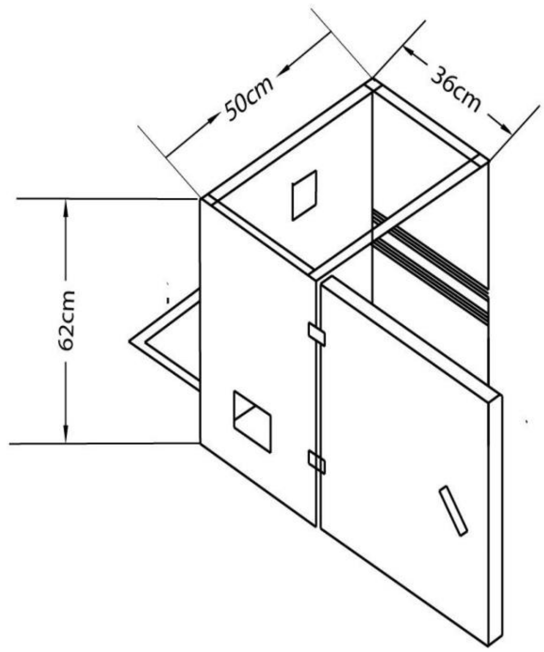


Figure 3.2 Drying chamber

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.

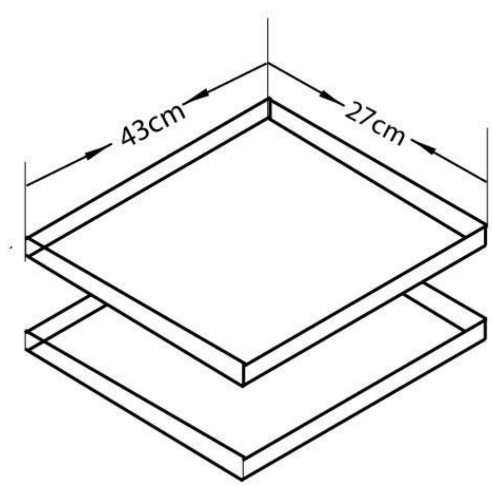


Figure 3.3 Trays

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.

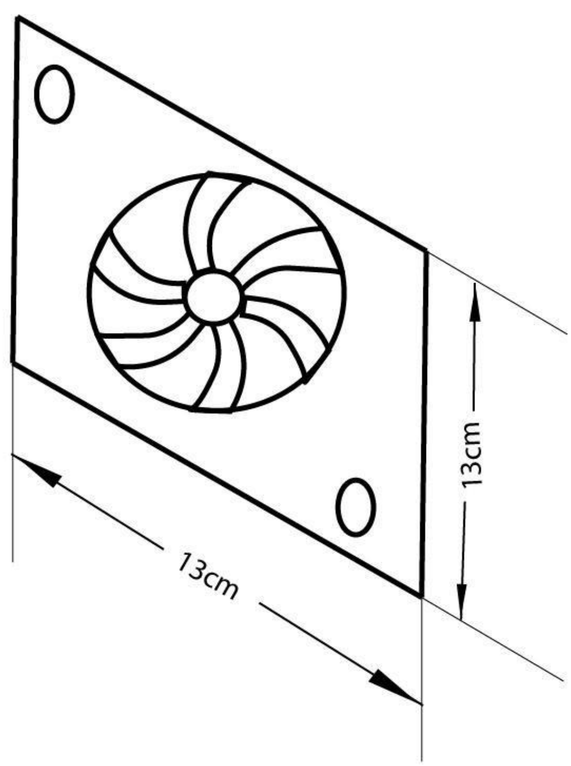


Figure 3.4 Fan

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.

