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TECHNICO-ECONOMICAL STUDY OF THE PERFORMANCE OF A SOLAR DRYER INSTALLED IN BOUIRA

By the jury

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Abstract

كميات ضخمة من الخضر و الفواكه يتم فقدها سنويا بسبب الفائض في الإنتاج و تكلفة التخزين ,وهذا ما يترتب عنه عواقب وخيمة على الموارد الطبيعة والإضرار بالإقتصاد الوطني. كل يجعلنا نفكر في طريقة اقتصادية وصديقة للبيئة لحفظ الأغذية من التلف وتصنيع الغذاء المجفف في الجزائر . وبما أن الجزائر تتمتع بإشعاع شمسي ضخم فقد قمنا بدراسة نجاعة المجفف الشمسي من الجانب التقنى والإقتصادي.

Huge quantities of vegetables and fruits are lost annually due to surplus production, lack of storage facilities and the high cost of preserving and storing food. All of this has adverse effects on natural resources and the national economy. This whole issue makes us think about an economical and eco-friendly way to conserve food and manufacturing and processing dried food in Algeria. Since it receives an enormous amounts of solar radiation, this latter makes the efficiency of solar drying significant and has a substantial positive impact on the environment and the national economy. According to that we establish a technical-economic feasibility study about the solar dryer.

On perd de grosse quantités de légumes et fruits chaque année due à l'excedent de production et au coût du stockage, Ce qui engendre de grosses pertes des ressources naturelles qui nuit à l'économie du pays. Ceci nous pousse à creer de nouvelles techniques écologiques et aussi économique pour préserver cette richesse et ça permet aussi à la fabrication des produits séchée , Notamment que l'Algérie a un temps généralement ensoleillé on fait une étude sur le séchoir solaire ainsi que la rentabilité de son utilization.

Acknowledgment

First and foremost I would like to express my heartfelt gratitude to my supervisor Dr. Nadir Mahmoud for correcting my drafts, his motivation, advice and expert guidance throughout my research work, I cannot thank him enough.

My profound and sincere gratitude also goes to my parents for their help and continuous support and my friends without whom this project would have never been completed on time.

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List of abbreviations

- G — Global solar radiation [W/m^2].
- Ac — Area of the collector [m^2].
- B — Tilt angle of the collector [°].
- Ic — Solar irradiation [W/m^2].
- V — Speed of wind [m/s].
- ec-ab — Space between glass cover – absorber [m].
- L — Thikness of polestar [m].
- Aedj — Space of the edge of the collector [m^2].
- ṁ — Mass flow rate [kg/s].
- $kpol$ — Thermal conductivity of the polestar .[W/m·K],
- $Kwood$ — Thermal conductivity of wood .[W/m·K],
- ε_c — Emissivity of the cover plate [-].
- ε_{ab} — Emissivity of the absorber plate [-].
- α_{ab} — Absorptivity of the absorber plate [-].
- τ_c — Transmissivity of the cover plate [-].
- $(\alpha_{ab*}\ \tau_c)$ — Transmitance- absorptace product $(\alpha_{ab*}\ \tau_c)$ [-].
- σ — Stefan-Boltzmann constant [-].
- Tfm — Average temperature of fluid pass in the collector [K].
- Tc — Temperature of the glass cover [K].
- Ta — Ambient temperature [K].
- Ts — Temperature of the sky [K].
- Tab — Temperature of the absorber [K].
- Qu — The energy gain by the absorber [K]
- F_R — Heat removal factor [-].
- S — Absorbed solar radiation per unit area [W/m^2],
- U_L — Collector overall heat loss coefficient [W/(m^2·K)],
- U_t — Top loss coefficient [W/(m^2· K)],
- U_b — The coefficient loss through the bottom of the collector [W/(m^2·K)]
- U_e — The coefficient edge losses [W/(m^2·K)].
- hw — Convective coefficient of wind. [W/(m^2·K)]
- hc,c,ab — Convective coefficient cover-absorber. [W/(m^2·K)]
- hr,c,ab — Radiation coefficient of cover-absorber. [W/(m^2·K)]
- hr,c,a — Radiation coefficient cover-asorber. [W/(m^2·K)]
- Cp — Specific heat capacity [kJ/kg·K]
- To — The outlet temperature. [k].
- Ta — The inlet temperature [k].

- η Efficiency of the solar air collector. [%].
- Mi Initial moisture content [%].
- Mf Final moisture content [%].
- hg Enthalpy of the water as a vapor[J/kg].
- hf Enthalpy of the water as liquid. [J/kg].
- W_w The moisture content [kg].
- mp The initial mass of the product [kg].
- Q1 The energy required raising the temperature of the wet material. [J].
- ΔT Temperature change[k].
- Q2 The energy required to evaporating the moisture from the produce[j].
- L Latent heat of vaporization. [J/kg].
- QT The total heat requirement [J].
- Td Drying time (days)
- NPV Net present value (dinars DZ)
- β Discount factor (%)
- C_{TO} Investment cost (dinars DZ)
- I_{TOT} Cash flow (dinars DZ)
- Cf Cost of fuel (dinars DZ)
- $C_{\_(O\&M)}$ Operating and Maintenance costs (dinars DZ)
- i Rate of return
- Is The specific investment cost (Dz / kg of a dried produce).
- M The mass of the produce (Kg).
- Itot The income (DZ)
- Myear The mass of dried produce in one year .(KG)
- P The price of 1 kg of the dried produce .(DZ/KG)

General Introduction

Many scientists argue that Algeria is considered as one of the best countries to exploit solar energy, and may play a very important role in world energy markets, Due to its geographical location and since it receives an important solar irradiation and high abundance of sunlight every year.

Solar energy can be used in different applications since it is easily accessible, abundant, particularly for countries located in tropical and subtropical regions like Algeria. One of the important solar energy applications in developing countries is solar drying since it is low-cost, easy to handle, and eco-friendly. Solar drying of fruits and vegetables has many advantages; it offers the possibility of planning for the harvest, minimizes the losses, enables storing food for a longer period of time without spoiling, store the food when prices fall to be sold when prices rise again, and give a superior quality product in other hand saves energy for the next generations.

The Algerian government intends to promote and encourage the exploitation of solar energy and has started by a serious step towards developing this sector which is the establishment of the Algerian Ministry of Environment and Renewable Energies in the past few years , and this leads us to say that now is the appropriate time for Algerian researches to contribute to the development of this sector. Thus, the object of this study is to define the potential solar energy in Algeria , describe solar drying technology, shed the light on the literature review available on the topic of solar dryer’s technology, and present various methods and strategies adopted by different researchers and research .

The study is conducted on indirect solar dyer and we have chosen the state of BOUIRA as the region to simulate our solar dryer, the study shows the influence of some parameters on the solar process, the curves that have been drawn aim to describe and explain the variation of the drying parameter by using a program that we created to help us study our solar dryer .The work ends up with an economic study to prove that investment in solar drying is incredibly profitable.

CHAPTER 1: REVIEW OF SOLAR ENERGY DRYING SYSTEMS

1.1. Introduction

Preservation of many product like fruits, vegetables, and food are important for keeping them for a long time without further deterioration in the quality of the product. Several process technologies have been employed on an industrial scale to preserve food products; the major ones are canning, freezing, and dehydration. Among these, drying is especially suited for developing countries with poorly established low-temperature and thermal processing facilities. It offers a highly effective and practical means of preservation to reduce postharvest losses and offset the shortages in supply.

Drying is a simple process of moisture removal from a product in order to reach the desired moisture content and is an energy intensive operation. The prime objective of drying apart from extended storage life can also be quality enhancement, ease of handling, and is probably the oldest method of food preservation practiced by humankind [1] Drying involves the application of heat to vaporize moisture and some means of removing water vapor after its separation from the food products. It is thus a combined and simultaneous heat and mass transfer operation for which energy must be supplied. The removal of moisture prevents the growth and reproduction of microorganisms like bacteria, , molds causing decay. It brings a substantial reduction in weight and volume, minimizing packing, storage, and transportation costs and enables storability of the product under ambient temperatures .These features are especially important for developing countries, in military feeding and space food formulations [2]

Drying in earlier times was done primarily in the sun, now many types of sophisticated equipment and methods are used to dehydrate foods. During the past few decades, considerable efforts have been made to understand some of the chemical and biochemical changes that occur during dehydration and to develop methods for preventing undesirable quality losses. [2]

In this chapter, I am going to talk about the estimation of the solar radiation in the world and in Algeria and shed the light on the drying technology, the solar dryers, and their types.

1.2. The solar radiation

1.2.1. The sun

The sun is the central energy producer of our solar system. It has the form of a ball and nuclear fusion take place continuously in its center. A small fraction of the energy produced in the sun hits the earth and makes life possible on our planet. Solar radiation drives all natural cycles and processes such as rain, wind, photosynthesis, ocean currents and several other which are important for life. The whole world energy need has been based from the very beginning on solar energy. All fossil fuels (oil, gas, coal) are converted solar energy. The radiation intensity of the solar surface is about 70,000 to 80,000 kW/m2. Our planet receives only a very small portion of this energy. In spite of this, the incoming solar radiation energy in a year is some 200,000,000 billion kWh; this is more than 10,000 times the yearly energy need of the whole world. The solar radiation intensity outside the atmosphere is in average 1,360 W/m2 (solar constant). When the solar radiation penetrates through the atmosphere some of the radiation is lost so that on a clear sky sunny day in summer between 800 to 1000 W/m2 (global radiation can be obtained on the ground). [3]

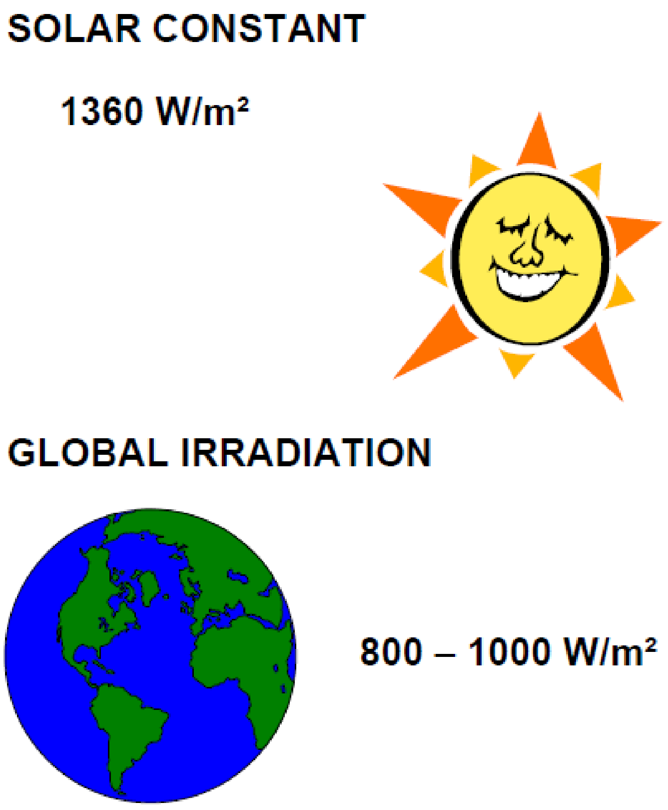

Figure 1.1 solar constant and global irradiation .

1.2.2. The global radiation

The duration of the sunshine as well as its intensity is dependent on the time of the year, Weather conditions and naturally also on the geographical location. The amount of yearly Global radiation on a horizontal surface may thus reach in the Sun Belt regions over 2,200 kWh/m^2. In north Europe, the maximum values are 1,100 kWh/m^2.

The global radiation composes of direct and diffuse radiation. The direct solar radiation is the Component, which comes from the direction of the sun. The diffuse radiation component is Created when the direct solar rays are scattered from the different molecules and particles I atmosphere into all directions, i.e. the radiation becomes unbeamed. The amount of Diffuse radiation is dependent on the climatic and geographic conditions. The global radiation And the proportion of diffuse radiation is greatly influenced by clouds, the condition of the Atmosphere (e.g. haze and dust layers over large cities) and the path length of the beams Through the atmosphere. [3]

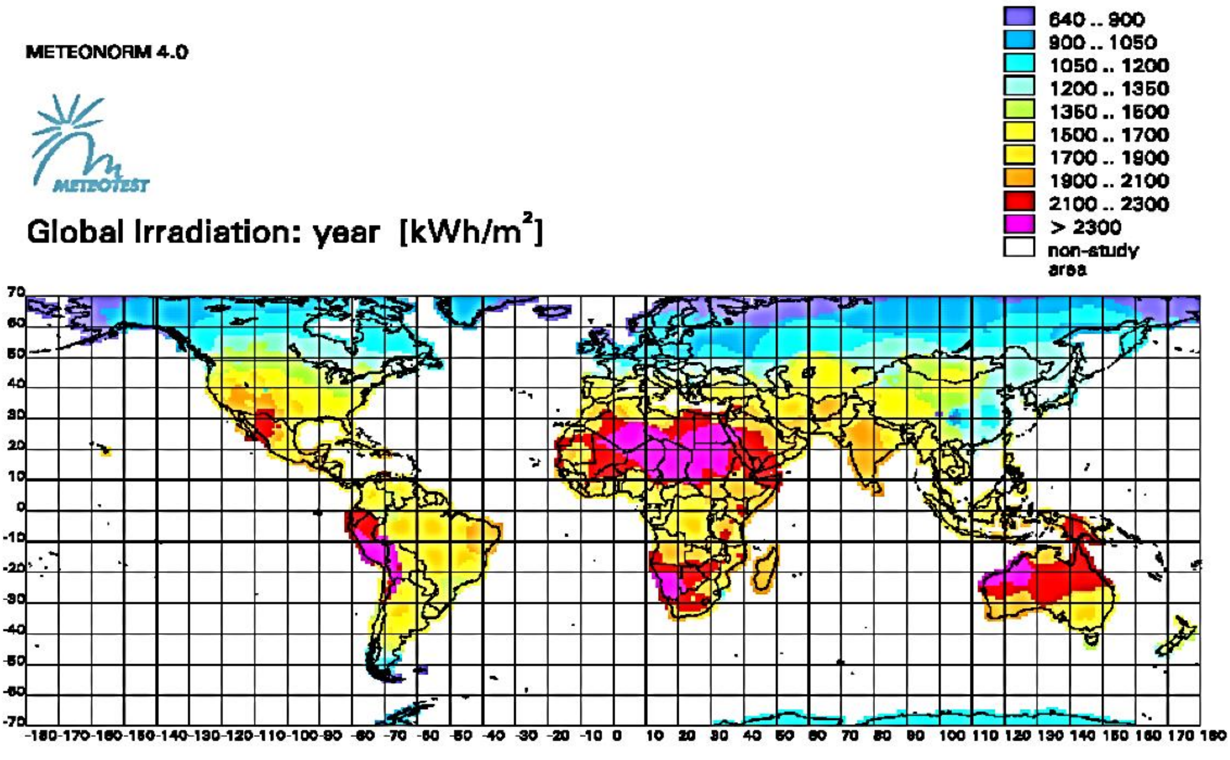

Figure 1.2 yearly average sums of global irradiation. [4]

1.2.3. The estimation of solar radiation of Algeria

Algeria, officially the People's Democratic Republic of Algeria, is a country of Northern Africa on the Mediterranean coast. Algeria ranges in latitude from 18.96 ° to 37.09 ° north, and in longitude from 8.68 ° west to 11.95 ° east. Its capital and most populous city is Algiers. It consists of 48 provinces and 1541 communes. With a population exceeding 37 million, it is the 34th most populated country on Earth [5].

Referring to its geographical situation, Algeria holds one of the highest solar reservoir in the world. The insolation time over the of the national territory and it is more than 2000 h annually and may reach 3900 h in high plains and Sahara. The daily obtained energy of 1 m^2 is of 5 kW h over the major part of the national territory, or about 1700 kW h/m2/year for the North and 2263 kW h/m2/year for the South of the country It is for these reasons that the solar radiation is an ample source in Algeria, which could be developed [5].

