DESIGN AND FABRICATION OF PROCESS AIR-CONDITIONING AND MOISTURE REMOVAL SYSTEM OF A FOOD DEHYDRATOR FOR POWDERED AKAMU PRODUCTION

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FACULTY OF ENGINEERING

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SUBBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING,

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IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF A

BACHELOR DEGREE (B.Eng) IN MECHANICAL ENGINEERING

SEPTEMBER 2023

CERTIFICATION

This is to certify that the project work titled "DESIGN AND FABRICATION OF PROCESS AIR-CONDITIONING AND MOISTURE REMOVAL SYSTEM OF A FOOD DEHYDRATOR FOR POWDERED AKAMU PRODUCTION" was carried out by:

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Of the Department of Mechanical Engineering, Faculty of Engineering, University of Benin, in partial fulfillment of the requirement for the award of Bachelor of Engineering, (B. Eng.) in Mechanical Engineering

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(HEAD OF DEPARTMENT)

DEDICATION

We dedicate this project to the Almighty God and all who have supported us throughout our academic journeys.

ACKNOWLEDGEMENTS

We express our sincere gratitude to our project supervisor, **PROF. P. O. B. EBUNILO**, for his immense support and contributions towards the success of our project. We also wish to appreciate all the members and staff of the Department of Mechanical Engineering, headed by **PROFESSOR GODFREY OMONEFE ARIAVIE**, at the University of Benin in Benin City. Our sincerest thanks also go to our beloved parents for their financial and emotional support, prayers, and encouragement throughout our studies at the University of Benin. We are also deeply grateful to **ENGR. EGHOSA OSAIKHUIWU** who provided us with his technical expertise and his workshop during the fabrication of our project.

TABLE OF CONTENTS

DESIGN AND FABRICATION OF PROCESS AIR-CONDITIONING AND MOISTURE REMOVAL SYSTEM OF A FOOD DEHYDRATOR FOR POWDERED AKAMU PRODUCTION i

DESIGN AND FABRICATION OF PROCESS AIR-CONDITIONING AND MOISTURE REMOVAL SYSTEM OF A FOOD DEHYDRATOR FOR POWDERED AKAMU PRODUCTION ii

CERTIFICATION iii

DEDICATION iv

ACKNOWLEDGEMENTS v

TABLE OF FIGURES ix

LIST OF TABLES x

CHAPTER ONE 1

INTRODUCTION 1

1.1 BACKGROUND OF STUDY 1

1.2 STATEMENT OF PROBLEM 5

1.3 AIM OF THE PROJECT 5

1.4 OBJECTIVES OF THE PROJECT 5

1.5 SCOPE OF PROJECT 6

1.6 ECONOMIC IMPORTANCE AND OPPORTUNITIES AVAILABLE WITH DRIED AKAMU 6

CHAPTER TWO 9

LITERATURE REVIEW 9
2.1 AKAMU 9
2.3 PRESERVATION TECHNIQUES FOR AKAMU 10
2.4 METHODS OF DRYING 13
2.5 DRYING AND ITS RELATIVE BENEFITS TO AKAMU 15
2.6 AIR DEHUMIDIFICATION TECHNOLOGIES 16
2.7 VAPOUR COMPRESSION CYCLE AND ITS APPLICATION IN AIR DEHUMIDIFICATION FOR FOOD DRYING 19
CHAPTER THREE 21
MATERIALS AND METHODS 21
3.1 PRELIMINARY EXPERIMENTS 21
3.2 CONCEPTUAL DESIGNS 21
3.3 DESIGN MATRIX TABLE 26
CHAPTER FOUR 33
RESULT AND DISCUSSSION 33
4.1 MOISTURE CONTENT ANALYSIS OF AKAMU (EXPERIMENT 1) **Error! Bookmark not defined.**
4.2 TEST RUN OF FABRICATED PROOF OF CONCEPT (EXPERIMENT 2)**Error! Bookmark not defined.**
4.3 DETERMINATION OF DRYING TIME FOR SYSTEM (EXPERIMENT 3) . **Error! Bookmark not defined.**

4.4 DETERMINATION OF RELATIONSHIP BETWEEN LAYER THICKNESS AND MOISTURE REMOVAL ....**Error! Bookmark not defined.**

4.5 COMPARISON OF PERFORMANCE OF NORMAL OPERATION VERSUS TYPICAL HEAT DRIVEN FOOD DEHYDRATOR ....**Error! Bookmark not defined.**

4.6 NORMAL OPERATION WHEN EMPTY .... **Error! Bookmark not defined.**

4.6 EFFECT OF MOISTURE REMOVAL ON SYSTEM WITHOUT LOAD **Error! Bookmark not defined.**

4.7 DISCUSSIONS .... **Error! Bookmark not defined.**

CHAPTER FIVE 44

CONCLUSION AND RECOMMENDATION 44

5.1 CONCLUSION 44

5.2 RECOMMENDATION 45

REFERENCES 46

TABLE OF FIGURES

Figure 1.1 Flowchart for the production of Akamu powder 4
Figure 2.1 Horizontal and Vertical air flow dehydrators (SousvideGuy, 2014) 15
Figure 2.2 Application of vapor compression cycle in cooling air 19
Figure 3.1 Double Condenser Design 21
Figure 3.2 Single Condenser with Heating Element design 24
Figure 3.3 p-h diagram of vapor compression cycle 28
Figure 3.4 Isometric and Orthographic views of the chosen concept 31
Figure 3.5 Photograph of the fabricated design 31
Figure 4.1: Temperature readings of test run of proof of concept 34
Figure 4.2: Humidity readings of test run of proof of concept 35
Figure 4.3: Readings from proof of concept operated without load 35
Figure 4.4: Readings of proof of concept operated any heating 36
Figure 4.5: Readings from proof of concept operation 38
Figure 4.6: Temperature readings of proof of concept under normal operation and as a heater .. 40
Figure 4.7: Humidity readings of proof of concept operated as normally compared to behavior as only a heater 41

LIST OF TABLES

Table 3.1 Components of the Single Condenser with Heating Element design 24
Table 3.2 (i & ii) Design Matrix Tables for selection of best design 27
Table 4.1: Table of values for moisture content analysis 33
Table 4.2: Table of values for experiment to determine drying time of proof of concept 37
Table 4.3: Table of values for experiment to determine effect of thickness on moisture removal 37
Table 4.4: Table of values for experiment to determine effect of drying thickness on moisture removal (residue) 38
Table 4.5: Table of values for experiment to compare proof of concept normal operation with typical heat driven dehydrator (normal operation) 39
Table 4.6: Table of values for experiment to compare proof of concept normal operation with typical heat driven dehydrator (heat driven operation) 39

ABSTRACT

This report details the design, fabrication, and testing of a system for producing dry powdered akamu, a traditional Nigerian porridge made from fermented corn, sorghum, or millet. Akamu is an important dietary staple in Nigeria, however its high moisture content and short shelf life pose preservation challenges. Converting akamu to a dry powder form can extend its shelf life for storage and distribution. The aim of this project was to develop a process for producing preservable akamu powder. The device utilizes a vapor compression refrigeration cycle for air dehumidification coupled with electric heating to create optimal drying conditions. A control system consisting of an Arduino microcontroller which monitors and controls the operation of the device based off key operational parameters of temperature and humidity. Data on changes in said parameter was collected to evaluate its operation. Sample of akamu with a 53% moisture content (w.b) was successfully dried to 26% moisture content (w.b). Test also showed the device capability to rival available commercial dehydrators, with the device removed 3% more wet mass in its normal operation than when solely heat driven (as most commercial dehydrator). The relationship between akamu layer thickness and moisture removal rate was also experimentally determined. The project demonstrates a practical approach to converting high-moisture akamu into a stable powder through an energy-efficient drying process. Controlling air dehumidification and temperature enabled high product quality and shelf life extension. Further work is recommended to enhance efficiency, evaluate nutritional changes, and assess commercialization feasibility. Overall, the project advances preservation technologies for an important traditional Nigerian food.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Nigeria boasts of a population of almost 240 million as of 2022, with projections looking at that value almost doubling as early as 2050 (The World Bank group, 2023). . Like any responsible country, maintaining food security is an important goal. Meeting this goal requires major development in cultivation, processing, preservation, packaging, marketing and delivery of agricultural goods. The country boasts of having fertile land capable of sustaining a plethora of cash and food crops, due to having a wide range of ecosystems (Patricia, 2021; Inter-réseaux, 2010). One of such crops is Maize. Maize stood as one of the most cultivated crop in Nigeria with about half of all farming household cultivating it as of 2019 (Sasu, 2023). In terms of quantity produced, maize is ranked at number three with more than 11 million tons produced in 2019 (Kareem, 2021) Maize is consumed in various forms; boiled, roasted or ground to make several dishes (PricewaterhouseCoopers (Nigeria Ltd, 2021). A popular form of consumption is the ground and fermented form (Ogbonnaya, 2012; Okara & Lokoyi, 2012). This form is referred to as 'Akamu' by the Igbos, Efiks, 'Ogi' by the Yorubas and Koko by the Hausas and Fulanis (ThriveAgric, 2022). Akamu serves as a popular weaning food for infants and a household staple for everyone with about quarter of the Nigerian population consuming it weekly (Bolaji, et al., 2015). Production is generally done traditionally and it is stored and sold in a wet paste form with limited shelf life (7 days without any form of intervention) (Ajobiewe, et al., 2022; Bolaji, et al., 2011). These two factors limit the quality and quantity that is produced, making it primarily for domestic consumption. This also leaves a lot of untapped market nationally and internationally.

Akamu is not to be confused with custard even though they are made from the same parent material. Custard is similar to Akamu in terms of appearance and viscosity, but it lacks the sour taste that can be found in Akamu (Salami, et al., 2019). Custard is made from edible corn starch and other concentrated nutrients or the combination of corn flour, egg yellow, milk, flavours, vitamins, glucose and tetra-zine to paste. Custard powder can be considered as a treated form of Akamu (Anon., 2020). The corn starch used for custard is a dense, powdery flour that is gotten from the endosperm protein of corn kernel (Duke, 1981).

Akamu holds a significant place in the diet of the average Nigerian. Maize is rich in carbohydrates, contains starch; a common polysaccharide; and significant amounts of crude protein and fibers (Atli, 2023; Obi & Okorokwo, 2022; Isirima & Ukpong, 2018; Obinna-Echem, 2017). Akamu contains the dietetically rich but the nutritional content varies depending on the means of processing (Adisa & Enujiugha, 2020). It also possesses high digestibility which is an advantage as a breastfeeding supplements for infants (Nwokolo, 2020; Obiegbuna, et al., 2019). Akamu is prepared as a pap with hot water and consumed with a variety of other food products such as beans in the form of its pudding (Moi-Moi) with oil or fried beans cake (Akara) (Obinna-Echem, 2017). Akamu is also paired with corn, groundnut etc. The demand for the dish isn't just local. With the ubiquity of Nigerians all over the world, several of our local dishes have also been shared with the world. Akamu is no exception to this (Lawani, 2020; Renne, 2007).

