DESIGN AND FABRICATION OF A SOLAR DRYER FOR FOOD PROCESSING

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ENG2002670

A PROJECT SUBMITTED TO THE DEPARTMENT OF PRODUCTION ENGINEERING

IN

PARTIAL FULFILMENT OF THE REQUIREMENT

FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG.) IN PRODUCTION ENGINEERING

UNIVERSITY OF BENIN

BENIN CITY

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NOVEMBER, 2025

CERTIFICATION

I hereby certify that this project was carried out by **Iyengumwena Blessed Aisosa** with matriculation number **ENG2002670** of the Department of Production Engineering, University of Benin, Benin City, Edo state, Nigeria under my supervision.

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DEDICATION

I dedicate this project of work to the Almighty God who in His infinite mercies made it possible for me to go through this hurdle and also in whose strength and grace I trust. I also dedicate this work to my always loving parents Deacon and Deaconess Iyengumwena and also my siblings Osamede and Osaruese Iyengumwena for always supporting me and making the journey possible.

ACKNOWLEDGEMENT

My pure and sincere thanks goes to God Almighty whose unequivocal love kept going throughout all these years even up till now (when the going became tough).

I also want to use this medium to express my profound gratitude to my ever loving and beloved father Deacon U. Iyengumwena, my sweet mother Deaconess P. Iyengumwena for their un-quantified moral encouragment, love and financial support. I equally extend my sincere appreciation to my brother Osamede Iyengumwena for his support and encouragement, my dearest sister Osaruese Iyengumwena for her love and constant prayers, my beloved aunt Mrs Lara Adeleye for her financial supports and prayers.

I wish to express my sincere gratitude to my ever supportive supervisor Engr. G.F. Aibangbee who had always been there to assist me whenever I am stucked on the way. I also want to say a very big thank you to Engr. Dr. F.O. Uwoghiren for his support, encouragement and advice to me and also Engr. Dr. N.H. Osadiaye and my course adviser Engr. Dr. R.O. Idada for their advice and encouragement. The other lecturers in my Department, (Production Engineering) who have affected my life in one way or the other, I am forever grateful.

I also want to express my unreserved gratitude to my ever supportive colleagues in the persons of Irogue William, Izuagie Ochuwa, Idemudia Isoken, Iwhiwhu Faustus, etc.

I can never forget one special being in the person of Agu Ifeanyi Peter for his constant love, support and encouragement.

Finally, I want to say may Almighty God bless each and every one of you abundantly.

IYENGUMWENA BLESSED AISOSA

ABSTRACT

This project focuses on the design and construction of a solar-powered food dryer aimed at improving the efficiency and sustainability of food preservation, particularly in off-grid and rural environments. The developed system utilizes solar energy as the primary heat source to dehydrate agricultural products, thereby reducing post-harvest losses and enhancing shelf life without reliance on fossil fuels or electricity from the grid.

The dryer comprises a solar collector unit, drying chamber, air circulation system, Lagging material and insulated drying trays. The design emphasizes passive solar heating, which harnesses thermal energy from the sun to generate hot air that is circulated over the food products to facilitate moisture removal. To ensure uniform drying and improved airflow, Two DC-powered fan connected to a photovoltaic (PV) panel is integrated into the system. This setup enables consistent airflow and temperature regulation within the chamber during operation.The solar collector was oriented due south and inclined at 16.2°, based on the optimal slope calculated from the local latitude of Benin City. Design calculations showed a collector area of 0.17 m^2, drying chamber volume of 0.044 m^3, and heat gain of 170 W/m^2, with heat loss through the chamber walls estimated at 8.9 W/m^2K.

Preliminary testing was conducted using sliced plantain to evaluate the drying performance in terms of moisture reduction rate, drying time, and product quality under typical October weather conditions. The internal dryer temperature ranged between **45°C and 65°C**, consistently higher than ambient conditions. Moisture content reduced from **approximately 100% to 39% (wet basis)**, corresponding to **0.075 kg amount of water removed**. Effective drying occurred within **17–20 hours**, significantly shorter than traditional open sun drying which typically exceeds 24 hours under similar conditions. The average drying rate was **0.0044 kg/hr**, and the solar dryer achieved a high overall efficiency of **94.76%**, indicating excellent heat utilization. Which is ideal for preserving color, texture, and nutrient quality of Agricultural Product.

The findings demonstrate that the constructed solar dryer offers a practical and energy-efficient alternative for small-scale food processors and farmers, particularly in regions with high solar potential. This work contributes to the advancement of sustainable food processing technologies and provides a foundation for future improvements, including hybrid systems and thermal energy storage integration for continuous operation during low-sunlight periods.

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I = rate of total radiation incident on the absorbers surface (wm^{-2})

A = collector area (m^2)

Q_u = rate of useful energy collected by the air (w)

Q_{cond} = rate of collection losses from the absorber (w)

Q_{conv} = rate of convective losses from the absorber (w)

Q_R = rate of long wave re-radiation from the absorber (w)

$Q\rho$ = rate of reflection losses from the absorber

T = transmittance of the top glazing

IT = total solar radiation incident on the top surface

T_{in} = temperature inside the collector chamber and dryer

T_{out} = ambient temperature

β = optimum collector slope

δ = Declination

Lat$\emptyset$ = latitude of the collector location

Q = quantity of heat transferred

E = heat Intensity

K = thermal conductivity

H_{hot} = convective heat transfer coefficient for hot side

H_{cold} = convective heat transfer coefficient for cold side

X = thickness of material

T_h = temperature inside dryer

T_c = ambient temperature

η = collector efficiency

ηd = dryer efficiency.
M_e = moisture content
M_l = moisture loss
V_d = volume of drying chamber
V_c = volume of collector chamber
D_r = drying rate
m_t = initial mass of specimen
m_{tdt} = mass of specimen at time t
dt = the time for successive measurement

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Food spoilage due to inadequate preservation techniques remains a major problem in many developing regions. Drying is the oldest preservation technique of agricultural products and it is an energy intensive process. The heat from the sun coupled with the wind has been used to dry food for preservation for several years. Solar drying is a sustainable and cost-effective method for preserving agricultural products. This project proposes the design and fabrication of a solar dryer aimed at improving the efficiency of food processing and preservation using renewable energy.

Solar drying goes back a long history. It traditionally began with drying by sun or better known as sun-drying. In this method,the product is exposed directly to sun rays allowing products to be dried up by radiation from the sun. However, this method has disadvantages such as exposure of products to wind, rain, moist, dust, animals, insects and fungus growth. This process is also time consuming and requires large area.

From the concept of solar drying, solar dryers came up. Solar dryer is a device that uses solar energy to dry substances, such as food, vegetables, fruits etc. The basic principle of a solar dryer is to pass hot, dry air heated by solar energy over products to be dried.

Solar dryers fall in two broad categories; active dryers and passive dryers. Active dryers require an external means, like fans or pumps for moving the solar energy in the form of heated air from the collector area to the drying beds. Another category is passive solar dryers which uses natural solar radiations to heat and move the air. The passive solar dryers can be subdivided into direct and indirect types.

In direct solar dryer, food is exposed directly to the sun's radiations. This type of dryer typically consists of a drying chamber that is covered by transparent cover made of glass or plastic. The drying chamber is a shallow, insulated box with holes in it to allow air to enter and leave the box. The food is placed on a perforated tray that allows the air to flow through it and the food. On the other hand, an indirect solar dryer is one in which the sun's radiations do not strike directly the food to be dried. In this system, drying is achieved indirectly by using an air collector that channels hot air into a separate drying chamber. Within the chamber,the food is placed on mesh trays that are stacked vertically so that the air flows through each one.

Various types of solar dryers have been designed to improve solar drying capabilities such as solar greenhouse dryers, solar cabinet dryers, forced convection dryers and many others. However, one major problem which exists with these solar dryers is their capability to dry products only within the existence of solar energy, enabling them to be operated only on hot days. This causes inconsistency in drying and a decrease in the production scale. The solar collector has an air vent (or inlet) where air enters and heated up. The hot air which is less dense than the cold air raised to the drying chamber and passing through the trays containing food, removing the moisture content and exits through the air vent (or outlet) near the top of the shadowed side. The hot air acting as the drying medium, extracts and conveys the moisture from the produce (or food) to the atmosphere under free (natural) convection, thus the system is a passive solar system and no mechanical device is required to control the intake of air into the dryer.

1.2. Statement of the Problem

One of the oldest uses of solar energy since the dawn of civilization has been drying and preservation of agricultural products. This traditional method, still widely used throughout the world, is open sun drying where diverse crops, such as fruits, vegetables, cereals, grains, etc. are spread on the ground and turned regularly until sufficiently dried so that they can be stored safely.

However, there exist many problems associated with open sun drying. It has been seen that open sun drying has the following disadvantages; It requires both large amount of space and long drying time. The disadvantages of open sun drying need and appropriate technology that can help in improving the quality of the dried products and in reducing the wastage. This led to the application of various types of drying devices like solar dryer, electric dryers, wood fuel driers and oil-burned driers. However, the high cost of oil and electricity and their scarcity in the rural areas of most third world countries have made some of these driers unattractive. Therefore, interest has been focused mainly on the development of solar driers.

1.3. Aim of the Study

The aim of this study is to design and construct a solar drying device for the reduction of moisture contents in an agricultural product.

1.4. Objectives of the Study

To achieve the aim of the study the following objectives will be pursed:

i. To carry out detail literature review on solar dryer for food processing.

ii. To carry the detail design of the various components that make up the solar dryer.

iii. To fabricate the components of the solar dryer.

iv. To assemble the parts to form a solar dryer.

v. To carry performance test on the solar device.

1.5. Significance of the Study

The development of a cabinet solar dryer for food preservation carries substantial significance, especially in the context of small-scale agriculture, rural development, and sustainable food systems.

Reduction in post-harvest losses is a major benefit of the cabinet solar dryer is its ability to significantly reduce post-harvest losses. In many regions like Tanzania, Nigeria, and Ghana due to lack of cold storage, a considerable portion of fruits, vegetables, and other perishable produce is lost due to poor preservation methods. By offering a controlled and protected environment, the solar dryer minimizes spoilage caused by microbial activity, pests, and unexpected weather conditions.

Cost-effective food preservation, the use of locally available and affordable materials in the construction of the cabinet solar dryer makes it an economical option for smallholder farmers and rural households. It offers a practical preservation method without the high costs associated with electric or industrial drying systems.

Environmental and Energy Sustainability, by harnessing freely available solar energy, the cabinet solar dryer eliminates the need for electricity or fuel-based heating, reducing both operational costs and environmental impact. This contributes to the promotion of renewable energy technologies and aligns with global sustainability goals, particularly those related to clean energy and climate action

Improved Hygiene and Enhancing Product Quality, the enclosed structure of the cabinet solar dryer shields food items from common contaminants such as dust, insects, animals, and airborne pollutants. This enhances the product quality and safety of dried foods compared to traditional open sun drying, which is often exposed to unsanitary conditions and alongside preserving the natural color, aroma, taste, and nutritional content of food items thereby making it appealing and marketable, supporting better consumer satisfaction and potential for premium pricing.

1.6. Scope of the Study

This study focuses on the development, design, fabrication, and evaluation of a cabinet solar dryer for the purpose of preserving perishable food items such as fruits and vegetables. The scope of the project covers both the technical development and performance assessment of the solar dryer, with emphasis on cost-effectiveness, energy efficiency, and usability for small-scale applications, especially in rural and off-grid communities. It involve the design, material selection, fabrication, and testing of the dryer. Analysis of drying time, temperature distribution, and food quality retention will be included.

1.7. Expected Outcome

A solar dryer is expected to efficiently reduce the moisture content of products like food, reducing deterioration and extending shelf life. It also provides a sustainable and cost-effective alternative to traditional drying methods, minimizing contamination and enhancing product quality.

i. A functional solar dryer prototype.

ii. Data proving improved drying efficiency and hygiene.

iii. Contribution to sustainable energy use in food processing.

