

DESIGN AND FABRICATION OF A SOLAR POWERED FISH DRYER



BY

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DEPARTMENT OF PRODUCTION ENGINEERING, FACULTY OF ENGINEERING,

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BENIN CITY.

JAN, 2023

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A PROJECT SUBMITTED TO THE DEPARTMENT OF;

**PRODUCTION ENGINEERING, FACULTY OF ENGINEERING, UNIVERSITY OF
BENIN
BENIN CITY.**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF
BACHELOR OF ENGINEERING (B.ENG)**

JAN, 2023.

CERTIFICATION

We the undersigned do thereby certify that this project was carried out by **Diakpomrere Ogheneruro Messiah** with Matriculation Number **ENG1504032**, submitted to the Faculty of Engineering, University of Benin, Benin City, Edo State in partial fulfilment of the requirements for the award of Bachelor of Engineering (B. Eng.)

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DEDICATION

This project is dedicated to God Almighty for His overwhelming grace and mercy upon my life and to my loving Parents, Siblings, Family both immediate as well as nuclear, and friends for their unwavering support.

ACKNOWLEDGEMENT

My everlasting appreciation is to God Almighty for his continuous grace and mercies upon my life and for his strength that has kept me and brought me thus far, I am indeed truly grateful.

I am as well very grateful and indebted to my Project Supervisor Dr. Ralph Ebhojiaye for his patience, support, supervision and guidance at all stages of this Undergraduate Final Year project despite his very busy schedule.

My sincere appreciation goes to my loving parents Prof. Vincent and Mrs Helen Diakpomrere for their continuous prayers, faith, undying, undiluted love, understanding and support all through the period of my stay in the University of Benin.

I am most thankful to my siblings Barr. Mrs Divine Otorbor, Barr. Miracle, Woro, Anointing, Covenant and also to my friends too numerous to mention for their show of love, motivation and support. Personally, you all have been a source of motivation and encouragement to me.

ABSTRACT

Introduction:

Post-harvest losses in developing Countries have contributed to the unavailability of foodstuffs. Estimation of these losses is generally cited to be of the order of 4% but under very adverse conditions, it is estimated as high as 100%. A significant percentage of these losses are related to improper and or untimely preservation of foodstuffs such as fish, meat. Fish being an important component of the diet for people throughout the World, has high protein and nutritional value. It supplies 6% of global protein and may be classed as either white, oily, or shell fish. In most developing countries where there is high rate of malnutrition, fish provides nutritious food which is often cheaper than meat and therefore available to a larger number of people.

Fish being an extremely perishable food which in most cases becomes inedible within twelve hours at tropical temperature, spoilage therefore begins as soon as the fish dies and processing should therefore be done quickly to prevent the growth of spoilage bacteria. Fish is a low acid food and is therefore very susceptible to the growth of food poisoning bacteria hence another reason why it should be processed quickly. Basically the moisture content of fish stands around 80%; if this is reduced to around 25% bacteria cannot survive and autolytic activity will be greatly reduced. Further moisture content of 15% or less mould and bacteria will cease to grow; well dried fish if stored under the right conditions can be kept for several months. The use of appropriate methods of preservation creates the possibility of having greater increase in the amount of fish available for human consumption. The purpose of preservation is to reduce the moisture content of the fishy because micro-organisms that are responsible for spoilage and wastage cannot survive without moisture. Some of the preservation methods/ techniques include the following; cooking (boiling or frying), salting, smoking and drying collectively known as curing (lowering the moisture content) and fermentation (lowering the pH).

However, it should be noted that the scope of this research project paper is basically aimed on drying as a means of fish preservation via a multipurpose solar powered fish drying mechanism devise. Drying is a dual process of heat and mass transfer of moisture from the interior of the product to the surrounding air. Drying involves the abstraction of moisture from the product by heating and the passage of air mass around it to carry away the released vapour. The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time normally regarded as the “safe period”

There are basically two common methods of drying fish namely; open air/sun drying and smoking. Open air/sun drying is probably the oldest method used for preserving fish and other foodstuffs primarily used in developing countries because it is the simplest and cheapest method of conserving fishes. This traditional method involves spreading of products on the ground or on rack in the open air/sun drying or on local three stone stove for smoking. Some disadvantages of open air/sun drying and smoking are; exposure of the fish to rain and dust, uncontrolled drying; exposure to direct sunlight which is undesirable for some foods; infestation by insect; attacks by animals etc. The use of solar powered drying mechanisms has not gained popularity in developing countries and reasons can be attributed to; poor problem definition which makes the developed dryers technically inadequate and economically unviable; inappropriate understanding of dryers designs due to the choice of construction materials; inadequate understanding of the operations of solar powered dryers and lack of design procedures.

Herein, a forced convection solar powered fish dryer is designed, constructed and characterized to yield a better means of drying fish. The designed solar powered dryer would incorporate a heat storage unit which would variably compliment the drying rate of the product during off sunshine hours. As envisaged the device would be characterized during rainy and dry seasons, however results, calculations and analysis clearly indicate the influence of seasonal variation on the performance of the device. Average hourly variation of the dryer and ambient temperatures measured on selected days of

different months of measurement during the two seasons, clearly indicated that temperatures were significantly enhanced by the device. This was due to the high ability of the designed solar collector to trap large amount of long waves.

Average daily moisture loss from the drying fish was notably high, especially during dry season which was due to the high dryer temperatures and decrease in atmospheric humidity.

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NOMENCLATURE

M_w = Mass of water to be removed

M_p = Mass of product

M_i = Initial water content in percentage

M_f = Final water content in percentage

ϕ = Relative humidity

P_v = Partial pressure of water vapour

P_{vs} = Partial pressure of water, when the air is fully saturated

P_t = Atmospheric pressure

W_1 = Specific humidity at inlet of dryer

W_2 = Specific humidity at outlet of dryer

m_a = Mass of dry air in kg/hr

m_v = Mass of water vapour

N = RPM of fan

V_a = Volume of dry air

V_v = Volume of water vapour

v_1 = Velocity of air inside the chamber

v_2 = Velocity of air in the outlet

V = Volume flow rate

A_1 = Transverse cross section area of dryer

A_2 = Area of circular hole at outlet

ω = Angular velocity

L = Length of dryer

b = Width of dryer

CHAPTER ONE

1. BACKGROUND OF THE STUDY

The largest economic sector in the majority of nations is agriculture. In the working population, agriculture employs 80–90% of the people. Despite these enormous numbers, the population's demands are still not being met by fish farming operations. The product supply was considerably reduced as a result of the inadequate preservation and storage systems, which resulted in large losses. Prior to this background investigation, it was thought that product failures and major seasonal availability swings could be eliminated by preserving food, such as by drying it. The traditional method of drying, which involves spreading the products in thin layers on mats, trays, or concrete surfaces and exposing them to the sun and wind, has significant drawbacks. These include lower fish quality brought on by dust pollution, insect attack, enzymatic responses, and microbial infection. Additionally, this approach requires a lot of labor and time because products must be covered at night, in poor weather, and constantly safeguarded from domestic animals. Additionally, uneven and inadequate drying causes items to degrade while being stored. In humid tropical climates where some products must be dried during the rainy season, serious drying issues are particularly prevalent. Effective and cost-effective drying techniques are required to give a steady supply of fish to the expanding population and to allow fish producers to create marketable goods of high quality. According to studies, the majority of farmers cannot use even the smallest and most basic oil-fired batch dryers because they lack the funds and the energy needed to operate them. Only huge plantations or large commercial establishments are proven to be economically viable in developing countries for the high temperature dryers utilized in industrialized nations. As a result, the development of inexpensive, locally made solar dryers presents a possible solution to lessen the enormous post-fish harvest losses. The chance to manufacture marketable goods of excellent quality appears to be an opportunity to help the farmers' financial predicament. The relatively high initial cost of solar dryers, however, continues to prevent their widespread use given the low income of the rural population in developing nations.

1.1 SOLAR RADIATION

The sun is the primary energy producer in our solar system and the energy source for solar drying. It has a ball-like shape, and in its center, nuclear fusion occurs continually. Earth receives a tiny portion of the energy supplied by the sun, which is what enables life to exist on our planet. All natural cycles and processes, including photosynthesis, ocean currents, rain, wind, and many others, are fueled by solar radiation. Oil, gas, and coal are all transformed into solar energy. Pollutants from inefficient fossil fuel use are altering the earth's atmosphere at a never-before-

seen rate. These changes pose a serious danger to global security and are already having negative effects throughout many regions of the world. Now is the time to take action. In other words, it's time to come up with some alternatives that would be useful for addressing these demands and shortages. Because of this, alternative energy sources like solar energy, wind energy, geothermal energy, etc. are utilized. Fish drying using solar energy is crucial, especially in Nigeria where fungal and microbial infections result in the loss of the majority of fish catches. These losses might be readily avoided with proper drying, which improves the longevity of product storage. Nigeria is fortunate to have year-round access to a lot of solar energy. One of the most vital and energy-intensive operations in the food-processing, chemical, printing, and fabric-dyeing industries, among others, is drying. The purpose of this project is to design, build, and test the effectiveness of a forced convection solar-powered fish dryer on fresh fish. A mechanically constructed air heating section makes up the system. The solar dryer is made up of various parts, including solar panels and D.C. heating elements. The main reason behind how our system is set up is to reduce costs. Following a design that calls for solar panels, charge controllers, batteries, and an inverter to convert alternating current (A.C.) to direct current (D.C.), the market is saturated with expensive components. As a result, we devised a method that uses D.C. heating elements rather than charge controllers, batteries, or an inverter, thus removing their need. The heating elements would be utilized to warm the fish in the compartment for mechanical fabrication so that the moisture would be released. In comparison to sun drying, it provides more control over the drying process and produces a higher-quality product.

1.2 STATEMENT OF THE PROBLEM

Although the idea of a solar-powered fish dryer is mostly an old one, in the present era many various factors are taken into account during its creation, construction, and design. The design of a solar-powered fish dryer has some benefits and drawbacks, including friction losses, vibration, the expansion of acrylic alloying metals owing to heat and air movement, friction losses at the shrinking cross-sections, and air leakages at microscopic, imperceptible areas. We have decided to create a solar-powered fish drier since it will be less expensive and, most importantly, more effective for all social classes, regardless of differences or economic difficulties. The end result of this research will be the creation of a solar-powered fish drier that dries fish simultaneously using warm air from solar collectors and indirect radiation from the cabinet's walls and roof. If the solar powered fish dryer system is planned and built with the concept of overcoming the restrictions of indirect kind of solar dryer, the issues of low and medium scale processor might be solved. In order to evaluate the performance of this solar dryer system, this work will be centered on the significance of a mixed mode solar powered dryer that is inexpensive, reliable, and designed and constructed using locally accessible materials.

1.3 AIMS & OBJECTIVES OF THE STUDY

1.3.1 AIMS:

1. Develop a solar-powered fish dryer using the knowledge gained from the study's background.
2. Material acquisition, mechanical construction, and electrical construction are majorly the three stages of production.

3. The effectiveness of a solar-powered fish dryer will be evaluated in comparison to various drying techniques for collector efficiency, drying air temperature, and weight loss.

