DESIGN AND FABRICATION OF A HYBRID (SOLAR-ELECTRIC) DRYER FOR AGRICULTURAL MATERIALS

BY

EKHOUTOMWEN SHARON UYI-OGHOSA

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SUPERVISOR: ENGR. Dr (Mrs) I. C ILUOBE

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CERTIFICATION

This is to certify that this project work titled DESIGN AND FABRICATION OF HYBRID (SOLAR-ELECTRIC) DRYER FOR AGRICULTURAL-PRODUCE was carried out by EKHOUTOMWEN SHARON UYI-OGHOSA with MAT NO ENG2006295 in the Department of Industrial Engineering, Faculty of Engineering, University of Benin, Benin City in partial fulfillment of the requirement for the Award of Bachelor of Engineering (B.Eng.) in industrial Engineering.

_________________________ ____________________

Engr. Dr. (Mrs) I. C Iluobe **Date**
Project Supervisor

____________________ ___________________

Engr. Prof. P.E Amiolemhen **Date**
Head of Department of Production Engineering

________________________ ___________________

Engr.Dr. (Mrs) I.C Iluobe **Date**
Project Co-ordinator

DEDICATION

This project is dedicated to God Almighty for His infinite grace, wisdom, and provision throughout this journey, It is also dedicated to my beloved family for their unwavering support, encouragement, and sacrifices and to my lecturers and supervisors in the Department of Industrial Engineering for their guidance and mentorship.

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ABSTRACT

This project focuses on the design and fabrication of a hybrid (solar–electric) dryer for agricultural materials. The aim is to develop a low-cost and efficient drying system that utilizes both solar and electrical energy to ensure continuous operation under varying weather conditions. The dryer was designed with major components, including a solar collector, drying chamber, heating element, and forced draft fan powered by both photovoltaic and electrical sources. Locally available materials such as sheet metal, glass, insulation, and mild steel were used in the fabrication process to promote affordability and sustainability. Performance tests were carried out using cassava chips as the sample material, and relevant parameters such as temperature variation, drying time, and moisture reduction were recorded. Results showed that the hybrid dryer achieved faster and more uniform drying compared to traditional open-sun drying. The system proved reliable, environmentally friendly, and capable of maintaining operation during periods of low sunlight. This innovation demonstrates a practical approach to reducing post-harvest losses and improving the preservation of agricultural produce in regions with inconsistent power supply.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

The drying process is as old as the transcending of man from medieval age to present day. Traditional or conventional method of outdoor drying using the sun is still very much practiced in the modern day, this include the spreading of food aggregates on the floor outdoor under the sun, the spreading of clothes on a line outside etc. open air drying though still being practiced universal, it however has some limitations. Man's quest for good health, environmental and personal safety, ease of accomplishing things, effective time utilization, energy savings and improved methods has brought about developed and advanced methods of drying while still utilizing the sun and other alternatives. Drying is one of the oldest methods of food preservation. For many years, people have been preserving agricultural produce by drying (Ekechukwu and Norton, 1997). Drying is a mass transfer process consisting of the removal of water or another solvent by evaporation from a solid, semi-solid or liquid. (Free online wikipedia, 2016) through the application heat. Heat is applied to drying and the term which is closely related to temperatures in bodies is generated via sources which can be natural such as the sun or mechanical such as stoves, electric, gas, biomass,wtc. Dryers are mechanical devices which generates heat by the ignition of a fuel and air mix. The fuel used in dryers can range from those from renewable sources such as wood, saw dust, biomass, (WHO 2002). nuclear fuel or non-renewable sources such fossil fuels. Conventional or traditional stoves have been in use for a long time and they include those that were made from composites such as soils. The drying process may be a pre or post production step before the general production, selling and or packaging of bio and non-bio products. Drying is essentially a process of moisture removal due to simultaneous heat and mass transfer. Drying could be of various methods such as open sun drying, direct and indirect solar drying etc. To be considered "dried", the final product must be solid, in the form of a continuous sheet (e.g., paper), long pieces (e.g., wood), particles (e.g., cereal grains or corn flakes) or powder (e.g., sand, salt, washing powder, milk powder).Plate 1.1 show the conventional outdoor drying.

Plate 1.1 Outdoor sun drying of food aggregate (pepper)

A source of heat and an agent to remove the vapor produced by the process are often involved. In bio-products like food, grains, and pharmaceuticals like vaccines, the solvent to be removed is almost invariably water. Desiccation may be synonymous with drying or considered an extreme form of drying. In the most common case, a gas stream, e.g., air, applies the heat by convection and carries away the vapor as humidity. Other possibilities are vacuum drying, where heat is supplied by conduction or radiation (or microwaves), while the vapor thus produced is removed by the vacuum system. Another indirect technique is drum drying (used, for instance, for manufacturing potato flakes), where a heated surface is used to provide the energy, and aspirators draw the vapor outside the room. In contrast, the mechanical extraction of the solvent, e.g., water, by centrifugation, is not considered "drying" but rather "draining". The traditional open sun drying is uncontrollable and could lead to damage and loss of quantity and quality of the dried produce. These losses may be due to contamination by dirt, dust, bird droppings and infestation by insects, rodents and animals (Hii et al., 2012). Improved drying methods such as solar dryers in developing countries have been promising in reducing crop losses and improve the quality of the dried produce significantly as well as controlled drying when compared to the traditional open sun method. Other forms of drying process which include electrical, gas and biomass drying have been explored but each with their respective setbacks. This has necessitated the exploration of hybrid system which combines two or more heat generating sources to develop a drying with advantages of both sources involved. The present work is focused on the use of hybrid electrical-solar dryers as an improved form of drying.

1.3 Statement of the Problem

The use of conventional methods like the outdoor sun drying is prevalent amongst rural and urban dwellers in Nigeria; this may not be unconnected with the fact that it is a cheap method of drying and a renewable source present in abundance in tropical regions like Nigeria. However, challenges and limitations abound from the use of this method which includes limited availability of space, uncertainty in sunrise, exposure to microbial and foreign impurities contamination, rodents and pest attack, hygiene factor, environmental factors such as rain etc. In a bid to curb these limitations there has been development of improved technologies such as mechanized dryers which utilizes electricity, gas, biomass etc, however each of these systems have their respective setbacks. This has necessitated the need to develop viable drying systems such as hybrid heat generation system like the sola-electrical dryer which combines the advantages of electrical and solar (photo-voltaic) powered drying for the drying of agricultural materials.

