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KALFALI IMAD & MENNANE ALI

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Improving the drying tool for agricultural food products by adding baffles to the solar collector

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Jury:

Mr.	Noureddine Moummi	Pr.	University of Biskra	President
Mr.	Foued Chabane	MCA	University of Biskra	Supervisor
Mr.	Adnane Labed	Pr.	University of Biskra	Examiner

College year: 2021/2022

Université Mohamed Khider de Biskra
Faculté des Sciences et de la Technologie
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Présenté et soutenu par :

MENNANE ALI & KALFALI IMAD

Le : Dimanche 26 juin 2022

Amélioration d'un outil de déshydratation de produit agroalimentaire par adjonctions des chicanes pour capteur solaire

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Jury :

Mr.	Noureddine Moummi	Pr.	Université de Biskra	Président
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Année universitaire : 2021 - 2022


بسم الله الرحمن الرحيم

Dedications

In the name of Allah, Most Gracious, most merciful.

Allah who gave me the power to continue my career, thank you Allah for enlightening my way in accomplishment and the strength to finish my work.

This work is dedicated to my mother OURIDA and father MOSTEFA, two of the most important persons in my life. The wellspring of life's happiness and prosperity, as well as everlasting love.

For their encouragements, I thank my wonderful dear brother TAYEB and my adorable sisters MOUNIRA, SAMIRA, and WIDAD.

To my sweet friends: M. ALI, B. RAMI, Z.M.ALI, H. BOUBKER, B. WALID, HANI, ABDERRAHMAN, M. AYMEN, J. ABDERRAHMAN, Z. OUAIL, T. BOUBKER and many more, thank you for the wonderful experiences and beautiful memories.

KALFALI IMAD

Dedications

In the name of Allah, Most Gracious, most merciful.

Praise be to Allah who gave me the strength to continue my path, and who helped me complete this work and gave me the strength to finish it.

This work is dedicated to my mother A. FARIDA and my father M. DJAMEL two of the most important persons in my life. The wellspring of life's happiness and prosperity, as well as everlasting love.

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MENNANE ALI

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Finally, we would like to thank our family, friends, and anyone who has supported us to finish this humble work.

Nomenclature

d: product diameter	(mm)
e: product thickness	(mm)
s: the amount of salt used	(g)
m: product mass	(kg)
G: solar radiation intensity	(W/m^2)
A: the area of the solar collector	(m^2)
$\dot{m}$: air mass flow rate	(kg/s)
Cp: specific heat of air	(J/kg .k)
M_0: initial moisture content	(%, wet basis)
M_d: dry mass of product	(g) or (kg)
M_{eq}: equilibrium moisture content	(%, wet basis)
M_{out}: liquid mass loss	(g)
MR: moisture ratio	(%)
M_t: moisture content at any drying time	(% , wet basis)
t: drying time	(s, min ,h)
$T_{product}$: product temperature	(°C)
T_a: ambient temperature	(°C)
T_{ch}: drying chamber temperature	(°C)
$T_{in\ ch}$: drying room inlet temperature	(°C)
$T_{out\ ch}$: drying chamber outlet temperature	(°C)
T_{sc}: the temperature of the solar collector	(°C)
$T_{in\ sc}$: solar collector inlet temperat	(°C)
$T_{out\ sc}$: outlet temperature of the solar collector	(°C)
η_{sc}: solar collector efficiency	(%)
η_{ch}: drying chamber efficiency	(%)
$\eta_{sc\ eff}$: true solar collector efficiency	(%)
$\eta_{ch\ eff}$: true drying room efficiency	(%)

FIGURE LIST

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Chapter III

Summary

Chapter I: Applications and process of solar drying

Chapter II: Bibliographic study

Chapter III: Experimental And Theoretical study

Chapter IV: Results and discussion

General introduction

Food products are generally heterogeneous and rapidly perishable media given their highwater content. Biologists have found that by reducing the moisture content of food products between 10 and 20%, bacteria, fungi and enzymes are almost all neutralized. Drying is one of the oldest unit operations that allows the preservation of food by the partial or total elimination of water.

Dried products can be stored for several months. In addition, a dried product weighs about 1/6 of the fresh food product. They do not need special equipment for storage and are easy to transport.

Direct sun drying is the most widely used method in most developing countries; the disadvantage associated with drying open to the sun, which is insufficient drying, is discoloration by UV radiation and contamination by dust, foreign materials, insects and micro-organisms. The use of various solar dryers has been developed to overcome the problems of open drying from the sun.

Solar drying is therefore a preservation process that promotes food storage and uses solar energy as a heating source. It is a cost-effective means for dehydrating food products at low temperatures.

The Solar drying in Algeria is one of the processes that have found applications, because of the important quantities of solar irradiations that can be exploited in this country. Nevertheless, the experience of Algeria in solar drying is recent and limited to drying of fruits, vegetables, medicinal and aromatic herbs.

The main purpose of this dissertation is to investigate the solar drying behaviour of potatoes as agricultural products by using an indirect solar dryer and drying room under force convection, in addition to determining a mathematical model by using the experimental data to calculate the moisture ratio of this drying behaviour.

Our dissertation consists of four chapters:

The first chapter presents a review of the importance of solar collectors and describes the process of solar drying and all the necessary to realize it.

The second chapter consists of a bibliographic study and presents several previous studies that have a common purpose with our work.

The third chapter describes the experiment steps and show all measuring tools and the necessary materials to ensure the drying operation, also the method of the model determination.

The last chapter explains and interprets the obtained experimental results, which were translated into curves, and it gives comparisons between the used models.

Chapter I: Applications and process of solar drying

I.1 Introduction

Drying is a process intended to remove a liquid impregnated with a solid by evaporation. The term "dehydration" has a more restrictive meaning. In fact, it merely relates to the disposal of water into a solid or into a liquid. It is a process consisting of reducing the activity of the product liquid down to a minimum below which enzymatic and oxidative reactions, as well as the development of microorganisms, are inhibited.

I.2 History

Drying is one of the oldest known methods of food preservation. Primitive people dried herbs, roots, fruits, and dried meat in the sun. They discovered that dry food enabled them to survive long, harsh winters when food was scarce or non-existent.

Dehydrated foods' lightness and high nutritional value also allowed ancient peoples to travel longer distances on hunting or exploration trips. Since the dawn of civilization, almost all humans have suffered from dehydration or food drying out. Indeed, the first written reports on the subject indicate that Phoenicians and other Mediterranean fishermen used to dry their catch in the open air. The Chinese were very fond of sun-drying tea leaves.

Many other cultures, on the other hand, have eaten a variety of dried foods. For example, scientists recently discovered a variety of dried foods, including wheat grains, in ancient Egyptian tombs. These foods were supposed to keep the deceased's soul safe on their journey to the afterlife. Grains that had been dried for centuries were rehydrated in one experiment. They sprout miraculously, demonstrating that dehydration is a natural and viable method of long-term food preservation [1], see figure (I.1).

A **B**

Figure I.1: The old method of sun drying A(wheat), B(tomato) [2].

I.3 Purpose of drying

The objective of drying is to reduce the moisture content of agricultural products to a low residual level, inhibiting the growth of all microorganisms. This importance helps the goods to be processed in environmentally friendly environments.

I.3.1 Drying habits in Algeria

The drying of agricultural products is one of the most important potential applications in the Algerian region, see figure (I.2).

Farmers and citizens dry their crops on tarpaulins, paving stones or on the ground, exposing them to the sun by spreading them in thin layers. However, Algeria's experience in solar drying is new and is limited to the drying of fruits, vegetables, medicinal plants and aromatic plants. [1]

Figure I.2: An example of drying figs in the old days in one of the villages of Algeria [3].

I.4 Drying process

I.4.1 Conduction dryers

In conduction dryers, the heat is supplied to the wet product by means of a heated surface, which is in contact with the product, causing boiling. this type of a dryers is called conduction dryer or contact-type dryer.[4][5]

I.4.2 convection dryers

Convection dryers are another type of dryer, in which the main mode of heat supply to the process is of convective. The thermal energy required to the drying process is supplied through any one convective medium like air, inert gas or superheated steam.[4][5]

I.4.3 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.[4][5]

I.5 types of solar dryers

Solar dryers are divided into several sections, which are:

- Direct solar dryers.
- Indirect solar dryers.
- Hybrid solar dryers.
- Mixed solar dryers.

I.5.1 Direct solar dryers

Solar direct dryers are designed to allow solar radiation to penetrate directly into the drying cabinet where it is converted into heat by the product to be dried by itself and the various opaque walls it faces.

In practice, direct-dryers consist of a shape-changing box that provides solar radiation with a transparent cover: glass or plastic. The racks are arranged inside the box in which air circulates mostly by natural convection, see figure (I.3).[6]

- **Advantages**
  - Better protection against dust, insects, animals and rain Compared to conventional drying.
  - No skilled labor needed.
- **disadvantages**
  - Quality deterioration due to direct exposure to sunlight, destruction of vitamins A and C, wilting, discoloration.
  - The fragility of polyethylene materials which must be changed regularly.
  - The relatively high temperature in the dryer which, combined with exposure to the sun, contributes to the destruction of nutrients.
  - Poor air circulation which limits the speed of drying and increases the risk of mold.

Figure I.3: Direct Solar dryers [7].

I.5.1.1 Types of direct dryers

I.5.1.1.1 Drying box or chest dryer

The box dryer is a simple dryer easily built by craftsmen, using locally available materials, it is intended generally for the preservation of fruits, vegetables, fish and meat.

In the box dryer, the air enters through the holes drilled in the bottom of the box, and escapes through holes located in the upper part of each side. The bottom of the box as well as the walls are painted black to better capture solar radiation. A plastic sheet or a glass plate serves as a roof, a door in the rear panel allows the temperature to be adjusted. Box of a direct solar dryer, see figure (I.4).

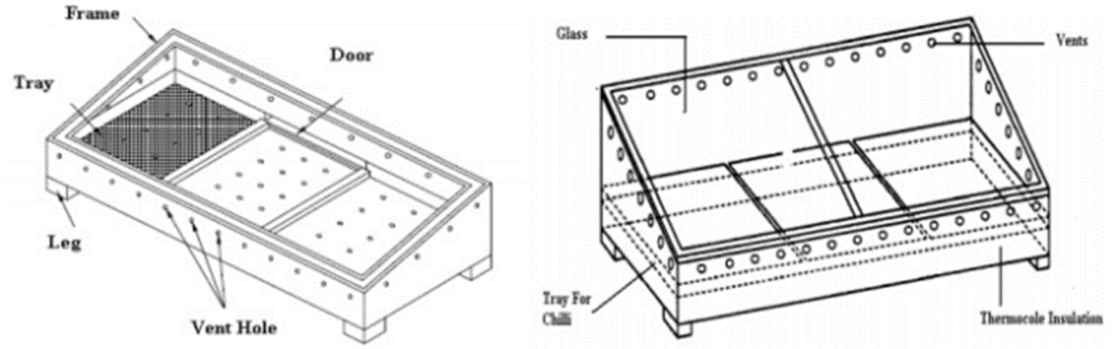

Figure I.4: Box of a direct solar dryer [8].

I.5.1.1.2 Integral dryer with natural convection

The integral dryer is a direct dryer whose product is placed in a drying chamber with transparent walls, the solar radiation impinges directly on the product. Direct exposure to solar radiation increases the proper color ripening of greenish fruits, and allowing the breakdown of chlorophyll in the tissue. For some varieties of grapes and dates, exposure to radiation is considered essential for the development of color required in the dry product. The dryer is equipped with a solar chimney which can be used to increase the buoyant force imposed on the air stream and therefore provide a high airflow and higher drying speed.[1]

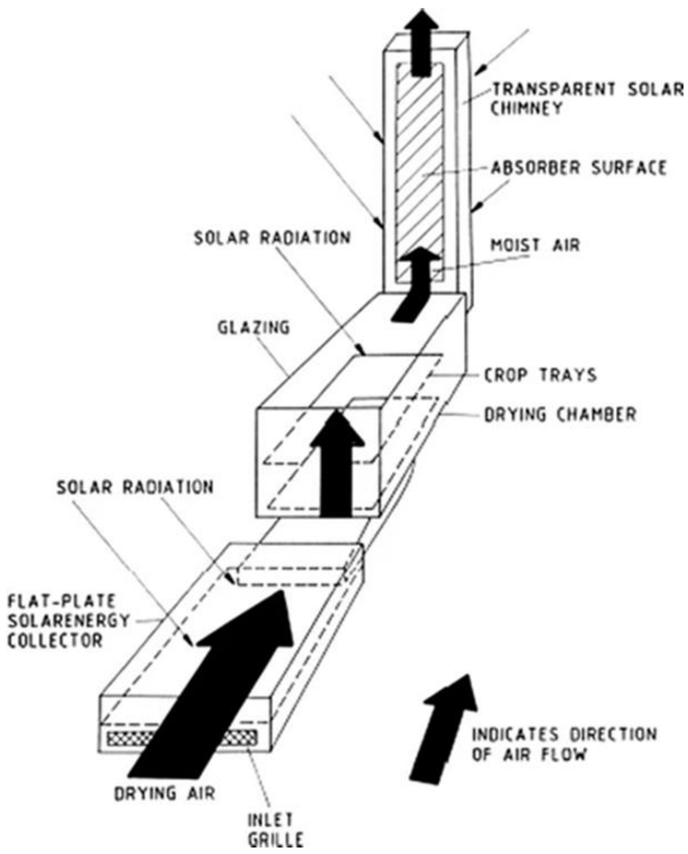

Figure I.5: Integral solar dryer [9].

I.5.1.1.3 Cabin dryer

The hut dryer is characterized by a capacity of 35 kg of fresh product for a surface area of 7 m² the products are placed in the dryer on racks raised off the ground. The plastic canvas captures solar energy, a door allows you to enter the tent and fill the racks, an air outlet is fitted in the upper part. This type of dryer is characterized by better protection against insects, removable equipment in the rainy season and simple construction and operation, among the disadvantages of this dryer: the cost is quite high, the need for a large surface of polyethylene and wind resistance which makes these models fragile if the location is badly chosen, see figure (I.6).

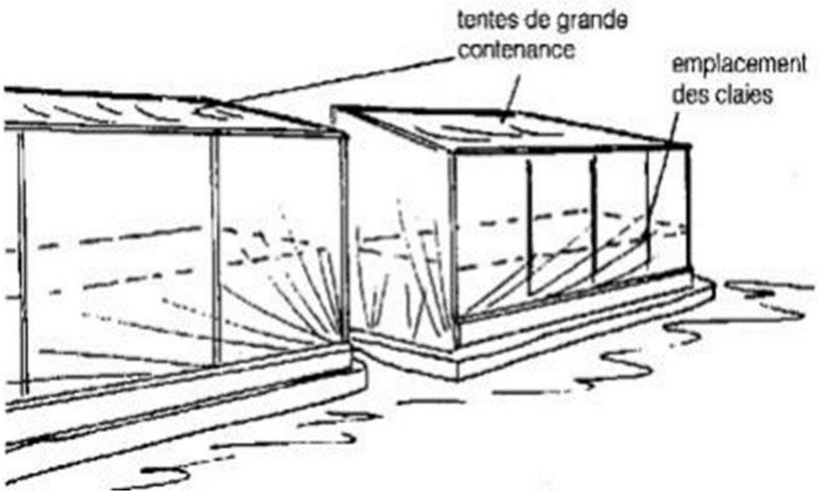

Figure I.6: Solar hut dryer [1].

I.5.2 Indirect Solar dryers

An indirect solar dryer consists of two parts: a collector that converts solar radiation into heat and a drying chamber containing the product. Hot air enters the room, the temperature increases. Natural convection heated air rises to the drying chamber. Drying time varies with climatic conditions, see figure (I.7) [6].

- **Advantages**
  - The product is not exposed to direct sunlight. It retains its color and nutritional value (especially vitamins A and C) better.
  - Their operation does not require electrical energy or fuels.
  - Time required for drying some product is less.
  - It is very efficient method than the direct type of solar drying. [10]
- **Disadvantages**
  - Very variable speed of drying according to the climatic conditions and the design of the dryer.
  - Fragility of polyethylene materials that must be changed regularly.
  - Need maintenance after particular period of time.

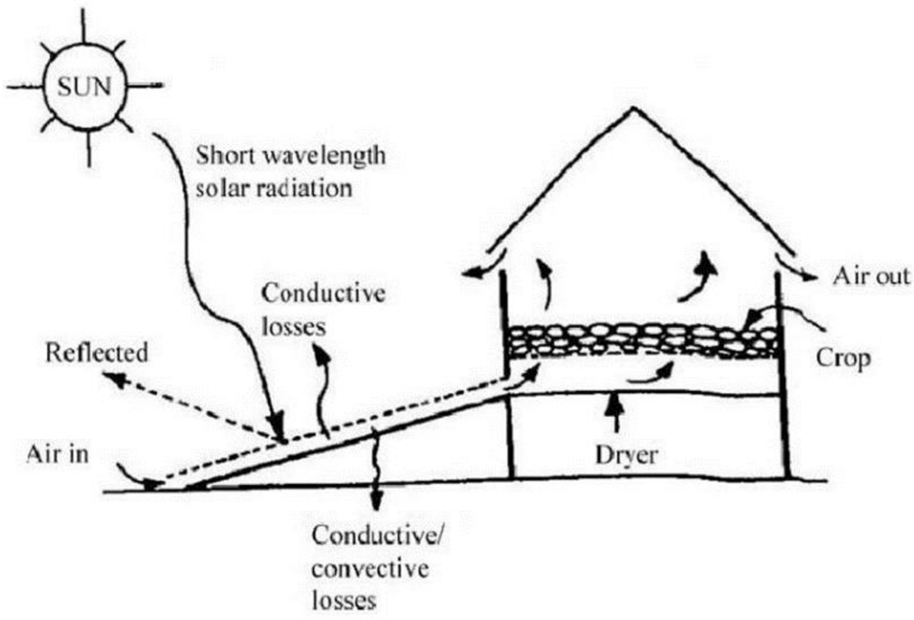

Figure I.7: Indirect solar dryer [11].

I.5.3 Hybrid solar dryers

Hybrid dryers using auxiliary energy: Fuel oil, electricity, wood, gas, etc. The additional energy supply can be located at two different places in the dryer:

- Maintaining a constant temperature in the dryer by a gas burner, electrical resistance, a wood fire. In this case solar energy becomes secondary.

- Increased air circulation by electric fans, here solar energy remains the heat source but the dryer has a greater evaporation capacity thanks to better ventilation, see figure (I.8).[6]

- **Advantages**
  - Better drying control.
  - Strong increase in productivity compared to other types of solar dryers, because the equipment can operate at night or in the rainy season if necessary.
- **Disadvantages**
  - High production and investment cost.
  - Need for local supply of fuel, electricity, gas.
  - Qualified maintenance personnel.

