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

BY:

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ND/23/ABE/FT/0023

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

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF NATIONAL DIPLOMA (ND) IN AGRICULTURAL AND BIO-ENVIRONMENTAL ENGINEERING TECHNOLOGY

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 Adegboye Ayomide Adebayo with Matric number ND/23/ABE/FT/0023 was carried out under my Supervision at the Department of Agricultural and Bio-environmental Engineering Technology, Institute of Technology, Kwara 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-environmental 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.

I am deeply indebted to my wonderful parents, Mr. and Mrs Adegboye and my beloved brothers and my sisters, whose love, sacrifice, and encouragement have been the bedrock of my life. Your constant prayers, moral support, and financial backing gave me the strength to keep going even during the most difficult times. Words alone cannot express how thankful I am for everything you have done for me.

My sincere appreciation goes to my project supervisor, Engr. Oyebanre Oluafemi, whose guidance, feedback, and dedication helped shape this research work. Your patience, constructive criticism, and academic mentorship greatly enhanced the quality of this project.

I also extend my gratitude to the Head of Department Engr. Dr. Dauda K.A and all the lecturers in the Department of Agricultural and Bio-Environmental Engineering for the knowledge and inspiration they have imparted to me throughout my studies. Your collective impact has been monumental in shaping my academic foundation.

To my friends who have walked this journey with me — Isaq Ali Ademola, Anjorin Mary Eniola, Onifade Emmanuel and others — thank you for your companionship, moral support, words of encouragement, and the memorable times we shared. Your presence made this academic journey worthwhile and bearable.

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.

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ABSTRACT

This research focused on the development und 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 (Theobroma cacao) beans constitute a global raw material for the chocolate industry, beverages, cosmetics, pharmaceuticals, and toiletry products [V. L. Deus, M. B. de Cerqueira e Silva, L. F. Maciel et al 2018]. Over fifty million people depend on cocoa for their livelihood with a global production capacity of 68% for Africa, 17% for Asia, and 15% by the Americas [M. E. Tardzenyuy and et al., 2020]. In Africa, the largest cocoa-producing countries by volume are Ivory Coast (1900 million tonnes (MT)/ear), Ghana (850 MT), and Cameroon with 250 MT of global supply in the cocoa market [PHAMA 2018]. This contributes significantly to the gross national incomes of these countries. The physics and chemistry of cocoa beans are very complex and change throughout its life span depending on the processing method and geographical origin [L. F. Maciel et al 2018]. As such, cocoa beans of commercial grade should conform to specified criteria among which are its moisture content, acidity, slatiness, polyphenol content, mouldiness, and mycotoxin production [S. Aroyeun, G. Adegoke and et al., 2009].

Cocoa bean quality depends on each of its production processes, from farming practices, region of origin, and transportation to industrial facility where transformation occurs. Fermentation and drying constitute key farmer based unit operations with strong influences in the final quality of cocoa beans and subsequent products. Recent studies on the drying process and effects on quality point to three principal issues—method, temperature, and duration of drying [J. M. Castellanos and et al., 2018]. Variations of these drying parameters impinge significant effects on moisture content, bean colour, pH, fatty acids, polyphenols, methylxanthines, proteins, and aromatic compounds that constitute outstanding quality parameters [J. E. Kongor and et al., 2016]. Although fermentation and drying have complementary influences on bean quality, a poor drying process of well fermented cocoa beans can result in beans of very poor quality since heat treatments affect bean quality parameters differently[M. R. Bikomo and et al., 2016]. In an attempt to optimize the drying process and obtain optimal cocoa bean quality with minimal cost, several modifications in drying parameters have been carried out.

This review focuses on the recent innovations in the cocoa drying process and effects on quality parameters. It starts with a brief description of the most popular drying methods used in the drying of cocoa beans, recent advancements in the drying technology, and effects on bean quality parameters and ends with a tabulated summary of the drying methods and quality parameters.

1.2 AIM & OBJECTIVES

The aim of this study is to investigate the effect of continuous drying on the physical properties of cocoa seeds. While:

Specific Objective

To investigate the effect of continuous drying on the moisture content of cocoa seeds

To evaluate the impact of continuous drying on the size and shape of cocoa seeds

To determine the effect of continuous drying on the color and texture of cocoa seeds

To compare the physical properties of cocoa seeds dried using different methods

1.3 PROBLEM OF STATEMENT

Cocoa seeds are a crucial component of the chocolate industry, and their quality is significantly affected by the drying process. Continuous drying is a common method used to reduce the moisture content of cocoa seeds, but its impact on the physical properties of the seeds is not well understood. There is a need to investigate the effect of continuous drying on the physical properties of cocoa seeds to optimize the drying process and preserve the quality of the seeds.

1.4 SCOPE OF THE STUDY

This study will focus on the effect of continuous drying on the physical properties of cocoa seeds. The study will investigate the impact of different drying conditions, including temperature, humidity, and airflow, on the physical properties of cocoa seeds. The study will also compare the effects of different drying methods, such as solar drying and mechanical drying, on the physical properties of cocoa seeds.

1.5 JUSTIFICATION

The study on the effect of continuous drying on the physical properties of cocoa seeds is crucial because it addresses a significant knowledge gap in cocoa processing. Understanding the impact of continuous drying on cocoa seeds' physical properties can improve cocoa quality, enhance shelf life, and increase the economic benefits for cocoa farmers and processors.