1.4 Aims and Objectives of the project work

Aim of the project work

The aim of the present research work is to design, develop, fabricate, test and evaluate a dual solar/electric dryer suitable for the drying of farm produce in Nigeria.

The objectives of this research are:

i. To determine the maximum amount of solar and electrical energy that can be harnessed for drying.
ii. To fabricate a solar-electrical powered dryer from local materials
iii. To compare the drying rate of the mechanical dryer operation with open sun drying.

1.5 Scope of the Project

This project is aimed at the design and fabrication of a solar dryer with dual energy source suitable for the drying of low moisture containing agro produce using locally sourced materials. It is intended for small scale drying in rural and urban areas. Therefore, larger scale or industrial drying may not necessarily be considered in the course of the project.

1.6 Significance of work

The present research projects will showcase the effective utilization of the sun and electrical energy in the drying of agricultural materials. It will reduce the waste encountered by rural farmers thereby increasing the food production in rural areas and encourage farming occupation by providing farmers with technologies with which waste can be minimized and profit maximized. The project will highlight ways improve the quality of the agricultural produce and eradicate food poisoning which is common in open air drying. It will be a foundation studies for further research into the drying process.

1.7 Methodology of Work

The method used in carrying out the present work include

i. Literature review.
ii. Measurement of weather conditions
iii. Development of concepts for the dryer
iv. Material selection
v. Calculation of design specifications
vi. Fabrication of the solar crop dryer
vii. Testing of the solar crop dryer

CHAPTER TWO

LITERATURE REVIEW

General applications of drying

Drying has found use in virtually all aspect of man's existence domestically, commercially, and industrially. The drying of products may be categorized into bio-products drying and non-bio products drying. The bio products may include food, wood and fluids from natural source, while the non-bio products may include electrical components, clothes etc/

2.1.1 Food drying

Foods are dried to inhibit microbial development and quality decay. However, the extent of drying depends on product end-use. Cereals and oilseeds are dried after harvest to the moisture content that allows microbial stability during storage. Vegetables are blanched before drying to avoid rapid darkening, and drying is not only carried out to inhibit microbial growth, but also to avoid browning during storage. On dried fruits, the reduction of moisture acts in combination with its acid and sugar contents to provide protection against microbial growth. Products such as milk powder must be dried to very low moisture contents in order to ensure flowability and avoid caking. This moisture is lower than that required to ensure inhibition to microbial development. Other products as crackers are dried beyond the microbial growth threshold to confer a crispy texture, which is liked by consumers.

2.1.2 Non-food products

Among non-food products, those that require considerable drying are wood (as part of Timber processing), paper, flax, and washing powder. The first two, owing to their organic origins, may develop mold if insufficiently dried. Another benefit of drying is a reduction in volume and weight.

2.1.3 Sludge and fecal materials from sanitation processes

In the area of sanitation, drying of sewage sludge from sewage treatment plants, fecal sludge or feces collected in urine-diverting dry toilets (UDDT) is a common method to achieve pathogen kill, as pathogens can only tolerate a certain dryness level. In addition, drying is required as a process step if the excreta based materials are meant to be incinerated.

2.2 Mechanics of Drying

In some products having relatively high initial moisture content, an initial linear reduction of the average product moisture content as a function of time may be observed for a limited time, often known as a "constant drying rate period". Usually, in this period, it is surface moisture outside individual particles that is being removed. The drying rate during this period is mostly dependent on the rate of heat transfer to the material being dried. Therefore, the maximum achievable drying rate is considered to be heat-transfer limited. If drying is continued, the slope of the curve, the drying rate, becomes less steep (falling rate period) and eventually tends to nearly horizontal at very long times. The product moisture content is then constant at the "equilibrium moisture content", where it is, in practice, in equilibrium with the dehydrating medium. In the falling-rate period, water migration from the product interior to the surface is mostly by molecular diffusion, i,e. the water flux is proportional to the moisture content gradient. This means that water moves from zones with higher moisture content to zones with lower values, a phenomenon explained by the second law of thermodynamics. If water removal is considerable, the products usually undergo shrinkage and deformation, except in a well-designed freeze-drying process. The drying rate in the falling-rate period is controlled by the rate of removal of moisture or solvent from the interior of the solid being dried and is referred to as being "mass-transfer limited". This is widely noticed in hygroscopic products such as fruits and vegetables, where drying occurs in the falling rate period with the constant drying rate period said to be negligible. (willey, 2016)

2.3 Drying Methods and utilization

The drying process may be categorized under any of the general methods as follows;

i. Application of hot air (convective or direct drying). Air heating increases the driving force for heat transfer and accelerates drying. It also reduces air relative humidity, further increasing the driving force for drying. In the falling rate period, as moisture content falls, the solids heat up and the higher temperatures speed up diffusion of water from the interior of the solid to the surface. However, product quality considerations limit the applicable rise to air temperature. Excessively hot air can almost completely dehydrate the solid surface, so that its pores shrink and almost close, leading to crust formation or "case hardening", which is usually undesirable. For instance in wood (timber) drying, air is heated (which speeds up drying) though some steam is also added to it (which hinders drying rate to a certain extent) in order to avoid excessive surface dehydration and product deformation owing to high moisture gradients across timber thickness. Spray drying belongs in this category.

ii. Indirect or contact drying (heating through a hot wall), as drum drying, vacuum drying. Again, higher wall temperatures will speed up drying but this is limited by product degradation or case-hardening. Drum drying belongs in this category.

iii. Dielectric drying (radiofrequency or microwaves being absorbed inside the material) is the focus of intense research nowadays. It may be used to assist air drying or vacuum drying. Researchers have found that microwave finish drying speeds up the otherwise very low drying rate at the end of the classical drying methods.

iv. Freeze drying or lyophilization is a drying method where the solvent is frozen prior to drying and is then sublimed, i.e., passed to the gas phase directly from the solid phase, below the melting point of the solvent. It is increasingly applied to dry foods, beyond its already classical pharmaceutical or medical applications. It keeps biological properties of proteins, and retains vitamins and bioactive compounds. Pressure can be reduced by a high vacuum pump (though freeze drying at atmospheric pressure is possible in dry air). If using a vacuum pump, the vapor produced by sublimation is removed from the system by converting it into ice in a condenser, operating at very low temperatures, outside the freeze drying chamber.

v. Supercritical drying (superheated steam drying) involves steam drying of products containing water. This process is feasible because water in the product is boiled off, and joined with the drying medium, increasing its flow. It is usually employed in closed circuit and allows a proportion of latent heat to be recovered by recompression, a feature which is not possible with conventional air drying, for instance. The process has potential for use in foods if carried out at reduced pressure, to lower the boiling point.

vi. Natural air drying takes place when materials are dried with unheated forced air, taking advantage of its natural drying potential. The process is slow and weather-dependent, so a wise strategy "fan off-fan on" must be devised considering the following conditions: Air temperature, relative humidity and moisture content and temperature of the material being dried. Grains are increasingly dried with this technique, and the total time (including fan off and on periods) may last from one week to various months, if a winter rest can be tolerated in cold areas.