Akamu is such a meal with health, economic and cultural significance but suffers a similar fate to many Nigerian food products due to poor processing and preservation (Okeke, et al., 2019). Akamu in its raw wet lump form has a high moisture content that makes it susceptible to attack and contamination by micro-organisms (Ladunni, et al., 2013). In this form it can barely be preserved beyond a week, without changes in colour and taste and compromise to the safety of its consumption. This situation isn't helped by unsanitary traditional methods of processing (Adisa & Enujiugha, 2020; Emeka-Ike, et al., 2019; Ogodo, et al., 2015).

Although demand for maize is all year round, a good number of local varieties are cultivated seasonally. This affects the availability and price of akamu also. A local preservation technique is air drying. Akamu is spread to have its moisture evaporate out. This takes about a week (Ilori, et al., 2022). Duration is primarily affected by humidity (which averages at about 86% in the southern part of Nigeria during the raining season) (WorldData.info, n.d.). Direct sun drying is avoided due to risk of coloration which affects market perception and quality. Modern forms of drying use drying chambers at about 50°C (Adisa & Enujiugha, 2020). The working temperature is limited due to coloration and damage to the product.

Air dehumidification processes have wide applications; from its most common use in residential air conditioning, to regulation of air in industrial settings and in food preservation (AlorAir, n.d.). Primitive works in this area dates as far back as in ancient Greece and Rome (Dehumidifier Critic, 2014). Modern advances date to the late 19th century and early 20th century. Primarily most air dehumidification processes are carried out by condensation or by the use of desiccants. Low moisture content deters the growth of several bacterial, fungi and molds that are harmful and makes preservation of food products possible for long periods (Precisa, n.d.).

Figure 1.1 Flowchart for the production of Akamu powder

1.2 STATEMENT OF PROBLEM

Akamu holds a strong position as part of the dietary consumption of the average Nigerian. As a breastfeeding supplement and weaning diet for infants to a snack or part of many staple diets, akamu is consumed very widely. Similarly to its source food item, akamu is rich in starch, proteins and fibers. Akamu also has the added advantage of higher digestibility.

Akamu lumps as popular sold in the market have a short shelf life. This is due to its high moisture content. This characteristic coupled with the seasonal availability of local corn varieties leads to flunctuations in supply and price hikes. There are also significant losses due to spoilage and contamination.

Akamu is an important meal in Nigeria and there's a viable market potential for it both domestically and internationally. A method of increasing the shelf life of Akamu is by converting the lumps to a dry powder form and this will help to improve food security while its sale internationally will earn foreign exchange for Nigeria.

1.3 AIM OF THE PROJECT

The aim of this project is to develop a process for producing preservable akamu powder

1.4 OBJECTIVES OF THE PROJECT

The objectives of this projects work are the following:

i. Obtain system parameters and product specifications.

ii. Designs of necessary flow charts, conceptual and detailed designs for process air-conditioning system.

iii. Designs of necessary flow charts, conceptual and detailed designs for moisture removal system.

iv. Test of process air-conditioning and moisture removal systems.

v. Fabrication of working proof of concept for powdered akamu production process.

vi. Test of proof of concept for powdered akamu production process and data collection.

vii. Production of akamu with adequately low moisture content for preservation and storage.

1.5 SCOPE OF PROJECT

The project work will involve the following:

a. Design,
b. Fabrication and;
c. Testing of proof of concept.

1.6 ECONOMIC IMPORTANCE AND OPPORTUNITIES AVAILABLE WITH DRIED AKAMU

Akamu powder holds significant economic importance in various ways, both at the local and global levels. Its economic importance is derived from its production to trade and commercialization, as well as its potential to generate income and employment in the long run. Below are some economic areas which reveal the importance of Akamu powder.

- **Employment Generation:** The production and processing of Akamu powder create employment opportunities for individuals involved in various stages of its value chain, including farmers cultivating maize or millet, Akamu processors, distributors, and traders. This can have a positive impact on the livelihood of the individuals involved especially in the rural areas.

- **Income Generation:** Akamu powder can be sold in local markets, national markets, and even international markets. The sale and commercialization of Akamu powder offer a source of income for producers, processors, and traders thereby contributing to the local economy and supporting household income.

- **Value Addition:** By processing Akamu into a powdered form, value addition occurs in the agricultural sector. Value-added products like Akamu powder can bring about higher prices than the raw materials which is a huge benefit to farmers and processors alike.

- **Export Potential:** As the interest in African foods and traditional dishes grows globally, there is an opportunity to export Akamu powder to international markets, particularly in areas with a significant diaspora population or a growing interest in african foods. Exporting Akamu powder to the international market can generate foreign exchange and contribute to the export earnings in Nigeria.

- **Preservation of Agricultural Surplus:** Akamu powder allows for the preservation of surplus maize or millet crops. Excess produce that would have gone to waste during peak harvest periods can be dried and processed into powder thereby extending its shelf life and allowing it to be sold or used during lean periods.

- **Food Security:** Akamu powder is a nutritious and easily digestible food product, particularly suitable for young children and infants. Its availability and affordability contribute to food security, ensuring access to nutritious food for vulnerable populations.
- **Entrepreneurship and Small Business Development:** The production and sale of Akamu powder can create opportunities for entrepreneurship and small business development. Local entrepreneurs can establish small-scale processing units to produce and package Akamu powder for the local markets.
- **Traditional Food Preservation:** Akamu powder preserves the cultural heritage of Nigerian and West African communities, as it is a traditional and culturally significant food product. Its continued production and consumption contribute to preserving traditional food ways and culinary practices.
- **Industry Linkages:** The production and processing of Akamu powder can lead to the establishment of industry linkages with suppliers of packaging materials, equipment manufacturers, and distribution channels. These linkages help to further support the local economy and other related industries.
- **Research and Development:** The economic significance of Akamu powder can spur research and development initiatives to improve production methods, enhance product quality, and explore new applications in food technology.

CHAPTER TWO

LITERATURE REVIEW

The preservation and processing of food products, especially in regions with high humidity and variable climatic conditions, pose significant challenges to food industries and communities alike (Karen, 2020) . In such environments, the drying of food items becomes an essential step in preventing spoilage and maintaining product quality (Samuel, et al., 2022) . Traditional drying methods, while effective, often consume substantial amounts of energy and time, making them less than ideal for many food processing applications.

Air dehumidification, as achieved through the utilization of vapor compression cycle, represents an innovative and energy efficient approach to food drying.

2.1 AKAMU

Akamu is a traditional lactic acid fermented cereal-based meal, made basically from maize (Zea mays), and other cereals; sorghum or millet. The traditional process of Akamu production involves steeping of the grain in excess water for 2 - 3 days, washing, wet milling and wet sieving. The extracted slurry are allowed to sediment overnight, during which fermentation by various microorganisms associated with the raw material takes place. The resultant product (Akamu), after pressing, varies in colour from white to yellow or dark brown depending on the variety of the cereal used. Addition of an equal part of boiling water to the fermented slurry with vigorous stirring yields a nearly gelatinized lump-less porridge. The porridge is often eaten with beans cake (akara) or beans pudding (moi-moi) and it constitutes an integral part of adults' main meals or food for convalescents in many African countries. The porridge when diluted to thinness of 8 - 10% total solid plays an important role in the nutrition of infants and young children as a complementary food. The fermented slurry when cooked with water produces a stiff gel called agidi that serves as convenient food for travelers (Obinna-Echem, 2017).

Akamu plays a vital role in the diet and nutrition of millions of people. However, the traditional production and drying of Akamu are labor-intensive and weather-dependent processes, which ican lead to inconsistencies in product quality and supply.

2.3 PRESERVATION TECHNIQUES FOR AKAMU

According to Bloomhood, 2020, common methods of preserving Akamu are as follows:

1. **WATER METHOD:** Preserving Akamu with water is done in two ways;

- **SOAKING DIRECTLY IN WATER:** One of the most common methods of preserving Akamu in Nigerian households is by soaking it in water. This is done by placing the Akamu in a bowl, then adding water into the bowl to completely submerge the Akamu, the bowl can be stored in a refrigerator or stored at room temperature. The water can be changed daily or every few days to prevent sour taste and odor. This method of preservation may not be a good option for a large quantity of Akamu.
- **TYING IN A NYLON AND SOAKING IN WATER:** This is very similar to the method above, the difference is that the wet akamu is divided in small portions and tied in nylon before placing in a bowl of water. The water can be changed every couple of days to prevent odor and sour taste. An advantage of this method is that it does not require refrigeration.

2. **REFRIGERATION OR FREEZING METHOD:** Here, the Akamu is stored in the refrigerator so as to keep it at a low temperature as this helps to slow down bacterial growth and

enzymatic reactions that cause spoilage. The Akamu can also be allowed to freeze so as to further extend its shelf life but the longer the time it is kept frozen, the lesser the quality of the Akamu. Freezing can preserve Akamu for as long as three months.

3. **DRYING METHOD:** Drying is one of the oldest methods of food preservation (Prabhat, 2022), a lot of food items are preserved by drying them. The aim is to remove as much moisture as possible from the food and once it is completely dried, it may be stored in an airtight container.

For Akamu, during the drying process, the heat causes chemical reactions, such as the Maillard reaction (Maria & Jose, 2019) which is responsible for the browning of the Akamu. The Maillard reaction is a complex chemical reaction which occurs between amino acids and reducing sugars, and it is responsible for the characteristic flavor and aroma of many baked, roasted, and dried foods (Gerhard, 2006)

The temperature at which Akamu begins to change color during the drying process can vary depending on the specific composition of the Akamu, the drying method used, and the duration of the drying process. However, generally, the color change can start to occur around 50°C to 60°C (122°F to 140°F) and as a result of this, it is essential to monitor the drying process closely so as to prevent over-drying or burning of the Akamu. If the color changes too quickly or unevenly, the drying temperature needs to be adjusted or changed so as to ensure the best quality and taste. It should be noted that the specific temperature and time required for drying can vary depending on the thickness of the Akamu layer, humidity levels, and other environmental factors. (Bolaji et al., 2021)

The dried product loses its moisture content during drying, which results in an increasing concentration of nutrients in the remaining mass. Hence, proteins, fats and carbohydrates are present in larger amounts per unit weight in the dried food than in the fresh food. (Hawlader et al., 2006).

