



**Peoples Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University Amar Thelidji- Laghouat**



**FACULTY OR INSTITUTE: Technology
DEPARTMENT: Mechanical Engineering**

MASTERS THESIS

PRESENTED BY: Akroum Yassine & Belhadi Zakaria

DOMAIN: Science and Technology

FIELD: Mechanical Engineering

OPTION: Mechanical & Production Manufacturing

Theme

**Drying study of an agricultural product (banana)
Experimental study**

Jury :

Full Name	Grade	Quality
Reug Hanan	MCB	Président
Mchekel Mohamed	MAA	Examineur
Bensahel Djamel	MCB	Rapporteur

2022/2023

عنوان المذكرة : دراسة تجفيف منتج زراعي

الإسم و اللقب: عكروم ياسين

الإسم و اللقب: بالهادي زكرياء

المؤطر: بن ساهل جمال

ملخص نتيجة للزيادة الكبيرة في ظاهرة الاحتباس الحراري ، أصبحت ضرورة استخدام مصادر الطاقة المتجددة واضحة. ونتيجة لذلك ، تحول اهتمامنا نحو تسخير الطاقة الشمسية ، وهي موارد متجددة نظيفة وفيرة متاحة بسهولة في الطبيعة. تماشياً مع هذا الهدف ، قررنا استخدام الألواح الشمسية الحرارية الموجودة داخل ورشة الهندسة الميكانيكية في جامعة الأغواط. كان الغرض هو استكشاف إمكانات استخدام الطاقة الشمسية في تجفيف المواد الغذائية القابلة للتلف. في هذا الصدد ، أجرينا دراسة تركز بشكل خاص على الموز ، وهو سلعة غذائية مستهلكة على نطاق واسع تحتوي على نسبة عالية من الماء تبلغ حوالي 70٪. كان التركيز الأساسي للدراسة هو التحقيق في تأثير المستويات المختلفة لتدفق الهواء على كفاءة عملية التجفيف.

كلمات مفتاحية: الاحتباس الحراري ، مصادر الطاقة المتجددة ، الطاقة الشمسية ، الألواح الحرارية الشمسية ، تجفيف المواد الغذائية ، الموز ، تدفق الهواء ، الكفاءة ، عملية التجفيف.

Memory title: drying study of an agricultural product

Full Name: Zakaria Belhadi

Full name: Akroum Yassine

Directed by: Djamel Bensahal

Abstract: As a result of the significant increase in global warming, the necessity of using renewable energy sources has become obvious. As a result, our attention has shifted towards harnessing solar energy, which is an abundant clean renewable resource readily available in nature. In line with this goal, we decided to use the solar thermal panels located inside the mechanical engineering workshop at the University of Al- Laghouat. The purpose was to explore the possibility of using solar energy in drying perishable foodstuffs. In this regard, we conducted a study focusing in particular on bananas, a widely consumed food commodity with a highwater content of about 70%. The primary focus of the study was to investigate the effect of different levels of air flow on the efficiency of the drying process.

Key words: global warming, renewable energy sources, solar energy, solar thermal panels, wood drying, bananas, air flow, efficiency, drying process.

Titre du mémoire : étude de séchage d'un produit agricole

Nom et Prénom: Zakaria Belhadi

Nom et Prénom: Akroum Yassine

Encadreur: Djamel Bensahal

Résumé : En raison de l'augmentation significative du réchauffement climatique, la nécessité d'utiliser des sources d'énergie renouvelables est devenue évidente. En conséquence, notre attention s'est déplacée vers l'exploitation de l'énergie solaire, qui est une ressource renouvelable propre abondante facilement disponible dans la nature. Conformément à cet objectif, nous avons décidé d'utiliser les panneaux solaires thermiques situés à l'intérieur de l'atelier de génie mécanique de l'Université d'Al- Laghouat. L'objectif était d'explorer les possibilités d'utiliser l'énergie solaire pour sécher des denrées périssables. À cet égard, nous avons mené une étude portant notamment sur les bananes, une denrée alimentaire largement consommée avec une teneur élevée en eau d'environ 70%. L'objectif principal de l'étude était d'étudier l'effet de différents niveaux de flux d'air sur l'efficacité du processus de séchage.

Mots clés : réchauffement climatique, sources d'énergie renouvelables, énergie solaire, panneaux solaires thermiques, séchage du bois, bananes, flux d'air, efficacité, processus de séchage.

Dedication :

Dear Mom, Dad, Aunt, Friends, and Teachers,

As I stand at the threshold of a new chapter in my life, I want to express my deepest gratitude for your unwavering support, guidance, and love throughout my educational journey.

Mom and Dad, your sacrifices and unconditional love have been the foundation of my success. I am forever grateful for your belief in me and the countless opportunities you have provided.

Aunt, your wisdom and encouragement have shaped my character. Your mentorship has shown me the importance of determination and perseverance.

To my dear friends, your laughter and support have made these years unforgettable. I treasure the memories we have created together.

And to my teachers, you have been my guiding lights. Your passion for knowledge and dedication to my growth have inspired me every step of the way.

As I graduate, I carry with me the lessons and values you have instilled in me. This achievement is as much yours as it is mine, and I am proud to share it with each of you.

Though my student journey ends, our bond will endure. I am excited for new adventures, armed with the knowledge, values, and love you have given me.

Thank you, from the depths of my heart, for being my pillars of strength. I am forever grateful for your presence in my life.

With love and gratitude,

[Zakaria Beshadi]

Dedication:

Dear Mom, Dad, Friends, and Teachers,

As I enter a new phase of life, I want to express my deepest gratitude for your unwavering support throughout my education.

To my parents, your sacrifices and love have been my foundation. Thank you for believing in me and providing countless opportunities.

To my dear friends, your support and laughter have made these years unforgettable. I treasure our memories together.

And to my teachers, your passion and dedication have inspired me. Thank you for nurturing my love for learning.

As I graduate, I carry your lessons and values with me. This achievement is a reflection of our collective efforts.

Although my student journey ends, our bonds remain strong. I'm excited for new adventures with your love and guidance.

With heartfelt gratitude,

[Yassine Akroum]

Nomenclature :

Symbols	Designations	Units
η	The efficiency	
Q	heat flux	(W)
H	Relative Humidité	
P_{W_0}	Saturation vapor pressure of water	(kPa)
P_W	Partial pressure pressure of water	(kPa)
Y	Absolut Humidity	
P_t	Total pressure	(kPa)
MR	Moisture ratio	
k, k_0, k_1	Constant drying	
t	Time of drying	(min)
a, b, c	The coefficient of drying	
n	The drying exponent	

List of figures

Figure 1: principle of a flat solar collector [5]	2
Figure 2: The main components of a flat-plate collector [6].....	3
Figure 3: Major angles in solar applications [8]	4
Figure 4: Natural drying [10]	6
Figure 5: Drying Fruit [14].....	8
Figure 6: Drying vegetables [16]	9
Figure 7: drying chamber [21]	13
Figure 8: A chimney solar dryer ready for drying fruits and vegetables. Leave the first tray space (left side of photo) empty as a “preheat area. [22]	13
Figure 9: Belt dryer [31].....	15
Figure 10: Freeze Dryers [31]	16
Figure 11: Spray drying [34].....	17
Figure 12: Vacuum tray Dryer for Pharmaceutical [36]	18
Figure 13: Superheated Steam Drying [39].....	19
Figure 14: Fluidized bed dryers [41].....	20
Figure 15: Front view of the test bench.....	24
Figure 16: Front view of the test bench.....	25
Figure 17: Expanded polystyrene for iso. Thermal by the ext. PRB 1.2x0.6m, Ep.40mm.....	27
Figure 18: Galvanized sheet e=1.5mm.....	29
Figure 19: MDF plate e=2.5 mm.....	30
Figure 20: before drying.....	39
Figure 21 : after drying.....	39
Figure 22: Humidity in relation to time	43
Figure 23: Flow rates madium	43
Figure 24:Flow rates max.....	43
Figure 25: Flow rates min	43
Figure 26: Humidity in relation to time	44
Figure 27 : Flow rates madium	44
Figure 28: Flow rates Max	44
Figure 29: Flow rates min	44
Figure 30: Humidity in relation to time	45
Figure 31: Flow rates min	45
Figure 32: Flow rates max.....	45
Figure 33: Flow rates madium	45

Figure 34 :Humidity in relation to time models	46
Figure 35: Humidity in relation to time	47
Figure 36: Humidity in relation to time	48
Figure 37: Humidity in relation to time	49
Figure 38: Mass changes relative to time.....	50
Figure 39: thickness 4mm	50
Figure 40: thickness 2mm	50
Figure 41 : thickness 1mm	50

List of tables

Table 1: Characteristics of the glass material.....	30
Table 2: Table of constants modals.....	34
Table 3: Sample results table	35
Table 4: Table of experience conditions	37
Table 5: the natural conditions	38
Table 6: Represents the mass before and after the drying of the banana of each stream.....	39

Summary

Summary	I
Nomenclature.....	II
Liste des figures.....	III
Liste des tableaux.....	VI
Index.....	VII
General introduction	XII

Index

Introduction:	1
1.1 Solar collectors :.....	1
1.1.1 Types of solar collectors:	1
1.1.2 Flat solar collector technology:	2
1.2 The efficiency of solar collectors:	4
1.3 Position and orientation of a sensor:.....	4
1.4 Application of Solar collectors :.....	5
1.5 Drying :.....	5
1.5.1 Fundamental Concepts of Drying :	5
1.5.2 Drying Process:	6
1.5.3 Natural Drying:	6
1.5.4 Drying and Dehydration:.....	6
1.5.5 Drying of Fruit and Vegetables:.....	7
1.5.6 Quality Changes During Drying :	9
1.5.7 Guides for Success in Drying:.....	11
1.5.8 Solar Assisted Biomass Fired Dryer for Dehydration of Fruits and Vegetables: 12	
1.5.9 Type of Dryers Used in Drying of Perishable Crops:	14
1.5.10 Other Drying Techniques Used in Food Industry:	15
1.5.11 Recent Advances in Drying Technology:	18
1.6 Methods of Drying.....	20
1.6.1 Sun Drying:	20
1.6.2 Air Drying:	20
1.6.3 Oven Drying:.....	20
1.6.4 The Relation of Drying:	21
1.7 Conclusion.....	22
Chapitre 2 :	23
Introduction:	24

2.1	The manufactured test Bench: [46]	24
2.1	The insulation and the materials used:	25
2.1.1	The thermal resistance:	25
2.1.2	The thermal conductivity:	26
2.1.3	The air flow:	26
2.3.4	The wood:	26
2.3.5	Polystyrene: [46]	27
2.3.5.1	The difference between an expanded polystyrene and a polystyrene extruded:	27
2.3.5.2	The advantages of expanded polystyrene:	28
2.3.5.3	The advantages of extruded polystyrene:	28
2.3.6	The Galvanized Sheet Metal (Galvanized Sheet Metal): [46]	28
2.3.7	The MDF:	29
2.3.7.1	The advantages of medium density fiberboard: [46]	29
2.3.8	The glass: [46]	30
2.4	The drying chamber:	30
	Conclusion:	31
Chapitre 3 :		32
3.1	Introduction	33
3.2	Model constants along with statistical parameters at different drying temperatures:	33
3.2.1	Lewis	33
3.2.2	Page	33
3.2.3	Henderson and Pabis	33
3.2.4	Logarithmic	33
3.2.5	Two-term	33
3.2.6	Wang and Singh	33
3.2.7	Constants of models:	34
3.3	Conditions of experience:	37
	The product before and after drying:	39
3.4	Conclusion	40
Chapitre 4		41
4.1	Introduction:	42
4.2	Humidity in relation to time	43
4.2.1	Thickness 4mm:	43
4.2.2	Thickness 2mm:	44

4.2.3	Thickness 1mm:	45
4.3	Humidity in relation to time with models.....	46
4.3.1	Thickness 4mm:	47
4.3.2	Thickness 1mm:	48
4.3.3	Thickness 2mm:	49
4.4	The Natural	50
	Conclusion.....	51

General conclusion	XIII
--------------------------	------

General introduction

General introduction:

In the ever-evolving world driven by convenience and technological advancements, even the art of food preservation has experienced a remarkable transformation. Drying food, an age-old practice deeply rooted in tradition, has embraced modern technology to revolutionize the process and extend the shelf life of our favorite ingredients. Among these innovations, the integration of solar collectors has emerged as a game-changer in drying food, particularly when it comes to bananas.

Gone are the days when we relied solely on natural sunlight or ambient heat sources for dehydrating fruits, vegetables, and herbs. Today, cutting-edge techniques and advanced equipment have taken center stage, allowing us to achieve superior results in drying with efficiency and precision. One of the most significant technological advancements in food drying is the advent of electric food dehydrators, which have harnessed the power of controlled heat and airflow to remove moisture from foods consistently and in a controlled manner. These dehydrators offer adjustable temperature settings, timers, and moisture sensors, providing unprecedented accuracy and convenience.