The drying of Agricultural produce which is a focus of the present work may employ any of the four major drying techniques namely: open air drying, fire wood/fuel drying, electrical drying and solar drying. Each of these drying techniques has their advantages, limitations and disadvantages.

2.3.1 Open air drying

Open air or outdoor sun drying is a conventional drying method that has been utilized by man since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other agricultural products. In order to benefit from the free and renewable energy source provided by the sun several attempts have been made in recent years to develop solar drying mainly for preserving agricultural and forest products. Open sun drying is generally done by spreading crops on the ground, mat, cement floor where they receive short wavelength solar energy during a major part of the day and also natural air circulation. A part of the energy received is reflected back and the remaining is absorbed by the surface depending upon the colour of the crops. The absorbed radiation is converted into thermal energy and the temperature of the material starts to increase. However, there are losses like the long wavelength radiation loss from the surface of the crop to ambient air through moist air, and also convective heat loss due to the blowing wind through moist air over the crop surface (El-Sebaii and Shalaby, 2012). The conventional open sun drying utilized widely by rural farmers has inherent limitations: high crop losses due to inadequate drying, fungal attacks, insects, birds and rodents' encroachment, unexpected down pour of rain and other weathering effects. More so, the process is labour intensive, time consuming and requires a large area for spreading the produce out to dry. For large-scale production the limitations of open-air drying are well known. Among these are high labour costs, large area requirement, lack of ability to control the drying process, possible degradation due to biochemical or microbiological reactions, insect infestation, time consuming, requires a large area for spreading the produce out to dry and so on. The drying time required for a given commodity can be quite long and result in post-harvest losses (more than 30%) (Xingxing et al., 2012).

2.3.2 Fuel drying

Fuel drying involves the use of fuel which may be fossil or natural fuel or synthesized fuel. The use of our common cooking (butane) gas is a modern discovering and entails the storage of synthesized gas under pressure and release through a piping or nozzle connection for utilization, while on the other hand the use of wood as a fuel for heat generation is an age long practiced by man virtually since creation as this was in addition to the sun the only known source of heat to man. According to World Bank statistics, 94 % of the African rural population and 73 % of the urban population use fuel wood as their primary energy source (Melanic, 2006). Unfortunately supplies of fuel wood are diminishing throughout the world. As the cost and collection time for fuel wood increases, people seek for alternative sources (Gary, 1994).

2.3.3 Electrical drying

Electrical drying is the use of electric current powered heat coils to generate heat which is then used for the drying of the material. It requires natural and or forced draft of the heat to properly carry out the drying process. Major limitations of electric drying include unavailability of power as experienced even in modern day Nigeria, high cost of operation and maintenance etc.

2.3.4 Solar Drying

Solar drying is often differentiated from ‘‘sun drying’’ by the use of equipment to collect the sun’s radiation in order to harness the radiative energy for drying applications. Sun drying is a common farming and agricultural process in many countries, particularly where the outdoor temperature reaches 30°C or higher, such as in many parts of South East Asia, East, Central and sub-Sahara Africa where spice crops and herbs are routinely dried. However, weather conditions often preclude the use of sun drying because of spoilage due to rehydration during unexpected rainy days. Furthermore, any direct exposure to the sun during high temperature days might cause case hardening, where a hard shell develops on the outside of the agricultural products thereby trapping moisture inside (Sharma et al.,2009). Plate 2.1 show a typical operational mode of a solar dryer as differentiated from the conventional sun drying.

Plate 2.1 Solar dryer for agro produce

Solar-drying technology offers an alternative, which can process crops and fruits in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, makes the process more efficient and protects the environment. A typical solar dryer and the accessories are shown in Solar drying can be used for the complete drying process or as a supplement to artificial drying systems, in which case reduced the fuel-energy required. Solar dryer technology can be used in small-scale food processing industries to produce hygienic, good quality food products. At the same time, this can be used to promote renewable energy sources as an income-generating option (Mekhilefa et al., 2011). In solar drying, solar-energy is used as either the sole source of the required heat or as a supplemental source. The air flow can be generated by either natural or forced-convection. The heating procedure could involve the passage of preheated air through the product or by directly exposing the product to solar radiation or a combination of both. Absorption of heat by the product supplies the energy necessary for the vaporization of water from the product. The process that occurs at the surface of the product is simply evaporation. Moisture replenishment to the surface is by diffusion from the interior, and this process depends on the nature of the product and its moisture content. The thermal conductivity of the crop is also important, particularly if the drying layer is deep enough to require heat conduction between particles (Toshniwal and Karale, 2013). Due economic reasons, maximum drying rates are desired though product quality must be considered. This requires effective control of the drying process. The control of the drying process in natural-circulation dryers presents a major problem, as such dryers are designed to minimize capital and running costs. Thus, special control mechanisms are inappropriate. The best approach is to incorporate into the design of the dryers such structural features that would guarantee that extreme conditions must not prevail in the dryer under the envisaged climatic conditions and crop properties. One such approach, which regulates the residency period of the drying air within the drying chamber for natural - convection solar dryers is the incorporation of "chimneys" (Ekechukwu and Norton, 1997).