2.0 CHAPTER TWO

2.1 Introduction

The drying of cocoa seeds is a critical step in the post-harvest processing of cocoa beans, which significantly affects the quality and flavor of the final product (Afoakwa, 2014). Traditional drying methods, such as sun drying, are often time-consuming, labor-intensive, and susceptible to weather conditions, which can lead to inconsistent quality and potential contamination (Bart-Plange et al., 2012). Solar drying, on the other hand, offers a promising alternative, providing a controlled environment that can enhance the quality and efficiency of the drying process (Duffie & Beckman, 20A13).

The integration of automation in solar drying systems can further improve the drying process by ensuring optimal temperature, humidity, and air flow conditions, thereby reducing drying time and improving product quality (Shahzad et al., 2019). This chapter focuses on the development of a prototype solar automated cocoa seed dryer, designed to optimize the drying process and improve the quality of cocoa beans.

2.1.2 Importance of Solar Drying in Cocoa Production

Solar drying can improve the quality of cocoa beans by reducing moisture content and preventing mold growth. This method is particularly beneficial in tropical regions where sunlight is abundant. According to Afoakwa (2014), traditional drying methods can result in significant post-harvest losses, which can be reduced by using solar dryers [1].

2.1.3 Benefits of Automated Solar Dryers

Automated solar dryers can further improve the drying process by ensuring optimal temperature, humidity, and air flow conditions. This can lead to reduced drying time, improved product quality, and increased efficiency. Shahzad et al. (2019) emphasize the importance of testing and debugging in ensuring the optimal performance of solar dryers.

2.2 Design Considerations

The design of a solar automated cocoa seed dryer requires careful consideration of several factors to ensure optimal performance and product quality. Climate and environmental factors, such as temperature, humidity, and solar radiation, play a significant role in determining the drying rate and quality of cocoa beans (Afoakwa, 2014). The design should also take into account the specific drying requirements of cocoa seeds, including temperature, humidity, and air flow rates (Bart-Plange et al., 2012).

2.2.1 Climate and Environmental Factors

The solar dryer's design should be tailored to the local climate and environmental conditions. For example, in tropical regions with high solar radiation, the dryer can be designed to maximize heat gain and minimize heat loss (Duffie & Beckman, 2013). In regions with high humidity, the design should incorporate features that enhance moisture removal, such as adequate ventilation and air flow (Shahzad et al., 2019).

2.2.2 Cocoa Seed Drying Requirements

Cocoa seeds require specific drying conditions to preserve their quality. The optimal temperature range for drying cocoa beans is between 40°C and 60°C, with a relative humidity of 50-60% (Afoakwa, 2014). The air flow rate should be sufficient to remove moisture from the drying chamber without causing excessive drying rates, which can lead to bean damage (Bart-Plange et al., 2012).

2.2.3 Solar Collector Design

The solar collector is a critical component of the solar dryer, responsible for capturing solar radiation and converting it into heat. The design of the solar collector should consider factors such as collector type, size, and material (Duffie & Beckman, 2013). Flat plate collectors or evacuated tube collectors can be used, depending on the desired temperature range and efficiency requirements.

2.2.4 Automation System Requirements

The automation system should be designed to monitor and control the drying process, ensuring optimal temperature, humidity, and air flow conditions. The system should include sensors for temperature, humidity, and air flow measurement, as well as control algorithms to adjust the drying conditions accordingly (Shahzad et al., 2019).

2.3 System Components

The solar automated cocoa seed dryer consists of several key components, including the solar collector, drying chamber, automation system, and other auxiliary components.

2.3.1 Solar Collector

The solar collector is responsible for capturing solar radiation and converting it into heat. Flat plate collectors or evacuated tube collectors can be used, depending on the desired temperature range and efficiency requirements (Duffie & Beckman, 2013). The collector should be designed to maximize heat gain while minimizing heat loss.

2.3.2 Drying Chamber

The drying chamber is where the cocoa seeds are dried. It should be well-insulated to minimize heat loss and designed to ensure uniform air flow and temperature distribution (Shahzad et al., 2019). The chamber should also be equipped with trays or racks to hold the cocoa seeds.

2.3.3 Automation System

The automation system is responsible for monitoring and controlling the drying process. It should include sensors for temperature, humidity, and air flow measurement, as well as control algorithms to adjust the drying conditions accordingly (Patel & Gami, 2017). The system can also include actuators to control fans, heaters, or other components.

2.3.4 Other Components

Other components that may be included in the solar automated cocoa seed dryer are:

- Fans or blowers to enhance air flow and moisture removal (Kumar et al., 2016)
- Heaters or backup heating systems to supplement the solar collector during periods of low solar radiation (Duffie & Beckman, 2013)
- Moisture removal systems, such as vents or condensers, to enhance drying rates (Shahzad et al., 2019)

2.4 Prototype Development

The development of a prototype solar automated cocoa seed dryer involves several key stages, including three-dimensional modeling, control module design, displacement module design, and removal module design. A study on the construction of an automated removal robot for natural drying of cacao beans highlights the importance of a modular design, comprising control, displacement, and removal modules, to ensure efficient and uniform drying (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.1 Three-Dimensional Modeling

The first stage of prototype development is three-dimensional modeling, which allows designers to detail the structural and functional characteristics of the robot. This stage is crucial in ensuring that the robot meets specific requirements for automatic removal of cacao beans during natural drying. Software such as Blender can be used for 3D modeling, providing a widely used tool in design and simulation due to its versatility (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.2 **Control Module Design**

The control module is a critical component of the prototype, responsible for driving the motor and directing the robot's operations. It includes a controller programmed in ladder language, a display for monitoring and adjusting parameters, and a communications switch for system interaction and control. A 24-volt power supply guarantees the robot's continuous power supply, while a 10 kΩ potentiometer allows for adjusting speed parameters in the frequency converter. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.3 Displacement Module Design