1.3.2 OBJECTIVES

The following are the primary objectives of this study:

1. To research the features and functionality of the fish dryer system powered by solar energy.
2. To choose and assess the ideal solar dryer design.
3. To dynamically test the product's functionality and compatibility for both home and campus use.

1.4 SIGNIFICANCE OF THE STUDY

The most critical demand in today's society and economy is energy. Our ability to work, enjoy ourselves, and maintain our economic, social, and physical well-being all depend on an adequate and consistent supply of energy. Year after year, there is an increase in the need for energy. One technique for preserving fish products for prolonged periods of time is drying. Fish has been dried for preservation using the sun's heat and the wind for many thousands of years. In the majority of tropical and subtropical nations, sun drying is still the most popular technique used to preserve fish. However, if left exposed to rain, wind-borne filth and dust, infestation by insects, rats, and other animals, and substantial deterioration from these factors, items may occasionally become inedible.

Technology known as solar thermal is quickly becoming popular as an energy-saving strategy in agricultural applications. It is favored above other renewable energy sources like wind and shale since it is plentiful, unrenowned, and non-polluting. Simple systems that use solar energy to heat air are known as solar powered air heaters or dryers. They are used in many applications that call for low to moderate temperatures below 80°C, such as space heating. Food drying is anticipated to become more significant. By 2025, it is anticipated that there will be more than eight billion people on the planet (Cliquet and Thienpont, 1995). The minimal estimates of post-harvest losses, including those from poor drying, vary between 10 and 20% just in impoverished nations (Pariser, 1987). Salunkhe and Kadam (1998) quote a 1978 report from the National Research Council of the National Academy of Sciences in Washington, D.C., that estimates post-harvest losses in both industrialized and developing nations to be as high as 30–40%. Many other goods, in addition to fresh fish for human consumption, need drying. These include organic crops like wood and rubber as well as inorganic materials that have drawn our attention to energy-intensive processes like drying where fossil fuels are frequently replaced with clean, renewable energy sources. The significance of drying in people's life is emphasized by each of the aforementioned arguments.

However, drying is the industrial operation that uses the greatest energy, according to Mujumdar (1990). One liter of water evaporation consumes about 2.4 MJ. A traditional dehydrator needs about 100 liters of oil to dry one metric ton of most fruits to the appropriate moisture level for long-term storage. Energy scarcity is a problem in many nations, especially those that are developing. Even in areas with an abundance of conventional energy, there is pressure to

consume fewer fossil fuels. Everybody is concerned about global warming, and one metric ton of fruit dehydrated in a standard dehydrator creates about 300 kg of carbon dioxide. It is apparent that solar energy can be used to dry a variety of goods, including fresh fish, which is the focus of this study, as well as food crops and their products.

A solar-powered dryer, which consists of a collector or panels, a drying chamber, and occasionally a chimney, can address some of the issues with open-air sun drying.

There are three types of solar drying: direct, indirect, and mixed. In direct solar dryers, the grains are heated by an air heater, and sunlight enters through a clear cover and is absorbed by the grains. Fundamentally, radiation to the top layers and subsequent conduction into the grain bed produce the heat needed for drying. In indirect dryers, solar energy is captured in a separate solar collector (air heater), and the heated air then circulates through the grain bed. In contrast, in a mixed-mode dryer, solar energy is simultaneously absorbed by the drying cabinet directly through its transparent walls or roof and heated air circulates through a grain bed from a separate solar collector.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This section includes reviews of previous research on solar dryers as well as current research. The history of open-air sun drying and the beginnings of fish dryers powered by solar energy are also covered. Also included are information on the operation of solar-powered fish dryers, their components, their advantages and disadvantages compared to open-air drying, a description of the issues they answer, and their physical characteristics.

2.2. Background on food drying:

Given that it contains both thermal and light energies, the sun is regarded as the most renewable energy source. Therefore, solar energy can be simply defined as the sum of the sun's radiant light and heat. The thermal system aims to store solar heat that can be used for a wide range of purposes. The sun's thermal energy is used in a wide variety of processes, including drying, and it has many other uses as well. The process of exposing an object to the process of dehydration is known as simple drying. One of humanity's earliest consciously used technologies was probably open air drying, which preserved food for humans and animals (Imre, 1995). Traditional open-air solar drying techniques are based on extensive research and are still used today all over the world to preserve agricultural products like plants, seeds, meat, and fish.

Due to the need for a vast area, the potential for quality degradation, air pollution, infestation by birds and insects, and intrinsic challenges in regulating the drying process, open air drying has gradually become less and less common over the past few decades (Imre, 1993). Open air sun drying is not included in the term "solar drying," which refers to processes that use the sun's energy for drying. An enclosed device called a solar dryer protects food from being harmed by birds, insects, and unexpected downpours. Utilizing solar thermal energy, the food is dried.

2.3. Main types of solar dryers;

1. Solar natural dryers
2. Semi-assisted dryers
3. Solar-assisted dryers.

1. Solar natural dryers:

These devices have no active components and merely rely on ambient energy. If there is any airflow, it is maintained by natural convection or, in rare situations, by the chimney's thermo-syphon effects. In places with no access to alternative energy sources, solar natural dryers are primarily used to replace conventional open-air drying techniques. The purpose-built construction, however, avoids losses and damage to the products caused by rain, dust, insects,

birds, and other animals as well as pollution from the atmosphere, in contrast to these conventional ways (i.e cabinet and tent type arrangements). Better products are produced as a result of their utilization, which should be viewed as a positive financial contribution in any economic assessment.

Solar natural dryers are of several types which include

i. Cabinet Dryers:

These solar dryers are the simplest and least expensive. They are typically utilized for sparingly drying agricultural products like fruits, herbs, vegetables, and spices (Wibulswas and Niyomkarn, 1980, Reuss, 1993 cited in Baker & Christopher G.J, 1997). Simple cabinet dryers have a drying area that faces south that is enclosed by a transparent material (glass or foil) that also acts as a roof to keep out rain and pollutants. On a tray with a perforated bottom, the material to be dried is spread out thinly and is exposed to the sun's rays. To encourage an air flow via natural convection, holes are made in the top portion of the back wall and the lower portion of the front wall of the cabinet. This removes the material's evaporating water and keeps it from overheating.

ii. Tent type dryers:

Enlarging the dryer's basic surface area will boost its drying capacity for dryers of the cabinet type. The simplest and least expensive method to accomplish this is using dryers in the tent style.

iii. Shelf type dryers:

Utilizing many trays or shelves stacked one on top of the other is another approach to improve drying capacity without increasing the fundamental surface area. To generate the necessary energy, thin layers of fruit and vegetable to be dried are loaded on the perforated shelves that are partially shaded. Natural convection creates air flow through the material layers on the shelves and the collector; damp air exits the dryer through an upper hole. The flow resistances of the various material layers are connected in series and added to determine the overall resistances in the shelf type configuration. The dryer's height must be sufficient to create a sufficient "chimney effect" in order to guarantee a satisfactory air flow rate.

2. Semi-artificial dryers:

These often have a fan to maintain a particular air flow across the drying space and a solar collector. Directly irradiated solar tunnel dryers may use a piece of the tunnel as a transparent solar collector wrapped in plastic (Imre, 1989, 1995; Lutz and Muhlbauer, 1986 cited in Baker & Christopher G.J, 1997). Semi-artificial solar dryers' uncomplicated and reasonably priced construction justifies their use. For drying materials that are not susceptible to changes in drying circumstances brought on by the periodic nature of solar irradiation and by shifting atmospheric conditions, they can be advised. These types of semi-artificial solar dryers exist:

i. Solar tunnel dryers:

Agricultural products are regularly dried using solar tunnel dryers (Imre, 1986a, 1995; Lutz and Muhlbauer, 1986; Esper and Muhlbauer, 1993; Bansal and George, 1993 cited in Baker & Christopher G J, 1997). A fan blows air into the tube at the desired mass flow rate. There is a clear covering above the tunnel. The first part functions as a solar collector and has a surface with a black bottom to warm the air. The drying room is created by the tunnel's connecting segment. The sun directly illuminates the material that needs to dry, which is laid out on the ground. By aligning the collector and the drying section in parallel, the length of the solar tunnel drier can be decreased. The fan is powered by a grid-connected electric motor or by electricity produced by solar photovoltaic or wind-powered machinery. A black foil sheet serves as an absorber and the bed surface for the item to be dried, and a transparent foil covering sheet is utilized to hold it in place. Concrete foundations support structural components. Solar tunnel dryers can be constructed using locally accessible materials and are effectively used on farms to dry fruit, fruits, vegetables, herbs, coffee, beans, cocoa, and coconuts. The dryer's size can be changed depending on the desired drying capacity. A biomass-assisted variation of the solar tunnel drier has been created for usage in tropical climates. The tunnel's cross section could be triangular, semi-circular, or flat (Muhlbauer et al., 1993; Janjal and Hirunlabh, 1993 cited in Baker & Christopher G J, 1997). The cross-section of a serial collector-dryer configuration is often curved or semi-circular in shape.

ii. Greenhouse-type solar dryers:

Agricultural items can also be dried in greenhouses using foil coverings (Bansal and George, 1993; Reuss, 1993; Muhlbauer et al., 1993 cited in Baker & Christopher G J, 1997). They always include a fan to keep the air moving continuously, sometimes partially recirculating it. A belt or conveyor must be used to transport some type of shade through the drying area where delicate items are being dried. To dry herbs and fragrant plants, greenhouse-style solar dryers with flat roof surfaces have been created. These have air recirculation and integrated plastic collection systems on the roof.

iii. Solar room dryers:

Solar room dryers with a static bed are successfully used to dry agricultural products in bigger volumes (such as grains and folder) (Dernedde and Peters, 1978; Wieneke, 1980; Imre, 1995 cited in Baker & Christopher G J, 1997). A fan is used to sustain air flow across a bed that has been chosen based on the flow resistance of the material layer. Air is blown into the distribution space underneath the bed through a perforation in the bottom of the bed. The integrated solar collector on the roof preheats the air by using the roof cover as a heat source. If necessary, preheated air can be combined with atmospheric air arriving through the intake to regulate the temperature of the inlet air. Through the air ports located on the side walls, moist air exits the space. A straightforward auxiliary gas-operated air heater can be added to the suction side of the fan in an emergency case, such as poor weather. Fruits like bananas and peanuts have been successfully dried using solar room dryers with roof-integrated collectors (Vaughan and Lambert, 1980; Bowrey et al., 1980 sited in Baker & Christopher G J, 1997).