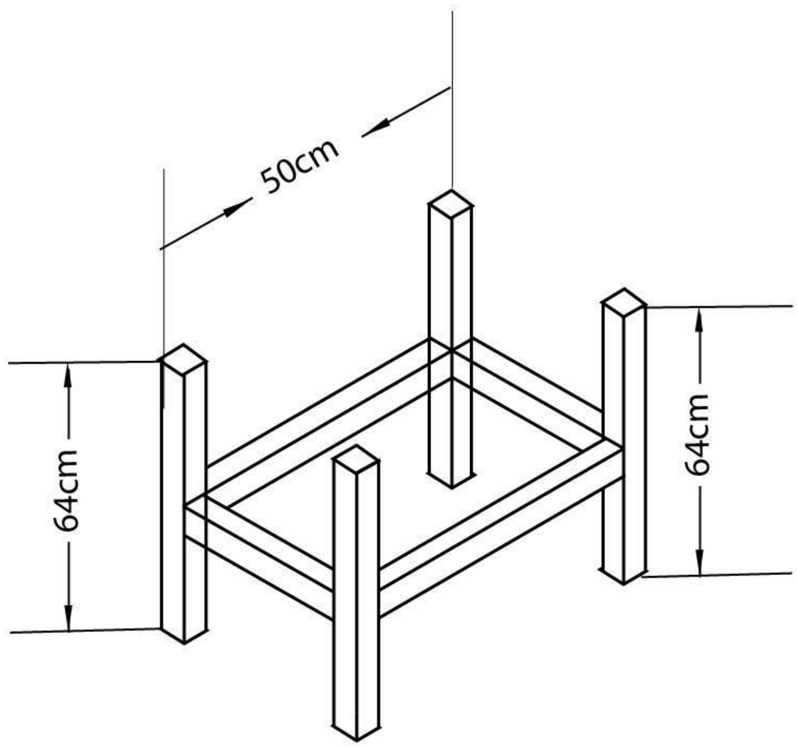


Figure 3.5 Frame

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.

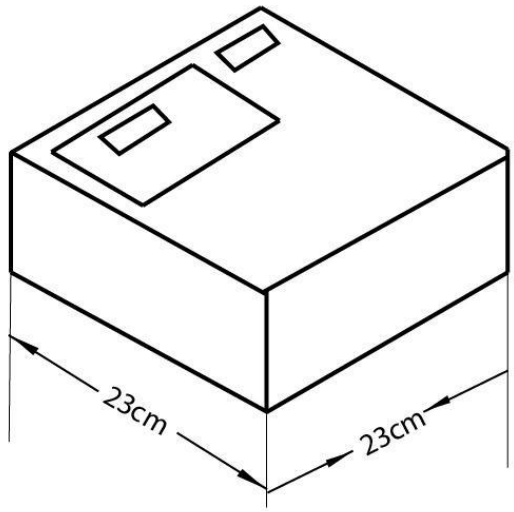


Figure 3.6 Monitoring equipment

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.

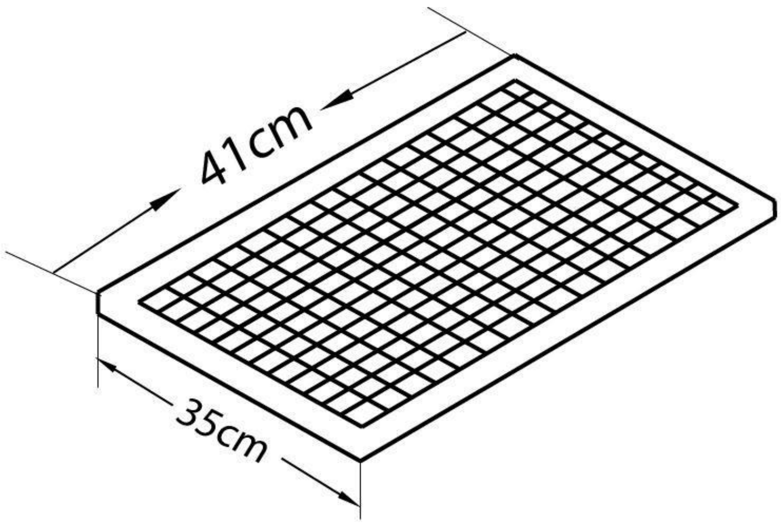


Figure 3.7 Solar panel

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)

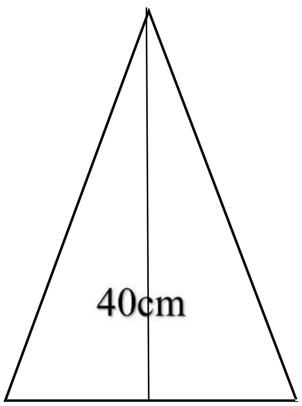
(3.01) Area of the isosceles triangle base = (√3/4) x side^2 (3.02