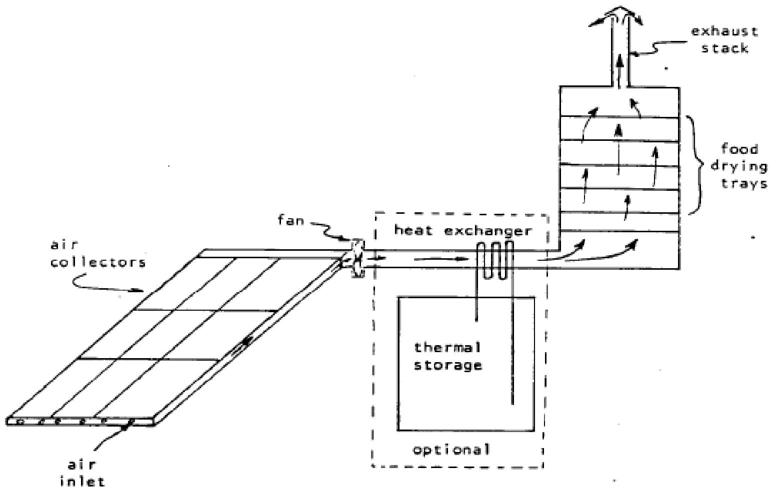

Figure I.8: Hybrid Solar Dryer [6].

I.5.4 Mixed solar dryers

These dryers combine the features of direct and indirect dryers. In this type of dryers, the combined action of direct solar radiation on the product to be dried and the sensor solar is to provide the necessary heat for the drying process.[6]

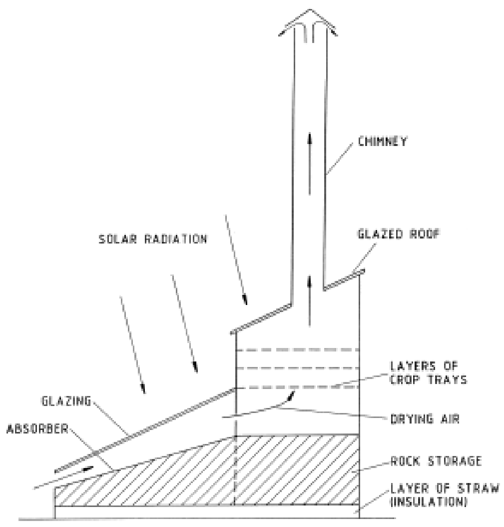

Figure I.9: Mixed solar dryer [6].

- **Advantages**
  - Rapid rate of drying with safe moisture level in product.
  - Time required for drying is less than other drying techniques.
- **Disadvantages**
  - Quality of dry grain obtained over a year is less than indirect type of dryer.
  - Cost required for maintenance.[10]

I.6 Forced Convection Solar Dryers

Natural convection solar dryers have had limited success due to low buoyancy-induced air flow rates, which prompted researchers to develop new models. solar dryers with forced convection. As a result, it is adding a fan. Providing the necessary air flow will result in much faster drying rates. higher than those obtained through natural convection solar dryers than those obtained through natural convection solar dryers. A fan can provide the necessary air flow. either by electricity/solar module or by fossil fuel. The PV-powered system has the advantage of being portable and operating independently of the power grid. Such dryers are available. Dried fruits, vegetables, spices, and even fish-quality dried products are produced on a small scale in an industrial setting [12].

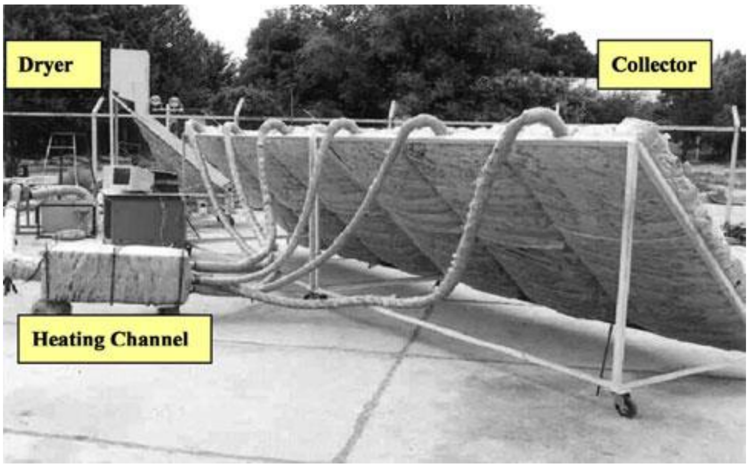

Figure I.10: The PV-powered system solar drying [12].

I.7 Technology of flat solar collectors

I.7.1 Thermal Conversion System Components

Flat collectors absorb solar radiation by means of a black painted plate. and fitted with thin pipes for the heat transfer fluid. When it crosses the ducts, it is the temperature of liquid or air due to the heat received by the absorber plate. solar collectors' main components are, see figure (I.11) [13].

- A surface to capture solar radiation.
- A heat transfer circuit which ensures the transfer of the energy extracted from the collector to the accumulation element (storage of calories), the fluids generally used as heat transfer fluid are: water and air.
- Thermal storage.

- A distribution Network.

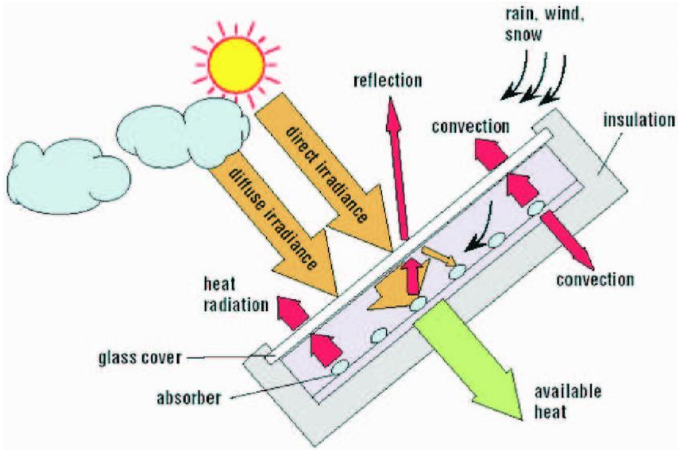

Figure I.11: Diagram of a flat air collector [14].

I.7.2 Principle of a flat solar collector

The principle of converting solar radiation into thermal energy is based on the absorbent wall, which heats up under the effect of the absorption of incident solar radiation, and the greenhouse effect, which consists of accumulating heat in a sensor to transfer it. directly or through the intermediary of a fluid which circulates under this wall and recovers by Convection is part of this absorbed energy and undergoes a rise in temperature (T_{fs}-T_{fe}). at the sensor crossing [15],

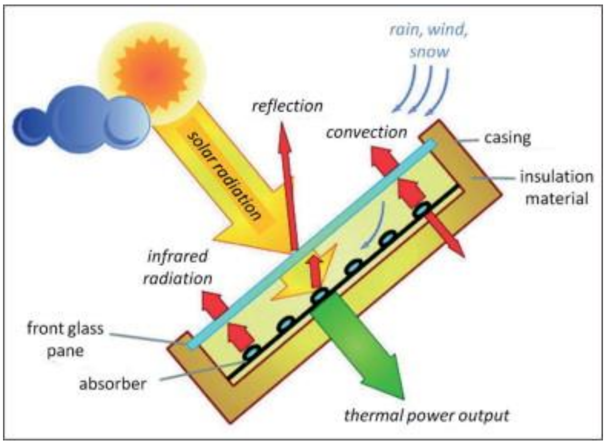

Figure I.12: principle of a flat solar collector [16].

I.7.3 Operation of a flat solar collector

The operating principle is said to be the greenhouse effect. The rays of the sun (of a visible wavelength, 0.5 m) passes through the upper transparent cover, made of glass or plastic. hit the plastic, then the absorber. This being black, it absorbs most of the light. Light is received, and as a result, it heats up. Indeed, any hot body emits radiation at usual temperatures. This is in the infrared range (9m). At this wavelength, the glass is perfectly opaque and therefore reflects all this infrared. the heat thus remains trapped in the sensor, see figure (I.13) [17].

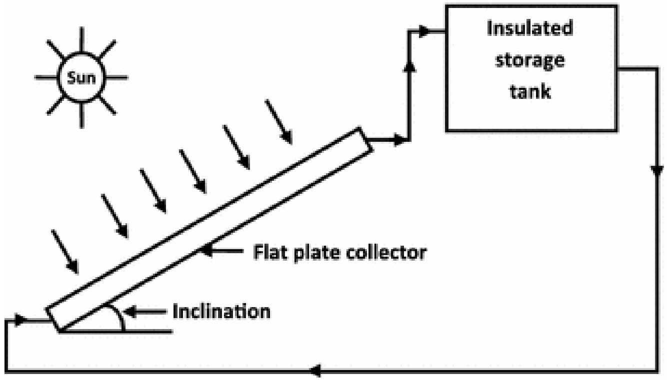

Figure I.13: operation of a flat solar collector [18].

I.7.4 Position and orientation of a sensor

in summer, when it is the best time for the sensor and the lowest in winter. the sensors are usually fixed and require no tracking of the sun. The sensor It should be oriented directly toward the equator, facing south in the northern hemisphere and north in the southern hemisphere. in the south. the optimum tilt angle of the sensor is equal to the latitude of the location with angle variations of 10 to 15°, more or less, depending on the application [19].

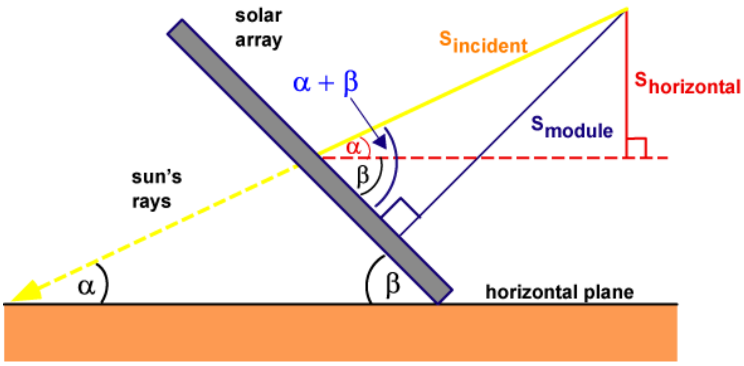

Figure I.14: A flat sensor angle (winter-summer) [20].

I.7.5 Application of solar collectors

Solar collectors are used for:

- Domestic hot water production
- Home heating
- Steam production

- Electricity generation
- Water distillation
- Solar cooking.

I.7.6 Components of solar air collectors

- **The glass**: A transparent surface to capture solar radiation (made of glass).
- **The absorber:** It is a black plate which absorbs solar radiation and transforms it in heat.
- **Insulation:** The role of insulation is to limit heat loss (in wood).
- **The heat transfer fluid:** The heat transfer fluid is a means of heat transfer

collected by the absorber to a heat exchange fluid called the working fluid. The heat transfer fluids used are air and water [21].

I.8 Effect of Air Coefficients on Drying Kinetics

I.8.1 Influence of air temperature

The temperature of the drying air has a significant influence on the drying rate. This influence is due to the heat input to the product which increases with the air temperature. It is also at the temperature of the product which is all the more important as the high air temperature.[22]

I.8.2 Influence of air speed

The air speed has a positive effect on the drying kinetics, especially at the start of the operation. However, for products whose drying kinetics are controlled by the internal migration of water, the influence of the drying rate of the air becomes very weak.[22]

I.8.3 Influence of air humidity

The water content of the air plays an important role in the behavior of the drying kinetics of certain products. It seems that this influence is more important at the beginning of drying and decreases when the air temperature increases.[22]

I.9 Conclusion

Through this chapter, a historical overview of solar drying and the ancient human use of this process is provided. We were also able to identify the types and methods of solar drying and study their advantages and disadvantages. We also studied solar sensors and their significant impact, As well as the effect of air factors such as air temperature, humidity and air speed on the solar drying process.

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Chapter II:

Bibliographic study

II.1 Introduction

Solar drying is a very broad field, and its applications vary in many ways, using different techniques as needed by using special materials. Therefore, a lot of studies have been carried out on solar drying. We will see in this second chapter a number of articles and dissertations that contain some of the previous experimental studies about the solar drying of agricultural products and their various techniques and the equipment used in this operation.

II.2 Bibliographic study

Mounir Boukerche [1], it was the object of this experimental study to investigate the solar drying behavior of three different food products under natural convection by using an indirect solar dryer, which was designed and constructed previously with local materials. We have extracted a mathematical moisture ratio model based on the obtained experimental data to compare it with the other used models as the logarithmic model, Newton model and Pabis and Henderson model.

The results show that, the drying kinetics depend, on the thickness and the size of samples in addition, that the logarithmic model was selected as the best model to describe this drying behavior.

Figure II.1: Wet and dried slices of potato with 1mm of thickness and 44 mm of diameter [1].

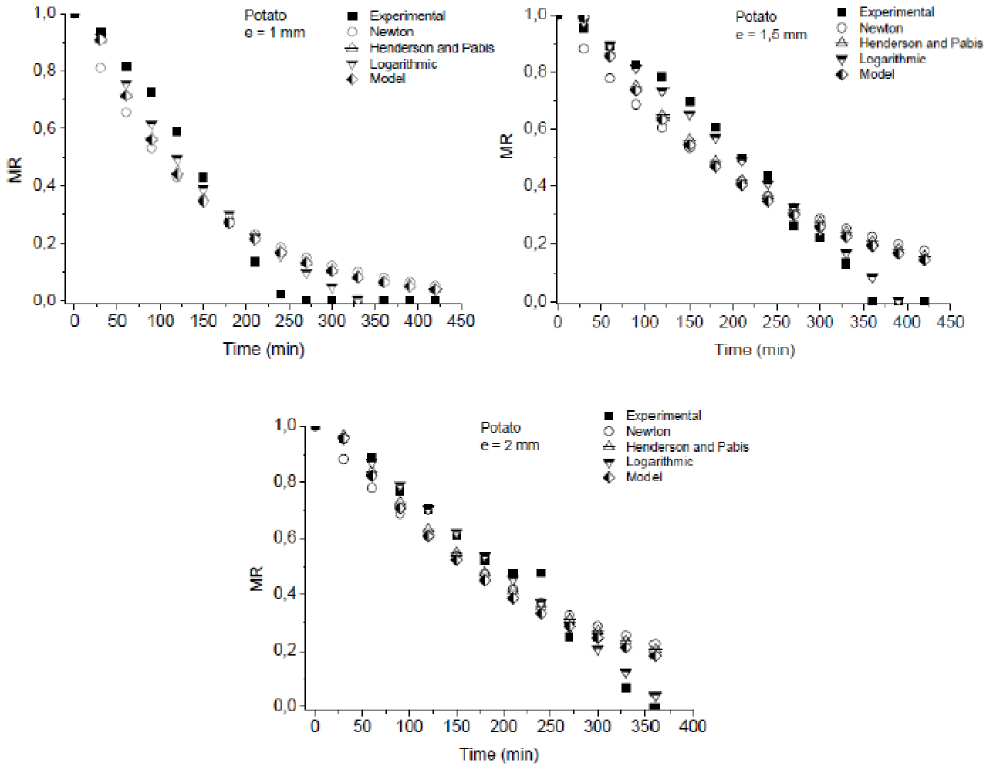


Figure II.2: The moisture ratio versus drying time for different models of potato slices with 1,1.5, and 2mm of thickness [1].

BAHADJ Ahmed [2], was conducted an experimental study on forced convection solar drying. of an agro-food product (potato) in an indirect solar dryer. The objective of this work aims on the one hand to improve the flat air solar collector. On the other hand, to study the parameters of the drying air (temperature and speed) on the product (potato) with an indirect solar dryer by forced convection for the conservation of the potato.

Figure II.3: The material before and after drying [2].

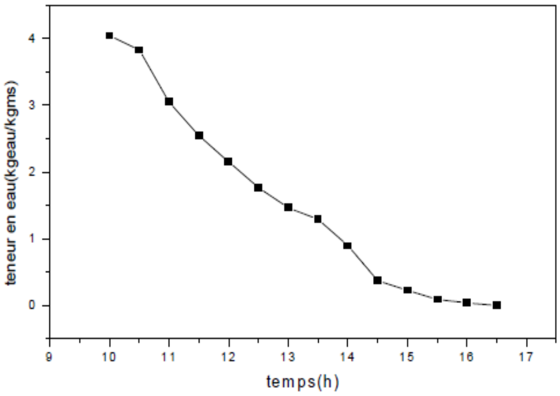
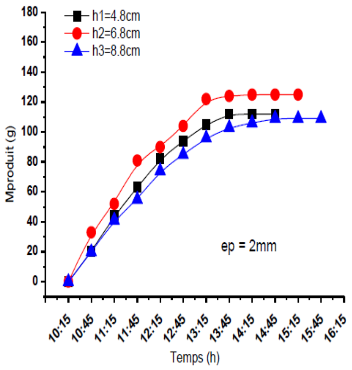


Figure II.4: Variation in water content as a function of time [2].

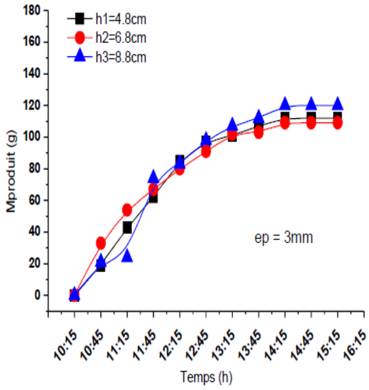
Aymen RAFAI [3], had experiment aimed to study the solar drying behavior of a food product in forced convection using an indirect solar dryer, previously designed and built with local materials. The main objective of this work is to study the mathematical modelling of humidity levels.

The results showed that the drying kinetics depend on the thickness and arrangement of the samples and the change in air flow.

Figure II.5: Wet and dried potato slices 2 mm thick, 40mm in diameter, flow rate 0.011 Kg/s grid height 4.8 cm [3].



A: thickness = 2 mm.



B: thickness = 3mm.

Figure II.6: Variation of liquid mass loss durin the drying time of the potatoes thickness= 2 mm and thickness = 3mm, flow rate = 0.01 kg/s [3].

AMANI Zriba et al [4], this research is part of a larger project to design and optimize a solar-powered tomato dryer**.** the program's overall goals are to reduce the energy consumption of industrial tomato drying while maintaining high product quality and to provide small businesses with access to low-cost dryers. the drying time of tomatoes and the properties of the drying air are calculated using experimentally obtained drying kinetics and the results were then fed into the TRNSYS thermodynamic model of the entire solar dryer system. The latter is responsible for air recycling. leaving the drying chamber and adjusting its humidity by mixing it with the appropriate amount of ambient air the temperature was the temperature of the air is then adjusted to the desired value using an air–water heat exchanger, the liquid.