But beyond household dehydrators, the impact of technology has reached industrial-scale drying processes as well. Vacuum drying, freeze-drying, and microwave drying techniques have transformed the commercial food industry, enabling large-scale production of dried foods while preserving their quality, taste, and nutritional value.

However, the integration of solar collectors in drying food, especially bananas, takes sustainability and efficiency to new heights. Solar collectors are carefully designed systems that capture and convert solar energy into usable heat. By directing this heat towards the drying process, optimal conditions for banana drying can be achieved. This approach not only preserves the natural flavors and textures of bananas but also significantly reduces our environmental impact.

The use of solar collectors for drying bananas offers several advantages. Firstly, it aligns with our commitment to sustainability by harnessing renewable energy and minimizing greenhouse gas emissions. Solar energy is clean, abundant, and readily available, making it a perfect fit for eco-conscious food preservation.

Secondly, the integration of solar collectors provides precise control over the drying process, resulting in superior flavor, texture, and nutrient retention. The captured solar energy powers advanced systems with temperature sensors, airflow regulators, and humidity controls, ensuring optimal conditions for drying bananas uniformly and consistently.

Moreover, solar drying with collectors offers long-term cost savings. While there may be initial investments in equipment, the ongoing operational costs are significantly reduced compared to traditional drying methods, making it an economically viable option for small-scale farmers and communities.

By blending ancient traditions with modern technology, we celebrate the fusion of tradition and innovation in the art of drying foods. Each dried fruit, vegetable, or herb we savor is a testament to the remarkable journey that combines the wisdom of our ancestors with the advancements of the present. Through the integration of solar collectors and other cutting-edge technologies, we continue to push the boundaries of food preservation, ensuring a vibrant, accessible, and ever-evolving future for drying foods in our modern world.

Chapter 1:

Bibliographic study

Introduction:

The integration of modern technology, particularly solar collectors, has revolutionized the age-old practice of drying food. Gone are the days of relying solely on natural sunlight or ambient heat sources. Instead, cutting-edge techniques and advanced equipment, such as electric food dehydrators, vacuum drying, freeze-drying, and microwave drying, have transformed the process, offering superior results in terms of efficiency, precision, and quality. Solar collectors, specifically in the context of drying bananas, have emerged as a sustainable and efficient solution. By harnessing renewable solar energy, these collectors create optimal drying conditions, preserving the natural flavors and textures of bananas while reducing environmental impact. The integration of solar collectors provides precise control over the drying process, resulting in superior flavor, texture, and nutrient retention. Moreover, solar drying with collectors offers long-term cost savings and economic viability. This harmonious fusion of tradition and innovation in the art of drying foods celebrates the wisdom of our ancestors while embracing cutting-edge technologies, ensuring a vibrant and ever-evolving future for food preservation in our modern world.

1.1 Solar collectors :

Solar thermal collectors represent one of the most widely used technologies for heat production from renewable energy sources to increase efficiency and to not increase too much cost different type of solar collectors. [1]

1.1.1 Types of solar collectors:

1.1.1.1 Photovoltaic solar collectors:

Hybrid photovoltaic solar collectors, or solar cogeneration systems, are power generation technologies that convert solar radiation into usable thermal and electrical energy collectors combine photovoltaic solar cells, which convert sunlight into electricity with a solar thermal collector. [2]

1.1.1.2 Solar thermal collectors:

Solar thermal collectors operate by absorbing solar radiation, converting it into thermal energy and then transporting it so that it can be used for heating a summary of the different designs and materials used in solar thermal collectors is shown. [3]

1.1.2 Flat solar collector technology:

1.1.2.1 Définition and principale of a flat Solar collector :

A Flat Plate Collector is another type of heat exchanger which converts the radiant solar rays or energy from the sun into the heat energy using greenhouse.

The main principle behind the solar collector If a sheet metal is directed or exposed to a radiant sun the temperature on the plate rises until the rate at energy is received is equal to the heat loss from the plate. Which termed as equilibrium temperature. If the backside surface of the plate is supported by insulating material to protect from radiant remedies, if the plate is painted black color and is covered by one or two glass then the temperature will be much higher compared to normal sheet exposed to the sun. [4]

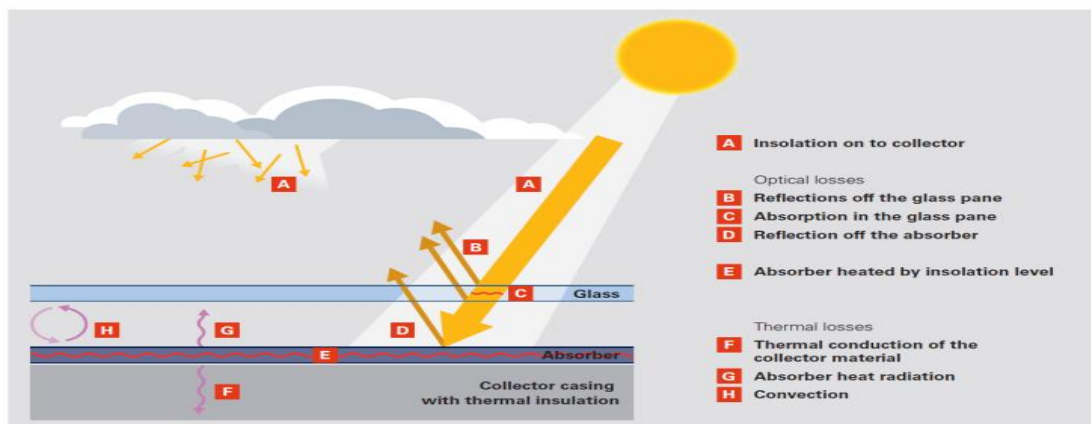


Figure 1: principle of a flat solar collector [5]

1.1.2.2 Components of Flat Plate Collector:

The main components of a flat-plate collector:

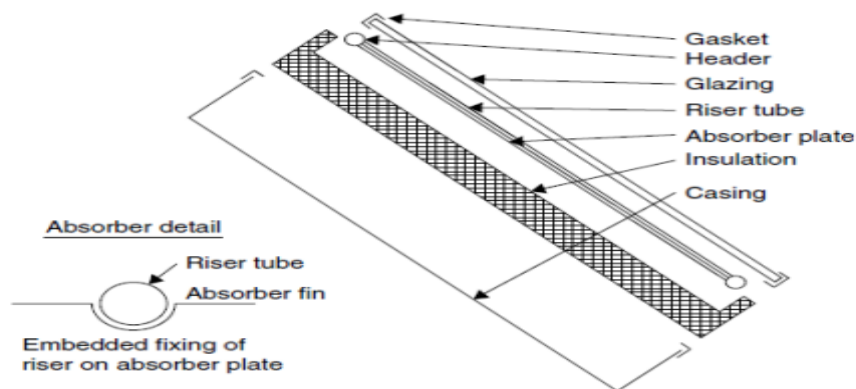


Figure 2: The main components of a flat-plate collector [6]

1.1.2.2.1 Cover :

One or more sheets of glass or transparent plastic [6]

1.1.2.2.2 Heat removal fluids pipes and passageways:

The layer responsible for moving the working fluid from bottom header to the top header in the rectangular region. It is usually including Tubes, pipes, fins, or passages which direct the working fluid from bottom header to the top header. [6]

1.1.2.2.3 Absorber plate :

It is a flat sheet made of metal with good conductivity. This sheet is usually coated with some thin layers of materials which enhance the absorption and reduce the emission from the absorber plate. [6]

1.1.2.2.4 Headers :

Two horizontal pipes on the both top and bottom end of the collector. It is an area that from one side is connected to the main rectangular region of the collector and on the other side it is connected either to inlet or outlet. [5]

1.1.2.2.5 Insolation :

Materials with low heat conductivity to reduce the heat transfer both from conduction and convection in the sides and the back face of the flat plate collector. [6]

1.1.2.2.6 Case :

The casing which surrounds all the different parts of the flat plate collector which protects the components of the system from dust, moisture, and any other material which is going to cause corrosion. [6]

1.2 The efficiency of solar collectors:

Thermal efficiency is a dimensionless size that shows the performance of thermal equipment thermal efficiency can be formulated as in flat plate solar collectors and can be calculated by the equation. [7]

$$\eta = \frac{Q_{used}}{Q_{incident}}$$

η : The efficiency

Q_{used} :Used heat flux (W)

$Q_{incident}$: Incident heat flux (W)

1.3 Position and orientation of a sensor:

The solar collector has to take the optimal position that will guarantee the highest generation of heat. The orientation of a collector can be described with the help of its slope and azimuth angles.[8]

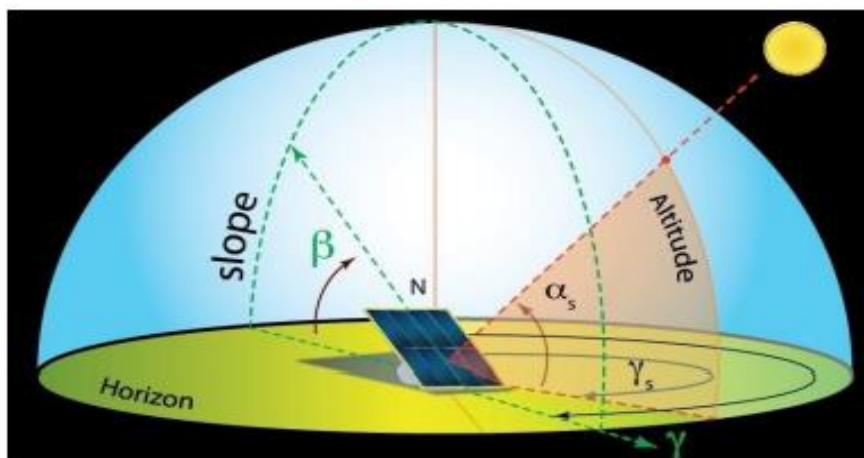


Figure 3: Major angles in solar applications [8]

1.4 Application of Solar collectors :

Solar thermal systems are mostly used in:

- ✚ Residential and industrial.
- ✚ Domestic water heating.
- ✚ Space heating.
- ✚ Water processes for industrial heating.
- ✚ Agricultural drying.

1.5 Drying :

1.5.1 Fundamental Concepts of Drying :

Classification of dryers based on the method of operation:

- Batch dryer.
- Radiation dryer.

1.5.1.1 Batch Dryer:

Batch dryers are mainly suitable for small-scale drying operations, in which the products are loaded in batches. A batch of wet products is loaded and the dryer is allowed to operate till the product reaches its desired moisture level, and the dryer operation is stopped, and then the dried products are unloaded. Again, the next batch will be loaded for drying operation. Batch dryers are very simple in design, construction and operation, but the efficiency of batch dryers is less due to the loading and unloading periods of dryers. Examples for batch dryers are kiln dryers, solar dryers. [9]

1.5.1.2 Radiation Dryers:

In radiation dryers, the method by which heat is transmitted to the product is radiation from a hot body or from the sun. This radiation energy increases the temperature of the product and causes the evaporation of moisture. Example for the radiation dryer is of sun drying or solar dryers. [9]

1.5.2 Drying Process:

Drying is one of the oldest and most important preservation techniques which involves reduction of moisture content of the food to the level where microbial growth is inhibited and rate of deteriorative chemical reactions is minimized. It is a thermophysical and physicochemical operation in which excess moisture is removed; hence the water activity of the food is reduced. Besides increasing the shelf life of food product, drying has various other advantages such as it makes material handling easier by reducing the bulk weight and hence reduces packaging and transport cost, makes product available during the off season. [8]

1.5.3 Natural Drying:

Natural air-drying is a technique to dry grain by forcing ambient air through the grain mass until the grain attains an equilibrium moisture content with the air. The energy contained within the ambient air is the energy used for reducing the moisture in the grain. The only fossil-based energy supplied for drying using this process is the electricity used to run the fan. [9]



Figure 4: Natural drying [10]

1.5.4 Drying and Dehydration:

1.5.4.1 Aim of drying:

The basic aim of drying is to reduce the biological water which is required for the growth and multiplication of microorganisms such as bacteria, fungi, mold, that causes food spoilage and decay. Since water acts as a potential vehicle for pathogens in the food chain and it has to be removed to increase the shelf life of the fruit products. [12]

1.5.4.2 Factors affecting rate of drying: [12]

Factors which should be considered while drying vary with the type of food and method of drying. Various factors that affect the rate of drying of produce include:

- Composition of raw materials
- Size, shape and stacking arrangement of produce
- Temperature, time, relative humidity and velocity of air
- Pressure
- Heat transfer to surface

1.5.4.3 Advantages of dehydration over sun-drying: [12]

- The process of dehydration is much more rapid than sun-drying
- Dehydration requires less floor area and fewer trays
- Dehydration is done under very hygienic conditions
- Sun-drying is not possible during cloudy weather or during rains, whereas dehydration or mechanical drying is not dependent on the weather
- The color of dehydrated or mechanically dried fruits and vegetables remain uniform due to uniform drying temperature.