Areas	Coastal area	High plateau	Sahara
Surface (%)	4	10	86
Average duration of sunning (Hours/year)	2650	3000	3500
Received average energy (KWh/m^2/year)	1700	1900	2650

Table 1.1 Solar potential in Algeria. [5]

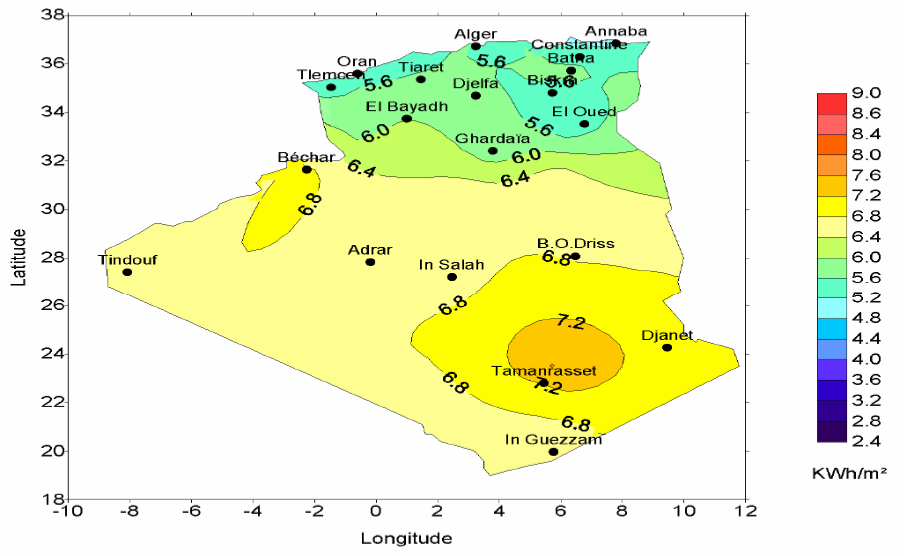

Figure 1.3 Potential sites for solar electricity supply and example of the overall daily exposure received (in KWh / m² / day) in Algeria. [5]

1.3. DRYING TECHNOLOGY

1.3.1. Drying Process

Drying process involves the application of heat to vaporize moisture from the food and agricultural products and therefore, simultaneous heat and mass transfer occurs in the drying process. In addition to the heat and mass transfer, physical changes such as shrinkage, puffing, and crystallization and biochemical changes such as color, texture, and odor also take place during the drying process. The heat is supplied to the drying material from an external source by convection, conduction, radiation or combination of them depending on the types of the drying method. Depending on the mode of heat transfer, the drying processes are mainly classified as convective drying, conductive drying, and radiative drying. In the convective drying, hot dry air directly comes in contact with the surface of the products and removes the moisture from its surface. In the conductive drying, the moist material is brought into contact with a hot surface. In the radiation mode, the material to be dried is placed in a microwave or radio frequency electromagnetic field. [6]

1.3.2. Industrial Drying Methods

In industrialized regions, mechanical dryers that exhibit faster drying rates, require less land, and provide higher quality product have replaced traditional drying methods. These industrialized areas employ advanced drying equipment such as steam dryers, infrared dryers , to process commercial products. However, this equipment is expensive and energy intensive since it requires relatively significant amounts of energy in the form of electricity or fuel to operate. While companies that generate substantial revenues can reasonably afford this technology, most small-scale organizations or communities that are directly involved with the farms are unable to afford implementation of these technologies [7] . Only large plantations or commercial establishments find these technologies economically viable in developing countries. Additionally, many rural areas in developing countries have limited resources. Construction supplies may be limited and energy sources such as fossil fuels and electricity may be unreliable or totally absent. Studies have shown that even small, simple oil-fired batch dryers are not applicable for rural farmers in these regions Hence, there is a need to identify an intermediate, practical drying technology that can easily be implemented in developing regions to ensure food supply to a growing population. Furthermore, appropriate drying technology can enable farmers to produce high quality, marketable goods. [8]

Figure 1.4 Industrial Electric Food dryer .

3.3.3. Convective drying

The convective drying is the most widely used drying method. In this method, the hot air is supplied either across a layer of products or parallel to one or both surfaces of the layer of the products. The heat is transferred from the hot air to the products due to the temperature gradient, and the moisture is released from the products to the air. The moisture is transferred from the drying materials by two mechanisms. [9]

- Transport of moisture from the inner structure of the material to the surface.
- Transfer of moisture from the surface of the material to the surrounding air.

The moisture transport within the material may take place by any or combination of the following mechanisms of the mass transfer. [1]

- Liquid diffusion; it takes place when the temperature of the liquid is below its boiling point.
- Vapor diffusion; it occurs when the liquid vaporizes within the material.
- Hydrostatic pressure diffusions; it occurs when the internal vaporization becomes higher than the transport of the moisture through the material to the surrounding.
- Combination of the above mechanisms.

In the convective drying, the moisture removal rate or the drying rate, which is defined as the mass of water vapor removed per unit time of the dry matter, depends on the following factors .[10]

- Internal conditions such as porosity, moisture content, size, and shape of the materials to be dried.
- External conditions: air temperature, velocity, and relative humidity .

1.3.4. Solar drying

1.3.4.1 Open sun drying

This method has been practiced for drying food and agricultural products for over many centuries. In the traditional open sun drying process, the products are spread out in thin layers on the ground, concrete floor, mat or tray and are directly exposed to the wind and the sun. The products surface directly absorb the direct and diffuse radiations resulting in rising of the temperature of products. Some percentage of the converted heat of the sun radiations evaporates the moisture from the products, and the major percentage is lost by convection, conduction, and re - radiation. The moisture is removed by the surrounding atmospheric air.

The open sun drying is one of the largest applications of solar energy. It is widely practiced in the rural areas of the developing countries. Small farmers of the rural areas in the developing countries (who produce around 80% of the food products) practice the open sun drying to dry food and agricultural products However, the open sun drying process has many limitations such as :

- contamination of the products due to dust, birds drop, etc.
- longer drying time due to slow drying rate as the product is dried at low temperature and high relative humidity .
- difficulty in controlling the drying process .
- losses of natural colors and minerals caused by the direct exposure to the sun radiation.
- losses of the products due to insects, birds, and adverse weather, and large drying area requirement and high labor cost.

In spite of having many disadvantages, the sun drying is widely practiced in the rural areas owing to the low cost and the requirement of unskilled labor. The drawbacks of the sun drying led to the development of the solar dryers. [11]

Figure 1.5 open solar dryer of the tomato slices . [13]

1.3.4.2. SOLAR DRYING BY SOLAR DRYERS

Solar drying has been used since time immemorial to dry plants, seeds, fruits, meat, fish, wood, and other agricultural, forest products. In order to benefit from the free and renewable energy source provided by the sun several attempts have been made in recent years to develop solar drying mainly for preserving agricultural and forest products. However, for large-scale production the limitations of open-air drying are well known. Among these are high labor costs, large area requirement, lack of ability to control the process, possible degradation due to biochemical or microbiological reactions, insect infestation, and so on. The drying time required for a given commodity can be quite long and result in post-harvest losses (more than 30%) . Solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and low quality of dried products associated with traditional open sun-drying methods [12]

Types of solar dryer

Numerous types of solar dryers have been developed for drying food and agricultural products. The solar dryers have been broadly classified into two categories depending on the movement of air, namely

- Passive solar dryers.
- Active solar dryers.

The active and passive solar dryers can be further classified as

- indirect – type solar dryer.
- direct – type solar dryer.
- mixed – mode – type solar dryer.

1.3.4.2.1. Passive solar dryers

Passive solar dryers are also known as the natural circulation or natural convection solar dryers. The flow of air in the passive dryer is purely due to density difference. It uses only renewable energy sources and runs without any electricity. The passive dryers are easy to construct with the locally available materials and suitable for any remote area where the electrical grid is not available. However, it has some disadvantages. The flow rate of air is not adequate for drying larger crops mass, and the flow of air does not take place during the night – time and the bad weather. The overall drying rate is slow due to poor moisture removal rate .[6]

1.3.4.2.1.1. Indirect – type passive solar dryer (IPSD)

Solar dryers are classified as the direct – type and the indirect – type depending on the exposure of the products to the solar radiation. In the IPSD, the products are not directly exposed to the solar radiation and are dried by the hot air. A simple IPSD consists of a solar air heater and a drying chamber. Ambient air is heated by the solar air heater and then flows to the drying chamber up through the bed of crops due to buoyancy forces caused by the temperature difference. The drying chamber generally consists of perforated trays or mats where the products are kept, and the hot air is supplied from the bottom of the trays. Figure 1.6 shows a typical indirect – type natural convection solar dryer developed by Pangavhane in 2002**.** [13]

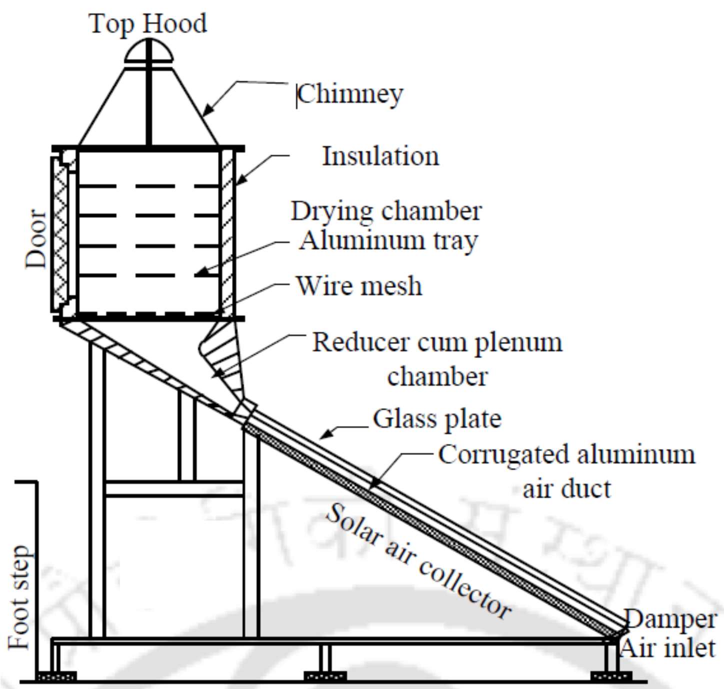

Figure 1.6 An indirect - type natural convection solar dryer developed by Pangavhane et al., 2002 . [13]

1.3.4.2.1.2. Direct - type passive solar dryer (DPSD)

The DPSD does not have a separate drying chamber. The product is placed in the air-heating unit and absorbs the solar radiation transmitting through a transparent sheet. There are different types of the direct - type solar dryer: box/cabinet - type, tent - type, and green house - type solar dryers. The box type cabinet dryer developed by the Brace Research Institute of Canada is shown in Fig.1.7. It consists of a wooden box, a transparent cover at the top of the box, and drying trays. The inner side of the box is painted black, and the bottom and sides of the box are insulated. The product to be dried is placed on the trays. The solar radiation transmitting through the transparent cover gets absorbed on the black surface. The temperature inside the dryer rises due to the accumulation of energy. The box is provided with vent holes for circulation of air. This type of dryer is simple and cheaper to construct but it has some limitations like overheating of the products, poor moisture removal, small capacity, and damage of colour due to exposure to the solar radiation. [6]

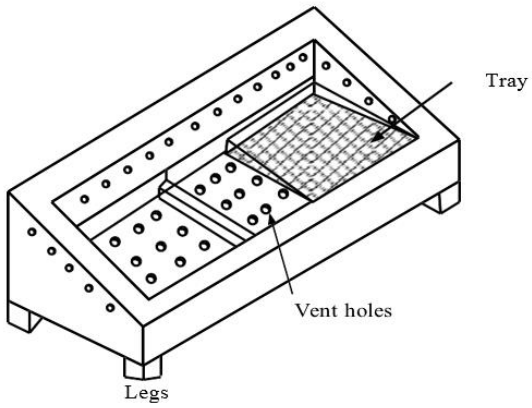

Figure 1.7 A box - type solar dryer . [6]

1.2.3.4.2.1.3. Mixed - mode - type passive solar dryer (MMPSD)

The structural features of the MMPSD are the same as the indirect - type passive solar dryer. The drying chamber of such dryer is constructed with transparent walls. An MMPSD developed by Jain in 2005 is shown in Fig. 1.8. The solar air heater produces the hot air by trapping solar radiation, and the air flows to the drying chamber from the solar air heater due to the natural convection. The product is heated by the solar radiation transmitting through the transparent walls as well as by the hot air generated by the solar air heater. The flow rate of air and the drying rate are high in this type of dryer due to high air temperature in the drying chamber.[14]

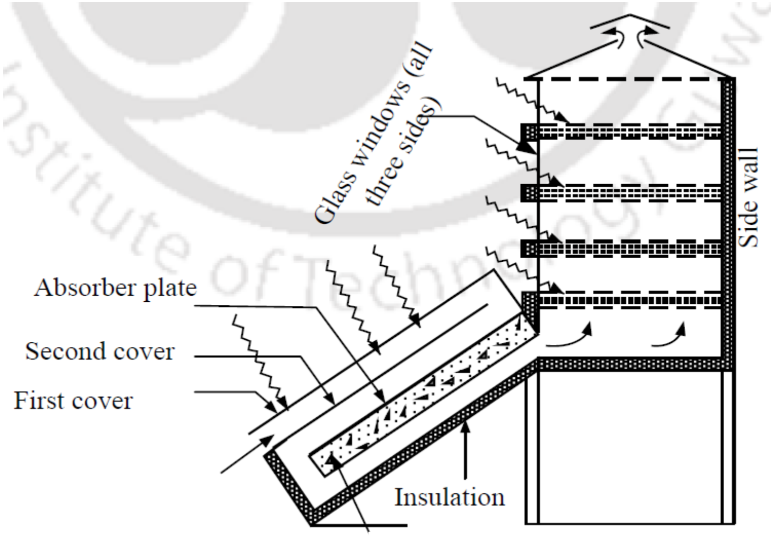

Figure 1.8 A mixed - mode - type natural convection solar dryer.[14]

1.3.4.2.2. Active solar dryers

Active solar dryers are also known as the forced circulation or forced convection solar dryers. In the active solar dryers, an external device like a fan or similar type of device supplies the hot air required for the drying operation. The electrical power required for running the fan or blower is supplied from either the grid or a solar photovoltaic module. The active dryer has some advantages over the passive dryer. It reduces the drying time by enhancing the rate of heat transfer. In this type of dryer, the flow rate of air and the temperature can be controlled.[6]

1.3.4.2.2.1. Indirect – type active solar dryer (IASD)

The IASD consists of a drying unit, and a fan for circulation of air and air ducts. The fan of the dryer helps in proper controlling of the air flow rate which is an important parameter affecting the drying rate. The indirect – type active solar dryer developed by Reyes in 2013 for drying chilli is shown in Fig. 1.9. A centrifugal fan is provided to supply air through the air heater to the drying chamber.[15]

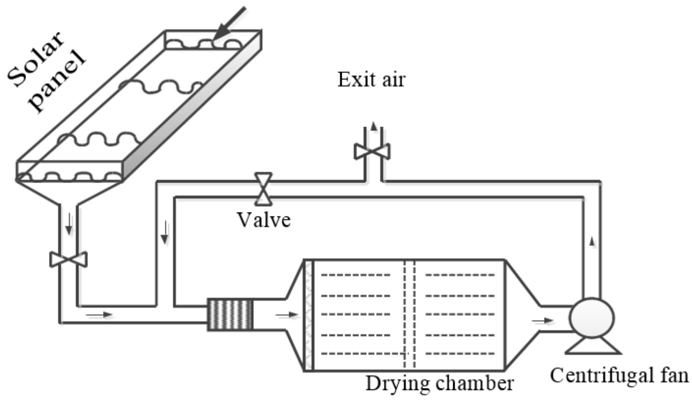

Figure 1.9 An indirect - type active solar dryer. [15]

1.3.4.2.2.2. Direct – type active solar dryer (DASD)

The constructional feature of the DASD is the same as the direct – type-passive solar dryer. In this type of dryer, an exhaust fan is provided to expedite the removal of saturated moist air from the drying chamber . The exhaust fan runs on electricity supplied by the grid or the solar photovoltaic module. Figure. 1.10 shows a greenhouse type DASD developed by Janjai in 2011 for drying banana. In this dryer, the fans run on the electricity produced by the photovoltaic panel .[16]