1.8. Timeline of the Project

Activity	Duration
Literature Review	2 weeks
Design and Material Selection	2 weeks
Fabrication	2 weeks
Testing and Analysis	1 weeks
Report Writing	1 weeks

CHAPTER TWO

LITERATURE REVIEW

2.1 Solar Dryer

Drying is an excellent way to preserve food and solar food dryers are appropriate food preservation technology for sustainable development. Drying was probably the first ever food preserving method used by man, even before cooking. It involves the removal of moisture from agricultural produce so as to provide a product that can be safely stored for longer period of time. “Sun drying” is the earliest method of drying farm produce ever known to man and it involves simply laying the agricultural products in the sun on mats, roofs or drying floors. This has several disadvantages since the farm produce are laid in the open sky and there is greater risk of spoilage due to adverse climatic conditions like rain, wind, moist and dust, loss of produce to birds, insects and rodents (pests); totally dependent on good weather and very slow drying rate with danger of mould growth thereby causing deterioration and decomposition of the produce. The process also requires large area of land takes time and highly labour intensive. With cultural and industrial development, artificial mechanical drying came into practice, but this process is highly energy intensive and expensive which ultimately increases product cost .Recently, efforts to improve “sun drying” have led to “solar drying”. In solar drying, solar dryers are specialized devices that control the drying process and protect agricultural produce from damage by insect pests, dust and rain. In comparison to natural “sun dries”, solar dryers generate higher temperatures, lower relative humidity, and lower product moisture content and reduced spoilage during the drying process. In addition, it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus, solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying. The solar dryer can be seen as one of the solutions to the world's food and energy crises. With drying, most agricultural produce can be preserved and this can be achieved more efficiently through the use of solar dryer

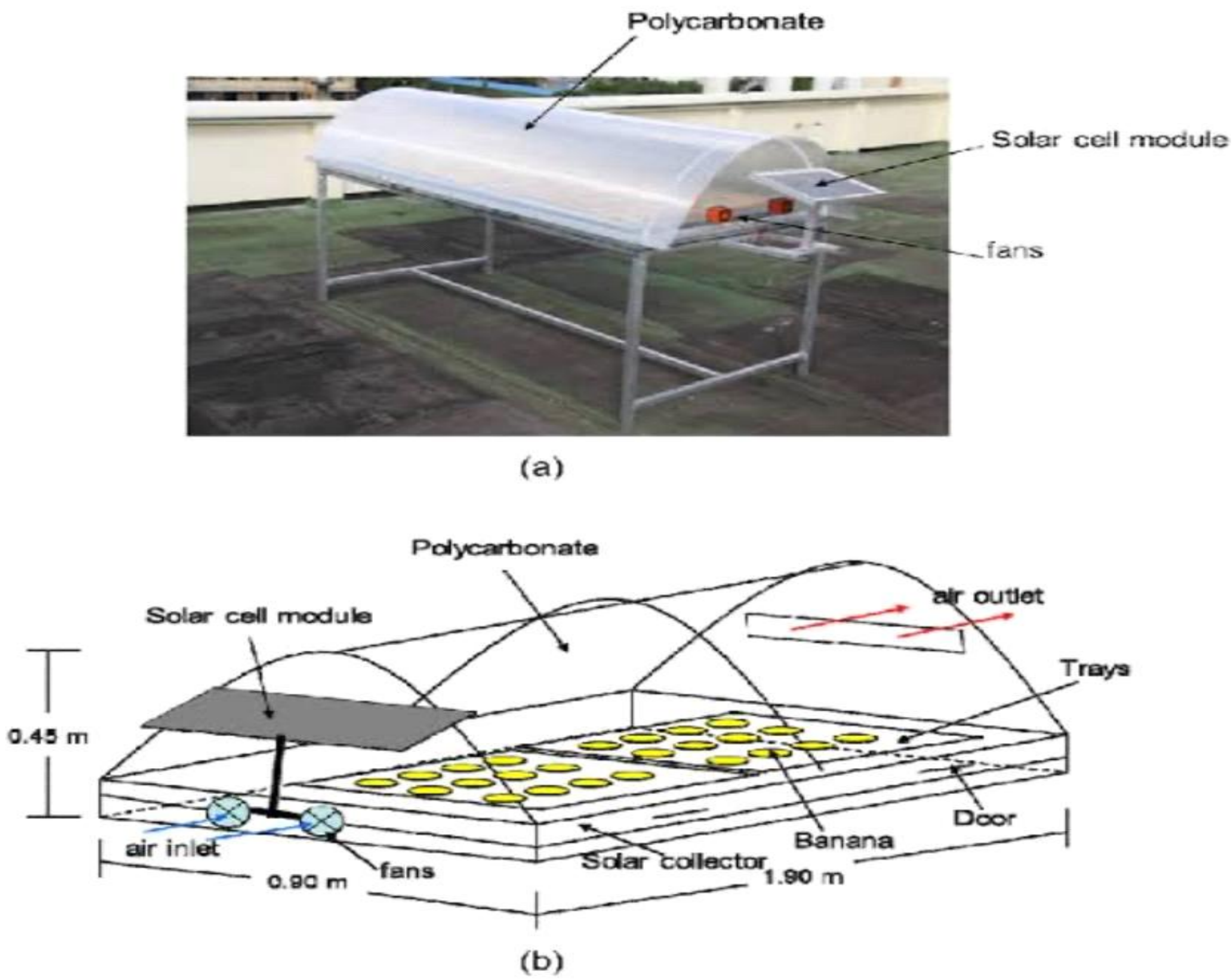


Figure 2.1 Pictorial view of the Food Processing Dryer

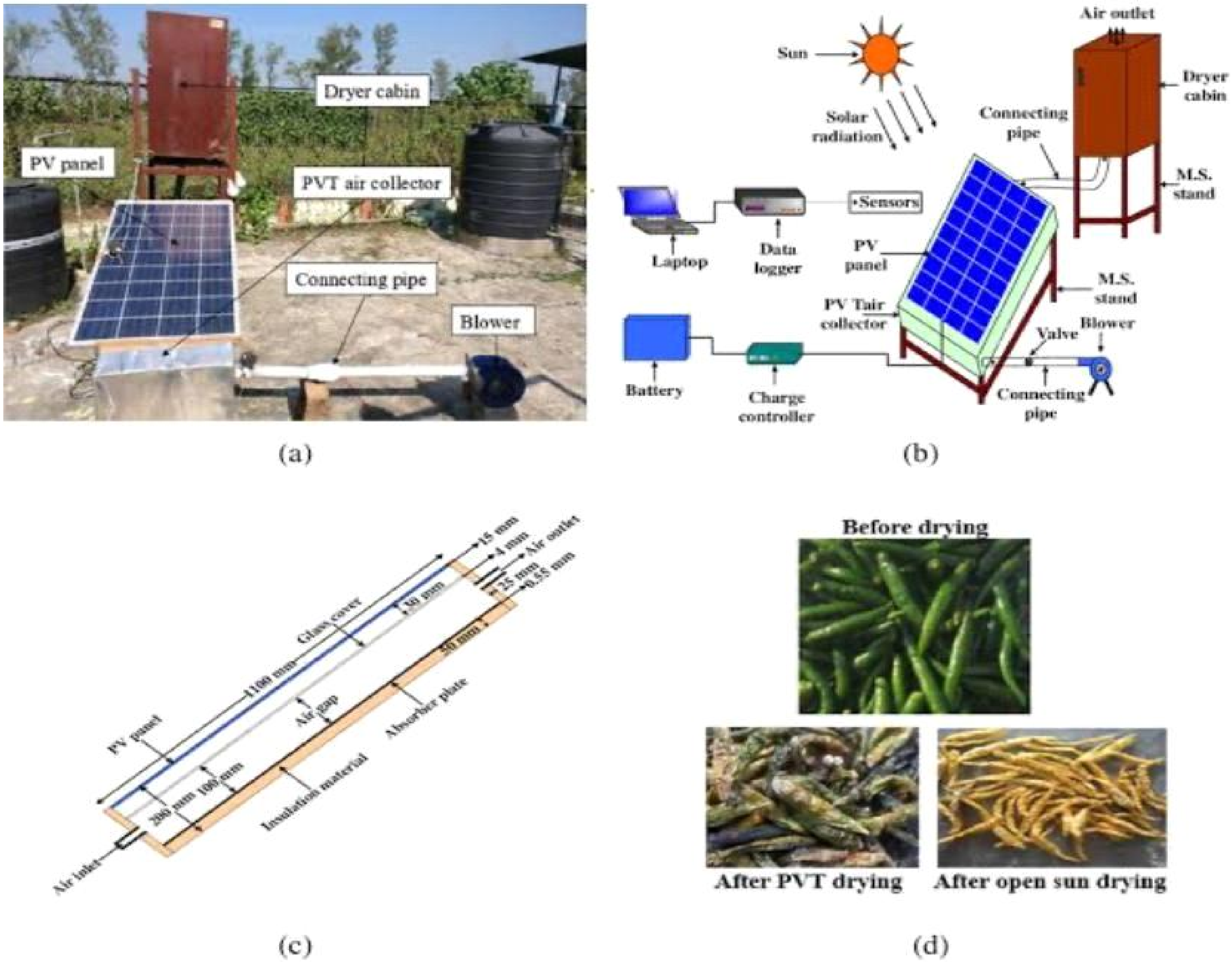


Figure 2.2 Pictorial view of the Solar Hybrid Food Processor

2.2 Principles of Solar Drying

The fundamental principle involves converting solar radiation into thermal energy, which is then used to evaporate moisture from the surface of the material being dried. The process primarily involves three key mechanisms:

1. Solar Radiation Absorption:

Solar energy is captured by a collector surface (usually painted black or dark-colored for higher heat absorption) and converted into heat. This surface heats the air, which then circulates through the drying chamber.

2. Heat Transfer:

The heated air comes into contact with the wet product. Through convection, the warm air transfers heat to the product's surface, while conduction transfers heat into the product's interior.

3. Mass Transfer (Moisture Removal):

As the product absorbs heat, moisture within the material migrates to the surface and evaporates. The now moisture-laden air is then vented out of the dryer, allowing fresh, dry air to enter and continue the process.

As stated by Ekechukwu and Norton (1999), solar drying enhances product quality and shelf life, especially in rural or off-grid areas, by leveraging renewable energy sources that are abundant and free.

2.3 Methods of Solar Drying

The methods of solar drying are as follows:

i. **Direct solar drying:-** Direct solar drying is a general method of drying the product by means of solar energy. In this process the energy which is obtained from sun is directly used for drying purpose. This is one of the convenient methods of drying, because energy is obtained from one of the cheaper source called as sun or renewable source of energy. It is the continuous operation of heat and mass transfer. Direct solar dryers dehydrates substance in direct sunlight. In the past., food and clothing were dried on rocks or with bamboo sticks. In some country, meat and dairy product are still dried in same way, which helps to dry the roots due to the flow of wind along with the heat of the sun. the some goes for solar trays and open cupboards.

One of the newer types is black paper, which is used for direct drying. Black paper combines sun light to increase the temperature and can have a glass cover or air vent to keep the increased temperature longer and increase efficiency. This technique involves the thin layer of product spread over large space to expose to solar radiation. This process for a long time until the products will dry to a required level. The surface floor made from the concrete or particular area of soil is making applicable for outdoor direct sun drying. This type of drying method is useful for grains. Material is led on outdoor floor for a long time, usually 10-30 days**. According to Sanjay P. Salve (2014),** drying is a very important process applicable for agriculture and industrial product. Drying reduces the bacterial growth of the product and helpful for preserving the product for long period of time. But this conventional process have some disadvantages therefore in that case it is very essential to use other methods of drying such as active, passive and mixed solar drying.

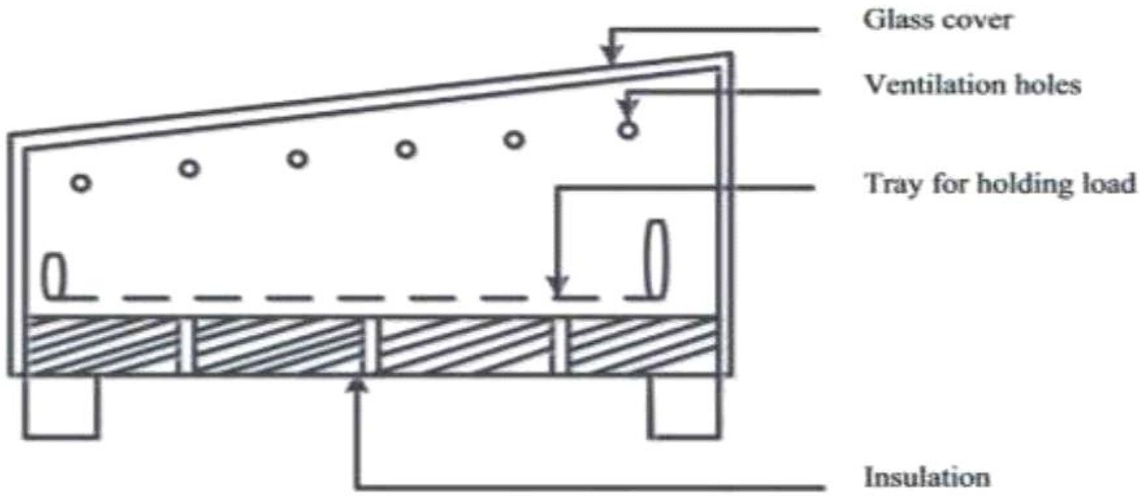


Fig 2.3 Direct Solar Dryer

ii. Indirect solar drying:-

Indirect or convective solar drying it is more efficient than direct type of solar drying. In an indirect solar dryer, the sun's heat is first collected by the solar collectors and is then passed on to the dryer cabinet, where the drying occurs. The air heaters are connected. The basic concept of reverse flat plate collector is used to dry food products in a solar cabinet-type dryer. Here, a solar air heater is used to heat the air that enters the chamber. The heated air then turns in to warm humid air, which passes through an outlet. This kind of dryer is better than other dryers in terms of solving various equations based on energy balance. It also has better performance than other conventional cabinet type of dryers. **According to A.G.M.B. Mustayen (2014)** method of drying is used to avoid direct exposing to the solar radiation. This method mainly reduces the disadvantages of direct solar drying