1.5.5 Drying of Fruit and Vegetables:

1.5.5.1 Drying Fruit:

Dried fruit is nature's candy, but unlike candy it retains most of the vitamins, minerals, and fiber inherent in the fruit, making it more nutritious and filling. Dried fruits retain the minerals, caloric content, and fiber present in the fresh fruit. [13]



Figure 5: Drying Fruit [14]

1.5.5.2 Drying Vegetables:

Though fruits and jerky are dehydrated most often, vegetables should not be overlooked. In fact, most of the dehydrated produce in my pantry is constituted of various vegetables. Dehydrated vegetables take up far less space than fresh, canned, or frozen ones. Vegetables tend to lose vitamin C during dehydration and storage, but all the other vitamins and minerals they contain remain intact. [15]



Figure 6: Drying vegetables [16]

1.5.6 Quality Changes During Drying :

1.5.6.1 Physical Quality :

1.5.6.1.1 Color:

Color is perhaps the most important attribute, apart from product appearance, that will determine the level of acceptance by consumers. Color pigments, Maillard reactions and enzymatic browning play significant roles in the color changes of the product. [17]

1.5.6.1.2 Texture:

Structural collapse in food due to moisture removal from the food product results in significant changes in texture. This causes shrinkage and change in porosity of the dried product. Texture attributes such as hardness, fractur ability, springiness, chewiness. [17]

1.5.6.1.3 Shrinkage:

When moisture is removed within the solid network of a food product during drying, a pressure unbalance is produced between the inner and external part of the food material, generating contracting stresses that lead to material shrinkage, changes in shape and

sometimes product cracking Visual appeal is affected too should severe shrinkage is experienced by the product [17]

1.5.6.1.4 Porosity:

Porosity is a measurement of pore or empty spaces of a material to that of the total volume or simply it can be defined as the volume fraction of air in the food product. [17]

1.5.6.2 Chemical Quality:

1.5.6.2.1 Flavor:

Flavor is the primary concern to consumers irrespective of the texture, shape and color of a dried product. Flavor of food consists of various food aroma compounds that constitute the taste and odor of the food. Some flavor compounds are volatile and these are carried away during moisture removal process. The change in shape and texture influence the microstructure of the food product and controls the release of flavor during processing and consumption. [17]

1.5.6.2.2 Water activity:

The removal of moisture content reduces the water activity of the product during drying. In general, the water activity in most dried food is relatively low, typically less than 0.6, which is the recommended level for safe storage. Low water activity inhibits the growth of various microorganisms and prevents oxidation and enzymatic reactions. [17]

1.5.6.2.3 Shelf life:

Storage and packaging play an important role in affecting the shelf life of a dried product. Typically, the optimum relative humidity for dried product storage is 55 – 70% at moisture content ranging from 2 to 20%. Packaging should be moisture proof and able to prevent the transfer of oxygen into the product and cause off flavor formation. Alternatively, modified atmosphere packaging technique can be used to extend the shelf life of the dried products. [17]

1.5.6.3 Nutritional Quality:

1.5.6.3.1 Food nutrients:

Food nutrients degrade during drying and the magnitude of change depends on the foodstuff and the drying conditions. Losses of nutrients can be minimized by applying suitable pretreatments, selection of appropriate drying methods and optimization of drying conditions. Generally, nutritional loss increases with the severity in the process conditions during processing nutritional changes that could occur during drying [17]

1.5.6.3.2 Antioxidants:

Drying causes nutritional losses and hence some antioxidants are destroyed, probably due to thermal degradation, depending on the drying condition and techniques used. [17]

1.5.6.4 Biological aspects:

Microbial growth on food product is a critical issue that cannot be tolerated. Information on microbiological specifications (mold and yeast, E. coli, Salmonella) Failure to comply with these specifications could cause fatality upon consumption of the food product. [17]

1.5.7 Guides for Success in Drying:

1.5.7.1 Selecting the Right Product:

Fruits and vegetables selected for drying should be sound, fresh, and in the "peak" of condition; ripe, but still firm and at the right state of maturity. Wilted or inferior material will not make a satisfactory product. Immature fruits will be weak in color and flavor. Over-mature vegetables are usually tough and woody. Over-mature or bruised fruits are likely to spoil before the drying process can be accomplished. Fruit and vegetables that are inferior before drying will be inferior after drying. [18]

1.5.7.2 Temperature:

Heat is supplied by the sun or electrical heat. If the drying temperature is too low, the product will sour. Drying should be done as quickly as possible, at a temperature that does not seriously affect the texture, color, and flavor of the fruit or vegetable. If the temperature is too high or the humidity too low, there is a danger of moisture being removed too fast. This can cause a hardening of the outer cells of the product (case hardening) which prevents water

vapor from diffusing from the inner cells. Drying is best accomplished when the process is continuous. When heat is applied intermittently, temperatures conducive to bacterial growth can develop. [18]

1.5.7.3 Circulation of Air:

Each piece of food should have good exposure to air. Food should be only one layer deep with space around it. This space does not need to be large since the product will shrink during the drying process. A good flow of air is necessary. The air will absorb all the moisture it can hold; therefore, fresh air should be forced to circulate to remove water vapor and carry moisture away from the food being dried. The force of the circulating air should not be so strong that it can blow the dried food off the rack. [18]

1.5.8 Solar Assisted Biomass Fired Dryer for Dehydration of Fruits and Vegetables:

1.5.8.1 Drying Chamber:

The drying chamber has aluminum wire screen trays to hold the products. The flat plate solar collector used has a single Plexiglas cover positioned about above a matt black painted metal absorber sheet. All collector walls except for the transparent glass cover are insulated to thickness to reduce heat losses. The solar collector is attached to the backside of the drying chamber. A exhaust fan fixed in the chimney of the drying chamber forces the ambient air to pass through the collector and rise up through the fruits being dried. The biomass gasifier stove assists drying whenever solar radiation is insufficient. [19] These dryers are characterized by low productivity and longer drying period. The drying is not even due to the uneven disposition of temperatures in the chamber, resulting from the partial flow of the air in upper layers through shorter ways Bad side of this type of dryers is the high need for manual work. [20]

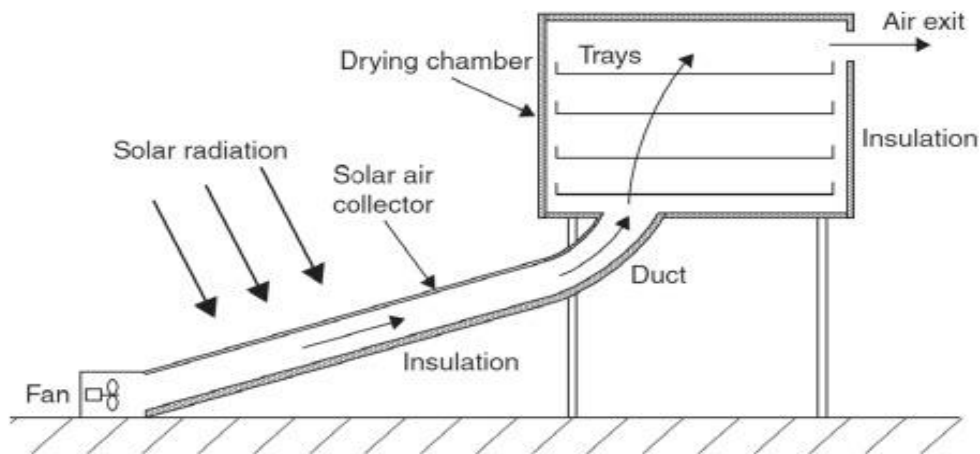


Figure 7: drying chamber [21]

1.5.8.2 Chimney:

The basic principle of the solar chimney is similar to that of the solar collector; a solar chimney aims to heat air. It consists of a dark surface that is exposed to solar radiation and is also in contact with the air to be heated. The chimney intakes air from the main drying chamber and by heating it further, decreases its density causing rise and exit the chimney thereby motivating air flow out of the solar drying chamber. The chimney increases the buoyancy force, which is dependent on the density of air outside the structure and within the chimney, and promotes higher airflows in solar dryers. [22]



Figure 8: A chimney solar dryer ready for drying fruits and vegetables. Leave the first tray space (left side of photo) empty as a “preheat area. [22]

1.5.9 Type of Dryers Used in Drying of Perishable Crops:

1.5.9.1 Tray Dryers:

Tray dryers are another type of batch dryer that is often used in small-scale food drying operations. In many respects, they resemble cabinet dryers [23] Tray dryers are classified as batch type and band dryer and can dry almost everything. However, because of the labors required for loading and unloading, they are expensive to operate. They find most frequent application when valuable products like dyes and pharmaceuticals are involved [24]

1.5.9.2 Tunnel Dryers:

Tunnel dryers are similar to continuous through-circulation dryers in many respects. The big difference is that the material is not placed on a moving conveyor belt. Instead, the material to be dried is spread on trays or racks that are then put onto carts that are pulled through long tunnels where heated air is blown across the material on the trays or racks [25] Tunnel dryers are adaptable for drying requiring longer periods and are mass-producing, but they require a large installation space [26]

1.5.9.3 Pneumatic Dryers:

Basic part of these dryers is the chamber or tube in which the disperse material is dried during pneumatic transport. Velocity of the air must be higher than the velocity of particles levitation (10 to 20% than levitation velocity of the largest particles) principally, the work of pneumatic dryers is continual. They are used for drying grains, chopped dairy food, vegetable leafs. [27]

1.5.9.4 Trough Dryers:

The agriculture materials to be dried are contained in a trough-shaped conveyor belt made from mesh, and air is blown through the bed of material. The movement of the conveyor continually turns over the material, exposing fresh surfaces to the hot air. [11]

1.5.9.5 Belt Dryers:

The belt dryer is particularly suitable for cut vegetables the main components of this dryer consist of finely woven wire mesh supported on rollers to form a belt trough, a duct supplying hot air at the bottom of the trough, and a rotary cleaning brush. [30]

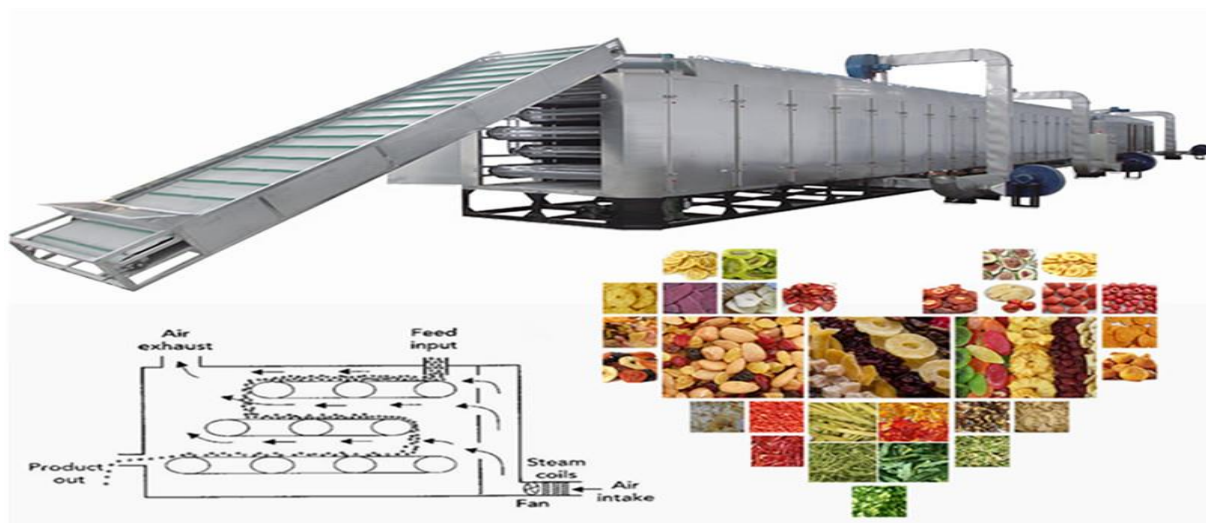


Figure 9: Belt dryer [31]

1.5.10 Other Drying Techniques Used in Food Industry:

1.5.10.1 Freeze Drying:

Freeze drying is a dehydration method, which can produce high quality of dried products. This method takes advantage of triple point of water. Triple point is a state in which substances coexist in different states such as solid, liquid, and vapor and remain in thermodynamic equilibrium. Water has triple point at 0.01°C and 611.73 Pa . Below triple point of water the ice can be directly sublimated into water vapor. This method of moisture removal gives many advantages over conventional methods [28]