The displacement module comprises a motor connected to a reducing box, enabling the removal support to move forward and backward based on the motor's rotation direction. This system utilizes shafts with bearings linked to a drag chain, allowing for smooth and efficient movement. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa -Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.4 **Removal Module Design**

The removal module consists of fingers distributed in two batteries, with a vertical movement that allows them to adapt to the surface of the drying bed. Each finger has stops at the bottom and top to limit travel, ensuring efficient removal of cacao beans. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.5 **Solar Power Supply**

The prototype can be powered by solar panels, reducing dependence on non-renewable energy sources and minimizing the carbon footprint. A study on the construction of an automated removal robot for natural drying of cacao beans used twelve TrinaSolar TSM-455DE17M solar panels, each 455 W, and a Growatt SPF 5000 ES 48 V 100 A inverter charger. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025).

2.5 **Control System Design**

The control system design is a critical component of the solar automated cocoa seed dryer, responsible for monitoring and controlling the drying process. A well-designed control system ensures optimal temperature, humidity, and air flow conditions, thereby improving the quality and efficiency of the drying process (Shahzad et al., 2019).

2.5.1 **Hardware Components**

The control system hardware typically includes:

- Temperature sensors (e.g., thermocouples or thermistors) to measure the temperature of the drying chamber (Duffie & Beckman, 2013)
- Humidity sensors (e.g., capacitive or resistive) to measure the relative humidity of the drying chamber (Patel & Gami, 2017)
- Air flow sensors (e.g., anemometers) to measure the air flow rate in the drying chamber (Kumar et al., 2016)
- Actuators (e.g., fans, heaters, or valves) to control the drying conditions (Shahzad et al., 2019)

2.5.2 **Software Components**

The control system software typically includes:

- ➤ Control algorithms (e.g., PID or fuzzy logic) to adjust the drying conditions based on sensor feedback (Patel & Gami, 2017)
- ➤ Data acquisition and logging capabilities to monitor and record the drying process (Kumar et al., 2016)
- ➤ User interface capabilities to allow operators to set drying parameters and monitor the drying process (Shahzad et al., 2019)

2.5.3 **Control Algorithms**

The control algorithms used in the control system can significantly impact the performance of the solar automated cocoa seed dryer. Common control algorithms include:

- PID (Proportional-Integral-Derivative) control, which adjusts the drying conditions based on the difference between the setpoint and the actual value (Patel & Gami, 2017)
- Fuzzy logic control, which uses fuzzy logic rules to adjust the drying conditions based on sensor feedback (Kumar et al., 2016)

2.6 **Prototype Testing and Debugging**

Prototype testing and debugging is a crucial stage in the development of a solar automated cocoa seed dryer. This process involves evaluating the performance of the dryer under various conditions to identify and rectify any issues.

2.6.1 **Testing Phase**

The testing phase of the solar collector for drying cocoa involved installing two prototypes in different locations, Tumaco and Policarpa, with varying ambient temperatures and relative humidity. The results showed that the prototypes achieved a grain moisture content of 7% in 12 days, reducing the drying time by 4 days compared to traditional methods (Solar collector for Drying Cocoa: Prototype testing 2012).

2.6.2 **Performance Evaluation**

The performance evaluation of the automated removal robot for natural drying of cacao beans involved assessing its effectiveness in reducing moisture content and preserving phenolic compounds. The results showed that the robot-dried beans had lower standard deviations in moisture content, indicating more uniform drying. Additionally, the total phenolic content was higher in the robot-dried beans, suggesting better preservation of bioactive compounds (José Tuanama-Aguilar et al. Sensors 2025)

2.6.3 **Debugging and Improvement**

Based on the testing and performance evaluation, several areas for improvement were identified, including:

- Control of Airflow: The need to control airflow inside the panel to prevent humidity from affecting the drying process.

- Tilt Angle: Adjusting the tilt angle of the solar collector to optimize energy gain.
- Sensory Analysis: Conducting sensory analysis and cutting tests to evaluate the quality of the dried cocoa beans (Solar collector for Drying Cocoa: Prototype testing 2012).

2.7 **Cost-Benefit Analysis**

A cost-benefit analysis is essential to determine the economic feasibility of the solar automated cocoa seed dryer. This analysis compares the costs of developing and operating the dryer with the benefits of improved drying efficiency, reduced labor costs, and enhanced product quality.

2.7.1 **Costs**

The costs associated with the solar automated cocoa seed dryer include:

Initial investment costs (design, materials, and labor)

Operating costs (energy, maintenance, and repairs)

Replacement costs (components and parts)

According to Shahzad et al. (2019), the initial investment cost of a solar dryer can be higher than traditional drying methods, but the operating costs can be significantly lower

2.7.2 **Benefits**

The benefits of the solar automated cocoa seed dryer include:

Improved drying efficiency and reduced drying time (Shahzad et al., 2019)

Reduced labor costs and improved working conditions (Kumar et al., 2016)

Enhanced product quality and reduced post-harvest losses (Afoakwa, 2014)

Environmental benefits from using renewable energy (Duffie & Beckman, 2013)

2.7.3 **Economic Feasibility**

The economic feasibility of the solar automated cocoa seed dryer can be evaluated using various economic indicators, such as:

- Net present value (NPV)
- Internal rate of return (IRR)

- Payback period (PBP)

According to Kumar et al. (2016), a solar dryer can have a payback period of 2-5 years, depending on the design and operating conditions

2.7.4 Comparison with Traditional Drying Methods

A comparison with traditional drying methods can help determine the economic viability of the solar automated cocoa seed dryer. Traditional drying methods often require more labor, energy, and time, resulting in higher costs and reduced product quality. Afoakwa (2014).