3. Solar Assisted Dryers:

Dryers equipped with solar collectors are known as solar assisted dryers. They typically have a heat storage system and are always equipped with a backup energy source, like a thermo-generator that runs on gas or oil, for use when the solar energy they have gathered is inadequate for drying. They frequently have contemporary control systems installed. There are various types of solar-assisted dryers, including:

i. Solar assisted dryers with heat storage:

The working fluid of the solar collector (water) is cycled by a pump along its adjacent pipe in a solar-assisted dryer with water heat storage. The heat storage tank receives the heated water in a flow. A fan draws atmosphere air through the water-air heat exchanger. Water circulated by the pump from the heat storage tank serves as the main working heat exchange medium. If necessary, an auxiliary air heater can be utilized to keep the incoming air temperature within the recommended range. In a static bed, the material to be dried is arranged.

ii. Integrated solar-assisted high performance dryers:

Since harvest time generally corresponds with the time of the most intense sun irradiation, the prospect of agricultural products being preserved by solar drying appears attractive. The annual working period and the use of solar energy are also constrained by seasonal fluctuations. The year-round functioning of the collectors is necessary in the case of high performance solar dryers with a big collector area and a high heat storage capacity in order to achieve an acceptable financial return. This objective can be met by making sophisticated use of solar collectors, which can provide heat for a variety of purposes, including heating or cooling greenhouses and animal stalls in addition to drying materials. Indirect solar dryers using a water-type collector are most suited for such uses. Both the hot-water system and the solar dryer can store heat in the water tank (HWS). At the same time, the solar dryer's auxiliary heater can be powered by the HWS's conventional energy source.

iii. Solar-assisted dryers with rock bed heat storage:

Rock bed, gravel bed, and pebble bed heat storage devices are often employed in solar-assisted direct type dryers (Auer, 1980; Read et al., 1974; Contier and Farber, 1982; Niles et al., 1978; Choudhury et al., 1995 cited in Baker & Christopher G J, 1997). The concept makes use of a high-performance raisin drier with a gravel bed storage system. On the ground is a collector surface area. By use of a fan attached to a heat recovery system, fresh air is circulated via a collector loop. Preheated air from the collector travels through the air duct to the spot where the gas burner is installed. When the air temperature coming from the collector is lower than needed, the burner acts as an auxiliary heater and ignites. A blower blows heated air into the drying tunnel. The heat recovery unit is used to exit the dryer with moist air. When the fan is running and the air valves are closed, the collector can charge the rock bed heat store. By properly regulating the dampers and running the fan, it is possible to partially charge the heat storage unit or utilize the stored energy. With this drier, it was demonstrated that 69% of the annual drying energy demand could be met by solar energy.

iv. Solar-assisted dryers combined with absorbent units:

Combining absorbent beds, which may be used for energy storage as well as supplementary heating, with sophisticated and integrated solar-assisted dryers can increase efficiency (Imre et al., 1982; Twidell et al., 1993; Imre, 1995 cited in Baker & Christopher G J, 1997). Sensible heat absorption and moisture absorption both contribute to an absorbent's ability to store energy (such as zeolite or silica gel). Compared to a physical heat store, the particular total energy capacity is about an order of magnitude more. Regeneration at a temperature typically higher than 150°C should be used to take advantage of the sub-soilers' dynamic adsorption capacity. But a sizeable portion of the energy consumed for regeneration can also be used for other things, such producing hot water. The dryer can be run on the adsorption capacity when solar energy is not available. Adsorbent-equipped solar dryers have shown to be competitive in price with those integrating rock bed energy storage. However, the local situation, opportunities, and requirements have a significant impact on the economic comparison (Imre,1974; Close and Dunkle,1977;Pinaga at el, 1981 cited in Baker & Christopher G J, 1997).

v. Solar-assisted dryers with heat pumps:

The enthalpy of moist air exiting the drying area is virtually identical to that of the dry air entering the dryer. By chilling the air and condensing its water vapor content, a sizeable portion of the energy consumed for drying can be recovered as latent heat. A heat pump that is attached to the dryer's air outlet can do this. Air travels from the dryer to the heat pump's evaporator. In this location, the air cools and moisture condenses. The working fluid of the heat pump passes via the compressor, condenser, expansion valve, and back to the evaporator, and this supplies the latent heat needed to evaporate it. Depending on the environmental circumstances, cold water is heated in the condenser and sent to the water heat storage tank. The dryer heat exchanger can receive air that has just left the evaporator.

2.4. HISTORICAL BACKGROUND OF OPEN SUN DRYING

Fish and fish items would have naturally dried in the past due to the sun and wind. According to available data, food was actively dried in the scorching sun by Middle Eastern and eastern societies as early as 12,000 B.C. More traces of later cultures can be found, and each would have methods and materials that would reflect their sources of sustenance, such as fish, wild game, domestic animals, etc.

Fruits and vegetables have also been preserved by drying since ancient times. Any form of dried fruit they could produce was especially beloved by the Romans. In the Middle Ages, "still homes" were purposefully constructed and used to dry fruits, vegetables, and herbs in places where there was little direct sunshine. The heat required to dry foods and, in some cases, smoke them was produced by a fire.

2.4.1. WORKING PRINCIPLE AND ELEMENTS OF THE SOLAR POWERED FISH DRYER

The basic idea behind the sun drying method is to harness solar energy by heating the air inside solar collectors and then transfer that heated air to a mechanically constructed cage, the fish drying chamber, which is attached to the collector. The items that need to be dried are arranged here. The idea behind the solar-powered fish drier is rather straightforward. The size of the solar panels or collectors is a key component of solar drying equipment. Collectors must be able to provide the drying chambers with enough hot air, depending on the volume of commodities to be dried. Fish will spoil if attempts to dry it are unsuccessful due to collectors that are too small relative to the amount of fish that has to be dried.

The fundamental ideas behind a solar dryer are:

1. Converting light into heat
2. Enclosing heat
3. Channeling heat toward the food.

2.5. DESIGN-METHODOLOGY AND WORKING ELEMENTS

The components of a solar-powered fish drier and how to maximize its performance are covered in the design process section.

2.5.1. SOLAR PANELS OR COLLECTORS

Three types of solar panels;

i. Monocrystalline Solar Panels:

Large silicon crystals are used to create monocrystalline solar panels. These solar panels are the most expensive, but they are also the most effective at absorbing sunlight and converting it into electricity. Compared to other types of solar panels, they perform a little bit better in lower light levels.

ii. Polycrystalline Solar Panels:

The most popular kind of solar panel on the market right now is polycrystalline. They resemble broken glass a lot. They cost less to construct and are marginally less efficient than

monocrystalline solar panels. This kind of solar panel is made of numerous tiny silicon crystals rather than a single giant crystal.

iii. Amorphous Solar Panels:

A thin, film-like layer of molten silicon is deposited directly over sizable plates of stainless steel or a material comparable to it to create amorphous solar panels. These solar panels are the least expensive to make but have a lesser efficiency than the other two varieties. Amorphous solar panels have the benefit of being shadow-protected over the other two. This means that even though some of the solar panel's cells are in the shade, the solar panel is still charging. On boats and other modes of transportation, these are excellent.

2.5.2. SOLAR POWER EFFICIENCY

The proportion of solar energy that is absorbed and transformed into electricity is known as solar panel efficiency. Since it is difficult to provide an exact figure, the figures below represent the average efficiency of the various solar panel types. Typically, crystalline solar panels degrade at a rate of 0.5% per year, compared to thin-film solar panels' annual degradation rate of about 1%. The approximate percentages for each type of solar panel are listed below;

Monocrystalline-18%

Polycrystalline-15%

Amorphous (thin-film) - 10%

2.6. HEATING CHAMBERS

To increase its efficiency, the heating chambers can be of any size or shape as long as they meet the requirements listed below.

- a. Should be dimensioned for its intended function.
- b. Should be of a reasonable height.
- c. The drying chamber's walls and floor must be a dark color.

2.7. OTHER COMPONENTS

a. Drying Trays:

The following qualities ought to be included in the drying trays:

- ✓ Be tough enough to support both the weight of the fishes and intensive cleaning.
- ✓ Be constructed using the proper materials to provide proper airflow through the tray.
- ✓ Should not be constructed of non-toxic materials like aluminum or galvanized steel.

- ✓ Designed to conveniently fit inside drying chambers.

b. Vents/ Blowers:

Characteristic of a good vent:

- Maximize as much as possible the height difference between the intake and outlet vents.
- Make both vents as wide as possible. Make both vents in a cabinet dryer 1/3 the size of the back wall.
- Use netting or screen to make the vent holes insect-proof.
- Create a door that hangs from the top side to cover the bottom vent.
- Make the both doors airtight against the night.

c. Glazing:

- Transparency is a must.
- May be two tiers (with a 2-4 cm air space in between).
- Cost, strength, thickness, and ease of installation should all be taken into consideration.
- If built-in, the compass ought to be oriented correctly.
- The right angle should be present for the season it will be used in. (Latitude -109 for summer; +30 Q for winter; +10 oC for spring, fall, and all other seasons.)

d. Heating Elements:

- ❖ The size of the inlet and output vents should match that of the dryer's.
- ❖ To optimize use all year long, the glazing angle may be different from the one on the dryer.
- ❖ The absorber surface on the preheater's bottom ought to be dark in color and, ideally, composed of metal.
- ❖ Although it can be removed, it needs to be well sealed to the dryer's bottom vent.

2.8. ADVANTAGES AND LIMITATIONS OF DIFFERENT TYPES OF SOLAR DRYERS.

Advantages of solar natural dryers.

- i. Comparatively little investment versus mechanical dryers.
- ii. Reduces the issues related to drying in the open sun.
- iii. There are several solar natural dryers on the market today.

Limitations;

- i. Only small-scale applications can make use of it because of its limited capacity.

- ii. Direct sun radiation exposure causes crop discoloration.
- iii. Glass' transitivity is decreased by moisture condensation inside the coverings.
- iv. Sometimes crop moisture removal is impacted by an insufficient temperature rise.
- v. Selective coatings are only occasionally used in the absorber plate.

Advantages of semi-artificial dryers:

- i. Can be used to dry agricultural items such coconuts, coffee, cocoa, crops, vegetables, herbs, and fruits.
- ii. Construction costs were reasonably low.
- iii. Dependable in comparison to solar-powered natural dryers.

Limitations:

Cannot be used to extensively dry agricultural items.

Advantages of solar assisted dryers:

- i. Best suited for dehydrating a majority of agricultural items.
- ii. Its design is cost-effective in terms of drying area.

Limitations:

- i. Expensive as a result of the design-related components.
- ii. Because of its intricate designs, it might be difficult to use in underdeveloped nations or densely populated places.
- iii. Expensive to use for drying on a small scale.

2.9. DESCRIPTION OF THE PROBLEM SOLVED BY THE SOLAR POWERED FISH DRYER

The technique offers a number of socioeconomic advantages. The issue of food security is one of the biggest problems that developing countries are currently experiencing. The fish dryer powered by solar energy can increase food security by enabling food to be stored for longer after drying as opposed to food that has not been dried. When used in place of dryer systems that depend on an external energy source, such as fossil fuels or electricity, the solar dryer can reduce both fuel and power use. In addition, compared to sun drying, solar food dryers reduce drying times. While dryers driven by fossil fuels or electricity may have some advantages (such as more constant air flow and higher temperatures), marginal farmers may find the financial obstacles posed by these technologies to be too great. For instance, fossil fuel-powered drying may have high upfront and ongoing expenses if electricity is unavailable or too expensive. Compared to fruits, vegetables, fish, and meat dried in the open sun, those that are dried in a solar-powered drier are higher-quality and more hygienic. As previously indicated, food contamination is avoided or reduced as a result of the closed system design. In contrast to the open system design

of open sun drying, the food is also not susceptible to rain and dust. Farmers that harvest fresh fish in rural locations without suitable fish drying facilities must sell their catch as soon as possible in the market. When there is a great volume of fish produced, the farmers must sell the fish at a loss to keep the fish from deteriorating and losing value. Thus, the solar fish dryer could be able to shield fish producers in these circumstances from suffering financial losses. Fish that has been dried can stay fresher for longer periods of time. Additionally, dried fruits and vegetables may be marketed as unique items, which could raise their market worth. For instance, dried meat can be used to create a variety of goods. Fish loses volume when it is dried. The fish is therefore easier to transport after drying, which may open up new markets for the food producer in addition to extended storage times.