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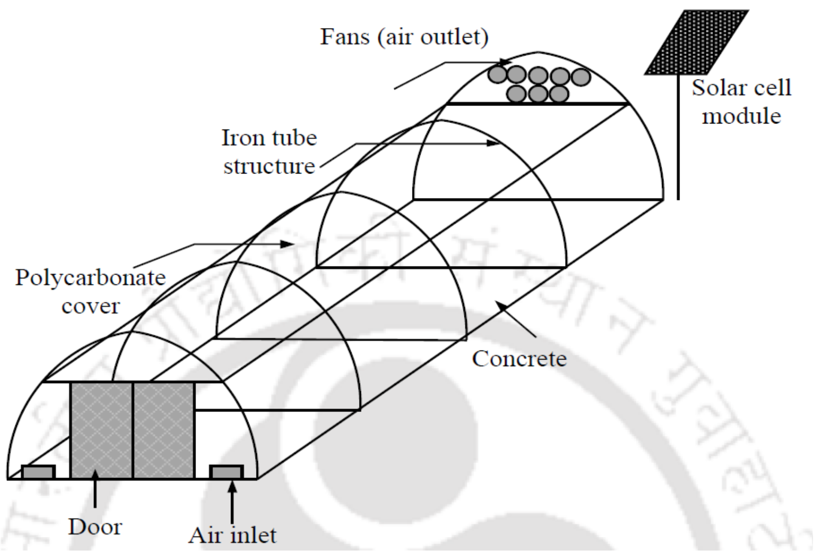

Figure 1.10 A direct - type active solar dryer . [16]

1.3.4.2.2.3. Mixed - mode - type active solar dryer (MMASD)

The MMASD generally consists of a solar air heater, a blower or fan, and a drying chamber with transparent walls. An MMASD developed and tested by Usub in 2010 is shown in Fig. 1.11. The working principle of the active mixed - mode - type dryer is the same as the passive mixed - mode - type. The solar radiation incident on the air heater surface and the product surface in the drying chamber produce the necessary heat required for the drying operation. However, in the active mixed - mode - type solar dryer, an external device is used to circulate the drying air . [17]

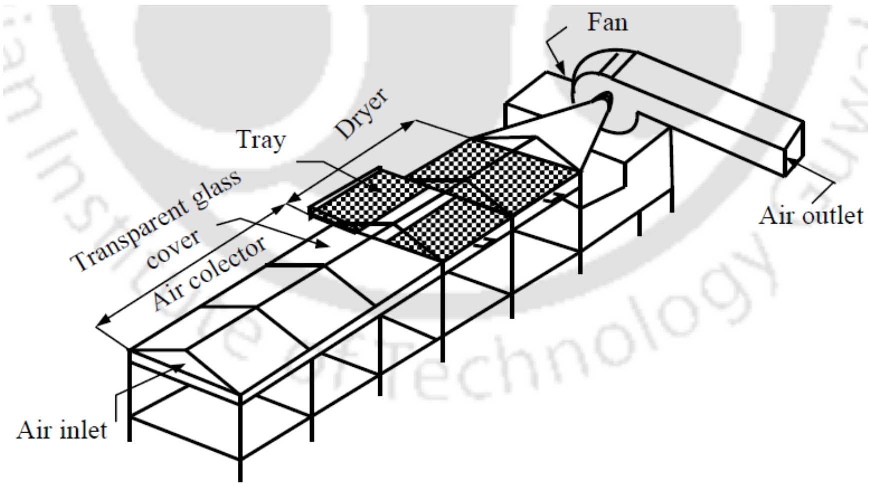

Figure 1.11 A mixed - mode - type active solar dryer . [17]

1.3.4.2.3. Components of Solar Dryers

Solar dryers are mainly made up of three parts. These are solar collector, drying chamber and chimney. These parts are briefly discussed below

1.3.4.2.3.1. Solar Collector

Solar collectors are used to convert direct and diffuse radiation from the sun into thermal energy [18] It is a special kind of heat exchanger that transforms solar energy to heat. Energy is transferred from a distant source of radiant energy to a fluid [19]. For applications requiring less than 80 oC, flat plate collectors are widely used [20]. Flat plate collectors are mechanically simpler and require little maintenance than concentrating type of collectors. [19] Generally, flat plate collector designs consist of three major parts. These are transparent cover, absorber plate and insulation. The transparent cover also called glazing is where the solar energy passes through the collector[21] .Using a transparent cover reduces heat loss and helps to obtain higher temperature. Glass is the common transparent cover for collectors, but some plastics have also desirable characteristics. Although plastics can transmit as much solar radiation as glass and resist impact stress better than glass, it allows more thermal energy loss than glass [22]. Absorber plate is made from a material which can rapidly absorb heat from the sun's rays. It is usually made from black painted metal sheet [23]. Insulation should be used at the back side of the absorber to minimize heat loss. The material chosen as insulator should be stable at high temperatures,. it should not break down at high temperatures. In order to reduce heat loss from the sides of the collector, it should be incorporated into a box. Collector boxes should be strong enough to resist loads imposed by wind and need to be sealed to exclude water. [22]

1.3.4.2.3.2. Drying Chamber

The drying chamber will be an enclosed structure where drying takes place. It will consist of trays for putting in the produce to be dried. At the drying chamber there should be means for loading and removing the material to be dried. This is usually provided by a door at the back side of the dryer. The drying chamber should be insulated and well sealed in order to contain the heated air without any leaks.

1.3.4.2.3.3. Chimney

All solar dryers should have a means to let out the exhaust air. Most solar dryers have a chimney to let out the hot air that picked up moisture from the produce kept in the dryer to be dried. When the air inside the chimney has a temperature greater than the ambient air such that the density of air outside the chimney is greater than inside, there would be a flow through the chimney . [24]

1.3.4.2.4. Materials Used for Constructing Solar Dryers

As described in the previous topic on different types of solar dryers, different designs used different material for constructing the driers. Most of the designs used the availability of the materials as a major criterion. Other criteria for choosing the materials were indicated as cost, quality and ability to withstand harsh environmental conditions such as very hot weather and rain. The summary of the materials used in the review are given in table below :

.

Component		Material
Collector	Transparent	Glass
		Plexiglas
		Plastic
		Polycarbonate
	Absorber	Galvanized steel sheet
		Aluminum sheet
		Granite stone
		Galvanized iron sheet
		Polyethylene film
Drying Chamber	Structure	Wood
		Metal
	Cover	Glass
		Plastic
Tray	Net	Chicken wire
		Stainless steel
		Bamboo net
		Aluminum wire net
		Plastic screen
	Frame	Wood
		Angle bar
		No frame
Chimney		Plastic
		Metal sheet
		PVC pipe
Air Vent Cover		Mosquito net
		Aluminum mesh
		No cover

Table 1.2 Material Usage. [25]

1.4. Conclusion

Due to its geographical location, Algeria holds one of the highest solar reservoirs in the world mainly solar energy and other kind of renewable energies, and also has considered as one of the best countries for exploiting solar energy in the world . Our future clearly depends on our ability to utilize solar energy and other renewable sources of energy. In addition, encouraging developments in the field of solar energy, it is high time to gain and Exploit this significance energy and Exploit it in several sectors and applications, to reduce its dependence on fossil fuels and to protect the environment by Reducing CO2 emissions, and one of the most important sector to use solar energy is solar drying due to the low cost and easy-handling of this technology, in addition to prevent the dependence on fuel .

There are many types of solar dryers, and each type has its advantage and disadvantage and the choice of a specific type depend on the natural condition, the mass, and the product to be dried. The construction of solar dryers has done by using different materials and the quality of materials used in the construction plays an important role to define the efficiency of the solar dryer.

Chapter 2: Review of literature

2.1. Introduction

This review is done to shed the light on the literature available in the topic of solar dryers technology, and present Various methods and strategies adopted by different researchers and research. and a lot of instructions to enhance the solar drying process and the quality of the product to be dried and make sure that the product could be stored for a long time. and I divided this chapter to five parts according to the kind of studies and researches or the enhancement Has done .

The parts of the review of literature:

- Solar drying of agricultural products.
- Drying Methods and drying characteristics of vegetables.
- Effect of dehydration on chemical composition.
- Modeling of drying.
- Several Designs of solar dryers.

2.2. Solar drying of agricultural products

Bolin and Salunkhe (1980, 1982)

Reviewed various solar drying techniques applied for fruits and vegetables. They have been systematically reviewed the drying techniques using solar energy, as well as those using solar energy along with auxiliary energy source . [26]

Jangam and Visavale

At point of view of quality of product and economic aspects, it is observed that, to produce a soaring quality product and economically it must be dried rapidly without undue heat. [27]

Karla and Bhardwaj (1981)

Illustrated two easy models of solar dryer with the functions of direct and indirect dryers for the drying of fruits and vegetables. [28]

Pangavhane and Sarsavadia

They observed after many experiments that Open sun drying of grapes has need of more time to dry and there is a problem of contamination, spoilage and browning of the product when exposed to the open ambience . [29]

And we have Many other researchers have investigated the natural convection solar dryers for studying the drying behavior of number of vegetables and fruits.

Sharma (1987).

The detailed design, development and performance of two types of low cost solar crop dryers such as conventional cabinet solar dryer and an integrated solar collector-cum-drying system based on the principle of natural convection is explained by Sharma in 1987 and The results of dehydration of vegetables such as potato, cauliflower and green peas showed the acceptable overall performance and efficiency of both of the dryers . [30]

Bennamoun (2003). **Nandwani (2007)**

A number of attempts have been applied for the developing of forced convection solar dryers. The forced convection solar crop dryers design includes: direct, indirect and mixed-mode solar dryers. The comparative studies on these three dryers reveal that, the performance of the mixed-mode forced convection solar dryer is most efficient than other two.

The effect of surface of the collector, the air temperature and the product characteristics during solar drying of onions was investigated by Bennamoun in 2003 and Nandwani in 2007 and he described the design and development of a fruits and vegetable solar dryer for domestic use . [31]

2.3.Drying Methods and drying characteristics of vegetables

Manchekar and associates (2008).

The drying effect for the drying of curry leaves under shade (24-28 ^{0}C), sun (29 ^{0}C) and conventional method at temperature at 40 ^{0}C, 100 ^{0}C, 140 ^{0}C and 180 ^{0}C was investigated by Manchekar in 2008. The time taken for drying and loss in weight was recorded. Their results revealed that, the conventional drying method was faster (8 hours) compared to sun drying (20 hours) and drying under the shed (34 hours) [32] They also showed that higher the temperature in conventional drying lower was the time taken for drying to a constant weight .

Sengar (2010)

A foldable direct solar dryer was designed and developed by Sengar in (2010) and evaluated it for mango flakes [33]. They showed the reduction of moisture content up to 10 per cent is safe for storage of mango flakes.

Alonge and Adeboye (2012)

Two passive solar dryers from locally available material was designed and developed by Alonge and Adeboye in 2012 , for the drying of some African vegetables [34**]**.. The solar dryers were tested for pepper and vegetables to evaluate the drying rates of these products. The results show that the drying rate of direct passive solar dryer was higher than indirect passive solar dryer. They also shown that, the crops dried faster in direct passive solar dryer than indirect passive solar dryer. Moreover, the highest temperature was reached in the direct passive solar dryer .

Bala and Janjai (2009).

The progress and potentials of solar drying skills for drying of fruits and vegetables such as spices, medicinal plants and fish were presented by Bala and Janjai in 2009. They have demonstrated and studied the performances of different types of solar dryers such as solar tunnel dryer, improved version of solar tunnel dryer, and green house type solar dryer for their potential drying of fruits and vegetables [35] They simulated the performance of solar tunnel dryer, improved version of solar dryer The results show that, the agreement between the simulated and experimental results was obtained fine.

The fresh vegetable had higher calcium, iron and zinc than the sun dried vegetables. On the other hand, sun drying decreased beta-carotene (Beta carotene is a red-orange pigment found in plants and fruits, especially carrots and colorful vegetables Beta carotene is converted into vitamin A, an essential vitamin) and ascorbate (vitamin C) as against those of the fresh samples .

Eze (2010)

Has designed a family size cabinet solar dryers and its performance was evaluated with cassava roots (Cassava is a root vegetable have a similar shape to sweet potatoes grown in tropics areas) [36] metallic and glass materials were used for the construction of the family size cabinet solar dryer. Freshly harvested cassava roots were used to evaluate the drying efficiency of the system in the preservation of cassava products. Moreover, the pH, water activity and moisture content, mold count of the various samples were determined. Results obtained that solar drying minimize the mold contents in cassava more than open sun drying .

Hassanian (2009)

A more simple and economical solar dryer was designed by Hassanian in 2009 particularly suitable for different agricultural fresh vegetables [37]. The performance of dryer was evaluated to dry the banana pulp. The construction of solar dryer was easy and collector angle was adjustable. Results shown that the drying efficiency for forced convection drying was higher for first day due to the fast drying in the moisture falling stage .

Ogunkoya (2011)

A low cost solar dryer was made by Ogunkoya in 2011 for the locally available agricultural products [38]. They used locally available material for construction of the solar dryer. The results show that the solar dryer can be substitute to the expensive conventional dryers.

Samaneh Sami (2011)

A dynamic mathematical model for drying of agricultural products in an indirect cabinet solar dryer was presented by Samaneh Sami in 2011 . The model describes the heat and mass transfer in the drying chamber **[39].** Results confirm that the model solution provides an effective tool to study the variation of temperature, humidity of the drying air, drying material temperature and its moisture content in each tray .

Wakjira (2011).

A cabinet solar dryer was designed and developed to determine the optimum thickness of banana slices by Wakjira in 2011. From their result they confirmed that the cabinet solar dryer was suitable for drying condition of Ethiopia [40]. However this dryer is expensive and not handy for small scale households. Finally, they suggested the modified rural cabinet solar dryer for medium scale drying. Further they also suggested that there is a need for additional studies to investigate the physico- chemical characteristic of dried banana Product .

Kaewkiew (2011)

The performance of large scale greenhouse type solar dryer was evaluated by Kaewkiew in 2011 for the drying of chili [41]. Their results shown that, the chili was completely protected from insects, animals and the rain .

Belessiotis and Delyannis (2010)

Shown that the solar energy not only used for food preservation but also for drying of other useful material such as cloths construction material . [42]

Janjai (2009).

The performance of PV ventilated solar green house dryer for drying of peeled longan and banana was studied by Janjai in 2009 Their result revealed that the required drying time for PV ventilated solar dryer was less than the open sun drying and Furthermore the quality of solar dried products in terms of color and test was high [43] .

2.4. Effect of dehydration on chemical composition

Dehydration is easy, uncomplicated and economical technique of preservation of green leafy vegetables. There is great value to produce dehydrated vegetables without noticeable loss of nutrients during the preparation and dehydration. It is uniformly important to prevent substantial losses during the period between dehydration and utilization. Dehydration techniques resulted into concentration of nutrients [44] .

Kiremire (2010).

Different drying techniques such as open sun drying, oven drying, and solar drying were carried out by Kiremire in 2010. The effect of sun drying, solar drying, and oven drying on the nutrient composition of selected vegetables were assessed by proximate analysis and compared with the nutrient content of the fresh vegetables [45] . Their results indicate that some nutrients were lost during the drying process but in general the nutrient content remained high. With respect to retention of the nutrient content in vegetables, solar drying was found to be best of the three methods .

Awogbemi (2009).

The effect of solar drying on the quality of three type of vegetables such as amaranths, vernonia and pumpkin was performed by Awogbemi in 2009. The proximate analysis and microbial load analysis were carried out in the vegetable samples after each day of drying for a total 5 days **[**46**]..** Solar radiations for the period varied from 89 W/m^2 and 203 W/m^2. Analysis showed that the nutritional composition of fresh vegetables and their microbial load decrease with each day of drying. For storage purpose, two days of drying is sufficient to prevent spoilage and at the same time retain an average 70 % of fat, 80 % ash, 70 % carbohydrate and 60 % protein of their initial nutritional composition .