Meeting the growing global food demand requires efficiently producing high quality dried foods and extracts with long storage life and consumer convenience. Drying processes play a major role in removing moisture from wet agricultural and food products such as Akamu. Products with high moisture content like vegetables, herbs, and starches are generally dried at low (10°C) to moderate (50-70°C) temperatures. This helps preserve valuable nutrients like proteins, vitamins, enzymes, and oils as well as physical qualities like color and texture. Drying at higher temperatures can degrade food components and alter texture and appearance. The main challenge is developing efficient drying processes that provide safe, high quality dried foods while retaining nutritional content and appealing textures and colors. Effective moisture removal is critical for producing shelf-stable dried products that can meet consumer demand for tasty and nutritious foods with long storage potential and ease of use (Ecourses online, 2013) . Drying processes that remove moisture at controlled low-moderate temperatures are essential for meeting increasing demand for high quality dried foods and ingredients that retain nutrients, flavors, colors and textures while extending storage life (Djaeni, et al., 2017).

Conventional drying with sunlight is very advantageous due to its low energy cost, and being environmentally benign. This method of drying has been widely used for a long time in various sectors, such as agriculture, fishery, forestry, and herbal medicine products. Unfortunately, the use of this method is also restricted by main drawbacks such as product quality, which are rooted from its climate dependence. (Djaeni et al., 2015)

2.4 METHODS OF DRYING

Different methods of drying food items are available but not all are suitable for drying akamu. The methods which can be adopted are;

- **SUN DRYING:** This involves the removal of water or moisture from food stuff by the heat from the sun, assisted by movement of surrounding air. It does not require any special equipment and is quite convenient but is relatively unsafe because of birds, insects, rodents, dirt and even rain. Therefore, it needs constant attention. Very sunny weather can properly dry the akamu within 2 days.

- **AIR DRYING:** Air drying is very similar to sun drying but this time the akamu is not placed directly under the sun but in a well-ventilated shady area. It takes longer time to dry than sun drying.

- **OVEN DRYING:** Oven drying is safer and faster than sun drying but due to the amount of akamu and size of oven, the akamu may have to be dried in batches. Crushed akamu is spread on the oven tray and the heating temperature is set, the oven door can be opened slightly to allow the moist air to escape. Oven drying uses a relatively large amount of energy (Suzanne, 2020).

- **USE OF DEHYDRATOR:** Dehydrators work by removing moisture from food to aid in its preservation. There are dehydrators with thermostatic controlled heat and forced air circulation that are commercially available, there are dehydrators that ae also constructed locally. Dehydrators require an enclosed cabinet, a controlled source of heat and forced air to carry away the moisture.

Controls to adjust temperature should be accurate. It is important to maintain uniformity of temperature inside the dehydrator so as to avoid rotating shelves during the drying process. There are different designs of dehydrators but all will have an air intake and exhaust (Charlotte, n.d.).

TYPES OF FOOD DEHYDRATORS

Food dehydrators generally fall into two broad categories:

- **VERTICAL AIRFLOW DEHYDRATORS:** They are typically circular, with their fans positioned on either the top or bottom of the unit, which blows air through the stacked trays. They are easier to use and tend to dry more evenly according to tests (Rennie, 2023) . They typically provide less square footage than horizontal units, their light weight and removable trays make them convenient to store when not in use.
- **HORIZONTAL AIRFLOW DEHYDRATORS:** Horizontal models are cabinet-shaped with a rear-mounted fan that blows hot air horizontally across the trays, which slide in and out like an oven. They tend to be bulkier and more expensive but they offer more space.

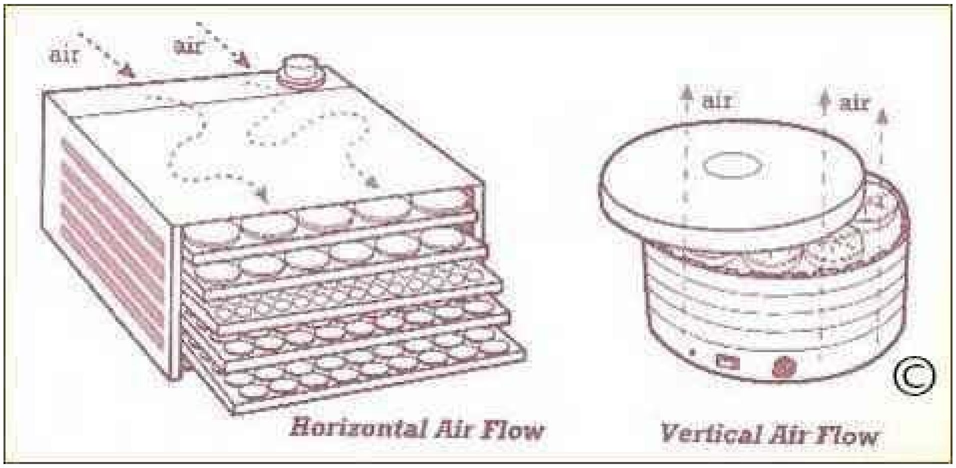

Figure 2.1 Horizontal and Vertical air flow dehydrators (SousvideGuy, 2014)

2.5 DRYING AND ITS RELATIVE BENEFITS TO AKAMU

Drying is a process that is used to remove moisture from a substance. The process of drying has various benefits with respect to Akamu. Below are some of the benefits of drying Akamu.

- **Extended Shelf Life:** Drying helps to reduce the moisture content in Akamu, which impedes the growth of microorganisms and molds that cause spoilage and this therefore extends it shelf life. This extension in shelf life allows the product to be stored for a longer period of time, reducing wastage and ensuring availability during off-seasons.

- **Convenience and Portability:** The extended shelf life and reduced perishability of Akamu powder makes it a convenient and portable food product. It can be easily stored and transported without the need for refrigeration or special handling, making it suitable for the domestic and international markets.

- **Reduced Bulk Transportation Costs:** Dried Akamu has a lower weight and volume compared to the fresh one. This reduction in weight in turn bring about a corresponding reduction in its transportation cost, especially when moving it over long distances.

- **Increased Convenience:** Dried Akamu can be more convenient for consumers as it is lightweight, easy to carry, and can be rehydrated with water to make instant pudding. This can be particularly useful for travelers as an emergency food supply

- **Versatility in Culinary Applications:** Akamu powder can be used in various culinary applications, including making porridge or pudding, baked foods, and other recipes. Its dry form allows for easy incorporation into different food preparations without altering their texture or taste.

- **Market Expansion:** By turning Akamu into a dried product, it become more accessible to a wider range of consumers beyond its traditional geographical regions. This can potentially open up new markets and increase its overall demand.

- **Infant and Child Nutrition:** Akamu is traditionally used as a weaning food for infants and young children. The powdered form allows for easy preparation and feeding, making it a suitable and easily digestible food for the young ones.

2.6 AIR DEHUMIDIFICATION TECHNOLOGIES

Dehumidification is the process of removing water from air i.e. it is the process of reducing the humidity of air. A primary concern with dehumidification system design is energy consumption. The majority of the energy expended for dehumidification is for the removal of moisture from the air stream because condensing moisture out of air is a change in the state of the vapor (Charles & Martin, 2005)

2.6.1 TYPICAL METHODS OF DEHUMIDIFICATION

Air can be dehumidified in different, the method employed depends on the specific temperature and humidity requirements of the space to be dehumidified. The dehumidification systems used in a specific application are selected based on their effectiveness and efficiency in achieving the desired conditions. According to Charles & Martin, 2005, the following methods are typically used in dehumidifying air:

- **COOLING:** The usage of cooling coils is the most common dehumidification technique. This procedure typically includes circulating a fluid through a coil in an airstream at a temperature below the air stream's dew point. The fluid (and coil) temperature affects how much moisture is extracted. Chilled water, refrigerants, glycol solutions, or engineered fluids are frequently utilized fluids. The moisture that condenses on the cooling coils is removed from the system by being collected in a pan since the coil temperature is below the air stream's dew point.

  According to National Weather Service, 2019, "*The dew point of a given body of air is the temperature to which it must be cooled to in order to achieve a relative humidity of 100%. At this point, the air cannot hold more water in the gaseous form. If the air was to be cooled even more, water vapor would have to come out of the atmosphere in the liquid form, usually as fog or precipitation*"..

- **LIQUID-DESSICANT SYSTEMS:** Where there is a greater need for dehumidification than cooling, desiccant dehumidification systems are frequently used. The liquid desiccant system is one form, and it works by spraying a liquid desiccant solution (usually lithium chloride) through an air stream, where it collects moisture and offers some cooling. By altering the lithium-chloride solution's concentration, the precise circumstances can be changed. The desiccant solutions operate as a biocide for the conditioned air, which is advantageous in applications where bacteria or viruses are least desired. This is one advantage of adopting systems like this. After losing its moisture through heating, the solution is then regenerated and sprayed across the air stream once more. Additionally, a hot, humid waste-air stream is discharged from the regenerator.

- **SOLID-DESSICANT SYSTEMS:** A solid desiccant, such as silica gel, is used in another sort of dehumidification technique. Moist air is drawn through the desiccant, absorbing moisture. The desiccant is transported into a warmer air stream (known as the reactivation air stream) as it reaches its capacity, where it rejects the moisture before being exposed to the moist air stream once more. Supply air is frequently passed through a desiccant wheel to achieve this. Regenerating solid desiccants can be done with the help of waste heat or an exhaust air stream.

- **COMPRESSION:** Compression is a technique used by some industrial systems to lower the air's absolute moisture content. When air is compressed until it reaches saturation, it loses its capacity to contain moisture and water condenses. This is the initial stage of dehumidification for a process like an instrument's air, and additional dehumidification (with a coil or desiccant) is typically done after this to prevent the air from becoming saturated.

2.7 VAPOUR COMPRESSION CYCLE AND ITS APPLICATION IN AIR DEHUMIDIFICATION FOR FOOD DRYING

The vapor compression cycle is the most widely used refrigeration cycle in practice. In this cycle, vapor is compressed to liquid, after which the pressure is dropped so that it can evaporate at low temperature. The purpose of refrigerating is to transfer heat from an enclosed space which is at a temperature lower than that of its surroundings. The vapor compression cycle consists of the Compressor, Condenser, Expansion valve and the Evaporator.

