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Speciality: Agricultural Mechanization

Design of a smart dryer for household use for fruits and vegetables

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PREFACE

The Burkina Technological Institute, inaugurated on October 15, 2018 in Koudougou, is a leading higher education institution in Burkina Faso. It is dedicated to training young talents to become leaders capable of transforming their technical skills into business opportunities. The institute emphasizes strong ethical values and a passion for national development.

When it was created in 2018, the Institute exclusively offered a program in computer science. Students learn to master programming languages for developing web, desktop and mobile applications. They also took introductory courses in artificial intelligence, such as data analysis, machine learning and deep learning. The first computer engineering class graduated in 2021. In 2019, the institute expanded its offering with the introduction of electrical engineering, specializing in renewable energy. This program aims to provide students with the skills needed to become experts in renewable energy systems. The first class of electrical engineering engineers graduated in 2022. In 2021, a new mechanical engineering program was launched, focusing on the mining and agricultural sectors. This course aims to meet the growing need for qualified technicians in Burkina Faso, capable of designing, innovating and adapting solutions for the country's mechanization. As a reminder, the very first class of this mechanical engineering program will graduate this year.

At the same time, entrepreneurship and management courses are integrated into the program, with regular workshops on various aspects of entrepreneurship. Students also benefit from at least one internship per year to better seize professional opportunities.

The Burkina Technological Institute operates according to the LMD (Bachelor-Master-Doctorate) system, which means that the training lasts three years to obtain a license.

QUOTE

"Creativity is intelligence having fun"

Albert Einstein

DEDICACES

To my precious Family

ACKNOWLEDGEMENTS

Here is a refined version of my expression of gratitude:

- I would like to first express my deep gratitude to my family. Your love, support and encouragement have been the foundations on which I built this thesis.

- This is also an opportunity for me to thank my fellow students at BIT, my friends and my classmates for their support and encouragement; I would like to thank the entire administrative staff of BIT and all the teachers for their dedication to our success and their infinite support in our studies.

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ABSTRACT

Food preservation is a major problem that affects the entire globe, particularly with perishable goods like fruits and vegetables that quickly deteriorate due to their high water content. Though popular, traditional drying techniques like sun drying are frequently ineffective and reliant on erratic weather. With a focus on fruits and vegetables, this project intends to design and create a smart drier for home use that is economical, effective, and user-friendly. The project, which is being carried out in partnership with the Institute of Research in Applied Sciences and technology (IRSAT), aims to enhance the drying process by integrating cutting-edge technology such as intelligent control systems, real-time monitoring, and sensors for temperature and humidity. The proposed dryer improves energy efficiency and sustainability while maintaining the goods' nutritional and organoleptic properties. A survey of the literature, equipment design and dimensioning, advanced technology development and prototyping.

Key words :

1 - Food Smart Dryer,

2 - Food Preservation

3 - Fruits and Vegetables

4 - Domestic Use

5 - Advanced Technologies

RESUME

La conservation des aliments est une problématique cruciale à l'échelle mondiale, en particulier pour les produits périssables tels que les fruits et légumes, qui ont une forte teneur en eau et sont sujets à une détérioration rapide. Les méthodes traditionnelles de séchage, comme le séchage au soleil, bien que largement utilisées, sont souvent inefficaces et dépendent de conditions climatiques imprévisibles. Ce projet vise à concevoir et développer un séchoir intelligent à usage domestique, spécifiquement adapté aux fruits et légumes, afin de fournir une solution efficace, facile à utiliser et économique. Réalisée en collaboration avec l'Institut de Recherche en Sciences Appliquées et Technologies (IRSAT), l'étude intègre des technologies avancées, y compris des capteurs de température et d'humidité, une surveillance en temps réel et des systèmes de contrôle intelligents pour optimiser le processus de séchage. Le séchoir proposé permet non seulement de préserver les qualités nutritionnelles et organoleptiques des produits, mais aussi d'améliorer l'efficacité énergétique et la durabilité. Les méthodologies employées comprennent une revue de la littérature, la conception et le dimensionnement de l'équipement, le développement de technologies avancées, la réalisation de prototypes.

Mots-clés :

1. Séchoir intelligent,
2. Conservation des aliments,
3. Fruits et légumes,
4. Usage domestique,
5. Technologies avancées.

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LIST OF ACRONYMS AND ABBREVIATIONS.

ACRONYM/ABBREVIATION	FULL FORM
IRSAT	Institute of Research in Applied Sciences and Technology
HMI	Human-Machine Interface
ESP32	Espressif Systems 32-bit Microcontroller
LCD	Liquid Crystal Display
DHT22	Digital Humidity and Temperature Sensor (AM2302)
HACCP	Hazard Analysis and Critical Control Point
ISO	International Organization for Standardization
PWM	Pulse Width Modulation
DC	Direct Current
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
TTC	Taxes Included
HT	Taxes Excluded
TVA	Value-Added Tax
XOF	West African CFA Franc
NF EN	Norme Française Européenne (French European Standard)
CAD	Computer-Aided Design
FCFA	Franc of the Financial Community of Africa
AFNOR	Association Française de Normalisation (French Standardization Association)

NOMENCLATURES

Symbol	Description	Unit
Φ	Heat flux	Watts per square meter (W/m^2)
α	Heat transfer coefficient	Watts per square meter per Kelvin ($W/m^2 \cdot K$)
A	Surface area	Square meters (m^2)
Ta	Ambient temperature	Kelvin (K) or Celsius (°C)
Ts	Surface temperature	Kelvin (K) or Celsius (°C)
λ	Thermal conductivity	Watts per meter per Kelvin ($W/m \cdot K$)
$\frac{dT}{dt}$	Temperature gradient	Kelvin per second (K/s)
Φ	Radiative heat flux	Watts per square meter (W/m^2)
σ	Stefan-Boltzmann constant	Watts per square meter per Kelvin to the fourth power ($W/m^2 \cdot K^4$)
ϵ	Emissivity of the surface	Dimensionless (no unit)
P	Power required	Watts (W)
ρ	Air Density	Kilograms per cubic meter (kg/m^3)
V	Volume of the drying chamber	Cubic meters (m^3)
C_p	Specific heat capacity of the air	Joules per kilogram per Kelvin ($J/kg \cdot K$)
ΔT	Temperature change	Kelvin (K) or Celsius (°C)
Δt	Time duration	Seconds (s)
A	Area of the drying chamber opening	Square meters (m^2)
v	Air velocity	Meters per second (m/s)

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GENERAL INTRODUCTION

Food preservation is a critical issue in the modern world, directly influencing food security and resource sustainability. Fruits and vegetables, in particular, are highly perishable due to their high water content, necessitating effective preservation methods to extend their shelf life while maintaining their nutritional and organoleptic qualities. Drying is one of the oldest methods of food preservation, but traditional approaches, such as sun drying, have significant limitations in terms of quality control and dependence on climatic conditions. In light of these challenges, the design of a smart dryer for domestic use emerges as an innovative solution, capable of meeting the specific needs of households in food preservation.

This project is undertaken as part of an internship collaboration with the Institute of Research in Applied Sciences and Technologies (IRSAT), a leading institution in Burkina Faso in the field of scientific and technological research. Founded in 1997, IRSAT specializes in areas such as natural substances, energy, food technology, and agricultural mechanization. The institute plays a crucial role in promoting scientific and technological innovation, particularly through the development of solutions tailored to the conservation and transformation of agricultural products, addressing the growing needs of consumers and the realities of local climates.

The development of a smart dryer for domestic use is based on several key findings identified during the diagnostic study. On the one hand, traditional drying methods do not guarantee optimal food preservation and are dependent on unpredictable climatic conditions. On the other hand, the dryers currently available on the market are often designed for industrial or semi-industrial applications and do not meet the specific needs of households in terms of size, ease of use, and cost. This situation presents an opportunity for the development of innovative, practical, economical, and environmentally friendly domestic solutions.

To achieve the objectives of this project, a rigorous and multidisciplinary methodology was adopted, comprising several key steps:

- **Preliminary Study and Analysis:** A comprehensive literature review was conducted to identify the existing drying techniques and their respective advantages and disadvantages. This analysis helped define the necessary characteristics for a smart domestic dryer, taking into account user needs and technical constraints.
- **Design and Sizing of Equipment:** The design process involved the development of detailed design plans, incorporating intelligent technologies such as temperature and humidity sensors to monitor real-time conditions inside the dryer. Simulations and

3D modeling were used to optimize the dryer's design and ensure maximum efficiency.

- **Development and Integration of Advanced Technologies:** The dryer incorporates cutting-edge technologies, including sensors and microcontrollers, to optimize the drying process management. The goal is to ensure uniform dehydration of food while preserving their nutritional and organoleptic qualities. The use of forced convection and an automatic regulation system allows achieving these objectives.
- **Evaluation and Optimization:** An in-depth evaluation of the results obtained was carried out to identify potential improvements and optimize the efficiency of the dryer.

The development project of a smart dryer for domestic use represents a significant advancement in the field of food technology.

This project is structured to provide a comprehensive analysis and a progressive development of the project focused on designing a smart dryer for domestic use. Initially, a literature review on existing drying technologies is presented, establishing a solid theoretical framework and identifying current gaps in traditional methods. The subsequent sections detail the design and sizing process of the equipment, with a particular emphasis on integrating advanced technologies to enhance the dryer's efficiency and adaptability. The following chapters outline the development stages, technological choices, and the evaluation of the 3D prototype's performance. Finally, the report concludes with a financial assessment for the deployment of this technological innovation in a domestic setting and a summary of the internship experience.

Part I:

Theoretical study

Chapiter I: General information on drying

Drying is a basic food preservation technique that lowers the moisture content of food to increase its shelf life. By preventing microbial development and enzymatic activity that might cause spoiling, this procedure preserves the food's taste, texture, and nutritional content. Different drying processes, such as sun drying, air drying, freeze drying, and spray drying, use different heat and airflow strategies to remove moisture. Food preservation is just one of the main objectives of drying; another is to make food more convenient and portable for use and storage. This chapter explores the fundamentals of drying, its goals, and the many methods employed, emphasizing their uses, benefits, and drawbacks.

I. Definition, Principle and Objectives of drying

1. Definition

Food drying is a preservation method that involves the removal of moisture from food products to inhibit the growth of microorganisms, enzymes, and other factors that can lead to spoilage. This process reduces the water activity in the food, thereby extending its shelf life while maintaining its nutritional value, flavor, and texture.[1]

Drying can be achieved through various techniques, including air drying, sun drying, freeze drying, and dehydrating, each of which utilizes different methods of heat and airflow to facilitate moisture removal. The goal of food drying is not only to preserve the food but also to enhance its portability and convenience for storage and consumption[1].

2. Principle

The process of converting food's water content to gas is part of the drying principle. After that, take it out of the meal to allow it to dry out[1]. Drying is the dehydration process that uses heat from the sun or hot air to remove water from food goods. Minimum parameters must be met for water removal to occur without compromising product quality. The dehydration process was created to make the most of the circumstances around the energy sources and raw materials utilized. Heat transfer during drying can be accomplished by radiation, convection, and conduction, except for freeze-drying, which forces water to evaporate. In the meantime, vapor removal is encouraged by the air[2].

3. Objectives of drying

The primary objective of drying is to reduce the moisture content of food products, thereby improving their preservation and extending their shelf life. This process serves several key purposes[3] such as:

- Reduced the water activity in food, which inhibits the growth of bacteria, yeasts, and molds responsible for spoilage. This ensures the long-term safety and quality of the food.
- Reduced moisture prevents chemical reactions that can cause spoilages. Then dried foods can be stored for a longer period of time without the need for refrigeration, making them more convenient for consumers and reducing caloric waste.
- The drying process allows for a significant reduction in the weight and volume of food products, making them easier to transport and store. This is particularly advantageous for bulk foods and when transporting over long distances.