2.9.1. AVAILABILITY AND SUSTAINABILITY OF SOLAR DRYERS IN NIGERIA

Solar Energy:

Solar power is power derived from the sun. Almost all life on earth is supported by this energy, which also controls the climate and weather. Because Nigeria has so many open plains and so much sunlight each day, solar power is a clean energy source that is readily accessible locally. Because of its favorable environment, Nigeria can produce electricity using solar energy.

Nigerian Solar Radiation

With a total land area of 923,768 km², Nigeria has an average annual solar incidence of roughly 1,831.06 kWh. According to a scientific assessment of Nigeria's solar energy potential, 5% device efficiency can produce 1591014 kJ of useable yearly energy. This amounts to 4.2 9 105 GWh of annual electricity generation, or around 258.62 million barrels of oil. The country experiences 6.25 hours of sunshine on average per year, ranging from 3.5 hours in the coast to 9.0 hours in the north. Similar to this, the average daily solar radiation is 5.25 kWh/m²/day, with coastal zones receiving 3.5 kWh/m²/day and northern regions receiving 7.0 kWh/m²/day. The map 1 below displays the dispersion of solar radiation. Three distinct solar radiation zones—zones I, II, and III—can be identified based on the map; each zone has a unique radiation level (whose respective values are shown on the figure legend) that may be required for a certain project selection and sizing.

The irradiation levels for each zone are listed in Table 1 and are dispersed across the 36 federated States. With high sun radiation impacting on the horizontal surface and all the states in the northeast geopolitical zones, Zone I offers outstanding and viable potential for large-scale solar photovoltaic, especially in the semi-arid region. In Zone II, which includes the northwest and north-central belt of the nation, there is also potentially useful solar radiation that could be needed for the majority of solar installations. Zone III, which includes all places in the southern zone and the coastline region, has a low potential for annual global solar radiation and can only support stand-alone PV systems.

However, it is noteworthy that some states and regions in the southwest and southeast can sustain decentralized energy initiatives with ease.

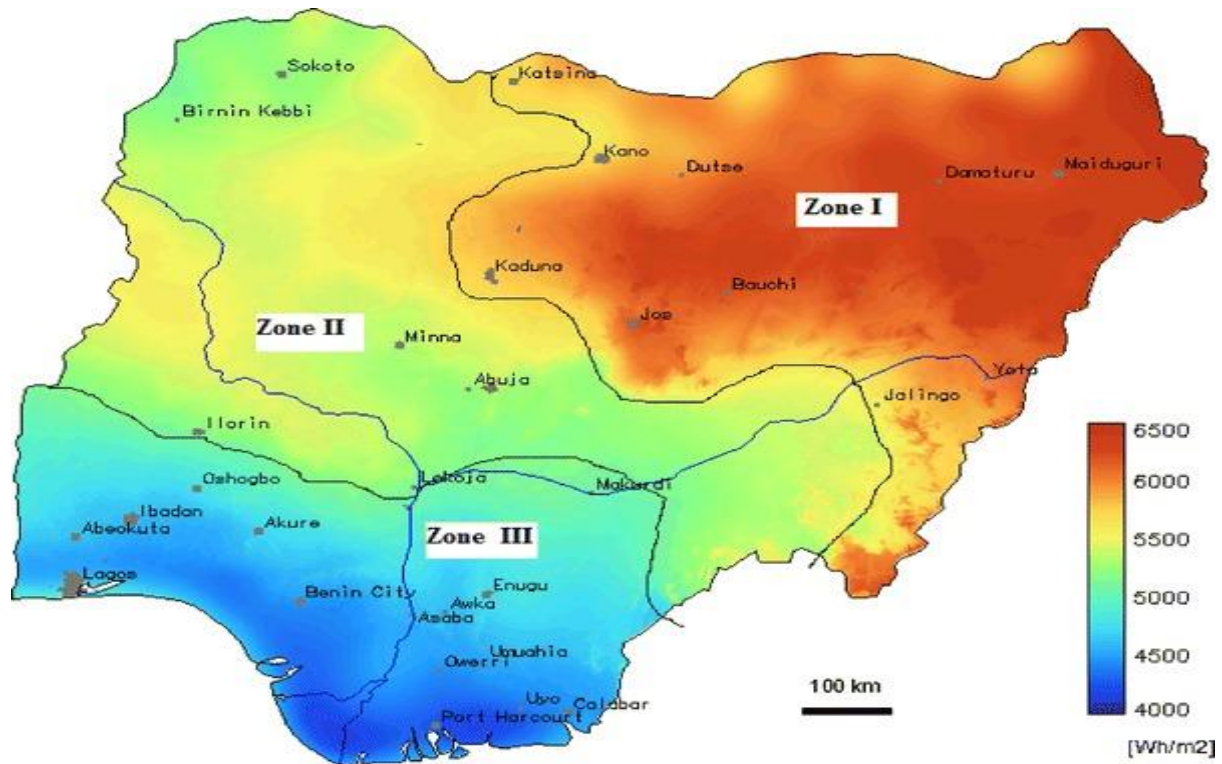


Figure 2.1

Zones	Annual Average of Global solar radiation (kWh/m ² /day)	Sunshine duration (h/day)	Annual average Of solar energy intensity (kWh/m ² /year)	States

Zone 1	5.7- 6.5	6.0	2,186	Borno, Yobe, Jigawa, Kano, Kaduna, Bauchi, Gombe, Adamawa, Plateau and Katsina.
Zone 2	5.0 – 5.7	5.5	2,006	Sokoto, Zamfara, Kebbi, Niger, FCT(Abuja), Nassarawa, Taraba, Kwara some sections of Plateau, Benue and Katsina.
Zone 3	<5.0	5.0	1,882	Lagos, Oyo, Osun, Ekiti, Kogi, Benue, Delta, Imo, Anambra, Abia, Enugu, Edo, Ondo, Bayelsa, Akwa-Ibom, Cross-Rivers, Ebonyi.

Table 2.1

What is solar PV?

Solar PV, or the rooftop solar panels you see on homes and businesses, uses solar radiation to directly generate electricity. Solar thermal methods produce heat from the sun's energy, which is then converted into electricity. Only roughly one millionth of this is now used directly by us for commercial energy.



Figure 2.2

Map showing Solar Electrification -PV in Nigeria, current status and affordability analysis.

CHAPTER THREE

3. DESIGN METHODOLOGY AND ANALYSIS

3.1. Design Considerations

A variety of design parameters and requirements were taken into account when creating the solar-powered fish dryer. A series of mathematical computations were used to identify some of these design characteristics and criteria, while literature reviews provided information for others. Environmental factors at the test site, drying temperature, the amount of moisture to be removed, the amount of heat needed, and the amount of airflow needed were some of these design criteria.

The machine had undergone various significant design considerations with respect to FIT, FORM, AND FUNCTION in order to achieve the intended output in terms of efficiency, effectiveness, dependability, and acceptability during operation and testing.

3.1.1. Machine System

The following design concerns should be considered by the machine system:

1. To minimize human effort when drying, the machine should be made as light as possible while yet being ergonomic (safe and convenient).
2. In order to assure efficiency and reusability, the machine should be developed using sound modeling techniques that apply industry standards for component parts (such as DIN, ANSI, or ISO standards), which in turn describes appropriate material choices.
3. The machine should be built with the proper FIT in mind for all component parts, while also being easy to assemble and disassemble.
4. In order to achieve sustainability, the equipment should be constructed to meet lifespan criteria for sufficient use, safety, and maintenance access.
5. When using computer-aided theoretical analysis and design techniques, the machine components or elements must be adequate and adhere to conventional manufacturing catalogues.

3.2. Materials and Methods

A solar panel PV module, a heating element, and a drying chamber make up the three main parts of the solar-powered fish dryer. The dryer's primary source of energy came from the sun's light, which was converted by the 36V solar panel PV module into the heat needed to operate the 48 heating element.

3.3. Design Analysis

The dryer's performance was assessed in Benin City, Nigeria, which is located between latitudes 6°23'55"N and 6°27'39"N and longitudes 5°36'18"E and 5°44'30"E (Aiyesanmi and Imoisi, 2011). The average solar radiation for Edo State, as determined by data made by the Meteorological Services Department, Benin City, was around 592.87 W/ m². According to Onaiwu et al. (2020), the test site's average ambient temperature, Ta, was 30.97 °C with a relative humidity level of roughly 74.36%. (Onaiwu et al, 2020).

Month	Temperature (°C)	Relative humidity (%)	Pressure (mmHg)	Wind-speed (km/h)	Wind-direction (°)	Solar-radiation (W/m ²)	Ultra-violet radiation (μW/m ²)
JAN	31.67 ± 0.25	71.10 ± 5.64	751.43 ± 1.16	3.76 ± 1.82	158.55 ± 59.95	703.60 ± 208.78	1133.78 ± 48.56
FEB	30.12 ± 0.77	73.74 ± 1.55	752.41 ± 1.30	5.44 ± 0.66	160.84 ± 22.41	603.11 ± 50.11	857.87 ± 131.45
MAR	30.78 ± 0.38	71.33 ± 2.33	748.66 ± 0.43	5.47 ± 0.45	182.78 ± 39.35	728.65 ± 50.07	970.82 ± 63.61
APR	33.47 ± 0.77	59.88 ± 2.11	748.46 ± 0.60	5.84 ± 0.77	186.49 ± 6.25	1073.46 ± 97.94	1067.52 ± 92.27
MAY	29.89 ± 0.37	72.07 ± 4.26	749.62 ± 0.78	5.21 ± 0.84	169.90 ± 34.57	561.32 ± 30.68	803.88 ± 77.01
JUN	29.43 ± 0.44	72.50 ± 1.95	751.71 ± 1.76	5.87 ± 0.70	169.89 ± 22.32	564.24 ± 42.15	779.84 ± 134.59
JUL	27.37 ± 0.44	82.32 ± 2.06	752.61 ± 1.38	5.54 ± 0.86	179.43 ± 24.42	571.24 ± 38.74	861.85 ± 31.92
AUG	27.92 ± 0.57	78.24 ± 1.95	754.31 ± 0.69	6.36 ± 0.37	154.96 ± 12.85	425.19 ± 38.53	784.49 ± 89.08
SEP	28.72 ± 0.47	86.16 ± 1.04	753.82 ± 0.32	6.95 ± 0.58	174.14 ± 17.38	458.05 ± 81.76	808.46 ± 225.24
OCT	27.87 ± 0.80	78.98 ± 3.13	752.11 ± 0.07	6.84 ± 0.28	175.73 ± 16.19	495.01 ± 80.84	717.31 ± 133.63
NOV	29.73 ± 0.83	78.96 ± 4.50	752.91 ± 0.14	2.99 ± 0.15	205.46 ± 12.15	468.33 ± 54.29	907.55 ± 132.94
DEC	30.06 ± 1.95	67.09 ± 16.88	752.71 ± 0.55	2.87 ± 0.14	179.11 ± 13.23	462.21 ± 36.15	753.14 ± 293.29
Seasonal mean (dry)	30.97 ± 1.43	70.35 ± 4.03	747.77 ± 7.76	4.40 ± 1.34	178.88 ± 17.43	673.23 ± 134.51	948.45 ± 139.32
Seasonal mean (wet)	28.53 ± 0.69	78.38 ± 2.55	752.37 ± 1.67	6.13 ± 0.86	170.68 ± 8.51	512.51 ± 62.30	792.64 ± 47.06
Annual mean value	29.75 ± 1.26	74.36 ± 3.39	750.07 ± 5.87	5.26 ± 1.09	174.78 ± 13.76	592.87 ± 115.46	870.55 ± 128.26

Figure 3.1: Meteorological Parameters in Benin City

3.3.1. Drying Temperature

According to research by (Komolafe, et al., 2013), suggested drying temperatures should range from 60 °C to 90 °C (90 °C at the early stage and 60 °C at the later stage), depending on the quality of the three fresh water tilapia fish species. Td, or the average drying temperature, was therefore taken into account when constructing the dryer.