- The absence of air during processing prevents oxidative and chemical deterioration of the product.
- Lower drying temperature, which preserves volatile and flavor components.
- Absence of moisture movement within the material during drying.
- Dried product has excellent re-hydration properties [29]



Figure 10: Freeze Dryers [31]

1.5.10.2 Spray Drying:

Spray drying is often used for heat-sensitive processes in the food industry. Its method has lower specific energy consumption than the freeze-drying way. Spray drying to convert a solvent, emulsion, or suspension material into a solid product. The principle of this spray drying process will be continuously pumped into the atomizer and divided into fine droplets in the chamber [32]

The drying time is short (1–20 s) so damages are limited and it can be used to treat heat-sensitive materials. The atomizer is essential because it determines the size of the droplets and conditions the efficiency of the process. Furthermore, spray drying is the most common microencapsulation process and has proven to be an effective technology in protecting bioactive compounds and probiotics [33]



Figure 11: Spray drying [34]

1.5.10.3 Vacuum Drying :

Vacuum drying technology is an important process for drying highly heat-sensitive materials, which are widely used in the pharmaceutical and chemical industries, as well as in food products and biotechnology. The processes of vacuum drying can be considered according to the physical conditions used to add heat and remove water vapor. The evaporation of water proceeds more rapidly at low pressures, and the heat is added indirectly through contact with a metal wall or by radiation. Low temperatures can also be used under vacuum for certain materials that might discolor or decompose at higher temperatures. [35]



Figure 12: Vacuum tray Dryer for Pharmaceutical [36]

1.5.10.4 Microwave Assisted Drying:

The microwave based the volumetric heating occurring when electromagnetic waves pass through the material causing a molecules oscillation. This oscillation generates thermal energy that is then used to remove water from the wet material. Microwave radiation is included in the electromagnetic spectrum, and its wavelengths range from 1 mm to 1 m. The most used frequencies within the food drying are 915 and 2450 MHz This drying method is able to obtain high quality dried products with reduced costs and high energy efficiency due to the volumetric heating that is spread through the whole sample reducing the time of drying when compared to the conventional However, it is considered to cause product damage due to improper heat control and mass transfer during the process. [37]

1.5.11 Recent Advances in Drying Technology:

1.5.11.1 Superheated Steam Drying:

It is known as an airless drying which used high-temperature steam to transport heat to a product, making moisture inside evaporated from the product at its boiling point with no diffusional resistance Superheated steam dryers have been developed and partly relied in praxis for a variety of products on the industrial and laboratory scale including: spent grain, potatoes, sugar beet pulp, and shrimp. In common, superheated steam dryer is designed to involve the use of superheated steam in place of hot air, combustion flue gases as the drying

medium to supply heat for drying and to carry off the evaporated moisture. Any moisture that is evaporated does not need to be exhausted, but instead becomes part of the drying medium. This commonest type of superheated steam dryer has been shown to have low energy consumption, enhanced drying rate, reduced risks of fires and explosion, and eliminated harmful emission. [38]



Figure 13: Superheated Steam Drying [39]

1.5.11.2 Heat Pump Drying:

Heat pump-assisted drying is a type of hybrid or combined drying. Hybrid or combined drying technologies include implementation of different modes of heat transfer, two or more stages of the same or different type of dryer. The heat pump assisted drying get by addition of heat pump to the drying processes that can be made in several different ways and also there are some of the most promising methods, heat pump drying and heat pump assisted drying, being used in food industries so far. [40]

1.5.11.3 Fluidized Bed Drying:

Fluidized bed dryers are designed such that a hot gas enters at the base of the bed, passes through a distributor plate, and then into the bed of solids. Each particle is completely surrounded by the gas and has free movement throughout the bed - causing instantaneous mixing. Due to the complete mixing the temperature of the bed becomes uniform. [41]



Figure 14: Fluidized bed dryers [41]

1.6 Methods of Drying

1.6.1 Sun Drying:

Sun drying is one of the most widespread and cheap methods practiced by most developing and underdeveloped countries, especially in tropics, where good sunshine hours available throughout the year. In this process food commodities are laid on a platform in a thin layer for uniform drying. The sun's heat not only reduces the moisture level as desired, but also kills insects present in the food product. [42]

1.6.2 Air Drying:

Air drying is an alternative to sun drying for such products as herbs and chili peppers. The material is tied into bunches or strung on a string and suspended out of the sun until dry. This can be in a shady porch, shed or corner of the kitchen. Enclosing produce in a paper bag protects it from dust and other pollutants. Some herbs can be dried simply by spreading on a dish towel or tray and leaving on the counter for 2 or 3 days [43]

1.6.3 Oven Drying:

You can use your oven to dry small amounts of food at one time. Depend on the weather. Although oven drying produces a safe, generally tasty product, don't expect top quality. Oven-dried food is more brittle and usually darker and less flavorful than food dried in a dehydrator. Another disadvantage of oven drying is its energy cost. Oven drying takes two or three times longer than drying in a dehydrator. [44]

1.6.4 The Relation of Drying:

1.6.4.1 Relative Humidity (RH) : [45]

Relative humidity (RH) is defined as the ratio of P_w to P_{w0} at the same temperature. It is a relative measure of the amount of moisture that wet air can hold at a given temperature:

$$H = \frac{p_w}{p_{w_0}} \times 100$$

p_w : Partial pressure pressure of water (kPa)

p_{w_0} : Saturation vapor pressure of water (kPa)

1.6.4.2 Absolut Humidity : [45]

The mass ratio of water to dry air is known as the absolute humidity, which can be defined as the amount of moisture in the air at any condition (Y):

$$Y = \frac{p_w}{p_t - p_w} \times 0,6207$$

p_t : Total pressure (kPa).

p_w : Partial pressure pressure of water (kPa)

1.6.4.3 Saturation Absolut Humidity : [45]

Equilibrium is reached when the partial pressure of water vapor in the air equals the water saturation pressure at a given temperature. Thus, the mass ratio of water to air is called the saturation absolute humidity. This is the maximum amount of moisture that the air can carry at that temperature, which can be expressed as:

$$Y = \frac{p_{w_0}}{p_t - p_{w_0}} \times 0,6207$$

p_{w_0} : Saturation vapor pressure of water (kPa)

p_t : Total pressure (kPa).

1.7 Conclusion

Solar energy has emerged as a highly valuable and environmentally friendly renewable energy source. Its abundance and non-polluting nature have led to an increased utilization of solar energy for various thermal applications, including heating, water distillation, and drying. The drying process itself aims to extract water from solid, semi-solid, or liquid substances through evaporation, with the ultimate goal of preserving food by inhibiting microbial growth and enzymatic reactions. Additionally, drying reduces the weight and volume of products, making them easier to transport and store. In this chapter, we have explored different methods and techniques of solar drying, delving into the operation, components, and efficiency of solar collectors specifically designed for drying purposes. We have also discussed the various types of dryers available in the market. By harnessing the power of the sun, solar drying offers a sustainable and cost-effective solution for preserving and preparing food while reducing our reliance on fossil fuels and mitigating ecological imbalances.

Chapitre 2:

Presentation of Solar Collector and Drying Room

Introduction:

The idea of this project is to collect a quantity of air, expose it to the hot sun and freeze it directly to the chamber where we put the food product "banana".

And in order to ensure access to hot air, a direct connection was established with the drying chamber. We have selected materials that offer us enough Insulation of the air from the outside and the ambient temperature.

2.1 The manufactured test Bench: [46]



Figure 15: Front view of the test bench.

- (1) The absorber;
- (2) The thermal sensors;
- (3) The metal structure;
- (4) The drying chamber;
- (5) The extractor;

(6) The mechanism of the weight scale;

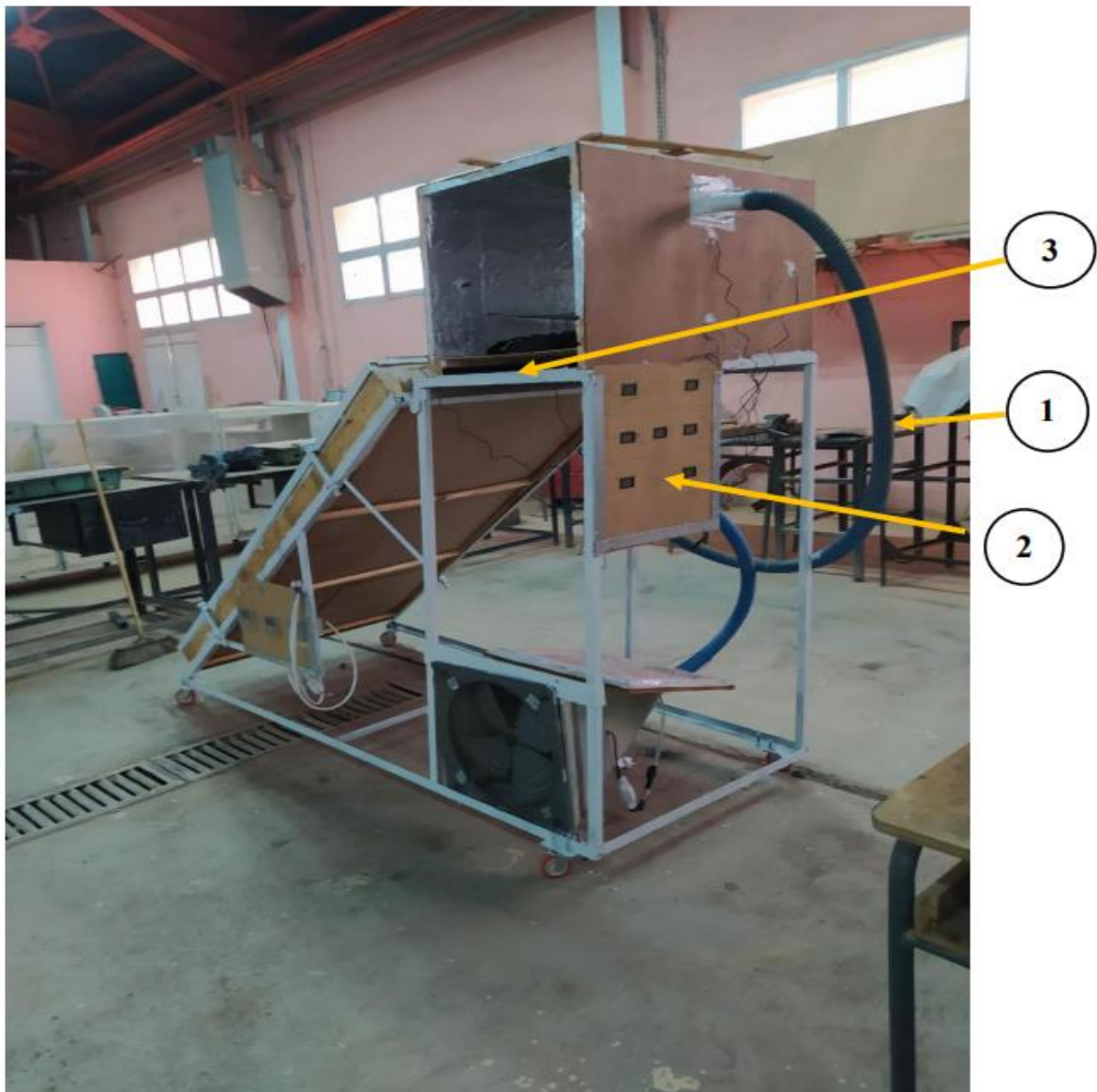


Figure 16: Front view of the test bench.

- (1) Air absorption pipe;
- (2) The plate of temperature and humidity sensors;
- (3) The air distribution plate. [46]

2.1 The insulation and the materials used:

2.1.1 The thermal resistance:

To choose an insulating or insulating product, it is enough to read the thermal resistance R which appears on the product label. The higher the number behind the R , the more the product

is insulation. The greater the thickness of an insulating material, the higher its coefficient of conductivity (λ) is lower the higher its thermal resistance will be. [46]

2.1.2 The thermal conductivity:

The lambda thermal conductivity (λ) is the amount of heat W/m.K that can pass through a material in a given time. The lower this value (λ) will be and the more the material, at equal thickness, will be insulating. The insulating materials have $\lambda < 0.060$ W/mK. N.B. Some manufacturers calculate the lambda of their insulation with an air temperature of 10° which is Wrong.

The lower the thermal conductivity will be, the greater the coefficient R will be and the more the product will be insulating and efficient. [46]

2.1.3 The air flow:

The long trial that opposed the powerful union of manufacturers of mineral wool (The FILMM) to a small manufacturer of thin reflective products who claimed that his product aluminized equivalent to 10 cm of glass wool resulted in an unexpected result. [46]

2.3.4 The wood:

Wood is a rigid plant tissue, composed of cells with lignocellulosic walls particularly efficient from a mechanical point of view. This is what allowed the trees to achieve records of size and longevity in the living world.