II. Dryer applications in the food industry

A significant portion of the food we eat has gone through a drying process[3]. Drying out can be a step in the production process that is required, or it can play a part in keeping food fresh.

- Pasta;
- Charcuterie: sausage, ham, etc. ;
- Cheeses: drying in a controlled environment;
- Vegetables (peas, carrots, onions, etc.) and dried fruit (prunes, grapes, apricots, etc.);
- Some aperitif cookies are produced by hot-air drying from corn dough;
- Dairy products: Milk powder, whey, cream powder;
- Beverages: Fruit juice powder, instant coffee, instant tea.
- Food Additives: Proteins, vitamins, flavorings;
- Protein products: soya protein, pea protein ;
- Many types of grain or plant are preserved by drying: coffee, cocoa, rice and other cereals, tea leaves, spices... ;
- Co-products of the food industry, often destined for livestock feed or the chemical industry (additives, etc.): beet pulp (sugar mills), oilseed cakes (oil mills), draff (breweries, apple juice), etc.

III. Drying technologies

The drying technologies[2] employed in food processing vary based on specific requirements for quality, energy efficiency, and cost. Each method offers distinct advantages and presents unique challenges, influencing the selection of the most appropriate technique for different types of products.

1. The sun drying technology

The sun drying method involves drying agricultural products by directly exposing them to sunlight. This method offers the advantage of cost and energy savings but is highly dependent on often unpredictable weather conditions. It is commonly employed in tropical regions, where there is at least 6 hours of sunlight with radiation levels ranging from 500 to 800 W/m² per hour. For instance, sun drying chili peppers can take up to a week, with average temperatures ranging from 20 to 37°C. Additionally, sun drying mangoes and wild bean leaves can reduce their moisture content to around 10-15%.

a b

Figure 1: Sun drying method (a&b)

2. Tunnel drying technology

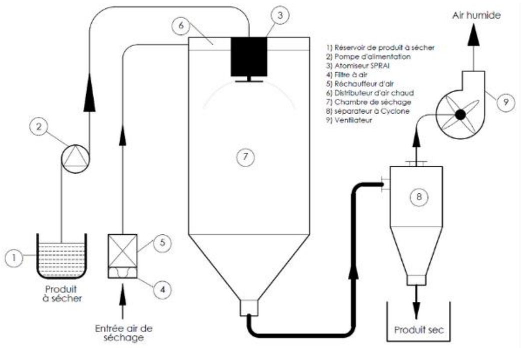
Tunnel drying employs a tunnel dryer equipped with a transparent flat collector to provide thermal energy via fans. Commonly used in the industry for drying horticultural and fishery products, this process relies on solar thermal energy and is more efficient than sun drying, though it still depends on weather conditions. For example, the drying of salted fish involves a process where the fish is salted for 16 hours until the moisture content reaches 16.78%[2].

Figure 2: Tunnel dryer

3. Spray drying technology

Spray drying is utilized for heat-sensitive processes in the food industry. It consumes less energy than freeze-drying and converts a liquid material into a solid product by spraying it into fine droplets, which are then dried by convection with hot air to form a powder. This method is quick, flexible, and cost-effective, but it may reduce protein quality, as seen in the case of egg whites[2]. It is commonly used for encapsulation, thereby stabilizing products like turmeric or blueberry polyphenols, extending their shelf life, and preserving their biological activity.

a



b

Figure 3: Spray dryer(a) & Spray dryer Schema(b) [5]

4. Drum drying technology

Drum drying employs a heated rotating drum, offering high energy efficiency (60-90%) and low operational costs[2]. The material, in liquid or paste form, is applied to the drum's surface to form a thin layer, which is quickly dried and cooked through thermal conduction. This process is well-suited for heat-sensitive products such as powdered milk, fruit purees, or soups. However, it may result in nutrient losses, such as lysine in skim milk, when compared to freeze-drying.

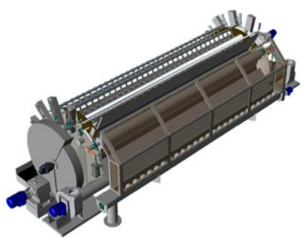


Figure 4:Double drump dryer

Figure 5: Continuous drump dryer

5. Freeze-drying technology

Freeze-drying, or lyophilization, sublimes water from a frozen product to preserve its bioactive components. This three-stage process (freezing, primary drying through sublimation, and secondary drying by desorption) effectively maintains nutrients and flavors while inhibiting microbial growth. Although freeze-drying excels at nutrient preservation and enhances food texture, it is costly and can lead to the loss of volatile compounds. It is particularly utilized for fruits and vegetables, but its high cost remains a significant barrier.

Figure 6: home Freeze-dryer for food

6. Microwave drying technology

Microwave drying utilizes electromagnetic waves to rapidly heat the water inside food, thereby accelerating the drying process[2]. While this method can reduce drying time by 25 to 90% and enhance energy efficiency, it is not ideal as a standalone process and often requires combination with other methods. Microwave drying is effective in preserving color and appearance but can cause tissue damage and browning, as seen with ginger[2]. It is commonly used for vegetables and fruits, offering better uniformity and reduced shrinkage.

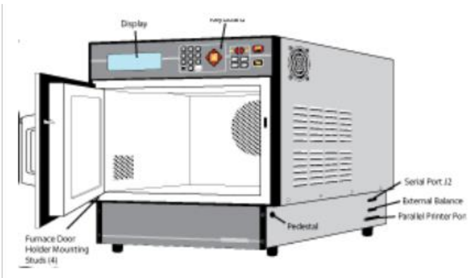
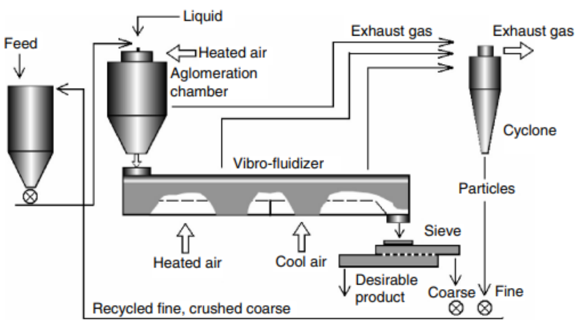


Figure 7: Microwave dryer

7. Fluidized bed drying technology

Fluidized bed drying employs a flow of hot air to uniformly and rapidly dry granular materials, wet particles, or agricultural products such as rice and maize. This method facilitates efficient heat and mass transfer and allows for easy temperature regulation. However, it is less energy-efficient and may adversely affect product quality, including color, texture, flavor, and nutritional components.



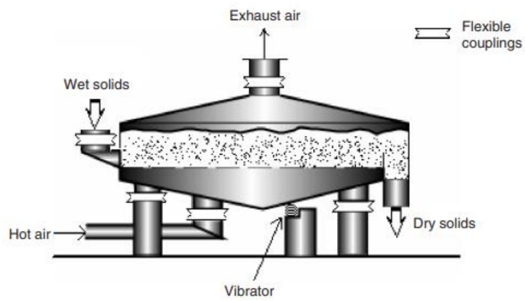


Figure 8 : Vibrating Fluidized bed dryer

Figure 9 : Multistage fludized bed dryer

8. Comparison of Drying technologies

Here's a comparative table(table1) of different drying technologies that summarizes the main characteristics, advantages, disadvantages, applications, product quality, energy efficiency, and costs of the various drying technologies:

Table 1:Comparison of different drying technologies

Drying Method	Drying Temperature	Advantages	Disadvantages	Applications	Product Quality	Energy Efficiency	Cost
Sun Drying	20-37 °C	Economical, simple to implement	Weather-dependent, long drying time	Fruits, vegetables, spices	Low control over quality	Low	Very low
Tunnel Drying	10-28 °C	More efficient than sun drying, good product protection	Weather-dependent, hard to predict	Horticultural products, fish	Average quality	Medium	Medium
Spray Drying	High temperature	Fast, flexible, low operating costs	Reduced quality of heat-sensitive proteins	Powdered products, encapsulation	Good quality for powders, reduced quality for proteins	Medium to high	Medium
Drum Drying	Very high temperature	Efficient, low operational costs, suitable for heat-sensitive products	Loss of lysine, lower quality compared to freeze-drying	Milk powder, fruit purees, baby food	Good for powdered products, but nutrient loss	High (60-90% efficiency)	Low
Freeze Drying	-10°C or lower	Preserves bioactive components, high sensory quality, minimizes nutrient loss	Expensive, high energy consumption	Pharmaceutical products, fruits, vegetables	Very high quality, preserves aromas and nutrients	Low	Very high
Microwave Drying	2450 MHz (12.24 cm wavelength)	Fast drying, better uniformity, energy-efficient	Can damage product structure, browning, texture degradation	Vegetables, fruits	Good color retention, but may cause texture damage	Very high	Medium
Fluidized-Bed Drying	Controlled temperature	Fast drying, temperature uniformity, good material handling	Less energy-efficient, quality loss (color, texture, flavor)	Agricultural products, cereals, fruits	Reduced quality (loss of color, texture)	Medium to low (< 50%)	Low

IV. Drying mechanism

Figure 10 shows an instance of the transport phenomena that occur during the thermal drying of a solid food material. During the convective drying of food materials in the air, two distinct transport mechanisms occur simultaneously: the transfer of heat from the drying air to the food material and the mass transfer, which is the movement of water (liquid or vapor) from the solid product's interior to its surface before evaporating into the atmosphere[3].

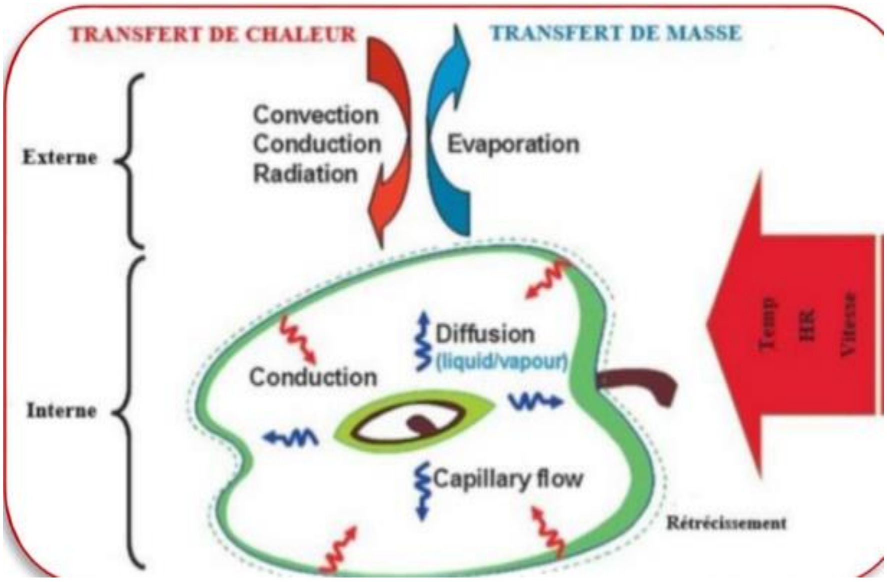


Figure 10: Theorical representation of thermal drying process in solid food

1. Heat transfer

The mechanism of heat transfer generally uses one of the following methods to transfer energy to the food material: conduction, convection, or radiation from a heated gas or heated metal surface[6].

a) Convection drying

This kind of heat transfer is influenced by a number of factors, one of which is the product's exchange surface, which can be difficult to define, particularly for hemisphere-granular solids. In this case, the calculation is done using particles diameter method. Reducing the size of the particles can enhance the drying process by facilitating the diffusion of humidity across the particle surface, as a larger surface area allows for more efficient heat transmission. The following equation mostly governs the movement of heat during convection drying:

$$\Phi = \alpha A(Ta - Ts) \quad (1)$$

b) Drying by conduction

The product to be dried is placed directly in front of a heated, solid wall, with the heated wall's surface in contact the product to facilitate heat exchange. The vapors released during drying are either aspirated (separated by ebullition) or entrained in a balayage gas whose debit is consistently lower than that required for a convective drying. This drying method is frequently employed in the paper and textile industries. The thermal flux in this transfer mode is given by the following relation:

$$\boldsymbol{\Phi = \lambda A \frac{dT}{dt}} \quad (2)$$

c) Drying by radiation

The process of drying by radiation transfers heat to the product to be dried by electromagnetic waves, mostly in the infrared spectrum. This process is based on the Stefan-Boltzmann law, which states that a surface's power output is proportional to the fourth power of its temperature. The amount of heat transferred is determined by the surface's emissivity, the source's temperature, and the exchange surface. This drying method works well and allows for precise temperature control without requiring direct contact with the heat source. The heat flux equation using Stefan-Boltzmann radiation is provided by:

$$\boldsymbol{\Phi = \sigma \epsilon A (T^4 - T_s^4)} \quad (3)$$

2. Mass transfer

The term "mass transfer" during drying refers to the movement of moisture from the product's inside to its surface, where it may evaporate. Two main mechanisms are involved in this process[7]:

- **Diffusion**: This mechanism primarily applies to continuous-structure products. According to Fick's second law, which states that material flow is proportional to the gradient of humidity concentration, water diffuses. Water moves within the product from highly concentrated areas to lowly concentrated areas.
- **Capillar migration:** Water moves through the material's pores in this mechanism. Capillarity allows water to move, and this is influenced by the product's porous structure and surface tension.