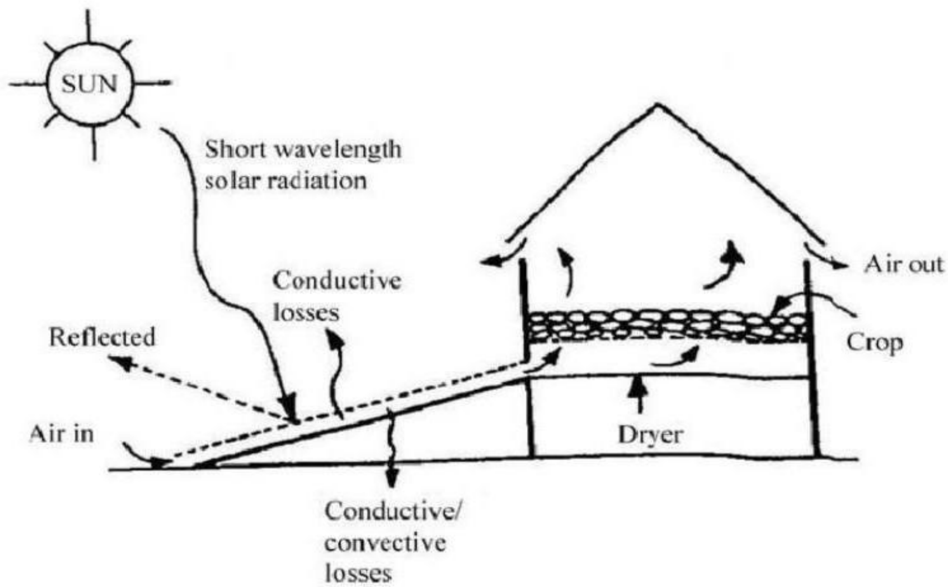
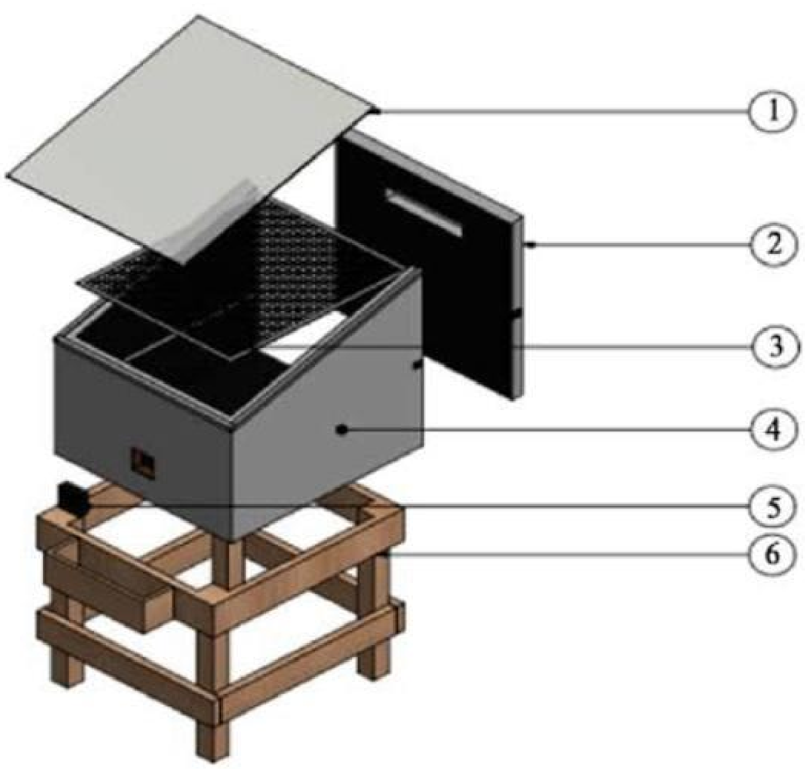


Fig 2.4 Indirect Solar Dryer

iii. Mixed mode solar drying:-

Mixed mode solar drying is one another advanced form of solar drying technique, in which both direct and indirect solar drying are performed simultaneously. This method also called as passive drier. The mixed-mode solar dryer has no moving parts, which is why it is called the passive dryer. This type of dryer acquires energy from the rays of the sun that enters through the collector lust-ring. The inside surface of the collector is painted black, and the sun's rays are harnessed by trapping the heat of the air that is collected inside the chamber. A previous study that examined the design and performance of this kind of solar dryer verified the accelerated drying process and its ability to dry agricultural products by quickly reaching better conditional moisture level, thus making it ideal for food preservation. **According to Mustayen and Saad Mekhilef (2014)** based on the results, they found that the mass flow rate effect and discharge rate of crop drying are good. Moreover, this system gives satisfactory result in terms of drying efficiency and moisture content. The maximum efficiency of the system was recorded at 21.24%, and the energy consumed during the drying process was 6–8%. Final moisture content was 13% at ambient temperature (25 degree Celsius).



PARTS LIST	
PART NUMBER	PART NAME
1	Transparent Glass
2	Door
3	Tray
4	Dryer body
5	Fan
6	Wood Stand

Figure 2.5 An Exploded view of the Solar Dryer Showing all the Components

2.4 Solar Drying

Solar dryers are mainly categorized as indirect or direct and open sun drying. This gives precision outcomes such as good product quality and dust-free results. These solar dryers can operate through natural or forced convection methods each impacts the overall efficiency. Natural convection dryers with an efficiency range of 20 to 40%. Forced convection dryers with an efficiency range of 60% to 80%. Further solar dryers integrate Thermal Energy Storage systems such as sensible heat or latent heat storage units. These thermal energy storage are good and gives precision product quality and much harmful for environmental conditions.

i. Natural convection solar dryer (passive mode solar dryer):-

Natural convection solar dryer is the easiest and convenient method of drying. In which a collector, a transparent sheet, and a unit for drying; it is covered by a shade on top. These parts are connected in a series, comprising a system that can obtain very satisfactory drying rates. This type of model was first introduced by Oosthuizen. This kind of solar dryer obviously plays a vital role in the drying sector because of its low cost. It has also become popular because of its simple maintenance and operation. Between a natural convection solar dryer and a forced convection dryer, the former is more suitable and is one of the oldest types of dryers available. However, the natural convection solar drying system has a limited capacity. Moreover, the drying rate is delayed and highly dependent on atmospheric conditions because of a little float for inducing air flow inside the dryer, thus reducing the quality of the drying products especially in adverse weather conditions. Later on such condition a new type of solar dryer has been designed and tested by Later Ezeike. This dryer has a very simple design and provides high efficiency in ambient atmosphere. It consists of a flat plate air collector, a drying cabin, and a dehumidification chamber. It is used in the low-isolation period because of its additional heat gain by two wall collectors in the cabinet in order to contain the desiccant which is a type of silica gel placed in the dehumidification chamber.

ii. Forced convection solar drier (active mode solar dryer)

In a forced convection solar drier the energy is needed to operate the fans to convey the heated air within the solar tube towards the food tray. This helps to dehumidify the food in less time. However, many rural areas either have no electricity or have to incur high costs to generate the electricity used to run this type of dryer. Therefore, these types of dryers are not widely applicable in many developing countries. To avoid the above- mentioned disadvantages, a natural convection solar dryer may be used. This type of dryer is not dependent on electricity like a forced convection solar dryer. Its advantages include low energy cost, ideal shrinkage in the drying period, better drying capacity, minimization of mass losses, and good quality of the dried products.

Ahmad Ghazanfari (2002) develops a prototype forced circulation cabinet the drying chamber was made up of dimensions with length of 170 cm; width of 210 cm; front height of the chamber is 30 cm and the back height of 65 cm. Four trays were used of sliding type of dimensions 80 cm x 70 cm x 10 cm. It was fitted in the chamber. The final moisture content of the nuts was 6.0%. This final moisture content reached in 36 sunshine hours.

2.5 Classification, Advantage and Disadvantages of Solar Dryer

Classification

i. Passive dryers.

ii. Active dryers.

iii. Hybrid solar dryers.

Advantages

a. Simplest.

b. Low capital.

c. Independent of the ambient climatic conditions.

d. Better control of drying.

Disadvantages

i. Low capacity.

ii. More complex.

2.6 Sources of Literature Review

Numerous articles dealing with theory and application of solar drier have been published over several years, but topic is still under considerable development. We have examined the work related to solar drier published in referred journals. The distributions of articles in various journals.

Distribution of Reviewed Article

1. Scientific research publishing.
2. Hindwai research publishing.
3. APRN Journal of Engineering & Applied Science.
4. Research gate.
5. International Journal of Research in Advent Technology.
6. International Journal of Sustainable Energy.
7. Drying Technology.
8. Multistage Drying Technology.

2.7 Scientific Researches

In rural areas, direct natural solar dryers are designed and fabricated to dry tapioca. A batch of 120 kg tapioca requires a minimum of 7.88 m2 solar collector area to dry in 22 hours (two days drying period). The initial and final humidity ratios were calculated on a wet basis of 82% and 12%, respectively. On a horizontal surface of 15 MJ / m2 / day the average ambient conditions with daily global solar radiation events is 34 ° C air temperature and 76% relative humidity. Wari (latitude 5 ° 30 ', long. 5 ° 41'), considering the climatic conditions in Nigeria. A sample dryer with a minimum collector area of 1.095 m. **(Diemuodeke and Momoh, 2011)**

Solar wind-ventilated cabinet dryers designed, constructed and tested at 7.51 latitudes in Nigeria, in comparison, drying by solar cabinet dryers showed better results than open air-drying. During the test period, the average velocity of air through the solar dryer was 1.52 m / s and the average daylight efficiency of the system was 46.47%. The maximum dry air temperature was found to be 64degreeC. The average dry air temperature in a dry cabinet is higher than the ambient temperature in the range of 50degreeC at the beginning of the day to 31.1degreeC in the middle of the day. 80% and 55% of the weight was lost while drying the pepper and yam chips in the dryer, respectively. inside the dryer. **(Bukola Bolaji et al., 2011)**

Designed and built a solar drawing system for corn kernels with a 2.04 m area U-groove collector, drawing chamber and blower. Thermal energy and heat loss from the solar collector were calculated for each of the three tilt angles (30,45 °, 60 "). Radiation occurred. Several other important results were found to be theoretical thermal energy, experimentally real heat increases. Radiation intensity increased, maximum values fell at 11 a.m. and then gradually decreased. **(Ahmed Abed Gatea, 2011)**

The performance of the indirect forced convection solar dryer combined with heat storage material was designed, fabricated and tested for chilli drying. A dryer with heat storage material enables the air to maintain a constant temperature in the dryer. The inclusion of heat storage material increases the drying time by about 4.5 hours per day. Chilies were dried in the bottom and top trays at 72.08% from the initial humidity to the final humidity, 9.12% and 9.72% (on a wet basis), respectively. He concluded that a forced convection solar dryer is more suitable for small holders to produce high quality dry pepper. The thermal efficiency of the solar dryer is estimated to be approximately 22% and the specific humidity removal rate is about 0.88 kg / kW h. **(Mohanraj and Chandrasekar, 2009)**

Created a simple and inexpensive blended mode solar dry local source material. The temperature in the drying cabinet rose to 23 ° C (74.2%) immediately after 12.00h (noon). The drying rate for yam chips, collector efficiency and moisture removal percentage (on a dry basis) were 0.628 kgh-1, 55.5 and 85.5%, respectively. The dryer has sufficient capacity to dry food at reasonable humidity level at safe humidity level and also high quality of dried product. **(Bukola Bolaji et al., 2008)**

The Double Pass Solar Dryer (DPSD) was designed to dry red chillies in central Vietnam, and the DPSD is compared to a cabinet dryer (CD) and a traditional open dryer. They found that the average drying temperature for DPSD, CD and open air drying in the sun was 61 ° C, 52.2C and 34.8 ° C and the corresponding humidity was 33%, 44% and 64%, respectively. The total drying efficiency of DPSD is 20.2% which is typical for a forced convection solar dryer. The humidity of fresh red pepper was almost the same in all drying tests, where initial values were 9.19kg kg.9.27kg kg and 10.30kg kg (db) for DPSD, CD and open air sun drying, respectively. Where the final humidity of DPSD 0.04kg / kg reached after 23.3 hours, 0.08kg / kg for CD after 29.5 hours and 0.19kg / kg after 37 hours in open sunlight (excluding night). The performance of the newly designed DPSD has been compared to that of traditional CD and sun drying for drying common CDs and red peppers. DPSD has resulted in minimal drying time to meet the desired humidity of the pepper (10.50% wb). Which is related to the highest drying rate compared to other methods. So, the double pass solar dryer was found to be technically and economically suitable for drying red chillies under certain conditions in Central Vietnam. **(J. Banout et al., 2010-2011)**

Mixed mode type Force Convection Solar Tunnel Dryer is designed and developed for drying hot red and greenchillies in the tropical climate of Bangladesh as shown in the figure. In dryer (1.Air inlet 2.Fan; 3.Solar module; 4.Solar collector; 5.Side metal frame; 6.Collector outlet7.Wold support; 8.Plastic net; 9.Plastic cover roof structure; 10. Base structure to support dryer; 11. Rolling bar, 12, drying tunnel outlet.) Red pepper humidity in solar tunnel dryer decreased from 2.85 to 0.052 kg / kg (db) in 20 .5hours and humidity was 0.08 and 0.41 kg / kg (db). It took 32.5 hours to subside.) In modified and traditional sun drying methods, respectively. **(Hossaina and bala, 2007)**