According to professionals, wood is 12 to 15 times more insulating than concrete, but wood is also 3 to 7 times more conductive than real insulators... This is indeed the conductivity thermal, which is one of the thermal characteristics of materials, which defines the performance of an insulator. The variation in the coefficient of thermal conductivity is close to 20,000 [W/mk] between the less insulating ones such as copper and the more insulating ones such as polyurethane.

The frame of the panel is made of hard wood, protected on all sides with an insulation of silicone, and connect to the chamber by a groove, its dimensions are 550mm x 550mm x960mm. [46]

2.3.5 Polystyrene: [46]

The term "polystyrene" coded PS, designates a polymer whose monomer understand the repeated molecular element -- is styrene. The latter is formed of a benzene attached to the compound CH-CH₂. The polystyrene is obtained in an autoclave, by polymerization of styrene. Styrene is, for its part, one of the products of the refining of the oil. Solid and hard, polystyrene can be mixed with a gas to create a very light.



Figure 17: Expanded polystyrene for iso. Thermal by the ext. PRB 1.2x0.6m, Ep.40mm

In our project we used Polystyrene to ensure effective insulation, we choose a polystyrene plate with a thickness equal to 40mm.

Polystyrene is a material from the family of synthetic insulators. There are some two types: expanded polystyrene (EPS) and extruded polystyrene (XPS). They are found under different shapes but the polystyrene panel is undoubtedly the most used. Panel polystyrene sheets are mainly used to insulate homes but they can also used in the realization of decorations for artistic projects.

2.3.5.1 The difference between an expanded polystyrene and a polystyrene extruded:

The main difference between these two materials lies in their density. The extruded polystyrene is much denser than expanded (on average 2.18 lbs for the XPS vs 0.93 lb for the PSE). [46]

2.3.5.2 The advantages of expanded polystyrene:

PSE is a lightweight insulator that has good mechanical strength. Its lightness makes it easy to handle and to install. It is mainly used in the form of a white panel or gray to insulate floors, walls, roofs or even terraces. Note that the gray-colored EPS reveals better thermal performance (about 10 to 20%), this makes it possible, for example, to reduce the thickness of the polystyrene panel when it is used as insulation. However, gray polystyrene is slightly more expensive. [46]

As it is quite fragile when it is in contact with fire, it is necessary to associate the expanded polystyrene with a non-combustible material. Plaster is often used with expanded and combined polystyrene in the form of a plate. These plates are mainly appreciated for interior insulation.

2.3.5.3 The advantages of extruded polystyrene

XPS has a good thermal conductivity (generally higher than PSE) It is also very resistant to different temperatures; heat, cold and water do not usually do not succeed in overcoming a quality extruded polystyrene. We will therefore, it is preferred for areas whose climatic conditions are quite extreme.

Extruded polystyrene has other advantages: it is for example equipped with a better mechanical strength than EPS. It deforms little, even over time and does not does not lose its thickness. These qualities are particularly appreciated in Quebec. XPS is mainly used in the form of blue panels for the insulation of floors and the roof (flat). [46]

2.3.6 The Galvanized Sheet Metal (Galvanized Sheet Metal): [46]

It is a steel sheet covered with a layer of zinc (by a dipping process at hot or electrolytic deposition) in order to make it more resistant to corrosion. Steel galvanized is used in particular in the automotive industry, the construction of buildings and structures such as pylons. Also, this plate collect heat, the thickness of the sheet metal used is equal to 1.5mm.

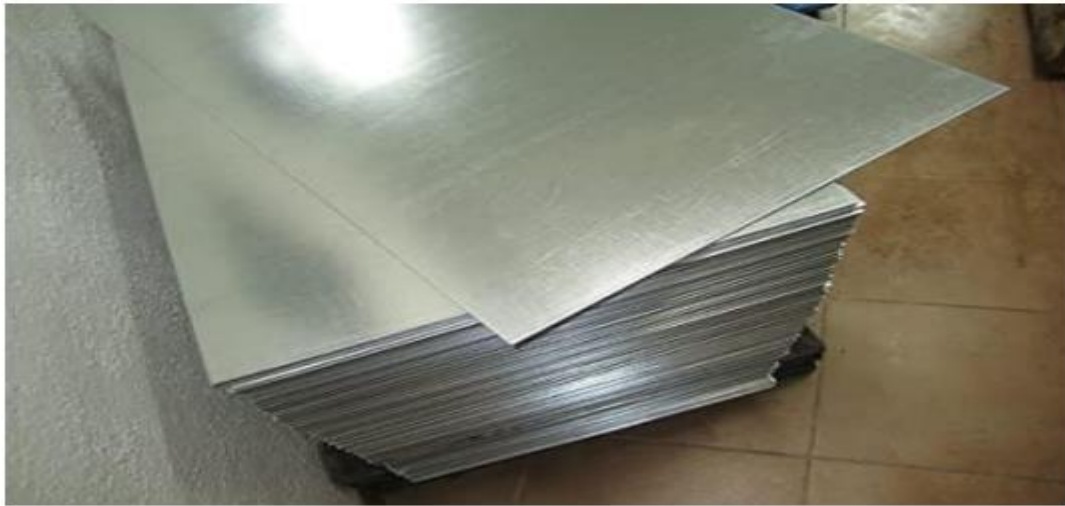


Figure 18: Galvanized sheet $e=1.5\text{mm}$

2.3.7 The MDF:

The MDF wood panel, "Medium density fiberboard" also called medium, is a building material widely used in the furniture and construction industry interior decoration. The production of MDF (Medium Density Fiberboard) began at the United States in the 1970s, following a machining error dating from 1966. The panel of medium density wood fibers, or MDF board, has multiple advantages for amateur and experienced do-it-yourselfers. Its versatility and its finishing facilities are accompanied by all the same, there are some disadvantages to take into account when carrying out work. The latter is a wood fiber composite material made on the basis of hardwood or resinous. Its manufacture takes place in several stages that can be summarized as follows:

After having been reduced to chips of 5 to 40 mm, the wood particles are washed and dusted off. They then undergo a steam defibrating operation and are mixed with a sticky material, composed of a binder such as urea-formalin or melamine formalin, a catalyst and sometimes other adjuvants. After having been dried, this material fibrous is subjected to high pressures in order to form it into panels, which are then cut into different formats. [46]

2.3.7.1 The advantages of medium density fiberboard: [46]

MDF offers multiple possibilities in terms of DIY that solid wood does not don't allow it. Its material, although very dense, is very easy to work with. Indeed, this material composite does not present a risk of breakage when cutting. It adapts without difficulty to each use for an appreciable versatility. As for finishes, the wood panel offers many possibilities thanks to its

ability to imitate multiple materials. In addition, its fine texture offers an extremely neat result. Since MDF is an isotropic material, it has perfectly homogeneous characteristics, unlike solid wood which contains knots making it less uniform. MDF wood panels are very resistant to humidity and temperature changes. They are therefore not likely to suffer from deformation, to expand nor to contract. To further improve its resilience, the MDF can be fireproof, lacquered, melamine, bent, and in some cases, water-repellent. Besides the fact that the medium is cheaper than solid wood, it turns out to be more respectful of the environment. Indeed, it is made from wood that would not have been usable in the classic sector.



Figure 19: MDF plate $e=2.5$ mm.

2.3.8 The glass: [46]

The role of glass in this project is that it condenses and concentrates the sun's heat on the sheet metal galvanize.

Table 1: Characteristics of the glass material

Property	Value
Modulus of elasticity	68935 N/mm ²
Coefficient of thermal expansion	9e-006/K
Thermal conductivity	0.74976W/ (m·K)
Specific heat	834.61 J/ (kg·K)

2.4 The drying chamber:

It is a chest with a height of 550 mm, a width of 550 mm and a length of 960mm. contains a thermal insulation inside by a polystyrene plate of 20mm thick, we closed all the joints by using silicone. The heated air enters through an opening to exit through an air extractor powered by an electric power source. [46]

Conclusion

This chapter is devoted to the design of the solar collector and the chamber to be dried, in this one the different constituent elements have been presented: the glass, the absorber, the lower plate, the polystyrene, the insulating plate MDF, plywood, and the upper and lower frame, plus the steps of manufacturing: woodwork, welding of the metal support and the implantation of probes in the panel and in the drying chamber. [46]

Chapitre 3:

Expérimental Condition

3.1 Introduction

In this chapter, we present all the models used in relative moisture (MR) and we apply a comparison between them and deliver the appropriate model with the results obtained experimentally for the samples, taking into account the flow rates as written below

3.2 Model constants along with statistical parameters at different drying temperatures:

3.2.1 Lewis

$$MR = \exp(-kt)$$

3.2.2 Page

$$MR = \exp(-Kt^n)$$

3.2.3 Henderson and Pabis

$$MR = a \exp(-kt)$$

3.2.4 Logarithmic

$$MR = a \exp(-kt) + c$$

3.2.5 Two-term

$$MR = a \exp(-k_0t) + b \exp(-k_1t)$$

3.2.6 Wang and Singh

$$MR = 1 + a t + b t^2$$

3.2.7 Constants of models:

Table 2: Table of constants modals

Model	A	B	C	K	K0	K1	n
Lewis				0.0146			
Page				0.0041			1.2881
Henderson and pubis	1.0199			0.0189			
Logarithmic	1.1197		-0.1146	0.0147			
Two-term	2.61165	-1.61165			0.07301	205.09803	
Wang and singh	-0.00754	1.45943E- 05					

Table 3: Sample results table

Time	Absorber		Lower plate	Ambient		Between chamber		Chamber output		Product				In the drying room				Mas s
	T1	T2		TA	HA	TI	HI	TS	HS	T1	H1	T2	H2	T1	H1	T2	H2	
9:10	71	68	11	26.3	35	33.4	28	33.7	23	33.7	35	33.9	27	31.5	28	35.7	27	100
9:20	75	72	37	26.6	34	36.1	22	37.3	18	37.3	28	37.3	22	31.9	25	40.7	20	94
9:30	79	75	40	27.7	34	38	21	41.9	16	40	24	40.3	23	34	24	42.7	19	93
9:40	82	78	44	28.1	32	40.6	20	45	16	42.5	21	43.2	18	37.6	21	44.4	17	91
9:50	87	81	48	29.1	30	43.3	18	47.3	15	45	18	45.9	17	38.7	19	46.6	16	90
10:00	90	85	51	30	29	45.4	17	49.5	16	47.5	18	48.5	17	39	18	49.2	16	87
10:10	92	86	52	28.6	28	45.9	17	51	15	49.1	17	50.1	16	41.1	17	50.1	16	85
10:20	94	88	55	31.6	26	47.5	15	52.7	17	51.1	15	52.1	15	41.7	16	51	15	81
10:30	96	90	56	29.6	28	48.1	17	53.6	17	52.3	15	52.9	17	41.9	16	52.2	15	78
10:40	98	91	58	29.8	28	48.4	17	54.2	15	53.3	17	53.9	17	41.7	16	52.8	17	74
10:50	99	93	60	30.5	27	49.3	16	55.5	15	54.5	16	55.3	16	43.3	17	53	17	70
11:00	101	94	61	30.7	27	50.3	16	56.7	14	55.9	16	56.2	15	43.7	17	54.3	16	64
11:10	104	97	63	30.4	25	50.8	16	57.1	14	56.9	15	56.8	14	44.9	16	55.5	16	59
11:20	103	97	63	32.1	24	51.6	15	58.6	16	57.9	16	58	16	44.8	16	55.6	16	54
11:30	106	97	63	29.6	24	51.5	15	58.3	16	58.1	16	57.8	16	43.8	17	56.7	14	50
11:40	106	98	64	30.9	23	52.8	17	59	15	58.9	16	58.5	16	43.3	17	57.7	16	42
11:50	97	90	65	29.3	25	50.9	14	58.7	16	58.9	16	58.4	16	43.8	17	55.5	15	37
12 :00	103	96	64	31.7	21	52.7	17	58.9	16	58.8	16	58	16	44	16	56	14	35
12 :10	105	98	64	32.9	21	52.7	17	59.9	15	59.7	15	59	15	45.1	16	57.2	14	32

Expérimental Condition

12 :20	106	99	64	31.5	21	52.6	16	59.9	15	60	15	59.1	15	44.1	16	57.7	16	30
12 :30	106	100	65	30	21	52.5	16	60.7	15	60.7	15	59.6	15	45.1	16	57.5	16	29
12 :40	101	93	66	30.9	22	53	16	60.2	15	60.3	15	59.4	15	44.3	16	56.2	14	28
12 :50	99	93	65	32.2	20	52.1	15	59.1	15	59.5	15	58.5	16	45.3	15	55.5	15	27
13 :00	102	96	64	32.8	20	51.8	15	59.3	15	59.5	15	58.5	16	44.5	16	56.4	14	27
13 :10	102	97	64	32.7	20	52.2	15	59.1	15	59.7	15	58.5	16	43.2	17	57.1	14	27

3.3 Conditions of experience:

Table 4: Table of experience conditions

Date	Flow Rate (m/s)	Thickness (mm)	Sky
28/05/2023	$1.1181 \cdot 10^{-2}$	2	Clear
29/05/2023	$1.2940 \cdot 10^{-2}$	2	Clear
31/05/2023	$1.2940 \cdot 10^{-2}$	4	Partial cloudy
01/06/2023	$1.1181 \cdot 10^{-2}$	4	Clear
11/06/2023	$4.1475 \cdot 10^{-3}$	4	Clear
12/06/2023	$4.1475 \cdot 10^{-3}$	2	Clear
13/06/2023	$4.1475 \cdot 10^{-3}$	1	Clear
14/06/2023	$1.2940 \cdot 10^{-2}$	1	Partial cloudy
15/06/2023	$1.1181 \cdot 10^{-2}$	1	Clear

Table 4 shows the experimental conditions during the nine test days.