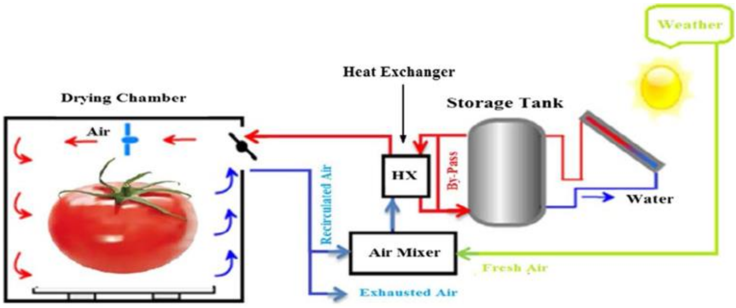


Figure II.7: Simplified schematic of the solar tomato dryer installation [4].

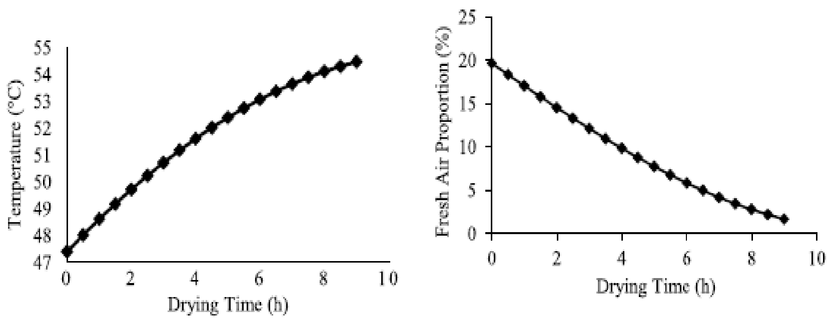


Figure II.8: Outlet Temperature and example of calculated fresh ambient air proportions admitted in the mixing chamber during drying air [4].

P.P. Tripathy et al [5], an attempt has been made to pilot heat transfer characteristics for certain energy consumption and heating rates. Drying experiments with potato cylinders have been performed in a natural convection on a laboratory scale that was built in-house the indirect solar dryer has a self-tracking mechanism. The convective heat transfer coefficient of cylindrical potato samples was calculated by taking into account the combined effects of heat and pressure. Food product capacities, as well as radiative heat transfer. from the drying chamber to the finished product. This research discovered the coefficient of convective heat transfer for potato cylinders the temperature ranged from 11.73 to 16.23

W/m^2 C, with An The experimental error is 7.86%. The specific amount of energy consumed decreased exponentially as drying time passed, and the average was calculated to be 3,491 kJ/kg. It was also used It was discovered that the specific heating rate for potato cylinders was decreased as moisture content decreased with dimensionless moisture content.

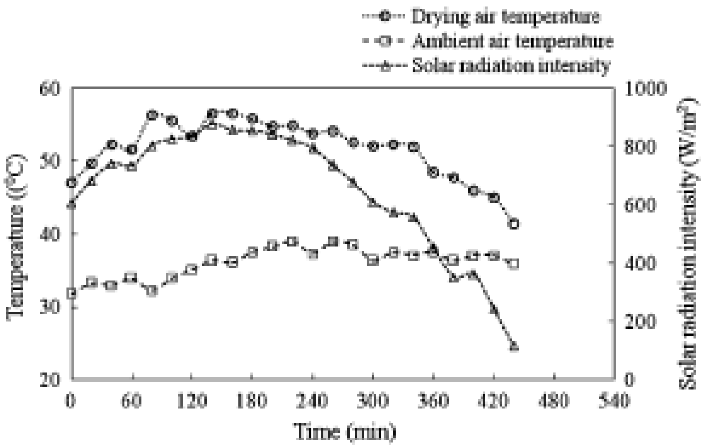


Figure II.9: Variation in drying air temperature, ambient air Temperature with solar radiation under no load condition [5].

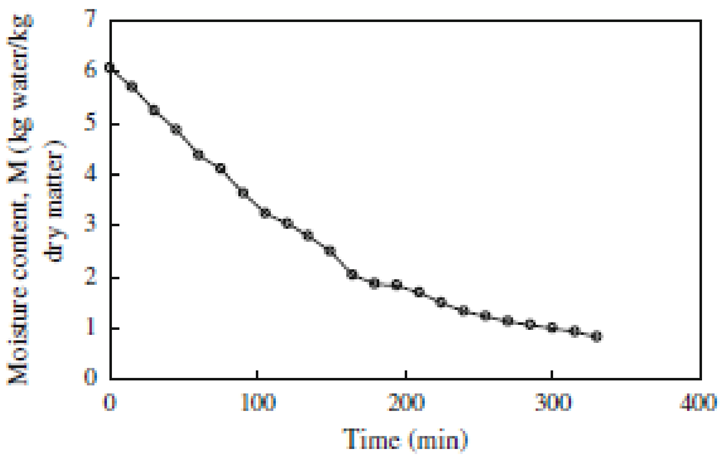
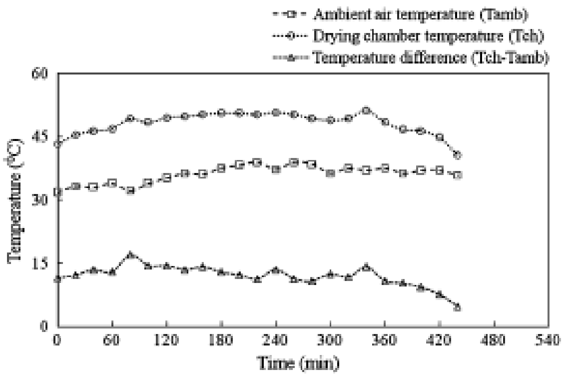
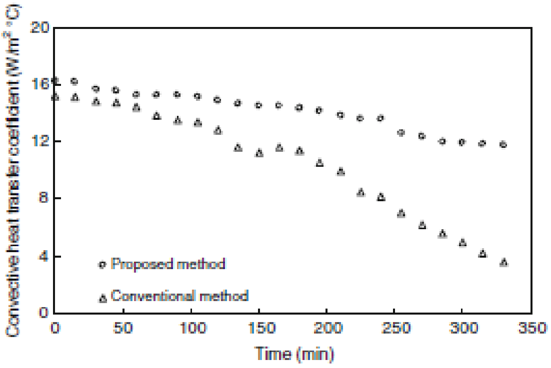


Figure II.10: Moisture content versus drying time for potato cylinders dried in indirect solar dryer [5].



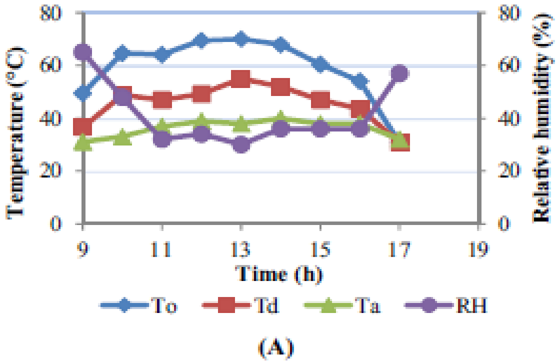


(A) **(B)**

Figure II.11: A: Variations of drying chamber temperature, ambient air coefficient temperature.

B: Comparison of convective heat transfer Obtained from proposed method and conventional method during indirect solar drying of potato [5].

TANJUM Haque et al [6], the reports study had designed, development, and tested of an indirect solar dryer for rural domestic use. Based on the local expectations and drying requirements, qualitative and quantitative methods were used to develop the appropriate design for the solar dryer.



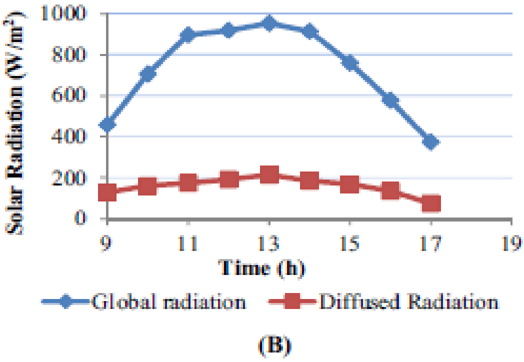


Figure II.12: Temperature (a) relative humidity and solar radiation (b) variation along the day [6].

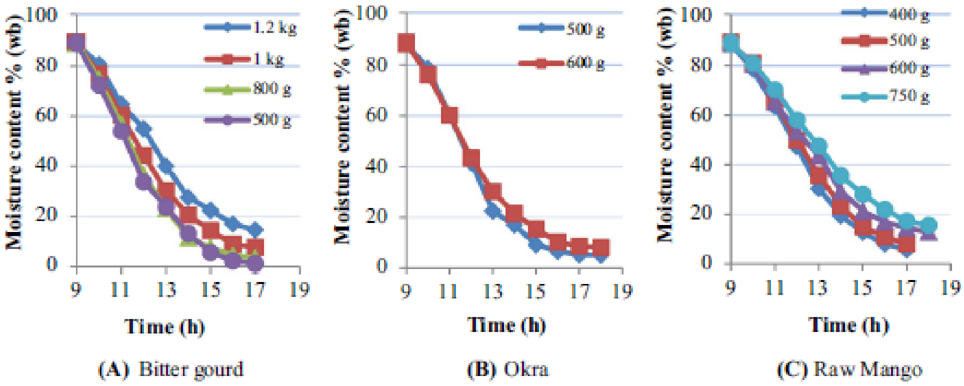


Figure II.13: Variation of moisture content of solar-dried products with drying time for varying loads. a Bitter gourd, b okra, and c raw mango [6].

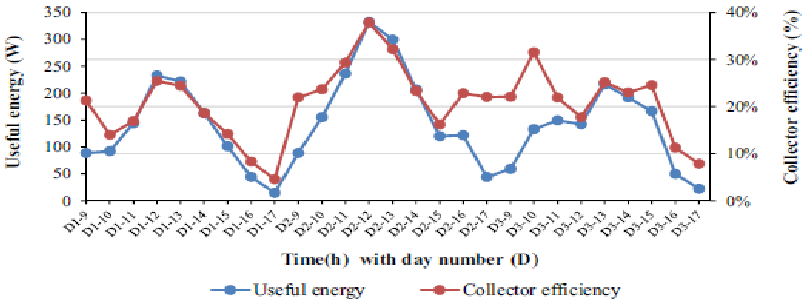


Figure II.14: Energy gained from the collector and thermal efficiency with drying time [6].

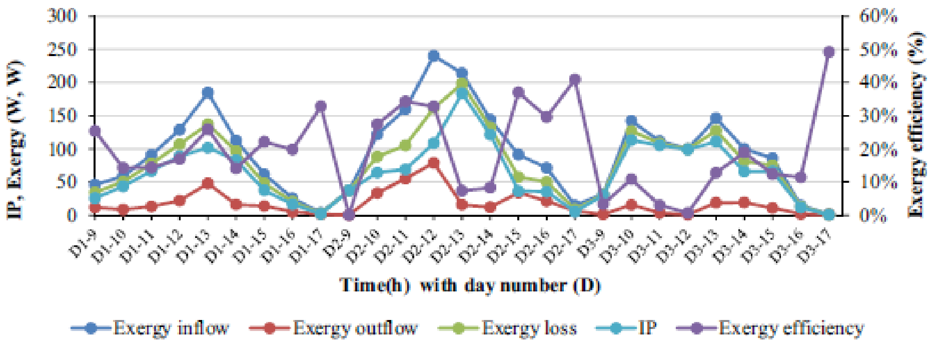


Figure II.15: Variation of hourly exergies (inflow, outflow, and loss), exergy efficiency and improvement potential [6].

S. Kesavan et al [7], had to drying potato slices, an indirect-type triple-pass forced convection solar dryer has been developed, and performance parameters such as heat storage (sand), pickup, and energy efficiency are being investigated. In 4.5 hours, the initial moisture content of the potato slices was reduced from 76% (wet basis) to 13% (dry basis). The solar collector's thermal efficiency ranged from 12 to 66 percent, with a mean value of 45 percent observed. the Midilli and Kucuk models were proposed as the best drying models.

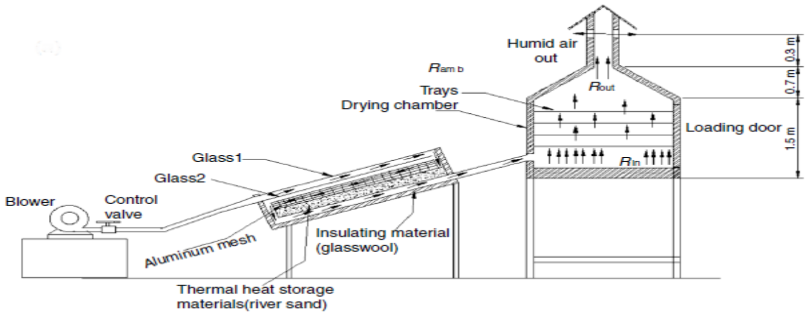


Figure II.16: Planned view of the experimental setup [7].

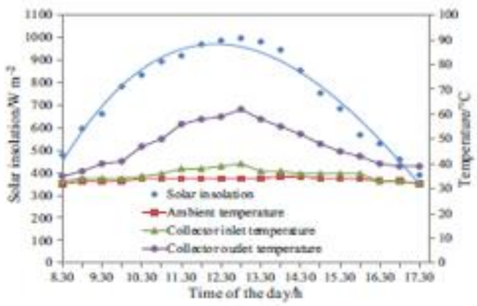


Figure II.17: Variations of solar insolation thermal and temperature [7].

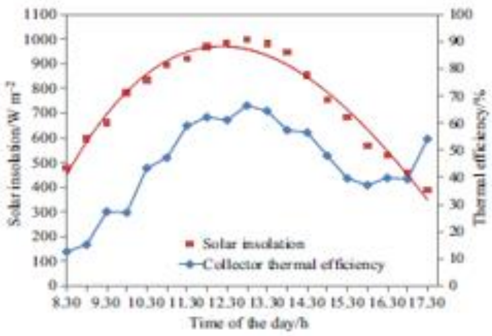


Figure II.18: Hourly variations of collector Efficiency [7].

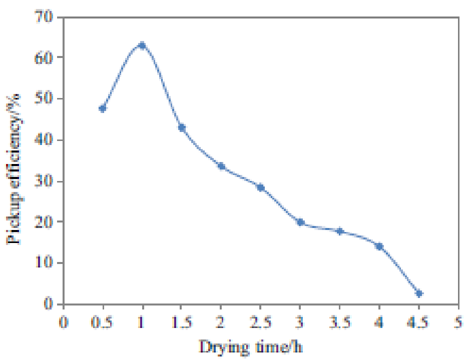


Figure II.19: Variation of pickup efficiency over drying time [7].

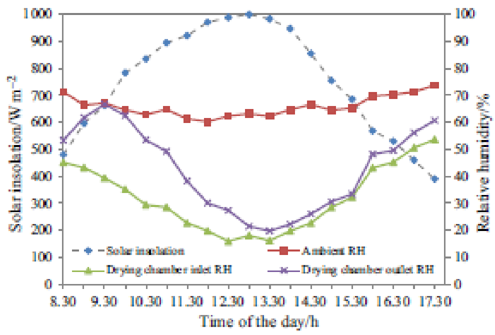


Figure II.20: Hourly variations of relative humidity of air [7].

N. S. Rathore et al [8], had reported work to designed and used natural convection house type solar tunnel dryers to dry surgical cotton on an industrial scale. A batch of surgical cotton of 600 kg by mass has an initial moisture content of 40% wet basis, from which 210 kg of water is required to get a desired moisture content of about 5%. A drying time of 7–8 h is assumed for the anticipated location (Udaipur, 27 N, 75 N, 330 E) with an expected average solar irradiance of 5.5 kW m-^{2}.

Figure II.21: Battery of solar tunnel dryer [8].

Figure II.22: Inside view of solar Tunnel dryer [8].

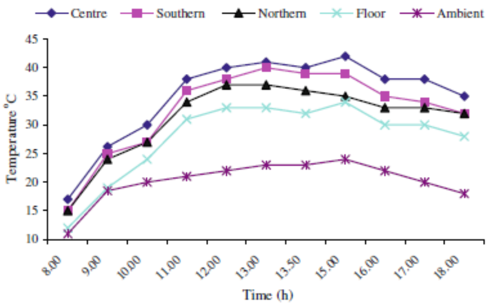


Figure II.23: Temperature variation at no full load [8].

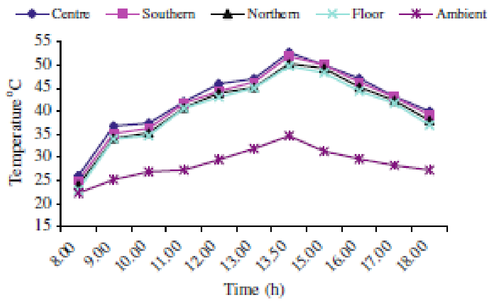


Figure II.24: Temperature variation at full load [8].

K. Kamble et al [9], a low-cost portable farm solar dryer was evaluated for drying gooseberry candy in the conditions of Vidarbha is a region in Maharashtra state. temperature profiles at the top, middle, and bottom of each of its seven loaded trays the performance of candy was studied with respect to ambient temperature during the course of drying and maximum solar at 11.30 to 12 h, a radiation of 1120 W/m² was observed. the solar radiation varied from 720–500 W/m² at 9.00 h to 16.00 h. A minimum temperature of 27°C was observed at the bottom tray of the dryer and a maximum of 44°C in the top tray at 9.00 a.m. At 11.30 h, the maximum temperature of 70°C was attained. The traditional drying method the method took 8 days to dry the product. The moisture content was reduced from 36.38 to 8.33 per cent (w b) in three days of the solar drying method.

Figure II.25: Conventional drying method [9].

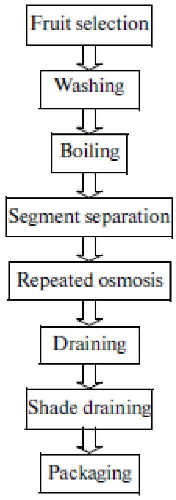


Figure II.26: Process flow chart for goose berry candy preparation [9].

Figure II.27: Farm solar dryer [9].

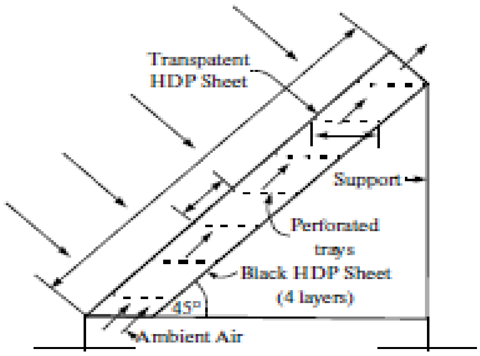


Figure II.28: Side view of farm solar dryer [9].