2.3.4.1 Methods of Solar Drying

Solar drying may be categorized on the basis of the mode of drying which may be direct or indirect. Consequentially the solar dryers may be classified as passive and active based on the operation mode of heat dynamics:

i. Passive dryers; here the crops are dried by direct heating from the sun's radiation with or without natural air circulation.
ii. Active solar dryers; here the hot drying air is circulated by means of a ventilator (forced convection). Active mode of drying was used in this project. Solar energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized (Belessiotis and Delyannis, 2011). Active solar drying systems are designed by incorporating external means, like fans or pumps, for moving the solar energy in the form of heated air from the collector area to the drying chamber. Thus all active solar dryers are, by their application, forced convection dryers. A typical active solar dryer depends on solar-energy only for the heat source, while for air circulation uses motorized fans or ventilator.

iii. Indirect-Type Active Solar Drying Systems: these are comprised of four basic components viz., a solar air heater, drying chamber, a fan for air circulation and ducting. Due to the separate air heating unit, higher temperatures can easily be obtained with a control on air flow rate. However, most solar collectors are made up of metal or wood absorbers with appropriate coating materials like black polythene are also used as they form an economic substitute. The efficiency of the indirect-type active solar dryer also depends on the location of the fan, though not so significantly in small batches. The prime objective of the fan is to maintain a desired flow-rate in the drying cabinet causing uniform evaporation of moisture from the wet material and in the collector, the heat collected is maintained by lagging to reduce heat losses. (Kanayo et al 2014)

iv. Direct-Type Active Solar-Energy Drying Systems**:** The direct-type active solar dryers are designed with an integrated solar energy collection unit. Three distinct designs of direct-type active solar dryers can be identified viz., absorption, storage and greenhouse type dryers. The direct absorption dryer as the name suggests are designs of the direct-type active dryers where the crops absorb the solar radiation directly. In the storage-type solar dryer designs the solar collector forms an integral part of the roof and/or wall of the drying and storage chamber. The solar collector-wall dryer design is painted black and glazed with concrete wall to form the solar collector and also serves as thermal storage.

v. Hybrid-Type Active Solar-Energy Dryers: The hybrid solar dryers combine the features of a solar energy with a conventional or some auxiliary source of energy and can be operated either in combination or in single mode with either source of energy. These dryers generally are medium to large installations.

2.4 Related Literature

Bena and Fuller, (2002) described a direct-type natural convection solar dryer combined with a simple biomass burner suitable for drying fruits and vegetables in regions without electricity. Sarsavadia (2007) developed a solar-assisted forced convection dryer for dehydration of onion slices for the controlled conditions of drying air temperatures and airflow rates similar to those employed in commercial onion dehydration. The dryer was also facilitated with recirculation of exhaust air.

The total energy required for drying of onion slices increased with increase in airflow rate and decreased with increase in drying air temperature. For drying of onion slices from initial moisture content of about 86% (w.b.) to final moisture content of about 7% (w.b.), the total energy required per unit mass of water ranged between 23.548 and 62.117 MJ/kg water without using any recirculation of air. The percent energy contribution by the solar air heater, electrical heater, and blower to the total energy requirement ranged between 24.5% and 44.5%, 41.0% and 66.9%, and 8.6% and 16.3%, respectively. Okonwanji et al (2014) designed and constructed a domestic active solar dryer which was composed of solar collector (air heater), fan compartment and a solar drying chamber with four tray racks. The air produced by the fan was heated up in the solar collector and channeled to the drying chamber where it is utilized for drying. The design was based on the geographical location of Benin City and meteorological data for relative humidity, solar irradiation, wind speed and ambient temperature were obtained for proper design specifications. Locally sourced materials were used for the construction, chiefly comprising of plywood, glass, aluminum metal sheet, galvanized iron sheets, sawdust and stainless steel trays. The testing was carried within specific times out from 17^{th} to 19^{th} December, 2014 with plantain flakes. The average temperature of the dryer was found to be 42.963°C with a corresponding average ambient temperature of 40.741°C. The drying process was completed in 2 days in the dryer, while open sun drying was completed in 3 days. The plantain flakes dried in the solar dryer, were of higher hygienic quality than that of open sun drying. The rapid rate of drying in the dryer revealed its ability to dry food items reasonably and rapidly to equilibrium moisture content and also to a safe storage period. Mumba (1995) designed and developed a solar grain dryer with photovoltaic powered air circulation. The important feature in this new dryer was the use of photovoltaic solar cells incorporated in the solar air heater section to power a D.C. fan. This photovoltaic powered air circulation induces passive control over the drying air temperature. The dryer could dry 90 kg maize grain per batch from an initial moisture content of 33.3% dry basis to under 20% dry basis in just 1 day. The controlled drying air temperature has an upper limit of 60^0C to prevent grain overheating and cracking. The dryer has been found to be cost-effective with a payback period of less than 1 year. Compared with the traditional sun drying method, drying with the dryer was found to be a viable option with many benefits, such as a protected drying environment, improved dried product quality and increased throughput. The drier is suitable for rural farm applications where grid electricity and fossil fuel are either non-existent or extremely expensive for the average farmer. Pande and Thanvi (1991) designed, developed and tested a solar dryer cum water heater. The system can be used for dehydrating fruit and vegetables or heating water exclusively. The important feature of this new gadget was that the drying process continues even in the night. Experiments have revealed that 10– 15 kg of fruit/vegetables can be dehydrated in 3–5 days. As a water heater, it can supply 80 liters of hot water of about 60^{o}c in winter afternoons. It was estimated that the unit can save 418 kWh of electricity as a water heater and, in addition, 500 kg of fruits or vegetables can be dehydrated in a year. Sarsilmaz et al. (2000) conducted experiments on drying of apricots in a newly developed rotary column cylindrical dryer equipped with a specially designed air solar collector. It was used to investigate optimum drying air rate and rotation speed of dryer, to maintain uniform and hygienic drying conditions and to reduce drying times. Drying operation is of prime importance which is applicable to almost all the agricultural products.

2.5 Limitations of past work

Following the studies of previous research works, the following observed limitations abound in the design and operation of solar dryers

i. The use of solar PV systems as utilized by Mumba (1995) is costly especially to the rural farmers whom mostly are involved in farming. Therefore, exploring alternative source of power will be worthy red to power the fan in the forced convection solar dryer.
ii. Modular Electrical heating systems pose challenges to rural farmers due to epileptic power supply and cost of operation and maintenance
iii. Okonwanji et al (2014) did not show data relating to off-peak or total sunset periods to reflect the effectiveness of the absorbing medium (gravel) utilized in the drying process.
iv. The use rotor-dynamic columns used by Sarsilmaz et al., (2000) will increase the operational cost by increasing the required power and will also increase losses due to friction by increasing the number of moving parts. It may be therefore necessary to exclude it for consequential

reduction in the operational cost. Better heated air circulation may be achieved by baffling the tray

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Materials

The materials required for the production of the proof of concept dryer include the followings:

i. Sheet metal
ii. Photo-voltaic cell
iii. Heating element
iv. Solar battery
v. Charge controller
vi. Forced draft fan
vii. CAD software for graphics design.
viii. Air inlet vent

3.2 Conceptual design.

Selected designs of hybrid dryer were considered for production based on certain operational and design criteria and the most suitable was selected using a decision matrix.