3.3.2. Amount of Moisture To Be Removed

Bassey and Schmidt (1987) provide the following equation to compute the total amount of moisture to be removed (M_w):

$$M_w = \frac{M_w (M_i - M_f)}{1 - M_f} \dots\dots\dots \text{Equation 3.1}$$

Where: M_w = amount of moisture removed

W_w = initial total weight

M_i = initial moisture content on wet basis;

M_f = the final moisture content on wet basis;

The amount to be dried dictates the drying space; in this case, an initial amount of 4.33g (D Narouchit, et al., 2012) needed to be taken into consideration when constructing the dryer

because the dryer is planned to have three trays and to be developed for small and medium scale drying applications. Fish would therefore be dried in batches from its initial average moisture content of 19.54% (Amponsahet al., 2018) on a wet basis (obtained via oven drying) to a final average moisture content of 8%. (A Jeyakumari, et al, 2019).

Weeks	Body weight (g)
0	5.57 ± 0.75
4	24.46 ± 5.11
8	65.42 ± 12.44
12	113.61 ± 21.73
16	157.44 ± 27.96
20	195.92 ± 37.95
24	243.00 ± 46.04
28	273.22 ± 49.48
32	312.76 ± 56.60
36	338.12 ± 59.93
40	343.88 ± 65.79
44	400.81 ± 78.93
48	433.33 ± 86.40

Figure 3.2: Body Weight of Tilapia

Using Equation 3.1

$$M_w = \frac{4.33 (0.1954 - 0.08)}{1 - 0.08}$$

$$M_w = 0.6g$$

3.3.3. Heat Required to Remove Water

Using the Mercer formula, the heat needed to extract water from a produce was estimated (2007). It views drying as a two-step process with the first stage consisting of increasing the temperature of the wet material to the required level, where the moisture will be removed. This comes from:

$$Q_1 = W_w C_p (T_2 - T_1) \quad (3.2)$$

Where:

C_p = Specific heat capacity of the produce (in kJ/Kg $^{\circ}C$)

$T_2 - T_1$ = Temperature change (in $^{\circ}C$)

Specific heat capacity of a food material can be determined using the following equation:

$$C_p = 1.424 m_c + 1.549 m_p + 1.675 m_f + 0.837 m_a + 4.187 m_w + 2.0505 m_i \quad (3.3)$$

Food	Water Content, %	Specific Heat, kJ/kg K	Latent Heat, kJ/kg
Apple	84	1.88	280
Banana	75	1.76	255
Watermelon	92	2.0	305.1
Peaches	87	1.92	288.4
Green beans	89	1.96	296.8
Cabbage	92	1.96	305.1
Carrot	88	1.88	292.6
Beef	75	1.67	255
Fish	70	1.67	275.9
Pork	60	1.59	196.5
Bread	32–37	1.42	108.7–221.2
Egg	--	1.67	275.9
Milk	87.5	2.05	288.4

Figure 3.3: Specific heat capacity of fish

Where:

m_c = Mass of fraction of carbohydrate

m_p = Mass of fraction of protein

m_f = Mass of fraction of fat

m_a = Mass of fraction of ash

m_w = Mass of fraction of water

m_i = Mass of fraction of ice

(Earle, 1983) provided information on the chemical makeup of fresh fish. When these numbers are entered into equation 3.3, the result is

$$C_p = 1.67 \text{ kJ/Kg } ^\circ\text{C}. \text{ Hence;}$$

$$Q_1 = 0.67 \times 1.67 \times (75 - 30.97)$$

$$Q_1 = 49.265\text{kJ}$$

Evaporating the produce's moisture is the second stage. After the product has been warmed to the drying temperature, water begins to evaporate, and the heat needed to cause it to do so comes from:

$$Q_2 = M_w (L) \quad (3.4)$$

Latent heat of vaporization is represented by $L = h_g - h_f$. Steam tables are used to determine the values for h_g (enthalpy of water as a vapor) and h_f (enthalpy of water as a liquid) at the drying temperature.

$$h_g = 2583\text{kJ/kg}$$

$$h_f = 188\text{kJ/kg}$$

$$Q_2 = 0.67 \text{ kg } (2583 - 188) \text{ kJ/kg}$$

$$Q_2 = 1,604.65\text{kJ}$$

Therefore, the total heat requirement = $Q_1 + Q_2 = 49.265\text{kJ} + 1,604.65\text{kJ} = 1,653.915\text{kJ}$.

$$Q_T = Q_1 + Q_2$$

$$Q_T = 49.265\text{kJ} + 1,604.65\text{kJ}$$

$$Q_T = 1,653.915\text{kJ}$$

The obtained result corresponds to the theoretical value. The heat lost via the dryer's walls and the heat that escapes through the chimney are not taken into account. In accordance with the PV-specification module's and the total heat need, the heating element's heat and power requirements are further determined.

3.4. Heating Element Design

The design will thus be based on a circular wire because the majority of heating components are typically made of this configuration with a known resistance, length, and diameter. In this situation, the solar panel PV-Module is the current that the element typically needs to function. Once a steady state temperature is attained, its temperature starts to rise. In order to prevent heat outburst from the heating element, it is advantageous for the voltage intensity from the solar panel PV-module to be lower than the necessary voltage.

One objective of this project is to utilize a DC 36V – 320watts solar panel PV – Module to power a DC heating element of 12V based on standard components in stock. Therefore, 3- 36V-320 watts for the solar panel and 12V PTC full clad heating element will be used as the standard design parameter throughout the design process.

Heat body = heating element = heat source

Charge = cold body = sink = element material (nickel chrome wire) to be heated

Therefore, the heating element start dissipating heat from the surface of the heating element material.

3.4.1. Properties of Heating Element

1. A little amount of wire should be needed to generate a certain amount of heat, hence it should have a high resistance.
2. In order to achieve high temperatures, it needs have a high melting point.
3. To provide a set quantity of heat, it should have a high specific resistance so that the overall wire length is reduced.
4. It should be low temperature efficient to ensure that resistance keeps relatively constant even as temperature rises.
5. It ought to not corrode.
6. It should be economical

According to Stefan's law,

$$\text{Heat radiated by hot body (H)} = 5.72 \times 10^4 \text{ Ke} \left[\left(\frac{T_1}{1000} \right)^4 - \left(\frac{T_2}{1000} \right)^4 \right] \text{ W/m}^2 \quad (3.6)$$

Where:

T_1 = Temperature of the heating source

$T_1 = 260 \text{ }^\circ\text{C}$ (maximum temperature for a PTC Full clad and wire heating element)

T_2 = Temperature of cold body

$T_2 = 30.97 \text{ }^\circ\text{C}$ (Fish to be dried at ambient temperature)

K = Constant = Radiating efficiency

K = 1 for one heating element

K = 0.5 – 0.8 for more than one heating element placed side by side

Since the heating chamber is a boxed enclosure, only one heating element is used for the three sides of the heating chamber.

Therefore, K = 1.

e = Emissivity

e = 1 for perfectly black body

e = 0.9 for resistance heating element

Since the heating element's heat source is the direct conversion of solar energy from the sun into heat energy, its emissivity was set at 0.9.

Therefore,

$$H = 5.72 \times 10^4 \times 1 \times 0.9 \left[\left(\frac{260}{1000} \right)^4 - \left(\frac{30.97}{1000} \right)^4 \right] \text{ W/m}^2$$

$$H = 0.0045 - 0.000000919 \times 51,480$$

$$H = 0.00456 \times 51,480$$

$$H = 235.20 \text{ W/m}^2$$

Therefore, the maximum heat radiated by the heating element is about 235.20 W/m^2 . For 1 m^2 area, 235 W is radiated.

Obtaining the electrical input power to the heating element

$$P = \frac{V^2}{R} \quad (3.6)$$

Where:

V = Supply Voltage from the heating element

R = Resistance in ohms:

In this design, the line voltage should be compatible with the heater's rated voltage because the solar panel PV-module has a voltage specification of 36 V , and a lower voltage specification is necessary for the heating element to operate safely and to prevent failure. As a result, the heating element was specified at 24 V .

$$235 = \frac{24^2}{R}$$

$$R = \frac{576}{235}$$

$$R = 2.45 \text{ ohms}$$

3.4.2. Power Requirements for Drying

Since 235.20 W/m^2 is the heat radiated from the heating element, then the power required by the heating element to dry food is required. The power required should not exceed the design power of the heating element.

Recall that heat energy required to remove 0.6g of moisture content from tilapia fish is about 1,653.915kJ. Obtaining the power required depends on the drying time of fish at an average initial drying temperature of $75 \text{ }^\circ\text{C}$.

Studies by (Osman A, et al, 2021), carried out at the Institute of Agricultural Engineering and Food Processing, Georg-August University, Göttingen, revealed that it takes tilapia fish around 5 hours to reach a temperature of $60 \text{ }^\circ\text{C}$ when heated in the microwave. Therefore, since this design tends to raise the temperature to about $75 \text{ }^\circ\text{C}$, drying time is approximately reduced to 4 hours.

Drying Methods	Drying Temperature ($^\circ\text{C}$)	Drying time (hours)
Microwave drying	40	22
Infrared drying	40	14
Oven drying	40	17
Microwave drying	50	8
Infrared drying	50	12
Oven drying	50	10
Microwave drying	60	5
Infrared drying	60	8
Oven drying	60	7

Figure 3.4: Drying Time at different drying temperatures

$$\text{Therefore, } P = \frac{Q_2}{T}$$

Where Q_2 = Total heat required to remove moisture content from the fish

T = Drying time

$$P = \frac{1,653.915\text{kJ}}{4 \times 60 \times 60}$$

$$P = 114.792\text{W}$$

Therefore, the power required by the heating element to remove moisture content from the fish over 4 hours is about 114.792W, which proves satisfactory because it is less than the total heat of 235W/ m² radiated by the heating element over 1 m² area. For greater drying efficiency, an PTC full clad heating element was used with a heating requirement of 918.84W.