Satwase (2012)

The drying characteristics and nutritional composition of drumstick (used in Indian kitchens) leaves were studied by Satwase et al. (2012) in different drying methods like sun, shadow, cabinet solar and oven drying **[47] ..** They also dried the leaves of Moringa oleifera in various methods mentioned above. After drying, samples were powdered and nutritive test such as moisture, carbohydrate, protein, fat, fibre and ash was analysed. The results of nutritive test showed that the cabinet dried samples were better than other and it had highest nutrient retention followed by shadow, sun drying and oven dried samples. Their study also revealed that the cabinet tray drying method was observed more suitable for dehydration of drumstick leaves .

Maharaj and Sankat (1996)

The quality change was investigated by Maharaj and Sankat in1996 in dasheen leaves (cultivated plants and it is a tropical plant grown primarily for its edible root vegetable most commonly known as taro) [48]. The results showed that, drying at 40 ^{0}C -70 ^{0}C under natural convection showed loss of vitamin C (91.6 % to 93.0 %). For forced convection, the loss of vitamin C ranged from 81.8 % to 72.6 %. Ascorbic acid losses increased by blanching in steam (It stops enzyme actions which can cause loss of flavor, color and texture) .

Singh (2003).

The effect of dehydration on nutritional composition of green leafy vegetables such as mint, carrot, amaranths, spinach, cauliflower leaves were studied by Singh in 2003. The results obtained that the dried mint and cauliflower leaves possessed higher amounts of protein (30.99 and 29.98 %) compared to carrot (9.82 %) [49] The value of ascorbic acid (vitamin A) content was higher in amaranths (96.92 mg/100gm) and β-carotene retention was found to be higher in spinach (60.25 mg/100gm) .

Soysal (2004)

Has **s**tudied the effect of microwave drying on quality of parsley leaves (it widely consumed in Algeria and especially in the month of Ramadan) [50].. The leaves were dried for seven different microwave output powers ranging from (360-900 Watt). The result indicates that the microwave drying showed a brilliant green colour close to that of the original fresh parsley leaves .

2.5. Modeling of drying

Majid rasouli (2011)

The drying activities of the garlic slices were explored by Majid rasouli in 2011**.** in a hot air dryer at various air temperatures such as 50 ^{0}C, 60 ^{0}C, 70 ^{0}C and slice thickness 2 mm, 3 mm and 4 mm [51].. Results obtained that the drying air temperature and slice thickness affected the drying rate and drying time. Furthermore nine various mathematical models were selected and fitted for experimental data. The statistical data shown that, the Weibull model was found more suitable for expressing the thin layer drying behaviour of garlic slices .

Sadi and Meziane (2015)

have studied the effects of microwave drying power on drying kinetics, effective moisture diffusivity and specific energy consumption of olive pomace (pomace is the solid remains of grapes, olives, or other fruit after pressing for juice or oil. It contains thepulp, seeds, of the fruit) [52].. Results revealed that Midilli and diffusion approach models were found to be most appropriate in describing the microwave drying kinetics of olive pomace .

Saxena and Dash (2015)

Have studied the drying kinetics and moisture diffusivity for ripe Jackfruit (Jackfruit is a unique tropical fruit that has increased in popularity in recent years. It has a distinctive sweet flavor and can be used to make a wide variety of dishes. It’s also very nutritious and may have several health benefits.) [53].. The value of effective moisture diffusivity was found to be increased with temperature. Midilli model was found to be most suitable model representing the drying behaviour of Jackfruit .

Samira (2015)

have found the effect of air temperature, air velocity and sample shapes on drying kinetic of potato slices in a tunnel dryer [54] The result shows that, the drying time depends on temperature, velocity and shapes. Among all models, Midilli-Kucuk was found best to explain the single layer drying of potato slices .

2.6. Several Designs of solar dryers

Raju (2013)

designed and fabricated a direct solar dryer of cabinet type. It was used to dry a batch of 20 kg of fresh vegetables such as chilly and tomato in two days. The dryer was constructed in India and experimental drying tests were carried out with a prototype of the dryer having 1.03 m^2 of solar collector area. This dryer has a dimension of 100x103x76 cm^3 where the sides are constructed from galvanized steel and the bottom from wood. A glass is used as a cover and a hole of 5 cm was made for air circulation. Optimum temperature of the solar dryer was designed to be 60 C° with ambient temperature or inlet air temperature of 30C°. At the end of the first day of drying 3000 grams of potato using this dryer, the weight of the produce was reduced to 1180 grams while when drying the same amount using open sun drying the weight reduced to 1550 grams. Final weight of the potato was reduced to 550 grams on the second day while using the dryer where as it was reduced to 920 grams when open drying The design also included a mechanism of collecting the heat coming out of the dryer using copper tubes for water heating system. The authors did not mention the particular application of the heated water, but the advantage of including this system should be compared with the increase in cost it will incur so that it can be afforded by small farmers . [55]

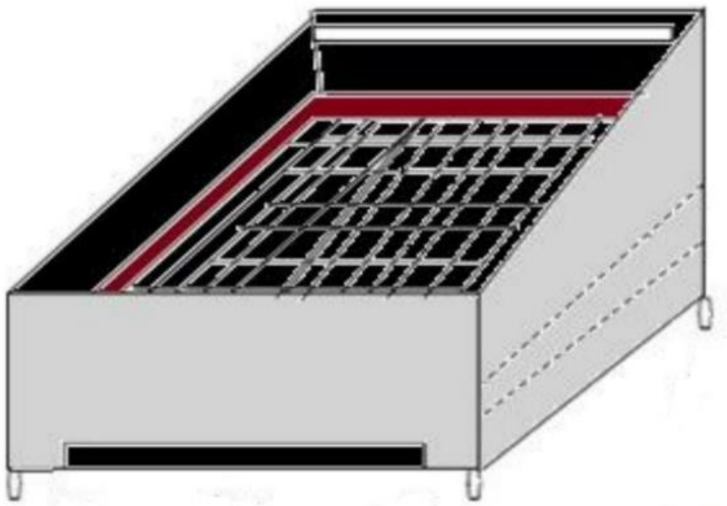

Figure 2.1 Pictorial View of Cabinet Dryer . [55]

Medugu (2010)

has fabricated and studied the performance of a forced convection direct mode solar dryer. In addition to the basic components of a solar dryer, this design consisted of a chimney and a 40 W photovoltaic module used to power and run a dc fan. Drying 50 kg of tomato with an initial moisture content of 90% using this type of solar dryer was completed within 129 h which is about 55% of the time required to dry using natural sun drying.

A drying period of 129 h for drying tomato, which is about more than 5 days, is longer compared to drying period reported by other solar dryer designs. No justification was given for the long drying periods but it could be due to the fact that the experimental tests were carried out during the wet season, when most of the days were cloudy. The author indicated that the solar dryer was constructed from entirely quality materials which may increase the cost of the dryer. In addition, the presence of photovoltaic module as a power source to operate a dc fan makes the fabrication of the dryer costly. [56]

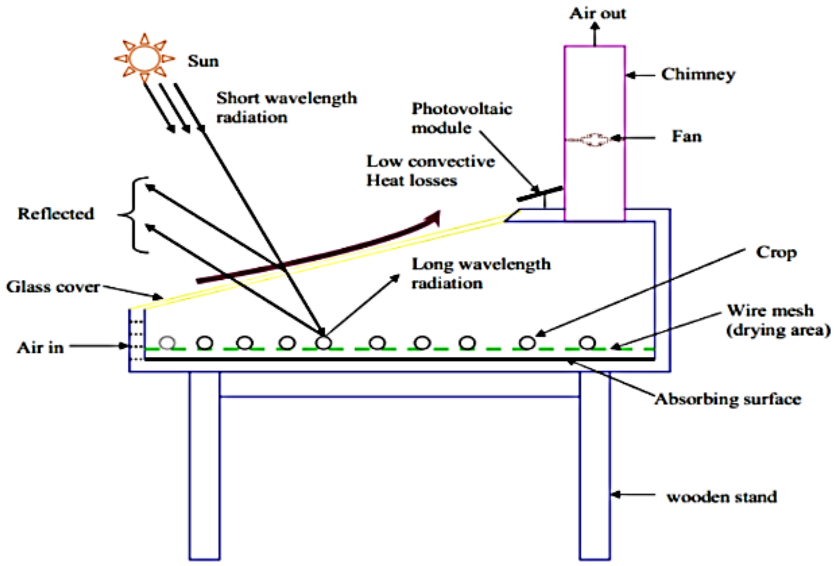

Figure 2.2 Forced Convection Direct Mode Solar Dryer . [56]

Svenneling (2012)

Has designed and tested an indirect solar dryer for drying pineapples in Ghana. The solar collector has an area of 1.05 m^2 and the air duct has a gap of 0.2 m. A 1.2 m long chimney with a diameter of 0.1 m was made from metal sheet and is connected to the drying chamber. Laboratory drying test of pineapples showed that the slices had become case hardened when dried at 70c° for five hours. But when dried at 50 C°, it took about 23 hours for the pineapple pieces to reach a moisture content of 10%. At this point, the pieces had become light yellow and were ready to be eaten. The longer drying period in the laboratory was attributed to inadequate ventilation in the oven**.** When using the solar drier at the test location, the temperature in the collector and the drying chamber reached approximately 60 C° and 50

C° respectively. The moisture content was reduced from 90 % on wet basis to about 10 % within 16 sunshine hours. It was also shown that the drying rate was faster on the lower shelf that is closer to the collector than the upper shelf It was i dicated that, due to high humidity in Ghana, some of the tools used to construct the dryer started to corrode after only a short period of time which affected the modification of dryer. The large size of the dryer had also made it difficult for handling while moving it from one place to another. [57]

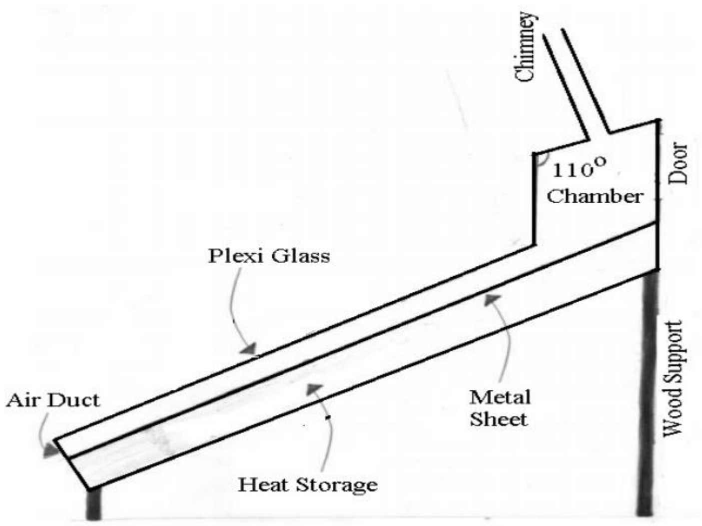

Figure 2.3 Sketch of Indirect Solar Dryer. [57]

Alonge and Adeboye (2012)

constructed an indirect mode passive solar dryer with easily available local materials such as wood, glass sheet, metal sheet, chicken net and mosquito net. They carried out tests under no-load and load conditions. During no load, test the maximum temperature in the indirect solar dryer reached up to 48 C° while the ambient temperature was 39 C°. For the loaded condition, 180 g of pepper with 78.9 % of initial moisture content on a wet basis was considered. It took 51 hours to reduce the moisture content of the pepper to 24% (w.b). The drying rate of the produce in the indirect passive solar dryer was 2.55 g/h while it was 2.17 g/h in open sun drying . [34]

Figure 2.4 Indirect Solar Dryer . [34]

Basumatary (2013)

Have designed and constructed a low cost mixed type solar cabinet dryer. The drying chamber is made from wood where the inside is coated with metal and is covered with transparent plastic paper. The authors indicated that the drying trays can be made from non-corrosive stainless steel, but instead preferred to use bamboo nets for their lower cost. The solar collector is made from dark black painted non-corrosive galvanized iron sheet that is covered with transparent glass sheet or plastic paper. During the experiment they carried out on a full sunny day, the average measured temperature on the upper tray was 63 C° while the ambient temperature was 31 C°. They have also designed another dryer by connecting three solar collectors with the drying chamber. In this case, the dryer temperature has increased by 2 C° than that of the dryer with only one collector. Within 7 hours of continuous chili drying in a full sunny day, 48.72 % of moisture was removed from the upper tray and 33.03 % from the lower tray. Sun drying of the chili under the same climatic condition removed only about 15.38% of the moisture content.

The mixed mode solar dryer constructed by Basumatary et al. (2013) was intended for drying low moisture content food products such as pepper, and cauliflower. This may limit the usage of the dryer by farmers producing high moisture content products such as fruits. In addition, the authors reported the performance of this dryer 19 only for a full sunny day. Its evaluation on less sunny days or cloudy days was not included **.** [58]

Figure 2.5 Mixed Mode Solar Dryer . [58]

Forson (2007)

Designed and reported a mixed mode natural convection solar dryer where the test location for their experiment was Kumasi, Ghana. They identified three main components of the dryer as an air-heater (primary collector), a drying chamber and a chimney. The top cover and sidewalls of the drying chamber are made to be transparent so that they serve as a secondary collector. The dryer was used to dry cassava and the drying efficiency was estimated to be 12.3% with a drying time of 35.5 hour. With 162 kg of test load, 28.2 C° mean ambient temperature and initial moisture content of 66%, the final moisture content of the dried product was measured to be 17.3% while the temperature of the heated air in the air heater rose by about 10.9 C°.

The research report of Forson in 2007. gave a detailed procedure on how to design a solar dryer. Basic design concepts and rules of thumb were also outlined in the paper. Accordingly, their design of solar dryer required 42.4 m^2 of solar collector for the expected drying efficiency. [59]

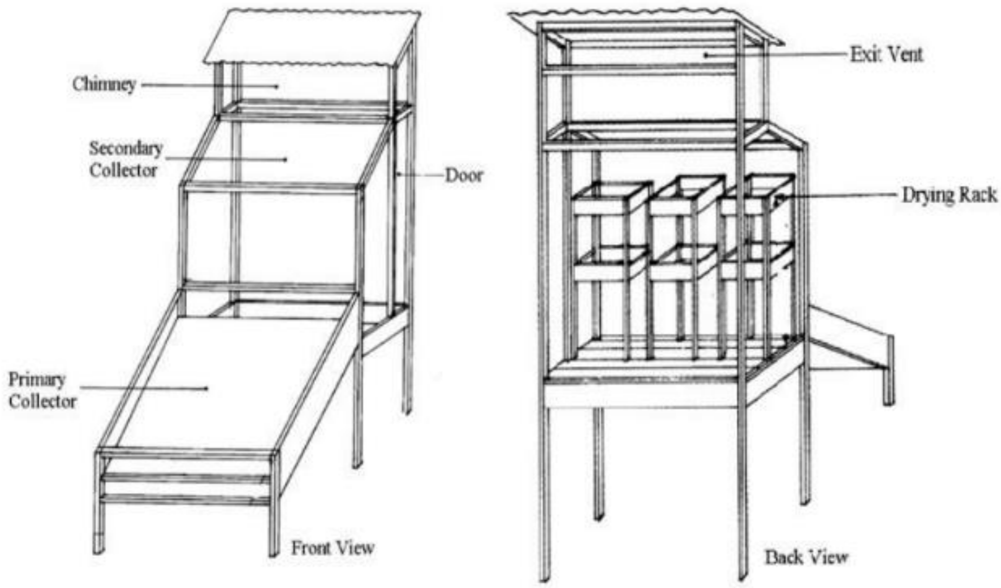

Figure 3.6 Mixed Mode Solar Dryer . [59]

Ringeisen (2014)

Have evaluated the effectiveness of a direct type solar dryer with a concave solar concentrator. The concentrator was made from materials that are readily obtainable in developing countries with lifetime expectancy of at least three years. It was made to be modular so that it can be adapted for dryers of various sizes. The solar dryer is constructed from lightweight wooden frame that is wrapped up with thick plastic sheet. A corrugated piece of black painted aluminum was placed on the floor of the dryer to be used for absorbing solar radiation. A concave solar concentrator made from polished aluminum sheet was fixed on a wooden L-shaped frame. Tests were carried out using 5 mm thick sliced tomatoes with initial moisture content between 92.2 and 94.4%. On a fully sunny day, the reduction in the drying time was about 1.54 h for the tomatoes to reach moisture content of 10%. This was 22.3% faster than that of the solar dryer without concentrator. It is also shown that the concentrators can effectively reduce the drying time during unfavorable ambient temperature and relative humidity conditions **.** [60]

Figure 3.7 Solar crop dryer and concave solar concentrator [60]

Bala and Janjai (2009).

