December 5 6 7
ICEUBI2017
University of Beira Interior
Faculty of Engineering Covilhã | Portugal
International Congress on Engineering
A Vision for the Future

Experimental study of a photovoltaic solar dryer

Tiago Grilo - t_grilo@msn.com
Engineering Faculty, University of Beira Interior
Luís Pires - pires@ubi.pt
Engineering Faculty, University of Beira Interior
Pedro D. Silva - dinho@ubi.pt
Engineering Faculty, University of Beira Interior
José Nunes - jnunes@ipcb.pt
Agriculture School, Polytechnical Institute of Castelo Branco

Abstract

This experimental work focuses specifically on the development and construction of a prototype and the study of different strategies to optimize food drying from solar energy. The main study variable is the efficiency of the solar dryer. In order to optimize the system and increase the drying rate it was decided to use a photovoltaic panel which will power a resistive load - thus obtaining higher air temperature which enters the drying chamber. First, are shown some considerations about the range of applications and methods of harnessing solar energy, emphasizing how important it is to conserve food products through solar drying. To elucidate this concept existing models of solar dryers are reviewed, highlighting the most efficient and representative of each category, in order to understand the work already developed in this area. All experimental results were obtained in drying trials during the summer of 2016. These results demonstrate the advantages and disadvantages of each strategy adopted. Calculations were made and performance parameters discussed, allowing to take conclusions about the modus operandi and design of this type of units. In order to benefit the most of the energy generated, and thus reduce waste, certain measures have been identified that promote the correct use of PV panels for drying agricultural products. All of this work is for the purpose of being adopted by local farmers.

Keywords

Solar dryer; Dryind methods; Photovoltaic energy

Experimental study of a photovoltaic solar dryer

I. Introduction

Alternative techniques to bring solar energy to different applications are quite old. The industry has made available to society the technology needed to convert solar energy into electrical energy for many years. Currently, in this period of polluted and salty environment, we have to be aware of the need to preserve the environment. It's in this combination of concerns that we must use the solar radiation available every day with notoriously energy goals.
The developed world as we know it, is based on compulsive consumption of fossil fuels taken from reservoirs made millions of years ago, since the Industrial Revolution in the 18th century. However, this extraction and consumption have a cost: the emission of toxic gases into the atmosphere. On the other hand, the production of electricity using solar radiation reaching the Earth's surface after traveling 150 million kilometers, has no such disadvantage [1].
A known fact about the less developed countries is that they face severe energy problems and therefore face obstacles in the conservation of their agricultural products. This lack of energy creates more poverty jeopardizing the preservation of food. This difficulty may be, by far, eased by using solar energy avoiding a possible waste of food products which are easily perishable. Consequently, the rationalization of food sources is critical. With this purpose handcraft processing methods and food preservation have been optimized in the last decade.
The sun that shines 250 days a year in Portugal, providing more than 3000 hours of natural light is an excessive source of energy. Solar drying is an ancient practice of low cost food preservation and, being agriculture a seasonal activity, obtaining food converges at certain times of the year. Thus, the relationship between agriculture and technology must be considered in a broad sense [2].
The foundation of the future sustainability of the planet is subject to decisions taken deliberately nowadays. Future generations must take into account the current levels of pollution; choosing renewable energy instead of fossil fuels is essential. In this sense, it's crucial to take advantage of the electricity from renewable resources [3]. However, regarding to PV panels, the technical documentation to help understand, design and implement a secure solar dryer with a PV system is scarce. This gap includes a range of intelligible reasons that served as motivation for this scientific work.
Within this context, the main goal of the present study is to evaluate the performance of a solar dryer under different conditions from the outside environment and therefore it was necessary to build an experimental prototype. This achievable project allows us to assess the process of photovoltaic solar drying so that later on it's possible to improve it.

A. Food Drying

The use of radiation from the sun for drying methods is one of the oldest applications of solar energy. This process has been adopted since the dawn of humanity with the purpose of preserving food. Furthermore, drying was employed in other useful materials such as animal skins and building materials. This energy source was the only one available to man until the discovery and use of wood and biomass.
The solar dryers are usually small capacity equipment and they're based on empirical knowledge. The majority of these projects are mainly used for drying various food products, whether in small remote communities, whether in industrial production of small-scale [4].
The process of drying food products is a challenging task and difficult to achieve due to the different structural characteristics of these products. Removing the water from the food products has to be done without compromising their physical and chemical properties in view of their final quality. To achieve the desired product quality, we must understand fully the existing methods of drying and all the related concepts.

B. Drying Methods

Agricultural products are indeed sensitive to drying conditions. The solar drying must be performed with caution so it does not affect the product's color, flavor, texture and nutritional value. That said, the selection of drying conditions is of utmost importance.
The modus operandi of solar dryers is based on a principle of mass and heat transfer designated convection, whereby water is forced to evaporate and this steam is removed by natural or forced convection. Once a mass amount of a fluid is heated, the respective molecules move rapidly, increasing the total volume. The principle of convection is explained by the upward movement of this less dense mass inside the fluid that fills the position of the masses which have a lower temperature. The densest fraction of the fluid, and obviously colder, moves to the bottom filling the position which was earlier filled by the portion of previously heated fluid. These formed currents, of natural convection, support the circulation fluid since this process is repeated several times [4].

C. Solar Dryers Classification

The solar dryers that have been designed and developed are characterized by various forms and designs. The choice of a drying method depends on the type of product to be dried, the availability of the same and the total cost of the system. Various methods of dehydration and different types of dryers are commercially available for drying a wide variety of food.
Solar dryers can be classified in various ways as shown in Figure 1. Regardless the classification and categorization of the drying technology, the application of a particular drying technique depends on the type of food and its characteristics. Usually, the choice of the type of solar dryer and the drying method is highly dependent on the capacity, efficiency and investment cost [5]. The solar dryers are divided into two main categories:

- Active dryers;
- Passive dryers.