3.5. DC PTC Heating Element Specifications:

1. Can take voltage from 5V to 600V. 12V was the design voltage in this design which proves satisfactory.
2. Can take power from as low as 20W to 10000W. Since the heat energy over 4 hours required to dry the fish was calculated to 344.376W, then the PTC heater will work fine.
3. Maximum Surface temperature it can take is about 260 degrees Celsius. Design temperature required to dry the fish was specified to be 75 degrees Celsius, which proves satisfactory.

4. Safety due to automatic temperature control, max temperature is lower than 300-degree Celsius which won't burn when contact with paper, clothes or others
5. Self-regulating function of power, no need the thermostat.
6. Low air resistance, low electrical noise.



Figure 3.5: DC PTC full clad heating element

3.6. Solar Panel PV-Module Design

3- 320W – 36V with a current of 8.88amps was chosen because it has a total voltage and power supply lesser than the power and voltage requirements of the PTC heating element. A solar panel with lower power and voltage supply was selected in order to avoid overheating and burning up of the heating element.

3.6.1. Solar Panel Orientation and Tilt Angle

The flat plate solar panel should be angled and positioned to receive the most radiation possible. The panel operates effectively when it is pointed directly at the sun. The ideal tilt angle changes with the season. Optimal tilt is typically equal to the site's latitude, as a general rule (Weiss and Buchinger, 2002). An ideal panel tilt angle of 11.1° (Anthony U, et al, 2022). was taken into consideration for this design as the test location is Benin City, Nigeria, in latitudes 6°23'55"N to 6°27'39"N and longitudes 5°36'18"E to 5°44'30"E (Aiyesanmi and Imoisi, 2011). In order to prevent rainwater from building up on the panel during rainy weather, this was done.

Station	Lat	Long	β Observed	β NASA	β (L&J) [50]	β M14	β M15	B M23 [67]	β M24 [54]	H NASA	H _T NASA	(L&J) model [50]	model 38	model 22	GRI NASA	GRI Model 38	GRI Model 22
Port Harcourt	4.4	7.2	8.8	4.5	8.5	7.5	11.5	10.2	12.0	172.8	179.2	177.0	178.9	179.6	0.037	0.040	0.045
Uyo	5.1	8.0	10.1	5.5	9.3	8.1	12.1	10.6	12.5	193.4	202.1	199.9	182.2	184.2	0.045	0.041	0.053
Asaba	6.8	6.8	12.0	7	9.8	9.6	13.6	11.9	13.7	197.3	207.4	204.3	207.5	210.0	0.051	0.041	0.053
Calabar	5.0	8.3	9.9	5	8.3	8.0	12.0	10.6	12.4	175.4	182.4	180.5	185.4	186.0	0.040	0.040	0.044
Yenagoa	4.9	6.3	9.9	5	8.9	8.0	12.0	10.6	12.4	169.5	175.9	174.2	177.5	177.4	0.038	0.040	0.040
Benin Cty	6.3	5.6	11.1	6.5	9.9	9.2	13.2	11.5	13.3	191.2	200.4	198.9	201.0	202.9	0.049	0.041	0.051
Umuahia	5.5	7.5	11.1	5.5	9.3	8.5	12.5	11.0	12.8	193.4	202.3	198.8	182.7	185.1	0.046	0.041	0.055
Awka	6.2	7.7	10.9	6.5	10.0	9.1	13.1	11.4	13.3	202.2	212.5	209.7	212.0	215.1	0.051	0.041	0.056
Abakaliki	6.4	8.1	11.2	6.5	10.5	9.2	13.2	11.5	13.4	207.4	218.3	214.9	216.7	220.3	0.053	0.041	0.058
Enugu	6.5	7.5	11.4	6.5	10.0	9.3	13.3	11.6	13.5	202.2	212.6	209.7	212.0	215.1	0.052	0.041	0.056
Oweri	5.5	7.0	11.0	5.5	9.5	8.4	12.4	10.9	12.8	193.4	202.3	197.2	200.0	202.0	0.046	0.041	0.051
Lagos	6.6	3.6	11.5	7	9.6	9.4	13.4	11.7	13.5	195.0	204.2	201.7	204.7	206.4	0.047	0.041	0.049
Ado-Ekiti	7.6	5.2	13.3	8	10.4	10.3	14.3	12.4	14.2	202.7	214.3	211.9	214.7	225.2	0.057	0.040	0.092
Abeokuta	7.2	3.3	12.5	7.5	9.8	9.9	13.9	12.1	13.9	201.5	212.2	208.0	211.0	214.8	0.053	0.041	0.060
Akure	7.3	5.2	12.7	7.5	10.7	10.0	14.0	12.1	14.0	202.7	214.0	212.1	214.7	220.4	0.056	0.041	0.068
Osogbo	7.8	4.6	13.6	8	10.1	10.4	14.4	12.5	14.3	200.8	211.9	208.2	210.7	218.0	0.055	0.040	0.077
Ibadan	7.4	3.9	11.1	7.5	10.5	10.1	14.1	12.2	14.0	201.5	212.3	209.0	211.0	215.1	0.054	0.041	0.061
Makurdi	7.7	8.5	11.6	8	11.3	10.4	14.4	12.5	14.3	213.2	226.0	223.8	223.8	227.2	0.060	0.041	0.057

Figure 3.6: Showing Optimum Solar Panel Tilt angles for some cities in Nigeria

3.7. Construction of the Solar Powered Fish Dryer

3.7.1. Solar Panel

The size of the solar panel was 1115 x 630 mm which was supported by an angel iron frame and tilted to about 12 degrees for maximum radiation of the sun to the heating element. In order to save machine space, the panel was positioned above the solar dryer itself.

3.7.2. Drying Chamber

The drying chamber was constructed out of mild steel sheet metal, supported by a mild steel rectangular pipe. It was made up of three trays, each measuring 250 mm × 250 mm, and was meant to hold about five dried fish, or about 25 kilograms, of tilapia. The trays were composed of stainless steel that had been perforated.

The trays were constructed of stainless steel to prevent rusting because of the high initial moisture content of the produce and were perforated to facilitate free loss of moisture content by draining. Three circular holes, each 10 mm in diameter, were created at the side of the chamber. When the charcoal stove was being used for drying, this opening was being used to pass hot air through the chamber. A hinged door will offer a way to load and unload the material to be dried at the back of the drying chamber.

3.7.3. PTC Full Clad and Wire Heating Element

1 PTC heating element was used for the construction of the solar powered fish dryer that can evenly distribute the heat to the top and the two sides of the drying chamber assisted by two blowers.

3.7.4. CAD Model of the Solar Powered Fish Dryer

The dryer was designed using a software called Autodesk Inventor. The drawing of the design and the corresponding side views with dimensions are shown in the figures below; also shows the pictorial view of the dryer.

3.7.5. Production Drawings

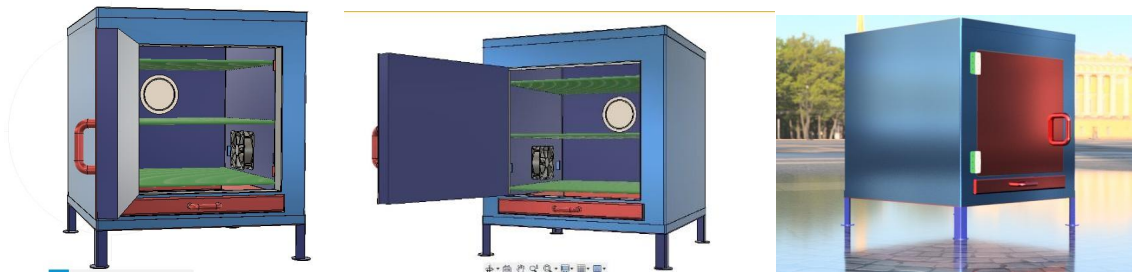


Fig3.7. Isometric View of the Solar Powered Fish Dryer

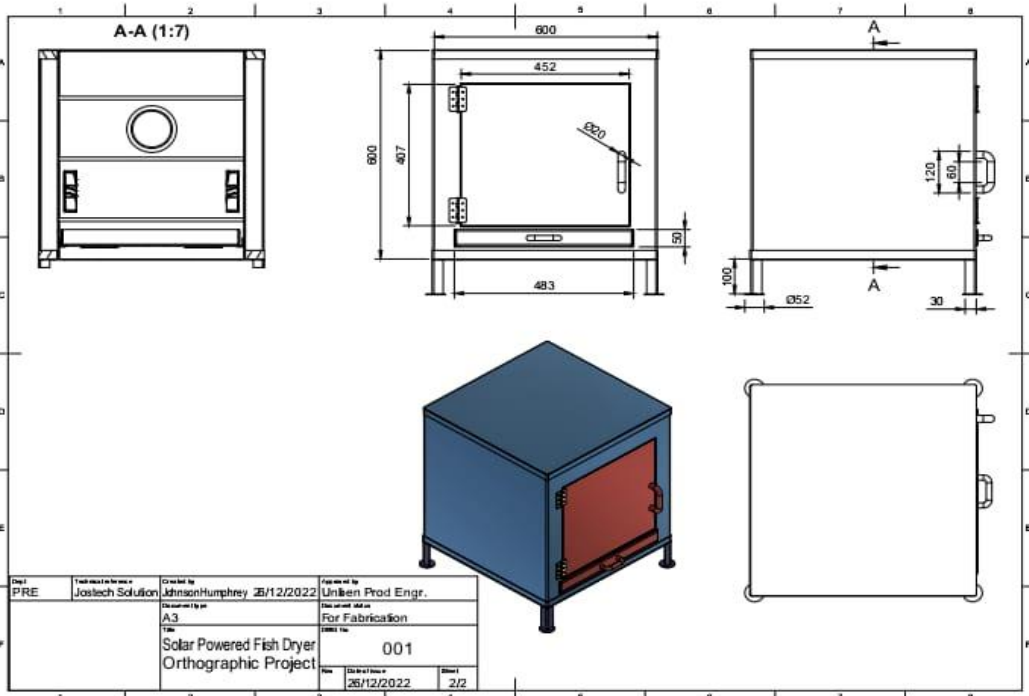


Fig.3.7.1. Orthographic Projection of the Solar Powered Fish Dryer.