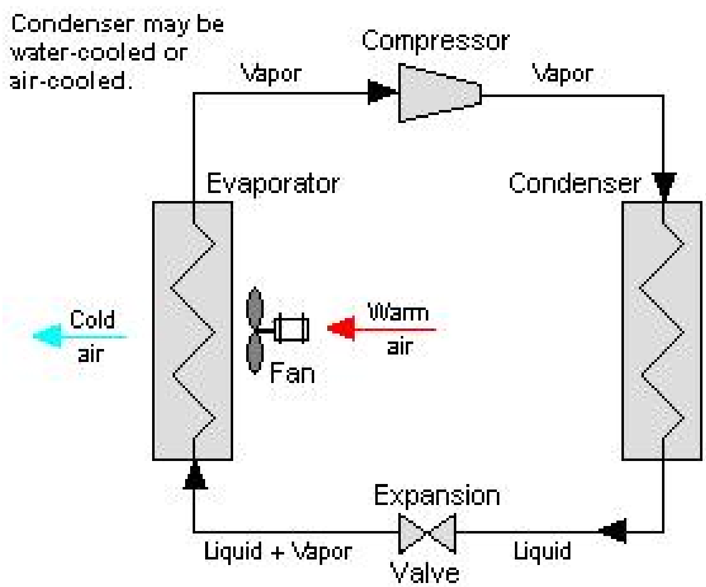

Figure 2.2 Application of vapor compression cycle in cooling air

The cycle starts with the refrigerant at low pressure, low temperature gaseous state as it enters the compressor. The compressor compresses the refrigerant vapor, significantly increasing its pressure as well as its temperature. The hot, high pressure vapor leaves the compressor and enters the condenser. In the condenser, the vapor condenses into a liquid state, releasing its latent heat to the surrounding environment. The refrigerant leaves the condenser as a high pressure, moderate temperature liquid.

After leaving the condenser, the pressurized liquid refrigerant passes through an expansion valve. This results in a drastic drop in pressure and a corresponding reduction in temperature, causing some of the refrigerant to evaporate. The cold, low pressure liquid-vapor mixture then enters the evaporator. The cold temperature of the refrigerant in the evaporator causes heat from the enclosed refrigerated space to be absorbed into the refrigerant, causing it to evaporate. This evaporation has a cooling effect on the enclosed space.

The refrigerant leaves the evaporator as a low pressure, low temperature vapor and reenters the compressor, resuming the closed vapor compression cycle. The compressor must add mechanical work to the system to drive the refrigerant around the loop and enable the heat rejection and absorption that provides the refrigeration effect. This cycle leverages changes in pressure and state of the refrigerant to provide cooling through the evaporation of the refrigerant in the evaporator (Apiste, n.d.).

Experiments have been conducted with and without a vapor compression refrigeration unit for varied air velocities and desiccant concentrations. Results indicated that the dehumidification efficiency, moisture removal rate, and mass transfer coefficient are increased by 8.3%, 7.3%, and 4.5% for the system with a vapor compression refrigeration cycle compared to the system without a vapor compression refrigeration cycle. Energy consumption details reveal that the vapor compression refrigeration integrated cycle requires slightly higher energy than without vapor compression refrigeration resulting in reduced system coefficient of performance (Salins, et al., 2021).

CHAPTER THREE

MATERIALS AND METHODS

3.1 PRELIMINARY EXPERIMENTS

The various experiment that was carried out in this work were:

i. Measurement of temperature and humidity of the evaporator coil

The evaporator coil in the refrigeration system plays a critical role of removing heat from the cooling chamber and lowering the air humidity level. With the aid of smart temperature and humidity sensors the inlet conditions the evaporator coil and outlet conditions of evaporator is measured and recorded. Result of this experiment is in the following chapter.

ii. Testing of various refrigerant for the compressor

3.2 CONCEPTUAL DESIGNS

Two conceptual designs were made for the project and they are explained below:

3.2.1 DOUBLE CONDENSER DESIGN

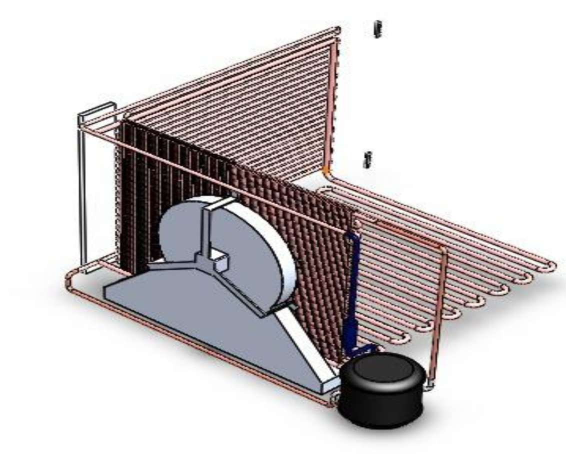

Figure 3.1 Double Condenser Design

This designed entails an innovative HVAC system that combines two condensers with a single evaporator, using the environmentally friendly refrigerant R600 (Isobutane) as it has high mobility and volatility and a very low ozone depletion potential (ODP) and global warming potential (GWP). This design aims to effectively manage both temperature and humidity levels in ambient air while optimizing energy consumption.

The components used include:

- **THE COMPRESSOR:** The compressor is used to compress the gaseous refrigerant from a lower pressure to a higher pressure. Due to adiabatic heating (which is a thermodynamic process in which the temperature of a substance increases due to the application of mechanical work without any heat exchange with its surroundings), the temperature of the refrigerant increases upon compression and then flows to the condenser for heat rejection.
- **THE CONDENSERS:** The system makes use of two different condensers. One of the condensers works alongside a cooling fan at the system's outset. The condenser with the help of the cooling fan takes on the responsibility of cooling the hot gaseous refrigerant flowing through the condenser tubes. Its primary role is to remove latent heat from the gaseous refrigerant, resulting in the change of state of the gaseous refrigerant to liquid. Following effective cooling and dehumidification in the evaporator, the air moves to the second condenser. The second condenser is placed inside the drying chamber and its primary function is to cool the hot gaseous refrigerant from the evaporator by transferring the heat to the dehumidified air flowing through the drying chamber, heating it up in the process.

- **THE EVAPORATOR:** The evaporator which is placed at the system's outset takes on the responsibility of interacting with incoming ambient air. Its primary role is to absorb heat from the air, cooling it in the process which in turn brings about moisture removal as the temperature approaches the dew point temperature of the air and finally resulting in the dehumidification of the air.

The process begins as ambient air is drawn into the system. It first encounters the evaporator, where it undergoes cooling and dehumidification. During this stage, the air releases moisture and loses heat to the refrigerant, resulting in a moisture-free environment at the drying chamber. The refrigerant, now carrying the heat absorbed from the ambient air, proceeds to the compressor for compression and then to the first condenser. At this stage, the refrigerant releases its latent heat to the surrounding environment with the aid of the cooling fan, condensing back into a liquid state as a result. This phase is essential for improving the efficiency of the refrigeration cycle. Following the cooling and dehumidification process, the air is directed to the second condenser. In this phase, the dehumidified air undergoes further heating as it receives heat from the hot refrigerant. This is because, the second condenser, through which the hot, gaseous refrigerant flows from the evaporator, transfers heat to the dehumidified air, raising its temperature to the desired level. Utilizing R600 (Isobutane) as the refrigerant along with a sophisticated control system, present a promising solution for precise air conditioning and humidity control.

3.2.2 SINGLE CONDENSER WITH HEATING ELEMENT DESIGN

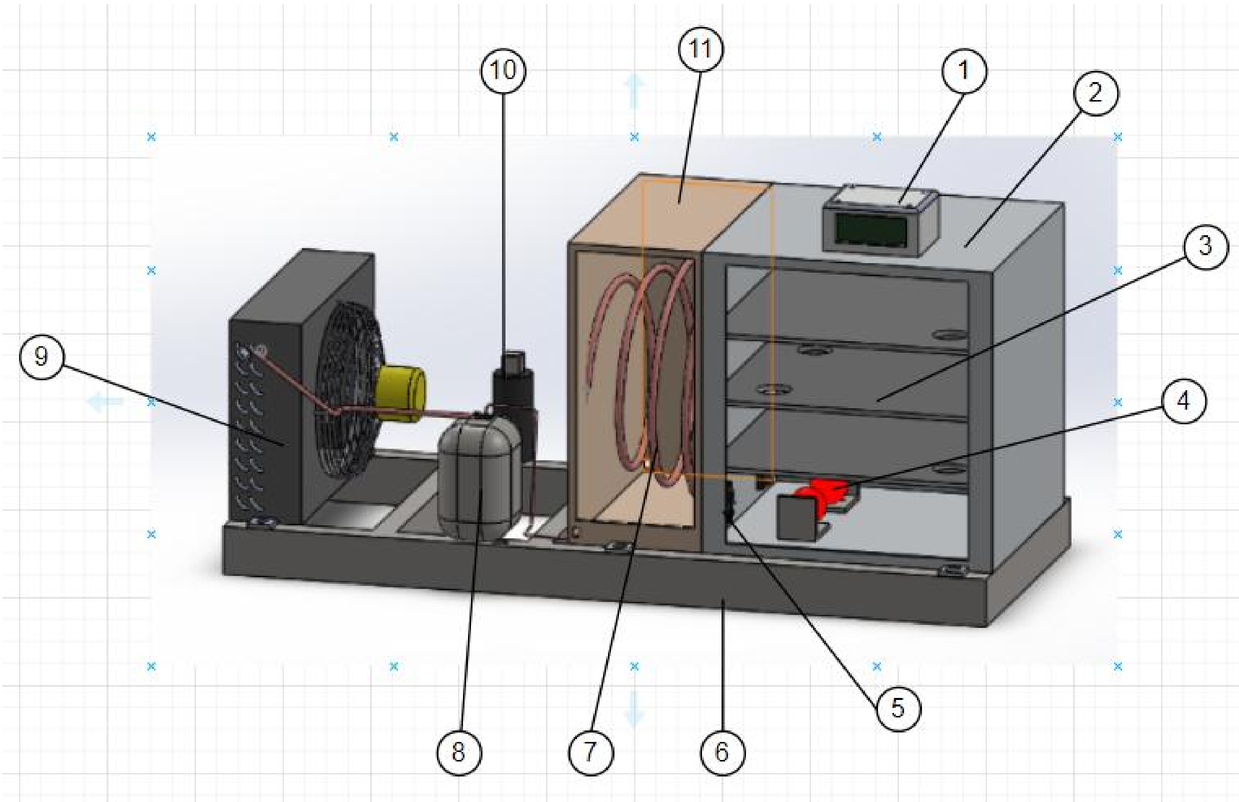

Figure 3.2 Single Condenser with Heating Element design

Table 3.1 Components of the Single Condenser with Heating Element design

NUMBER	NAME	QTY
1	CONTROLLER CASING	1
2	DRYING CHAMBER	1
3	TRAYS WITH HOLES FOR AIR PASSAGE	3
4	HEATING BULB	2
5	PROCESS FANS	2
6	BED	1
7	EVAPORATOR COIL	1
8	COMPRESSOR	1
9	CONDENSER	1
10	DRYER	1
11	REFRIGERATING CHAMBER	1

The second design proposed a system that incorporates a single evaporator, a single condenser for the vapor compression cycle, and a heater to heat the dehumidified air. This configuration aims to efficiently manage temperature and humidity levels while providing precise control over the heating process. Let's explore the key components and operation of this system.