Samira Chouicha et al [10], has dried the solar hybrid of potato slices by forced convection in an indirect solar dryer using extra energy via a heater by joule effect generated by photovoltaic modules connected in parallel. The main results show that hybrid drying (solar energy) improves the delivery of solar panels, drying time, and quality of the product. Air flow speed of 0.51 m/s was used for a duration of 2 hours 45 minutes between May 06th, 2012 and May 28th, 2012. Hybrid drying (conventional electric power) was used for a duration of 1 hour 15 minutes between May 13th, 2012 and Mai 18th, 2012.

Figure II.29: Schematic of the drying system and Visual quality of the dried potato [10].

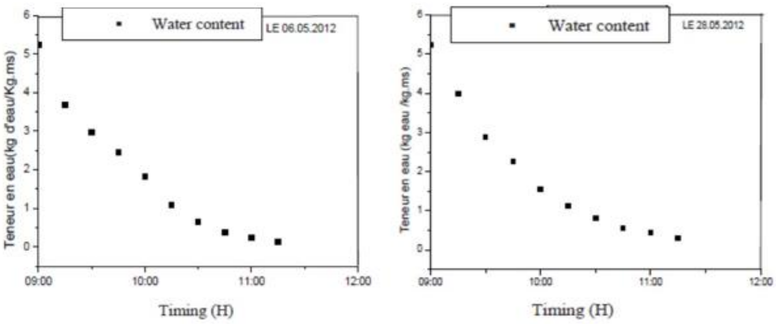


Figure II.30: variation of water content as function of time associate with one panel (a) and two panels (b) [10].

Sonu Sharma et al [11], had experiment aimed to study computer vision technology was adopted to study the effects of direct solar drying on the quality attributes of turmeric in terms of color, morphology, texture, browning factor, and shrinkage. Turmeric slices were placed in an in-house built natural-convection direct solar dryer. Results showed a decrement in BD with drying time, revealing a higher total phenolic content in dried turmeric in comparison to the fresh sample.

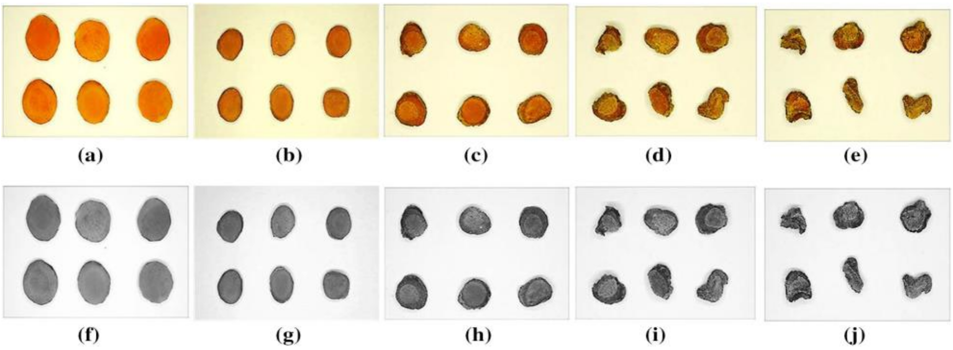


Figure II.31: RGB and Gray scale images of turmeric slices at different moisture content (w b) a and f 93.5%, b and g 39.39%, c and h 16.46%, d and I 3.90%, e and j 3.46% [11].

(A) (B)

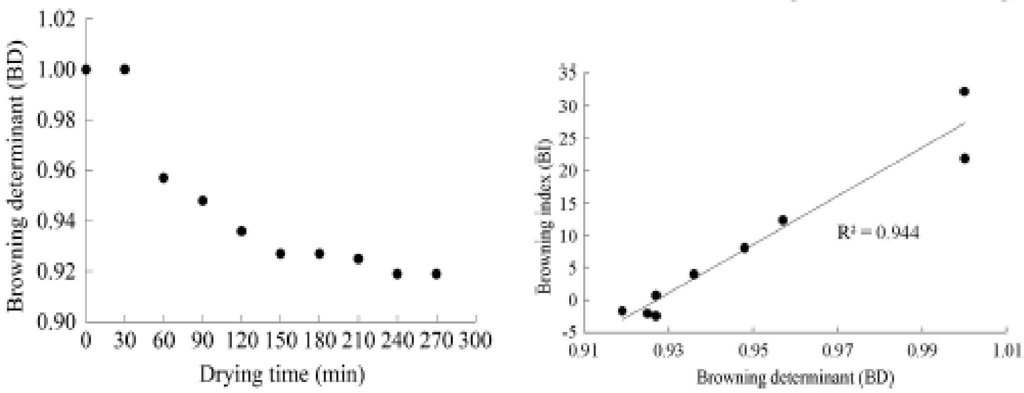


Figure II.32: A: Variation in BD of turmeric slices during direct solar drying.

B: Variation of BI with BD of turmeric samples [11].

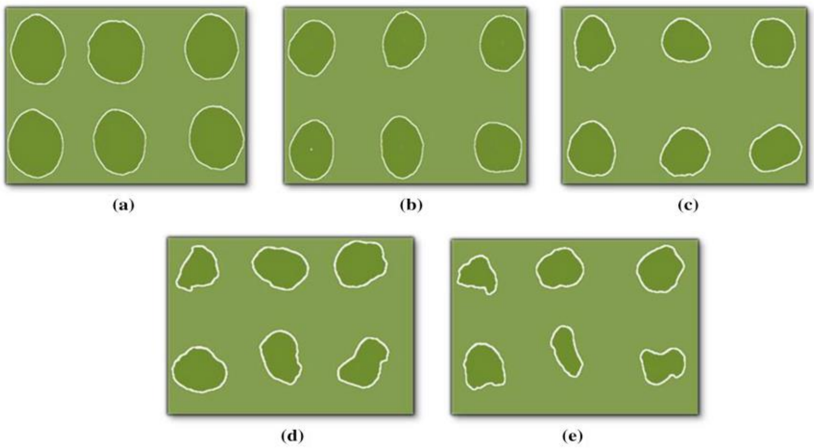


Figure II.33: Binary images of turmeric slices (25 mm diameter and 6 mm thickness) at

drying time of a 0, b 60, c 120, d 180 and e 240 min, respectively [11].

K. R. Jolvis Pou et al [12], the purpose of this study was to design and test the effects of vacuum-assisted solar drying on the quality attributes of crushed, torn, and curled (CTC) black tea. methods the impact of process parameters on tea quality was investigated using Design Expert 7.1.1 software. the According to the rotatable central composite design, independent parameters such as vacuum level and loading rate were varied, and the Liquor color (LC), aroma index (AI), drying time (t), and energy consumption were the responses (EC). Results The optimum drying conditions were discovered to be a vacuum level of 570.71 mmHg and a loading rate of 0.96 kg. dry solid surface area of m² the LC redness and yellowness indexes, AI, t, and EC were calculated to be 20.08, 11.65, 4.44, and 140.66 min, respectively.

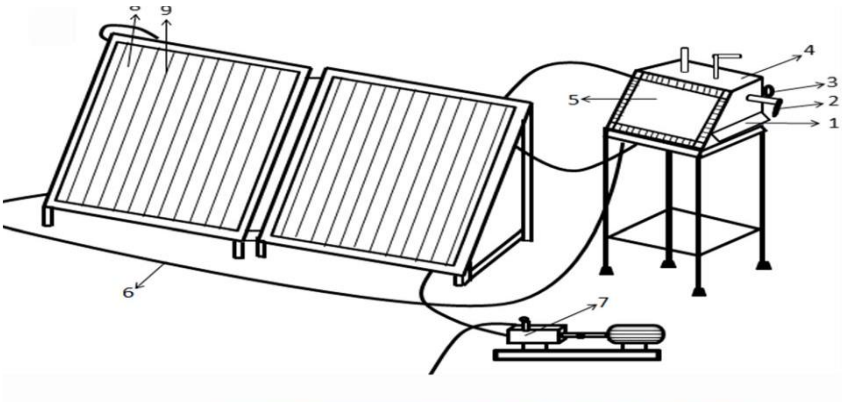


Figure II.34: Vacuum-assisted solar drying system (a) schematic diagram where (1) drying chamber (2) vacuum release valve (3) vacuum gauge (4) storage tank (5) drying chamber glass cover (6) pipe (7) water ring vacuum pump (8) solar collector (9) riser pipe, and (b) photograph of the drying set up [12].

Benoit Haut et al [13], had experiment aimed to study widely used technique in sub-Saharan Africa that allows food conservation, weight-reduction, and added value for some products. A rational method for the design and construction of a fruit and vegetable solar dryer is presented. A prototype was designed and constructed at the University Libre de Bruxelles (Belgium) and was capable of drying more than 40 kg of fresh tomatoes in 10 h. A second prototype was constructed in Bandager (Mali) by both local craftsmen and students from the University Libre de Bruxelles, using local materials. The drying time is the prevention of food spoilage was far superior to that of traditional solar dryers. Based on these prototypes, a dryer an industry is being constructed in Bandager in order to increase food self-sufficiency.

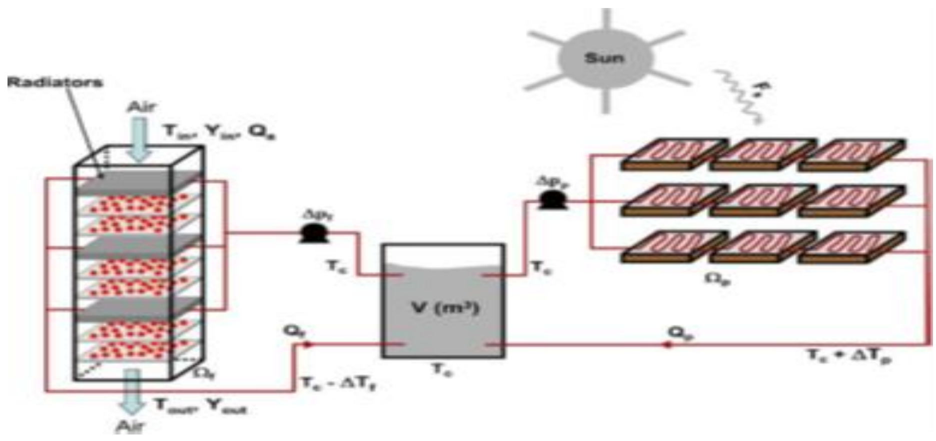


Figure II.35: Diagram of the proposed drying unit [13].

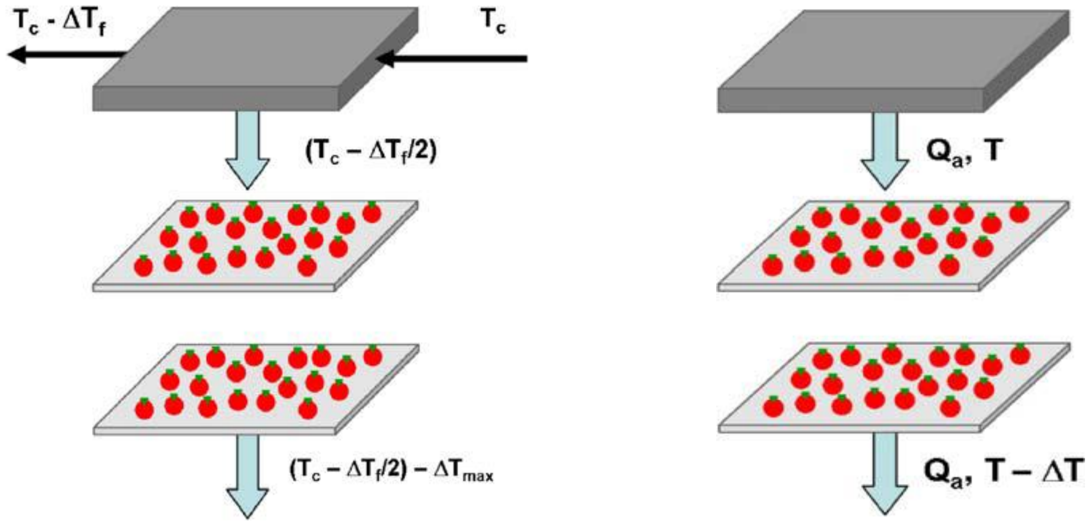


Figure II.36: Minimum outlet temperature if the radiators are perfect heat exchangers and Temperature drop in a drying zone between two radiators [13].

Sunil et al [14], the primary goals of this research are to first investigate and compare the thin layer drying characteristics of fenugreek leaves by open sun and solar drying. and then to choose a mathematical model by describing the drying process in the open sun and using solar thin layer drying models were used to dry fenugreek leaves. There are thin-layer drying models available in the literature. these, which are empirical or semi-empirical in nature, are validated.

Figure II.37: a Pictorial view of experimental set up, b schematic diagram of experimental set up [14].

The results of the experiment A non-linear regression analysis was performed. a statistical computer program is used to do so. These determine the model constants.

A

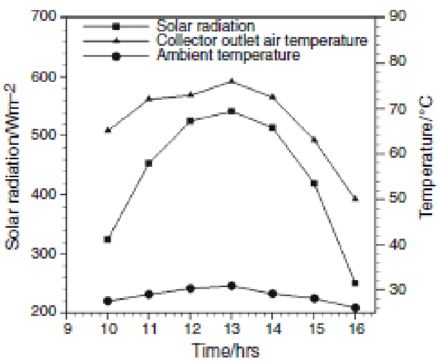


Figure II.38: Variation of solar radiation , ambient temperature and collector outlet air temperature with time of day (December month) for experimental run during drying of fenugreek leaves [14].

B

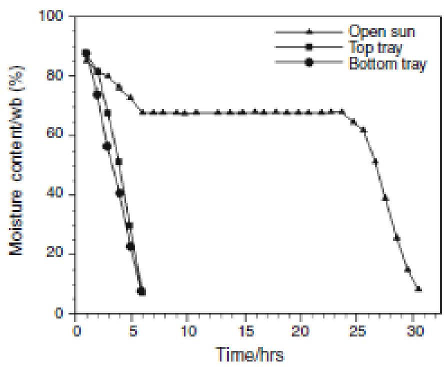


Figure II.39: Hourly variation of moisture content at different trays (top, bottom and open) with drying Time of fenugreek leaves [14].

Mohamed Yacine Nasri et al [15], in this experiment were conducted on solar drying of potatoes cut into three different shapes: cylindrical, cubical, and rectangular parallelepipedic, all with the same quantity, and using the diffusion model and experimental drying kinetics curves. The results show that the drying kinetics are affected by the shape and size of the items that make up each quantity.

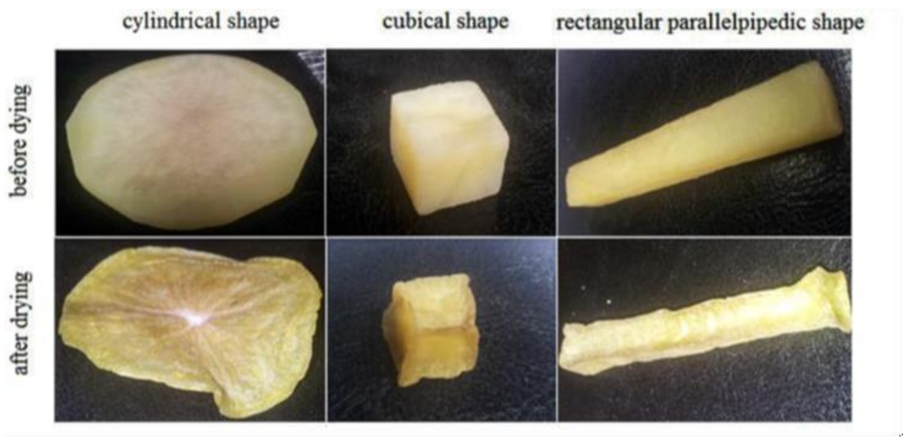
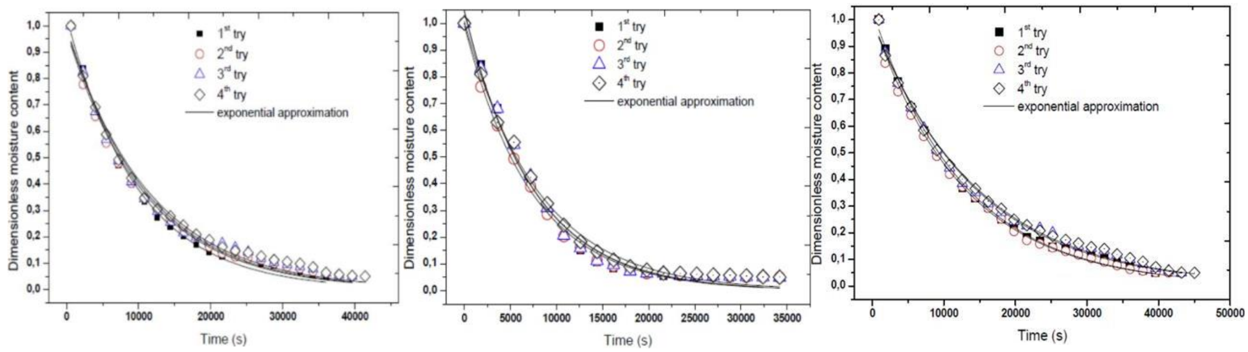


Figure II.40: Part of the beginning and the end of drying [15].



A B C

Figure II.41: Experimental with exponential approximation average dimensionless moisture ratio vs drying time for the four try of A: cube and B: disc and C: paralyses shape [15].

II.3 conclusion

Following a review of previous studies on the solar drying of agricultural products. We can say that these studies can be developed and improved by using as many techniques as needed, so researchers are always looking for ways to improve drying yield. They also rely on a number mathematical models to compare their studies with, and the goal of all of this is to get the best quality while reducing drying time.

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Chapter III:

Experimental And Theoretical study

III.1 Introduction

Solar drying is one of the most important processes applied in Algeria due to the large amount of solar radiation in this country, and solar drying is exploited to preserve various agricultural products for use at other times.

This chapter aims to describe the solar drying behavior of an agricultural product (potatoes) using a pre-designed and constructed indirect solar dryer and a pre-designed and installed forced convection drying room. Mathematical models were also used to describe this process based on the experiment data. The experiments were conducted at the University of Biskra between February and April 2022.

III.2 Experimental location and zone climate

III.2.1 Experimental set-up

The experiments were carried out near the technological hall of mechanical engineeringdepartment from university of Biskra, which is located at latitude 34°48’ and longitude 5°44’, see Fig.III.1 in the south-east of Algeria with 120 m of altitude in relation to the level of the sea, the city liesabout 400 km from Algiers [1]. see figure (III.1)

Figure III.1: Satellite picture of the experience area [1].

III.2.2 Experiments zone climate

Biskra takes place in the arid region, it is characterized by a very hot and dry summer; the average temperature is 43.5 °C with 21% of relative humidity in the average, and a very cold winter; average minimum temperature of 4 °C with an average maximum relative humidity of 58% [2].