Present the experimental condition for three thickness, for each thickness we use three flow rates (Max Medium Min), we give you information about the state of sky during our experimental days study in table 4

Table 5: the natural conditions

Date	Thickness (mm)	State of Sky
29/05/2023	2	Clear
30/05/2023		Rainy
31/05/2023		Clear
29/05/2023	4	Clear
30/05/2023		Rainy
31/05/2023		Clear
13/06/2023	1	Clear
14/06/2023		Clear

Table 5 shows the natural conditions on the test days. We made three thickness

Present the experimental for natural convection days study Present the experimental condition for three thickness, we give you information about the state of sky during our Present the experimental for natural convection days study in table 5

The product before and after drying:

Experimental measurements were recorded between 9:00 and 16 p.m. in June & May 2023. With three different flow rates. Where we weighed the water removed from the banana every 10 min as shown in **Table 6**

Table 6: Represents the mass before and after the drying of the banana of each stream.

Date	Flow rate (m /s)	Thickness (mm)	Mass before drying (g)	Mass after drying (g)
28/05/2023	$1.1181 \cdot 10^{-2}$	2	100	25
29/05/2023	$1.2940 \cdot 10^{-2}$	2	100	25
31/05/2023	$1.2940 \cdot 10^{-2}$	4	100	28
01/06/2023	$1.1181 \cdot 10^{-2}$	4	100	27
11/06/2023	$4.1475 \cdot 10^{-3}$	4	100	28
12/06/2023	$4.1475 \cdot 10^{-3}$	2	100	23
13/06/2023	$4.1475 \cdot 10^{-3}$	1	100	25
14/06/2023	$1.2940 \cdot 10^{-2}$	1	100	27
15/06/2023	$1.1181 \cdot 10^{-2}$	1	100	27



Figure 20 : after drying



Figure 21: before drying

3.4 Conclusion

In this chapter we have presented all the results obtained from drying the product (bananas) using a solar air collector and a drying chamber, and by the direct method (traditional method)

We can say that the results obtained are good

Chapitre 4

Result and discussion

4.1 Introduction:

Drying is the process of removing moisture or water from a substance to reduce its moisture content. It is commonly used to preserve food, prevent spoilage, and improve product stability. Drying can be achieved through various methods such as evaporation, air drying, or using specialized equipment. It is also used in industries for materials like chemicals, textiles, and construction to remove excess moisture and enhance quality. Drying helps extend shelf life, inhibit microbial growth, and facilitate further processing.

In this chapter, we will study the effect of solar drying on the product used (bananas) with three thicknesses with different flow rates and we will therefore present a set of results in the model curves that translate the results obtained experimentally in nine days in addition to the study of the drying of the product mentioned above in the traditional way, which will be followed by a discussion of the results.

The target parameters of this study are for the drying chamber is:

- ✚ Monitor the ambient temperature and humidity;
- ✚ Temperature and humidity of the room entrance;
- ✚ Temperature and humidity of the room outlet;
- ✚ Variation of the mass variation and drying;
- ✚ Temperature and humidity of the product.

4.2 Humidity in relation to time

4.2.1 Thickness 4mm:

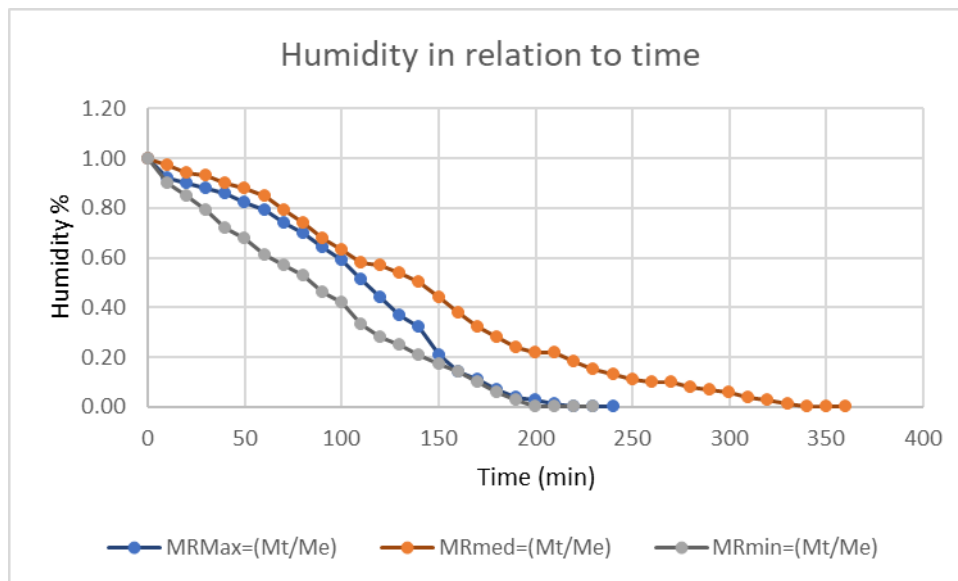


Figure 22: Humidity in relation to time

The three curves on the graph represent the moisture levels of the fruit (banana) over time during the drying process,

By comparing the humidity curves, we can observe a correlation between the blue and gray curve in the level of low humidity despite the difference in the flow level and due to the weather condition

As we experienced high temperatures during the drying process with a low flow, the temperature reached a minimum of 31.5°C to a maximum of 52°C degrees. While we observe an acceptable decrease relative to the curve in Orange by analogy with the flow level and temperature



Figure 25: Flow rates min



Figure 24: Flow rates
medium



Figure 23: Flow rates max

4.2.2 Thickness 2mm:

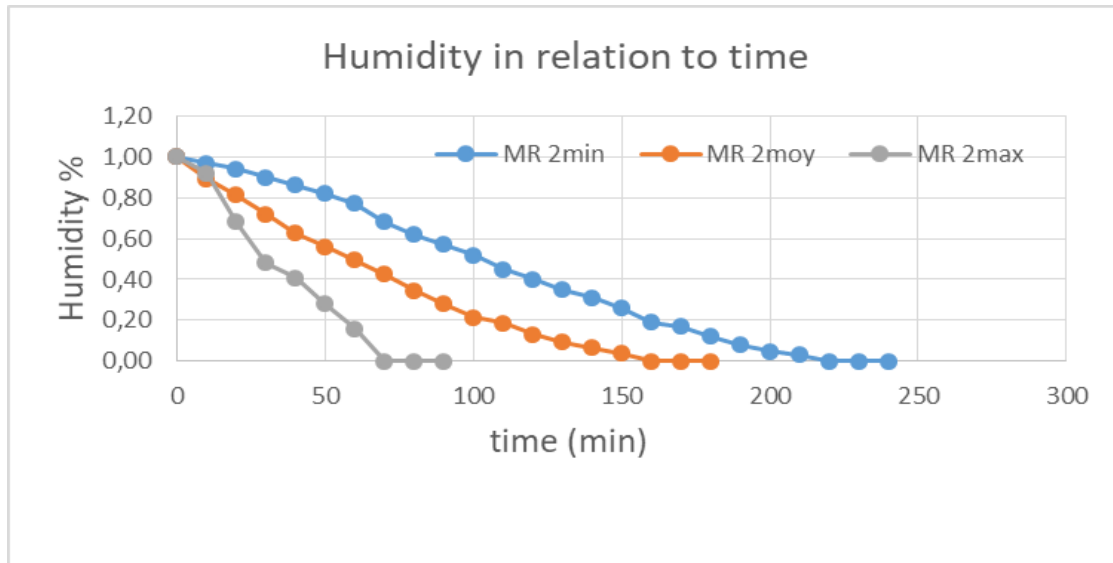


Figure 26: Humidity in relation to time

The three curves on the graph represent the moisture levels of the fruit (banana) over time during the drying process

The three curves on the graph represent the moisture levels of the fruit (banana) over time during the drying process,

Comparing the humidity curves, we can observe a logical decrease in the humidity level, where the main factor was the flow difference due to the temperature stability from 34.7°C to 50.3°C during the study days

We can say that this study was the best



Figure 27 : Flow rates madium



Figure 29: Flow rates min



Figure 28: Flow rates Max

4.2.3 Thickness 1mm:

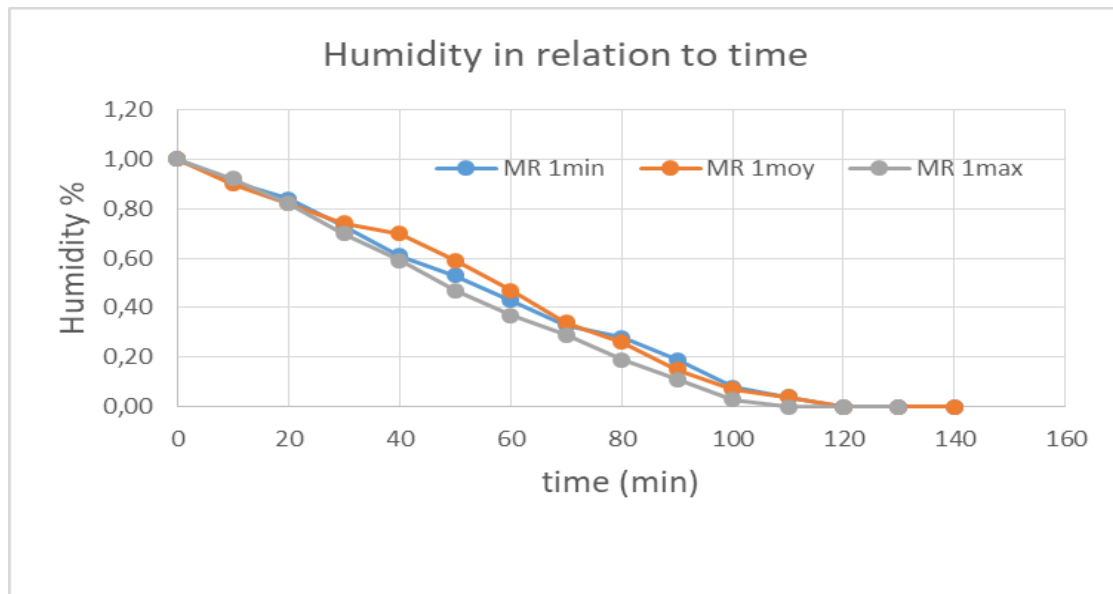


Figure 30: Humidity in relation to time

The three curves on the graph represent the moisture levels of the fruit (banana) over time during the drying process,

Comparing the humidity curves, we can notice a significant convergence in the level of low humidity, we exclude the flow factor due to the stability of the temperature on the study days, where it ranged in total from 31.8°C to 47.7°C, and from it we conclude that the factor here is the size of the thickness of the pieces of fruit (bananas)



Figure 33: Flow rates medium



Figure 31: Flow rates min



Figure 32: Flow rates max

4.3 Humidity in relation to time with models

We have studied the process of drying fruit (Bananas) in terms of the percentage of moisture decrease over a period of time controlled by multiple factors, including the level of air flow and the thickness of the fruit, and based on this, we measured a study on a group of models in the field of drying

- ✚ Lewis
- ✚ Page
- ✚ Wang and singh
- ✚ Logarithmic
- ✚ Henderson and pabis
- ✚ Two- term

We have selected the two closest models for our study to find out the appropriate model at the level of our State (laghaout)