The key components of the system include:

- **THE EVAPORATOR:** The evaporator which in this system serves as the primary component for cooling and dehumidifying the incoming ambient air. It absorbs heat and moisture from the air to create a controlled and moisture free environment.
- **THE CONDENSER:** The condenser is responsible for removing the latent heat absorbed by the refrigerant during the evaporator's cooling process, ensuring that the refrigerant transitions back to its gaseous state, facilitating the continuation of the vapor compression cycle.
- **THE HEATER:** The heater is used to raise the temperature of the dehumidified air by heat addition. A heater is integrated into the system to provide controlled heating to the dehumidified air after it has undergone the cooling and dehumidification processes.

The operation of this system unfolds in several distinct phases which are:

Cooling and Dehumidification phase: The process begins with ambient air being drawn into the system. The air encounters the evaporator, where it undergoes cooling and dehumidification. During this phase, excess moisture is removed, and the air temperature is reduced.

Heating Phase: After the cooling and dehumidification, the air proceeds to the heating phase, were it encounters the heater. This heater raises the temperature of the dehumidified air to the desired level, contributing to a more controlled and moisture free environment.

In summary, the second design, featuring a single condenser for the vapor compression cycle, and a heater, provides a practical solution for controlling temperature and humidity while offering precise heating capabilities. This design simplifies the system while maintaining its effectiveness. Evaluating energy efficiency and implementing a reliable control system will be essential to ensure the overall success and performance of this configuration.

3.3 DESIGN MATRIX TABLE

The following weight factors was considered before selection of a best design for the project.

1. Power consumption – 0.1
2. Heat Flow rate – 0.15
3. Complexity – 0.15
4. System response – 0.1
5. Functionality – 0.3
6. Cost of production – 0.2

Below is a design matrix table based on these factors:

Table 3.2 (i & ii) Design Matrix Tables for selection of best design

Factors	**Power consumption**	**Heat flowrate**	**Complexity**	**System response**	**Functionality**	**Cost of production**
Weights	(0.1)	(0.15)	(0.15)	(0.1)	(0.3)	(0.2)
Design 1	9	4	9	3	7	7
Design 2	5	8	6	9	9	5

Factors	**Power consumption**	**Heat flowrate**	**Complexity**	**System response**	**Functionality**	**Cost of production**	**Total value**
Weights	(0.1)	(0.15)	(0.15)	(0.1)	(0.3)	(0.2)	(1.0)
Design 1	0.9	0.6	1.35	0.3	2.1	1.4	6.65
Design 2	0.5	1.2	0.9	0.9	2.7	1	7.20

From the above tables, being that design 2 has a total value of 7.2, therefore the "Single condenser with heating element" design is selected.

3.2 DESIGN SPECIFICATIONS

The parameters for the machine are as follows

i. Compressor power = 1.25 horsepower

ii. Refrigerant = Isobutane (R600)

iii. Refrigerating power is given as 3000W

iv. Condenser temperature is 55°C

v. Evaporator temperature is 10°C

vi. Heater = 500 W

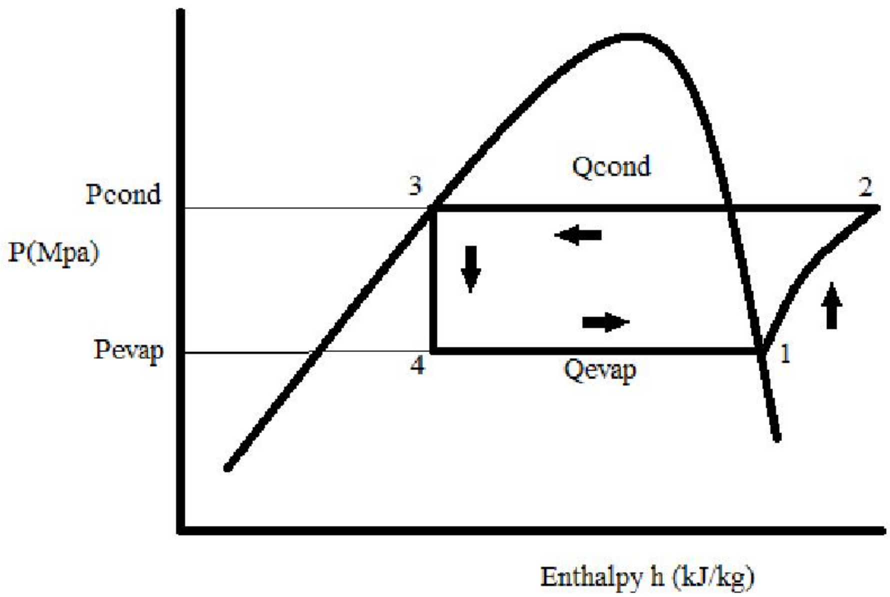

Figure 3.3 p-h diagram of vapor compression cycle

3.2.1 CALCULATIONS

1. Convert compressor power to watts:

1.25 hp x 746 W/hp = 932.5 W

2. Find refrigerant mass flow rate:

Refrigerating power = Mass flow rate x Latent heat

3000 W = m x 260 kJ/kg

m = 3000 W / 260 kJ/kg = 11.54 kg/h

3. Find heat rejected in condenser:

Heat rejected in condenser (Q_c) = Refrigerating power x (1 + 1/COP)

Q_c = 3000 W x (1 + 1/3.22)

Q_c = 3931.67Watt

4. Find Coefficient of performance (COP):

COP = Refrigerating power / Compressor power

COP = 3000 W / 932.5 W = 3.22

5. Find the overall rate of heat transfer:

Refrigerating power (cooling done by evaporator) = 3000 W

Heat rejected by condenser (Q_c) = 3931.67Watt

Additional heating by heater = 500 W

Overall heat transfer rate = Heat rejected - Cooling done + Additional heating

= Q_c - Refrigerating power + Heater

= 3931.67 W - 3000 W + 500 W

= 1131.67 W

3.3 FABRICATION PROCESS

The structural framework of the machine is fabricated from 50mm x 25mm rectangular mid-steel tubing, joined together via manual metal arc welding techniques.

A refrigeration system comprising of a reciprocating compressor and air-cooled condenser coil are affixed to the steel framework. 19.05 mm outer diameter annealed copper tubing connects the compressor discharge port to the condenser inlet, the compressor suction port to the evaporator outlet, and the condenser outlet to the metering device inlet. These tubing joints are brazed using an oxy-acetylene torch and copper brazing alloy filler rod.

The metering device selected is a capillary tube, connected between the condenser outlet and the evaporator inlet. This creates a pressure drop to allow liquid refrigerant flashing and metering into the low pressure evaporator. A finned evaporator coil is situated within the cooling compartment and is connected to the capillary tube and compressor suction line.

Adjacent to the cooling compartment is a rectangular drying chamber, also mounted to the structural steel framework. Two axial fans are installed on the partition wall between the compartments, serving to circulate dehumidified air from the cooling compartment into the drying chamber. Open coil electric heating elements are located within the drying chamber to reheat the dehumidified air before it flows upwards through the multi-level wire mesh trays containing the wet akamu product, providing energy for moisture evaporation.

3.4 DIAGRAM OF MACHINE

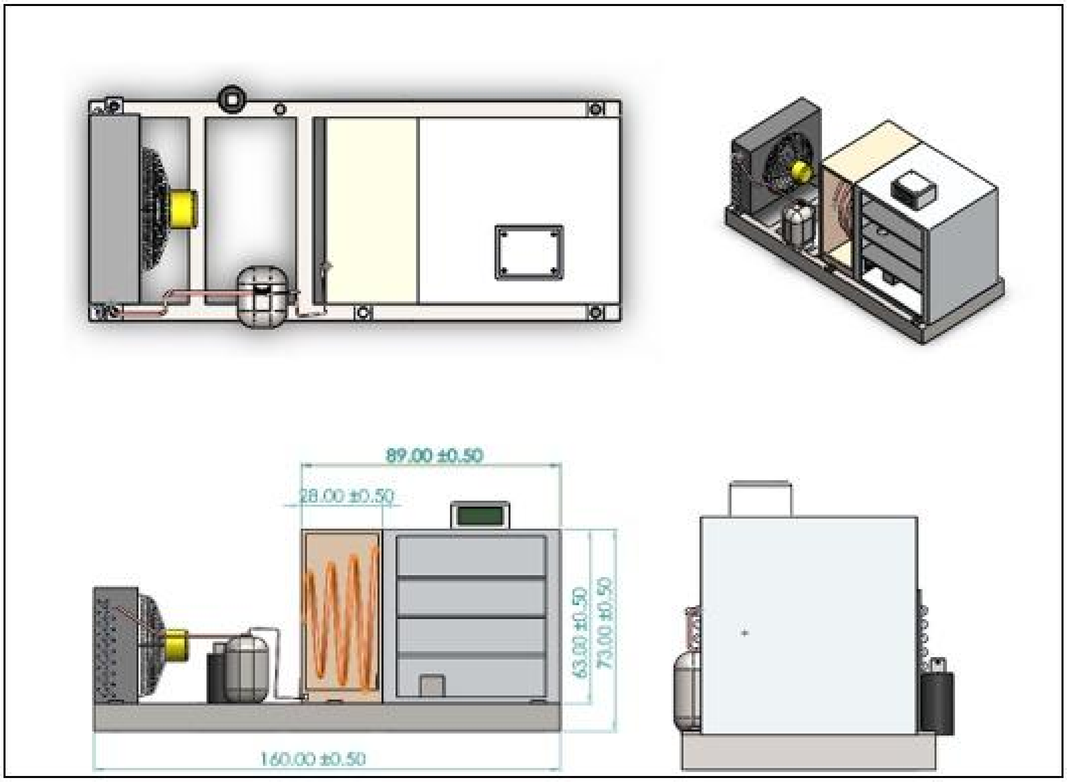

Figure 3.4 Isometric and Orthographic views of the chosen concept

Figure 3.5 Photograph of the fabricated design

3.5 BILL OF ENGINEERING MATERIALS

S/N	Item	Dimension	Quantity	Unit cost	Total cost
1	Compressor (Aspera NJ6226Z)	1.25HP	1	40,000	40000
2	Evaporator coil	1	1	5000	5000
3	Dryer		1	3000	3000
4	Tube condenser	250v	1	21000	21000
5	Electric Switch		1	2000	2000
6	Copper pipes	¾ inches	3	5000	15000
7	Rectangular mid-steel pipes	2 inches	2	15000	45000
8	Capillary tubes	¾ inches	1	5000	5000
9	Heating bulb	200W	4	500	2000
10	Lamp holders		4	500	2000
	TOTAL				184000