These two mechanisms are crucial to understanding how moisture is removed from the product during drying, and their effectiveness is dependent on a number of variables, including the temperature, humidity rate, and material type.

V. Advantages and disadvantages of drying

Food drying is a widely used preservation method that presents several advantages and disadvantages, influencing its application in the food industry[8]:

1. Advantages

- ❖ Dry a product reduces the moisture content of foods, inhibiting microbial growth and extending their shelf life. This characteristic is crucial for minimizing food waste and ensuring product safety.
- ❖ By removing water, drying decreases the weight and volume of foods, facilitating their storage and transport. This is particularly beneficial for products intended for export or retail.
- ❖ Certain drying techniques, such as freeze-drying, effectively retain the nutrients and sensory characteristics of foods, providing high-quality products.
- ❖ Traditional drying methods, such as sun drying and hot air drying, are relatively simple to implement and have low operating costs, making these techniques accessible to many producers.
- ❖ Modern technologies, such as spray drying, allow for rapid and uniform drying, promoting large-scale production and meeting market demand.

2. Disadvantages

- ❖ The drying process can lead to nutrient degradation and alteration in flavor, aroma, and texture, especially when high temperatures are used.
- ❖ Some methods, such as sun drying and freeze-drying, may require prolonged drying periods, potentially limiting their efficiency in large-scale production contexts.
- ❖ Sun drying exposes foods to environmental contaminants, increasing the risk of spoilage and food safety issues.
- ❖ While some drying methods are simple and inexpensive, more advanced techniques, such as freeze-drying and microwave drying, may require significant investments in equipment and energy.

- Certain drying techniques require specific adjustments to products or strict control over drying conditions, which can complicate the production process and necessitate technical expertise.

Chapter 2: State of the art on smart dryers and products to be dried

I. Definition of smart dryer

A Food Smart Dryer is an advanced drying system that efficiently removes moisture from food products while preserving their quality, flavor, and nutritional value. It utilizes vacuum technology to lower the boiling point of water, allowing for moisture evaporation at lower temperatures, which is ideal for heat-sensitive foods. The device features forced convection to enhance heat transfer, along with temperature and humidity control for optimal drying conditions. Overall, the Food Smart Dryer is energy-efficient and effective for drying various perishable items, making it a valuable tool for food preservation[9].

II. Evolution towards smart dryers

The evolution of food dehydrators, from traditional methods to "smart dryers," highlights significant technological advancements and improved control mechanisms. Initially, traditional dryers relied on natural air drying, which gradually gave way to industrial dryers that employed controlled heat and forced convection to achieve faster and more uniform drying.

Domestic versions of these dryers were later developed, incorporating temperature and humidity sensors to enhance the precision of the drying process. Today, "smart dryers" represent a further evolution by integrating microcontrollers, IoT connectivity, and customizable drying cycles. These advanced devices enable remote monitoring and control via mobile applications, optimize energy use, and offer an enhanced user experience while ensuring the highest quality of drying.

These innovations signify a shift toward smarter, more efficient, and adaptable appliances designed to meet contemporary food preservation needs.

III. Structure of a SMART dryer

A smart dryer, designed to meet the modern demands of food preservation, is built upon several key components that ensure its efficiency and functionality. First and foremost, intelligent temperature regulation is critical, as it ensures uniform drying while preserving the nutritional quality of the products[5]. This regulation is optimized through sensors and algorithms that adjust drying conditions in real-time, taking into account ambient humidity and the specific characteristics of the fruits or vegetables being processed.

Moreover, the integration of a cycle management system is indispensable. This system allows for the programming of drying periods, the control of ventilation phases utilizing forced convection technologies and the adjustment of parameters according to the specific needs of each type of product. This not only enhances energy efficiency but also ensures optimal preservation of nutrients.

Another fundamental aspect is the ability for remote monitoring and control. Through a connected interface, often accessible via a mobile application, users can track the progress of the drying process, receive alerts in case of malfunctions, and adjust parameters remotely. This feature significantly increases the convenience and flexibility of the dryer's use.

Lastly, ease of cleaning and maintenance is a critical factor. An ergonomic design and materials resistant to moisture facilitate cleaning and extend the appliance's durability, while also preventing the risk of cross-contamination.

IV. Mechanism of smart dryers

The forced convection mechanism is the fundamental phenomenon that drives the smart dryer's operation. Also, the drying process will be conducted in a vacuum or low pressure atmosphere, allowing the liquid to evaporate without raising the temperature[9].

1. Forced Convection Mechanism

Convection is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion. Depending on how the fluid motion is started, convection can be categorized as forced or natural (or free). Any fluid motion in natural convection is brought about by organic processes like the buoyancy effect, which causes warmer fluid to rise and cooler fluid to fall. In contrast, forced convection occurs when a pump or fan or other external device forces a fluid to move over a surface or through a tube. The process of forced convection involves the generation of fluid motion by an external source. In a smart dryer, this mechanism is achieved through the use of a vacuum pump to convey hot air from the heat source into the drying chamber.

2. Low Pressure Drying

Low Pressure Drying, commonly referred to as vacuum drying, is a technique that removes moisture from materials in a controlled low-pressure environment. By employing a vacuum pump, the pressure within the drying chamber is reduced, which lowers the boiling point of water. This allows moisture to evaporate at lower temperatures, making it particularly advantageous for heat-sensitive materials that may be adversely affected by high temperatures.

The key benefits of low pressure drying include significantly reduced drying times and the preservation of product quality. The vacuum environment minimizes oxidation and reduces the risk of combustion that can occur when certain materials are exposed to air. This method is especially effective for drying fruits, vegetables, and other agricultural products, as it helps maintain their nutritional content and sensory attributes.

V. Drying parameters

1. Product to dried

Because of their high nutritional value and perishability, fruits and vegetables are essential ingredients in food processing and preservation. Fruits are often sweet or sour and can be eaten raw or cooked. They are commonly described as the mature ovary of a blooming plant. They are prone to spoiling because of their high vitamin, mineral, and water content. On the other hand[5], vegetables are rich in nutrients and include a wide range of plant components, such as leaves, stems, roots, and tubers. Generally speaking, vegetables have less sugars than fruits.

An essential step in increasing the shelf life, cutting down on transportation expenses, and maintaining the nutritious content of these items is drying them. Fruits and vegetables vary in terms of water content, structure, and nutritional makeup, all of which affect how they dry out and, ultimately, how well-dried the final product turns out. The table that follows highlights several important drying qualities for specific fruits and vegetables that can be effectively dried with a smart drier.

Table 2 : Products and their drying caracteristiques

Products	Cutting Form	Initial Moisture (%)	Final Moisture (%)	Max Temp. (°C)	Approx. Time (hours)	Other Parameters
Fruit						
Mango	Thin slices	82-86	12-15	60-65	10-14	Blanching recommended before drying
Pineapple	Slices or cubes	85-90	12-15	55-60	12-16	Use of anti-browning agents recommended
Banana	Rounds	74-80	18-20	60-65	8-12	Pre-drying at low temperature suggested
Papaya	Thin slices	85-88	12-15	50-55	8-12	Acidic treatment for color preservation
Orange	Segments or slices	85-88	10-12	55-60	10-14	Slicing thin to ensure uniform drying
Guava	Slices or chunks	78-83	10-12	55-60	10-12	Peel and slice thinly for faster drying
Watermelon	Small cubes	91-93	15-18	50-55	8-10	High sugar content may require lower temp
Avocado	Slices or halves	60-70	10-12	50-55	8-12	Ensure even airflow to prevent browning
Vegetables						
Okra	Thin slices	89-92	10-12	55-60	10-14	Low-temp drying preserves vitamins
Spinach	Whole leaves	90-93	4-6	40-45	6-8	Blanching before drying to preserve color
Tomato	Rounds	93-95	10-12	55-60	8-12	Anti-browning agent recommended
Carrot	Thin slices	85-90	8-10	60-65	10-14	Ventilation crucial to retain Vitamin C
Eggplant	Thin slices or cubes	92-94	10-12	50-55	10-14	Uniform cutting for consistent drying
Onion	Rings or slices	86-90	5-8	50-55	6-8	Low-temperature drying to reduce odor
Pepper	Halves or slices	90-92	8-10	55-60	8-10	Ensures preservation of flavor and color
Cassava	Chips or small pieces	60-70	10-12	60-65	12-16	Pre-treatment with boiling reduces drying time

2. Characteristics of the product to be processed

The specific characteristics of fruits and vegetables play a crucial role in their drying behaviour. Fruits, which are generally richer in sugars and organic acids, have a higher initial water content than vegetables. This water content, ranging from 70% to 90%, affects the drying duration and the conditions required for uniform drying. The cellular structure of fruits, often more delicate, requires careful management of temperature and air velocity to avoid surface hardening a phenomenon where a dry crust forms before the interior is adequately dehydrated. This can not only alter the texture but also reduce the nutritional quality of the dried product.

Regarding vegetables, their fibber and starch composition generally makes them less susceptible to surface hardening, but they present other challenges. Leafy vegetables, for example, require lower drying temperatures to avoid the degradation of chlorophyll pigments, which are sensitive to heat. Additionally, the density and size of vegetable pieces directly influence the drying duration, necessitating uniform cutting to ensure even drying.

3. Drying parameters

The drying parameters, such as air temperature, relative humidity, and air velocity, are crucial in optimizing the dehydration process. These parameters must be carefully controlled to ensure the preservation of the nutritional and organoleptic qualities of fruits and vegetables while achieving efficient drying.

- **Temperature**

The drying temperature needs to be sufficiently high to promote water evaporation without reaching levels that could degrade heat-sensitive compounds, such as vitamins or volatile aromas. Temperatures between 40°C and 70°C are often ideal for drying fruits and vegetables, though this range can vary depending on the type of product. For instance, more delicate fruits might require lower temperatures to prevent nutrient loss, while sturdier vegetables could withstand slightly higher temperatures for faster drying.