CHAPTER THREE

Materials and Methods

[redacted]

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.

[redacted]

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.

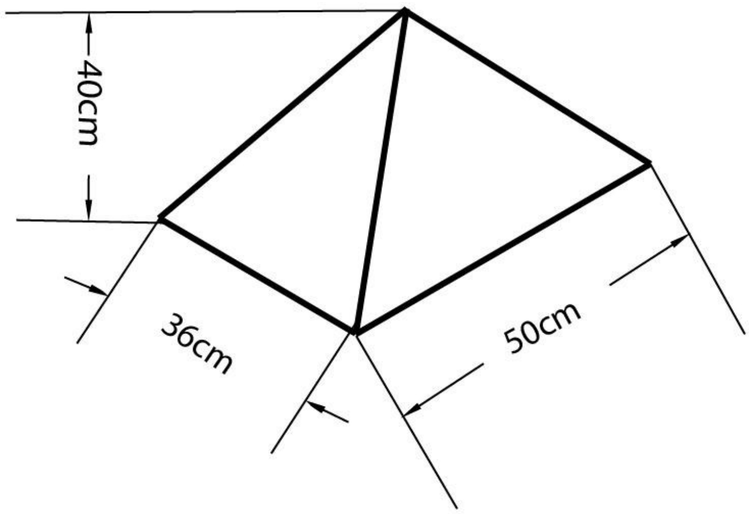


Figure 3.1 Collector

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.

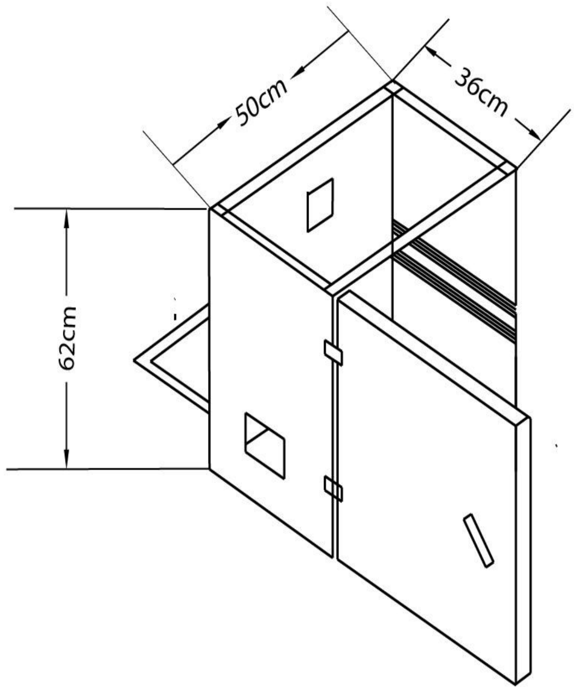


Figure 3.2 Drying chamber

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.

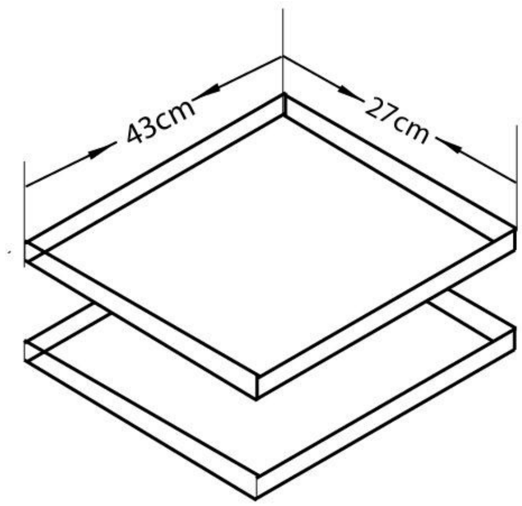


Figure 3.3 Trays

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.

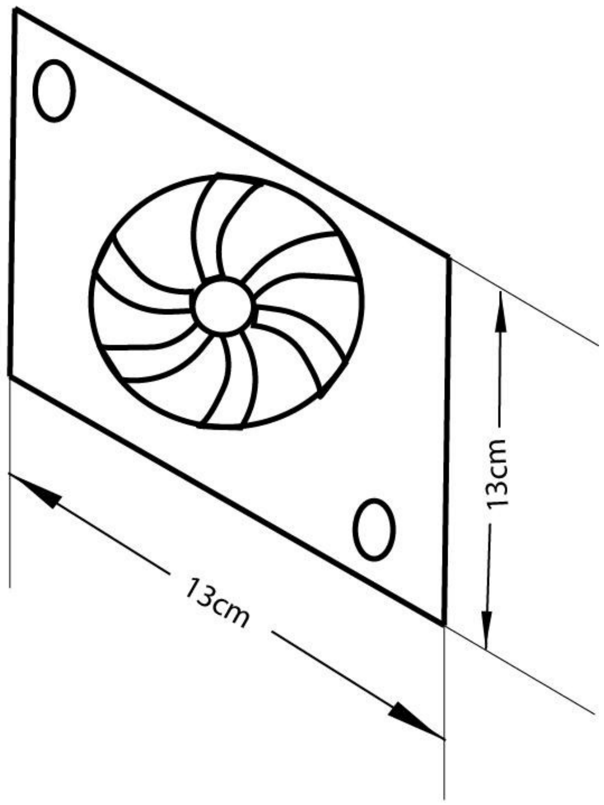


Figure 3.4 Fan

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.