CHAPTER FOUR

RESULT AND DISCUSSSION

4.1 MOISTURE CONTENT ANALYSIS OF AKAMU SAMPLE

The experiment was targeted at determining the moisture content (based on wet mass) of the sample of akamu. This physical property is an important index in evaluating the effectiveness of the device operation. Samples of different mass are weighed. Each sample is heated at about 110°C and weighed every 10 minutes until there is no change in mass after 2 measurements

$$Moisture\ Content\ (w.b)(\%) = \frac{Wet\ mass - Dry\ mass}{Wet\ mss}$$

Table 4.1: Table of values for moisture content analysis

Drying Temperature (°C)		110		
Dish A weight (g):		1.30		
Dish B weight (g):		1.70		
Dish C weight (g):		3.00		
S/N	Time (mins)	Dish A (g)	Dish B (g)	Dish C (g)
1	0	81.30	71.70	78.00
2	10	81.00	71.50	65.20
3	20	77.90	59.20	57.00
4	30	72.50	52.80	50.50
5	40	69.30	46.60	46.60
6	50	61.00	43.20	45.20
7	60	51.60	41.60	43.90
8	70	47.00	40.50	41.50
9	80	42.40	38.50	41.50
10	90	41.50	38.50	-
11	100	41.50	-	-
Moisture content A (w.b) (%):				50.25
Moisture content B (w.b) (%):				52.57
Moisture content C (w.b) (%):				51.33
Average moisture content C (w.b) (%):				51.38

4.2 TEST RUN OF FABRICATED PROOF OF CONCEPT

Data on the temperature and humidity was collected from the drying chamber and moisture removal chamber. This data gives insight on the changes that the process air undergoes in respect to the temperature and humidity. It also carried as a preliminary test of the proof of concept. The moisture removal system is kept running throughout the test. The heating system was outputting about ¼ of its heat output (200W).

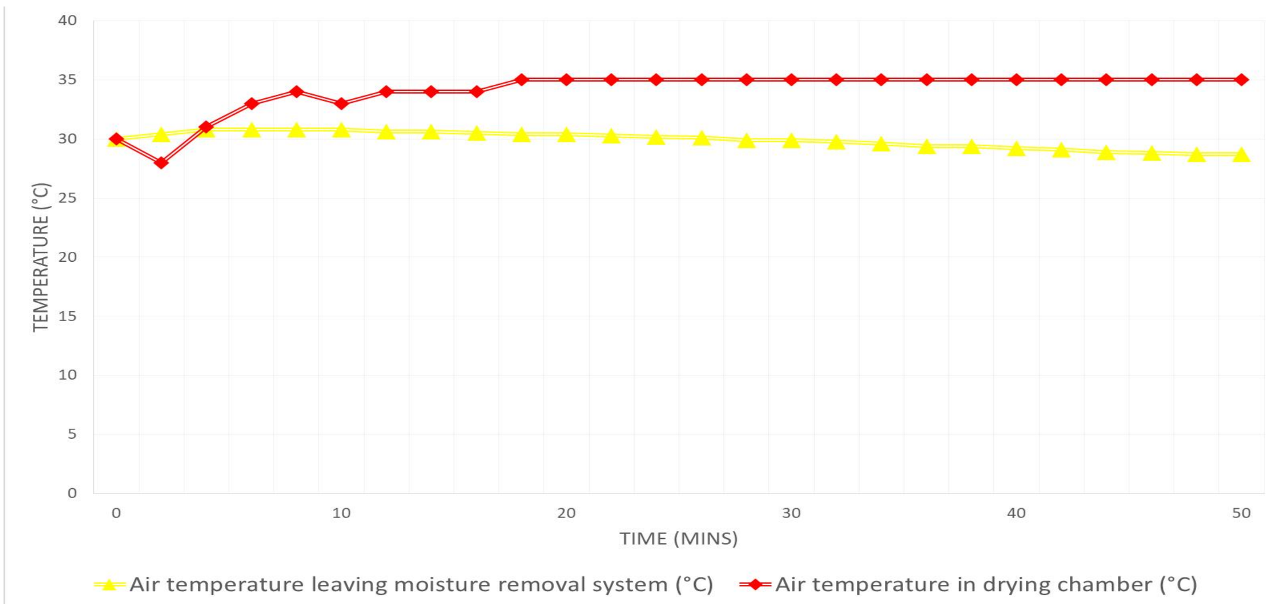

Figure 4.1: Temperature readings of test run of proof of concept

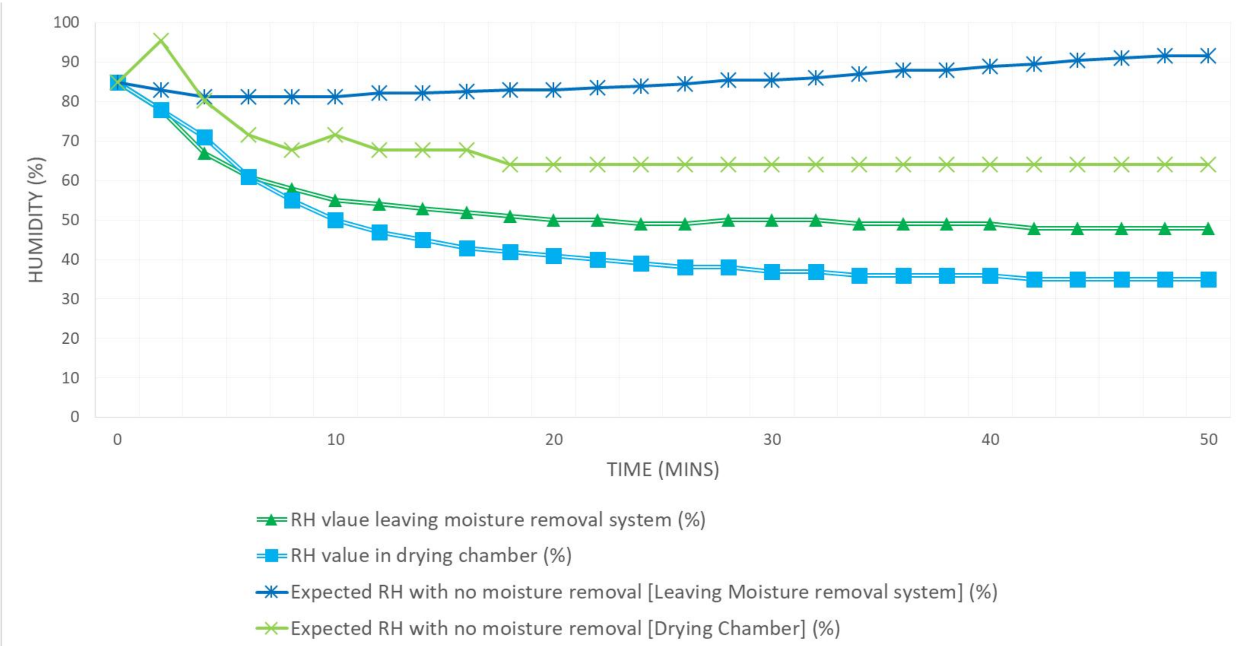

Figure 4.2: Humidity readings of test run of proof of concept

4.3 DATA ON PROOF OF CONCEPT OPERATION WITHOUT LOAD UNDER NORMAL OPERATION

After final adjustment to the device, it is ran with data collected from the air in the drying chamber. The data gives a representation on the device behavior. A plot of the expected humidity values in the drying chamber if moisture isn't removed or added to the air in the system is also plotted. This is based on the calculated starting temperature and humidity condition at the start of the process, and how it will change based on temperature only.

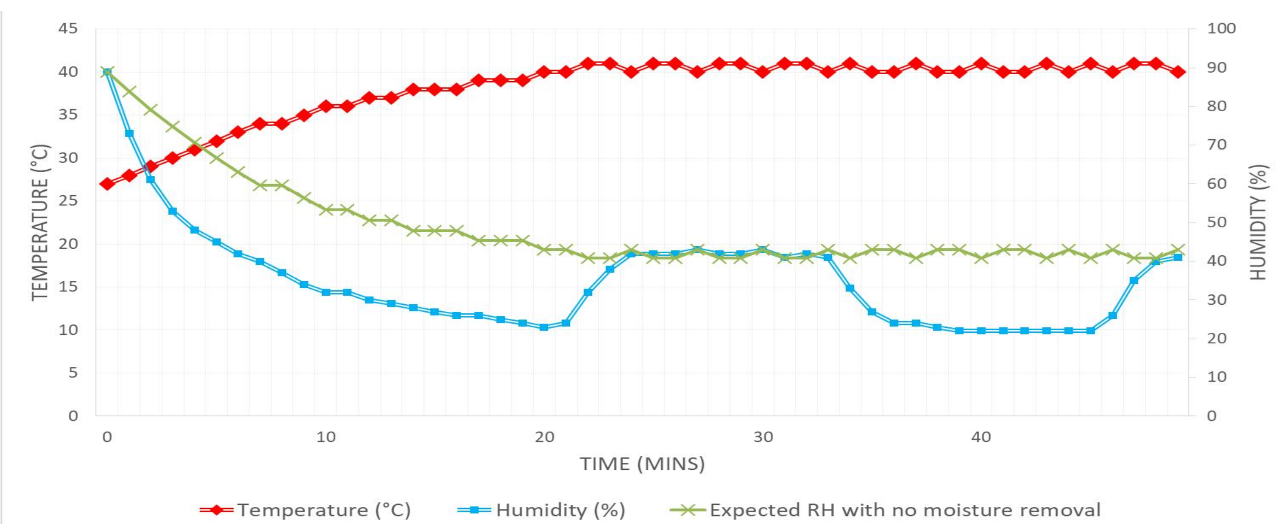

Figure 4.3: Readings from proof of concept operated without load

4.4 DATA ON EFFECT OF MOISTURE REMOVAL SYSTEM ON SYSTEM WITHOUT LOAD

The experiment was carried out to access the operation of the moisture removal system, without interference of the heating system. A plot of the expected humidity values in the drying chamber if moisture isn't removed or added to the air in the system is also plotted. This is based on the calculated starting temperature and humidity condition at the start of the process, and how it will change based on temperature only.