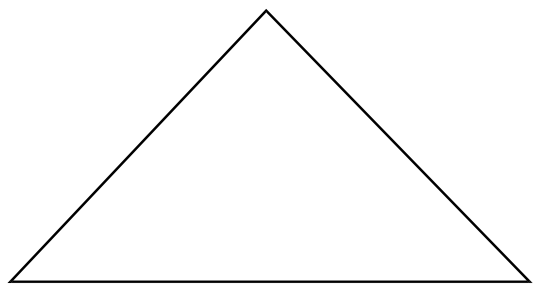
)

Area of the rectangular sides = length x width

(3.03

)





25cm **50cm**

Side view of the collector front 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 = 1000cm^2

Area of the isosceles triangle base = $(\sqrt{3}/4)$ x (50cm)^2

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

(1000) = 5165.06cm^2

(b) Absorber Surface Area,

The surface area of the absorber A_{ab} is approximately equal to the area of the collector surface area, A_c; this is related to the length, L_c and width, W of the solar collector as follows:

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

L_c = height of prism + height of drying chamber

= 40cm + 62cm

=102cm A_{ab} =

102 x 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 x H (3.05)

= 62 x 50

= 3100cm^2

L = length of

the dryer H

= Height

3.4 Moisture Content (M.C.):

The moisture content is given as:

$$MC\ (\%) = \left[\frac{Mi - Mf}{Mi}\right] x100\%;\ \text{wet basis}\quad (3.06)$$

Where;

M_i = mass of sample before

drying and M_f = mass of

sample after drying.

3.5 The mass of water evaporated or moisture loss

Moisture loss is given as;

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

Where:

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

M_e = equilibrium moisture content (%

dry basis); M_i= initial moisture content

(% dry basis).

Also this can still be obtained by using equation 3.05

$m_w = (m_i - m_f)$ (3.08)

Where;

m_i is the mass of the sample

before drying m_f is the mass of

the sample after drying

3.6 Average drying rate

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

$M_{dr} = \frac{M_w}{T_d}$

Where:

M_{dr} = average drying rate, kg/hour;

M_W = mass of wet

products and t_d =

overall drying time

(3.09)

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.

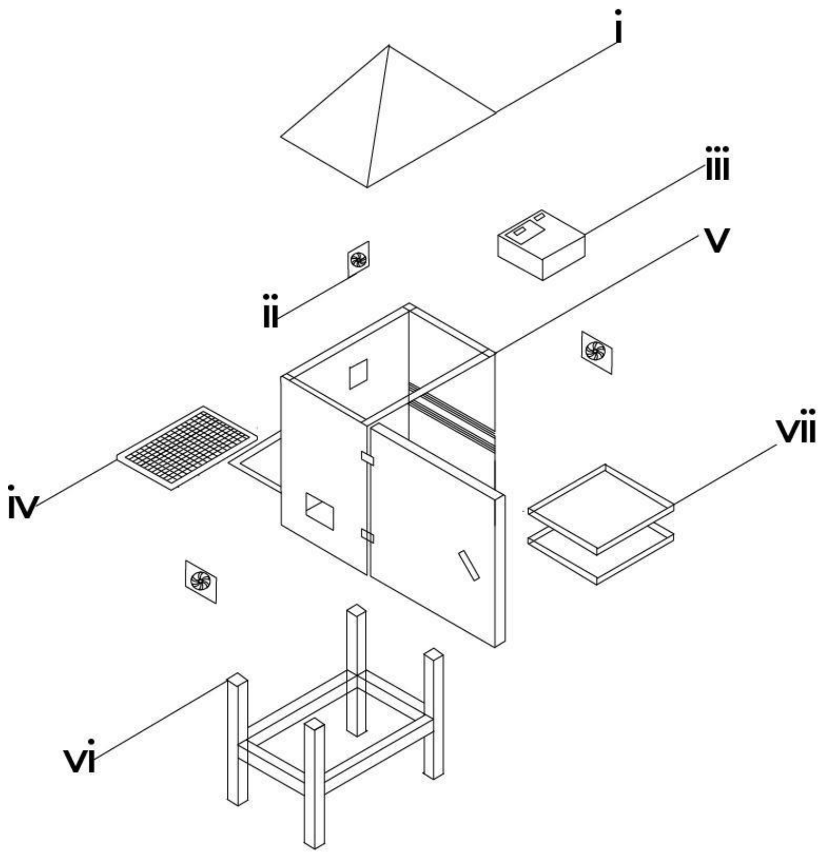
After an hour, the trays were brought out to be weighed, and they were placed back after weighing. Then, the temperature and relative humidity was recorded. The stopwatch was set to an interval of an hour again.