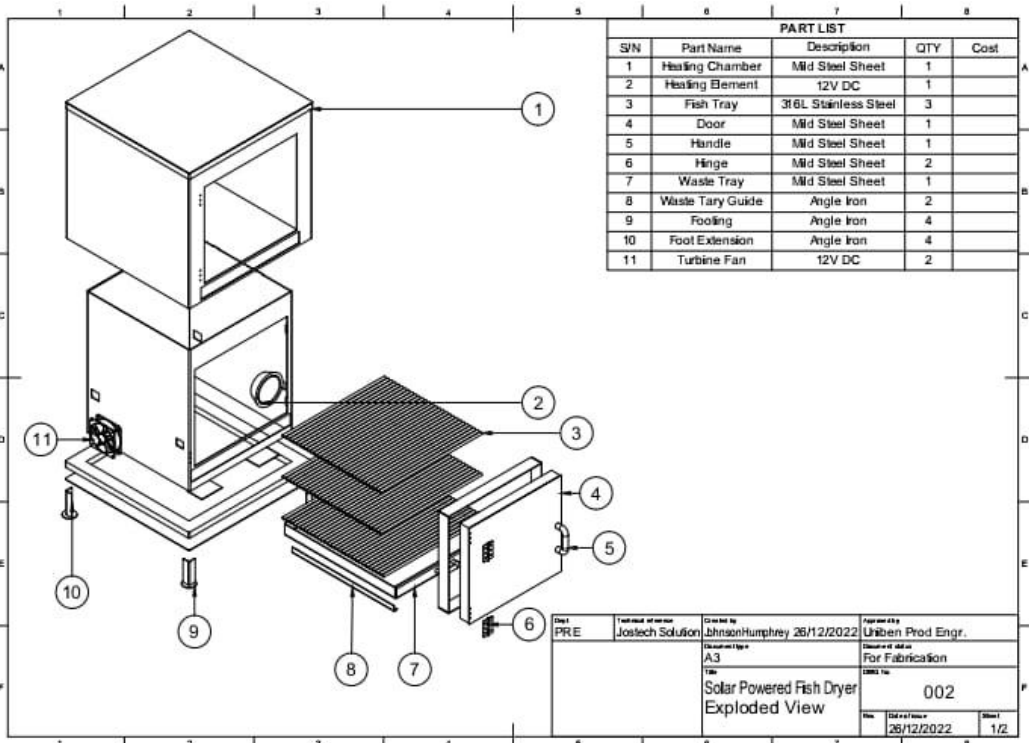


Fig 3.7.2. Exploded View of the Solar Powered Fish Dryer

3.7.6. Budget (BOQ) Proposal for Solar Dryer

The broad objective of this budget proposal is to develop an affordable, reliable and high quality solar dryer to be used for drying raw fish. Our design is made by aluminium sheets, S.S. sheet, angle bars (Specification given). The total prototype constitutes of four broad things;

- 1) Aluminium sheets are cut as per the dimension by shearing machine.
- 2) The frame and trays are fabricated as per the dimension.
- 3) Sheets are drilled as per the dimension and joined by riveting process.
- 4) Trays are drilled for proper airflow.

3.7.7. Fabrication process

The dryer has been fabricated with the help of aluminium sheets, S.S. Bolts, Angle bars. The various parts of the dryer have been fabricated by various processes. The fabrication is explained below.

Sheet Metal Cutting: Sheets are cut to the dimension of top and bottom frame, side frame, back supporting frame and four trays by shearing process. The frames are joined by riveting process. Fans are fixed in sideways for proper airflow into the system. Trays are perforated for proper airflow and placed inside the dryer at equal space. To keep the trays, the angle bars are fixed on the side frame of the dryer. The fabrication of different parts of dryer is shown in figure below;

Item no	Description of item	Unit	Quantity	Total	Total Cost
1	Aluminium sheets	Sq.	Length=600mm Width=600mm, Height=700mm	27 Sq.	50,000
2	Trays, made of Aluminium	Sq.	980mm x 480mm	5.06 Sq.	20,000
3	S.S Bolts	Nos	M6/10mm	50nos	5000
4	NUTS	Nos	M4/10mm	30nos	5000
5	NUTS	Nos	M3/10mm	12nos	5000
6	L-Angle for Foot Support	Nos	L-Angle	4nos	10,000
7	D.C Heater/ Labor	Nos	0.5L	- -	50,000/ 35,000
8	Solar Panel	PC	320W, 12V	----	-----
				Total	180,000

Table 3.7. Budget Breakdown

CHAPTER FOUR

4. Dryer Performance, Evaluation, Tests, Results and Discussions.

The solar-powered fish drier tests have been carried out in this chapter. 20 kilograms of several fish species have been selected for the experiment. Final changes were made to the solar-powered fish dryer after it had been constructed and properly designed. However, before doing so, the dryer was given an idle run to make sure it was stiff and functioning as a whole. The dryer was then turned off after five minutes of doing this. and was later turned back on and made to run for three days in a row, allowing us to collect data, conduct analyses, perform tests, and obtain findings. The dryer was checked for overheating and general operating effectiveness while it was in use.

4.1. Inside Temperature of Dryer.

The dryer is placed in an open field so that it can be exposed to sunlight while being measured to determine the interior temperature. The parameters that were taken into consideration for the experiment are shown in table 5.1. The experiment begins at nine in the morning, and indoor temperatures are recorded using non-contact type pyrometers every hour thereafter. The results of the experiment's temperature are displayed in table 5.2.

Name of the Product	Fish, Tilapia
Zoological Name	Oreochromis Niloticus
Month	December
Starting Hour	9:00AM
Ending Hour	4:00PM
Total Weight Before Drying	2000gm
Weight of the fish tested in solar dryer	1000gm
Weight of the fish tested in Traditional Direct Sunlight drying	1000gm

Table 4.1. Various Parameters Considered for Experiment

Table 4.2 shows the hourly change of the solar collector and drying chamber temperatures in relation to the surrounding air temperature. The pattern indicates that the temperature rises from morning (9am) till afternoon (2pm), when the solar irradiation reaches its peak and begins to fall. When the ambient temperature, drying chamber temperature, and collector temperature are plotted against time, it can be seen that the temperature and solar radiation are both at their highest at 2:00 p.m., but after a few hours, they start to slow down and return to normal. Throughout the duration of the investigation, the temperatures inside the drying chamber and solar collector were substantially higher than the surrounding air. The capacity of the air to hold moisture increases with temperature, which also improves the dryer's efficiency. Relative humidity decreases when air temperature rises, and warm air absorbs moisture from food to become saturated with moisture. In figures 4.1 to 4.3, the temperature variations are displayed.

Day/Time		9am	10am	11am	12Noon	1pm	2pm	3pm	4pm
Day-1	Temp inside the dryer	31.3°C	35°C	41°C	44°C	50°C	50°C	46°C	44°C
	Atm. Temp	32°C	35.6°C	37.8°C	38°C	39°C	37°C	36°C	31°C
Day-2	Temp inside the dryer	35°C	37°C	42.5°C	47.1°C	53°C	50°C	47°C	42°C
	Atm. Temp	35°C	36°C	39°C	40°C	38°C	36°C	33°C	31°C
Day-3	Temp inside the dryer	36°C	40°C	44.5°C	51°C	53°C	48°C	46°C	44°C
	Atm. Temp	36°C	38°C	39°C	40°C	39.5°C	38°C	37°C	35°C

Table 4.2 Inside Temperature of the solar dryer

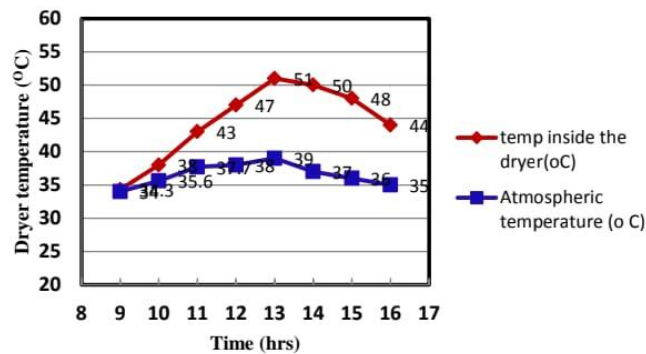


Fig 4.1.1. Temperature measurement in °C inside the dryer on Day-1.

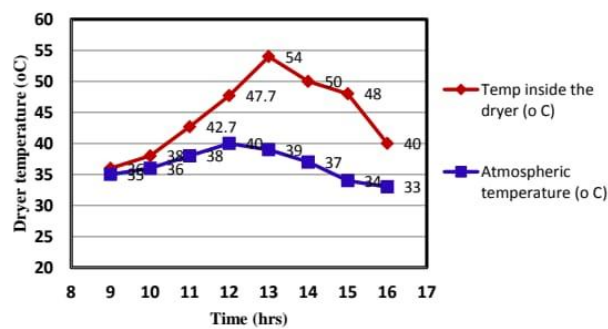


Fig 4.1.2. Temperature measurement in °C inside the dryer as on Day-2.

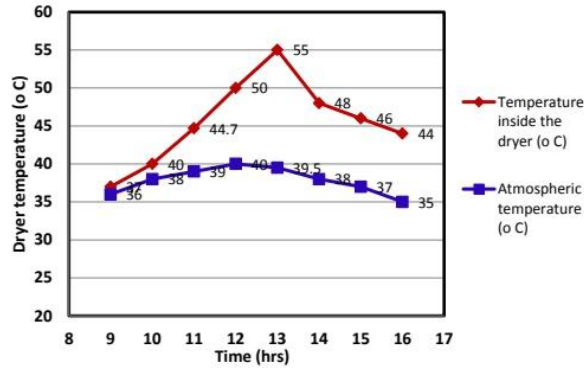


Fig. 4.1.3. Temperature measurement in °C inside the dryer as on Day-3.

4.2. Temperature Variation in three Trays.

To measure the inside tray temperature, the same parameters shown in Table 4.1 have been considered and the temperatures measured. The temperature measure from the experiment are shown in Table 4.2.1. It has been found that there is a small variation in temperature from tray 1 to tray 3 as per the thermodynamics second law, heat always flows from higher temperature to lower temperature.

Day/Time	Time	Temp in Tray 1. (°C)	Temp in Tray 2. (°C)	Temp in Tray 3. (°C)	Day/Time	Time	Temp in Tray 1. (°C)	Temp in Tray 2. (°C)	Temp in Tray 3. (°C)	Day/Time	Time	Temp in Tray 1. (°C)	Temp in Tray 2. (°C)	Temp in Tray 3. (°C)
am	9	34.3	33	32.7	am	9	35.9	32.5	29	Am	9	29.1	33.2	37
	10	37.5	36.3	35.3		10	37.8	34.1	33		10	36.9	37.1	38.1
	11	42.8	42.1	41.5		11	42.3	39.9	39		11	42.6	40	43.2
	12	46.9	46.5	46		12	47.5	42	40.3		12	51.3	46.9	48.5
pm	13	50.8	50.5	50.1	pm	13	53.8	51	44.6	Pm	13	58.6	56.1	54.3
	14	49.8	49.5	49		14	49	44.1	38.4		14	49.1	48.3	45
	15	47.7	47.1	46.5		15	47.3	39.2	35.1		15	44	44.5	41
	16	43.9	43.5	43		16	38.1	33.8	33.2		16	41	43.2	30.7

Table 4.2.1. Different Temperature on different Trays

4.3. Testing of Dryer

To study the performance of the dryer, varieties of fishes have been dried. The table 5.2.1. shows the comparison of weight reduction of fish dried in open sunlight and dried in solar dryer. It can be seen that the percentage of weight reduction is more in case of dryer with a less time.