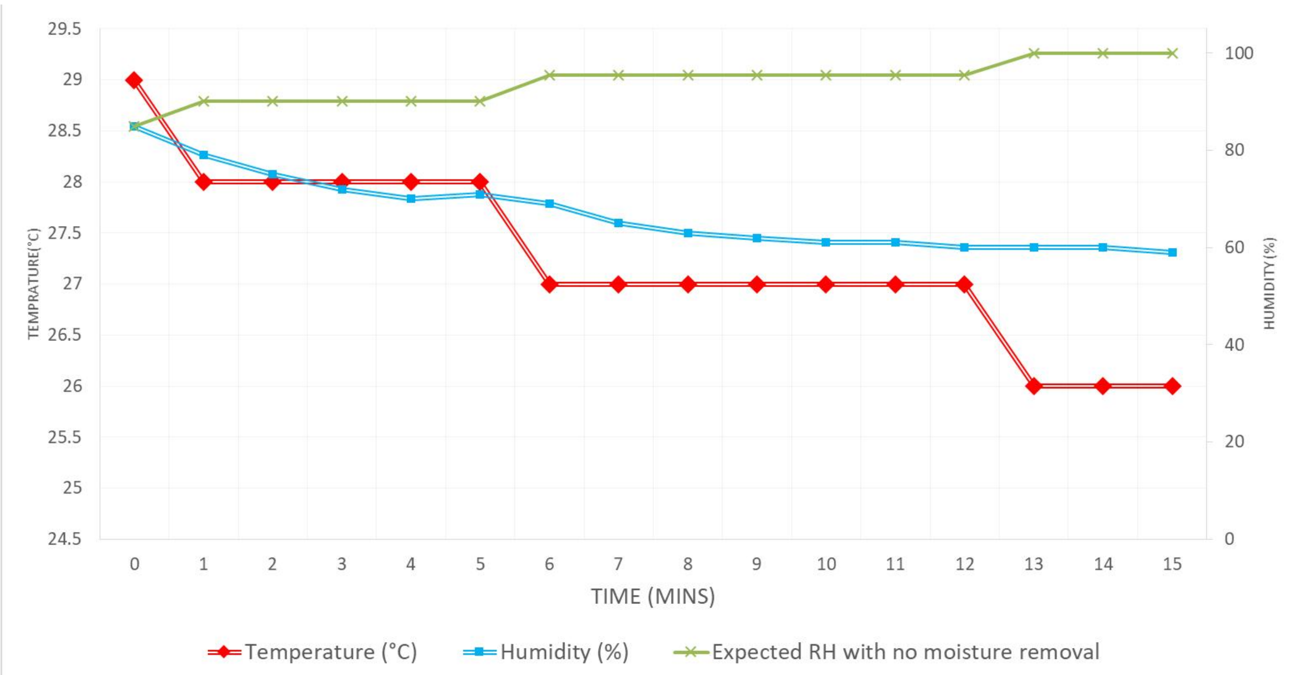

Figure 4.4: Readings of proof of concept operated any heating

4.5 DETERMINATION OF DRYING TIME OF PROOF OF CONCEPT AND EFFECT OF LOADING THICKNESS ON MOISTURE REMOVAL

About 1.2 kg of akamu was sieved and loaded on the first (topmost) and third (bottommost) shelf of the proof of concept with an average thickness of 10mm.

4 dishes of akamu are sieved and pre-weighed and loaded into the second (middle) shelf of the device. Each tray are of different thickness. Residue are also loaded without a pre-defined thickness on the second shelf.

The device is set to 45°C and 25% RH and allowed to run till it completes.

A plot of the expected humidity values in the drying chamber if moisture isn't removed or added to the air in the system is also plotted for comparison. This is based on the calculated starting temperature and humidity condition at the start of the process, and how it will change based on temperature only.

Table 4.2: Table of values for experiment to determine drying time of proof of concept

Weighing dish mass (g):	246.9
Average layer thickness (mm):	10
Theoretical max moisture content (%):	51.38

Shelf	Wet mass + dish (g)	Dry mass + dish (g)	Wet mass (g)	Dry mass (g)	Mass of moisture removed (g)	Percentage mass removed (%)	Theoretical dry mass (g)	Moisture content (w.b) (%)
1	1172.00	932.50	925.10	685.60	239.50	25.89	449.78	34.40
3	1191.90	871.80	945.00	624.90	320.10	33.87	459.46	26.47

Table 4.3: Table of values for experiment to determine effect of thickness on moisture removal

Sample	Thickness (mm)	Dish mass (g)	Wet mass + dish (g)	Dry mass + dish (g)	Wet mass (g)	Dry mass (g)	Mass of moisture removed (g)	Percentage mass removed (%)	Theoretical dry mass (g)	Moisture content (w.b) (%)
A	5	3.50	133.70	103.90	130.20	100.40	29.80	22.89	63.30	36.95
B	15	2.80	194.50	176.40	191.70	173.60	18.10	9.44	93.20	46.31
C	20	2.90	266.30	238.20	263.40	235.30	28.10	10.67	128.07	45.57
D	10	2.70	92.80	74.70	90.10	72.00	18.10	20.09	43.81	39.16

Table 4.4: Table of values for experiment to determine effect of drying thickness on moisture removal (residue)

Weighing dish mass (g) :				246.9			
Wet mass + dish (g)	Dry mass + dish (g)	Wet mass (g)	Dry mass (g)	Mass of moisture removed (g)	Percentage mass removed (%)	Theoretical dry mass (g)	Moisture content (w.b) (%)
375.20	332.30	128.30	85.40	42.90	33.44	62.38	26.96

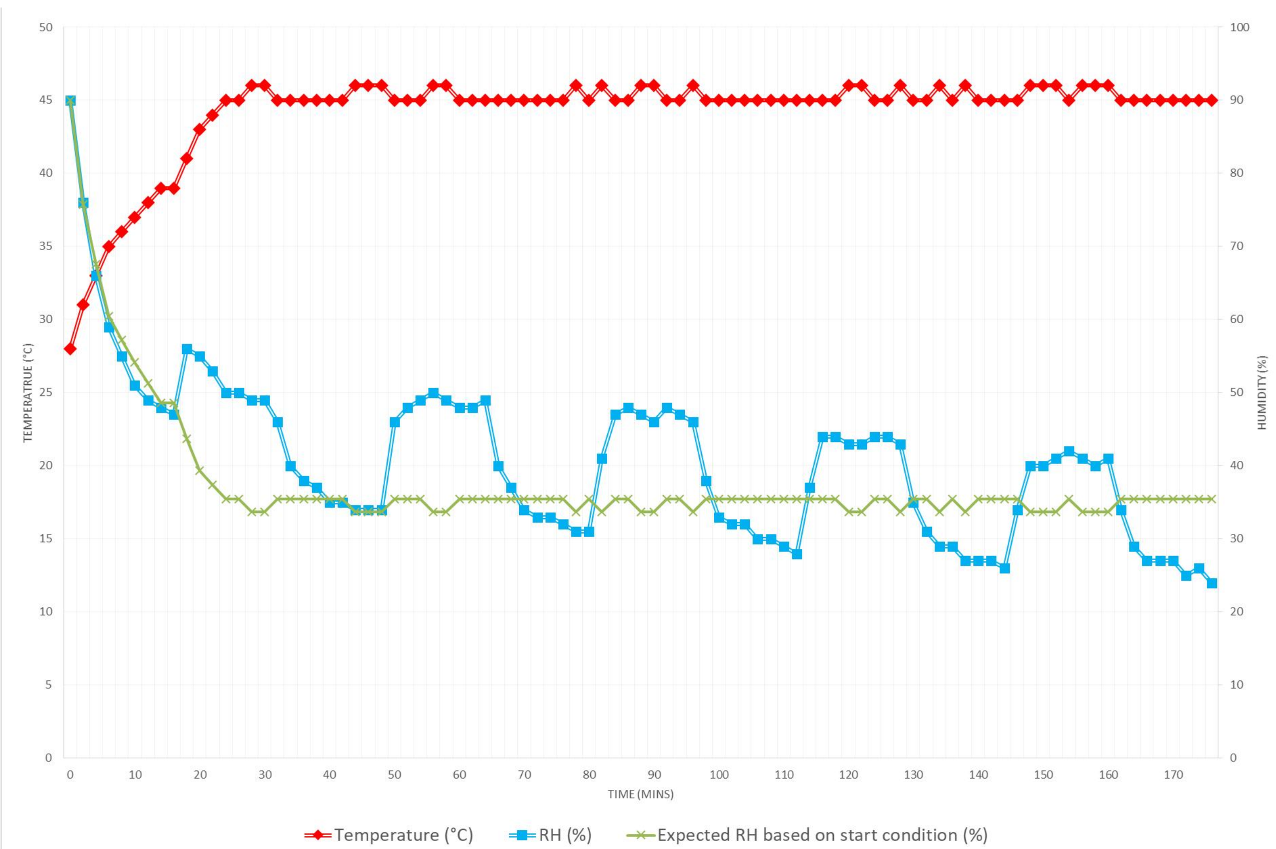

Figure 4.5: Readings from proof of concept operation

4.6 COMPARISON OF PERFORMANCE OF NORMAL OPERATION VS TYPICAL HEAT DRIVEN FOOD DEHYDRATOR

This is experiment was carried out to compare the effectiveness of the device to a heat driven dehydrator.

750g of akamu was sieved and measured. It was loaded on the bottommost shelf of the device. The device was programmed to run at 50°C and terminate at 20% RH. A wait time of 15 minutes was observed before the drying chamber was opened.

750g of akamu was also sieved, measured and loaded on the bottommost shelf of the device. The moisture removal system was switched off and temperature of operation was set at 50°C. The devices was timed to run as long the previous sample dried for comparison. The device was manually switched off, when the time elapsed.