- **Relative Humidity of Air**

The relative humidity of the drying air is another critical factor. Air that is too dry can cause surface hardening, leading to a phenomenon known as case-hardening, where the exterior of the food dries too quickly and traps moisture inside. Conversely, air that is too humid slows down the dehydration process and can promote mold growth. A relative humidity level of around 30% to 50% is generally recommended for effective drying, as it strikes a balance between sufficient moisture removal and the prevention of undesirable effects on the food's texture and safety.

- **Air Velocity**

The velocity of the drying air should be high enough to remove moisture effectively without creating excessive turbulence, which could damage the fruits and vegetables or result in thermal losses. A moderate air velocity, typically between 1 and 3 m/s, is often recommended to balance water evaporation with the protection of the products' organoleptic and nutritional qualities. Higher air speeds can expedite drying but may also lead to uneven drying or mechanical damage, particularly in fragile products.

Mastering the drying parameters for fruits and vegetables requires a rigorous approach, integrating the specificities of each product and the optimal drying conditions. These insights, based on solid scientific data, are essential for designing an efficient dryer and ensuring the quality of dried products.

Part II:

Design and Implementation

Chapter 1: Functional Analysis of the Smart Dryer

This chapter provides a thorough functional analysis of the intelligent domestic dryer. The goal of functional analysis is to identify the product's key requirements and essential features in order to ensure that it meets user needs and adheres to current standards. By focusing on the key functions, service, technical, and constraint aspects, we create a strong foundation for the dryer's development while guaranteeing its peak performance, dependability, and compliance with market expectations. This systematic approach makes it possible to translate functional requirements into precise technical specifications, facilitating an efficient and targeted conceptualization.

I. Definition of need analysis

Functional analysis, according to NF EN 1325- NF X 50-153, involves the identification, characterization, organization, prioritization, and evaluation of all the functions of a product throughout its entire life cycle[10]. In this context, the aim is to define the specific requirements related to the smart dryer, including the specifications and the technical and technological solutions to be implemented to meet customer expectations.

For any given product, functional analysis employs two interdependent perspectives:

- ❖ The external perspective, which is user-oriented, focuses on expressing needs in terms of functions. This leads to the definition of the future equipment essentially the "*what*" through functional specifications. This process is referred to as functional analysis of needs.
- ❖ The internal perspective, which is designer-oriented, is concerned with fulfilling the defined functions. It seeks to determine the "*how*" to satisfy the needs expressed through these functions.

This study aims to clearly identify and delineate the functions that the dryer must fulfill, which we will categorize into four distinct groups[11]:

- ❖ **Primary functions (FP):** These functions are the core reason for the product's existence.
- ❖ **Service functions (FS)**: These are associated with the product’s usage. They are directly perceptible to the user, and the product's quality is therefore largely dependent on them.

- **Technical functions (FT)**: These are internal to the product, and they influence the selection and design of technological solutions that must satisfy the service functions.
- **Constraint functions (FC)**: These functions impose limitations on the primary functions. They primarily reflect the constraints related to product acceptance, such as compliance with standards, environmental resistance, aesthetics, and so forth.

While this classification could be further refined, given the relatively low complexity of the machine to be designed, we have limited our analysis to these four categories.

II. Need analysis

According to AFNOR, "A need is a desire (or necessity) experienced by the user of a system." Defining the need involves answering three fundamental questions:

- Whom is the product useful for?
- What does it act?
- For what purpose?

Answering these questions will facilitate the development of the "horned beast" diagram (Fig.11), which justifies the design of the system.

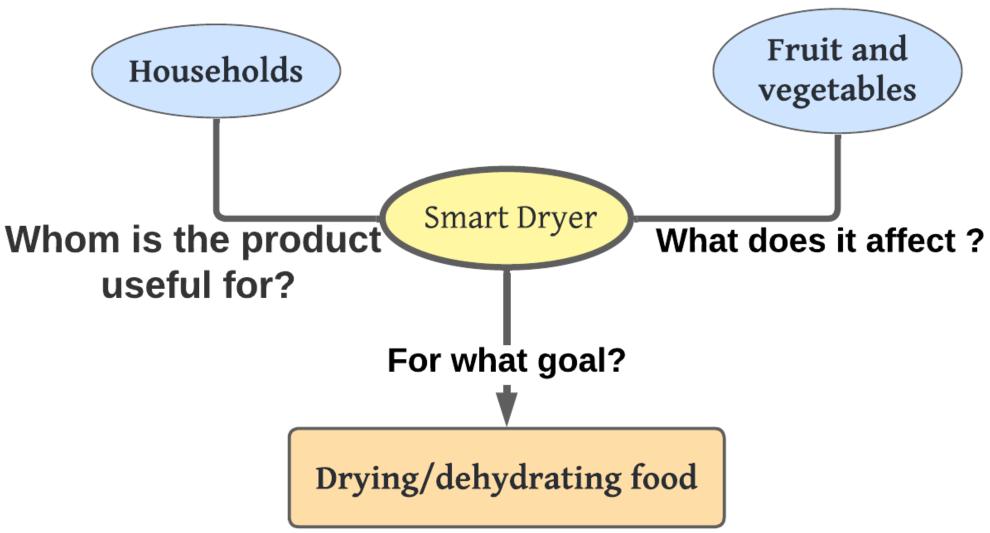


Figure 11:Horned beast

"The smart dryer serves households by enabling them to dehydrate their fruits and vegetables at will."

III. Function and criteria identification and definition of the charge sheet

Service functions describe the value of a product by defining actions that meet the user's needs. These functions are often categorized into primary functions, complementary functions, and constraints. The various described functions and their characterization will be considered essential elements of the product specifications.

The tool most commonly used to identify all service functions is the octopus's diagram. This interactors' graph facilitates the identification of elements within the environment that are likely to interact with the product. The octopus's diagram for our smart dryer is illustrated in Fig. 12:

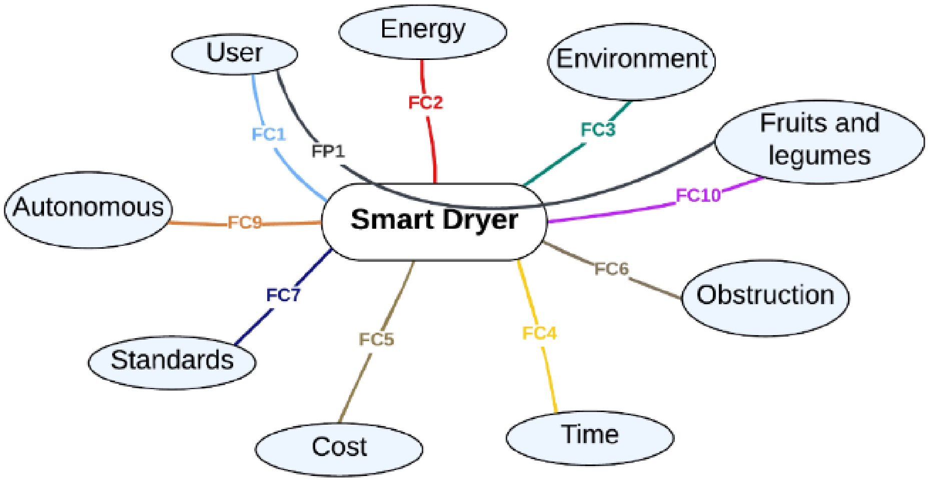


Figure 12: Octopus Diagram

Thus, we can list the following service functions:

- **FP1**: Enable the user to dynamically dry common tropical agro-food products (fruits and vegetables).
- **FC1**: Be ergonomic, meaning it should display real-time operating parameters of the machine, which are adjustable by the user.
- **FC2**: Adapt to the available electrical power source.
- **FC3**: Not degrade the surrounding environment.
- **FC4**: Achieve optimal drying time.
- **FC5**: Be cost-effective.
- **FC6**: Maintain optimal dimensions.
- **FC7**: Comply with quality, safety, and design standards.
- **FC8**: Be easily maintainable and cleanable.
- **FC9**: Include self-regulation functions.
- **FC10**: Produce finished products that meet drying standards.

1. Main Functions

Main functions are those that justify the creation of the product. In this case, there is only one main function, stated as follows:

FP: Enable the user to dynamically dry common tropical food products (fruits and vegetables) to achieve a moisture level approximately equal to 10%.

2. Service Functions

Service functions are defined based on the product's acceptability criteria for consumers in Burkina Faso:

- **Fs1**: Be easy to handle.
    - The procedures for starting, stopping, adjusting drying temperature, and monitoring should be simple and executable by any potential user.
- **Fs2**: Dry a wide range of food products.
- **Fs3**: Be reliable and easily maintainable.
    - The dryer should offer reliability comparable to that of a domestic refrigerator, with maintenance requiring no additional skills beyond those needed for conventional household appliances (refrigerators, washing machines, etc.).
- **Fs4**: Have an acceptable capacity.
    - Maximum quantity of products: 15 kg (capacity for processing in a single batch).
- **Fs5**: Dry quickly.
    - Time required to reach the target moisture level for products: < 3 hours.
    - Maintain a constant optimal temperature for rapid drying.
- **Fs6**: Be cost-effective.
- **Fs7**: Utilize local materials.
    - Use wood or recycle refrigerator
- **Fs8**: Have an acceptable capacity.
    - Maximum quantity of products: 15 kg (capacity for processing in a single batch).
- **Fs9**: Dry quickly.
    - Time required to reach the target moisture level for products: < 3 hours.
    - Maintain a constant optimal temperature for rapid drying.
- **Fs10**: Comply with food preservation and environmental standards.
    - Adherence to local and international standards for food safety and environmental protection (HACCP, ISO 22000, etc.).
    - Materials in contact with food must meet food safety standards.

- **Fs11**: Have a highly communicative human-machine interface (HMI).
  - User-friendly and easy-to-use interface displaying drying parameters (air and humidity), remaining time, etc.
- **Fs12**: Automatically stop when drying is complete.
  - System capable of detecting when products have reached the desired moisture level and automatically shutting off to prevent over-drying.

3. Technical Functions

Technical functions describe the internal actions between the product's components, defined to meet the technical requirements for optimal domestic drying by convection:

- **Ft1**: Provide electrical power from the domestic network.
  - The characteristics of the power supply are: 220V-50Hz.
- **Ft2**: Utilize hot air convection by ventilation combined with a heating element.
  - Air circulation speed should be between 0.5 m/s and 3 m/s, depending on the product type.
- **Ft3**: Monitor and visualize internal temperature and humidity constants.
- **Ft4**: Have a monobloc design.
- **Ft5**: Insulate to limit heat and air mass transfer.
  - Sealing and thermal insulation should adhere to the temperature gradient constraint of function Ft6.
- **Ft6**: Maintain low temperature gradients.
  - Temperature drop should be less than 1°C per drying shelf.

4. Constraints Functions

Constraint functions are defined according to the standards applicable in the field of food-related home appliances:

- **Fc1**: Do not contaminate the products
- **FC2**: Have a footprint similar to that of conventional household appliances.
  - The dimensions of the dryer should be comparable to those of a domestic refrigerator, ideally: Maximum length: 50 cm, Maximum width: 50 cm, Maximum height: 80 cm
- **Fs3**: Consume low energy.
  - The power of the dryer should not exceed 2 kW.

Chapter 2: 3D Design of the Dryer

Using sophisticated tools and procedures that guarantee optimal performance is crucial when creating a technologically innovative and efficient smart dryer. This chapter explores the complex process of creating a smart dryer, technical drawing, and 3D modeling that are essential to its design. This chapter outlines the methodical process used to envision, model, and enhance the dryer's functionality using SOLIDWORKS, a top computer-aided design (CAD) program. It offers a thorough overview of the design process by carefully analyzing the component arrangement, the connections between crucial parts, and the thermal dynamics within the drying chamber. This process turns the initial concept into a workable product that is prepared for accurate fabrication and effective operation.