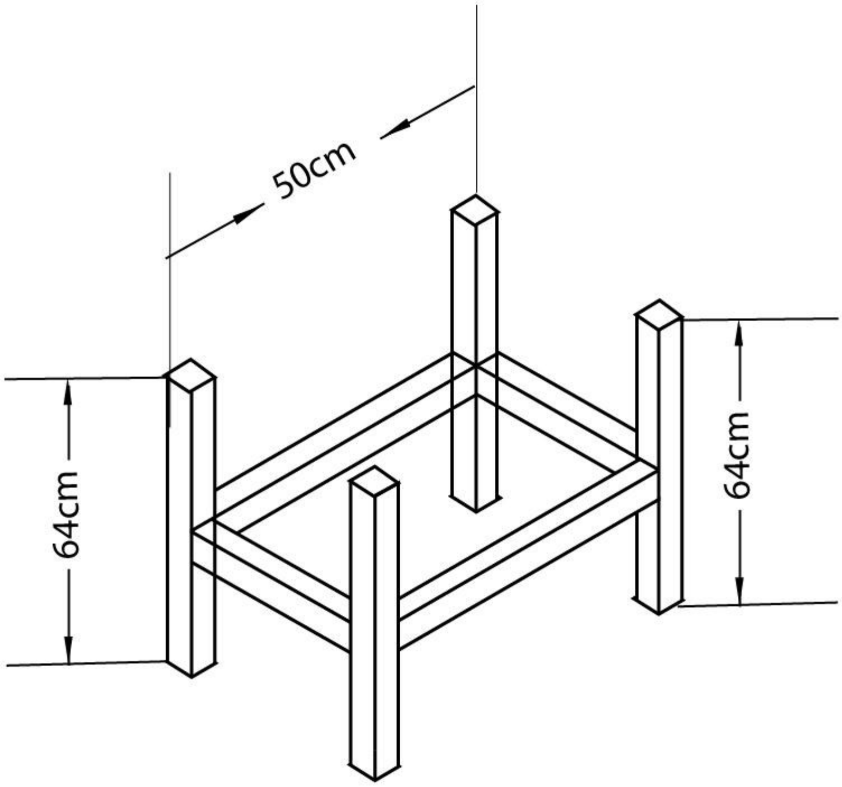


Figure 3.5 Frame

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.

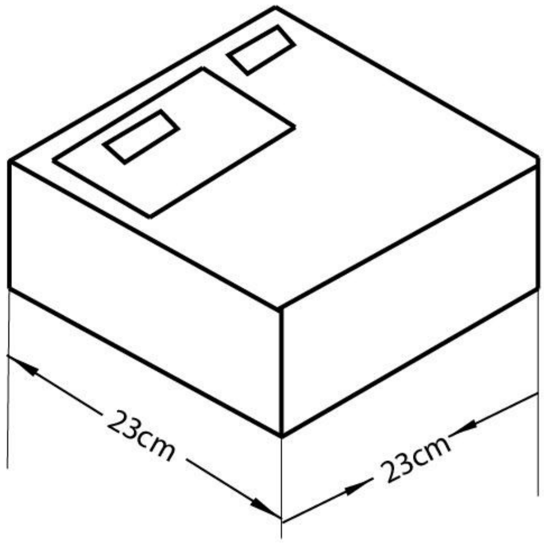


Figure 3.6 Monitoring equipment

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.

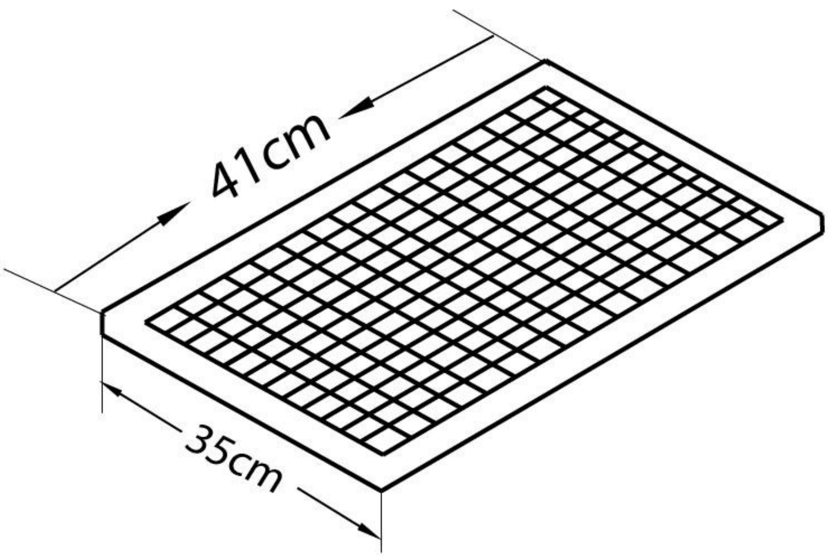


Figure 3.7 Solar panel

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.