3.2.1 Concept 1: Electrical /Inverter dryer

The first concept is a dual power source comprising of a inverter initiated heat source and electric heat element. The electric heat source is intended to be dual itself with the energy source being from direct current from mains electricity and solar panel installations. The arrangement will comprise of an inverter and battery. The dual system is necessary to mitigate the disadvantages of absence of electric power and sun set times. The power from the electrical energy sources which are from mains electric supply and from battery arrangement inverted to generated heat for the dryer. This setup is supposed to mitigate power failure or its absence, but the set up cost and periodical battery charging during depletion and long mains power outage becomes a major setback, leading to its unavailability.

3.1.2 Concept 2: The dual electric/solar dryer.

The electric/solar dryer is shown in Fig 3.1. The dryer consists of a structural frame made of a rectangular pipe to which galvanized mild steel plate is wrapped and firmly welded to it externally and internally to form a void between the widths of the rectangular bar. The void is filled with an insulator material like wood dust, fiber glass to prevent heat from escaping from the inside compartment to the external. The dryer consists of heating element and materials holding plates. A thermostat is attached for temperature regulation. A fan is attached to the upper compartment to cause a forced draft of air through the black plate perforators to enhance the convective and uniform heat supply. A natural draft is created through the incorporation of chimney holes made of pipe to cause air drift. Solar facilities comprising of a PVC, solar battery, charge controller and inverter are incorporated into the system to power it in the absence of electric power.

3.2.3 Concept selection through Decision Matrix

The two concepts of dryer considered were compared based on some key criteria which include; versatility, cost, simplicity, the criteria were allocated some weighting values by order of their importance. For each criterion, a grade value multiplied by its weighted value was scored by the concept and the total sum added up to give the suitability level of the concept. The decision matrix for the two concepts is computed as shown in the Table 3.1.

Table 3.1 Decision matrix table for the solar powered air condition

Weighted Criteria	Weighting		
		Concept 1	Concept 2
Energy conservation	5	4	5
Versatility of use	4	3	4
Low cost of production	3	3	2
Ease of production	2	2	2
Total		12	13

From the decision matrix in Table 3.1 using weight scale of 5 to 2 in order of importance of the considered criteria, the concept 2 with a total weighted criteria average of 13 was selected as against the concept 1 with total weighted criteria average of 12, hence the concept 2 was selected.

3.3 Detailed design

3.3.1 Amount of agricultural produce to be dried

The amount of agricultural materials intended for drying determines the space requirement of the dryer and its energy requirement.

For the intended materials to be dried like plantain, fish and yams a proposed weight of 5kg of the material is proposed.

3.3.2 The sheet metal casing estimation

This is the main sheet metal covering of the dryer consisting of the internal and external face of the dryer. The enclosed space is proposed to hold the entire 5kg of materials to be dried. A experimentally determined, a 5kg of plantain or yam or fish could be held in a basin of $0.2m^3$ by volume. This volume is space is transformed to a rectangular space with equivalent dimensions in volume. Owing to the need for allowances and space for effective air circulation a rectangular volume of the drying chamber with the following dimension was arrived at.

Dimensions of outer box = 35cm by 30cm by 25cm

Dimensions of inner box = 25cm by 22cm by 17cm

Therefore, total surface area of sheet material for the TSA = total area of outer box + total area of inner box

$$= (2lb + 2lw + bw)_o + (2lb + 2lw + bw)_I \quad (3.1)$$

Where l= length, b = breadth, w = width, o = outer, i = inner

= [2(35x30) + 2(35x25) + 2(30x25)] + [2(25x22) + 2(35x17) + 2(22x17)]

i.e TSA = [2100 + 1750 + 1500] + [1100 + 1190 + 748] =8388cm^2 approx. = 9000cm^2. The additional sheet material is to make up for wastages during fabrication.

3.3.2.1 Air Volume and flow inside drying chamber

The volume of drying chamber is also the amount of air that fills and recirculates the chamber per unit given time. but since drying is dependent on so many factors amongst which include the temperatures and humidity of ambient, materials and drying chamber, it is pertinent to note their initial and expected values

Required temperature to dry or remove moisture from agricultural material = 80^{0}C

It is expected that at this temperature the moisture will heat up in the produce and will be evaporated with the help of a forced draft air.

Expected drying chamber temperature therefore = T_2 = 80^{0}C (assuming no heat lost from input air temperature)

Air speed (Natural draft) = 1.2m/s and (Forced draft) = 4.8 m/s……from fan specification

Initial temperature of agro materials being dried = 32^{0}C (experimentally measured)

Therefore, let initial temperature of drying chamber = 32^{0}C

Assuming final temperature of dried materials inside chamber = x^{0}C

Therefore, heat gained by chamber/dried materials = x - 32 = ^{0}C

The temperature of the drying chamber is to be retained over a time period for which the moisture in the material being dried can evaporate and transferred out to the ambient via the exhaust. This is dependent on the temperature of the drying chamber, relative humidity, density and speed of the air, surface area and mass of the clothes amongst other drying parameters.

The amount of heat entering the drying chamber is given as

$$Q = V \times \rho \times CP \times \Delta T \quad (3.2)$$

Where;

Q (J) = heat content of the air

V = the flowrate of the air (m3/s) = speed (m/s) x area of air inlet vent (m2) = (4.8 x 0.5 x 0.2)

ρ = density of air = 1.16kg/m3 @ 300C (from psychometric chart)

Cp = the specific gas constant for dry air = 1.005kJ/kgK) (from psychometric chart)

ΔT = the difference in temperature (K) of the outlet gas (Tout) and the inlet gas (Tin) of the system.

Q = 4.8 x 0.5 x 0.2 x × 1.16 × 1.005 × (56 – 30)0C = 14.5j (this heat is to be supplied from the solar collector)

But the heat required to remove moisture from the clothes is in two stages (Mercer, 2007): The first stage is the energy Q1 required to raise the temperature of the wet clothes material to the stage which the moisture will be removed. It is expressed as

$$Q1 = W_w \; C_{pm} \; \Delta T = W_w \; C_{pm} \; (T_o - T_a) \quad (3.3)$$

where;

W_w = Weight of wet textile, C_{pm} = Specific heat capacity of fabric material

T_o and T_a are drying and ambient temperatures respectively.