They have demonstrated and studied the performances of different types of solar dryers such as roof integrated solar dryer, solar tunnel dryer, improved version of solar tunnel dryer, and green house type solar dryer for their potential drying of fruits and vegetables They simulated the performance of solar tunnel dryer, improved version of solar dryer and roof integrated solar dryers. The results show that, the agreement between the simulated and experimental results was obtained fine. [61]

Ampratwum (2010)

Has evaluated the performance of solar cabinet dryer at no load as an air heating system [62].. The dryer was operated for 28 days. The results explicate that for the period of operation, dryer attained an average temperature of $81.3C^0$.

Sansaniwal (2017)

showed designed and developed an indirect solar dryer to investigate the drying kinetics of ginger in terms of convective heat transfer coefficients, moisture removing rates and collector efficiency under natural and forced convection drying modes. The convective heat transfer coefficients obtained under natural and forced convection drying modes were reported to vary from 0.59 to 5.42 W/m2°C° and 2.52 to 6.33 W/m2C° respectively. Further, the average collector efficiency under natural convection drying mode was calculated to be varied from 14.97 to 16.14%. However, it was obtained to be higher in forced convection drying mode and found to lie in between 27.90 to 33.92%, respectively. Therefore, the forced convection drying method was recommended for the drying of products having high moisture contents and requires either immediate consumption or quick preservation . [63]

Halewadimath (2015)

Studied designed of a solar air dryer with a collector area of 2m2 dries agricultural products from 89.6% to 13% moisture content under ambient conditions during harvesting period from February to April. Experiments was performed on solar air heater, the maximum temperature rise is 20°C and the solar intensity was found to be in the range of 402-509 w/m^2. Maximum collector efficiency of 55.15% was obtained for forced convection. Drying time was less in forced convection than the natural convection. So forced convection is preferred than natural convection for drying of agricultural products .[64]

Prakash (2014)

Studied concerned with performance analysis of solar drying system for Guntur red chili where Chili was dried to final moisture content of 9 % w.b from 80% w.b within 24 hrs.Their Experimentation period was conducted from 9:30 AM to 5:30 PM daily basis, the daily mean values of the drying chamber air temperature, drying Chamber and solar radiation ranged from 30 0C to 57 0C, and 180W/m2 to 950W/m2. The drying temperature and relative humidity under solar drying continuously varied with increasing drying time. The efficiency of the solar collector is 71.4%, drying system is 42.18%, at the solar radiation of 950 w/m2 and a mass flow rate of 0.01 kg/sec . [65]

Amedorme (2013)

studied designed and Construction of an indirect forced convention solar crop dyer for the purpose of drying moringa samples using locally available materials. A batch of moringa leaves 2 kg by mass, having an initial moisture content of 80% wet basis from which 1.556 kg of water is required to be removed to have it dried to a desired moisture content of 10% wet basis, is used as the drying load in designing the dryer. A drying time of 24-30 hrs was assumed for the anticipated test location (Kumasi; 6.7N, 1.6W) with an expected average solar irradiance of 320 W/m2 and ambient conditions of 25C$^{\circ}$ and 77% relative humidity. A minimum of 0.62 m^2 of solar collection area, according to the design, is required for an expected drying efficiency of 25%. They recommended that a test under full loading conditions should be carried out in order to know if all the design parameters have been met and laboratory experiment should be done to know the effects on the nutritional values of the moringa leaves when sun dried and solar dried. [66]

Research by Om Prakash & Anil Kumar (2013)

showed an comprehensive review of the various designs, details of construction, and operational principles of the wide variety of practical designs of solar energy drying systems has been described. Two major groups of solar dryers can be identified ,passive or natural-circulation solar dryers and active

or forced convection solar dryers. Some easy-to-construct and user-friendly dryers that can be suitably employed at small-scale factories or at rural farming villages has been presented. These low-cost food drying technologies can be readily used in rural areas to reduce spoilage and improve product quality thus resulting in overall processing hygiene. Scientifically designed active solar dryers are generally found to be more effective and more controllable than the natural-circulation types. In most of the active solar dryers, the fan is driven by the solar photovoltaic cell. It makes the active dryer totally independent from the dependency over fossil fuel/electricity. Therefore, solar photovoltaic-thermal (PV/T) dryer is agreed to be suitable for remote rural village farm application in most developing countries .
[67]

2.7. Conclusion :

- in the recent years the sector of solar drying takes the attentions of many scientists and researchers in order to develop this very important technology for preserve food for a long time Moreover, for the advantage that solar drying has is as follow :

- Solar drying is a simple, low-cost way to preserve food that might spoil.
- When fruit ripens. Surplus grain, vegetables, and fruit preserved by drying which can be stored for future use.
- Solar drying method they produce better looking, better tasting, and more nutritious foods.
- Allows the food to be stored for a long time.

Chapter 3: Solar dryer and mathematical modeling .

3.1. Introduction

In the ancient and modern life Drying is one of the essential method to preserve food and increase the self – life period as well, and it is one of the most practical methods of preserving food and the quality of many product like vegetables, herbs. If the drying process is not completed fast enough, growth of microorganisms will take place because of the high relative humidity. This often leads to severe deterioration of the quality of the product. Traditionally, the food products are dried by spreading in open sun. And this method has many drawbacks like; no control over the rate of drying, non-uniform drying, chances of deterioration due to exposure of products against rain, dust, storm, birds, rodents, insects which results in poor quality of dried products , Nowadays, we have solar dryers in way we can control the drying process and get ride of many disadvantage like we find in open solar drying .

In this chapter, we are going to study the effects of some parameters on drying process like the outlet air temperature, mass flow rate, and solar insolation.

3.2. Design Procedure

In this project I will chose the indirect passive solar dryer with the climatic data of Bouira city as an example to perform my study and do the mathematical calculations and after that I will create a simple program by using MICROSOFT DEVELOPER STUDIO (FORTRAN) , and as I mentioned in chapter number one the indirect passive solar dryer type consist of two parts, solar collector, drying champer :.

3.2.1. The mathematical calculations of the collector:

The design of the solar dryer took into consideration different design criteria and parameters. Some of these design criteria and parameters were from literature review while others were determined using a series of mathematical calculations.

Symbol	Materials	Specifications
Ac	Area of the collector	2 m^2
β	Tilt angle of the collector in boumerdes city	$\beta = 10^{\circ} + \text{lat } \Phi = 46°$
Ic	Solar irradiation	900 w/ m^2
V	Speed of wind	3.3 m/s
ec-ab	Space between glass cover – absorber	0.08 m
L	Thikness of polestar	0.02 m
Aedj	Space of the edge of the collector	1.2 m^2
ṁ	Mass flow rate	7.22*10^-3
k_{pol}	thermal conductivity of the polestar	0.033
K_{wood}	thermal conductivity of wood	0.07
ε_c	emissivity of the cover plate	0.88
ε_{ab}	emissivity of the absorber plate	0.2
α_{ab}	absorptivity of the absorber plate	0.95
τ_c	transmissivity of the cover plate	0.95
$(\alpha_{ab} * \tau_c)$	Transmitance- absorptace product $(\alpha_{ab} * \tau_c)$	0.90
σ	Stefan-Boltzmann constant	5.67*10^-8
Tfm	average temperature of fluid pass in the collector	315 k (42C)
Tc	Temperature of the glass cover	303 k (30C)
Ta	Ambient temperature	291 k (18C)
Ts	Temperature of the sky	Ts = 0.0522(Ta)^1.5
Tab	Temperature of the absorber	333 k(60C)

Table 3.1 Design Specifications of the solar dryer

- **a) the energy gain by the absorber :**

In order to define the energy balance of the solar air collector the following equation shall be used:

$$Q_u = A_c F_R \left[S - U_L \left(T_{fm} - T_a \right) \right] [W] \qquad (3.1)$$

Where:

- Qu= the energy gain by the absorber [W] .
- A_c – collector area [m^2].
- F_R – heat removal factor [-].
- S – absorbed solar radiation per unit area [W/m^2].
- U_L – collector overall heat loss coefficient [$W/(m^2 \cdot K)$].
- T_{fm} – mean fluid temperature [K].
- T_a – ambient temperature [K].

- **b) Collector overall heat loss coefficient**

In our study, we have a solar air collector with one glass cover and in order to calculate the collector overall heat loss coefficient, we present the thermal network:

- From the thermal network :

$Ul = U_{top} + U_{edj} + U_{bottom}$ [W/(m^2·K)]. (3.2)

Ul= Collector overall heat loss coefficient [W/(m^2·K)].

U_t – top loss coefficient [W/(m^2·K)].

U_b – the coefficient loss through the bottom of the collector [W/(m^2·K)].

U_e – the coefficient edge losses [W/(m^2·K)].

U_t – top loss coefficient :

$$Utop = \left(\frac{1}{hw+hr,c,a} + \frac{1}{hr,c,ab+hc,c,ab} \right)^{-1}$$

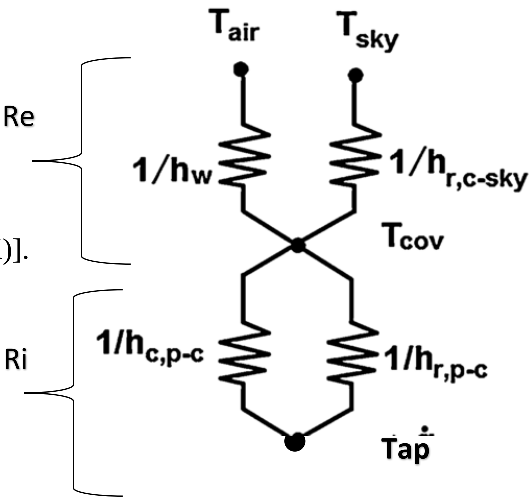

Figure 3.1 The thermal network

- hw= convective coefficient of wind. [W/(m^2·K)]
- hr,c,a= radiation coefficient cover-asorber. [W/(m^2·K)]
- hc,c,ab= convective coefficient cover-absorber. [W/(m^2·K)]
- hr,c,ab=radiation coefficient of cover-absorber. [W/(m^2·K)]

- $hw = 5.7 + 3.8\,(V)$ [W/(m^2·K)] (3.3)

- $hr,c,a = \sigma.\ \varepsilon c.\ (TC + Ts).(TC^{2} + Ts^{2}).$ [W/(m^2·K)] (3.4)

- $hc,c,ab = 1.14.\frac{(Tab-Tc)^{0.35}}{2^{0.07}}\ .\ (1 - 0.0018\ (\frac{Tab-Tc}{2} - 10\ ))$ [W/(m^2·K)] (3.5)

- $$hr,c,ab = \frac{\sigma\ (Tab^4 + Tc^4)}{(((1/\ \varepsilon ab) + (\ 1/\ \varepsilon c)).(Tab - Tc))}$$ [W/(m^2·K)] (3.6)

- **U_b – the coefficient loss through the bottom of the collector :**

- $Ub = \frac{kpol}{L}$ [W/(m^2·K)], (3.7)
- k – insulation thermal conductivity POL .[W/m·K],
- L – thickness of insulation [m].

- **U_e – the coefficient loss through the edge :**

- $Ued = \dfrac{Kwood \,.\, Aedj}{e.A}$ [W/(m²·K)] (3.8)

- Kwood – insulation thermal conductivity of wood .[W/m·K],
- Aedj= area of the edj of the collector [m^2].
- eab-c= Space between glass cover – absorber [m].

- **c) Heat removal factor :**

$$F_{R}= \left[1+\frac{U_L}{h_{c,c,ab}+(\frac{1}{h_{c,c,ab}}+\frac{1}{h_{r,c,ab}})^{-1}}\right]^{-1} \frac{\dot{m}C_p}{A_c U_L F'}[1-\exp(-\frac{A_c U_L F'}{\dot{m}C_p})] \quad [\ -\ ] \qquad (3.9)$$

$$F' = \left[1+\frac{U_L}{h_{c,c,ab}+(\frac{1}{h_{c,c,ab}}+\frac{1}{h_{r,c,ab}})^{-1}}\right]^{-1} \quad [\ -\ ] \qquad (3.10)$$

- *FR* = heat removal factor [-].
- *UL* = Collector overall heat loss coefficient [W/(m²·K)] .
- *hr,c,ab* = radiation coefficient cover-asorber. [W/(m²·K)] .
- *hc,c,ab* = convective coefficient cover-absorber. [W/(m²·K)] .
- *ṁ* = flow rate [kg/s],
- Cp – specific heat [kJ/kg·K]
- Ac = area of the collector.

- **Absorbed solar radiation :**

S = (τα) * Ic (3.11)

- S = the radiation absorbed by unit area of absorbing surface [W/m^2].
- (α_{ab*} τ_c) = Transmitance- absorptace product. [-]
- Ic= the solar irradiance [W/m^2].

- **The outlet temperature :**

$$To= Ti + \frac{Qu}{\acute{m}.cp} \qquad (3.12)$$

- To = the outlet temperature. (K)
- Ti =Ta = the inlet temperature .(K)
- Qu= the energy gain by the absorber [W]
- $\acute{m}$ = flow rate [kg/s],
- Cp – specific heat [kJ/kg·K]

- **Efficiency of the solar air collector:**

$$\eta= \frac{Qu}{Ic.Ac} *100 \ [\%] . \qquad (3.13)$$

- Ƞ= Efficiency of the solar air collector .
- Qu= the energy gain by the absorber [W] .
- Ic= the solar irradiance [W/m^2] .
- Ac = area of the collector .

3.2.2. The mathematical calculations of drying chamber:

The drying chamber was made from plywood (good insulation) with wood support. It consisted of three trays, each with size of (60 x 50 cm), for the produce to be dried. The trays were made from perforated stainless steel. Stainless steel was chosen to avoid rusting due to high initial moisture content of the produce and for the product to be dried in this study is the mint leaves , and in the table below I put the and the mint leaves in our study :

	Dimension (m)	The material	N° of the trays	The material of the trays
Drying chamber	(0.6*0.5*1)	plywood	3	Perforated Stainless steel

Table 3.2 specification of the drying chamber

	The mass (kg)	Mi (%)	Mf (%)	Cp (kJ/kg. k)	hg(kj/kg)	Hf(kj/kg)
Mint leaves	5	70 %	6%	3.58	2583	188

Table 3.3 specification of the leaves mint.[68]

Mi = initial moisture content (%).

Mf = final moisture content (%).

hg= enthalpy of the water as a vapor. (kj/kg)

hf= enthalpy of the water as liquid. (kj/kg)

Cp= Specific heat capacity (kJ/kg. k)

- **The moisture content :**

$$Ww = mp * \frac{(Mi - Mf)}{(100 - Mf)} \quad (kg) \quad (3.14)$$

- Ww = the moisture content (kg)
- mp= the initial mass of the product (kg).
- Mi = initial moisture content (%).
- Mf = final moisture content (%).

- **The energy required to remove water :**

The heat required to remove water from a produce was calculated using the formula provided by Mercer in 2007 [69]. It considers drying as a two stage process where the first one is raising the temperature of the wet material to a desired level at which the moisture will be removed. This is given by:

$$Q_1 = mp * C_p * \Delta T \ldots\ldots\ldots\ldots\ldots (k\,j) \quad (3.15)$$

- Q1 = the energy required raising the temperature of the wet material.
- mp = the initial mass of the product (kg).
- Cp= Specific heat capacity (kJ/kg. k).
- ΔT = temperature change (Tout –Ti) (C).

The second stage is evaporating the moisture from the produce. As water starts to evaporate after the produce is warmed up to the drying temperature, heat required to evaporate it is given by:

$Q_2 = W_w * L$ ………. (kj)

- $Q2$= the energy required to evaporating the moisture from the produce
- Ww = the moisture content (kg)
- L = hg- hf,, is latent heat of vaporization .
- hg= enthalpy of water as a vapor (kJ/kg).
- hf = enthalpy of water as a liquid (kJ/kg).