[redacted]

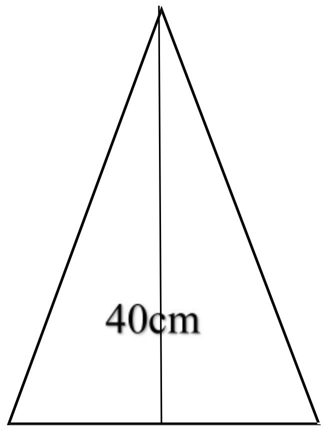
(a) Solar collector area

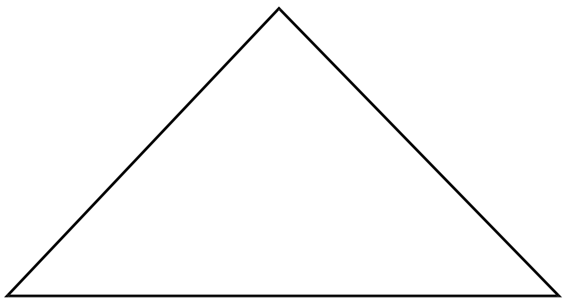
The solar collector is a triangular prism and it is an isosceles triangle. The solar collector area is given by;

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 = (√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:

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

[redacted]

The moisture content is given as:

$$MC\ (\%) = \left[\frac{M_i - M_f}{M_i}\right] \times 100\%;\ \text{wet basis} \qquad (3.06)$$

Where;

M_i = mass of sample before drying

and M_f = mass of sample after drying.

[redacted]

Moisture loss is given as;

$$m_w = m_i\left[\frac{M_i - M_e}{100 - M_e}\right] \qquad (3.07)$$

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

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

Where;

m_i is the mass of the sample before drying m_f is the mass of the sample after drying

[redacted]

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

$$M_{dr} = \frac{M_w}{t_d} \qquad (3.09)$$

Where:

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

M_w = mass of wet products

and t_d = overall drying time

[redacted]

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.

[redacted]

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.

[illegible]

- 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

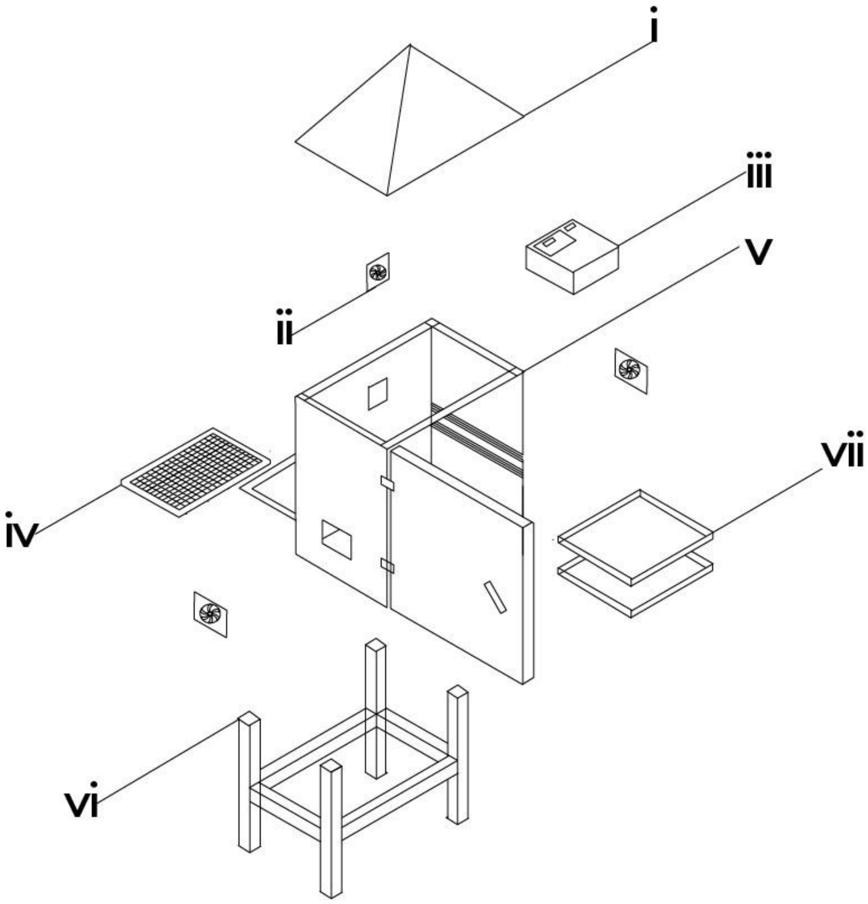


Figure 3.8 Exploded view and labeling of components of the hybrid dryer.