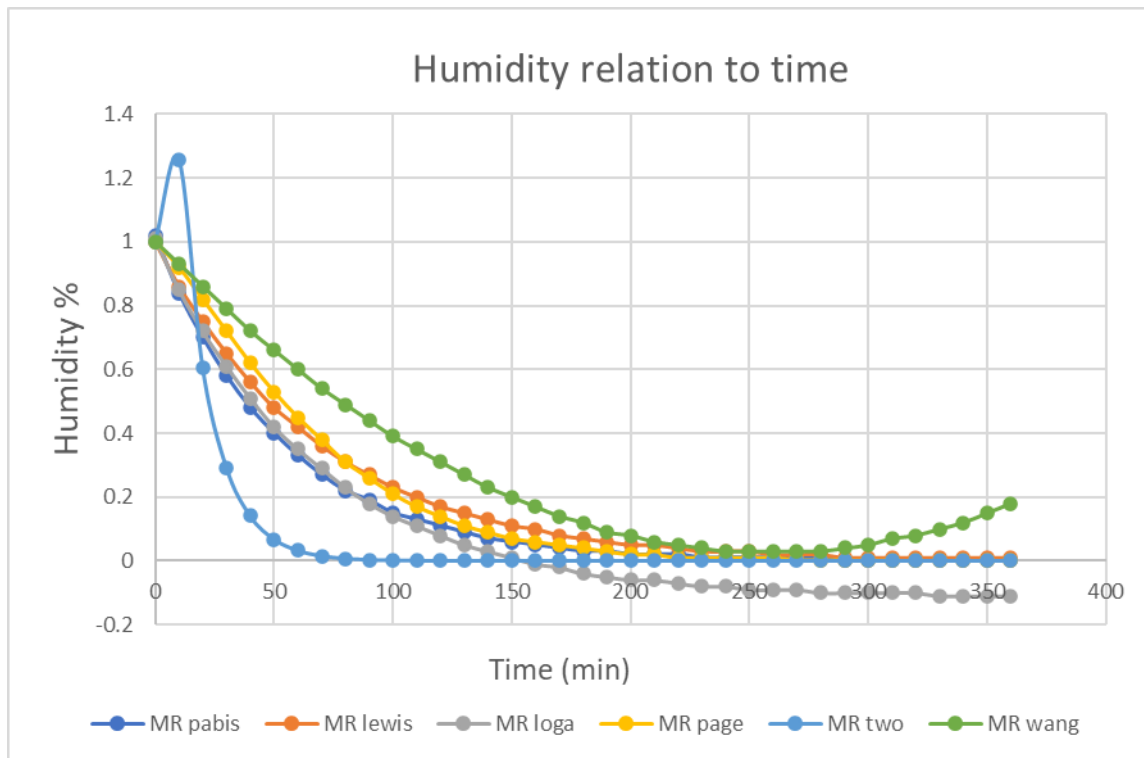


Figure 34 :Humidity in relation to time models

4.3.1 Thickness 4mm:

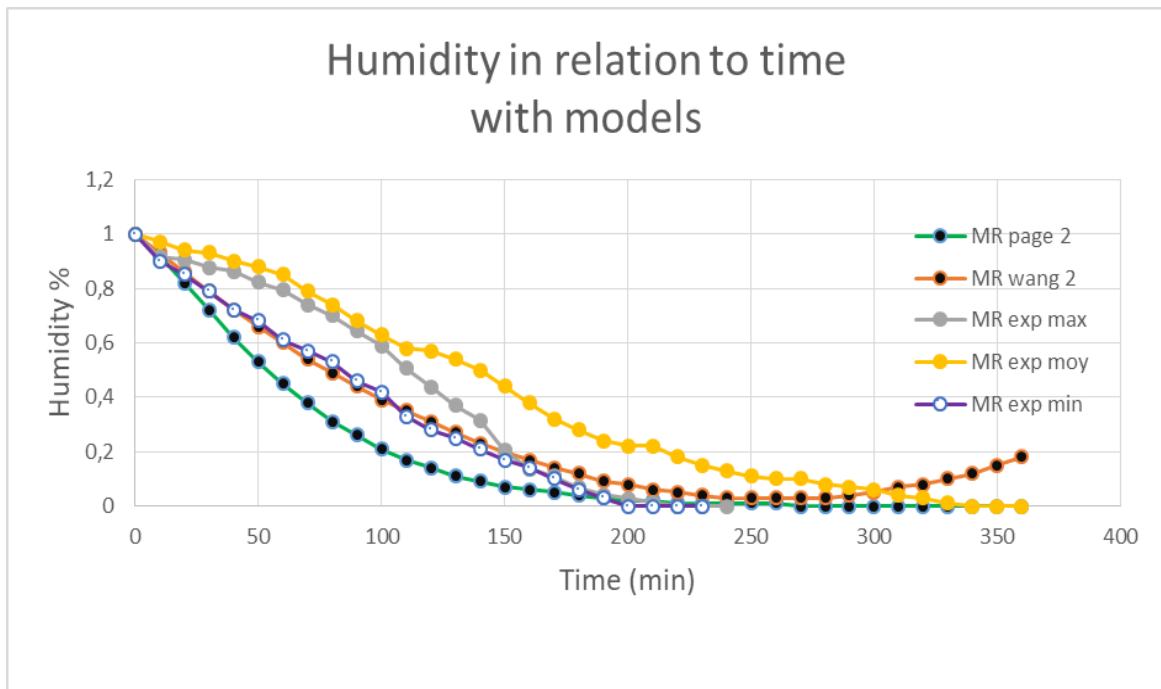


Figure 35: Humidity in relation to time

The three curves on the graph represent the moisture levels of the fruit (banana) over time during the drying process, according to the difference in the flow ratio, the green and red curves of the page, Wang and singh study models, in order, where we observe a significant convergence between the levels of low humidity of the wang and singh model and the flow curve of the minimum flow

4.3.2 Thickness 1mm:

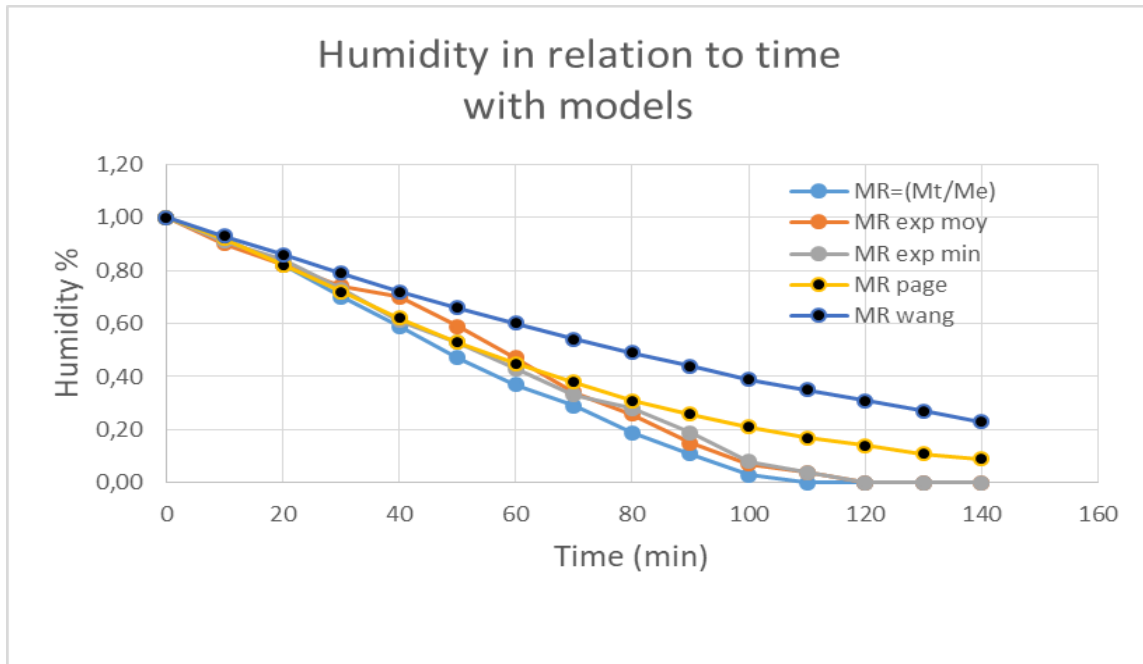


Figure 36: Humidity in relation to time

The three curves on the graph represent the moisture levels of the fruit (banana) over time during the drying process, the yellow and blue curves of the page, Wang and singh study models, in order, where we observe a significant convergence between the levels of humidity drop of the page model and all curves with different flow ratios, where we observe a significant convergence between the levels of humidity drop of the page model and all curves with different flow

4.3.3 Thickness 2mm:

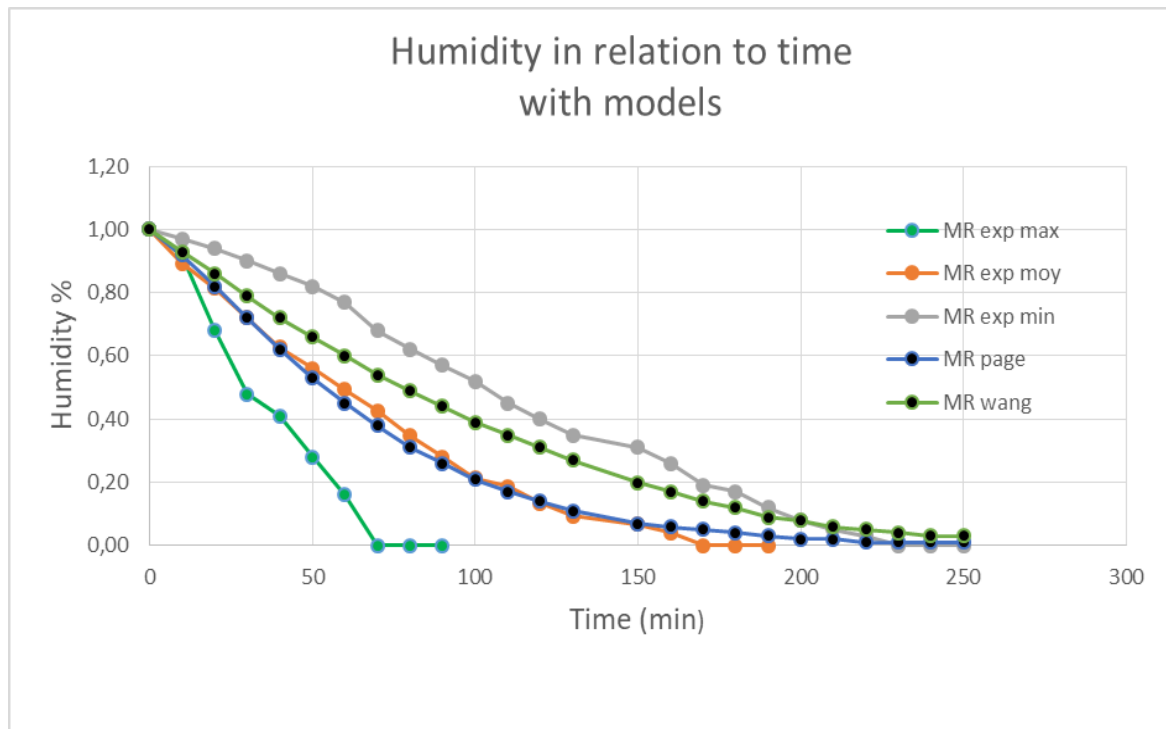


Figure 37: Humidity in relation to time

The three curves on the graph represent the moisture levels of the fruit (banana) over time during the drying process, depending on the flow ratio, the blue and green curves of the page and Wang and Singh study models differ, respectively, where we observe a significant convergence between the low humidity levels of the page model with the low humidity level of the average flow

4.4 The Natural

Mass changes relative to time

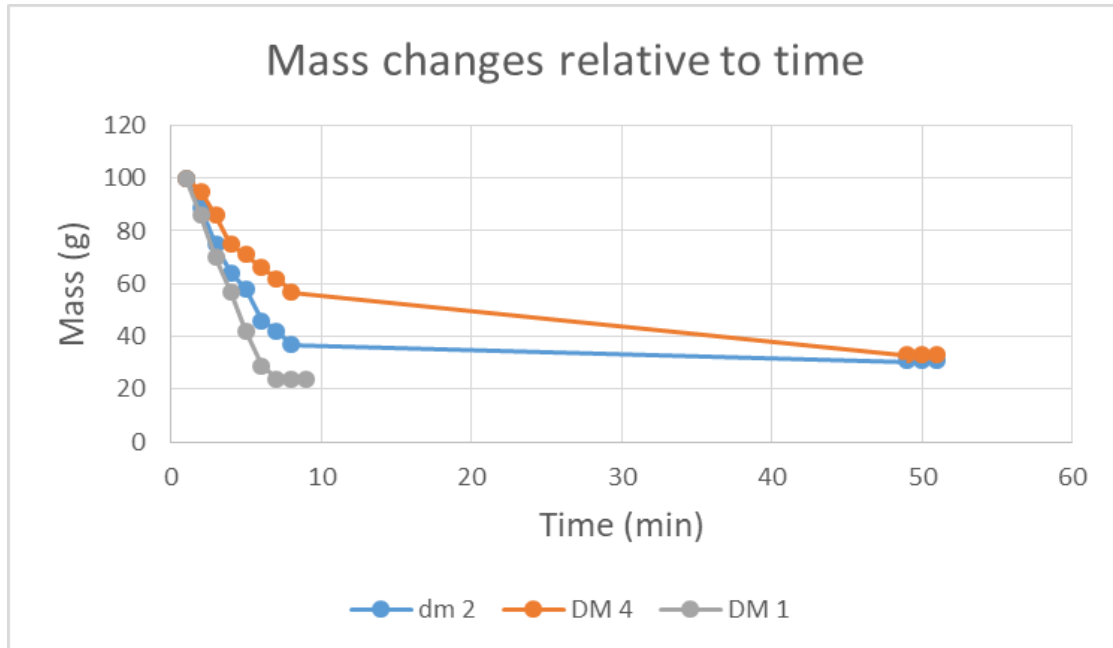


Figure 38: Mass changes relative to time

The three curves on the graph represent the mass state of the fruit (banana) over time during the conventional drying process note the decrease in the mass of the product over time the differences are due to the thickness of the pieces of the product