I. Detailed operation description

The smart domestic dryer developed within this project operates on a drying process optimized by forced convection technology, designed to ensure uniform and efficient dehydration of food products. The fundamental principle underlying the dryer’s operation is the removal of moisture from food by exposing it to a regulated flow of heated air, while maintaining specific temperature and humidity conditions tailored to the type of food being processed.

At the core of the system lies an axial fan, a heating element, and sensors (notably for temperature and humidity), all governed by an ESP32 microcontroller. Upon activation, the heating element raises the temperature of the air within the drying chamber. Once heated, this air is propelled by the axial fan, generating a directed airflow across the food items placed on the drying racks.

The forced convection mechanism ensures a continuous flow of warm air that circulates evenly around the food, facilitating rapid and uniform moisture evaporation. The integrated sensors continuously monitor the temperature and relative humidity within the drying chamber, providing essential data to the microcontroller, which automatically adjusts the power of the heating element and the speed of the fan as needed. For instance, if the humidity sensor detects a significant reduction in ambient moisture, the heating power can be decreased to prevent the overheating of the food.

The dryer is also equipped with several intelligent features aimed at enhancing the user experience. The control system allows users to select from predefined settings based on the type of food (fruits, vegetables, etc.) or to manually configure customized drying cycles via a mobile application connected through Bluetooth. The user interface, accessible via an LCD screen, displays real-time drying parameters such as temperature and humidity.

A critical aspect of the dryer's operation is its safety system. In the event of a malfunction detected by the sensors or if critical temperature thresholds are exceeded, the dryer automatically enters standby mode or shuts down completely, alerting the user through the mobile application.

Furthermore, the dryer incorporates an adaptive drying system based on intelligent algorithms that analyze real-time drying data and adjust the parameters to optimize the process. This capability not only reduces drying time but also preserves the nutritional and organoleptic quality of the food.

Thus, this smart dryer represents a comprehensive and innovative solution for domestic food drying, combining energy efficiency, precise control of drying conditions, and user safety, while offering maximum flexibility through its customization and real-time monitoring capabilities.

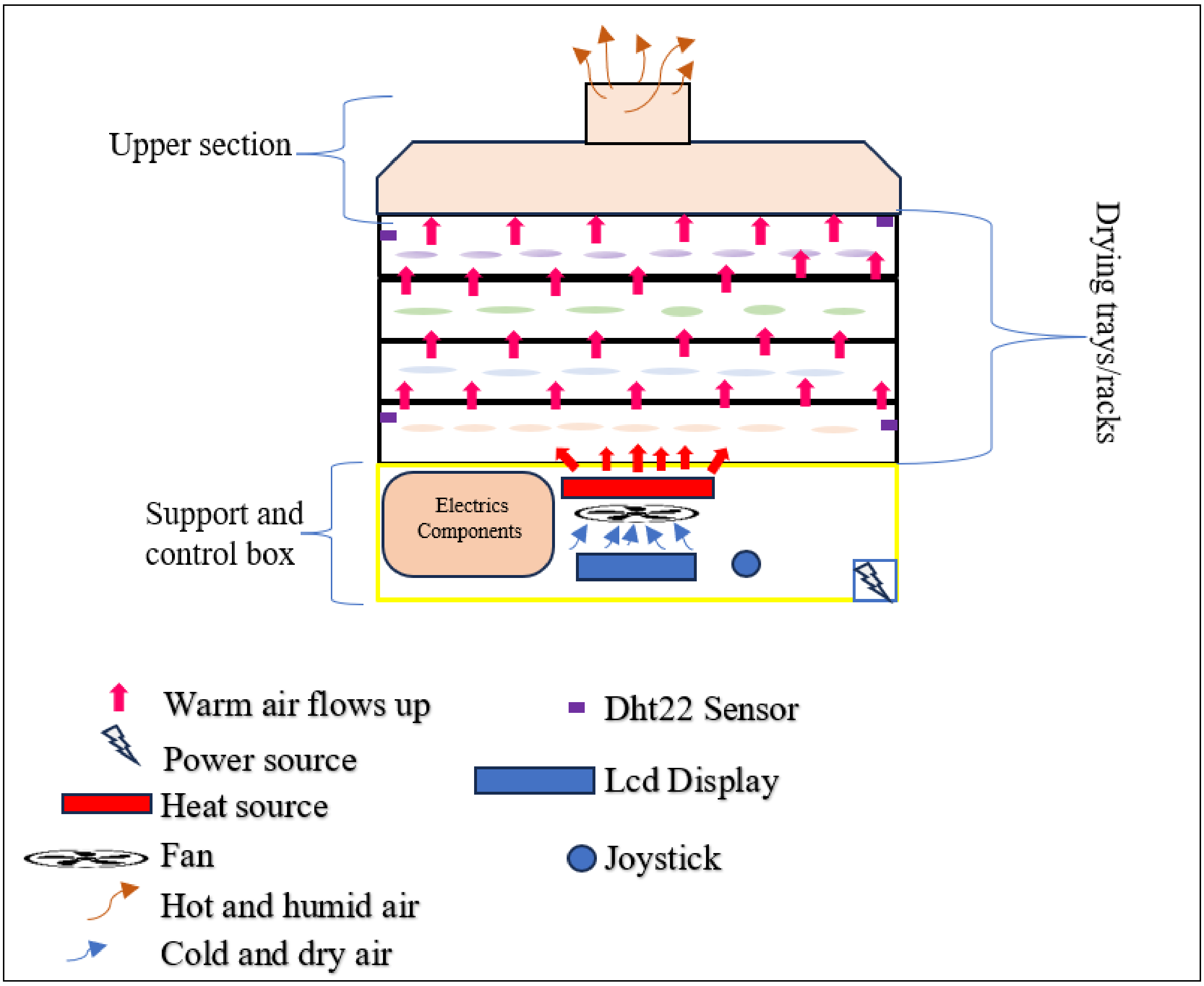


Figure 13: Descriptive Diagram of the Smart Dryer's Functionality

II. Design software Overview

In the context of designing my smart dryer, SOLIDWORKS proves indispensable for 3D modeling, technical drafting, and thermal simulation. This software enables the creation of precise representations of components, the testing of various configurations, and the optimization of the overall design. The drafting process facilitates production by generating detailed technical drawings, ensuring precise manufacturing. Thermal simulation further assesses the dryer's performance, guaranteeing optimal conditions for uniform drying. Thus, SOLIDWORKS in figure 14 transforms the conceptual idea into a product ready for fabrication, while maximizing both thermal and mechanical performance.

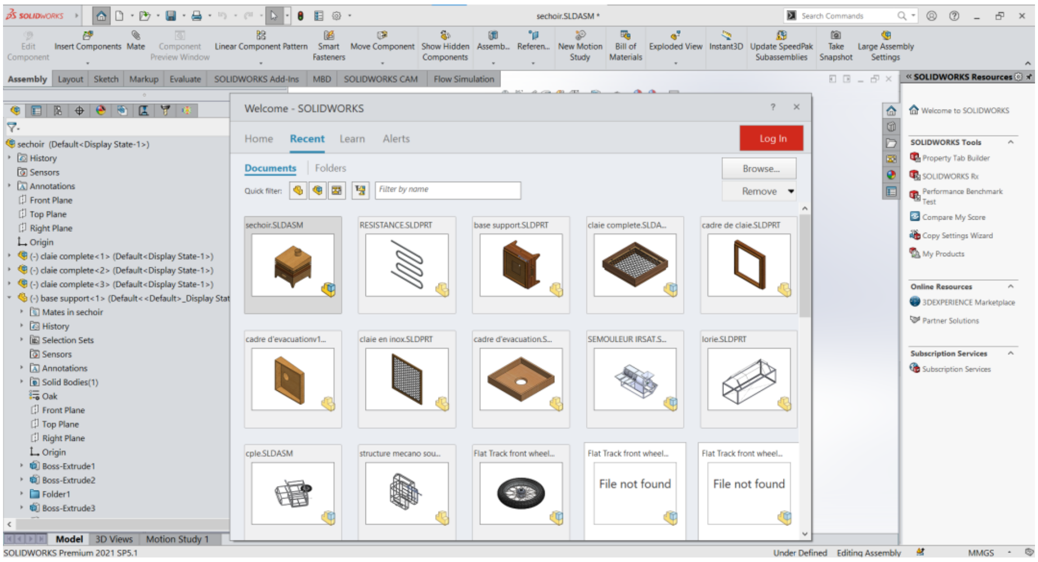


Figure 14: SOLIDWORKS Interface

III. 3D Model Proposal

The proposed 3D model of the smart food dryer is depicted in Figure 16, which illustrates the complete 3D assembly of the dryer. Additionally, Figure 15 provides a more detailed view.

In the appendix, it includes layout drawings that demonstrate the arrangement and interconnection of the key components. The detailed technical drawings and assembly diagrams provided with the project offer essential information for precise manufacturing and provide a comprehensive understanding of the constituent elements. These drawings give detailed views of each part and their assembly relationships, allowing for a thorough analysis of the construction and functionality of the smart dryer.

It is also worth noting, as referenced in FS7, that part of the project's specifications includes the innovative reuse of an old refrigerator. This approach not only gives a new purpose to an otherwise obsolete appliance but also aligns with sustainable practices by repurposing existing materials for the creation of the smart dryer. This consideration forms a crucial aspect of the project's commitment to sustainability and resource efficiency, demonstrating an effort to reduce waste and promote the circular economy in technological development.

Figure 16:3D Proposition Model of smart dryer

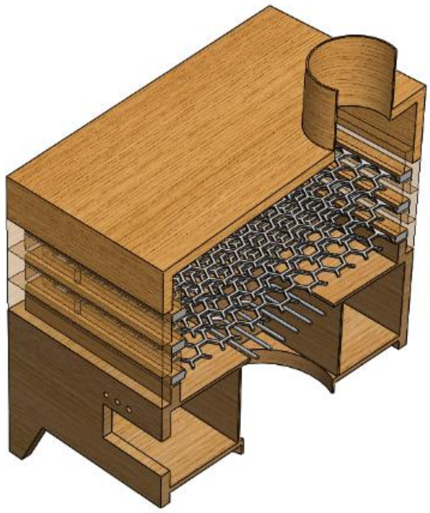


Figure 15: Intern section view

Chapter 3: Implementation of Electrical and Electronic Circuits

This chapter is dedicated to the design and implementation of the electrical and electronic circuits of the smart dryer. It thoroughly examines the selection of key components, justifying their choice based on technical and functional criteria. The circuit assembly is also detailed, illustrating the integration process of various elements to ensure the dryer operates optimally. This meticulous approach to design and assembly aims to ensure maximum efficiency of the device while adhering to safety and reliability standards.

I. Selection and sizing of Electrical and Electronic Components

The following elements represent the essential components required for this project.

1. ESP32

The ESP32 is an advanced microcontroller [12]chosen for the smart dryer due to its integrated Bluetooth connectivity, which enables precise control via a mobile application. Its processing power and multitasking capability ensure smooth management of connected sensors and components, while its low energy consumption extends the device's lifespan. The ESP32 also stands out for its compatibility with a wide range of peripherals, making it an optimal choice for a modern domestic dryer that combines efficiency with connectivity.

Figure 17 : ESP32 Board

2. Temperature and Humidity Sensor (DHT22)

The digital DHT22 sensor, also known as AM2302, is employed to measure temperature and humidity in a smart domestic dryer project. It is recognized for its accuracy of ±0.5°C for temperature and ±2-5% for humidity, covering a broad measurement range (-40°C to +80°C for temperature and 0% to 100% for humidity). This sensor uses a single-wire interface, simplifying its integration with the ESP32. By providing digital data, it eliminates the need for analog conversions, thus facilitating its use in the dryer's control system. With its precise measurements, the DHT22 allows real-time adjustments of heating and ventilation, ensuring uniform and efficient drying while preventing conditions conducive to mold or bacterial growth.