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

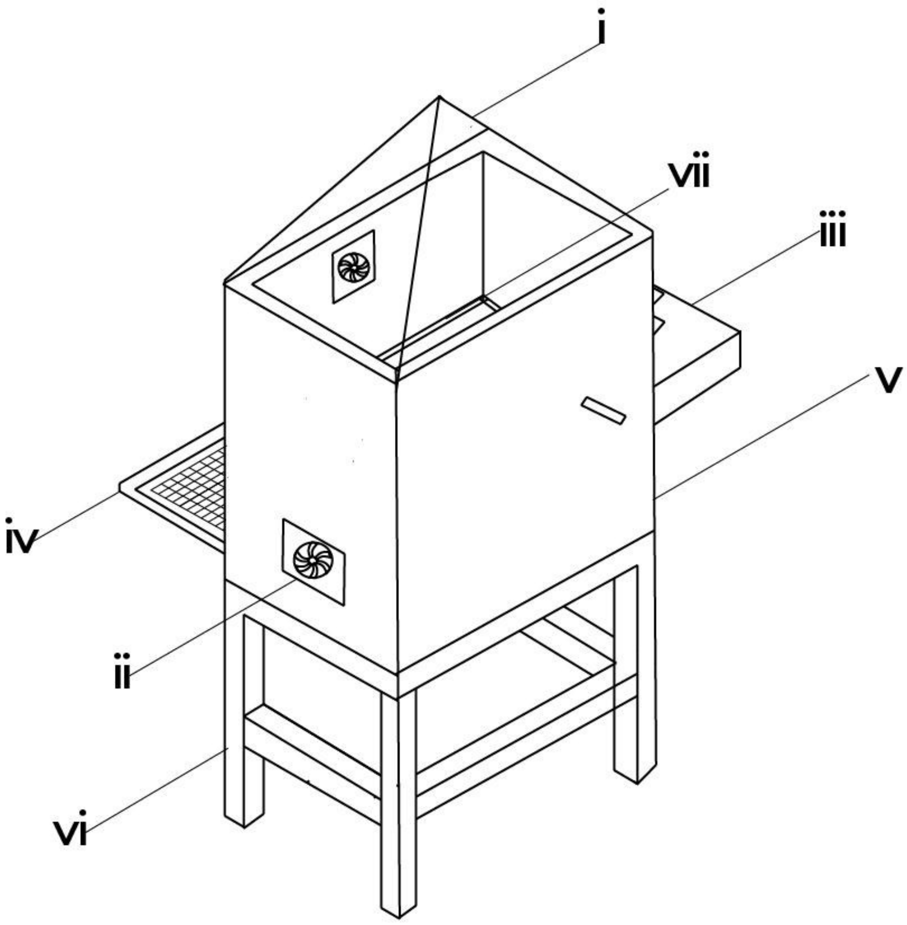
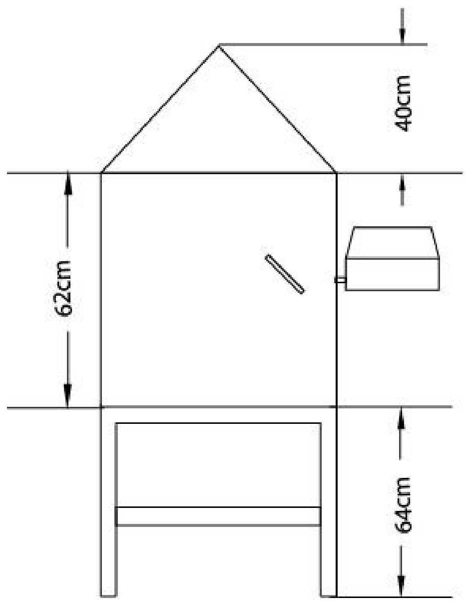
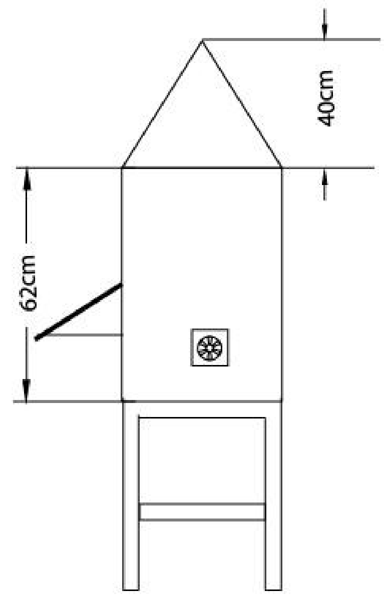


Figure 3.9 Isometric view of hybrid dryer

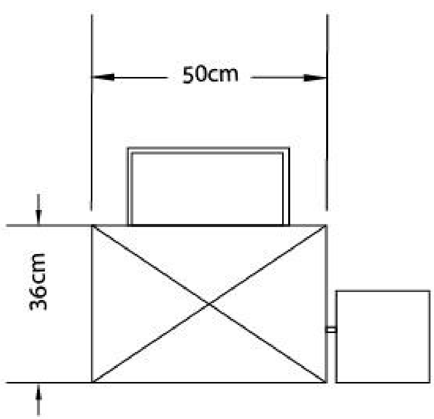
MACHINE PARTS' LIST		
S/N	KEYS	PARTS' NAME
1	I	COLLECTOR
2	II	FAN
3	III	MONITORING EQUIPMENT
4	IV	SOLAR PANEL
5	V	DRYING CHAMBER
6	VI	FRAME
7	VII	TRAYS