Figure 41 : thickness 1mm



Figure 40: thickness 2mm



Figure 39: thickness 4mm

Conclusion

The factors contributing to the drying process using a solar dryer can be summarized as follows:

- Solar radiation: sufficient availability and intensity of sunlight are crucial for effective drying.
- Collector design: the design of the solar collector plays an important role in maximizing the absorption of solar radiation and reducing heat loss.
- Air flow: proper circulation of air inside the drying chamber helps in removing moisture and enhances drying efficiency.
- Drying room design: the design of the drying room should facilitate efficient heat transfer, air flow and protect food from contaminants.
- Ambient temperature: high ambient temperatures speed up the drying process by creating a greater temperature difference between the air and the food.
- Relative humidity: low relative humidity accelerates the evaporation of moisture from food.
- Drying surface area: increasing the surface area of food products exposed to drying air speeds up the drying process.
- Food preparation: pre-processing techniques such as blanching or slicing can affect the drying process and the quality of the finished product.

Consideration and improvement of these factors contribute to effective drying, quality improvement, preservation of flavor, texture and nutrients of dried food products.

As for the study of drying models, through our experience we can say that the page model is the most suitable model at the level of our region –laghaout

General Conclusion

The integration of solar collectors in drying food, particularly bananas, represents a remarkable fusion of tradition and innovation. In a world driven by convenience and technological advancements, the art of food preservation has evolved significantly. Solar collectors have emerged as a game-changer, harnessing renewable energy and offering precise control over the drying process,

in this thesis we presented the types of solar drying, the field of its use, and the purpose...

After giving a brief presentation about the solar dryer and the uses of the solar dryer in particular and solar drying in general on the theoretical side, we did the drying process in two different ways

By exposing the product directly to the sun (the traditional method) while following the mass changes at intervals of 30 minutes

Using the solar dryer located at the level of the mechanical engineering-laghaout, we conducted experiments on drying fruits (bananas) by adjusting the flow rate factor and the thickness of the product this experiment is scheduled for nine days. The experiment lasts an average of 3 to 7 hours every day, the results are taken every 10 minutes, the tables are filled in and converted into curves by the Excel program and the latter is discussed taking into account the Metrological conditions.

Our task is to record the results obtained using solar and humidity sensors for the perimeter, absorption, entrance and exit of the room, in the room and the product. Then calculate the mass variation, humidity changes.

We also studied our experience on a range of drying models to find out the most suitable model at the level of our region-laghaout

From the above we can enumerate a set of the main factors that contribute to the effectiveness and efficiency of the drying process:

We start by highlighting some points between the direct drying process (the traditional method) and the drying process by solar dryer

In general, the drying process by solar dryer provides many advantages over conventional drying methods. It provides precise control of drying parameters, improves drying efficiency, reduces environmental impact, and provides greater reliability and consistency in the drying process. While there may be initial investments and limitations in terms of drying time, solar

dryers offer a sustainable and effective solution for food preservation, especially in areas with abundant sunlight.

The factors contributing to the drying process by means of a solar dryer can be summarized as follows:

- ✚ Solar radiation: sufficient availability and intensity of sunlight are necessary for effective drying.
- ✚ Collector design: the design of the solar collector should increase the absorption of solar radiation and reduce heat loss.
- ✚ Air flow: proper air circulation inside the drying chamber facilitates moisture removal and enhances drying efficiency.
- ✚ Drying chamber design: the drying chamber should allow efficient heat transfer, air flow and protect food from contaminants.
- ✚ Relative humidity: low relative humidity enables moisture to evaporate faster from food.
- ✚ Drying surface area: increasing the surface area of food products exposed to drying air speeds up the drying process.
- ✚ Food preparation: pre-treatment methods such as blanching or slicing can affect the drying process and the quality of the finished product.

Consideration and improvement of these factors contribute to effective drying, quality improvement, preservation of flavor, texture and nutrients of dried food products.

As for the study of drying models, through our experience we can say that the page model is the most suitable model at the level of our region –laghaout

Référence :

- [1] Marco Riccia, Enrico Boccie, Emanuele Michelangelib, Andrea Micangelic, Mauro Villarini, Vincenzo Nasoc (2015). Experimental Tests of Solar Collectors Prototypes Systems. *Energy Procedia* 82 (2015) 744 – 751
- [2] Manuel Lämmle, María Herrando, Glen Ryan, (2020). Basic concepts of PVT collector technologies, applications and markets
- [3] James Allan^{1,2}, Zahir Dehouche¹, Sinisa Stankovic² & Lascelle Mauricette¹ (2015). Performance testing of thermal and photovoltaic thermal solar collectors. *Energy Science & Engineering* 2015; 3(4): 310–326
- [4] r. Vipul Mahajan¹, Prof. A.K. Battu² (2022). Case Study of Solar Flat Plate Collector. *International Research Journal of Engineering and Technology (IRJET)*
- [5] Daniel Trier, PlanEnergi (2012). Solar collectors. Solar district heating guidelines
- [6] Dr. Dimitrios Misirlis (2020). CFD Investigation Inside Solar Flat Plate Collectors. *SCHOOL OF SCIENCE & TECHNOLOGY*
- [7] Eko Yohanes Setyawan¹, Arif Kurniawan¹, Febi Rahmadianto¹, Richard A. M Napitupulu², Parulian Siagian²(2019). Flat Plate Type Solar Collector Performance Using Double Thermal Insulation. *Materials Science and Engineering* 852 (2020) 012044
- [8] Jasmina Skerlic¹, Danijela Nikolic¹, Dragan Cvetkovic¹, Aleksandar Miškovic (2018). optimal position of solar collectors: a review. *Applied Engineering Letters* Vol.3, No.4, 129-134
- [9] Om Prakash. Anil Kumar (2017). *Solar Drying Technology*. Library of Congress Control Number: 2017949696
- [10] <https://www.gourmeturk.com.tr/en/natural-dried-apricots>
- [11] Guangnan Chen (2018). *Advances in Agricultural Machinery and Technologies*. International Standard Book Number-13: 978-1-4987-5412-5
- [12] Thanjavur, Tamil Nadu (2020). *Drying and Dehydration of Fruits and Vegetables*. Indian Institute of Food Processing Technology
- [13] Brett L. Markham (2014). *The Food Dehydrating Bible*. E-book ISBN: 978-1-62914286-9
- [14] <https://www.tastingtable.com/883380/why-you-may-want-to-avoid-dried-fruit/>
- [15] brett l, markham (2014). *the food dehydrating bible*. E-book ISBN: 978-1-62914286-9
- [16] <https://www.growveg.com/guides/cooking-with-dehydrated-vegetables/>
- [17] Sachin V. Jangam, Chung Lim Law and Arun S. Mujumdar (2010). *Drying of Foods, Vegetables and Fruits (Volume 1)*.

- [18] **Charlotte P. Brennand (1994). Home Drying of Food. Extension Food Science Specialist (FN-330)**
- [19] **Werner Weiss. Josef Buchinger. solar drying**
- [20] **Sanja Popovska - Vasilevskiy. DRYING OF AGRICULTURAL PRODUCTS WITH GEOTHERMAL ENERGY. Faculty of Technical Sciences - Bitola**
- [21] <https://www.sciencedirect.com/topics/engineering/solar-dryer>
- [22] **Caitlyn Chappell & Sarah Lebel (2009). Solar Drying Shed for Cassava in Malawi.**
- [22] **Angelos Deltsidis, Khush Bakht Aalia, Michael Reid, James Thompson, Elizabeth Mitcham, Britta Hansen, Mark Bell, Brenda Dawson, Archie Jarman (2018). CHIMNEY SOLAR DRYER MANUAL. the U.S. government's global hunger and food security initiative called Feed the Future**
- [23] **M. Veerakumar¹, KCK.Vijayakumar², P. Navaneethakrishnan³ (2014). Different Drying Methods for Agriculture Products and Eatables – A Review. International Journal of Mathematical Sciences and Engineering (IJMSE)**
- [24] **Donald G. Mercer (2014). An Introduction to the Dehydration and Drying of Fruits and Vegetables.**
- [25] **Donald G. Mercer (2014). An Introduction to the Dehydration and Drying of Fruits and Vegetables.**
- [26] **Arun S. Mujumdar (2006). Handbook of Industrial Drying.**
- [27] **Sanja Popovska - Vasilevska.DRYING OF AGRICULTURAL PRODUCTS WITH GEOTHERMAL ENERGY. Faculty of Technical Sciences - Bitola**
- [28] **Arun Muthukumarana; Cristina Rattib; Vijaya G. S. Raghavana (2010). Foam-Mat Freeze Drying of Egg White—Mathematical Modeling Part II: Freeze Drying and Modeling. Drying Technology**
- [29] **Arun Muthukumaran (2007). FOAM-MAT FREEZE DRYING OF EGG WHITE AND MATHEMATICAL MODELING.**
- [30] <http://kerone.com/blog/tag/trough-dryers/>
- [31] <https://www.alliedrentalco.com/freeze-dryers/>
- [32] **Raquel P. F. Guiné (2018). The Drying of Foods and Its Effect on the Physical-Chemical, Sensorial and Nutritional Properties. nternational Journal of Food Engineering Vol. 4**
- [33] **Rossi Indiarito, Awwaliyah Hodizah Asyifaa, Fatsyarien Citra Angiputri Adiningsih, Ghina Almira Aulia, Sarah Rahmalia Achmad (2021). Conventional And**

Advanced Food-Drying Technology: A Current Review. INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 10

[34] https://www.manufacturingchemist.com/news/article_page/Spray_drying_taking_the_heat_out_of_processing_sensitive_products/137471

[35] LA Bazyma^{1*} and VA Kutovoy² (2005). Vacuum drying and hybrid technologies.

[36] <https://www.syrupmanufacturingplant.com/vacuum-tray-dryer.html>

[37] Ángel Calín-Sánchez¹, Leontina Lipan¹, Marina Cano-Lamadrid¹, Abdolreza Kharaghani², Klaudia Mastalerz³, Ángel A. Carbonell-Barrachina¹ and Adam Figiel³ (2020). Comparison of Traditional and Novel Drying Techniques and Its Effect on Quality of Fruits, Vegetables and Aromatic Herbs.

[38] Rashid eang. Nakorn Tippayawong (2017). Superheated Steam Drying of Cashew Kernels with Testa.

[39] <https://www.eurobest.co.th/en/superheated-steam-dryer/>

[40] Krishna Kumar Patel & Abhijit Kar (2011). Heat pump assisted drying of agricultural produce—an overview. Association of Food Scientists & Technologists (India)

[41] James Gerard Gerstle (1957). Fluidized bed drying. University of Louisville

[41] <https://www.nupharmamachine.com/working-principle-of-fluidized-bed-dryer/>

[42] LOKESH R. DHUMNE¹, VIPIN H. BIPTE², Prof. Y. M. JIBHKATE³ (2015). SOLAR DRYERS FOR DRYING AGRICULTURAL PRODUCTS

[43] Charlotte P. Brennand (1994). Home Drying of Food. Extension Food Science Specialist (FN-330)

[44] Romdhane Ben Slama¹, Fethi Mechlouch² & Houcine Ben Daoud³ (2009). EXPERIMENTAL INVESTIGATION OF SOLAR DRYING FOR ORANGE PEELS BY FORCED CONVECTION. on Convective Heat and Mass Transfer in Sustainable Energy

[45] Cristina Ratti (2009). Advances in Food Dehydration, International Standard Book Number-13: 978-1-4200-5252-7

[46] Dameche Missoum Abdelghani & Benniche Ilyasse. 2021. Conception et fabrication d'un panneau solaire et étude de séchage de pommes de terre différents débits. MEMOIRE DE MASTER