Figure 18: DHT22 Sensor

3. 16x2 LCD Display

The 16x2 LCD display, chosen for its ease of use and its ability to clearly display real-time information, offers two lines of text to simultaneously visualize essential data such as temperature and humidity. Its I2C interface simplifies wiring and optimizes space within the dryer's enclosure. Powered by 5V and compatible with the Arduino ESP32[12], this display ensures a durable and energy-efficient solution, enhancing ease of use and precise control of drying parameters.

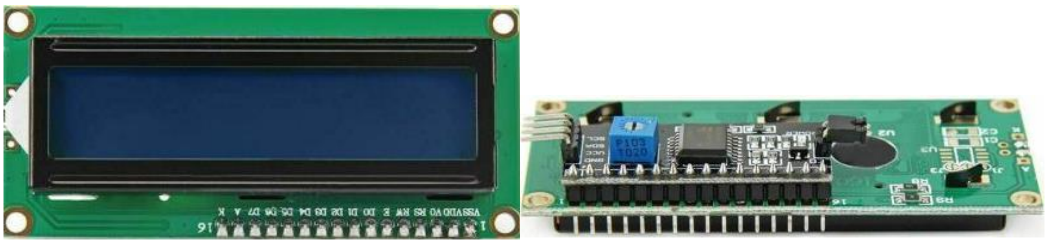


*Figure 19: LCD 16*2 Display*

4. Analog Joystick

The analog joystick was chosen for its smooth and precise control of drying options, offering multidirectional navigation that advantageously replaces traditional buttons. It allows for accurate parameter selection due to its sensitivity to movements along the X and Y axes, while also reducing the footprint of the control panel. Additionally, its compatibility with the Arduino ESP32 simplifies integration, thereby enhancing the system’s ergonomics and efficiency.

Figure 20: Analog Joystick item

5. Operation Status LEDs

These status LEDs provide immediate visual feedback on the dryer's operational state, thereby improving ease of use and process monitoring.

- Red: Indicates that the dryer is powered on but inactive;
- Orange: Indicates that the drying process is in progress;
- Green: Indicates that the drying is complete.

6. Electronic Components for Power Management

To ensure effective power management in the smart dryer, several essential electronic components are required[12]:

- **Relays**

The 12V relay plays a crucial role in controlling the circuits within the smart dryer. It is used to switch low-power signals from the Arduino, allowing for control of the command circuits while isolating electronic signals from the rest of the system. This isolation is vital for protecting sensitive components and enhancing the overall reliability of the system. The relay is chosen for its ability to switch the necessary power to components such as the fan and the heating element, ensuring safe and reliable power switching, and providing precise control over the drying conditions.

Figure 21: Relay

❖ **Cables and Connectors:**

Cables and connectors are necessary for linking the various electronic and electrical components of the dryer. The cables must be suited to the voltage and current of the circuits they power, while the connectors must provide secure and reliable connections. Proper management of cables and connectors is essential for ensuring the durability and safety of the system.

Figure 22: Cables

❖ **Power Button:**

The power button is essential for controlling the dryer’s power supply, allowing the user to safely and easily turn the device on or off.

Figure 23: Switch

❖ **H-Bridge:**

An H-Bridge is an electronic circuit designed to control the direction and speed of a direct current (DC) motor using a continuous voltage source. This device consists of four switches, typically in the form of MOSFET or bipolar transistors[12], arranged in an H shape, allowing for bidirectional current regulation through the motor. The integration of an H-Bridge in the smart dryer is justified by the need for precise fan control, which is essential for modulating airflow to ensure uniform hot air distribution and maintain optimal drying conditions. This circuit enables the regulation of the fan speed by adjusting the pulse width modulation (PWM) signal sent to the motor, thereby adapting the airflow according to temperature and humidity variations within the drying chamber.

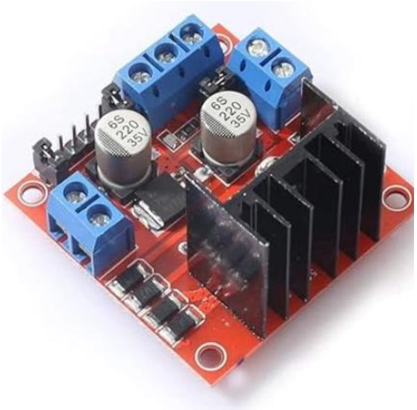


Figure 24: H Bridge item

7. Axial Fan Sizing

To appropriately size the fan element for smart forced-air convection dryer, we must adopt an approach that considers both the thermal requirements and the airflow demands within the drying chamber

Air Velocity: The desired air velocity for convection is a maximum of 5 m/s. This velocity is crucial to ensure uniform and efficient heat transfer throughout the drying chamber. A sufficiently high airspeed minimizes drying time.

Airflow Calculation: The required airflow Q to achieve this velocity within the drying volume is calculated using the formula:

$$Q = A * v$$

The drying chamber has a rectangular opening with approximate dimensions of 0.2 m x 0.15 m:

$$A = 0.2 * 15 = 0.03m^2$$

$$Q = 0.03 * 5 = \mathbf{0.15}m^3/\mathbf{s} = \mathbf{150L/s} = \mathbf{540}m^3/\mathbf{h}$$

Thus, the required airflow is 540 m^3/h. However, this calculation represents the maximum airflow. In practice, an axial fan with adjustable airflow up to 100 m^3/h is more appropriate, as it allows for adjusting the airspeed according to the specific drying needs.

Axial Fan Selection

For implementation, a 12V DC axial fan, with a power rating of 6.6W and a current of 0.55A, capable of providing an airflow of up to 200 m^3/h, would be ideally suited for this project. This fan, paired with an air filter to maintain the quality of circulating air and prevent unwanted particles from entering the drying chamber, will operate at a maximum speed of 5 m/s. This ensures effective convection of the heated air, thereby guaranteeing uniform drying of the food within the entire drying chamber.

Table 3: Caracteristics of fan

Filter	**FK6622.012**
Fan model	YF12038M12B
Rated voltage	12VDC
Rated current	0.55A
Power	6.6W
Max Air flow	113m³/h
Noise level	35dB(A)
Size	148.5×148.5×68.5mm
Exit filter	FK6622.300
Scope of temperature	-20℃~+65℃

Figure 25: Axial fan item

8. Heating Element Sizing

The sizing of the heating element for a smart dryer, we will consider two hypotheses (H1 and H2) and analyze the relationship between the heating element and the fan operation. The fan provides fresh air flow as long as the moisture content of the products exceeds 15%, ensuring effective moisture removal while maintaining optimal drying conditions.

Heating Element and Fan Interaction

The heating element and fan work in tandem to maintain a controlled drying environment. The fan provides a continuous supply of fresh air, which aids in the removal of moisture from the drying chamber. As long as the moisture content of the products is above 15%, the fan introduces new air to replace the moisture-laden air.

The heating element compensates for any temperature drop caused by the introduction of fresh air, ensuring that the chamber temperature remains stable and conducive to drying. The balance between heating and airflow is crucial for achieving efficient drying without over-drying or under-drying the products.

Hypothesis 1 (H1): Calculating the Power of the Heating Element Based on Chamber Volume

Assumption: The power of the heating element is determined by the volume of the drying chamber and the energy required to raise the chamber temperature to 75°C.

- Volume of Drying Chamber (V): The volume is determined by the physical dimensions of the drying chamber. For example, let's assume a chamber volume of 0.02 m³.
- Target Temperature (T_target): 80°C

- Initial Temperature (T_initial): Assuming an initial ambient temperature of 25°C.
- Temperature Difference (ΔT):

$$\boldsymbol{\Delta T = Ttarget + Tinitial} \tag{4}$$

$$\boldsymbol{\Delta T} = 80°\text{C} - 25°\text{C} = 55°\text{C}$$

- **Energy Requirement (Q):** The energy required to heat the air in the chamber is calculated using the formula:

$$\boldsymbol{Q = \rho \cdot V \cdot Cp \cdot \Delta T} \tag{5}$$

$$Q = 1.2 \cdot 0.05 \cdot 1005 \cdot 55 = 3316.5 Joules$$

- Power Requirement (P): To maintain this temperature rise, the power required over a period (Δt) can be calculated:

$$\boldsymbol{P = \frac{Q}{\Delta t}} \tag{6}$$

- If we aim to reach the target temperature in 5 minutes (300 seconds):

$$\boldsymbol{P = \frac{3316.5}{300} \approx 11\ \text{W}}$$

However, considering thermal losses and ensuring the element is capable of maintaining the temperature under dynamic conditions, a safety factor of approximately 10 is applied[13]:

$$\boldsymbol{P = 11 * 10 = 110W}$$

In practice, a heating element with a higher rating, such as 200W, would be chosen to ensure rapid temperature stabilization and compensate for thermal losses.

Hypothesis 2 (H2): Estimating the Time to Reach 75°C in the Drying Chamber

Assumption: The efficiency of the heating element is also assessed by the time required to reach 80°C within the drying chamber in 2 min.

- Heat Energy (Q): The total energy required to heat the chamber remains 3015 Joules (as calculated above).
- Power of Heating Element (P):
- Assuming a 200W heating element: P=200 W=200 J/s
- Calculation of Required Power (P): The power needed to reach 75°C in 120 seconds can be calculated using the formula:

$$\boldsymbol{P = \frac{Q}{\Delta t}}$$

- Substituting the values: P=3316.5/120≈28 W

Adjustment for Thermal Losses: In practice, to account for thermal losses and inefficiencies, a safety factor is often applied (typically around 4 for a dryer)[14].

Therefore, the adjusted power would be: $Pcorrected = 28 \times 4 = 112\,W$.

To compensate for thermal losses and ensure effective heating, a heating element of minimum 200W would be ideal.

Selection of the Heating Element

Therefore, a heating element rated minimum 200W, operating at 220V, 12V, or 24V, would be suitable for reaching and maintaining the temperature of 85°C in a 0.05 m³ drying chamber. This power ensures an effective temperature rise while compensating for thermal losses due to convection and conduction. In our case, the heating element that will heat our drying chamber will be with power of 500W:

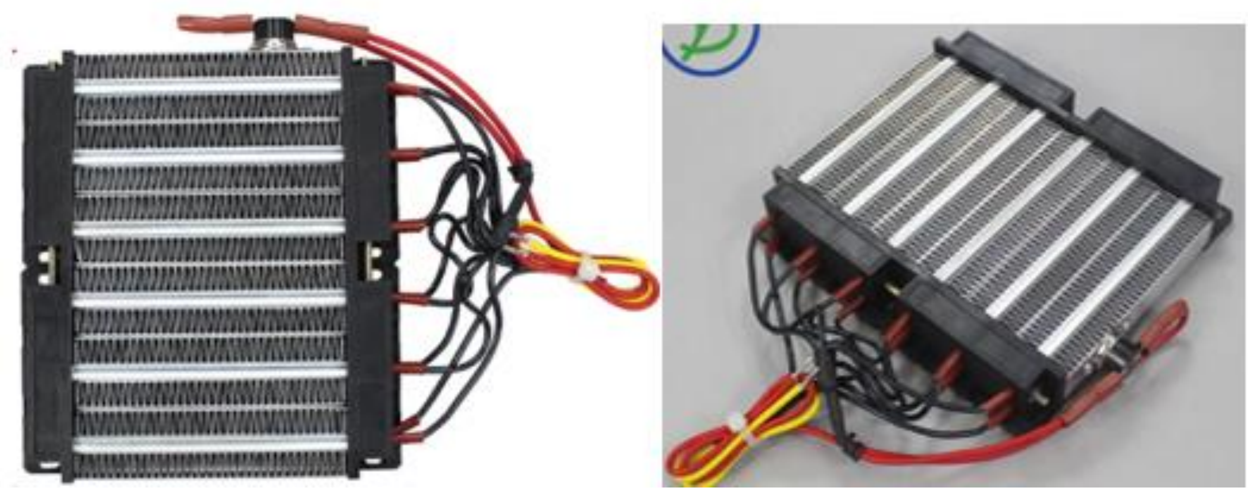


Figure 26: heating item

II. The Schema wired

The following picture show us the wire of electric elements which will be put in the command box to control the smart dryer