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	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 3.8 Exploded view and labeling of components of the hybrid dryer.

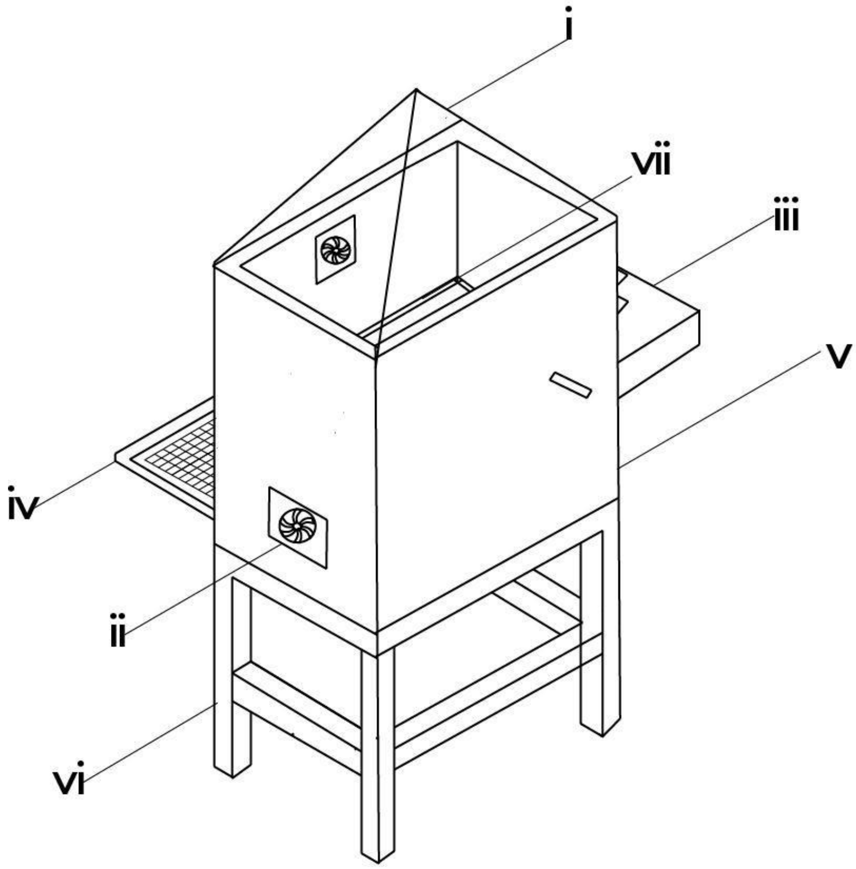


Figure 3.9 Isometric view of hybrid dryer

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

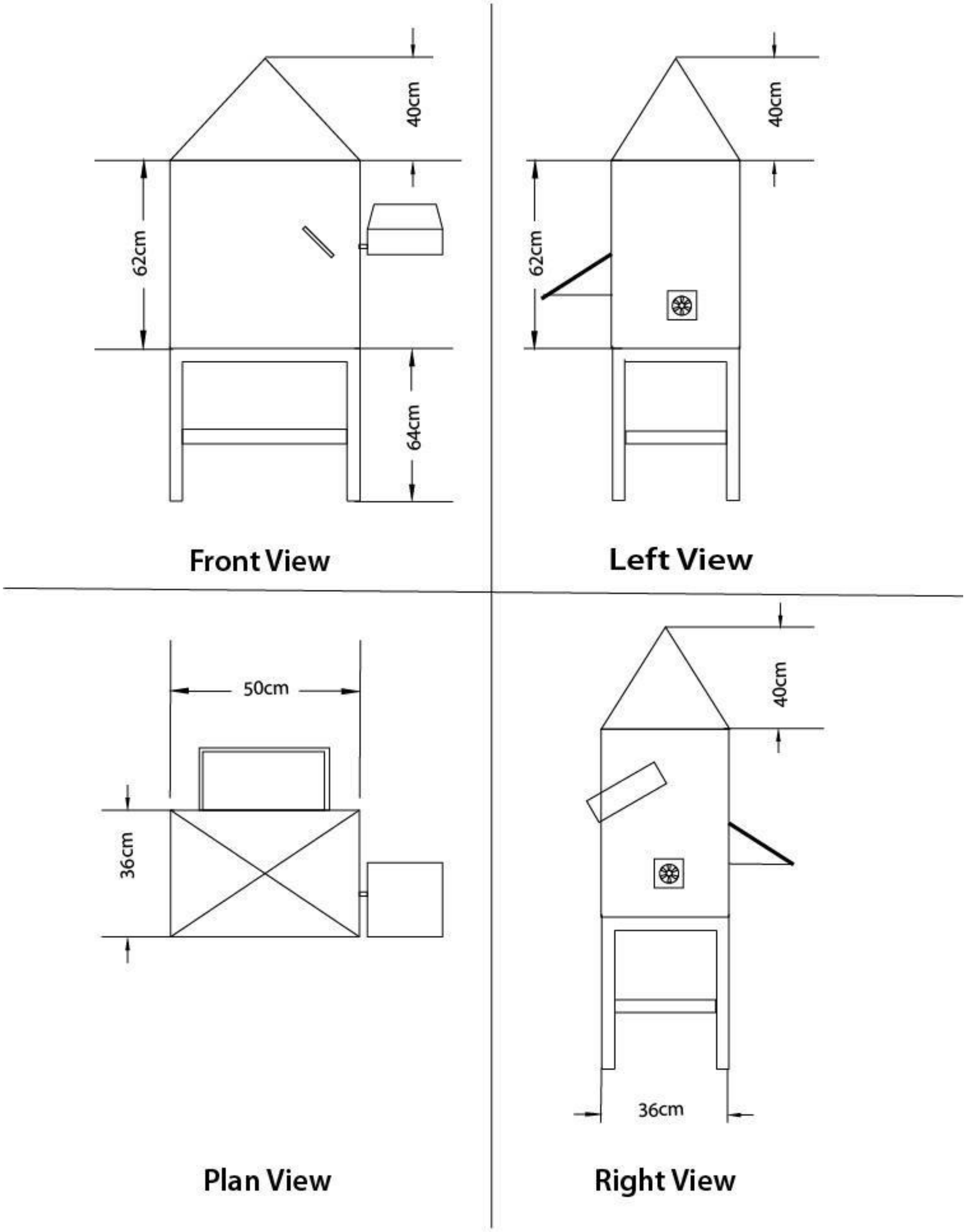


Figure 3.10 Views of The Machine Drawing

3.10 Tools 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 Welding

plate 3.1b: Grinding

Plate 3.1c: Thong

plate 3.1d Electrodes

Small Grinder

Hammer

3.11 Design 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	12	3000	0.5
8	13	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

Run	Mass of Sample (g)	Air Flow Rate (kg/h)	Drying Rate (kg/h)	Drying Efficiency (%)
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.