QT = Q1+Q2………… (KJ)

- QT= the total heat requirement (KJ)
- Q1= Q1 = the energy required raising the temperature of the wet material .(KJ)
- Q2= the energy required to evaporating the moisture from the produce (KJ)

- **The time required to dry an amount of mint leaves :**

$Td = \frac{Qt}{Qu*\eta}$.

- Td = drying time (days).
- QT= the total heat requirement (KJ).
- Qu= the energy gain by the absorber in one day [W].
- Ƞ= the efficiency of the collector (%).

3.3. conclusion

The previous calculation is essential to determine the most important parameters like energy absorbed by the collector, overall lose coefficient ,collector efficiency , outlet temperature ,drying period , and to facilitate the obtaining of these parameters we will build our program to calculate these parameters .

Chapter 4: The economic study.

4.1. Introduction

Solar drying is an ancient and inexpensive technique used for the preservation of agricultural item like fruits. Vegetable, herbs and this system is quite useful for people living in remote areas and the solar drying of agricultural item has been popular and feasible. Especially by using solar dryer which is a simple, low-cost, easy handled and without any extra cost of fuel or maintenance.

in this chapter I am going to make a Comparison economic study between drying mint and Saffron And notice which drying item is gainful and before that we will shed a light about the most important criteria that we will apply it in this study

4.2. The Criteria of the economic analysis

Economic profitability can be assessed according to several criteria which make us able to establish which projects are likely to turn the greatest profit and also give us a clear picture about the project and that would help us to take a lot of measurement for establish a successful project .

4.2.1. Net Present Value

This Criteria is a good indicator of the economic profitability of a project, it represents the discounted net profit over the life of the project. It is expressed as follows

$$NPV = -\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n} \tag{4.1}$$

NPV = NET PRESENT VALUE (dinars DZ)

β = discount factor (%)

CTO = investment cost (dinars DZ)

Itot = The income (dinars DZ)

Cf = cost of fuel (dinars DZ)

C (O&M) = Operating and Maintenance cost (dinars DZ)

n= number of years

i = rate of return (between 6% - 12%.)

Net present value, or NPV, is used to calculate how much we earn every year . If the NPV of a project or investment is positive, it means that the discounted present value of all future cash flows related to that project or investment will be positive, and therefore attractive. To calculate NPV you need to estimate future cash flows for each period and determine the correct discount rate

4.2.2. Payback Period

Payback Period of Solar Dryer System Payback period is the time required to recover the money invested in fabrication of solar dryer system. A system with short payback period is considered to be more economical.

And in other way, The payback period refers to the amount of time it takes to recover the cost of an investment. The desirability of an investment is directly related to its payback period. Shorter paybacks mean more attractive investments. It is expressed as follows, and it is mean that the payback period is the number of years when the equation becomes equal to zero :

$$-\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n} = 0 \qquad (4.2)$$

β = discount factor . (%)

CTO = investment cost (dinars DZ)

Itot = The income . (dinars DZ)

Cf = cost of fuel . (dinars DZ)

_C(O&M) = Operating and Maintenance . (dinars DZ)

n= number of years .

Ny= number of year .

i = rate of return (between 6% - 12%. and we take the average 9%) .

4.2.3. The specific investment cost

The specific investment cost represents the investment cost per unit of produce to be dried (Dz / kg of a dried produce):

$I_s = \frac{C_{T0}}{M}$. (4.3)

Is = the specific investment cost (Dz / kg of a dried produce) .

CTO = investment cost (Dz).

M = the mass of the produce (Kg) .

4.2.4. The income (Itot) :

The Income is the money (or some equivalent value) that an individual or business receives, usually in exchange for providing a good or service or through investing capital Business income can refer to a company's remaining revenues after paying all expenses and taxes. In this case, income is referred to as "earnings” Or we can say in another way that Income is money what an individual or business receives in exchange for providing labor, producing a good or service, or through investing capital .

In our study the income will be calculated by the following formula :

$$\mathbf{Itot = Myear * P} \qquad (4.4)$$

- Itot = the income (DZ)
- Myear = the mass of dried produce in one year (KG).
- P= the price of 1 kg of the dried produce(DZ/KG).

4.3. The calculation:

In this part, we are going to start our calculation, and our economic study will include two products, which is **the mint leaves** and **apricots :**

4.3.1. The mint leaves:

In the table below, we will give all the cost of the parameters of the investment which we will need it in our economic study of the mint leaves, and we must put in consideration that we operate the solar dryer from May to November as we follow:

- April: 30 days.
- May: 31 days.
- June: 30 days.
- July: 31 days.
- August: 31 days.
- September: 30 days.
- October: 31 days.
- November: 30 days.

and that lead to 214 days of operation of the solar dryer in one year.

Td = 13 hours = one day and half .(from the program)

One day and half = 3.4 kg dried mint .(from the program)

The average price of fresh mint = ~ 380 Dz (average price in the Algerian market)

The average price of dried mint = ~ 1800 Dz (average price in the Algerian market)

the parameters	The price / the value (Dz / %)
Solar dryer	110000 DZ
β = discount factor (%)	1
i = rate of return	negligible
1 kg fresh mint	380 Dz
1 kg dried mint	1800 Dz
The total amount of mint to be dried in 1 year (713 kg).	713*380=270940 Dz Global Average Price
The total amount of dried mint in 1 year (228 kg).	228*1800= 410400 Dz.

Table 4.1 the parameters of the economic study of the mint leaves

- **Calculate The yearly income (Itot) :**

Itot = (Myear * P) – expenses

Myear= 228 KG (The total amount of dried mint in 1 year)

P= 1800 Dz (the price of 1 kg of dried mint)

Expenses is the price of the total fresh mint in one year .

Itot = (228*1800)- 270940= **139460 Dz**

Net Present Value:

$$NPV = NPV = -\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n}$$

$$-\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n}$$

- **1 st year :**

$$NPV = -(1) * 110000 + \frac{139460}{(1)\text{^}1}$$

NPV= + 29460 Dz

- **Payback Period**

The payback period is the year, which the equations (4.2) becomes equal to zero

$$-\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n} = 0$$

From the calculation of the Net present value, the payback period is **1 year.**

- **The specific investment cost :**

$$I_s = \frac{C_{T0}}{M} .$$

- Cto= 110000 Dz.
- M= 380 kg .

$$I_s = \frac{110000}{380} = 289 \text{ Dz/kg} .$$

- **Observation and results :**

From the results above about the investment in the mint leaves we conclude that :

- In addition to the easy handling and low – cost price of the solar dryer we can also make an important benefits from the dried product, and in short period like we have in our example of the drying of leaves mint, where we reach **139460 Dz** as an income in just one year , and a payback period of 1 year , and if we compare the income to the cost of investment it is nearly 126 % , and that is a remarkable value .
- and for the specific investment cost which is 289 Dz / kg and that lead us to say that this project is a profitable investment .
- we can achieve more profit especially if we establish our investment of solar dryers in a hot areas like in the south of the country which is mean more solar energy and more dried product and drying rate .
- in our study I took just one solar dryer to perfume my calculation , and that does not mean that the investment do not have the potential to expand , we can step up the number of solar dryer and the benefit as well .

4.3.2. The apricots:

Every year Algeria produces a significant amount of the apricots fruit, and the fresh apricots is much cheaper than the dried apricots

The initial moisture content	85 %
The final moisture content	25%
Specific heat capacity of apricot	3.68 kj/kg.k
The mass to be dried	5 kg
The moisture content in 5 kg	4 kg

Table 4.2 the specifications of the apricots fruit.

214 days of operation of the solar dryer in one year.

By using the program we get the drying period Td = 14 hours to dry 5 kg of apricots .

14 hours (one day and half) = 1 kg dried apricots.

The average price of fresh apricots = ~ 100 Dz (29/06/2020 average price in the Algerian market).

The average price of dried apricots = ~ 1000 Dz (29/06/2020 average price in the Algerian market).

the parameters	The price / the value (Dz / %)
Solar dryer	110000 DZ
β = discount factor (%)	1
i = rate of return	negligible
1 kg fresh apricots	100 Dz average price in the Algerian market
1 kg dried apricots	1000 Dz average price in the Algerian market
The total amount of apricots to be dried in 1 year (713 kg).	713*100=71300 Dz Global Average Price
The total amount of dried mint in 1 year (142 kg).	142*1000= 142000 Dz.

Table 4.3 the parameters of the economic study of the apricots fruits.

- **Calculate The yearly income (Itot) :**

Itot = (Myear * P) – expenses

Myear= 142 KG (The total amount of dried mint in 1 year).

P= 1000 Dz (the price of 1 kg of dried mint).

Expenses is the price of the total fresh mint in one year .

Itot = (142*1000)- 71300= 70700 Dz

- **Net Present Value:**

$$NPV = NPV = -\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n}$$

$$-\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n}$$

- **1 st year :**

$$NPV = -(1) * 110000 + \frac{70700}{(1)^\wedge 1}$$

NPV= -39300 Dz

- **2 nd year :**

$$NPV = -(1) * 110000 + 70700 + \frac{70700}{(1)^\wedge 2}$$

NPV= +31400 Dz

- **Payback Period**

The payback period is the year, which the equations (4.2) becomes equal to zero.

$$-\beta\, C_{T0} + \sum_{n=1}^{Ny} \frac{I_{Tot} - C_f - C_{O\&M}}{(1+i)^n} = 0$$

from the calculation of the Net present value the payback period is **2 years.**

- **The specific investment cost :**

$I_s = \frac{110000}{100}$.

- Cto= 110000 Dz.
- M= 100 kg .

$I_s = \frac{110000}{100}$ = 1100 Dz/kg .

- **Observation and results :**

From the results above about the investment in the apricots fruits we conclude that :

- we reach **70700 Dz** as an income in just one year , and a payback period of **2 year** , and if we compare the income to the cost of investment it is nearly **70 %** , and that is a remarkable value.
- and for the specific investment cost which is **1100 Dz / kg** and that lead us to say that this project is a profitable investment .
- in addition to that and as I mentioned before we can scale up the investment and make more profit .
- every year we produce a large amount of apricots fruit and that mean we can buy it with a low price compare to the average price I took in my study and that will increase the profitability .

4.4. Conclusion:

The economic study allowed us to evaluate the provability in the investment on the solar drying by using our modal of solar dryer in Bouira city , and from the results we get we conclude that the investment is gainful and make an important profit , in the investment on drying mint leaves we reached an income of **139460 Dz** and with payback period **of 1 year** , and in our second example in the investment on the drying of the apricots fruits we reach an income of **70700 Dz** with a payback period of **2 years** which is a remarkable period too .

And as we mentioned before we can make more profit by scale up the investment , in other hand and according to the Algerian ministry of commerce the Algerian's imports of dried fruits every year is nearly 100 million dollars , and this kind of investment can reduce the imports pill and post-harvest losses as well ,and we can even become and an exporting country of dried fruits , especially the one that we produce an important quantity of it , like grape , prune ,tomato .

Chapter 05: Results and discussion.

5.1. Introduction

After completing the calculations and creating the program to study our modal solar dryer, different tests were performed in order to evaluate its performance. Mint leaves were dried during the study. The curves of different tests performed are presented below.

5.2. Curves and observations:

5.2.1. curves of the solar collector:

- a) The outlet temperature in terms of the ambient temperature at a fixed mass flow of air:

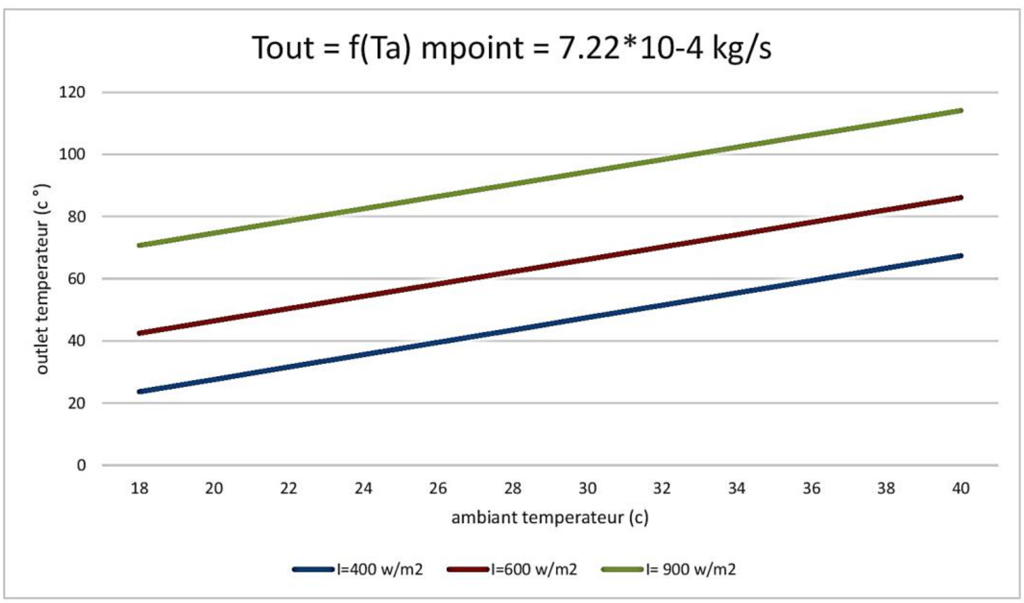

Figure 5.1 the outlet Temperature variation with ambient temperature at mpoint = 7.22*10-4 kg/s .

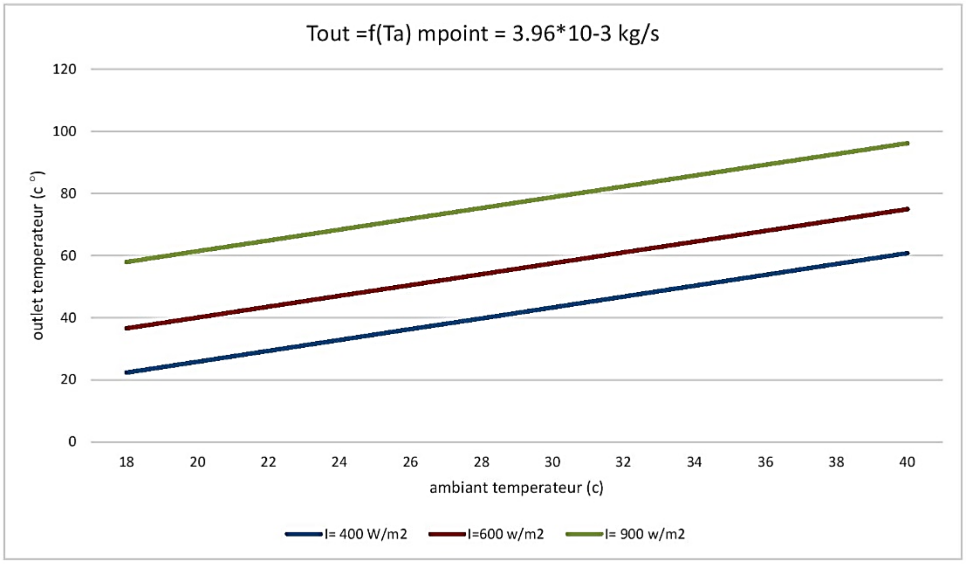

Figure 5.2 the outlet Temperature variation with ambient temperature at mpoint = 3.96*10-3 kg/s .