The second stage is the heat required to evaporate the moisture from the material and is obtained from the relation:

$$Q2=M_wL_f \quad (3.4)$$

where;

M_w= Mass of moisture evaporated, kg, and it is expressed as

$M_w = \frac{Ww(Mi - Mf)}{1 - M_f}$ Bassey and Schimdt (1987): (3.5)

where;

W_w = Weight of wet materials being dried kg

Mi = Initial moisture content

Mf = Final moisture content

L_f = Latent heat of evaporation at the drying temperature.

Therefore, the total heat energy required to remove moisture from the materials is

$$Qt = Q1 + Q2 \quad (3.6)$$

3.3.3 Volume of Air required for moisture removal

The total volume of air required to remove moisture from the materials being dried is given by Amedorme et al. (2013) as;

$$Va = \frac{MwLfRaTa}{Cpa\, Pa\, (To - Tf)} \quad (3.7)$$

Where;

Va = Volume of air required for moisture Cpa = Specific heat capacity of air

Pa = Atmospheric pressure

Tf = Exhaust air temperature

Ra = Air gas constant KJ/KgK

At an ambient temperature of 32^0C and drying temperature of x^0C, the exhaust air temperature can be experimentally determined... From steam table the latent heat of evaporation at the drying temperature is determined as L_f

3.3.4 Moisture content of the agricultural materials being dried

The moisture content of the clothes can be determined from the expression;

$$MD = 100\% \frac{w-D}{w}$$ (Chung et al, 2010) (3.8)

where;

MD= Percentage moisture content, W= Wet weight and D= Dry weight

3.3.5 Heat transfer within the dryer.

The heat transfers between the dryer compartment and the materials being dried can be analyzed based on the mode of heat transfer within the system as follows:
For the Conduction heat transfer
It is assumed the outer surface of the rectangular drying compartment. Heat is conducted through the internal wall and the materials being dried.
This quantity of heat is mathematically expressed as:

$$Q = \frac{KADT}{DX}$$ (3.9)

Q = heat conducted in (KJ/h)
k= Thermal conductivity of the steel material of the dryer = (W/mk)
DT = Temperature difference between the internal and outer surfaces of the metal walls
DX = Thickness of the metal walls (mm)
A = Area of the section at right angle = $\pi r^2 h$

For the Convection heat transfer

Convection is usually the dominant form of heat transfer in liquids and gases. The dominant fluid in the drying chamber space is the circulated air within the internal space. It is mathematically, expressed as;

$$Q = h_c A [T_2 - T_1]$$ (3.10)

where;

h_c = Coefficient of convective heat transfer for air
A = Area of surfaces not perpendicular to direction of heat flow

$T_2 - T_1$ = thermal difference between surface temperature t_2 and air temperature t_1

The rate of heat is transfer across the enclosed dryer compartment where the drying takes place is calculated from a coefficient based upon the temperature differences of the surfaces.

h_c = 10 -100 (W/(m^2 K) or W/(m^2 ° C) for free moving air

Radiation heat transfer

The total radioactive flux throughout the internal surface of area A of the dryer and absolute temperature T is given by the Stefan- Boltzmann law, which is mathematically expressed as;

$$Q = FA\sigma T^4 \quad (3.11)$$

where;

Q = rate of radiation heat transfer (KJ/h),

T = Absolute temperature of hot and cold bodies respectively

F = Factor depending on surface geometry,

σ = Stefan – Boltzmann constant = 5.6703 x 10^{-8} (W/m^2 k^4)

A = total area of emitting surfaces of the food warmer

3.3.6 Heat Losses in the Dryer

Considering the energy balance of the oven heat system, ideally, the heat losses can be represented in terms of temperature change of the sample, energy into the sample, conductive losses, radiation and convective losses in equation (3.12)

$$mc_p(T - T\infty) - \frac{kA\Delta s}{L}(T - T\infty) - h_{air}Af\Delta t(T - T\infty) - A\sigma T4 = 0 \quad (3.12)$$

3.3.7 Solar power capacity evaluation for the hybrid dryer

The solar facilities required to power the system include a dc battery, inverter, charge controller and solar panel. The sizes and capacity of these facilities are dependent on the power requirements of the dryer. The power requirements of the dryer is computed through an energy audit of the dryer as follows:

Let total electrical energy requirement of dryer supplied by the heat element and draft fan = W

The solar devices are selected accordingly as follows;

1. Battery Capacity in ampere-hour (A-h) rating of the solar dc battery. Its power rating capacity is expressed as;

$$\text{Battery Capacity} = \frac{total\ load\ units\ (watts)}{operating\ voltage} \times \text{desired operating time} \quad (3.13)$$

Battery power should be greater than the electric element and draft fan power rating.
Typical voltage rating of dc batteries are 12v, 24v, 6v, 7.5v, 11.5v
Considering operating time of Xhrs which is estimated duration for drying of materials, solar radiation is expected between 8am and 4pm that's 8hrs period,

The battery capacity = 8 * (total amperage of electrical components)

A 12V 100A is to be utilized due to cost constraints, hence electrical components were sourced within the limits of battery rating with consideration of factor of safety of 0.5.

2. Solar panel capacity; this is the watts rating of the photo-voltaic cell shown in Figure 3.1 required to charge the DC battery in watts-hour. The solar panel power capacity is expressed as

$$P_p = \frac{Battery\ energy}{charge\ time} \quad (3.14)$$

Plate 3.1 solar panel

Considering the power rating of the electrical elements

$$\text{Then;} \quad P_p = \frac{12}{2hrs\ of\ charge\ time} \quad (3.15)$$

To charge the battery to full capacity in a given time is dependent on conditions such as irradiation of the sun.

3. Calculation of inverter size

The nominal power of the inverter should be smaller than the PV nominal power. This depends on the inverter optimum power ratio which invariably depends on the regional climate, the inverter efficiency curve and the inverter/PV price ratio. Therefore, the inverter nominal power is expressed as:

Inv. nominal power(KW) = PV array power (KW) x Inv safety factor (3.16)

The purpose of over sizing of the inverter is to compensate for unexpected long cloudy periods.

4. Solar Charge Controller Sizing

The solar charge controller is typically rated against Amperage and Voltage capacities. Selection of solar charge controller depends on the voltage of PV array and batteries. The charge controller is rated by the output Amperage that it can handle, not the input current from the solar panel array. To determine the output current that the charge controller will handle in wattage, it is computed as:

$V_{in} = V_{DC} = 24V$

$I_{in} = \frac{Ppeak}{Vdc}$ (3.17)

$I_{out} = \frac{P_{out}}{V_{out}}$ (3.18)

Where; $V_{out} = V_{DC} = 24V$

P_{out} is rated in watts

3.3.8 Electrical design and circuitry of the device

The system is powered by a 220V AC power and a 12V, 100A DC solar battery.