Table 4.5: Table of values for experiment to compare proof of concept normal operation with typical heat driven dehydrator (normal operation)

Set temperature (°C):				50			
Set humidity (%):				20			
Wait time before opening drying chamber (mins):				15			
Weight of dish (g):				47			
Wet mass + dish (g)	Dry mass + dish (g)	Wet mass (g)	Dry mass (g)	Mass of moisture removed (g)	Percentage mass removed (%)	Theoretical dry mass (g)	Moisture content (w.b) (%)
750.00	699.60	703.00	652.60	50.40	7.17	341.80	47.63
RH after wait period (%):				44			
Temperature after wait period (°C)				45			

Table 4.6: Table of values for experiment to compare proof of concept normal operation with typical heat driven dehydrator (heat driven operation)

Set temperature:	50		
Wait time before opening drying chambers (mins):	15		
Weight of dish (g)	47		

Wet mass + dish (g)	Dry mass + dish (g)	Wet mass (g)	Dry mass (g)	Mass of moisture removed (g)	Percentage mass removed (%)	Theoretical dry mass (g)	Moisture content (w.b) (%)
750.00	719.70	703.00	672.70	30.30	4.31	341.80	49.19
RH after wait period (%):				37			
Temperature after wait period (°C)				45			

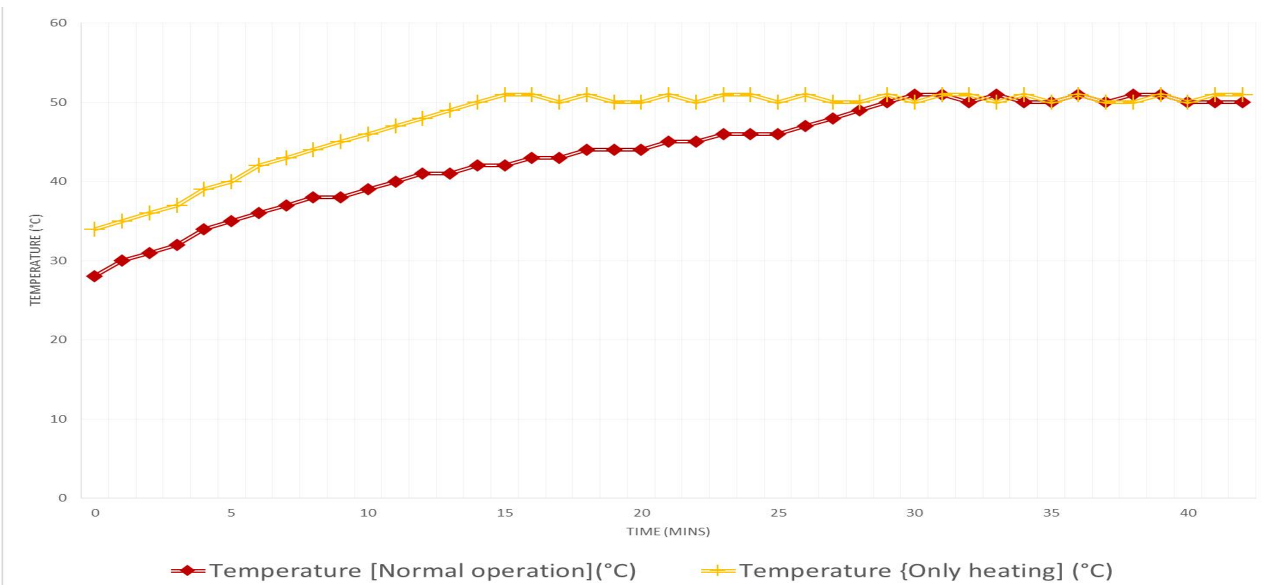

Figure 4.6: Temperature readings of proof of concept under normal operation and as a heater

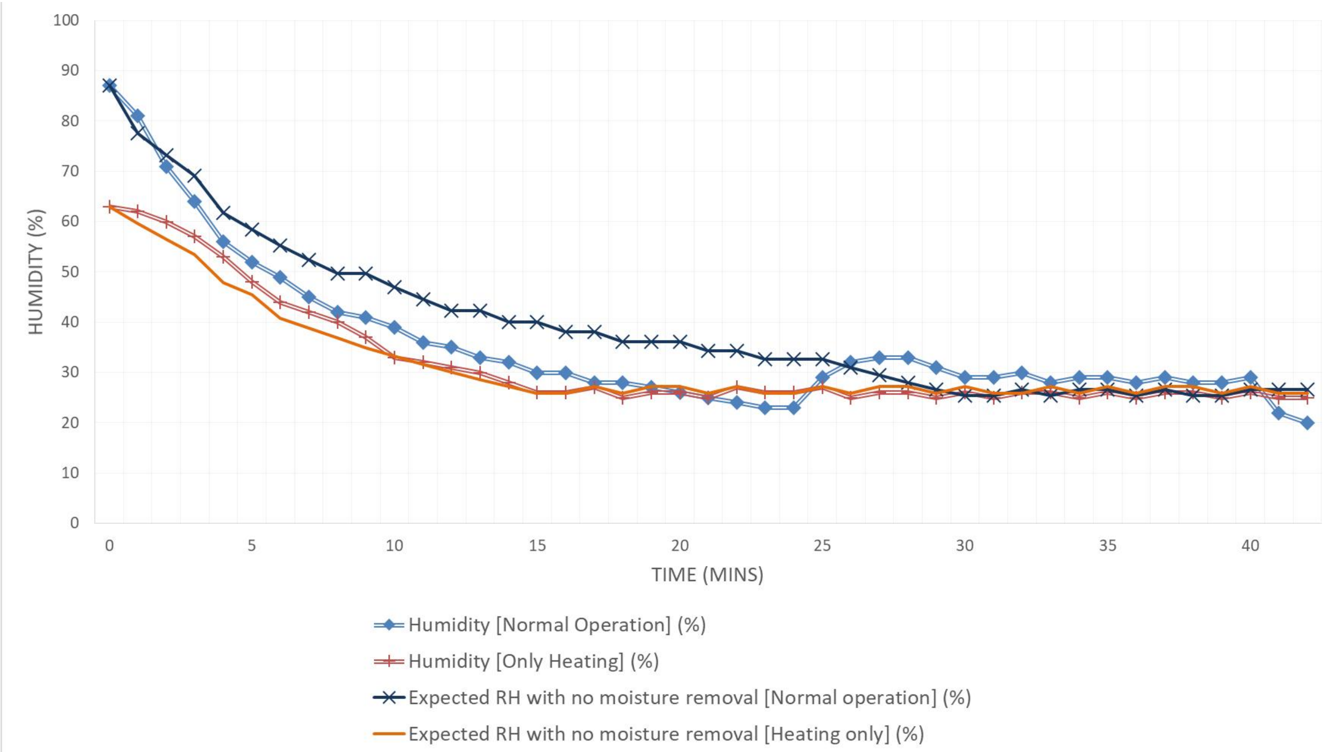

Figure 4.7: Humidity readings of proof of concept operated as normally compared to behavior as only a heater

DISCUSSION

The results from various experiments and tests carried out on the fabricated proof of concept as well as the test samples presented earlier can be interpreted thus.

Moisture content

The moisture content of akamu was determined to be about 51.38% with the range of the samples being 1.08%.

Humidity (RH)

From Figure 4.2, it is observed that as the temperature in the remains constant at 35°C, the temperature of air from the moisture removal system slowly drops. The humidity values in the drying chamber and of the air from the moisture removal system drop steadily before slowing down as it approaches 40% RH. It was observed during experiment that frosting covered most of the evaporator coil around the 10 minute mark.

Similar behavior of the humidity and temperature was observed in Figure 4.3. However spikes in humidity occurred around the 20th minute mark. The humidity value raised to the expected humidity value if there wasn't any moisture removal. At the 35th minute the humidity begins to drop back down to about 20%.

Humidity spikes also occurred in Figure 4.5. The maximum value of the spike progressively drops after each spike (from about 60% on the first spike to 50% and 45% on the 3rd and 5th spikes). The minimum value between each spike also progressively lowers and approaches the set point of 25%. These lower value also remains below the expected humidity value without any moisture removal employed.

Spikes occurred when the moisture removal system was switched off, and began dipping when restarted.

Some inferences gotten from the above where;

- The moisture removal system lowers the humidity value. These occurs in two primary stages, a rapid drop and a slow drop.
- Spikes are caused by the moisture removal system being switched offed. This may be due to moisture trapped on the coil and condensate not removed from the system.
- Some moisture in the air is removed from the drying chamber as shown by drop in maximum spike value and minimum values between spikes.
- The RH value without loading remains below the expected RH without moisture removal throughout the experiment, while when loaded it takes significant time for this to be achieved. This is due to the moisture loss from the akamu in the system.

Temperature

Temperature in the drying chamber rises and remains fairly constant fluctuating only about 1°C above the set value when the heater is running (shown in Figure 4.3 and Figure 4.5).

With the heating system switched off, the temperature drops due to the drop in air temperature from the moisture removal system.

Moisture content removal from akamu

It is observed from the data from Table 4.2 that the lower shelf loosed more moisture than the uppermost shelf (about 8% more in mass lost). The minimum moisture content (w.b) (%) achieved in the system was 26.47%. This took 3 hours to achieve.

The experiment to determine the effect of thickness on the moisture content removal (data shown in Table 4.3) shows a negative correlation between the loading thickness and amount of moisture removed in a given time.

Table 4.2 and Table 4.3 shows that the moisture content removal of the system was slightly higher when ran with its normal operation versus when it was ran as a heat driven system.

Some inferences from the above are;

- More moisture is removed from the lower shelf than the lower level. This might be due to more heat reaching the lower shelf, moisture pick up by the process air as it flows over the shelves or a combination of both factors.
- Lower thickness yields more moisture removal in a given time.
- There's more moisture removed by the system normal operation than when only heat driven.
- The device terminates the process at the set humidity, irrespective of the moisture content of the loaded akamu. The process terminated faster with the 750g wet mass load in experiment 4.1.6 than that in experiment 4.1.5 where about 4kg was loaded.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Akamu being a traditional Nigerian porridge made from fermented corn, sorghum or millet, has high nutritional value but spoils quickly due to its high moisture content therefore, this project aimed to develop a process for producing powdered akamu with extended shelf life.

The project involved the design and fabrication of a system to reduce the moisture content of akamu so as to produce a dry, powdered form of akamu which brings about better preservation therefore improving its shelf life for a longer period of time. The system utilized a vapor compression refrigeration cycle along with electric heaters and a smart control system which helps to control temperature and humidity during the drying process.

Experiments were conducted to determine the optimal conditions for drying akamu. The average initial moisture content of akamu was found to be 51.38%. Drying experiments revealed a relationship between layer thickness and moisture removal rate. Thinner layers allowed for faster moisture evaporation.

The fabricated system was able to effectively reduced the moisture content of akamu to below 30% within 3 hours when loaded with about 4kg of akamu. This moisture level allows long term storage. Comparative tests showed that the system removed moisture more efficiently compared to a typical food dehydrator which relied solely on heating.

In essence, the project successfully designed and built a smart system for producing shelf-stable akamu powder. The powder can enhance food security, reduce waste, and create economic opportunities which can improve the economy of Nigeria at large. Further work can refine and further improve the process and explore more commercial applications. The project successfully demonstrates the potential for improved preservation of traditional foods using appropriate technologies.

5.2 RECOMMENDATION

Future enhancements include the following;

1. A heat recovery system to capture and reuse waste heat from the vapor compression cycle should be implemented as this can be used to preheat the dehumidified air entering the drying chamber further improving the efficiency while reducing operating cost.
2. Improved algorithm and additional sensors to determine completion of drying process.
3. Reducing or eliminating return of moisture from the moisture removal system to the drying chamber.

Overall, this project lays the foundation for further research and advancements in the field of food dehydration technology, presenting opportunities for innovation and sustainable solutions in food processing and preservation.

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