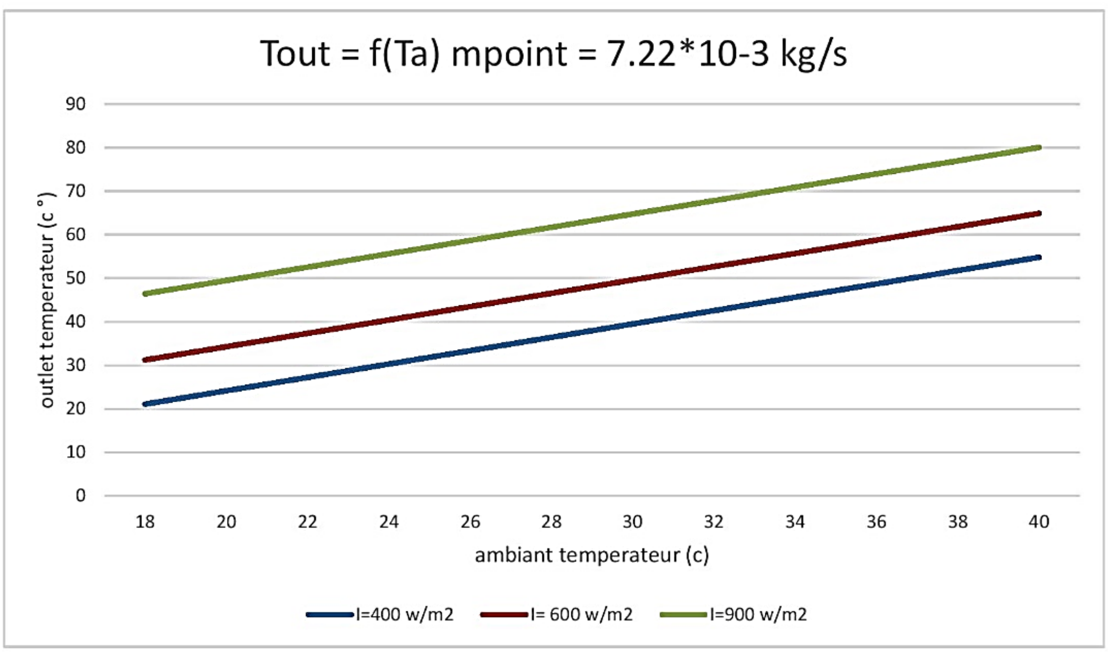

Figure 5.3 the outlet Temperature variation with ambient temperature at mpoint = 7.22*10-3 kg/s .

- **observations :**

- **figure 5.1** represents the three outlet Temperature variation with ambient temperature at a fixed mass flow of air (mpoint = $7.22*10^{-}4$ kg/s) with three different solar irradiation (I= 400 W/m^2 , I= 600 w/m^2 , I= 900 w/m^2) , we observe a positive coloration between the outlet temperature of the solar collector and the ambient temperature , and that lead to the high temperature areas is more suitable and reach a high drying rate for drying products and the efficiency would be more higher compared to cold areas . in addition to that we also observe the positive effect of the solar irradiation on the outlet temperature due to the solar intensity which is the more solar irradiation is the more heat absorbed from the collector .

- **figure 5.2** represents the three outlet Temperature variation with ambient temperature at a fixed mass flow of air (mpoint = 3.96*10-3 kg/s) with three different solar irradiation (I= 400 W/m^2 , I= 600 w/m^2 , I= 900 w/m^2) ,we notice the effect of the ambient temperature ,solar irradiation on the outlet temperature . we also observe that because we increase the mass flow of air compared to **figure 5.1** the maximum temperature also decrease and that lead to the important of the mass flow of air in drying process and we need to give the enough mass flow of air no more no less .

- the increasing of the solar irradiation, ambient temperature lead to the increasing of the outlet temperature and From **figure 5.3** we notice that the increasing of the ambient temperature from 18 C -40 C lead to an increasing of the outlet temperature from 35C- 80 C.

b) The outlet temperature in terms of the mass flow

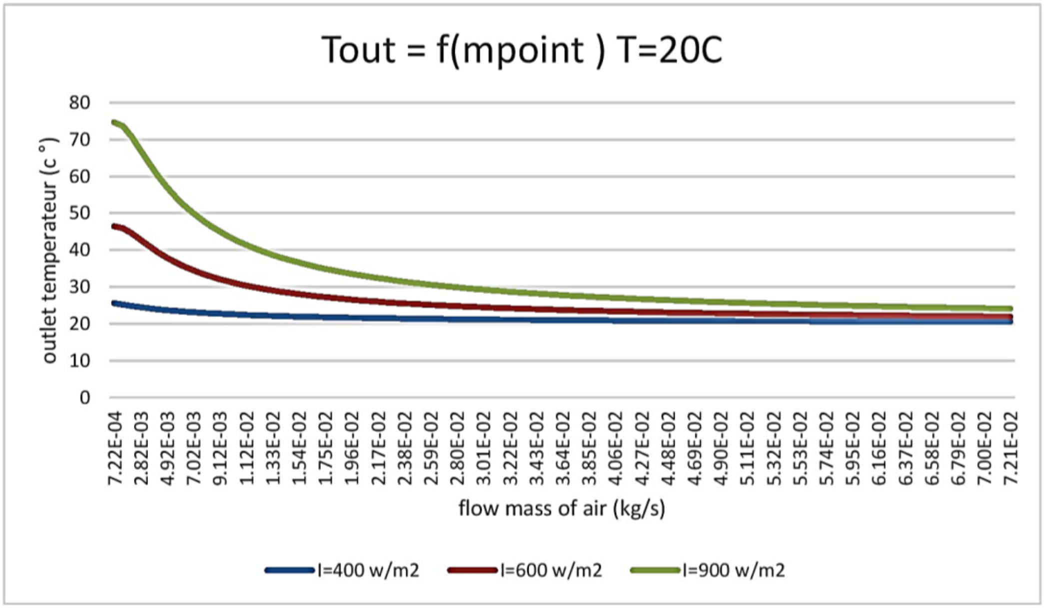

Figure 5.4 the outlet Temperature variation with flow mass of air at Ta=20 C .

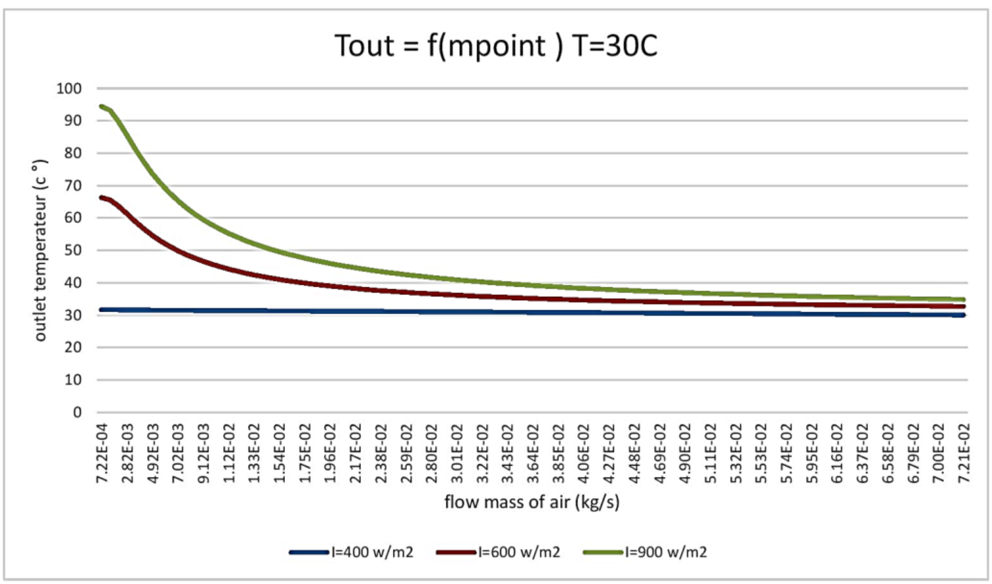

Figure 5.5 the outlet Temperature variation with flow mass of air at Ta=30 C .

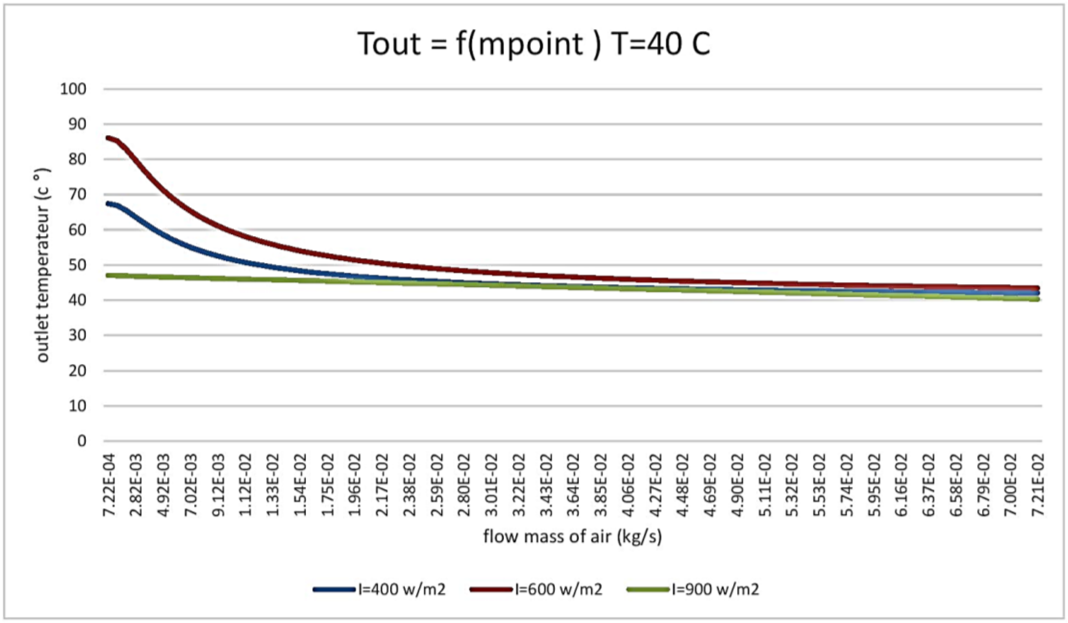

Figure 5.6 the outlet Temperature variation with flow mass of air at Ta=40 C . .

- **observations :**

- **figure 5.4** represents the outlet Temperature variation with flow mass of air at ambient temperature of Ta=20 C , we observed here the important relation between the mass flow of air and the outlet temperature we see that once we increase the mass flow of air the outlet temperature it decrease from about 80 C to 24C for the irradiation of I= 900 w/m^2 and the same thing to the others irradiations just a slightly difference in the pick outlet temperature and the low one ,this value of outlet temperature will stabilize at fixed outlet temperature because we are giving a higher amount of mass flow of air in addition to that we also observe that the ambient temperature play an important role on the drying process because once the ambient temperature is low we reach a low outlet temperature also about 24 C for the three of the solar irradiation .

- **figure 5.5** represents the outlet Temperature variation with flow mass of air at a fixed ambient temperature , we observed here at 30 C ambient temperate the low irradiation of 400 w/m^2 does not affect the outlet temperature because when the ambient temperature is high and the solar irradiation is low we do not need to operate the solar dryer . we also notice the important relation between the mass flow of air and the outlet temperature we see that once we increase the mass flow of air the outlet temperature it decrease from about 95 C to 32 C with 900w/m^2 .

- **figure 5.6** represents the outlet Temperature variation with flow mass of air at ambient temperature of Ta=40 C , we observed how the mass flow of air affect the outlet temperature and we see that once we increase the mass flow of air the outlet temperature it decrease from about 95 C to 43 C and the same thing to the others irradiations . and because the ambient temperature is 40 C the outlet temperature stabilize 40 C .

- c) The efficiency of the collector in terms of the solar irradiation at a fixed ambient temperature :

T= 20 C

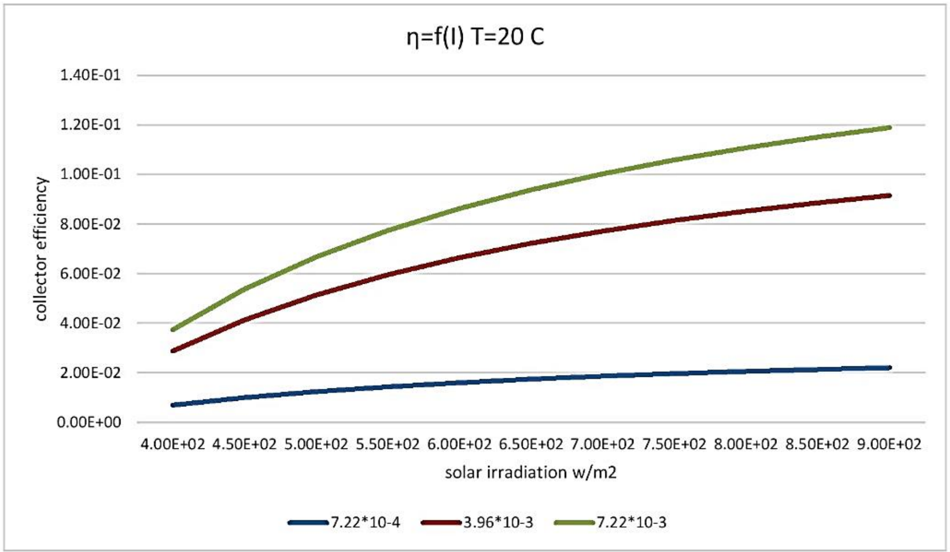

Figure 5.7 the collector efficiency variation with solar irradiation at Ta= 20 C .

T= 30 C

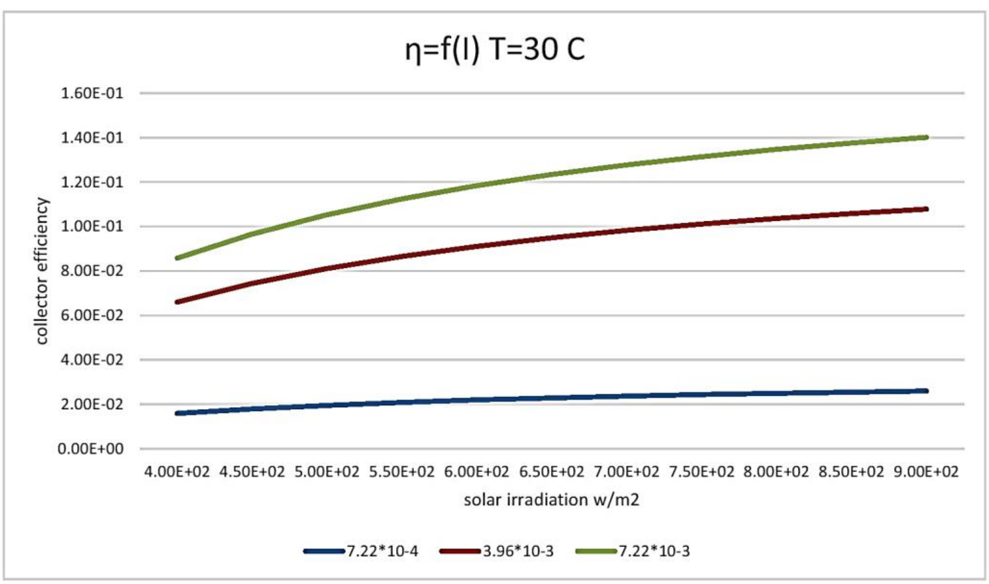

Figure 5.8 the collector efficiency variation with solar irradiation at Ta= 30 C .