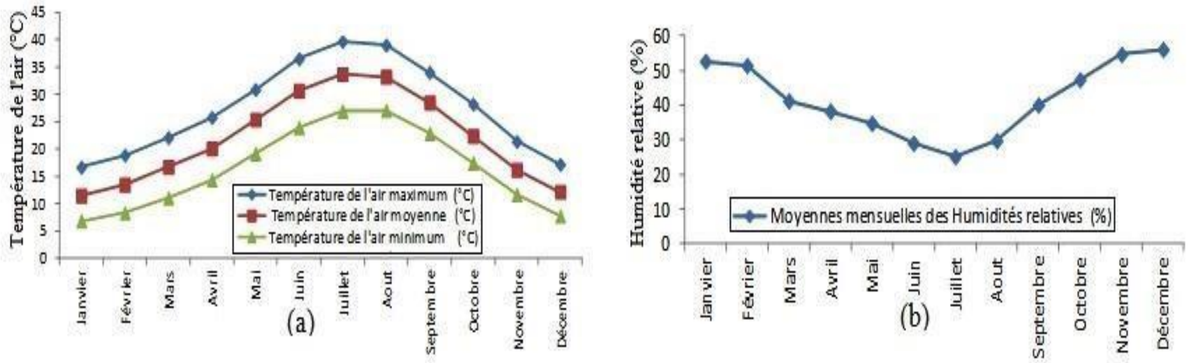

Figure III.2: Temperature and relative humidity curves of Biskra [2].

III.2.3 Experimental study

In this study, we focused on drying agricultural food, specifically on drying the potato product, using a solar collector that contains beams, a drying chamber and an air suction motor, which was previously designed and constructed in the technological hall of the Mechanical Engineering Department located in the centre of Biskra. University implemented from February to April 2022.see figure (III.3)

Figure III.3: Experimental setup (solar collector with drying chamber and air suction motor)

III.3 Solar panel components

III.3.1 solar collector

- **Solar capture :**

The thermal collector for the experiment consists of three thermal collectors, one near the place where the air enters(T1), another from the place where the air enters the drying chamber(T3), and one in the middle of the thermal collector(T2), see figure (III.4)

Figure III.4: Thermal pickup locations.

- **Baffles:**

In an attempt to improve the thermal collector performance of an indirect agricultural solar dryer, the study was started with the aim of studying the effective effect on the thermal performance of flat plate assembly, and adding baffles or rows of fins placed in the air vein. So as to improve its performance. The results showed a significant improvement in the collector outlet temperatures and its performance, and the following are pictures showing the location of the septum and a diagram of the dimensions of the air vein septum. see figure (III.5).

Figure III.5: Pictures showing air barriers.

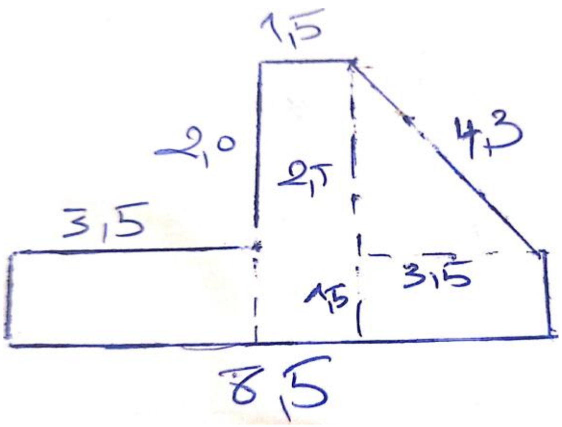

Figure III.6: Air barrier dimensions diagram.

III.3.2 Drying Chamber

The room is made of several types of wood, protected on all sides with good quality insulation. It is connected to the solar panel by a tube that passes air through the holes to distribute this air to the dried product; Dimensions 80 cm x 50 cm x 50 cm. the samples are placed evenly inside the drying chamber. In this chamber there are two thermostats to measure the temperature at the entrance and exit of the chamber. See figure (III.7).

Figure III.7: Experimental setup of drying chamber.

- **Holes:**

The drying chamber has 10 mm holes in a 30 cm x 30 cm square plate to distribute air to the product and avoid burning as shown in Figure (III-8).

Figure III.8: Orifices into drying chamber.

- **The grate :**

a support on which the product is arranged, with holes to withdraw water. This net is characterized by its hardness and resistance to rust, as well as the ease of withdrawing the product to take all measurements on it.

And also, one of its advantages is to help study several samples at the same time (the same factors) see Figure (III-9).

Figure III.9: Support of the drying product.

III.4 The balance system modification

The speed of the drying process depends entirely on the weight of the samples, so we focused on the exact measurement of this process, which is divided into two stages, the salt weighing stage and the samples weighing stage.

- **Salt weighing phase :**

At this stage, we make molds in the form of rectangles and fold them on three sides so that they can hold weighted salt (0.25 g 0.50 g 0.75 g), which is subsequently applied to the samples. The Following figure shows the process of Figure (III-10).

Figure III.10: Weighted salt in molds**.**

- **Semple weighing stage :**

At this point, we take the samples with the grid from the drying chamber and put them on an electronic scale, after which we subtract the grid scale alone from the aggregate scale (sample + grid) to find out the net weight of the sample.

III.5 Experimental Procedure

Experimental observations were recorded between 9:00 AM and 16:00 PM during February and April 2022 at the University of Biskra. Three different sizes of thin potato slices, 2 mm, 3 mm and 5 mm were shown on three different streams with salt and without salt. These slides were placed on rectangular wire mesh plates attached to heat sinks, which were used to accommodate different blocks of our samples. These plates were taken on a digital electronic balancing machine to determine the percentage of moisture content removal for each drying half hour. The equipment used in the experiment is as follow.

Figure III.11: A digital electronic balance machine.

A thermometer-control (Model TPM-10) see Fig (III-12), was kept just above the sliceof the product surface to measure the temperature and the humidity.

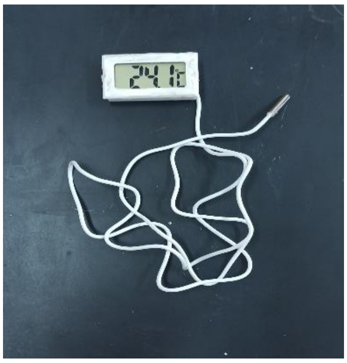

Figure III.12: A thermometer-control (Model TPM-10).

The temperature was measured using k-type calibration thermocouples as shown in Figure (III-13), at different locations, namely, the inlet and outlet temperature of the dryer, the three-level product surface temperature, the inlet and outlet temperature of the drying chamber, and the inlet and outlet temperature of the dryer. The outlet and center of the solar collector, and the temperature of the inlet, outlet and center of the absorber plate of the collector.

Figure III.13: A thermocouples type k.

Hygrometer (Model PCE-555) It is used to measure the relative humidity of the outside and the temperature of the outside medium.

Figure III.14: Hygrometer (Model PCE-555).

A pyranometer (Model Volt craft 4890.20) robust and easy to use device for measuring the intensity of solar radiation per unit of W/m² as shown in figure (III-15).

Figure III.15: Hand pyranometer 4890.20.

A digital anemometer (Model PCE-TA30) See figure (III-16), having a readability of 0.01 m/s was used to measure the wind velocity.

Figure III.16: A digital anemometer (Model PCE-TA30).

The voltage regulator (AC 220V 4000W) see figure (III-17) was used to adjust the voltage of the electric motor 4000W 220V SCR voltage regulator and electric motor speed control.

Figure III.17: Voltage regulator (AC 220V 4000W).

The Air Suction Motor which allows the forced flow to convert the hot temperature in the drying chamber to the outside. See figure (III.18).

Figure III.18: Represents Air Suction Motor.

A device for measuring electrical energy in watts, through which we can know the amount of electricity that was consumed.

Figure III.19: A device for measuring electrical power in watts.

We used a device to measure the percentage of air loss on the solar collector for a side experiment. Where the maximum and minimum value of the passing air pressure is recorded. See figure (III.20).

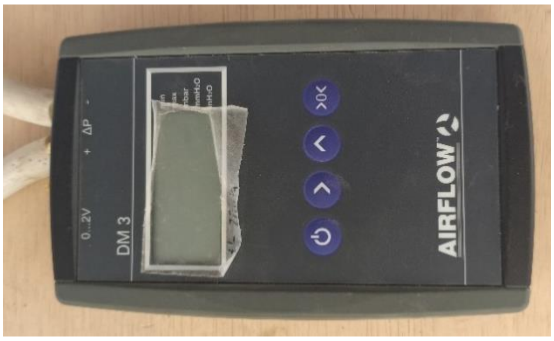

Figure III.20: Air loss measuring device (DM3).

Electronic scale to measure the amounts of salt used on the dried product.

Figure III.21: Electronic scale.

Experimental observations were recorded at each 30-minute interval. The measurement was stopped when the fixed mass of the samples was completed. These specimens have a diameter of 44 mm, wet and dried potatoes are shown in Figure (III-22,23).

Figure III.22: Sample of potato slices before drying and after drying without salt

Figure III.23: Sample of potato slices before drying and after drying with salt.

Experiment steps:

A table representing the stages of conducting the experiment with the quantities of salt, temperature, and the amount of solar radiation, and the moisture ratio for the various cases that we studied in this experiment.

Number of Case	MR (kg water/ kg prs) T (c°) R (w/m²)	Ep (mm)	Air flows (Kg/s)	Nacl (g)
Case 1	MR T R	2 mm 3 mm 5 mm	0.01884 0.024 0.032	0
Case 2	MR T R	2 mm	0.01884 0.024 0.032	0.25 0.50 0.75
Case 3	MR T R	3 mm	0.01884 0.024 0.032	0.25 0.50 0.75
Case 4	MR T R	5 mm	0.01884 0.024 0.032	0.25 0.50 0.75

Table III-1: A table showing the steps of an experiment.

III.6 Theoretical study

Several experimental or quasi-experimental models are used to describe drying kinetics and to predict the decrease in water content as a function of drying time. the moisture content was expressed in percentage wet basis (%, w.b) and then converted to kilogram water per kilogram dry matter. this table (III.2) represents some of the examples:

Models	Equation	References
Newton	MR = exp (-k*x)	(Ayensu, 1997)
Henderson and Pabis	MR=a exp (-kt)	(Rahman et al. 1998)
Logarithmic	MR=a exp (-kt)+c	(Lahsasni et al. 2004)

Table III-2: Some mathematical models applied to drying curves.[2]

The moisture ratio of the sample during drying was expressed by the Equation (III-1):

$$\boldsymbol{MR} = \frac{\mathbf{Mt - Meq}}{\mathbf{M0 - Meq}} \qquad (\boldsymbol{III-1})$$

Where (Mt) is the moisture content at any drying time (%, wet basis), (M0) is the initial moisture content (%, wet basis), and (Meq) is the equilibrium moisture content (%, wet basis). However, the moisture ratio (MR) was simplified by modifying the Equation (1) to $\frac{\mathbf{Mt}}{\mathbf{M0}}$ Instead of equation **(III-1).**

III.6.1 Efficiency of the solar collector

The measurement of the efficiency of the collector is the ratio between the thermal power that it provides to the heat transfer fluid and the power of the solar radiation that arrives on the useful surface of the collector. This ratio is called the efficiency of the collector.

$$\boldsymbol{\eta_{cs}} = \frac{\dot{\mathrm{m}}\,.\,\boldsymbol{cp}\,.\,(\boldsymbol{T_{out}} - \boldsymbol{T_{in}})}{\boldsymbol{G.A}}\,.\,\mathbf{100} \qquad (\boldsymbol{III-2})$$

$$\boldsymbol{\eta_{eff_{cs}}} = \frac{\dot{\mathrm{m}}.\,\boldsymbol{cp}(\boldsymbol{T_{out}} - \boldsymbol{T_{in}})}{\boldsymbol{A.G + P_e}}\,.\,\mathbf{100} \qquad (\boldsymbol{III-3})$$

Also, Equation **(III-3)** is the equation that gives the true value of the solar collector efficiency measurement.

III.6.2 Efficiency of drying room

It is the efficiency that the drying chamber provides. Where it derives energy from the solar collector, which gives it a better efficiency.

$$\boldsymbol{\eta_{ch}} = \frac{\dot{\mathrm{m}}\,.\,\mathbf{cp}(\mathbf{T_{out_{cs}}} - \mathbf{T_{in_{cs}}})}{\dot{\mathrm{m}}\,.\,\mathbf{cp}(\mathbf{T_{out_{ch}}} - \mathbf{T_{in_{ch}}})}\,.\,\mathbf{100}$$

After simplifying the equation, we get:

$$\boldsymbol{\eta_{ch}} = \frac{(\boldsymbol{T_{out_{cs}}} - \boldsymbol{T_{in_{cs}}})}{(\boldsymbol{T_{out_{ch}}} - \boldsymbol{T_{in_{ch}}})}\,.\,\mathbf{100} \qquad (\boldsymbol{III-4})$$

There is also another equation for this efficiency, which gives the real value that is obtained through this work, which is as follows:

$$\eta_{ch_{eff}} = \frac{\dot{m}\,.\,cp(T_{out_{ch}} - T_{in_{ch}})}{\dot{m}\,.\,cp(T_{out_{cs}} - T_{in_{cs}}) + \dot{m}\,.\,cp(T_{out_{cs}} - T_{in_{ch}})}\,.\,100$$

We simplify the equation

$$\eta_{ch_{eff}} = \frac{T_{out_{ch}} - T_{in_{ch}}}{T_{out_{cs}} - T_{in_{cs}} + T_{out_{cs}} - T_{in_{ch}}}\,.\,100$$

$$\eta_{ch_{eff}} = \frac{T_{out_{ch}} - T_{in_{ch}}}{2\,.\,T_{out_{cs}} - (T_{in_{cs}} + T_{in_{ch}})}\,.\,100 \qquad (III - 5)$$

In this table we can control the mass flow through electric potential

Voltage (volt)	Speed (m/s)	Surface (m^2)	Mass flow (kg/s)
60	2	0.00785	0.01884
62	2.63	0.00785	0.0247746
68	3.5	0.00785	0.03297

Table III-3: Adjusting the flow in terms of voltage.[5]

III.7 conclusion

In this chapter, we describe the experimental steps step by step for the experiment that was carried out during the period between February and June 2022, and depending on the materials and the necessary measuring tools, the experiments were conducted in good conditions, and that was a main reason for recording positive results after drying samples of potatoes with thicknesses and amounts of salt different.

References

[1]: Aymen RAFAI: Étude d'un Séchoir solaire à convection forcée pour le séchage de la pomme de terre à Biskra. Université Mohamed Khider de Biskra. 26 avril 2018.

[2]: Mounir Boukerche: Etudes expérimentales du séchage solaire par convection naturelle. Université Mohamed Khider de Biskra. 8 juillet 2019.

[3]: https://fr.wikipedia.org/wiki/Capteur_solaire_thermique . 23/05/2022.

[4]: Foued Chabane, Noureddine Moummi, Said Benramache: Experimental analysis on thermal performance of a solar air collector with longitudinal fins in a region of Biskra, Algeria. Journal of Power Technologies 93 (1) (2013) 52–58.

[5]: Foued Chabane, Djamel Bensahal, Abdelhafid Brima, Noureddine Moummi: Solar drying of drying agricultural product (Apricot). Mathematical Modelling of Engineering Problems Vol. 6, No. 1, March, 2019, pp. 92-98.

Chapter IV: Results and discussion

IV.1 Introduction:

The process of solar drying depends on removing moisture from a food product using many techniques and special equipment, and this process is affected by many external factors such as solar radiation, temperature, thickness, and adding of salt on product so in this chapter we will study the results obtained during the drying process that we have done at Mohamed Khidr University of Biskra. We then explain and explain these results and the curves that describe the main factors influencing this process.

We did our experiment in two parts, the first part we put the potato product without salt and in the second part we added salt to the potatoes and the results were as follows.

IV.2 Part I: Without Nacl (salt):

IV.2.1 Moisture ratio MR:

CASE 1

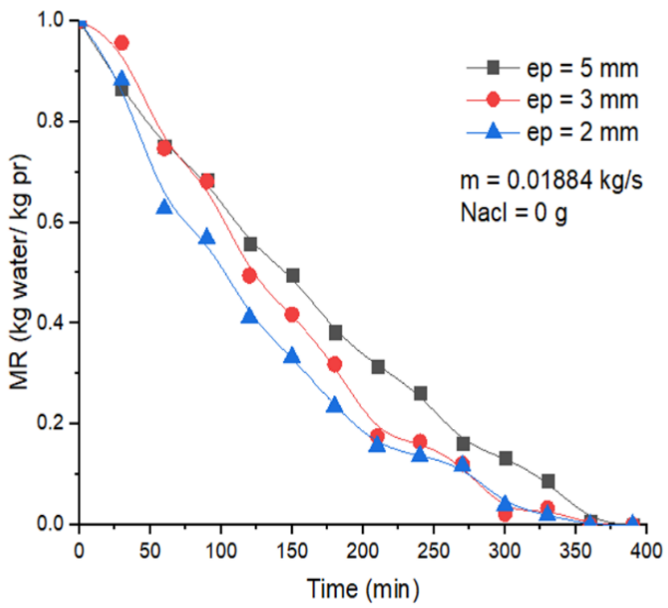

Figure IV.1: Moisture Ratio vs Drying Time for Different Models of 2,3 and 5mm Thickness Potato Chips, with air flows 0,01884 kg/s **(A).**

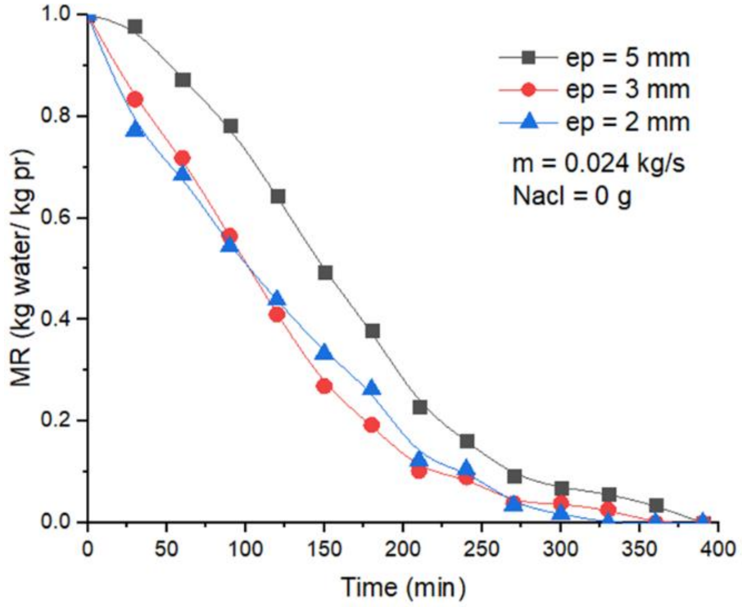

Figure IV.2: Moisture Ratio vs Drying Time for Different Models of 2,3 and 5mm Thickness Potato Chips, with air flows 0,024 kg/s **(B).**

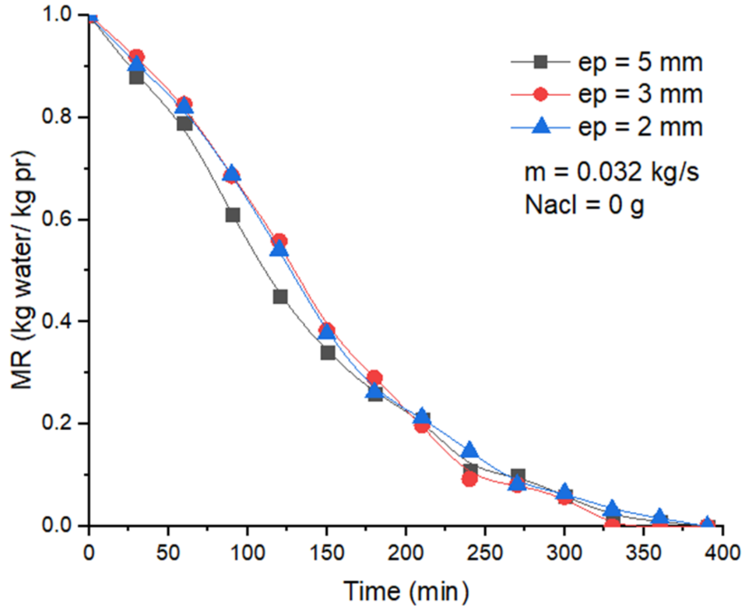

Figure IV.3: Moisture Ratio vs Drying Time for Different Models of 2,3 and 5mm Thickness Potato Chips, with air flows 0,032 kg/s **(C).**

Figures (IV.1, 2 and 3) shows the variation of moisture content as a function of time, according to three differences thickness such as 2, 3 and 5 mm, respectively, and depending on the three mass flow rates, we note that in the configuration A and B in the field (0-300) min the thickness curve was 2 And 3 are almost identical, due to the absence of a large difference between the two samples and a clear divergence in this field with the sample curve 5 mm (C) due to the clear difference in terms of thickness, and in the field (300-400 min) all curves converged for three samples, which indicates the end of the drying process. We also note that the thickness of 2 mm was the fastest in the three configurations in the absence of salt.