The Mixed-Mode Natural Convection Solar Dryer (MNCSCD) is designed for drying cassava and other crops. A batch of 170 kg cassava by mass, in which the initial humidity is 67% on a wet basis from which 101 kg of water must be removed so that it has to be dried to the desired moisture of 17.5% wet base, is used as dry load. Drying time for the expected test location (Kumasi; 6.72N, 1.62W) is assumed to be 35-37 hours with ambient conditions with an average solar radiation of 410W / m2 and 24 IC and 76.8% relative humidity when designing the dryer. They concluded that a minimum of 40.4m² solar collection area is required by design for 11.5% expected drying efficiency. With an average ambient condition of 28.2 IC with 340.4W / m² solar radiation and relative humidity of 72.12%, 35 hours drying time was observed and when tested under a fully designed load process the drying efficiency was assessed as 12.35%, indicating that the design ratio Is. That's enough. **(F.K Forson et al., 2007)**

A natural solar dryer (cabinet type) was designed and built to dry the mango pieces. He concluded that the dryer designed with 16.8m2 collector area, 195.2 kg fresh mango (100 kg chopped mango) on 81.4% to 10% wet basis is convenient to dry in one to two days during April to June harvest period. A prototype of the dryer has been designed and built with a maximum collector area of 1.03m². **(El-Amin Akoy et al., 2014)**

A cylindrical section of the solar drying system was designed and the efficiency is analyzed. The system consists of a solar collector flat plate 1.11 m long and 1.11m wide and a fan was built and designed for the purpose of drying 71 kg of bean crop. The performance of the solar air collector has been tested using three air flow rates. The highest temperature (71.4 degree C) of the outlet solar collector is received at 11 a.m. 751 W/m² was obtained for air flow of 0.0400 kg / s at radiation intensity and minimum temperature (41.0 degree C) was obtained when air flow rate at radiation intensity was 0.0674 kg / s 460 W / m' was obtained. The maximum value of average thermal efficiency is 25.64% with an air flow rate of 0.0675 kg / s of the solar air collector and the minimum average thermal efficiency is 18.63% with an air flow rate of 0.0405 kg / s. The initial humidity of soybeans was 70% and final 14% when air flow rate was 0.0405 kg / s 18% d, b flow rate of 0.0540 kg/s and air flow rate of 0.0761 kg / s was 20% d.b **(Ahmed Abed Gatea, 2011)**

2.8 Materials used for Solar Dryers

Different authors and many other researchers have designed and developed the solar dryer with different materials. Materials used for the solar dryers are wood, cast iron ,aluminium sheet and hybrid composite. The insulating materials which are used in solar dryers plays an important role in the solar drying system. Cast iron is mostly used as a storage in the dryer for the storage of the hot fluid.

1) Materials Used

The following materials were used for the construction of the domestic passive solar dryer:

i. Wood - as the casing (housing) of the entire system; wood was selected being a good insulator and relatively cheaper than metals.

ii. Glass - as the solar collector cover and the cover for the drying chamber. It permits the solar radiation into the system but resists the flow of heat energy out of the systems.

iii. Mild steel sheet of 1mm thickness (dimension 115cm × 65cm) painted black with tar – for absorption of solar radiation.

iv. Net cloth (cheesecloth) and wooden frames for constructing the trays.

v. Nails and glue as fasteners and adhesives.

vi. Glass wool insulation.

vii. Paint (black).

2) Types of Solar Greenhouse Dryer

Greenhouse dryers are classified based on the mode of heat transfer:

i. Greenhouse dryer under natural convection.

ii. Greenhouse dryer under forced convection. The greenhouse dryer under natural convection works on the principle of thermosyphic effect. Air gets out through the chimney. In greenhouse dryer under forced convection the humid air is gets out by the help of an exhaust fan which is at the ventilator.

2.9 Application of Solar Dryer in various Field

a) Agriculture crop drying.

b) Food processing industries for dehydration of fruits, potatoes, onions and other vegetables.

c) Dairy industries for production of milk powder, casein etc.

d) Seasoning of wood and timber.

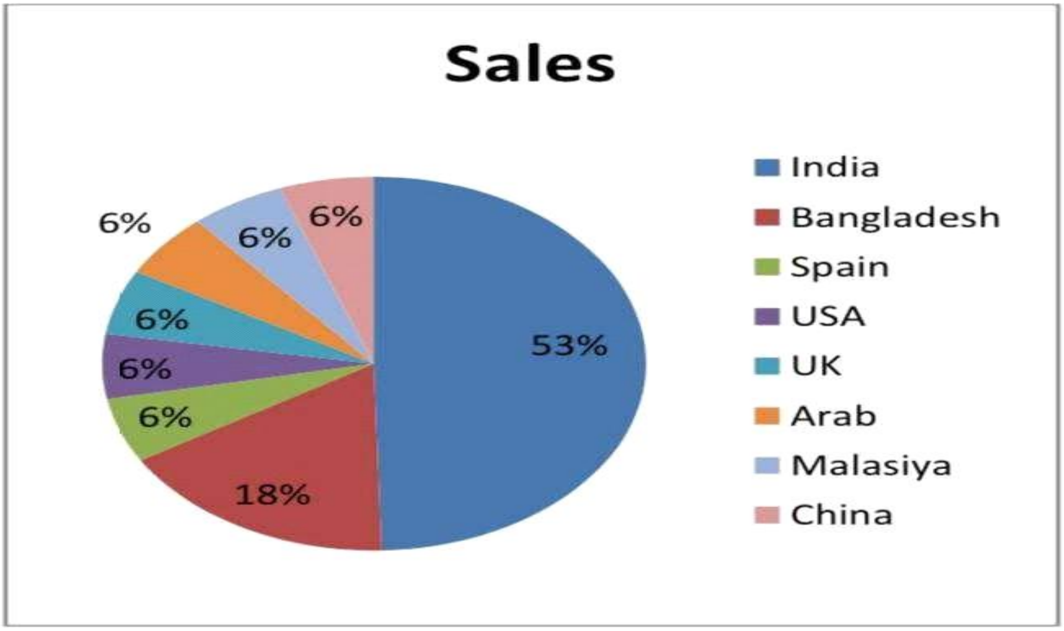
e) Textile industries for drying of textile material.

f) Food product dryer.

g) Fruits and Vegetables solar dryer.

h) Solar hot air generation for industry and space heating.

2.10 Location Wise Awareness in Field of Solar Dryer



From the above pie chart and as per our study, the percentage of India on solar dryer is more than the other 7 mentioned countries.

According to the revised paper it is found that the authors of different countries mostly focused on the indirect and mixed type of solar dryer.

2.11 Gaps in Literature Research

i. Can be only used during day time when adequate amount of solar energy is present.

ii. Lack of skilled personnel for operation and maintenance.

iii. Less efficiency as compared with modern type of dryers.

iv. A backup heating system is necessary for products require continuous drying.

2.12 Summary of Literature Review

The literature reviewed has shown that while numerous cabinet solar dryer designs have been developed, many of these systems face challenges such as poor airflow distribution, heat loss, high construction costs, and limited adaptability to specific local conditions. Most existing models are either too technologically advanced for rural adoption or too basic to ensure consistent drying performance and food safety. This project seeks to build on previous research by incorporating locally available and cost-effective materials in the design and construction of a cabinet solar dryer that is both affordable and efficient for small scale users.

CHAPTER THREE

METHODOLOGY

3.1 Materials

The materials used for fabrication of this solar dryer are affordable and it can easily be obtained in our local market where metals are sold. The major materials of the machine are:

i. Galvanized Sheet Metal

ii. Solar Panel

iii. Transparent Plain Glass

iv. Welding Electrodes

v. Oil Paint

vi. 1' Angle Iron

vii. Cutting stone

viii. Aluminum Sheet

ix. Fan

x. Hinges

xi. Sealer Tube

xii. Wire Gauze

xiii. Quick Fill

3.2 Methods

The solar dryer consist of the following components and they include,

i. Transparent plain Glass

ii. The drying chamber

iii. The base frame (structural stand)

iv. The drying tray

v. The solar panel

vi. Fan

3.2.1 Transparent Plain Glass

A transparent glass solar collector serves as an essential component in harnessing solar radiation for the drying of plantain slices. It functions as a specialized heat exchanger that allows sunlight to penetrate through the glass cover while trapping heat within the system, thereby increasing the temperature of the drying air. Unlike conventional heat exchangers where energy transfer occurs primarily between two fluids, this collector depends on solar radiation from the sun and transfers the absorbed energy to air, which in turn removes moisture from the plantain. The transparent glass permits shortwave solar radiation, typically in the range of 0.3 to 3 μm, to pass through and strike a dark, heat-absorbing surface beneath it. This absorber plate, often made of black-painted metal, converts the incoming radiation into heat and re-emits long wave infrared energy. Because glass is less transparent to this long wave radiation, it traps much of the heat inside the collector, creating a greenhouse effect that maintains higher temperatures for efficient drying. The solar radiation incident on the glass surface can reach up to 1100 W/m^2, although it fluctuates depending on weather conditions. One of the key advantages of using transparent glass in the solar collector is its ability to utilize both direct (beam) and scattered (diffuse) sunlight, enabling continuous drying of plantain slices even on partially cloudy days without the need for sun tracking. The system can achieve operating temperatures suitable for dehydration—approximately 50-60 °C (120-140 °F) in a general guide from the Food and Agriculture Organization (FAO) —which is ideal for removing moisture from plantain without compromising its nutritional value or color. In addition to its effectiveness, the transparent glass collector is mechanically simple, durable, and requires minimal maintenance. When in operation, it reaches thermal equilibrium when the heat gained from solar radiation equals the losses through convection and radiation, ensuring a steady, efficient, and hygienic drying process. This makes the transparent glass solar collector a practical and sustainable solution for processing and preserving plantain in both rural and small-scale industrial applications

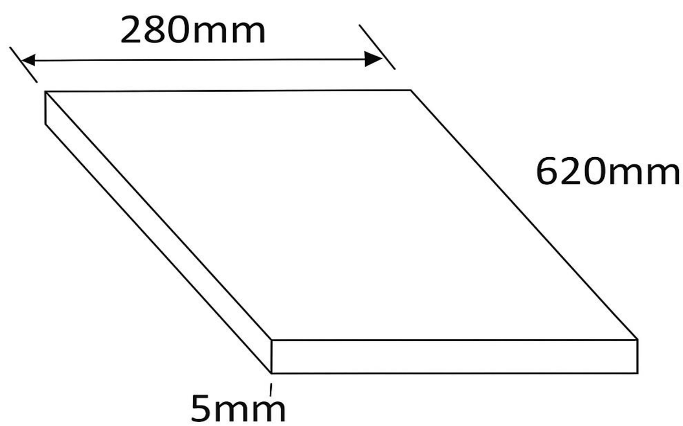


Fig 3.1 Transparent plain glass

3.2.2 Drying Chamber

The drying chamber is a rectangular-shaped enclosure designed to provide a controlled environment for the efficient drying of plantain slices. It is constructed with double walls made of mild steel metal sheets, each with a thickness of 0.0001 m, and dimensions of 0.61 m in depth, 0.61 m in length, and 0.30 m in width. The space between the double walls is filled with Lagging Material, which serves as a thermal insulator to minimize heat loss across the chamber walls and maintain a stable internal temperature during operation. Inside the chamber, plantain slices are placed on perforated drying trays that allow heated air to circulate evenly around the product, ensuring uniform moisture removal. The drying chamber is equipped with air outlets located on both sides near the top, which facilitate the escape of moist air and enhance airflow during the drying process. This continuous circulation of hot air helps to reduce the moisture content of the plantain efficiently, improving drying speed and product quality. A hinged main door is positioned at the back of the chamber, providing easy access for loading and unloading the drying trays, as well as for cleaning and maintenance. The overall design ensures that heat is effectively retained within the system while maintaining adequate ventilation, resulting in a consistent drying process that preserves the nutritional value, color, and flavor of the plantain. This drying chamber configuration makes it suitable for small-scale or rural-based solar drying operations focused on plantain preservation.

Fig 3.2 Drying Chamber

3.2.3 The Base Frame (Structural Stand)

The structural stand of the solar dryer serves as the foundation that supports and elevates the entire drying unit, ensuring stability, durability, and optimal positioning for maximum solar exposure. It is fabricated from angle iron and mild steel materials, chosen for their strength, rigidity, and resistance to deformation under load. The stand is designed to firmly hold the drying chamber and solar collector at a suitable height above ground level, typically between 0.5 m and 1.0 m, to facilitate proper air circulation beneath the system and to protect the unit from ground moisture or debris. The framework is welded together to form a strong rectangular base with cross braces that enhance structural integrity and prevent vibration or movement during operation. The legs of the stand are reinforced and may be fitted with rubber or metal pads to provide stability on various surfaces. In some designs, the stand is slightly inclined—usually between 10° and 15°—to ensure that the solar collector is oriented towards the direction of maximum sunlight for effective heat absorption. The elevated and well-anchored design not only ensures user convenience when loading or unloading plantain trays but also contributes to improved airflow and thermal efficiency. Overall, the structural stand plays a vital role in maintaining the durability, safety, and functional performance of the solar dryer throughout its operation.