T= 40 C

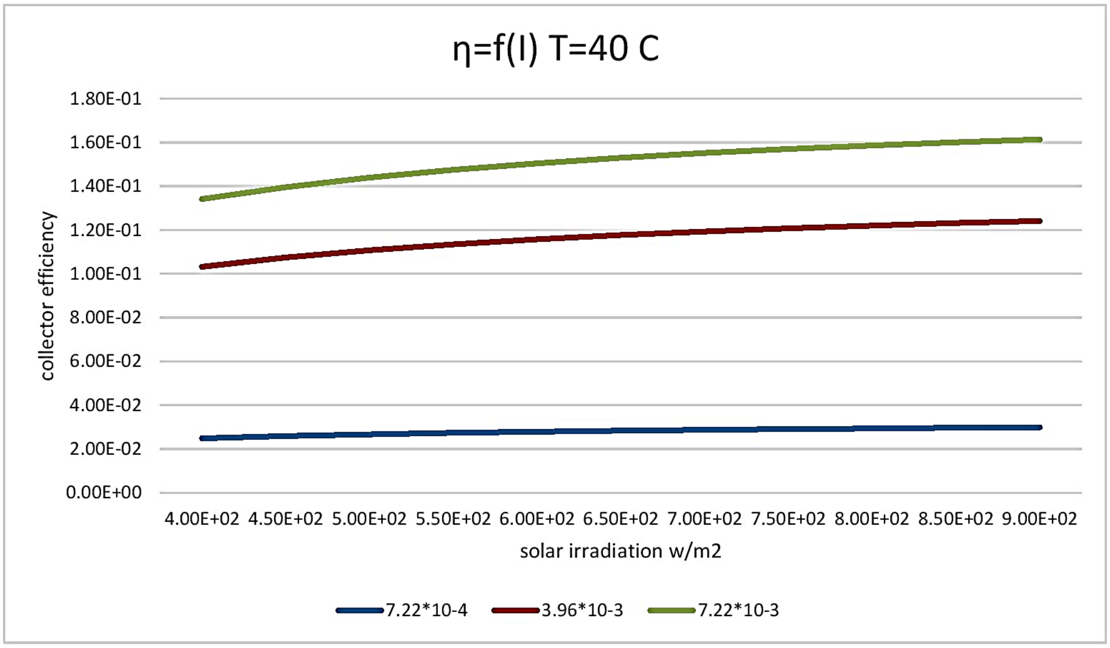

Figure 5.9 the collector efficiency variation with solar irradiation at Ta= 40 C .

observations :

- **figure 5.7** represents the collector efficiency variation with solar irradiation at Ta= 20 C. we observe the positive correlation between the intensity of the solar irradiation and the collector efficiency and we reach a 12 % efficiency with I= 900 w/m^2 and mass flow of air of 7.22*10-3 , and we also observe that once we increase the solar irradiation we must increase the mass flow of air to obtain the maximum collector efficiency .

- the increase in the ambient temperature lead to the increase in the collector efficiency and that what we observe in **figure 5.8** where we reach a maximum efficiency of 14 % with I= 900 w/m^2 and mass flow of air of 7.22*10-3, we also observe that the low mass flow of air affect negatively the collector efficiency because of that we reach just 2% with mpoint = 7.22*10-4 kg/s .

- **figure 5.9** represent the collector efficiency variation with solar irradiation at Ta= 40 C we reach a maximum efficiency of 17 % with I= 900 w/m^2 , and mass flow of air of 7.22*10-3 , we notice that once we increase the solar irradiation we must increase the mass flow of air to obtain the maximum collector efficiency , and we also observe that the low mass flow of air affect negatively the collector efficiency because we reach just 3% with mpoint = 7.22*10-4 kg/s **.**

5.2.2. curves of the solar dryer:

The simulation was performed in 01 July 2020 for the location of BOUIRA CITY, ALGERIA (latitude: 36.3°, Longitude 3.9°). During this period, hourly solar radiation levels varied between 398w/m^2 – 893w/m^2 , ambient air temperature fixed at Ta= 20 C , Ta= 40 C , humidity of 90% .

Ta=20C

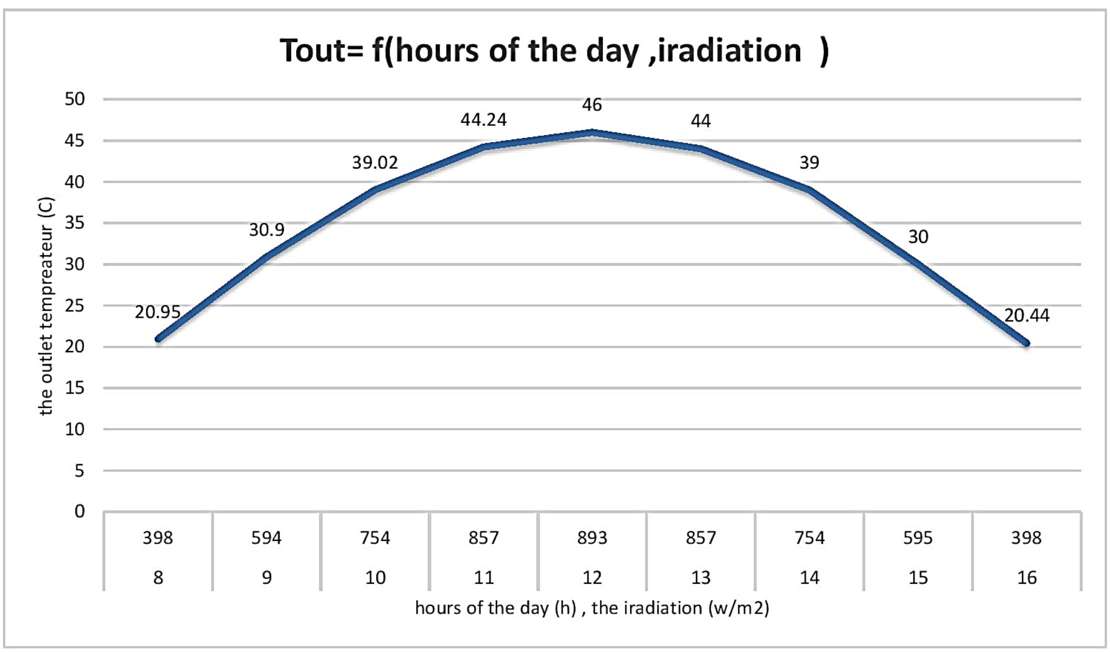

Figure 5.10 the outlet temperature variation with hours of the day, the irradiation at Ta= 20 C

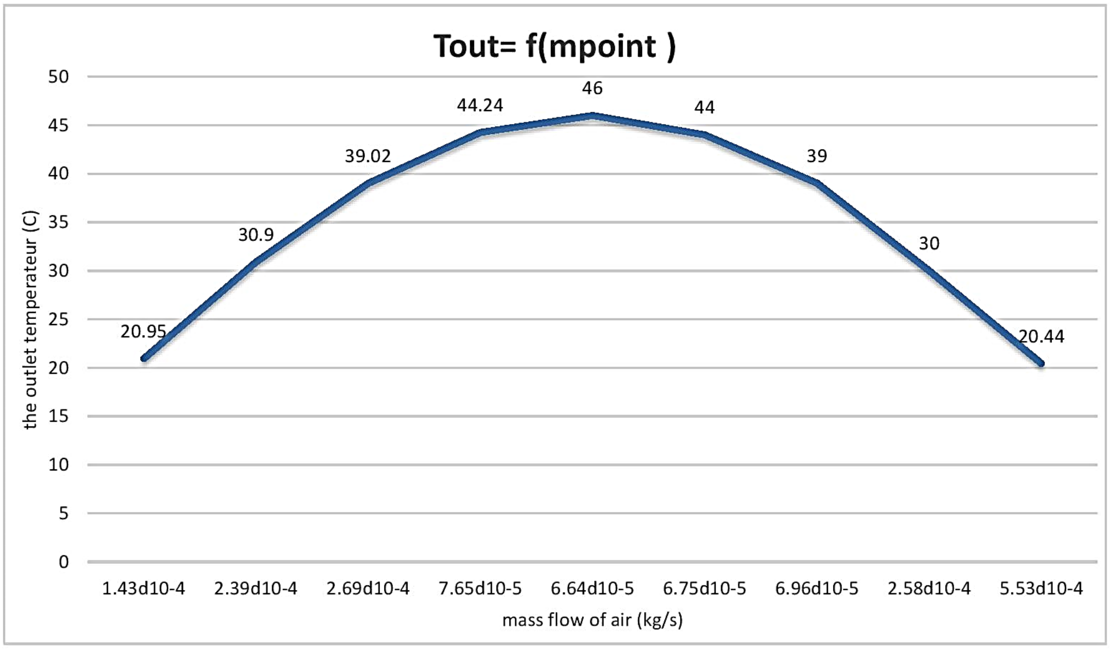

Figure 5.11 the outlet temperature variation with mass flow of air at Ta= 20 C

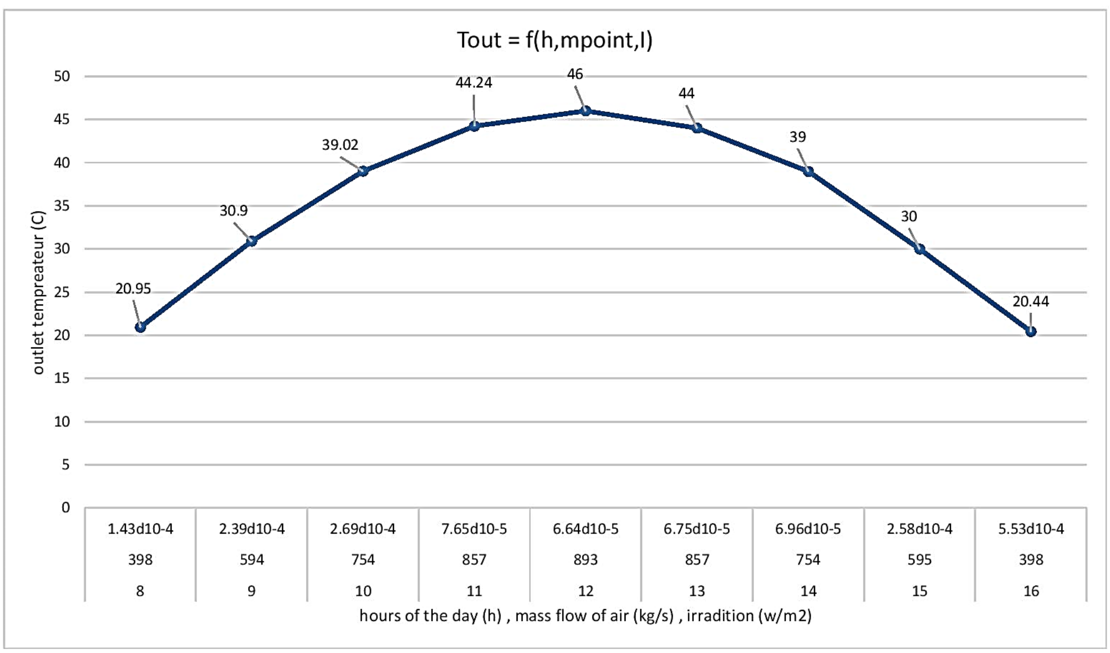

Figure 5.12 the outlet temperature variation with hours of the day, mass flow of air, the irradiation at Ta = 20 C

Ta=40C

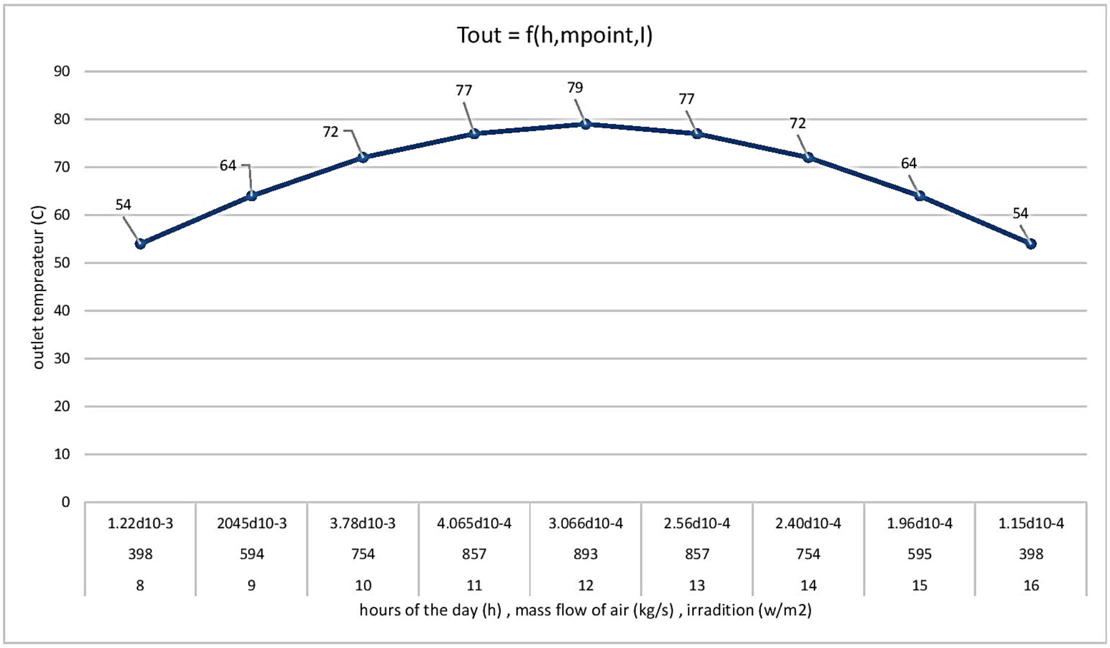

Figure 5.13 the outlet temperature variation with hours of the day, mass flow of air, the irradiation at Ta = 40 C

OBSERVATIONS :

- **Figure 5.10** represents the outlet temperature variation with hours of the day, the irradiation at Ta= 20 C, we reach the maximum value of the outlet temperature Tout= 46 C with irradiation of I= 893 w/m2 at 12.00 h (midday) and that time from the day has the high drying rate .

- The mass flow of air required depend on other parameters like ambient temperature of air and solar irradiation and in **Figure 5.11** we notice that at each hour of the day the solar irradiation is varied thus the mass flow of air is also varied,

- **Figure 5.12** represents the outlet temperature variation with hours of the day, mass flow of air, and the irradiation at Ta = 20 C , we observe that once the outlet temperature is increasing the mass flow of air is decreasing until stabilize at a fixed value at midday which is the enough mass flow of air required ,
-
- The **Figure 5.13** represent the outlet temperature variation with hours of the day, mass flow of air, and the irradiation at Ta = 40 C , we observe that once the outlet temperature is increasing the mass flow of is decreasing until stabilize at a fixed value at 16 h , we also observe that there is a positive correlation with the solar irradiation and the outlet temperature and as I mentioned before the hot areas gives a better outlet temperature and drying efficiency which is mean more drying rate and more quantity of dried product , in addition to that these last three curves they all measured at an ambient temperature of T= 20 C and once we increased that value to Ta= 40C we reach better maximum outlet temperature Tout = 79 C which is a rise of 30 C .

5.3. conclusion

This work allowed us to study the effects of some parameters on drying and specify the most influential parameters and after this evaluation and study , it was determined that an average of 5 kg of mint leaves could be dried in only 13 hours and gives 1.6 kg of dried mint. With the ability of increasing this amount by scale-up the solar dryer by adding other dyers. In this way, a larger system can be developed to process more products in the same time period. It is also expected that the drying time could be reduced by controlling the mass flow of air. hence ,This would potentially increasing the drying rate.

The solar collector can also be modified to evaluate more effective designs. Like expanding the area of the collector , and reduce the losses from the sides and from the bottom by using a good insulation material . The solar dryer can also be modified to incorporate a direct radiation component in the top portion of the drying cabinet. Which to absorb more solar irradiation.

General conclusion

Solar energy has an enormous potential for different applications , solar drying we employed in our study might stand as an example; it is easy handling and suitable for rural areas especially in Algeria where the majority of the farmers have limited resources and are not able to afford the expensive drying equipment's , and they do not have the adequate storage ability to preserve the food from losses and decay, these losses have many negative impacts on the environment since food waste ends up in landfills and produces a large amount of methane which is a more powerful greenhouse gas than even CO_2 , the losses have also a negative impact on the national economy.

In order to overcome this situation, thinking about investing in solar drying has become more than necessary .The recent years have witnessed an ever-increasing political support for renewable energies both at the national and international level.

The main object of our work has been to study the technological and economic performance of an indirect solar dryer in Bouira city in Algeria and that has allowed us to study the effects of some parameters on drying and specify the most influential parameters in the drying process like mass flow of air , irradiation , and climate parameters in order to reach a better drying rate and quality of the product to be dried and develop the most appropriate solar dyers which would be suitable for the Algerian climate and give a greater quantity and a better quality . And it is necessary to indicate that the results obtained and represented by the different curves and economic study according to the studied model are very good and promising results.

For the future prospects and the enhancement on our solar dryers we will add a backup heater using LPG to ensure the operation during the cold season and the cloudy weather , design a solar dryer with PV ventilated to accelerate the movement of mass flow of air through the solar dryer in order to increase the drying rate , and mix three solar collector in one solar dryer to increase the outlet temperature and the efficiency of the drying .

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