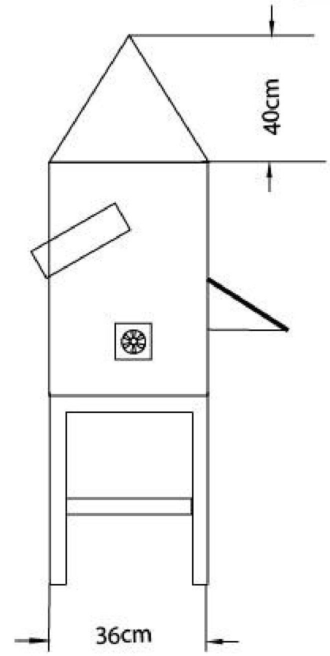
Front View



Left View



Plan View



Right View

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

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

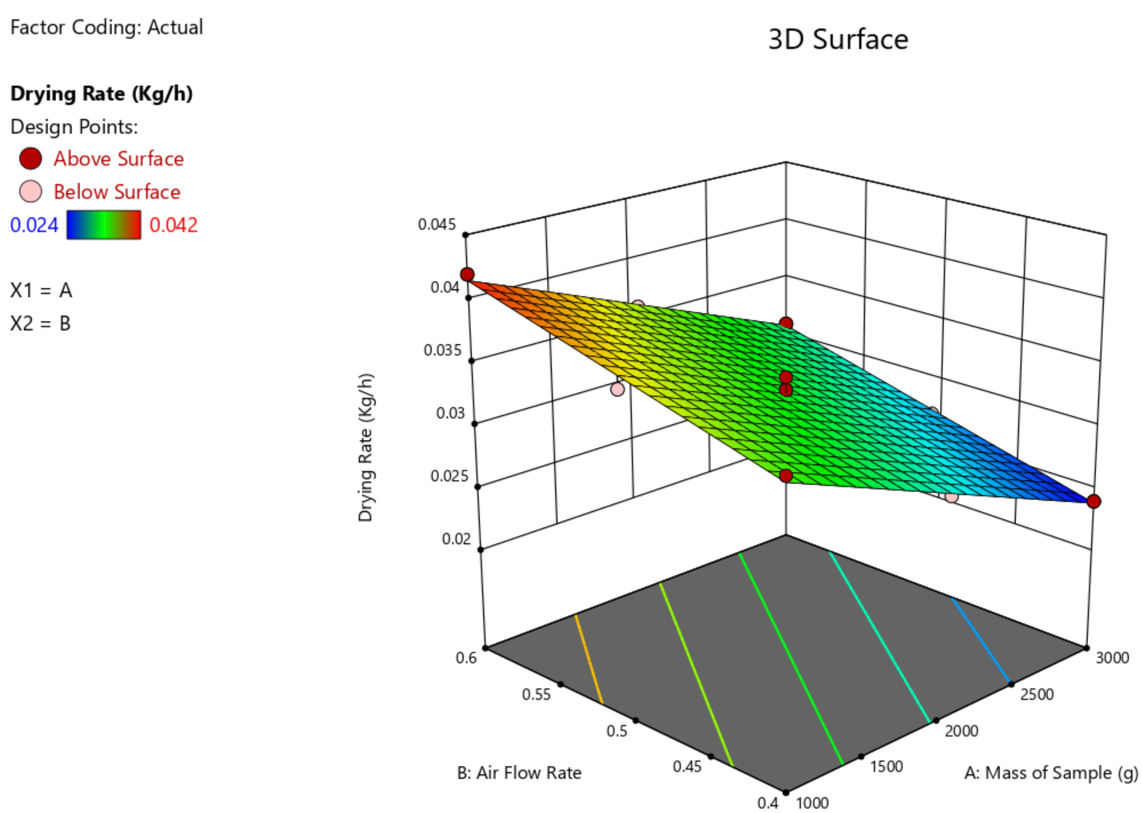


Fig 4.1: Effect of Air Flow Rate and Mass of Sample on the Drying Rate of Cocoa

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.

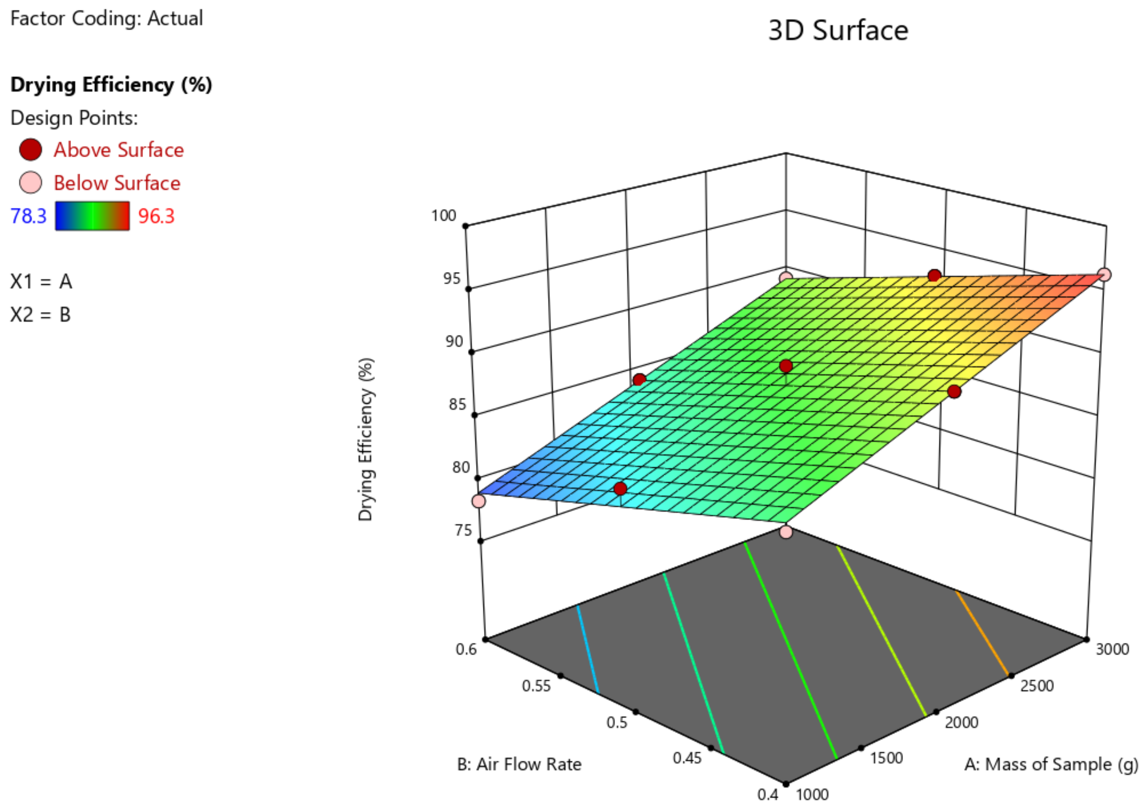

Factor Coding: Actual
Drying Efficiency (%)
Design Points:
Above Surface
Below Surface
78.3
96.3
X1 = A
X2 = B
3D Surface
Drying Efficiency (%)
100
95
90
85
80
75
0.6
0.55
0.5
0.45
0.4
B: Air Flow Rate
1000
1500
2000
2500
3000
A: Mass of Sample (g)

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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