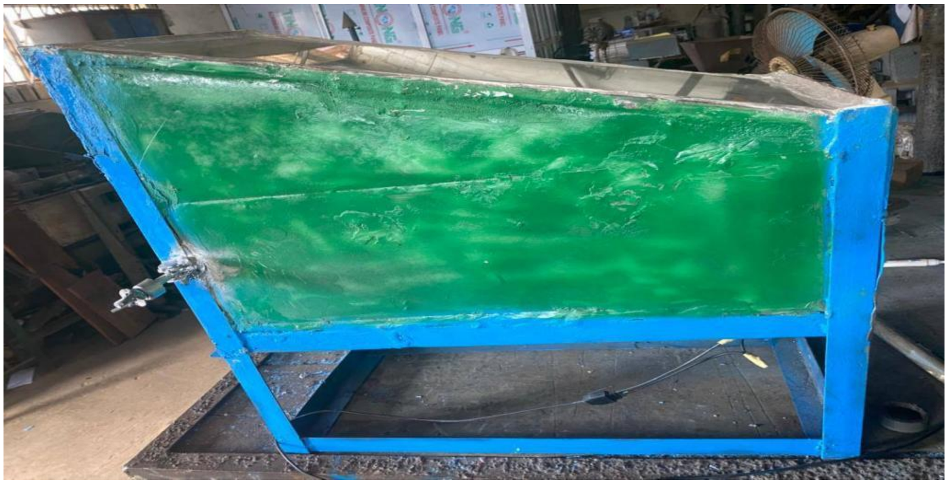


Fig 3.3 The Base Frame

3.2.4 Drying Tray

The drying tray is a removable component designed to hold plantain slices during the drying process. It is constructed from durable, food-grade materials such as stainless steel mesh or perforated aluminum sheet to allow uniform airflow and efficient heat transfer around the product. The perforations enable the warm air from the solar collector to pass freely through the tray, ensuring even moisture removal from all sides of the plantain slices. Each tray is lightweight and easy to insert or remove from the drying chamber, facilitating convenient loading, unloading, and cleaning. The tray design also prevents the plantain pieces from overlapping, promoting consistent drying and preventing spoilage. By maintaining adequate spacing and ventilation, the drying tray plays a crucial role in achieving uniform dehydration while preserving the color, texture, and nutritional value of the plantain. Overall, it enhances the efficiency, hygiene, and reliability of the solar drying system.

Fig 3.4 The Drying Tray

3.2.5 Solar Panel

The solar panel used in the plantain drying system serves as the primary source of electrical energy for powering auxiliary components such as fans or temperature control units within the solar dryer. With the dimension of 24 X 15 X 1.8 CM, Optimum operating voltage of 6V and Optimum operating current of 500mA. Amorphous solar panels are often preferred for this purpose due to their affordability, flexibility, and shadow-resistant characteristics. These panels are made of a thin film of molten silicon deposited directly onto large stainless steel or similar substrates. Although amorphous panels have lower efficiency compared to monocrystalline and polycrystalline panels, they are cost-effective and perform reliably under partially shaded conditions—a useful feature for outdoor drying systems that may experience intermittent sunlight. When integrated into the solar dryer, the panel converts solar radiation into electrical energy, which can be used to operate low-voltage DC fans that enhance air circulation within the drying chamber, ensuring uniform and faster removal of moisture from the plantain slices.

The simplicity, lightweight nature, and adaptability of amorphous solar panels make them particularly suitable for small-scale or rural-based plantain drying applications where cost efficiency and energy independence are essential.

Fig 3.5 Solar Panel

3.2.6 Fans

The solar dryer is equipped with two axial-flow fans rated at 12V DC and 0.25A each, and dimension of 80mm which play a vital role in ensuring efficient airflow throughout the drying chamber during the plantain drying process. These fans are housed in barrel-shaped casings containing impellers with large hubs and multiple short blades designed to move air effectively in a linear direction. They are direct-driven, meaning the impellers are mounted directly on the motor shaft, and the motors are cooled by the same airstream generated during operation. In the solar dryer system, the fans help to distribute heated air uniformly over the plantain slices, enhancing moisture removal and maintaining consistent drying conditions. The continuous air circulation prevents uneven drying, discoloration, and microbial growth, thereby improving the overall quality of the dried plantain. The fans operate using electrical energy supplied by the solar panel, making the system fully independent of external power sources. Although axial-flow fans are generally efficient and compact, a notable disadvantage is their tendency to produce noise during operation. Despite this, their high airflow rate, low power consumption, and compatibility with DC solar systems make them ideal for small-scale plantain drying applications.

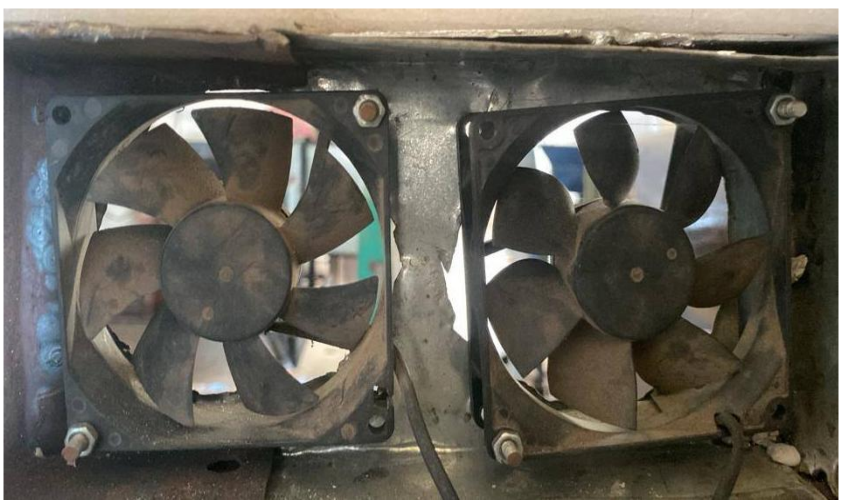


Fig 3.6 The Fans

3.3 Operation of the Solar dryer

The operation of the solar dryer for plantain is primarily passive, utilizing solar energy as the main power source to drive the drying process. The system functions by capturing sunlight through the transparent glass cover of the solar collector, which allows solar radiation to enter and heat the absorber surface painted black to maximize heat absorption. The absorbed energy increases the temperature of the air inside the collector, creating a greenhouse effect that enhances heat retention. This heated air is then directed into the drying chamber, where plantain slices are arranged on perforated trays. Two solar-powered axial-flow fans rated at 12V DC and 0.25A assist in circulating the warm air evenly throughout the chamber, ensuring efficient and uniform drying. When the vents are opened, the hot air rises naturally and escapes through the upper vent of the drying chamber, while cooler ambient air enters through the lower vent of the collector, thus maintaining a continuous airflow cycle. This natural convection process, supported by the fans, ensures that moisture-laden air is consistently removed and replaced with dry, heated air. As a result, the moisture content of the plantain gradually decreases until the desired dryness is achieved, producing a high-quality, hygienic, and well-preserved final product.

The operation of the solar dryer for plantain is based on the principle of utilizing solar energy to heat air and circulate it through the drying chamber to remove moisture from the plantain slices efficiently. The system begins operation when sunlight strikes the transparent glass surface of the solar collector. The glass allows shortwave solar radiation to pass through and reach the black-painted absorber plate beneath it. This absorber plate converts the solar radiation into heat energy, thereby raising the temperature of the air within the collector. The glass cover also helps trap the heat by limiting the escape of long wave infrared radiation, creating a greenhouse effect that maintains a higher temperature inside the collector compared to the surrounding air.As the air inside the collector heats up, it becomes less dense and starts to rise. This warm air is directed into the drying chamber through an air inlet located at the lower end of the chamber. Two DC axial-flow fans rated at 12V and 0.25A each, powered by a solar panel, are used to assist in moving the heated air evenly across the drying trays. The plantain slices, which are spread in single layers on the perforated trays, receive the flow of warm air that transfers heat to their surface. This causes the moisture in the plantain to evaporate gradually. The moisture-laden air then exits the drying chamber through the upper vents, while cooler, dry air is drawn in through the lower vent of the collector to continue the cycle.

This natural convection process, combined with the fan-assisted airflow, ensures that there is a continuous exchange of air, preventing stagnation and uneven drying. The system automatically achieves a dynamic balance where the rate of heat input from the collector equals the rate of heat loss and moisture removal, maintaining a steady operating temperature suitable for drying plantain—typically around 50°C to 70°C depending on sunlight intensity. This temperature range is ideal for preserving the nutritional quality, color, and texture of plantain while efficiently reducing its moisture content to safe storage levels.The solar dryer operates entirely on renewable energy, with the solar panel providing power for the fans, making it both eco-friendly and cost-effective. The simplicity of its operation allows for easy monitoring and maintenance. Once the desired level of dryness is achieved, the plantain slices can be removed, cooled, and packaged for storage or further processing. Overall, the operation of this solar dryer combines thermal and aerodynamic principles to achieve efficient, hygienic, and sustainable dehydration of plantain, minimizing post-harvest losses and improving product shelf life.

3.4 Orientation of the Solar.

The orientation of the flat-plate solar collector is a crucial factor in maximizing the efficiency of the plantain drying system. To ensure optimal solar radiation absorption, the collector is positioned and tilted in such a way that it receives the highest amount of sunlight during the intended drying season. In accordance with standard design practice, the best stationary orientation for solar collectors in the northern hemisphere is due south, while in the southern hemisphere it is due north. Therefore, in this project, the solar collector is oriented facing south and tilted at an angle of 16.2° to the horizontal. This tilt angle is approximately 10° greater than the local geographical latitude of Benin City, Nigeria (6.2°N), which, according to Adegoke and Bolaji (2000), provides the most favorable inclination for stationary absorbers. The selected tilt not only enhances the collector's exposure to direct and diffuse solar radiation but also facilitates the natural runoff of rainwater and prevents dust accumulation on the glass surface. Additionally, this inclination supports better airflow within the system, contributing to more efficient heat distribution and uniform drying of the plantain slices.

3.5 Fabrication Process/Assembly

The fabrication and assembling of the solar dryer involves:

i. Cutting and welding of the frame.

ii. Fabrication of collector and chamber.

iii. Installation of trays, fans, and vents.

iv. Electrical wiring of the solar panel.

v. Painting, insulation and testing.

3.6 Machine Orthographic Components

Below are the orthographic drawings of the solar dryer:

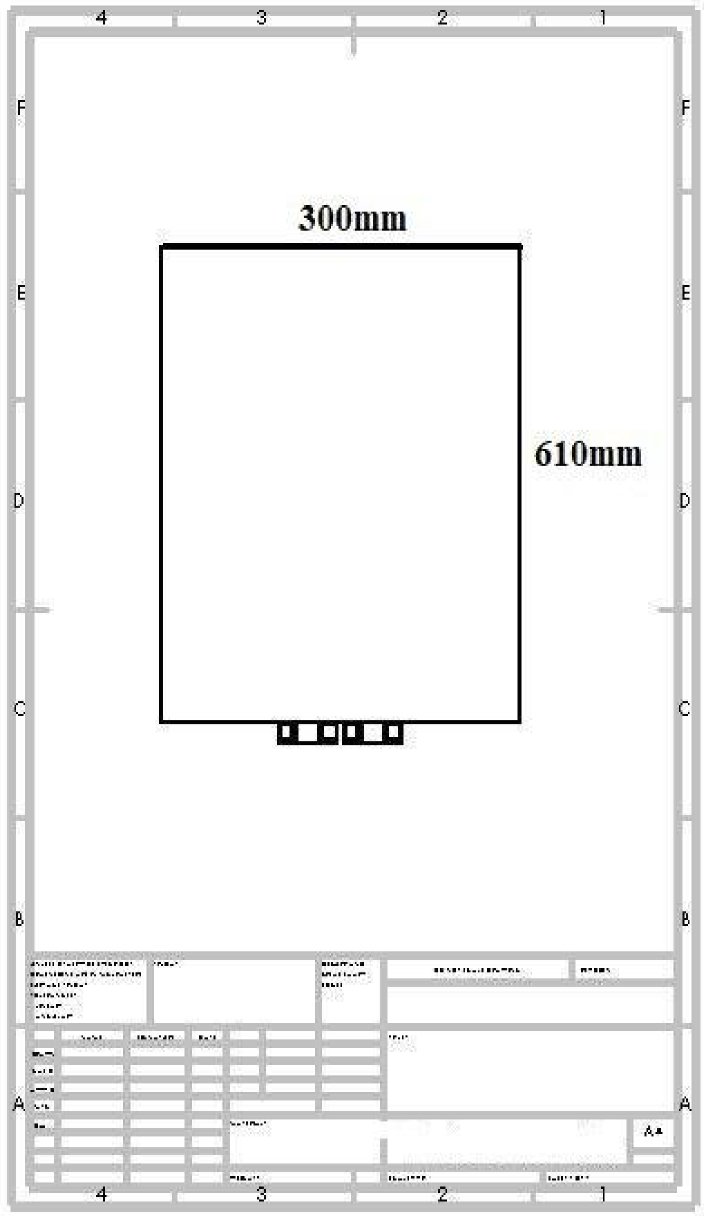


Fig 3.7. Top View of the Solar Dryer

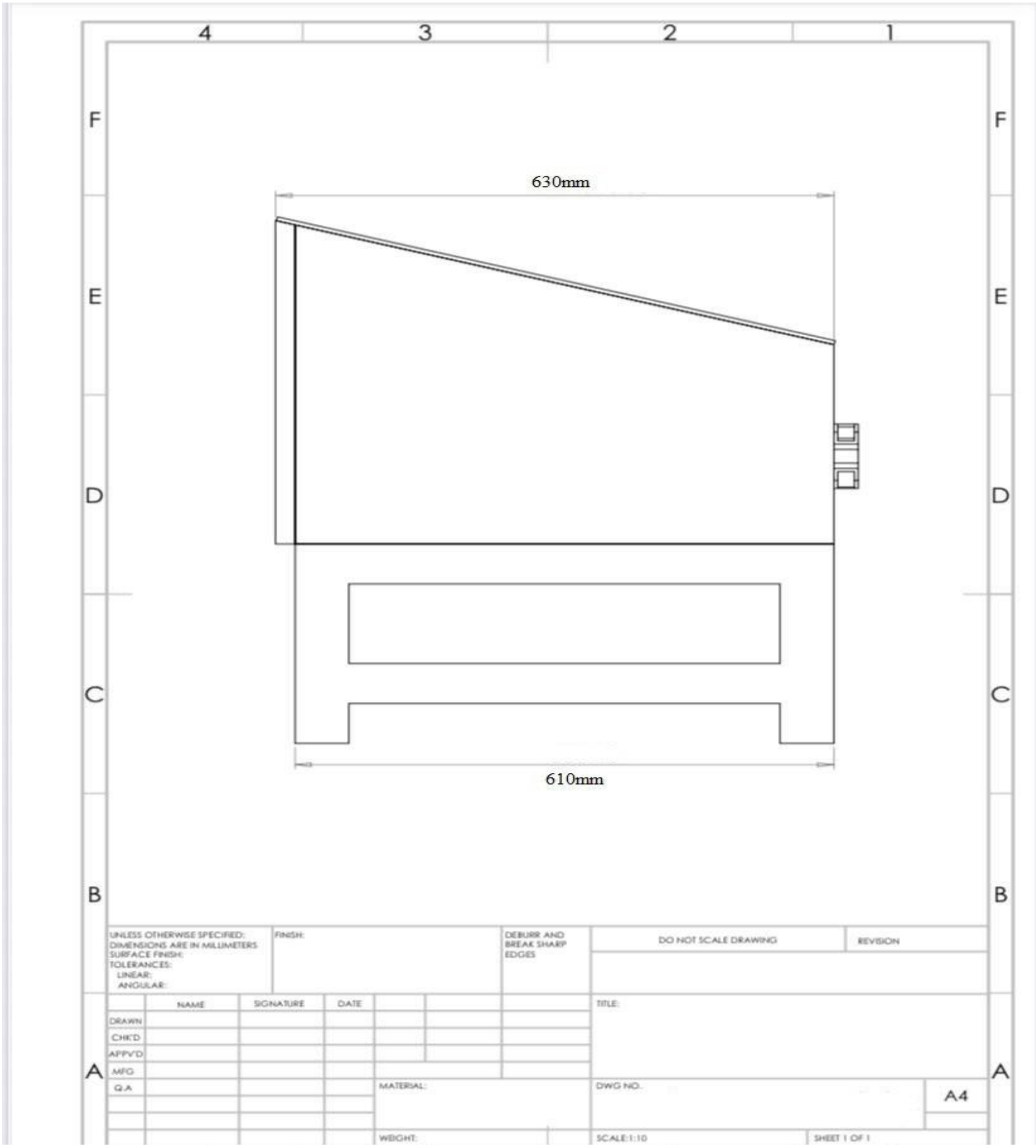


Fig 3.8 Side View of the Solar dryer

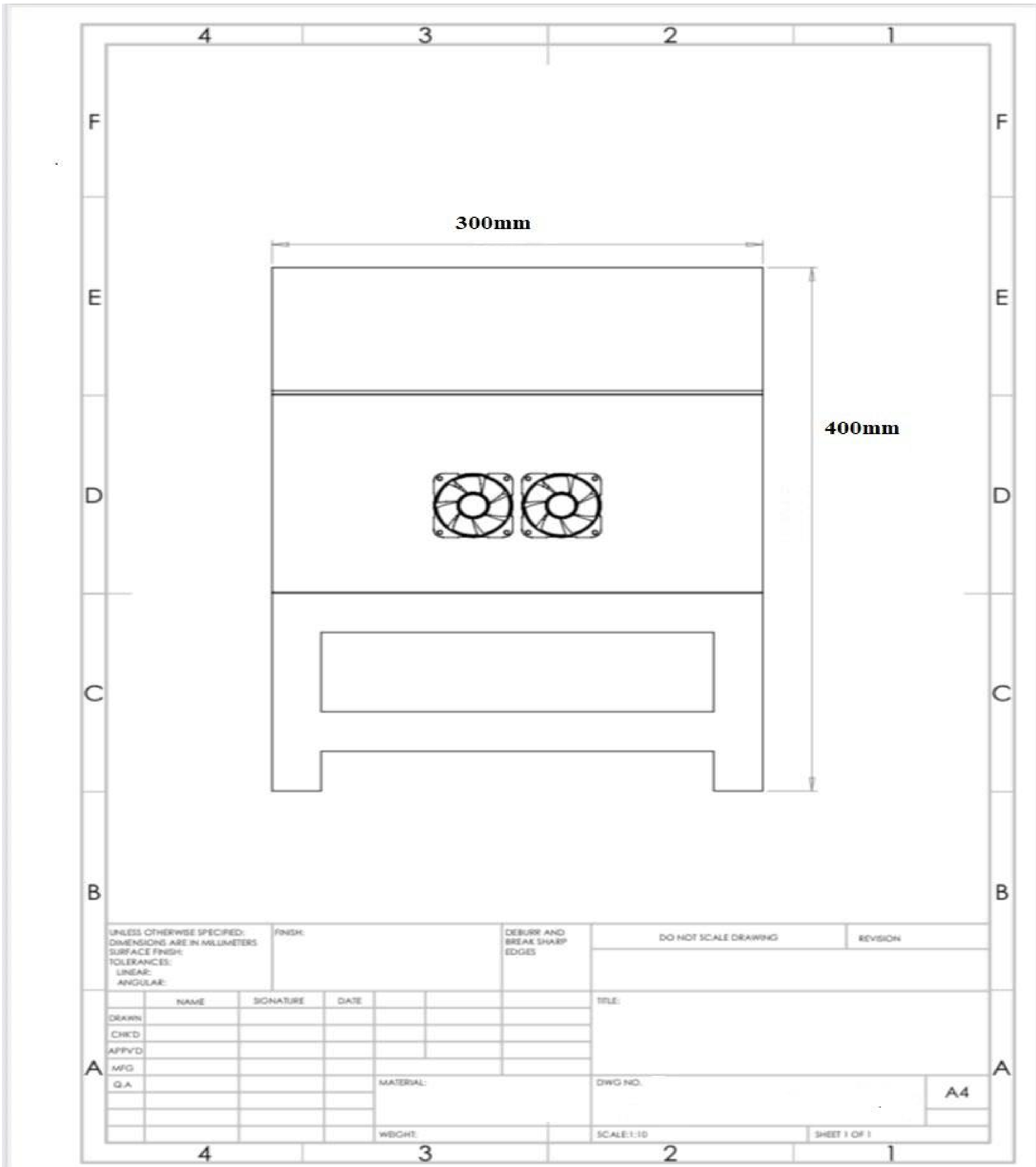


Fig 3.9 Front View of the Solar Dryer

3.7 DESIGN EQUATIONS

The design equations necessary for this project are as follows;

3.7.1 The Energy Balance On The Absorber

The energy balance on the absorber is obtained by equating the total heat gained to the total heat lost by the heat absorber of the solar collector. Therefore,

$IAC = Q_u + Q_{cond} + Q_{conv} + Q_R + Q_\rho$ ....(3.1) (Bolaji, 2008)

where:

I = rate of total radiation incident on the absorber's surface (Wm^{-2});

Ac = collector area (m^2);

Q_u = rate of useful energy collected by the air (W);

Q_{cond} = rate of conduction losses from the absorber (W);

Q_{conv} = rate of convective losses from the absorber (W);

Q_R = rate of long wave re-radiation from the absorber (W);

$Q\rho$ = rate of reflection losses from the absorber (W).

The three heat loss terms Q_{cond} , Q_{conv} and Q_R are usually combined into one-term (Q), i.e.,

$$Q_L = Q_{cond} + Q_{conv} + Q_R \quad ...(3.2)$$

If τ is the transmittance of the top glazing and IT is the total solar radiation incident on the top surface.

Therefore,

$IAc = \tau ITAc$. ... (3.3)

The reflected energy from the absorber is given by the expression:

$Q\rho = \rho\tau$ **ITAc** ...(3.4) (Bolaji, 2008)

where ρ is the reflection coefficient of the absorber. Substitution of Eqns. (2), (3) and (4) in Eqn. (1) yields:

τITAc=Qu+$Q\tau$+$\rho\tau$ITAc, or Qu=τITAc(1-ρ)-QL.

For an absorber (1-(ρ))=a and hence,

Qu=(aτ)ITAc-Q_L. ...(3.5)

where a is solar absorbance.

QL composed of different convection and radiation parts. It is presented in the following form (Bansal, 1990):

$QL = U_L Ac(Tc - Ta)$ ...(3.6)

where:

U_L = overall heat transfer coefficient of the absorber ($Wm^{-2}K^{-1}$);

Tc = temperature of the collector's absorber (K)

3.7.2 Optimum Collector Slope (β)

The optimum collector slope is determined from

$$\beta = \delta + lat\emptyset \qquad ...(3.7)$$

Where δ is the declination

lat $\emptyset$ is the latitude of the collector location (Alamu, 2010)

3.7.3 Heat Transfer Into The Collector

$$q = \mathrm{E} \times A \qquad ...(3.8)$$

Where; E = Heat intensity, q = quantity of heat transferred, A = surface area of collector

From Fourier law of heat conduction; we have that,

Rate of heat flow, $Q \propto \mathrm{A}\frac{\mathrm{dt}}{\mathrm{dx}} = -\lambda A\frac{\mathrm{dt}}{\mathrm{dx}}$

Such that, $Qdx = -\lambda Adt$

$$\int_0^x Qdx = -\int_{t_{in}}^{t_{out}} \lambda Adt$$

$$Qx = -A\int_{t_{in}}^{t_{out}} \lambda dt$$

Therefore, $Q = -\frac{\lambda A}{\mathrm{x}}(t_{out} - t_{in}) = \frac{\lambda A}{\mathrm{x}}(t_{in} - t_{out})$

$$q = \lambda\frac{A}{\mathrm{x}}(T_{in} - T_{out}) \qquad ...(3.9)$$

Where; A = total surface area of the glass (0.17 m^2), x = thickness of the glass (0.005m), T_{in}= temperature inside the drying chamber, T_{out} = temperature outside the dryer (ambient temperature)

3.7.4 Heat Transfer In The Dryer

Since the conduit length from the collector to the dryer is small and lagged, the heat loss may be assumed to be negligible.

Therefore; temperature in collector is equal to temperature in the drying chamber. Since the drying chamber is a composite wall, comprising of sawdust at the middle and the Galvanized Sheet wall (at both ends).

Composite wall: For composite material the combined heat transfer coefficient may be used, thus the following equations are applicable.

Therefore, the overall heat transfer is given by

$$\mathbf{Q} = \frac{T_h - T_c}{\frac{1}{h_{hot}A} + \frac{x_1}{k_1 A} + \frac{x_2}{k_2 A} + \frac{x_3}{k_3 A} + \frac{1}{h_{cold}A}} \quad ...(3.10)$$

T_h = temperature inside the drying

T_c = temperature outside (ambient temperature)

h_{hot} = convective heat transfer coefficient for the hot side (35.6m^2k)

h_{cold} = convective heat transfer coefficient for the cold side (42.3w/m^2k)

x_1 = thickness of the outer wall Galvanized Sheet (0.001m)

x_2 = thickness of the middle lagging material (0.012m)

x_3 = thickness of the inner wall Galvanized Sheet (0.001m)

λ_1 = thermal conductivity of Galvanized Sheet (48.5)

λ_2 = thermal conductivity of lagging material (0.045)

In this case; $k_1 = k_3$ and $x_1 = x_3$

Therefore the equation becomes;

$$Q = \frac{T_h - T_c}{\frac{1}{h_{hot}A} + 2\frac{x_1}{\lambda_1 A} + \frac{x_2}{\lambda_2 A} + \frac{1}{h_{cold}A}} \quad ...(3.11)$$

h for ambient air (about 42.3w/m^{2}k)

h for hot air is about 35.6m^{2}k (Engineering Heat transfer, 1978)

3.7.5 Determination Of Collector

Therefore, area of the collector A_C

AC = length of the collector multiply by the width of the collector

3.7.6 **Collector Efficiency:** This is computed from:

$$\eta = \frac{\rho C p V \Delta T}{AIC} \quad ...(3.12) \quad \text{(Ezekoye, 2006)}$$

where (ρ) is the density of air(kg/m), (Ic) is the insolation on the collector, (ΔT) is the temperature elevation, (Cp) is the specific heat capacity of air at constant pressure (

J/kgK), (V) is the volumetric flow rate (m^3/s), and (A) is the effective area of the collector facing the sun (m^3).

3.7.7 Dryer Efficiency: This is given as

$$\eta d = \frac{output}{input} \times 100 \qquad ...(3.13)$$

3.7.8 Moisture Content (M.C.): The moisture content is given as

$$M \cdot C = \frac{M_i - M_f}{M_i} \qquad ... (3.14a) \qquad \text{(Ezekoye, 2006)}$$

Where; Mi = mass of sample before drying and Mf = mass of sample after drying.