Fish	Initial Weight	Final Weight	Time Taken	Weight
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	(gm).	(gm).	(Hrs).	Reduction %
Dried in Open Sunlight	2000	903.24	56	54.8
Dried in Solar Dryer	2000	757.9	21	62.01

Table 4.3. Weight of fish before and after drying.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

If the proper design is implemented, solar radiations can be effectively and efficiently used for drying a variety of fishes. Fish could be dried to a substantially lower moisture level using the solar drier that was built and manufactured. Construction utilized affordable local resources, making it accessible and affordable to all people living in rural areas. Since it may be utilized widely for the majority of agricultural food crops, this will significantly reduce general food wastages and at the same time, food shortages. In addition to this, solar energy, which is easily accessible in the tropics and is also a clean form of energy, is needed for its operation. Since it dries food items faster, it saves money and time compared to open-air sun drying of agricultural goods. It also helps the environment. The food items are better protected in the solar dryer than they would be in the open sun, which reduces the risk of contamination and pest and insect attack. The various transformations that society has gone through have changed how production and consumption are done. Due to human actions, environmental challenges have gained centre stage in scientific discussions as dangers to the planet's quality of life. There are many different solar dehydrator designs on the market, and some of them require expensive components, making them challenging for small companies to get.

Due to its simple design and use of readily accessible local materials, solar dryers are typically inexpensive. Additionally, less energy is needed to dry food than to can or freeze it, which reduces the need for traditional energy sources and lowers CO₂ emissions.

By using dehydration curves and temperature/RH monitoring, it was possible to successfully dehydrate items with less than 10% water content. For such drying methods to be optimized and high-quality dried products to be obtained, it is essential to understand the kinetics of fish dehydration. Solar dryers provide a number of benefits, but they also have some drawbacks that affect how well they operate and adversely affect how quickly things dry. These limits include the fact that they can only be used during the day and only when there is enough solar radiation.

A crucial technology for preserving fresh fish in rural regions and consequently lowering food waste is dehydration. The solar dryer is an alternative for small and medium-sized producers and can lower production costs, energy consumption, and waste. The utilization of solar energy allows for the efficient operation of solar fish dryers. The solar fish dryer keeps the environment clean and conserves the nation's limited resources because it produces no smoke, soot, or offensive odors. When solar rays with a small angle of incidence spread over a big surface with less energy per unit area during a stunning sunset, the effect is evident. In the end, the temperature reached is defined by striking a balance between the amount of energy absorbed and the rate at which the environment loses heat; but above all, it depends on how well the temperature is used to dry fish.

For drying purposes, solar radiation was captured and collected. The findings demonstrate that as the earth rotates around its axis with the rising of the sun, temperature rises, and when dusk sets (between 2:00 and 4:00 pm), temperature lowers. It needs solar energy to operate, which is easily accessible in tropical climates and is also a clean source of energy. Since it dries food items

faster, it saves money and time compared to open-air sun drying of various agricultural produce. It also helps the environment. The food items are better protected in the solar dryer than they would be in the open sun, which reduces the risk of contamination and pest and insect attack.

In conclusion, it took around two months to complete the design and manufacture of the Solar Powered Fish Dryer because there were multiple conceptual designs and many design considerations to be made. Unexpected constraints resulted in some detrimental consequences, but the dryer nonetheless passed its idle run test and produced the intended efficiency. The performance evaluation showed that it had functioned satisfactorily, and the dryer is also appropriate for use on a relatively small scale. The dryer that was built not only had a strong capacity for retention, but it also heated up quickly. The fundamentals of thermodynamics, heat and mass transfer, engineering materials, and fluid dynamics were applied to assure product reliability while keeping in mind the necessity to cut costs. This was done in order to achieve the basic engineering design parameters and value engineering analysis.

However, there is still room for improvement in the efficiency of the current solar food dryers, particularly in terms of speeding up the drying process and possibly storing heat energy. In order to guarantee the system's full efficiency and efficacy, customers of solar products should also have easy access to meteorological data. A local farmer will likely be guided by such knowledge when deciding whether or not to dry his agricultural products.

5.1 REFERENCES

- Gulma, M.A., Application of solar technology (Ahmadu Bello University press, Zaria 1996)
- International conference (2000), on “solar cooking” Kimberly, south Africa, <http://www.Solarcooking.org/drying.Whitefield-drying/htmn-edu20>
- Ayyappan, S. and Diwan, A.D. (2003). Fish for food security: An opportunity, Indian farming. *J. Agric. Eng. Res.*, 53; 47-51.
- Barnwal, P and Tiwari, G.N. (2008). Grape drying by using hybrid photovoltaic thermal (PV/ T) greenhouse dryer: an experimental study. *Sol. Energy*, 82; 1131–1144.
- Bolaji, O.B. and Olalusi, A.P. (2008). Performance evaluation of a mixed mode solar dryer. *AU J.T.*, 11; 225-231.
- Brown, P. (2000). Basics of evaporation and evapotranspiration. The University of Arizona Cooperative Extension publication, 4; 955-963.
- Chegere, M.J. (2018). Post-harvest losses reduction by small-scale maize farmers: the role of handling practices. *Food Pol.*, 77; 103–115.
- Dare, A.A., Kolawole, A.O. and Surajudeen, O.O. (2016). Development of a Multipurpose Solar Dryer, *FUOYE J. Eng. Technol.*, 1 (1), 78 – 82.
- Debashree D.B., Biswajit, N., Shiv, S.D. (2017). Design and Fabrication of Solar Dryer for Sustainable Livelihoods of Fisher Women, www.ijemr.net, ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962 (Accessed 21 September 2020)
- Dhanushkodi, S., Wilson, V. H. and Sudhakar, K. (2014): Thermal Performance Evaluation of Indirect Forced Cabinet Solar Dryer for Cashew Drying. *American-Eurasian. Agric. Environ. Sci.*, 14(11): 1248–1254. Duraisamy Sridhar., Dhanushkodi, S.
- Paneerselvam, K. and Sudhakar, K. (2019). Thermal performance of natural convection solar dryer for drying chilli. *Inter. J. Emerging Technol.*, 10; 133-138.
- Divo, M. J., Martinez, C. H., Mannino, D. M. (2014). Ageing and the epidemiology of multimorbidity. *Eur. Respir. J.*, 44; 1055–1068.
- El Hage, H., Herez, A., Ramadan, M., Brazzi, H., Khaled, M. (2018). An investigation on solar drying: a review with economic and environmental assessment. *At. Energy*, 157; 815–829.
- Food and Agriculture Organization (FAO), (2010). The State of Food Insecurity in the World. Addressing Food Insecurity in Protracted Crises. FAO, Rome, Italy.
- Food and Agriculture Organization (FAO), (2011). The State of Food Insecurity in the World 2011. How Does International Price Volatility Affect Domestic Economies and Food Security? FAO, Rome, Italy.
- Forson, F. K., Nazha, M. A., Akuffo, F. O. and Rajakaruna, H. (2007). Design of Mixed-mode fruit and vegetable dryer. *Res. J. Appl. Sci. Eng. Technol.*, 1; 44-53.
- Hodges, R. J., Buzby, J. C., Bennett, B. (2010). Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use. *J. Agric. Sci.*, 3; 1–9.

- Irtwange, S. V., Adebayo, S. (2009). Development and performance of a laboratory-scale passive solar grain dryer in a tropical environment. *J. Agric. Exten. and Rural Development*, 1; 42-49.
- Komolafe, C. A., Ogunleye, I. O. and Adejumo, A. O. D. (2011). Design and fabrication of a convective fish dryer. *The Pacific J. Sci. Technol.*, 12; 89 – 97.
- Kumar, A., Tiwari, G. N. (2007). Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying of onion flakes. *J. Food Eng.* 79; 1337–1350.
- Longwe, P. and Kapute, F. (2016). Nutritional composition of smoked and sun-dried pond raised *Oreochromis Karongae* (Trewavas,1941) and *Tilapia rendalli*, *Am. J. Food Nutr.*, 4;157-160.
- Mohanraj, M., Chandrasekar, P. (2009). Performance of a Forced Convection solar drier integrated with gravel as heat storage material for chilli drying. *J. Eng. Sci. Technol.*, 4; 305-314.
- Munesue, Y., Masui, T., Fushima, T. (2014). The effects of reducing food losses and food waste on global food insecurity, natural resources, and greenhouse gas emissions. *Environ. Econ. Pol. Stud.* 17; 43–77.
- Ogunleye, I.O. and Awogemi, O. (2008). Lining material and air flow effects on the performance of solar fish dryer. *Global J. Eng. Technol.*, 1; 427 -434.
- Oluwole, F. A., El-Jummah, A. M., Ben, M. Oumarou K.M, Wanori, A. (2016). Performance evaluation of solar fish dryer, *Continental J. Eng. Sci.*, 11; 28 –33.
- Patchimaporn Udomkun, Sebastian Romuli, Steffen Schock, Busarakorn Mahayothee, Murat Sartas, Tesfamicheal Wossen, Emmanuel Njukwe, Bernard Vanlauwe, Joachim Müller, (2020). Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach, *J. Environ. Manag.*, 268; 110730-110738.
- Raju, R. V., Reddy, R. M. and Reddy, E. S. (2013). Design and fabrication of efficient solar dryer. *J. Eng. Res. Appl.*, 3; 1445–1458.
- Sandip sengar., Yashwant Khandetod, (2009). Low cost solar dryer for fish. *African J. Environ. Sci. Technol.*, 3; 265-271.
- Scanlin, D. (1997). The design, construction and use of an indirect, through-pass, solar food dryer. *Homebrew*,57; 22-27.
- Singh, P., Shrivastava, V., Kumar, A. (2018). Recent developments in greenhouse solar drying: a review. *Renew. Sustain. Energy Rev.* 82; 3250–3262.
- Tibebu T. B. (2015). Design, construction and evaluation of performance of solar dryer for drying fruit. Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology. 10 – 38.
- Tomar, V., Tiwari, G.N., Norton, B. (2017). Solar dryers for tropical food preservation: thermophysics of crops, systems and components. *Sol. Energy*,154; 2–13.
- Ahmed, T.M., Agbelege, O.O., An Appraisal of the Traditional Fish Handling and Processing Methods in Lake Chad, proceeding of the Fisheris Society of Nigeria, 22nd Annual Conference Kebbi 46-51, 2007.

- Anyanwu, A. 2006. Design and Construction of a User Friendly Universal Solar Food Dryer Using Programmable System on Chip. B. Sc. Thesis, Department of Physics.pp. 11-17, University of Lagos, Nigeria.
- Boyo, A. O. 2003. Comparative efficiencies of different storage materials for solar collectors and their applications solar drying. Journal of Engineering Applications 3: 19-24.
- Boyo, A.O. 2001. Solar radiation on inclined surfaces in Lagos, Nigeria. The Nigerian Journal of Research and Review in Science. 2: 60-65.
- Ikejiofor, I.D. 1985. Passive solar cabinet dryer for drying agricultural products. In: Proceedings of the Workshop of the Physics and Technology of Solar Energy Conversion. pp. 157-165, African Union of Physics, University of Ibadan, Nigeria.