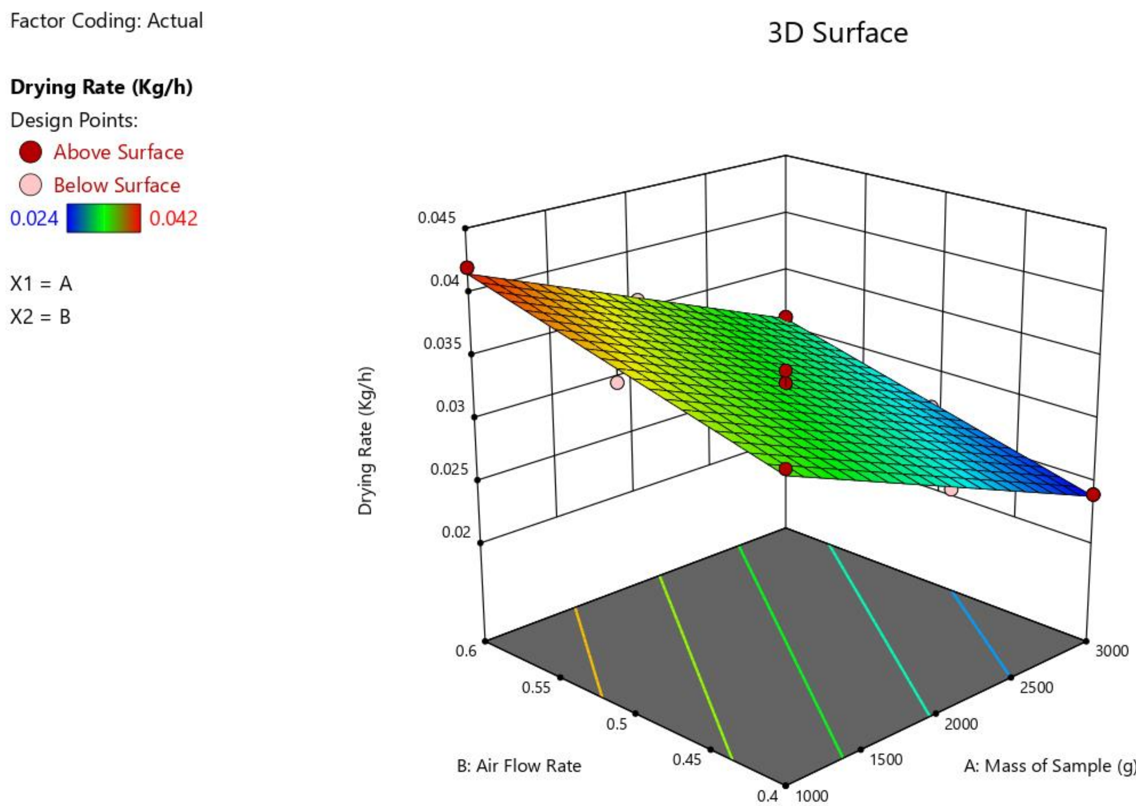


Fig 4.1: Effect of Air Flow Rate and Mass of Sample on the Drying Rate of Cocoa

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.

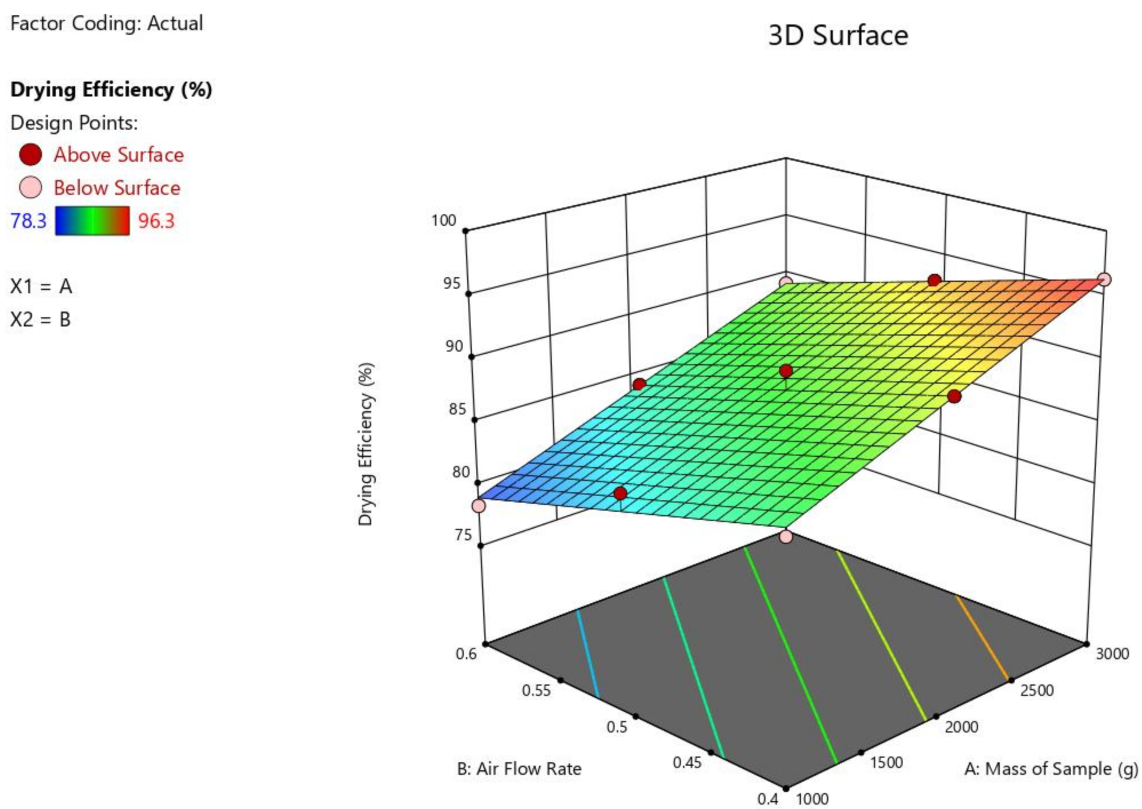


Fig 4.2: Effect of Air Flow Rate and Mass of Sample on the Drying Efficiency of Cocoa

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

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.

5.2 Recommendation

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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