The voltage requirement is that it is a stable direct current (DC) voltage. This indicates that the voltage does not fluctuate (ripple) to the extreme, which can cause the electronic components of the system not to work properly. The power supply circuit is shown in Figure 3.2

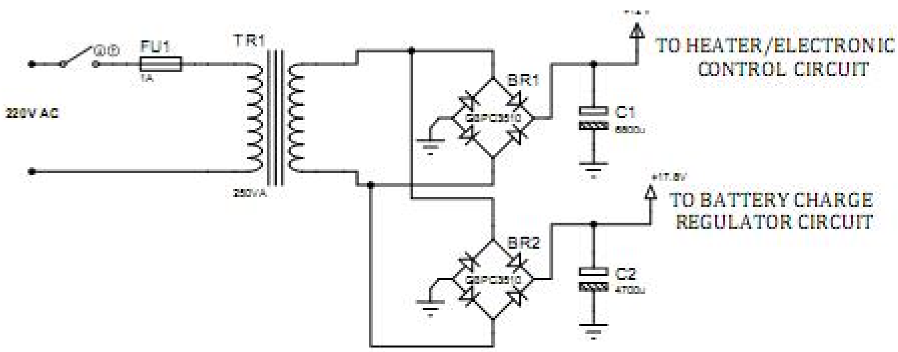

Plate 3.2 Power supply circuitry (Olajide *et al*, 2024)

a. ***Heat source***

The heat sources are a 100 watts' heat element.

Power requirement of the system = power (watts) heat element + indicator light+ fan + losses

Since mains supply voltage V = 220v

Power of Heating coil = 1000w = $\frac{V^2}{R} = \frac{220^2}{R}$ and

R = resistance of the coil = $\frac{220^2}{1000} = 48.4\Omega$

But $R = \frac{pl}{A}$

(3.16)

where, p = resistivity of the coil, l = length of coil and A = area of coil.

Based on availability of heating coils in the local market, a coil of 4mm diameter of the calculated resistivity is required. A Nichrome coil of 4mm diameter within the range of the calculated resistivity was procured for use in the dryer.

3.4 Manufacturing methods for the production of the set up

The various manufacturing method utilized in the production of the machine setup include the followings

i. Cutting and pairing
ii. Milling and machining
iii. Boring
iv. Wedding

v. painting

3.5 Bill of Engineering Materials and Evaluation

The bill of materials and evaluation of the machine is shown in Table 3.2

Table 3.2 Bill of Engineering Materials and Evaluation of Fabricated Hybrid Dryer

Item	Units	Quantity	Unit cost	Total cost
1. Sheet metal (A)	$5m^2$	1	25000	25000
2. Paint	1	2	3500	7000
3. Angle bar and rods	1m	2	15000	15000
4. Regulator		1	4000	4000
5. Electricals		Sum	12000	12000
6. Insulator	Sum	Sum	10000	10000
7. Rivets and screws	Sum	Sum	3000	3000
8. Blower (fan)	0.25watts	1	15000	15000
9. Heat element	1000watts	1	7000	7000
10. Miscellaneous	sum	Sum	20000	20000
11. Solar Accessories	Lump	Sum	45000	450000
12. Labor	Lump	Sum	100000	100000
13. Total				636000

The graphics of the fabricated hybrid powered dryer is shown in the Plate 3.3.

3.6 Testing of the Hybrid Powered Dryer

The hybrid solar/electrical dryer was operated to estimate its drying power with respect to given amount of materials dried. The experiment was performed with cassava chips of approximately same mass placed in each of the compartments for test round involving the electrical and solar power. The drying operation was carried out for a given time after which the drying is stopped and the heat cut off, while measurements of the weights of the cassava chips are taken. The cassava chips were placed in the drying compartments while the device was energized. The cassava chips were allowed to stay in the dryer and after a given period, time they were weighed. The process was repeated using for different runs. After drying using the electrical and solar power energy sources, comparison was made between the two heat source.

CHAPTER FOUR

RESULT AND DISCUSSION

. Result of the test was documented as shown in Tables 4.1 and 4.2. The Table 4.1 shows the result data of the test carried out on the dryer.

Table 4.1: Time to dry cassava chips using hybrid power dryer

Calibrated mark					
Time taken for drying (min)	60	150	220	260	300
Amount in (kg) before drying	2	4	6	8	10
Amount in (kg) after drying	1.32	2.4	3.90	5.12	6.2
Moisture content	0.68	1.6	2.1	2.88	3.8
Average peak temperature (^0C)	70	78	92	102	110

Table 4.2 Temperature distribution for drying of cassava chips

Time (min)	0	15	30	60	120	150	180	210	240	270	300	330
Temperature (^0C)	25	30	60	78	85	105	110	108	80	60	50	25

From the Tables 4.1 and 4.2 it is observed that as the amount in load of the cassava chips increased, it took longer time for drying to take place. The amount of moisture also increased as the load increased. Temperatures peaked at 110^0C at for drying inside the hybrid dryer for the given amount of 10kg of cassava chips dried. The graphs in Figures 4.1, 4.2 and 4.3 show the dryer behavior with respect to the parameters considered. The drying oven performed effectively. Though different food items have their varying moisture content and hence time to dry, it is however a general deduction from the tables that as time progresses, the food or materials being dried takes lesser time to dehydrate and the temperature requirement increases at earlier stage of drying, peaking at some intermediate stage and finally decreasing when the materials is finally drying up; this is so for all loads of the materials dried and for the gas fired or electric element energized dryer. This can be deduced from the graph in Figure 4.3. Maximum temperatures are recorded at the air inlet side of the dryers where moisture content of the food items is higher at initial time of the drying process, while minimum temperatures are recorded at the air outlet end at the exhaust here moisture content of the food is lower; this is in agreement with the behavior of dryers with concurrent air flow. After the dryer has been tested, it was realized that it is efficient and fast, it does not blacken the food items and it is pollution free.