Also moisture content can be computed as

$$M_{c_{db}} = \frac{Wt_w}{Wt_{dm}} \qquad ...(3.14b)$$

Where M_{Cdb} is the moisture content on a %dry basis

Wt_w is the weight of the sample's water

Wt_{dm} is the weight of the sample's dry matter

3.7.9 Moisture Loss (M.L): The Moisture Loss is given as:

$$\text{ML} = (Mi - Mf)(\text{g}) \qquad ...(3.15) \qquad \text{(Ezekoye, 2006)}$$

Where; (Mi) is the mass of the sample before drying and (Mf) is the mass of the sample after.

3.7.10 Volume Of The Dryer V_d

$$V_d = d_d \times l_d \times w_d \quad ...(3.16)$$

3.7.11 Volume Of Collector Chamber V_c

$$V_c = d_c \times l_c \times w_c \quad ...(3.17)$$

3.7.12 Drying Rate

$$\text{Dr} = \frac{m_t - m_{tdt}}{dt} \quad ...(3.18)$$

Where m_t = initial mass of specimen

$$m_{tdt} = mass\ of\ specimen\ at\ time\ t$$

dt = the time for successive measurement

3.8 Design Calculation

Optimum collector slope (β)

$$\beta = \delta + lat\,\phi$$

lat $\emptyset$ of Benin City = 6.2°

$$\delta = 10°$$
$$\beta = 10 + 6.2$$
$$= 16.2°$$

Heat transfer into the collector chamber

$q = \mathrm{E} \times A$ Taking $\mathrm{E} = 1000 \mathrm{w/m^2}$

The area of the flat plate collector was calculated

as

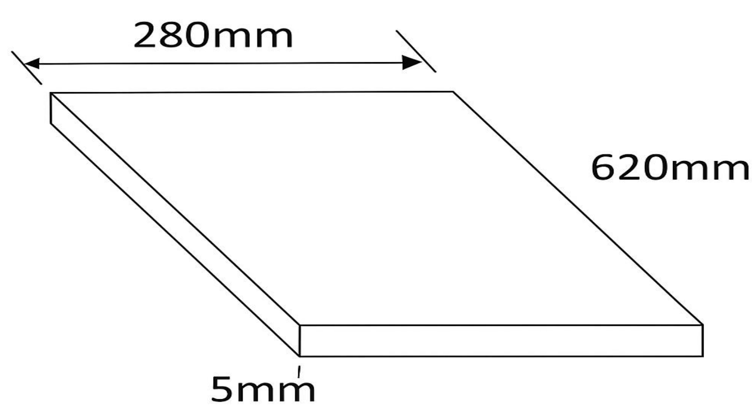


Fig : 3.10 Transparent Plain Glass

Area = length x Breadth = 620mm x 280mm = $0.17m^2$

The area of drying chamber is calculated from

A_C= (LxBxH)+ABsinα

A_C = (610x300x400)+0.5(240x300tan14.7) = $0.07321m^3$

Therefore Q = 1000 X 0.17 = 170 w/m^2

Using fourier law of conduction we have that,

Rate of heat flow, $Q \propto A\frac{dt}{dx} = -\lambda A\frac{dt}{dx}$

Such that, $Qdx = -\lambda Adt$

$\int_0^x Qdx = -\int_{t_{in}}^{t_{out}} \lambda Adt$

$Qx = -A\int_{t_{in}}^{t_{out}} \lambda dt$

Therefore, $Q = -\frac{\lambda M}{x}(t_{out} - t_{in}) = \frac{M}{x}(t_{in} - t_{out})$

Using $q = \lambda\frac{A}{x}(T_{in} - T_{out})$

= 170 = 1.005 X (0.17/0.005)[T_{in} - T_{out}]

Taking T_{out} for a very sunny day to be 32°c+273=305k (31.85°C)

170 =1.005 X (0.17/0.005) [T_{in} X 305]

170 = 34.17[T_{in} X 305]

10455.17 = 34.17 T_{in}

T_{in} = 309.98K (36.83°C) for a Sunny Day

Using 28°C+273=301k (27.85°C) as T_{out} for a cloudy day

$q = \lambda\frac{A}{x}(T_{in} - T_{out})$

170 =1.005 X (0.17/0.005) [T_{in} X 301]

170 = 34.17[T_{in} X 305]

$10455.17 = 34.17\ T_{in}$

$T_{in} = 305.98K$ (32.83°C) for a Cloudy Day

Overall heat loss in the dryer chamber

$$Q = \frac{T_h - T_c}{\frac{1}{h_{hot}A} + 2\frac{x_1}{\lambda_1 A} + \frac{x_2}{\lambda_2 A} + \frac{1}{h_{cold}A}}$$

$T_h = 309.98\ K = 36.83°C$

$T_C = 305.98\ K = 32.83°C$

$h_{hot} = 35.6$

$h_{cold} = 42.3$

$A = 0.17\ m^2$

$\lambda_1 = 48.5$

$\lambda_2 = 0.045$

$X_1 = 0.001m$

$X_2 = 0.012m$

Therefore Q = 4/0.461

=8.9 w/mk

Volume Of Drying Chamber

$V_d = d_d \times l_d \times w_d$

Vd = 0.61 X 0.24 X 0.30 = 0.044 m^3

Volume Of Collector Chamber

$$V_c = d_c \times l_c \times w_c$$

Vc = 0.62 X 0.005X 0.28

= 0.001 m^3

Power Of Fan

$P=I^2R$, where V=IR

Where V is 12 and I is 0.25

R=V/I

= 12/0.25 = 48

Therefore $P=0.25^2 \times 48 =$ 3w

We used 2 fan, so the fan as 2 power consumption, therefore 3w of one fan + 3w of the other fan = 6w in total

Specifications

Mass Of Plantain = 0.0615kg

Number of plantain = 2

Total mass of plantain = 2 x 0.0615 = 0.123kg

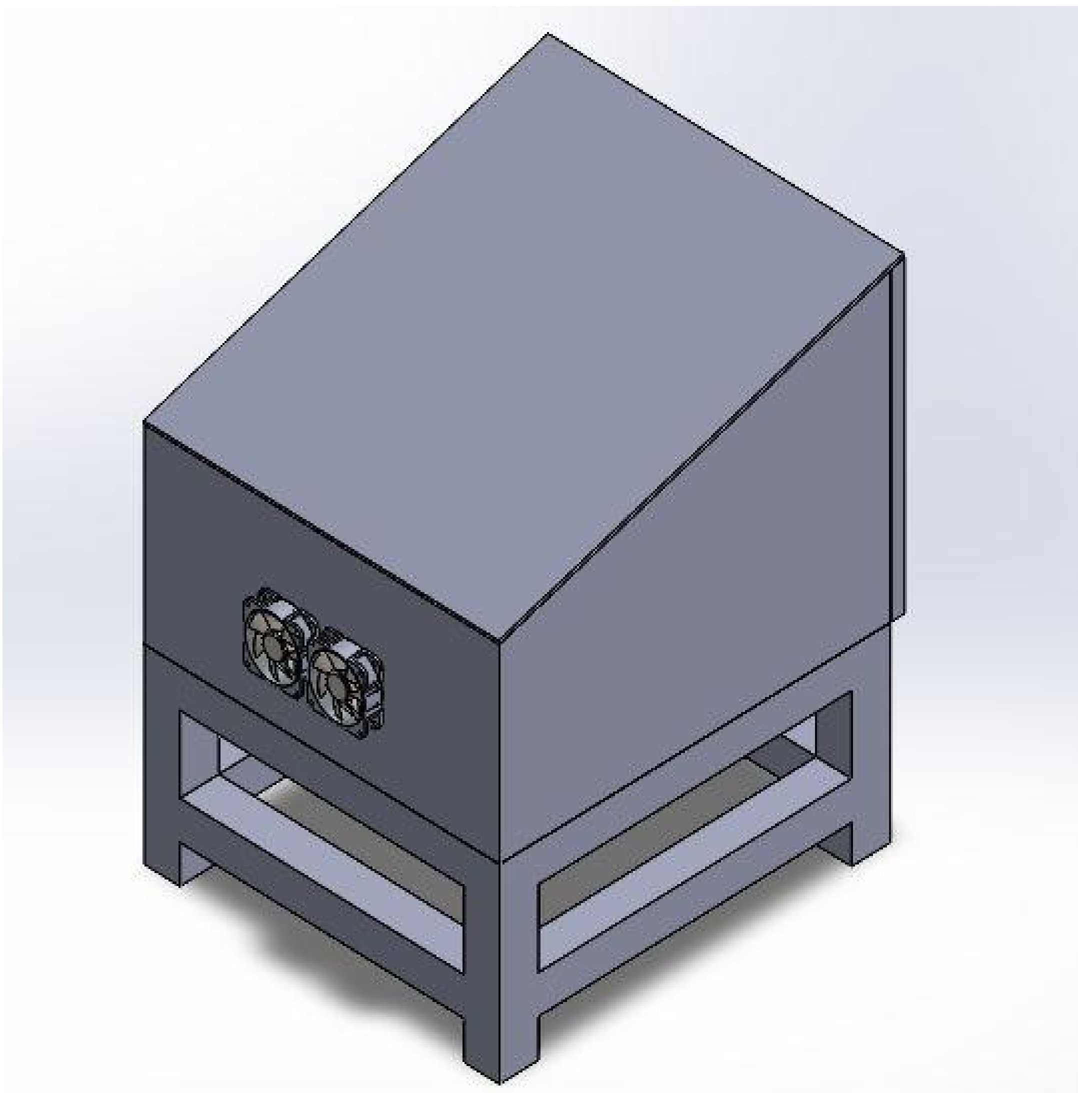


Fig 3.11 ISOMETRIC DRAWING OF THE SOLAR DRYING

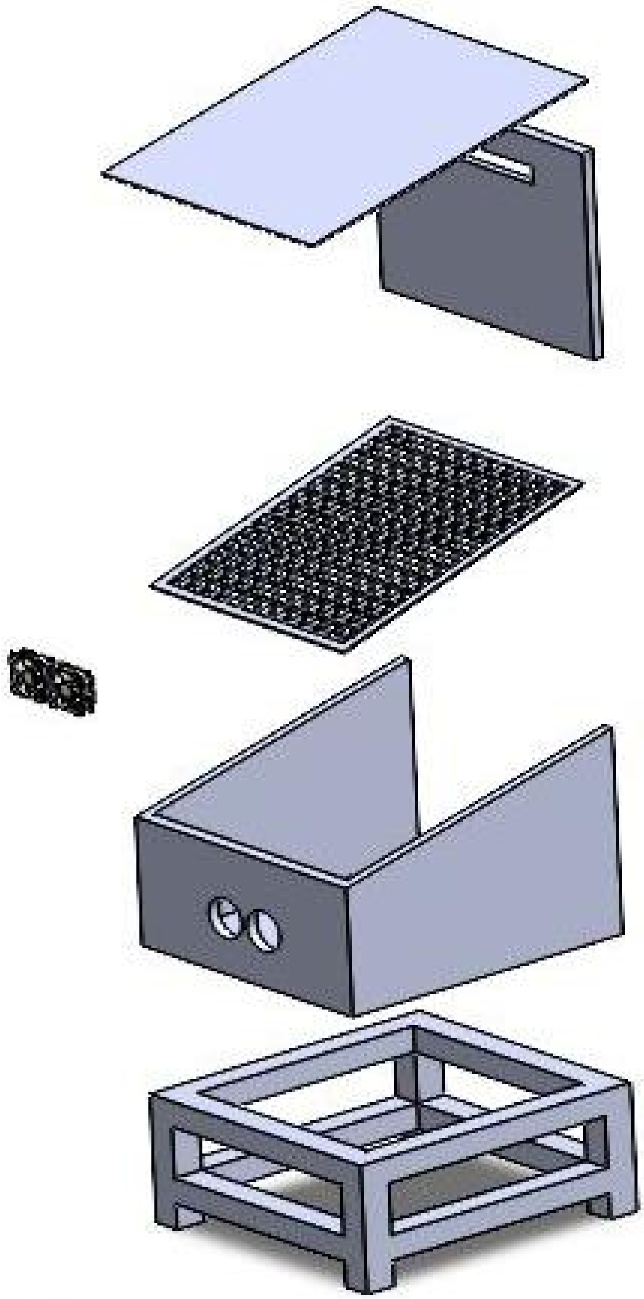


Fig. 3.12 Exploded View Of The Solar Dryer

Table 3.1 BILL OF MATERIALS

S/N	ITEMS	QUANTITY	AMOUNT SPENT
1	Aluminium sheet	1	10,000
2	Solar Panel	1	18,000
3	Fan	2	6,000
4	Angle Iron	1 full length	4,500
5	Plain Glass	1	5,000
6	Hinges	2	2,000
7	Cutting Stone		4,500
8	Galvanized Sheet	1mmx1200mmx1200	15,000
9	Sealer Tube	1	5,000
10	Welding Electrode	10 pcs	5,000
11	Oil Paint	3	10,000
			Total = 85,000

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The performance evaluation of the solar dryer was carried out in the month of October under typical weather conditions. The dryer was placed outdoors with the collector surface oriented due south and fixed at an inclination angle of 14.7° to the horizontal, ensuring that the collector received an approximately perpendicular beam of solar radiation during the test period. The drying chamber was loaded with plantain slices weighing 0.123 kg and 5 mm in thickness. Measurements were taken at hourly intervals over a total drying duration of 20 hours. A dry bulb thermometer was used to record the temperatures at the collector, drying chamber, and ambient environment, while the variation in sample weight was measured using a digital weighing scale. The experiment aimed to determine the system's drying efficiency and its effectiveness in reducing the moisture content of plantain slices to a safe storage level.