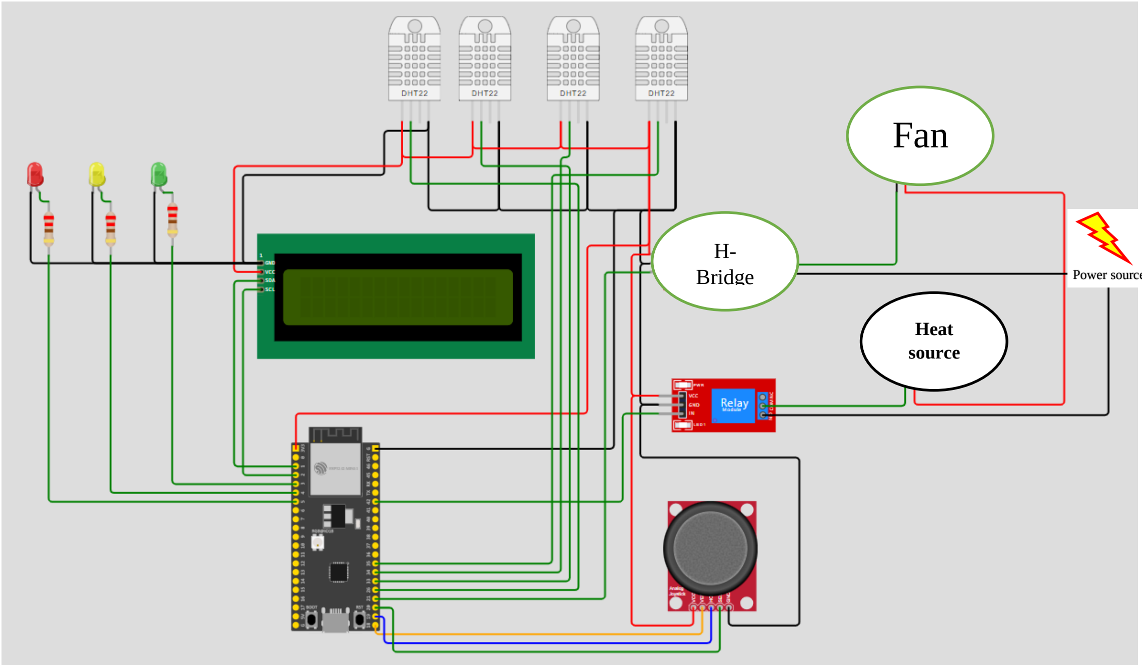


Figure 27:Wiring Shema of electronic elements

III. Implementation of Wireless Control for Custom Drying Settings

1. Description of operation

The dryer will operate using a programmed logic system, defined as follows:

After powering on the device, the system has 10 seconds to initialize its data and check the status of the sensors. The drying process offers two options:

Standard Option:

- ❖ The user can select the type of product to be dried (fruit, vegetable, or a combination) using the selection buttons. The choice is displayed on the LCD screen.
- ❖ Based on the selected type, the dryer applies pre-configured temperature and airflow parameters optimized for each product category.
- ❖ Once drying begins, the internal temperature and humidity are displayed on the LCD screen in real-time. The drying process will only stop when the predefined final humidity level for standard drying in the chamber is reached. At that point, the fan

and heating element will cease operation, and the LCD display will show “Drying Complete.”

Customized Option:

- Using a smartphone interface, the user can set customized drying parameters.
- This customization includes setting a constant internal temperature within the drying chamber and adjusting the airflow.
- The system automatically calculates the optimal drying time based on the detected humidity within the chamber and adjusts the parameters accordingly to ensure uniform and efficient drying.
- Once drying begins, the internal temperature and humidity are displayed in real-time on both the LCD screen and the user’s smartphone. The drying process will only stop when the final humidity level, predefined by the user, is reached. At that point, the fan and heating element will cease operation, and the LCD display, along with the user's smartphone, will show “Drying Complete.”

2. Flowchart of Operation

Figure 26 is the logical flowchart that allow the great operating of smart dryer:

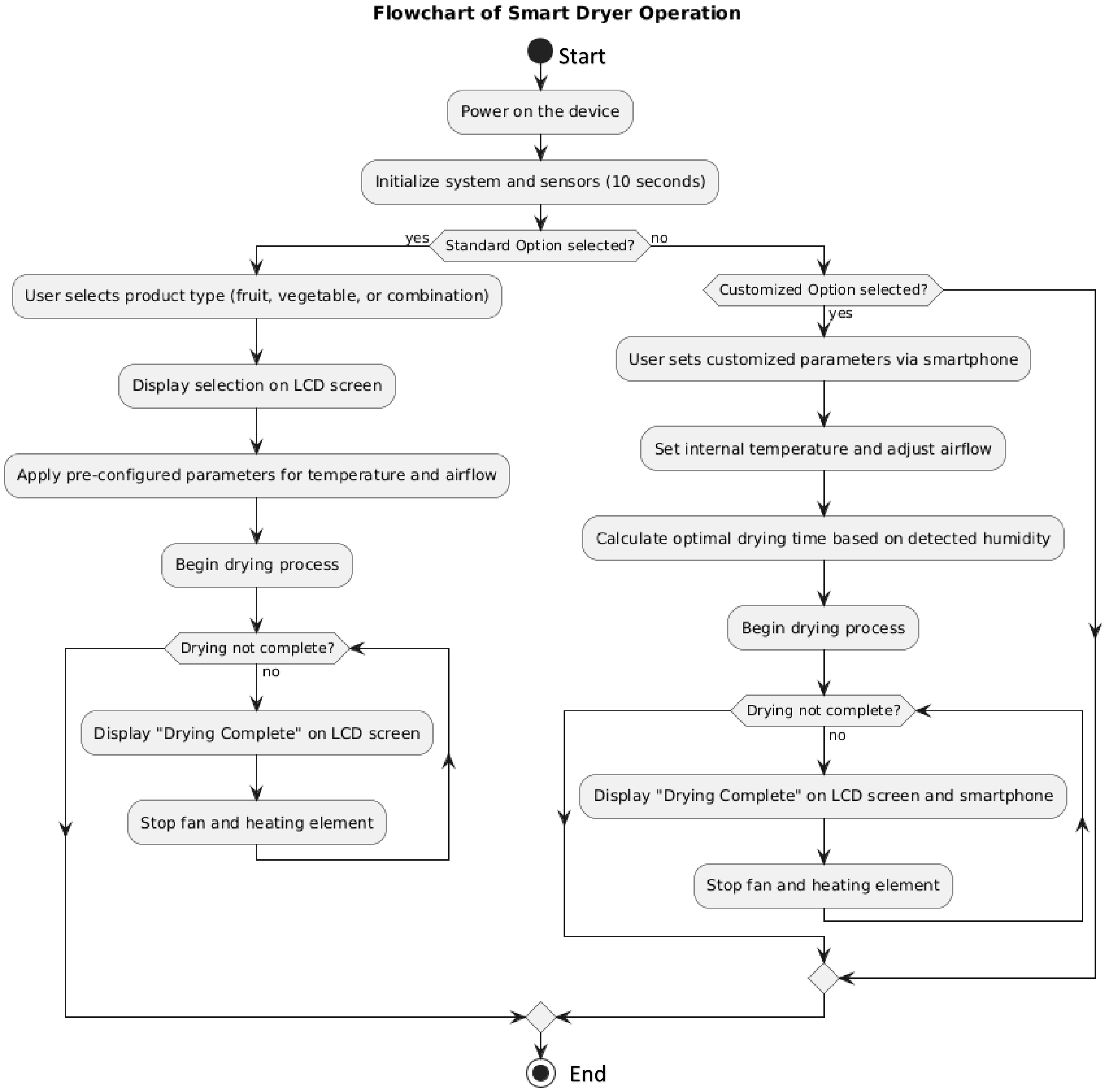


Figure 28: Flowchart of smart dryer operating

3. Portion of Code to Implement

The following code snippet was developed and tested using the Arduino IDE, designed specifically for the ESP32 microcontroller to control a smart dryer. The code handles various functionalities including Bluetooth communication, sensor data acquisition, and drying process control.

Smart_Dryer_code | Arduino IDE 2.2.1

Smart_Dryer_code.ino

```
#include <BluetoothSerial.h>
#include <DHT.h>
#include <LiquidCrystal.h>
// Definitions for pins and components
const int relayFanPin = 12;        // Pin for controlling the fan
const int relayHeaterPin = 13;     // Pin for controlling the heating element
const int dhtPin = 14;             // Pin for the DHT22 sensor (temperature & humidity)
const int lcdRs = 15, lcdEn = 16, lcdD4 = 17, lcdD5 = 18, lcdD6 = 19, lcdD7 = 21; // Pins for LCD display
const int joystickXPin = 32;       // Pin for joystick X-axis
const int joystickYPin = 33;       // Pin for joystick Y-axis
// Variables for sensor readings
float temperature = 0.0;
float humidity = 0.0;
float targetHumidity = 0.0;
float targetTemperature = 0.0;
// Variables for drying process
int dryingOption = 0;  // 0 for Standard, 1 for Customized
unsigned long dryingTime = 0;
unsigned long startTime = 0;

// Variables for display status
String dryingStatus = "Idle";
// Initialize Bluetooth, DHT sensor, and LCD display
BluetoothSerial SerialBT;
DHT dht(dhtPin, DHT22);
LiquidCrystal lcd(lcdRs, lcdEn, lcdD4, lcdD5, lcdD6, lcdD7);
void setup() {
```

Figure 29: Part of system code

4. Graphical Interface of the Custom Settings Application on Blynk

Here is the graphical display of dryer control app to be design on blynk for the countrol and set up of differente drying type:

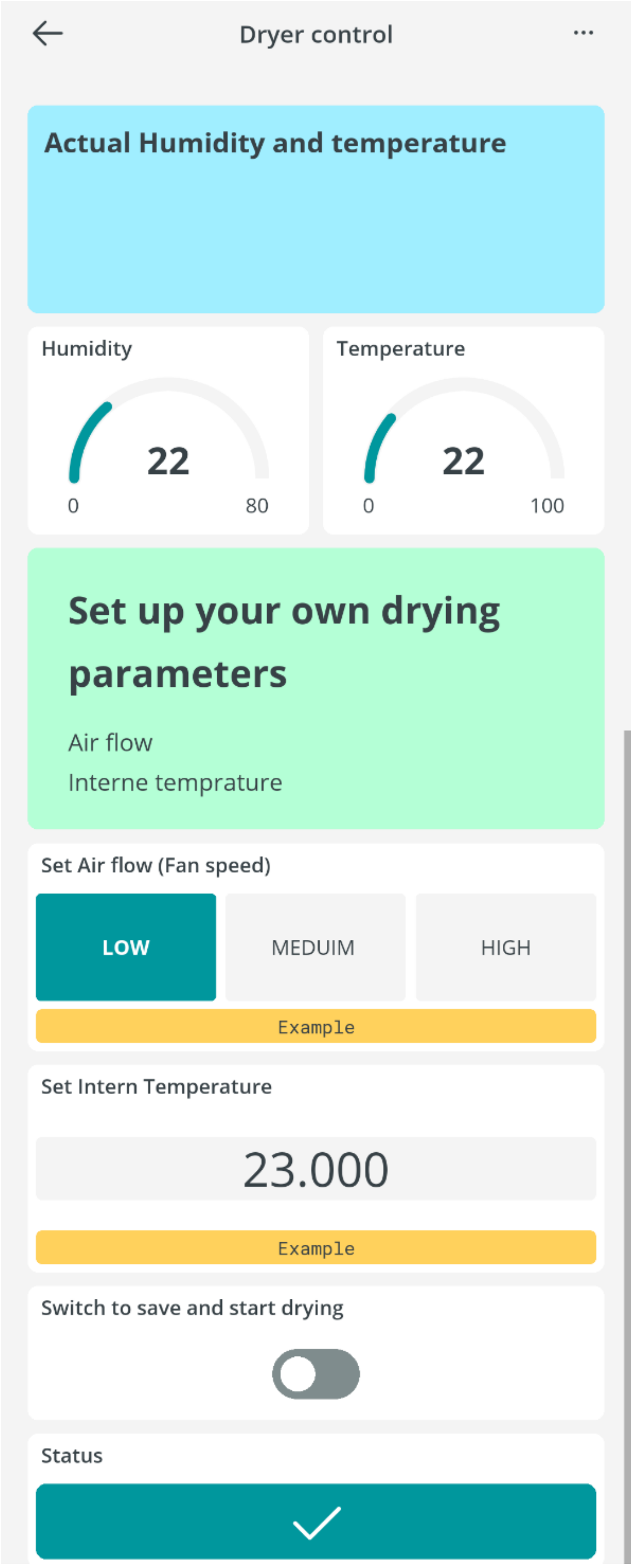


Figure 30: Smart Phone graphic interface design for dryer control

Chapter 4: Finance and internship report

An extensive summary of the financial factors and internship experiences associated with the smart dryer project is given in this chapter. To make sure the project stays within the budgetary constraints, the finance section provides a thorough breakdown of the expenses related to the equipment, materials, and intellectual services that are required. The internship report also highlights the activities completed and the abilities acquired, reflecting on the academic and professional development obtained during the internship at the Institute of Research in Applied Sciences and Technology (IRSAT). These components work together to create a vital component of the project that connects financial planning to real-world learning objectives.

I. Finance overview

In this chapter, we present a comprehensive financial overview of the equipment and services required for the smart dryer project. This includes a detailed breakdown of each component, material, and intellectual service, along with their respective costs. The financial summary provides a clear picture of the project's budget, ensuring that it stays within the allocated financial resources.

1. Equipment, Materials, and Service Cost Breakdown

The table below provides a detailed list of the equipment, materials, and intellectual services required for the smart dryer, along with their corresponding costs:

Table 4: Financial sheet of Smart dryer

Item	Quantity	Unit Cost (XOF)	Total Cost (XOF)
Electronic Components			
Arduino ESP32	1	6,500	6,500
DHT22 Sensor	4	2,000	8,000
Axial Fan (12V or 24V)	1	3,000	3,000
Heating Element (150°C) and joystick	1	8,000	8,000
LCD Display	1	3,500	3,500
H-Bridge Motor Driver	1	3,000	3,000
Relay Module (5V and 12V)	1	1,000	1,000
Power Supply (12V or 24V)	1	8,000	8,000
Wirings LEDs and Connectors	1	3,000	3,000
Mechanical Components			
Wooden Frame	1	10,000	10,000
Insulation Material(facultative)	1	10,000	10,000
Others	-	-	10,000
Assembly Screws	20	100	2,000
Intellectual Services			
Mobile App Development	1	5,000	5,000
Mechanical Design Consulting	2	5,000	10,000
Total HT			**91,000**
Total TVA 18%			**16,380**
Total TTC			**107,380**

2. Financial Analysis

The total estimated cost for the smart dryer project is 107.380FCFA (XOF) TTC. This budget covers all essential components, materials, and intellectual services necessary for the construction, operation, and smart functionality of the dryer.

II. Internship report

1. Activities Performed

During the internship at the Institute of Research in Applied Sciences and Technology (IRSAT), extensive research was conducted on topics directly relevant to the smart dryer project. Leveraging access to high-quality Internet and technical resources, the following activities were undertaken:

- Exploration of Technical Concepts: In-depth investigation into various drying technologies and their operational mechanisms was carried out. This included studying the materials and components essential for designing efficient drying systems. The research enhanced understanding of technological challenges and broadened perspectives on effective methods for processing agricultural products.
- Analysis of Case Studies: Examination of similar projects provided valuable insights into the challenges and solutions encountered by other entities in the agro-food sector. This comparative analysis offered practical examples and innovative solutions that were instrumental in refining the approach for the smart dryer project.

2. Skills and Competencies Developed

Although the internship did not involve hands-on practical activities, it significantly contributed to the development of crucial skills for future professional endeavours:

- Research and Critical Analysis: The process of evaluating diverse information sources and synthesizing complex data facilitated the ability to draw relevant conclusions. This skill is essential for any research or development project, providing a foundation for evidence-based decision-making.
- Autonomy and Time Management: Independent work on research projects honed time management and organizational skills. This experience underscored the importance of self-discipline and effective scheduling in a professional setting.
- Communication and Collaboration: Regular interactions with the internship supervisor and team members improved communication skills. The internship fostered a deeper appreciation for teamwork and collaboration, highlighting its significance in achieving research and project goals.
- Creativity: The research challenges encountered necessitated creative problem-solving approaches. This experience enhanced the ability to innovate and adapt solutions to complex issues, expanding the scope for novel approaches in project development.
- Positivity and Versatility: A proactive attitude and adaptability in handling diverse tasks demonstrated an ability to engage fully with various aspects of the project. This versatility is crucial for navigating complex and evolving project requirements

GENERAL CONCLUSION

The development of a smart dryer for household use represents a significant advancement in the field of food preservation. This project effectively addresses the urgent need to improve drying methods for perishable products, particularly fruits and vegetables, which are especially prone to spoilage due to their high water content. By incorporating advanced technologies such as temperature and humidity sensors, intelligent control systems, and real-time monitoring, the proposed dryer optimizes the dehydration process while preserving the nutritional and organoleptic qualities of the food.

The results demonstrate that this smart dryer offers substantial improvements in energy efficiency and the quality of dried products. Through the use of forced convection and vacuum drying mechanisms, the device ensures uniform and rapid drying, thereby reducing the time required to achieve the desired moisture level and minimizing the loss of essential nutrients. This makes the dryer particularly well-suited for domestic use, where quality, ease of use, and energy efficiency are key considerations.

Furthermore, this project is part of a successful collaboration with the Institute of Research in Applied Sciences and Technology (IRSAT), showcasing the effectiveness of academic and industrial partnerships in developing technological innovations. This initiative not only meets the immediate needs of households for food preservation but also contributes to reducing food waste and promoting more sustainable food practices.

The future prospects for this project are promising. On one hand, the integration of more advanced technologies, such as artificial intelligence and machine learning, could further enhance the precision and efficiency of the drying process. On the other hand, exploring new materials for dryer design could increase its durability and further reduce its environmental footprint. Finally, the potential for larger-scale commercialization opens opportunities for economic development while raising consumer awareness of the benefits of smart preservation technologies.

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APPENDICES

General organization of the company

The organization of IRSAT is divided into 2 entities, each with specific responsibilities: At the administrative level:

- ❖ A main management supervising five separate administrative services: the administrative and financial service, the human resources development service, the accounting service, and financial control.
- ❖ Deputy management in charge of programs, to which are attached the Research-Development liaison service, the Study and Project service, the scientific, technical and communication information service (including the library) as well as the mechanical workshop.
- ❖ A regional management located in Bobo-Dioulasso, which completes this administrative structure. This administrative organization is supported by the model of the scientific organization of IRSAT.

At the scientific level:

The IRSAT is subdivided into four distinct scientific departments:

- ❖ The Energy Department, responsible for studies, research and technological development in the field of energy, including the analysis of the impact of energy use on the environment.
- ❖ The Natural Substances Department, focused on the inventory, studies and research on the exploitation and sustainable management of natural substances of plant, animal and mineral origin.
- ❖ The Food Technology Department, responsible for studies and research on the processing and conservation of agricultural, forestry and fishery products, as well as their adaptation to consumer requirements.
- ❖ The Mechanization Department, which is dedicated to studies, research and development2of mechanization in the fields of agriculture and the processing of agricultural and forestry products. This well-defined organizational structure enables IRSAT to carry out its research, development and management activities in the key areas of its expertise.

The following table show us the organisation chart of irsat compagny:

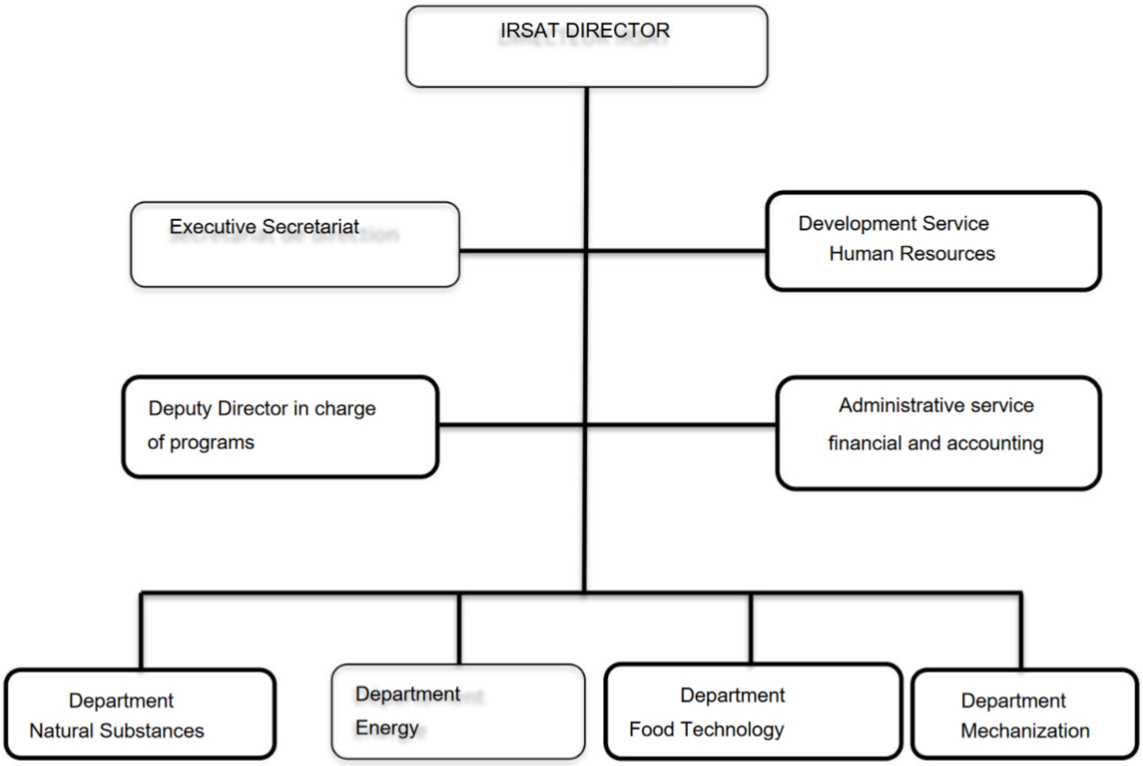

Figure 31: IRSAT Organization Chart

2D drawing of the components of the smart dryer

Before organizing the 2D drawings of the intelligent drying component parts in the final report, it is critical to emphasize their significance. These technical drawings show the exact placement and measurements of each critical component of the intelligent dryer. They act as a comprehensive visual reference that covers the concept and functionality in detail, ensuring clarity and accuracy throughout the manufacturing and assembly processes. Their inclusion not only strengthens the technical rigor of the report but also offers a professional and easily available reference for any future improvements or revisions.