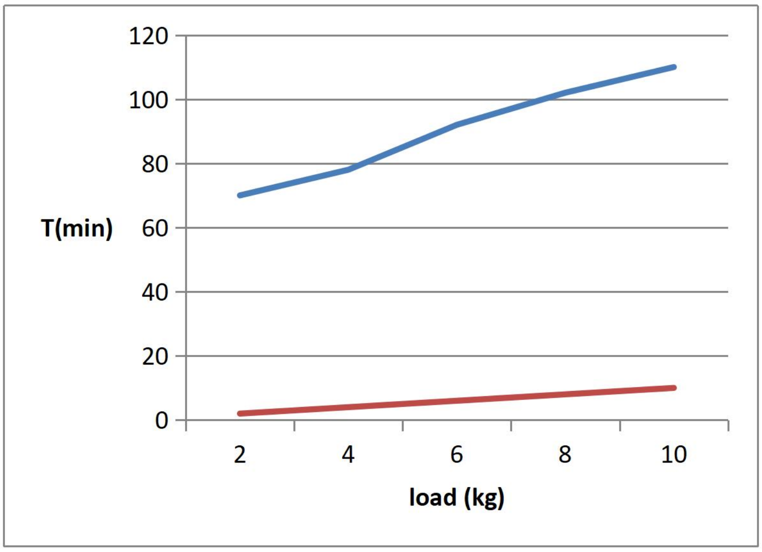

Plate 4.1 graph of time (min) against load (kg) of cassava chips

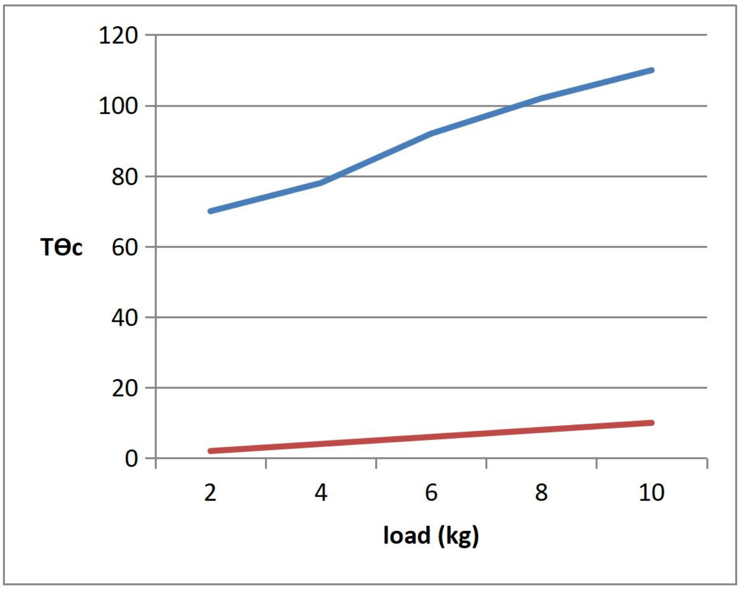

Plate 4.2 graph of temperature (^{0}C) against load (kg) of cassava chips

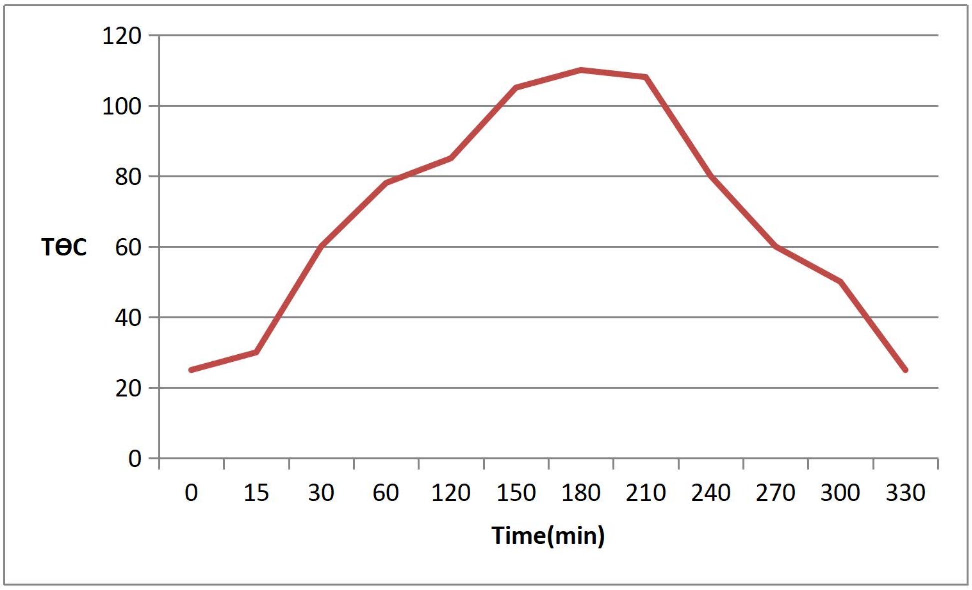

Plate 4.3 Temperatures against time curve for cassava chips drying

A comparison between the electrical and solar energies operation of the dryer is show in Table 4.3

Table 4.3 Test data for hybrid AC/DC powered drying

Time (min) of operation to reach drying temp (100^0C) using AC power	Time (min) to reach drying temp (100^0C) using DC power	Ambient temp. (^0C)
1	2.4	30
1.2	3.3	31
1.7	4	31
2.1	4.8	30.2
2.19	5.1	29
2.5	5.47	30

From Table 4.3 The is increased time to reach drying temperature with the use of DC power compared with the use of AC power. This may be due to the slow dissipation of energy from the battery compared to the use of power from grid. As the DC battery supplies energy to the heat element and fan, its energy depletes and it discharges resulting in fluctuating power dissipation that affects the drying process. For the entire drying process, the drying temperature was higher than ambient temperatures measured periodically indicative of good working condition of the device. The battery charging and depletion were dependent on the sun irradiation as well as the usage level of the system respectively.

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATION

5.1 Conclusion

The research outlined in this thesis was completed to help achieve the goal of developing aN affordable, hybrid powered dryer system that can be used in Nigeria for food and other materials processing through drying. The development of a proof of concept of a hybrid powered dryer is a promising technology for local and commercial production to solve the problem of food security and material processing in Nigeria. The test data obtained from the experimentations revealed that the nature of materials to be dried, material heat capacity, moisture content, air supply, amount of materials to be dried, and power source were critical to the drying potential of a dryer and the time it takes for it to reach operational drying temperatures.

5.2 Recommendation

Following the successful design, fabrication and testing of hybrid powered dryer, the following recommendations are made.

i. Further research work should be carried out on the project for optimization

ii. Government intervention should be sought to promote our local capacity building and to bring about mass production of machines such as the hybrid dryer.

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