IV.2.2 Variation of temperature (solar capture):

- **Outlet temperature of solar collector**

In this part we will study the temperature that leaves the solar collector towards the drying chamber.

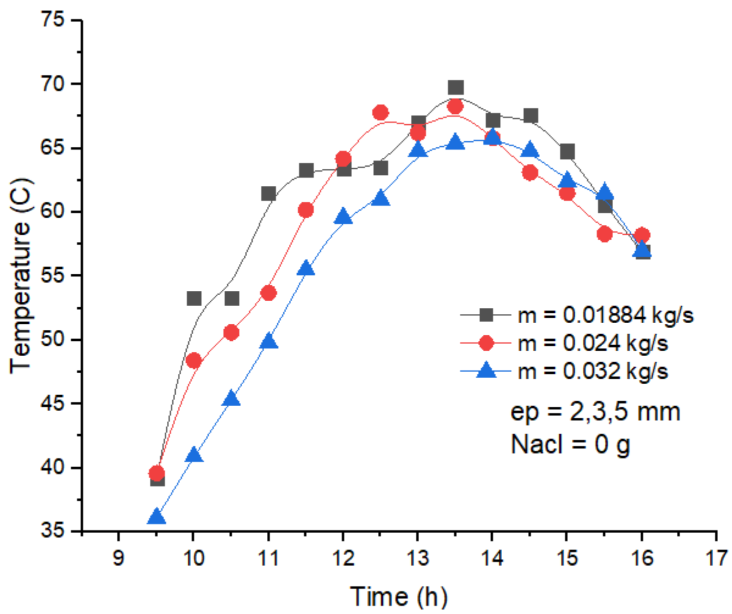

Figure IV.4: potato drying temperatures for three different samples 2,3,5 mm with three different air flows.

Figure (IV.4) represents the temperature changes in terms of time for a sample of 2, 3, and 5 mm. The highest outlet temperature of solar collector recorded 70 degrees Celsius during the day of April 17, which is equivalent to 1150 W/m² of solar radiation at 13h30, while on other days the temperature exceeded a value confined between 65 and 68 degrees Celsius.

IV.2.3 Variation in the intensity of solar radiation:

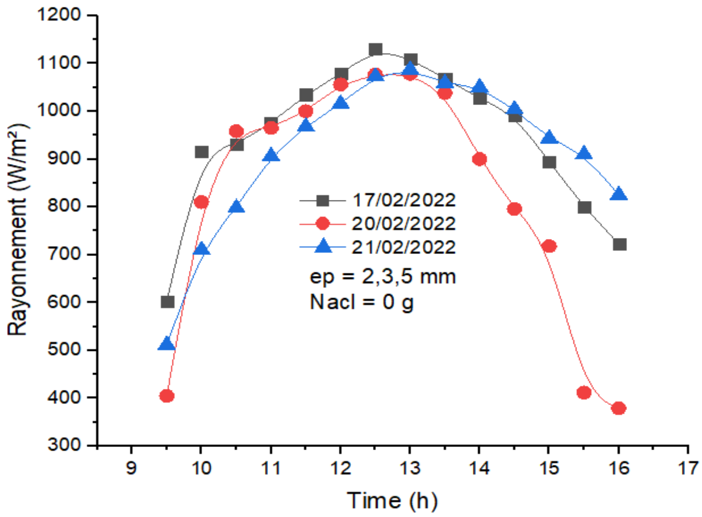

Figure IV.5: Variation of solar radiation intensity in 1-3 days of potato drying for three different samples.

Figure (IV.5) represents the variation of solar radiation in terms of time for a sample of 2,3,5 mm. We note from this figure that the intensity of solar radiation exceeded 1000 W/m² on all three days in these configurations without salt, but the maximum value recorded was 1110 W/m² on February 17, 2022, at 13 pm, with a relative decrease in solar radiation after this hour.the sudden decrease in the amount of solar radiation is due to the appearance of a passing cloud in the solar field.

IV.3 Part II: (In the presence of salt):

IV.3.1 Moisture ratio MR:

CASE 2

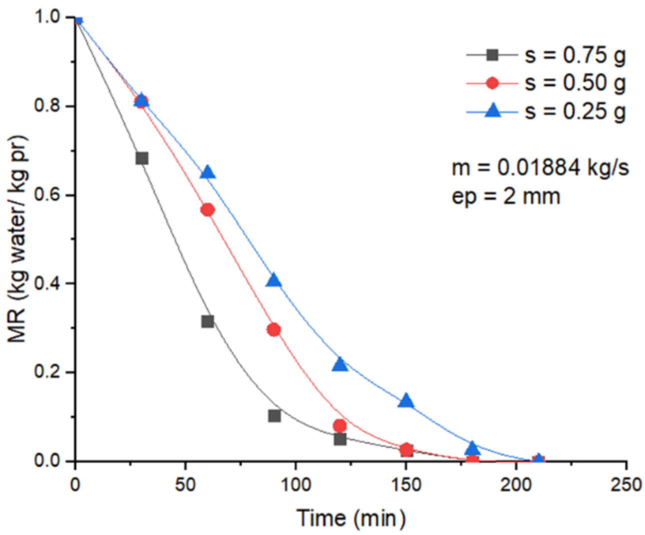

Figure IV.6: Moisture versus drying time of 2 mm thick potato chips with air flows 0,01884 kg/s **(A).**

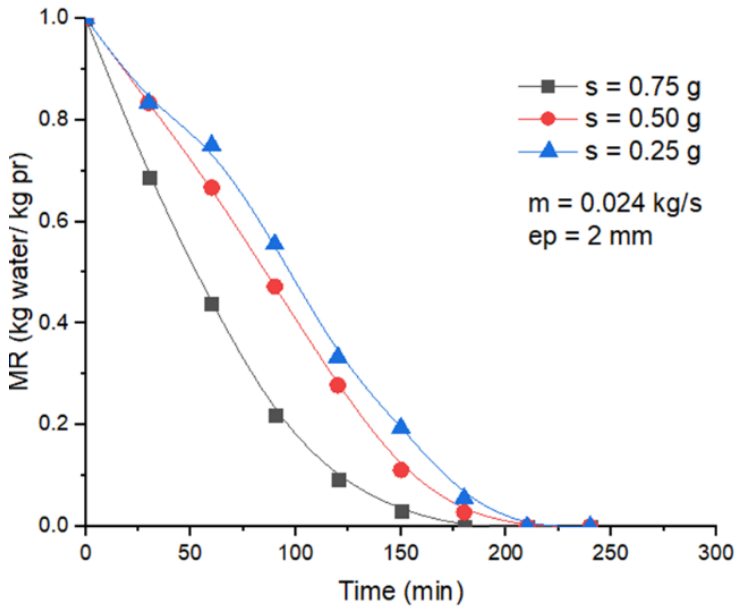

Figure IV.7: Moisture versus drying time of 2 mm thick potato chips with air flows 0,024kg/s **(B).**

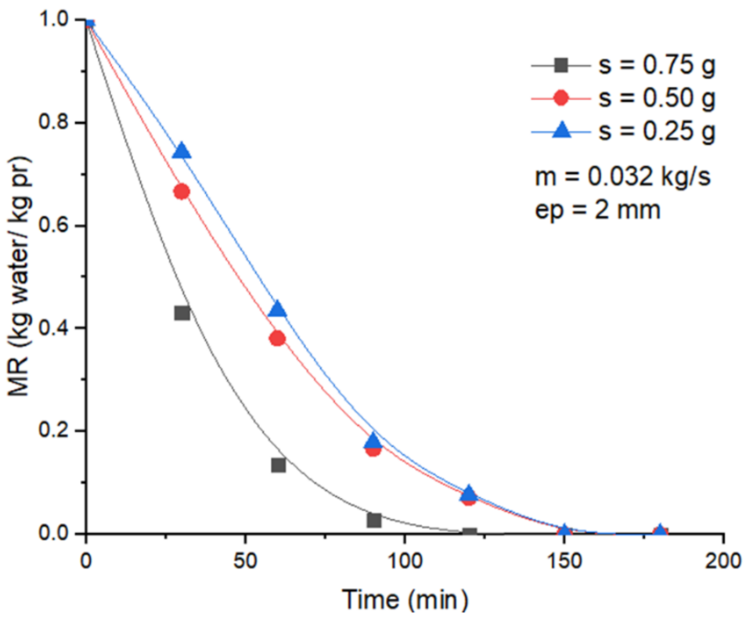

Figure IV.8: Moisture versus drying time of 2 mm thick potato chips with air flows 0,032 kg/s **(C).**

Figures (IV.6, 7, and 8) show the variation of moisture content as a function of time, according to a thickness of 2 mm, and depending on the three mass flow rates, we note that in configuration A, B and C in the drying domain (0 - 200 min) the salt curves were 0.25g and 0.50g was close to the drying speed, while the 0.75g curve was divergent from it in the three configuration and it was the fastest in terms of drying speed, especially at the largest air flow.

IV.3.1.1 Variation of temperature (solar capture):

- **Outlet temperature of solar collector**

The temperature leaving the solar collector towards the drying chamber for a thickness of 2 mm.

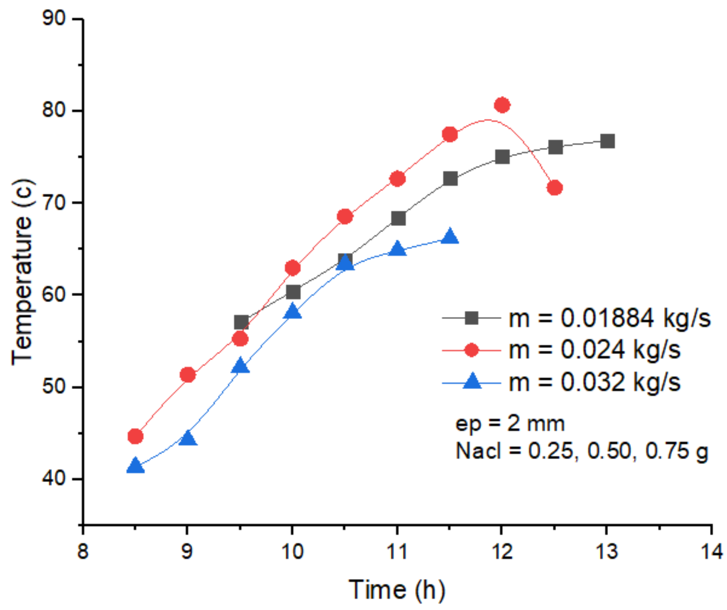

Figure IV.9: potato drying temperatures for samples 2 mm with three different air flows, with three different amounts of salt for this sample.

Figure (IV.9) represents the temperature changes in terms of time for a sample of 2 mm, we note through this curve that the highest average temperature recorded for this absorber was 80 degrees Celsius during the day of April 26, which is equivalent to 1050 watts /m² of solar radiation at 13 pm, while on other days the temperature exceeded a value confined between 60 and 75 Celsius.

IV.3.1.2 Variation in the intensity of solar radiation:

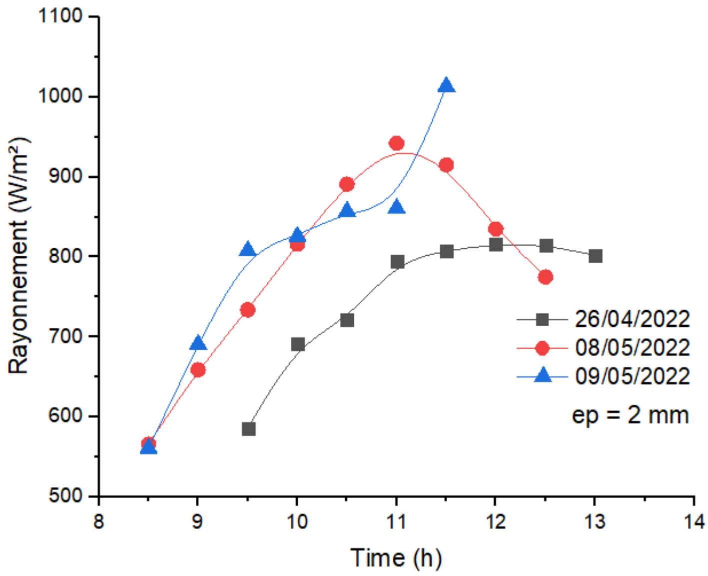

Figure IV.10: Variation of the intensity of solar radiation in 1-3 days of drying potatoes for a sample with a thickness of 2 mm.

Figure (IV.10) represents the variation of solar radiation in terms of time for a sample of 2 mm. we note from this graph that the intensity of solar radiation exceeded 1000 W/m² on all three days in the presence of salt, but the maximum value recorded was 1050 W / m² on April 26, 2022 at midday 12, and solar radiation decreases after this hour in the rest days knowing the sample dries quickly.

IV.3.2 Moisture ratio MR:

CASE 3

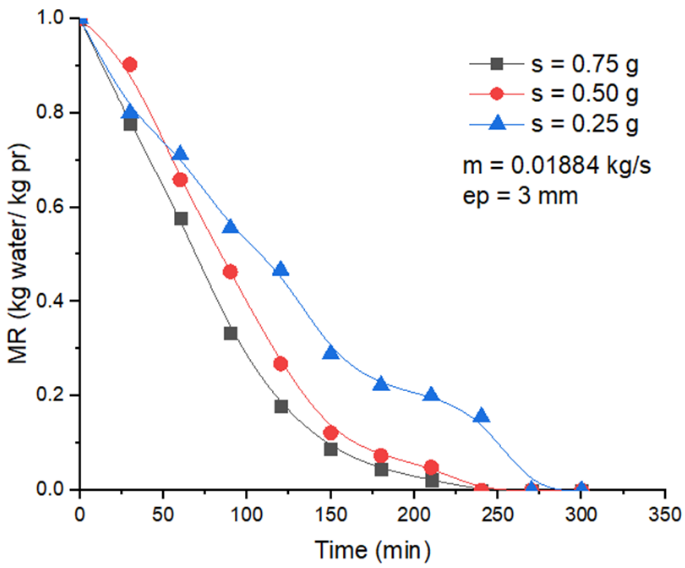

Figure IV.11: Moisture versus drying time of 3 mm thick potato chips with air flows 0,01884 kg/s **(A).**

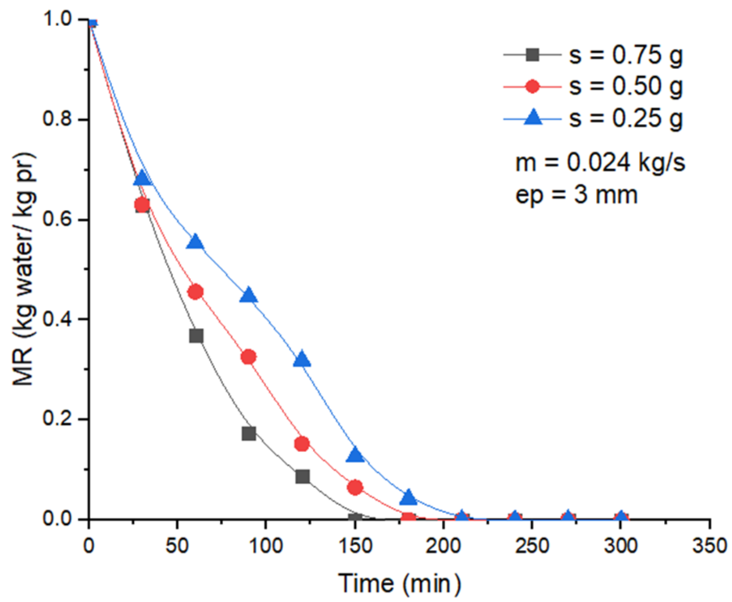

Figure IV.12: Moisture versus drying time of 3 mm thick potato chips with air flows 0,024kg/s **(B).**

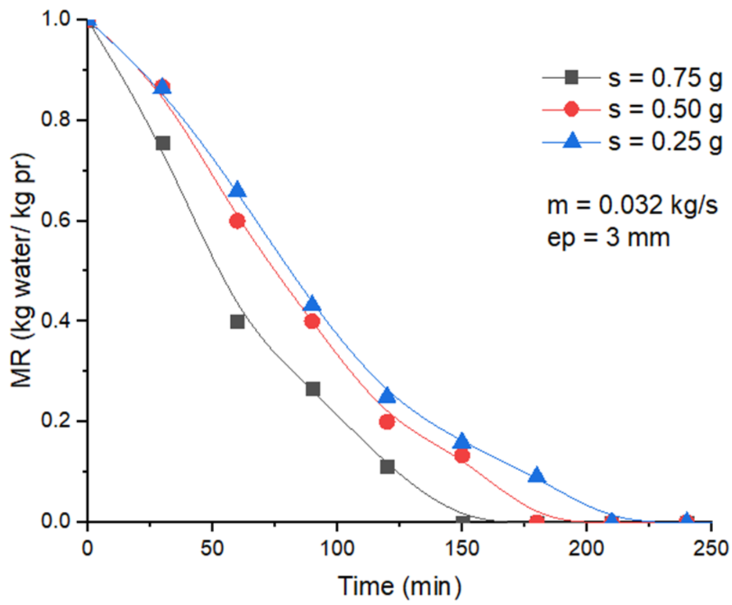

Figure IV.13: Moisture versus drying time of 2 mm thick potato chips with air flows 0,032 kg/s **(C).**

Figures (IV.11,12 and 13) show the variation of moisture content as a function of time, according to three thickness variations, such as 3 mm, respectively, and depending on the three mass flow rates, we note that in configuration A in the field (0–250 min), was

Curves 0.50g and 0.75g have nearly identical drying speeds, but curve 0.25g is divergent on them, and in configuration B and C in the range (0-150 min), we notice that curve 0.75g has the fastest drying speed, especially at high air flow of 0.032 kg/s.