4.1.1 Variation of Temperature in the Solar Dryer

The temperature distribution within the solar dryer showed a distinct pattern that followed the intensity of solar radiation throughout the day. The dryer recorded its highest temperatures around midday, when the sun was directly overhead. During most daylight hours, the temperatures inside both the drying chamber and the solar collector were consistently higher than the ambient temperature, indicating efficient heat absorption and retention within the system. The temperature inside the drying chamber continued to rise steadily for about four hours after 12:00 noon, reaching its peak in the early afternoon. This behavior demonstrates the dryer's ability to effectively utilize solar energy for thermal conversion, maintaining higher internal temperatures than open-air conditions. Consequently, the system shows a clear potential for superior drying performance and shorter drying time compared to traditional open sun drying methods.

4.1.2 Drying Behaviour Of Plantain In The Dryer

The drying behavior of plantain slices in the solar dryer exhibited a direct relationship with temperature variation throughout the day. It was observed that the drying rate increased, corresponding to the period of highest solar intensity and elevated drying chamber temperature. Beyond this period, the drying rate gradually decreased as solar radiation weakened in the late afternoon. This pattern indicates that moisture removal from the plantain occurred more rapidly during the hours of peak temperature, resulting in earlier and faster dehydration during the initial drying phase. The effective reduction in mass observed confirms that the solar dryer successfully facilitated efficient water removal from the plantain slices through the combined action of heat and continuous airflow, achieving uniform drying and improved product quality compared to open sun drying.

Table 4.1: Hourly moisture loss and moisture content of plantain

Drying time (hr)	Weight (kg)	Moisture loss	Moisture content (%)	Drying rate (kg/hr)
0	0.123	-	-	-
1	0.120	0.003	98	0.0030
2	0.116	0.007	94	0.0035
3	0.112	0.011	91	0.0037
4	0.108	0.015	88	0.0038
5	0.105	0.018	85	0.0036
6	0.100	0.023	81	0.0038
7	0.095	0.028	77	0.0040
8	0.091	0.032	74	0.0040
9	0.085	0.038	69	0.0042
10	0.081	0.042	66	0.0042
11	0.077	0.046	63	0.0042
12	0.070	0.053	57	0.0044
13	0.066	0.057	54	0.0044
14	0.059	0.064	48	0.0046
15	0.055	0.068	45	0.0045
16	0.050	0.073	41	0.0046
17	0.048	0.075	39	0.0044
18	0.048	0.075	39	0.0042
19	0.048	0.075	39	0.0039
20	0.048	0.075	39	0.0038

4.1.3 Evaluated Parameters Of The Solar Dryer

Table 4.2 shows evaluated parameters of the solar dryer such as heat transfer into the collector chamber, heat loss through the walls of the dryer, volume of the dryer, surface area of the collector and the dryer and the area of the heat storage chamber, collector slope and the declination which were calculated in chapter three and also the moisture loss and content when the solar dryer was used. And table 4.3 shows the summary of drying result.

Determination Of Amount Of Water Removed From The Plantain

From Table 4.1,

Amount of water removed = initial mass of the plantain - final mass of the plantain

Where initial mass = 0.123 kg and final mass= 0.048kg

Therefore, amount of water removed = 0.123kg - 0.048kg

= 0.075kg

Determination Of % Amount Of Water Removed From The Plantain

% amount of water removed = initial moisture content of plantain - final moisture content of plantain

100% - 39%

= 61%

Determination Of The Dryer Efficiency

Output = Heat Gained - Heat Loss

= 170 - 8.9 = 161.1w/m^2K

Input = Heat Gained = 170 w/m^2K

161.1/170 X 100

= 94.76 %

TABLE 4.2: EVALUATED PARAMETER OF THE SOLAR DRYER

Parameter	Values obtained
Heat transferred into the collector chamber	170 w/m^2K
Moisture content	61.29% average
Moisture loss	0.041 kg average
Volume of dryer	0.044 m^3
Collector area	0.17m^2
Volume of collector chamber	0.001 m^3
Declination	10°
Collector slope	16.2°
Area of drying chamber	0.07321m^3
Area of collector chamber	0.17m^2
% amount of water removed	61%
Drying rate	0.0044
Drying time	17 hrs

TABLE 4.3: SUMMARY OF DRYING RESULT.

Sample	Initial mass	Final mass	Drying rate	Drying time (hr.)	Amount of water removed (%)	Weight of water removed (kg)
Plantain	0.123	0.048	0.0044	17	61	0.075

4.2 Discussion

The fabrication of the solar dryer followed a systematic procedure aimed at achieving efficient heat capture, retention, and airflow distribution for optimal drying performance. The process began with the design and drafting of diagrams showing the dimensions of all major components, including the solar collector, drying chamber, and structural frame. After completing the drawings and dimensioning, the various components were marked out accurately on metal sheets using a scriber, steel rule, and measuring tape to ensure precision during assembly.

Following the marking-out process, each component was cut to the required dimensions and joined together through welding, forming a strong and stable structure. The collector cover plate was then installed to enclose the collector chamber. The drying chamber was constructed with galvanized steel, and the space between them was filled with foam, serving as an insulating material to minimize heat loss to the environment and maintain a stable internal temperature during operation.

The collector chamber, also known as the heating chamber, was painted black to enhance heat absorption and reduce thermal radiation losses, ensuring that solar energy trapped within the system was retained for effective air heating. Two small DC fan, powered by a solar panel mounted at the top of the dryer, was incorporated to facilitate faster air circulation. This forced convection helped transfer the heated air from the collector chamber to the drying chamber, improving drying efficiency and ensuring uniform heat distribution around the plantain slices. Each stage of the fabrication process contributed directly to the functional performance of the solar dryer during testing. The integration of proper insulation, an efficient heat-absorbing surface, and a solar-powered fan system ensured that the dryer achieved consistent temperature levels and stable airflow. These

design and construction features collectively enhanced the rate of moisture removal, reduced drying time, and produced high-quality dried plantain under clean and controlled conditions.

4.3 Material Selection

The choice of materials for the fabrication of the solar dryer was based on factors such as mechanical strength, thermal performance, durability, cost, and local availability. Galvanized Metal Sheet was selected as the primary construction material due to its combination of favorable properties and practicality for local fabrication.

Galvanize was chosen because it is ductile, meaning it can easily be deformed or shaped without losing its structural toughness, making it ideal for forming the body and Mild Steel Metal was use for the frame of the dryer. It is also readily weldable, as it does not require special electrodes or advanced welding techniques, thereby simplifying the fabrication process. In addition, mild steel is widely available in local markets and affordable, making it an economically feasible choice for small-scale and experimental projects. Furthermore, mild steel components used in the solar dryer do not directly contact the food material being dried, reducing the risk of contamination.

The wire mesh on which the plantain slices rest during drying was also made of mild steel instead of stainless steel. This decision was primarily influenced by cost considerations and the experimental nature of the project. Stainless steel, though more suitable for food-grade applications due to its resistance to corrosion and ease of cleaning, is considerably more expensive and requires special electrodes for welding. Given the project's educational purpose, mild steel provided a more practical and affordable alternative.

However, it is important to note that for commercial or human consumption purposes, stainless steel should be used for all food-contact components to prevent contamination and ensure compliance with food safety standards.

It is also worth noting that solar heat intensity is not constant; it varies throughout the day and across different seasons. The solar radiation intensity generally fluctuates between 1000 W/m^2 and 1125 W/m^2, depending on weather conditions and time of year. As a result, the temperature inside the collector and drying chamber also varies accordingly, influencing the amount of heat stored and transferred within the system at any given time. These variations highlight the dynamic nature of solar energy utilization and the importance of selecting materials that can withstand repeated thermal expansion and contraction without deformation or damage.

4.4 Working Principle of the Solar Dryer

The working principle of the solar dryer is based on solar energy collection, heat transfer, and air circulation to remove moisture from the plantain slices efficiently. The system operates using both solar radiation and forced convection to achieve rapid and uniform drying.

When sunlight strikes the transparent glass cover of the solar collector, the solar radiation passes through and is absorbed by the black-painted absorber plate inside. This plate converts the incoming solar radiation into heat energy, which warms the air present in the collector. As the air temperature increases, its density decreases, causing it to rise naturally toward the drying chamber.

To enhance this movement, Two 12V DC fan powered by a solar panel is positioned within the air conduit. The fan draws the hot air from the collector and forces it into the drying chamber, ensuring a steady and controlled flow of warm air. The plantain slices placed on the drying trays are then exposed to this stream of hot air. As the heated air passes over the moist plantain, it absorbs moisture from their surface through evaporation.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research project's primary objective is to develop, build, and simulate a solar dryer for food processing system. The investigation discovered that the solar heat gain was 170 w/m^2K and heat loss was 8.9w/m^2K and given an efficiency of temperature was 94.76%. The flat plate collector took up 0.17 m^2 of the 0.0732 m^2 of area that the drying chamber was supposed to have. It was discovered that the temperature of sunlight on a sunny day inside dryer was 309.98K (36.83°C) when outside the dryer is 305K (31.85°C) and on a cloudy day temperature inside the dryer is 305.98K (32.83°C) when temperature outside is 301K (27.85°C) with an effective heat gain of 170 w/m^2K, despite losses from side heat transfer and aluminum absorption. The volume of the drying chamber was 0.044 m^3 and Volume of the collector chamber was 0.001 m^3. The optimal drying temperatures were discovered to occur between 11:00 am and 3:00 pm, hence exposure at this time is recommended for optimal outcomes. Performance testing confirmed the solar dryer's effective operation, offering a clean and environmentally responsible alternative to existing methods.

The solar dryer project for food processing has proven to be efficient, sustainable, and environmentally friendly method of preserving agricultural product. by utilizing renewable solar energy, the system significantly reduces post-harvest losses that are common with traditional sun drying and short shelf life of fresh plantain. The variation between collector and chamber temperature was minimal, showing that heat losses through conduction, convection, and radiation were effectively minimized by proper insulation and material selection (galvanized sheet with lagging Material). The use of a transparent glass cover increased heat absorption due to the greenhouse effect, improving drying rate.

The drying curve followed the typical pattern observed in food drying processes, with a rapid moisture removal at the initial stage (constant rate period) followed by a falling rate period, during which internal moisture diffusion became the limiting factor. Compared with traditional open-sun drying, the solar dryer reduced drying time by about 40–50%, protected the plantain from contamination by dust, insects, and rain, and produced a cleaner, more hygienic product suitable for further processing into flour or chips. Overall, the solar dryer demonstrates great potential for improving the value chain of plantain by enabling efficient drying for the production of plantain flour, chips, and other processed products. It offers a viable means of increasing income, promoting food preservation, and supporting rural development through the use of clean, renewable energy.

5.2 Recommendation

This research project has the potential to greatly improve the efficiency and scalability of solar-powered plantain drying systems, enabling organizations and communities to sustainably store their plantain harvests. This initiative, which put an emphasis on affordability and ease of use, has the potential to encourage a wider adoption of this kind of technology, which would have numerous benefits for both economic growth and food security.

i. Optimization of Dryer Design: The dryer′s design should be further optimized to ensure uniform heat distribution and faster drying, especially under fluctuating weather conditions.

ii. Incorporation of Thermal Storage or Hybrid Systems: Adding thermal energy storage (such as phase change materials or rocks) or a backup heating source would allow drying to continue during cloudy or rainy periods.

iii. Quality Control and Standardization: Establishing standard drying parameters (temperature, humidity, and time) specific to plantain will help ensure consistent product quality suitable for commercial markets.

iv. Training and Capacity Building: Farmers and processors should be trained on the proper operation, maintenance, and hygiene practices to maximize the efficiency and longevity of the solar dryer.

v. Use of Local Materials: The dryer should be constructed using durable and locally available materials to minimize cost and encourage local adoption and replication.

vi. Promotion and Support: Government agencies, NGOs, and agricultural cooperatives should promote the adoption of solar dryers through subsidies, demonstration projects, and awareness campaigns on their economic and environmental benefits.

vii. Further Research: Continued research should focus on improving dryer performance, evaluating the economic feasibility at different scales, and exploring hybrid systems to enhance reliability in various weather conditions.

viii. Mitigated Post-Harvest Losses: Fish, being highly perishable, often incur substantial losses during conventional drying methods. Solar fish dryers, offering a reliable and controlled drying environment, mitigate spoilage and ensure a greater portion of the catch is conserved for consumption or trade.

ix. Augmented Food Security: In regions lacking access to electricity or refrigeration, solar dryers serve as a means to prolong the shelf life of fish, thereby enhancing food availability year-round. This could potentially diversify diets and improve nutritional intake, especially in communities heavily reliant on fish as a protein source.

x. Economic Empowerment: Through minimizing spoilage and enabling the preservation of larger product quantities, solar dryers can elevate the income-generating capabilities of farmers and individuals. The ability to store their product for extended periods allows them to seize better market prices or reach more distant markets.

xi. Environmental Stewardship: Solar dryers harness clean, renewable energy, negating the reliance on fossil fuels for operation. This not only curtails greenhouse gas emissions, mitigating climate change, but also obviates the necessity for firewood or other conventional drying methods, thereby contributing to forest conservation efforts.

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