IV.3.2.1 Variation of temperature (solar capture):

- **Outlet temperature of solar collector**

The temperature leaving the solar collector towards the drying chamber for a thickness of 2 mm.

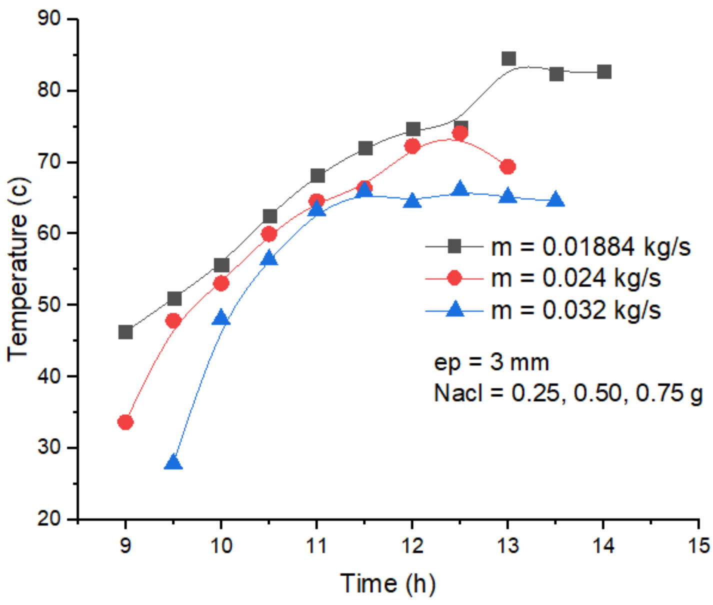

Figure IV.14: potato drying temperatures for samples 3 mm with three different air flows, with three different amounts of salt for this sample.

Figure (IV.14) represents the temperature changes in terms of time for a sample of 3 mm, we note through this curve that the highest average temperature recorded for this absorber was 85 degrees Celsius during the day of April 10, which is equivalent to 1100 watts /m² of solar radiation at 13:30 pm, while on other days the temperature exceeded a value confined between 62 and 75 Celsius.

IV.3.2.2 Variation in the intensity of solar radiation:

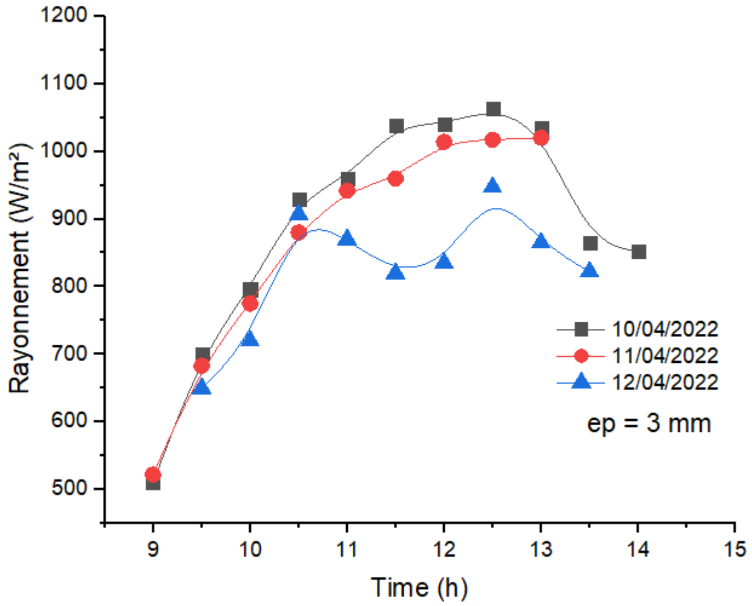

Figure IV.15: Variation of the intensity of solar radiation in 1-3 days of drying potatoes for a sample with a thickness of 3 mm.

Figure (IV.15) represents the variation of solar radiation in terms of time for a sample of 3 mm. we note from this graph that the intensity of solar radiation exceeded 1000 W/m² in most cases in the presence of salt, but the maximum value recorded was 1100 W/m² on April 10, 2022 at midday 12:30, and there was a noticeable decrease in solar radiation after this time.

IV.3.3 Moisture ratio MR:

CASE 4

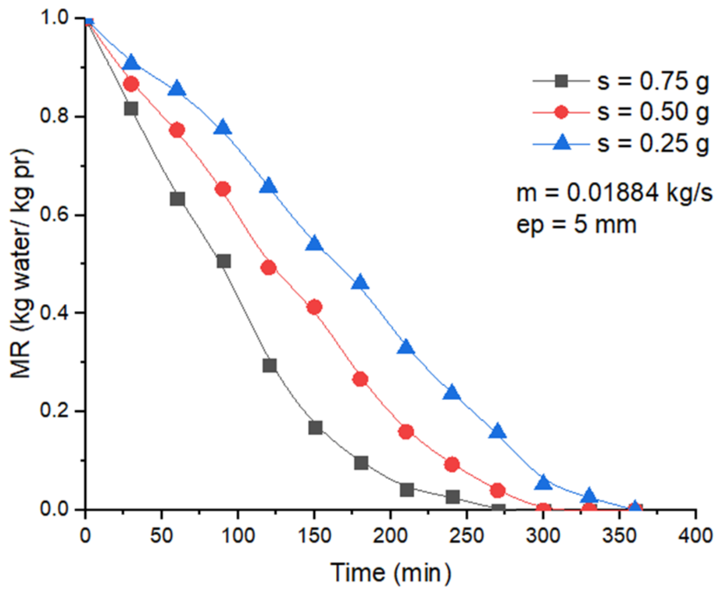

Figure IV.16: Moisture versus drying time of 5 mm thick potato chips with air flows 0,01884 kg/s **(A).**

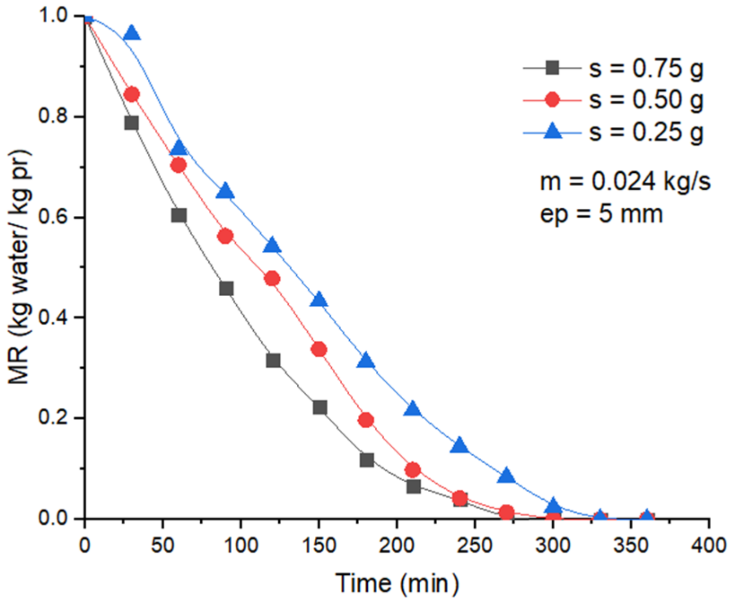

Figure IV.17: Moisture versus drying time of 5 mm thick potato chips with air flows 0,024 kg/s **(B).**

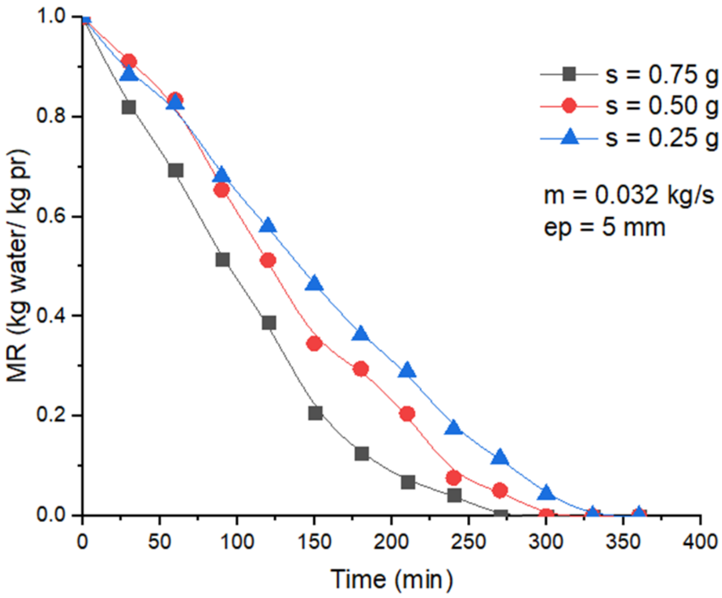

Figure IV.18: Moisture versus drying time of 5 mm thick potato chips with air flows 0,032 kg/s **(C).**

Figures (IV.16,17 and 18) show the variation in moisture content as a function of time according to three thickness differences, such as 5 mm, and depending on the three mass flow rates, we notice that in the configurations A, B, and C, through the drying field curves, there is a clear difference between them as it was The curve of 0.75 g was always the fastest during the drying process, while the curve of 0.25 g was the slowest during the three cases due to the slow exit of water from the potato material due to the large sample thickness.

IV.3.3.1 Variation of temperature (solar capture):

- Outlet temperature of solar collector

The temperature leaving the solar collector towards the drying chamber for a thickness of 5 mm.

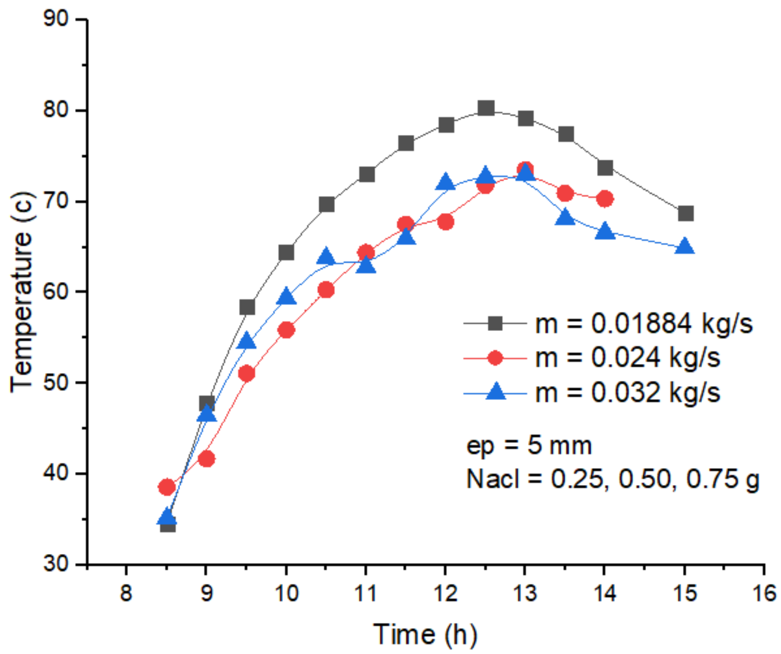

Figure IV.19: potato drying temperatures for samples 5 mm with three different air flows, with three different amounts of salt for this sample.

Figure (IV.19) represents the temperature changes in terms of time for a sample of 5 mm, we note through this curve that the highest average temperature recorded for this absorber was 83 degrees Celsius during the day of April 17, which is equivalent to 1050 watts/m² of solar radiation at 12:30 pm, while on other days the temperature exceeded a value confined between 70 and 75 Celsius.

IV.3.3.2 Variation in the intensity of solar radiation:

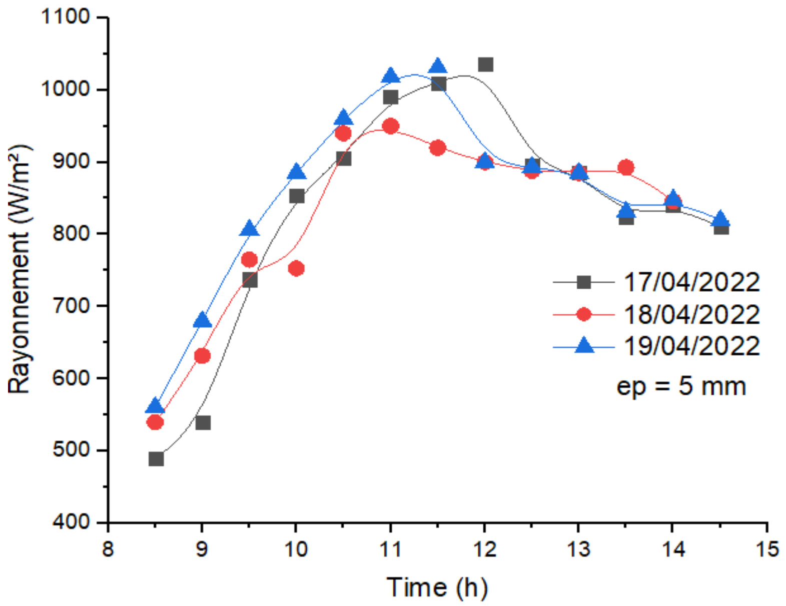

Figure IV.20: Variation of the intensity of solar radiation in 1-3 days of drying potatoes for a sample with a thickness of 5 mm.

Figure (IV.20) represents the variation of solar radiation in terms of time for a sample of 5 mm. we note from this graph that the intensity of solar radiation exceeded 1,000 W/m² in the best case with the presence of salt, but the maximum value recorded was 1050 W/m² on April 19, 2022 at mid-day 12, and there was a marked reduction in solar radiation after this time as the process of drying the potato product ended.

IV.4 Comparison:

IV.4.1 Moisture ratio MR:

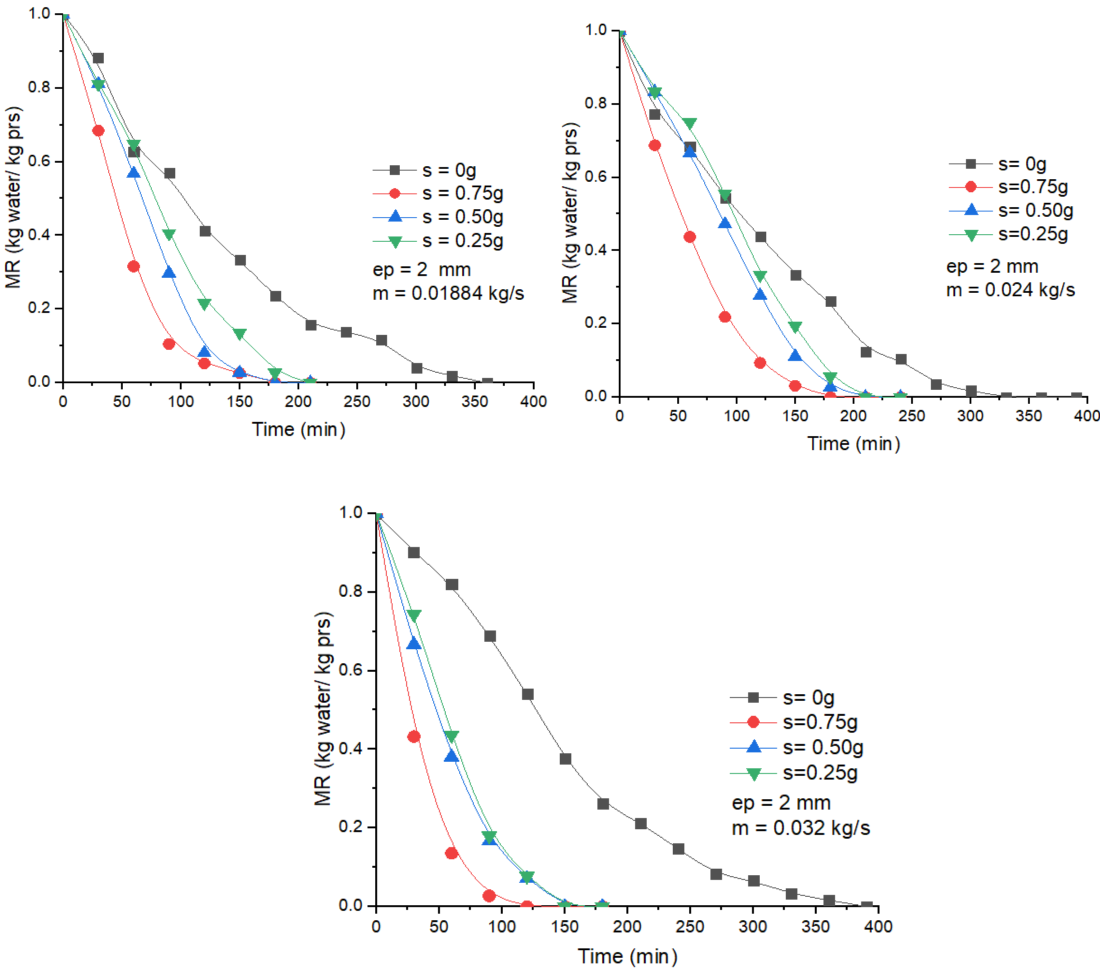

Figure IV.21: Moisture ratio versus drying time for 2 mm thick potato chips with three different air flows 0.01884, 0.024, 0.032 kg/s with amounts of salt 0 g, 0.75g, 0.50g, 0.25g.

Figure (IV.21) presents the differences in the experimental and expected values of moisture ratio with the drying time for a sample with a thickness of 2 mm. We note that the results differed in the three cases due to a difference in the flow of air emitted to the drying chamber, as well as a difference in temperatures and salt amounts. used, where we note that the high flow 0.032 kg / s with the amount of 0.75 g of salt is the fastest and best in the three cases during the drying process.

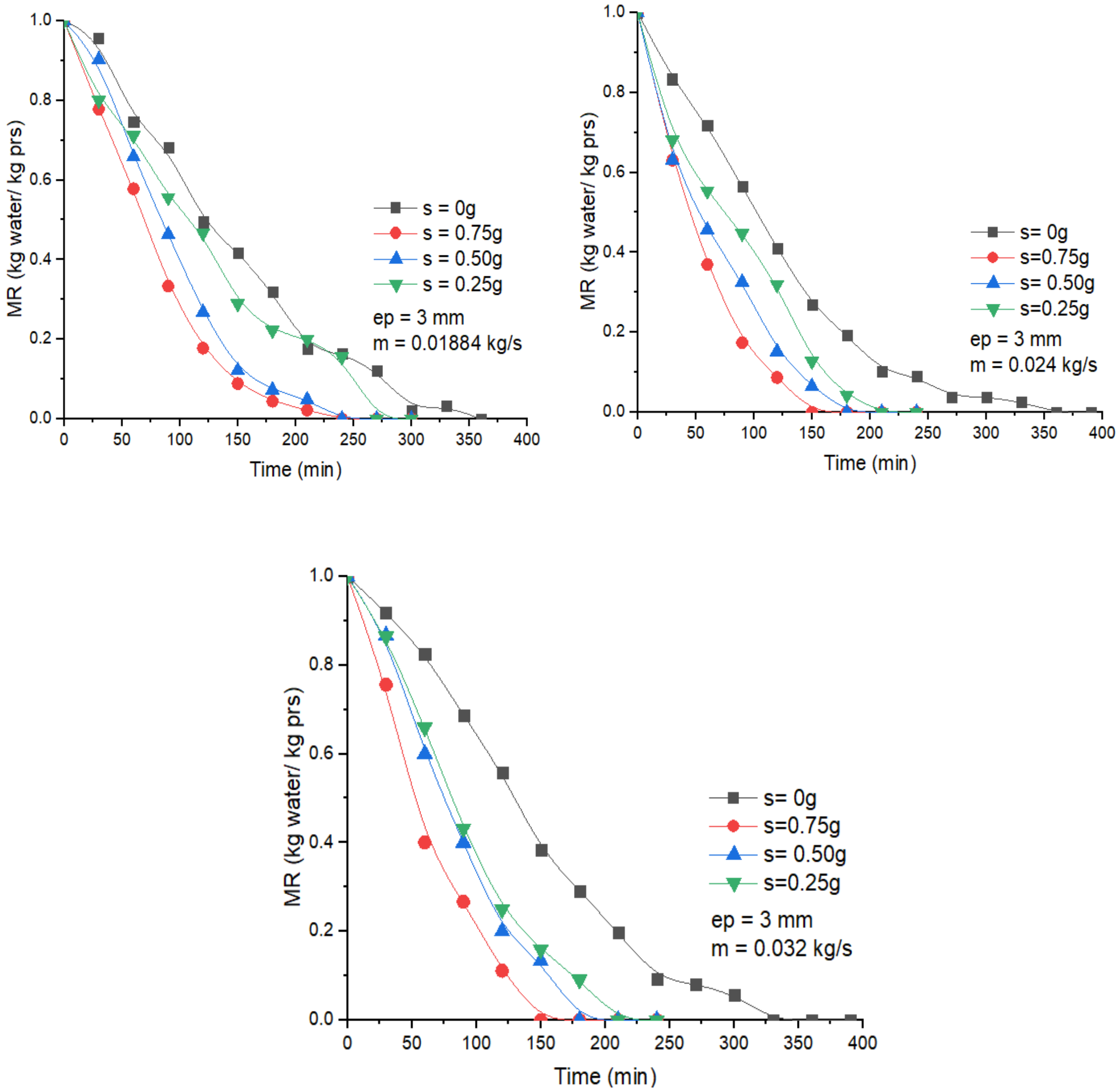

Figure IV.22: Moisture ratio versus drying time for 3 mm thick potato chips with three different air flows 0.01884, 0.024, 0.032 kg/s with amounts of salt 0 g, 0.75g, 0.50g, 0.25g.

Figure (IV.22) presents the differences in the experimental and expected values of moisture ratio with the drying time for a sample with a thickness of 3 mm. We note that the experimental results differed in the three cases due to a difference in the flow of air emitted to the drying chamber, as well as a difference in temperatures and salt amounts. used, where we note that the high flow 0.032 kg / s with the amount of 0.75 g of salt is the fastest and best in the three cases during the drying process, with a slight increase in drying time for the sample 2 mm.

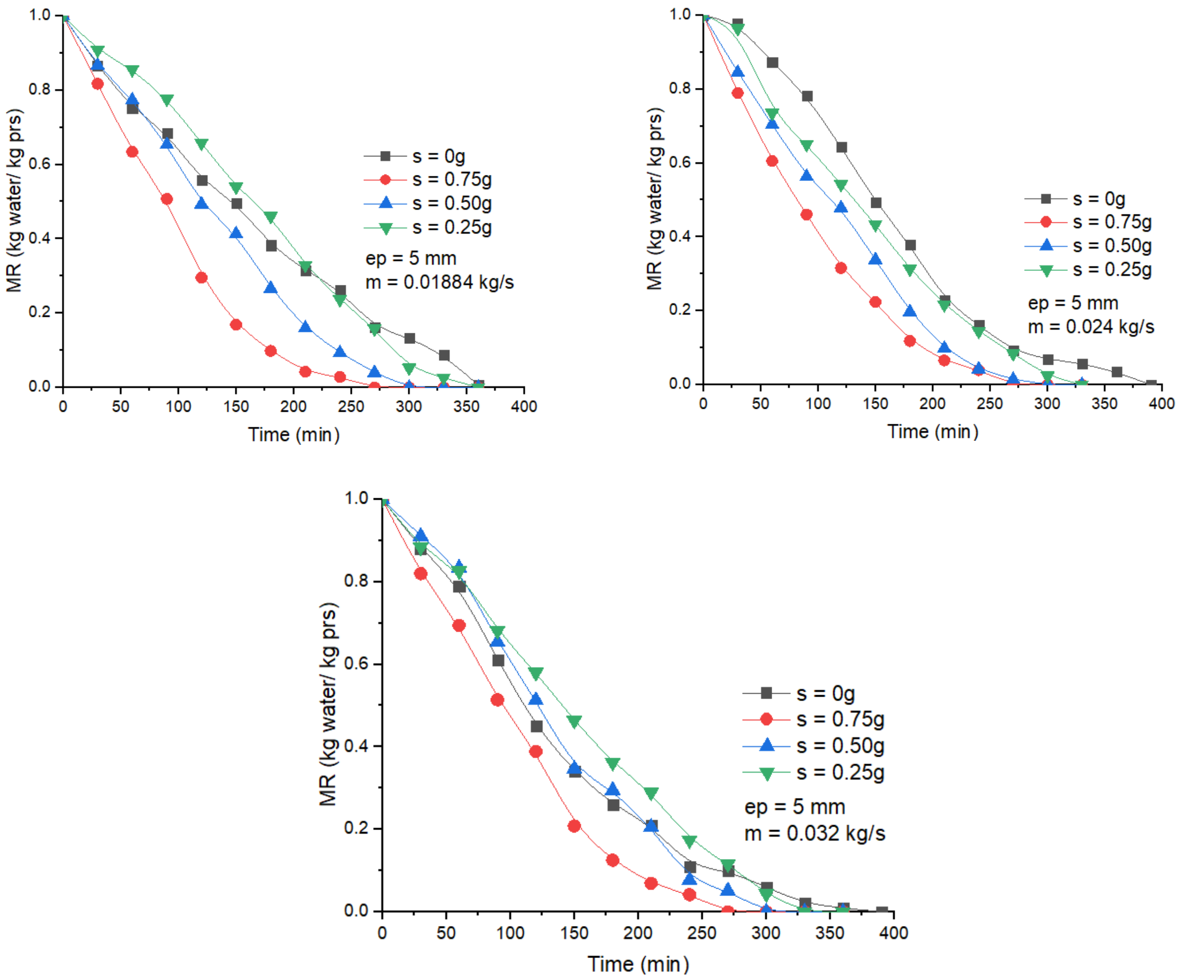

Figure IV.23: Moisture ratio versus drying time for 5 mm thick potato chips with three different air flows 0.01884, 0.024, 0.032 kg/s with amounts of salt 0 g, 0.75g, 0.50g, 0.25g.

Figure (IV.23) presents the differences in the experimental and expected values of moisture ratio with the drying time for a sample with a thickness of 5 mm. We note that the experimental results differed in the three cases due to a difference in the flow of air emitted to the drying chamber, as well as a difference in temperatures and salt amounts. used, where we note that the high flow 0.032 kg /s with the amount of 0.75 g of salt is the fastest and best in the three cases during the drying process, with a slight increase in drying time for the sample 2 mm.

IV.5 Performance of the solar collector and drying room

We have studied the yield of the solar collector and the drying room for a case of the experiment (3 mm) and the results are as follows:

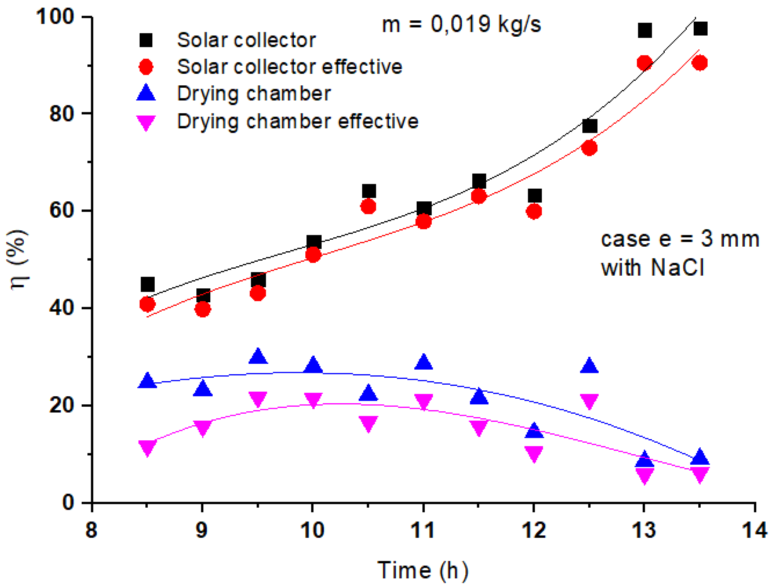

Figure IV.24: Performance of the solar collector and drying room with air flows 0.019 kg/s.

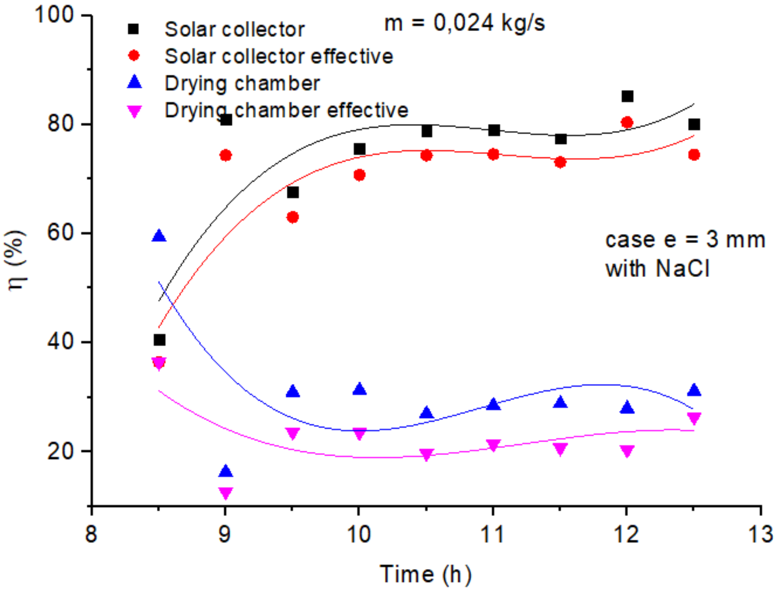

Figure IV.25: Performance of the solar collector and drying room with air flows 0.024 kg/s.

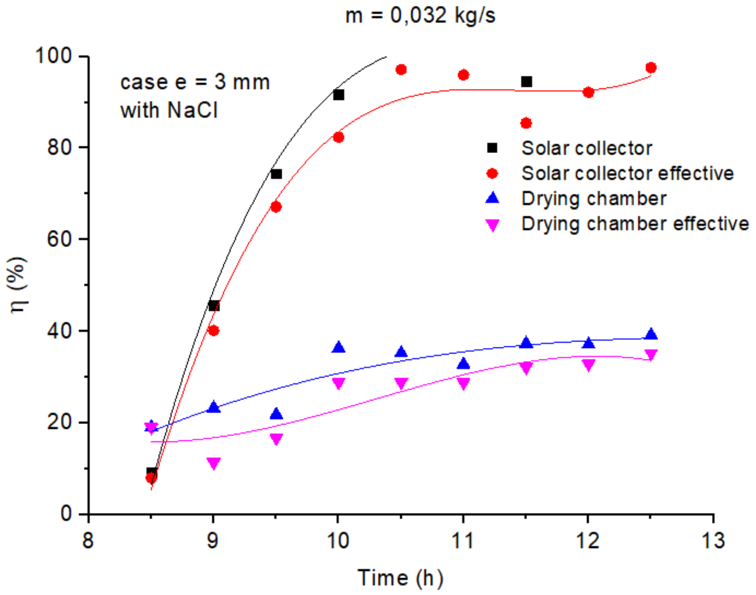

Figure IV.26: Performance of the solar collector and drying room with air flows 0.032 kg/s.

Figure (IV.24, 25 and 26) represents the performance of the solar collector and drying chamber with an air flow 0.019, 0.024, 0.032 kg/s and the thickness of the sample 3 mm. where we note that the performance of the solar collector without energy loss was better than the effective performance in the collector and drying room, and this is due to the fact that the real yield calculates the loss of energy, which makes it less profitable.

IV.6 Conclusion:

We've seen a set of curves in this last chapter that reflect the most important factors affecting the solar drying process, which gradually change over time. The main objective of this chapter was to investigate and explain the various changes that occur in the basic factors from the beginning to the end of the drying process. It was discovered that these factors interact with each other, such as solar radiation, which directly affects the average temperature of the absorbing plate. The highest value of the intensity of solar radiation is 1110 W/m², which is equivalent to 95 ° C as the value of the absorbing plate. In terms of the hot air temperature at the entrance to the drying room, it is the first factor that affects the temperature and relative humidity of the drying room and the dried product. Also, salt was the most important element for increasing the drying process, as the results of the presence of salt in the samples were faster than the results of its absence in the various samples, which led us to conclude in the end that the greater the air flow and the greater the amount of salt used with a small sample size, the faster the drying behavior of the potato product was described. and the best for the process of solar drying.

General conclusion

Finally, the goal of this pilot study was to investigate the behavior of solar drying agricultural products under forced convection using an indirect solar dryer that had already been designed and built. This paper investigates the drying of a thin film in the form of round slices under three different thicknesses, different amounts of salt for a potato product, and three different mass flow rates.

Experiments show that the drying speed is affected by the size of the samples, the mass flow rate, confirms that the selection of small thicknesses of the product and high mass flow rate is always associated with an acceleration of drying time.

The effect of solar radiation density and mass flow rate were key factors to accomplish the drying process by heating the absorption plate; Tests recorded good solar radiation results and average absorption temperature at maximum values of 1110 W/m^2 and 95 ° C, respectively.

The temperature of the product is directly affected by the temperature in the entrance and inside the drying room that works to remove moisture by evaporation, this explains the temperature rise with relative humidity drop, and the relative humidity of the product to be dried is high at the beginning of experiments due to the high moisture content of the dried product samples, then gradually decreases over time until the end of the test.

The addition of certain amounts of salt to the samples also helped to speed up the drying process. Added salt distracts liquids within wet tissue. Salt also changes the value of the balance and created the pressure drop of water-containing materials, the higher the amount of salt the faster the drying of the sample and vice versa is true. In addition, the sampling inside the drying room had an exclusive relationship with the process, as the sample approached the hot air entry hole the speed of drying that sample.

Finally, we would like to say that we have been able to accomplish the experiences in a good way. We have also drawn satisfactory and excellent results that demonstrate the seriousness of this work as it can evolve. So, we hope in the future to add new ways with better equipment under new graduation projects to improve the process of solar drying in the context of the importance of drying, which lies in its low cost because solar energy is very abundant in our region and is good to exploit for science.

Abstract:

This study aims to describe the solar drying behavior of potato agricultural product using an indirect solar dryer, a pre-installed, designed drying room and using forced convection. This study focuses on drying three different layers of potatoes, which are cut into circular slices of three different thicknesses (2, 3 and 5 mm), with salt and without salt in three different air flows (0.01884, 0.024 and 0.032 kg/s) and three amounts of salt (0.25, 0.50 and 0.75 g), and results showed that the drying speed depends on the thickness of the sample, the speed of air flow and the amount of salt added. In addition to monitoring temperature and solar radiation values.

الملخص:

تهدف هذه الدراسة إلى وصف سلوك التجفيف الشمسي لمنتج زراعي البطاطس باستخدام مجفف شمسي غير مباشر وغرفة تجفيف مصممة ومركبة مسبقا و باستعمال الحمل الحراري القسري. تركز هذه الدراسة على تجفيف ثلاث طبقات مختلفة من البطاطس, والتي تم تقطيعها إلى شرائح دائرية بثلاث سماكات مختلفة (2,3,5 ملم), مع وجود الملح و عدم وجوده بثلاث تدفقات هواء مختلفة (0.01884, 0.024, 0.032 kg/s) وثلاث كميات من الملح (0.25, 0.50 , 0.75 غرام). حيث أوضحت النتائج أن سرعة التجفيف تعتمد على سمك العينة مع سرعة تدفق الهواء وكمية الملح المضافة. بالإضافة إلى مراعاة درجات الحرارة وقيم الاشعاع الشمسي.

Résumé :

Cette étude vise à décrire le comportement de séchage solaire du produit agricole de la pomme de terre à l'aide d'un séchoir solaire indirect, d'une salle de séchage pré-installée et conçue, et utilisant la convection forcée. Cette étude se concentre sur le séchage de trois couches différentes de pommes de terre, qui sont coupées en tranches circulaires de trois épaisseurs différentes (2,3 et 5 mm), avec du sel présent et non présent avec trois débits d’air différents (0,01884, 0,024 et 0,032 kg/s) et trois quantités de sel (0,25, 0,50 et 0,75 g). Les résultats ont montré que la vitesse de séchage dépend de l’épaisseur de l’échantillon avec la vitesse du débit d’air et la quantité de sel ajoutée. En plus d’observer les températures et les valeurs de rayonnement solaire.