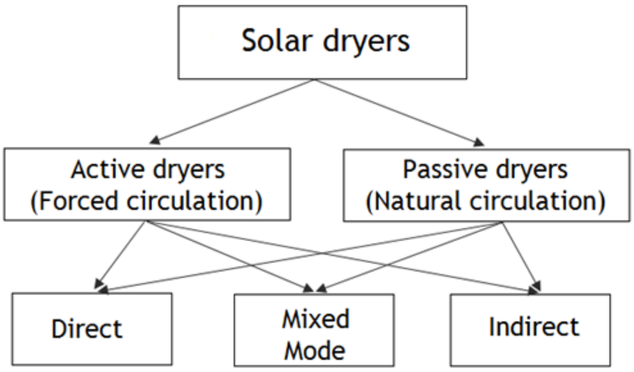

Figure 1 - Classification of solar dryers according to Leon et al. (2002)

In active solar dryers, with forced circulation, the hot air flows through a fan that is usually powered by small PV panels. In this moisture removal process, there's a greater temperature control and air flow that is forced out to the outside. In active dryers, the drying process is pretty fast and does not require large areas to place the products. Usually, foods are distributed vertically in separate trays in order to increase the system's capacity. Therefore, solar dryers with forced circulation are suitable for large quantities of agricultural products [6].
On the other hand, the natural drying consists on placing the food exposed to the sun inside a chamber capable of retaining heat. This method has become quite economical when compared with solar dryers with forced circulation. The fact that a fan is not necessary, doesn't lead to an energy consumption and thus there's no complex equipment attached.

However, this method is slower and it requires large areas to expose the product to dry, as in the specific case of these dryers, gravity is presented as the only force responsible for convection currents [7]. Another factor to take into account is the weather conditions of the site. The climate is important since, as mentioned above, to obtain a final product quality we have to control the physical and chemical properties of the product to be dried.
In direct sun drying, the agricultural products are exposed for longer times to solar radiation under the prevailing conditions. This method proves to be very time consuming and the possibility of contamination due to micro-organisms and insects is higher. However, there is another type of direct solar dryers in which the product to be dried is usually within curtains, greenhouse, or in glazed boxes. Thus, the product is heated by solar radiation and the humid air is removed by the movement of the ambient wind. These dryers have accelerated the rate of moisture loss and the product is safe from the weather. In indirect drying systems for air heating it's possible to use various energy sources making the use of fans advantageous. In addition, developed mixed solar dryers have been developed that use both the principles of direct and indirect dryers.

II. Experimental Setup

Photovoltaic systems, as well as other energy production systems, are based on principles of operation and interface with other electrical systems that are also guided by well-established norms and electrical standards.
Although a PV panel produces electricity when exposed to solar radiation, a number of other components are necessary to conduct, control, convert, distribute and store the energy produced by the panel.
Depending on the functional and operational requirements of the system, the necessary specific components include extremely important elements such as a power inverter DC-AC, batteries and charge controllers. These installations are composed essentially by four main components:

- 250Wp Polycrystalline PV panel;
- MPPT Charge Controller 75|15;
- Electric resistance – 295Ω;
- Gel Deep Cycle Battery 60Ah – 12V;
- Inverter 12V – 180VA.

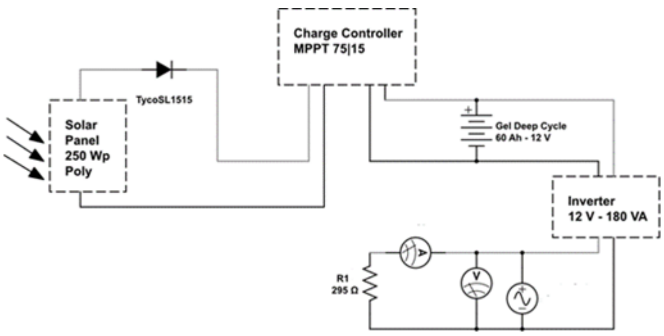

Figure 2 - Electric circuit of the assembling of all the components used

A. Prototype

The developed prototype is based on the concepts of existing solar dryers. In order to promote the circulation of hot air, two air vents were attached to the upper area of the dryer, as shown in Figure 3.

Thus, the hot air after releasing heat in the drying chamber is expelled by convection forces, thereby renewing the hot air inside the solar dryer. Furthermore, the renewal of the air in the drying chamber is held at the bottom of the dryer through an adjustable rectangular aperture through which cold air enters from the outside. Consequently, it ensures the air circulation throughout the entire process, promoting the drying of agricultural products. The solar dryer was dimensioned by modules and attachment systems. Thus, it's possible to adjust the input section of the air.
The developed photovoltaic solar dryer is unique in the heating circulating air – when the air enters the solar dryer is heated by the heat released by the electric resistance placed in the middle of the route, powered by the PV panel.

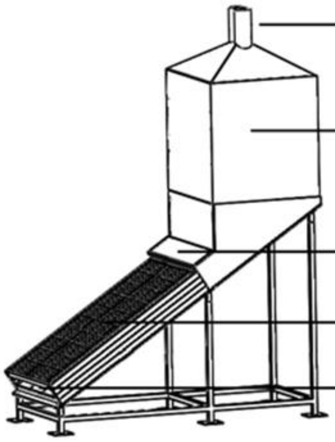

Figure 3 - Solar dryer prototype

Although it may seem logical and rational to build large solar dryers it was not possible to do it. One of the biggest obstacles is the complexity related to transport and installation of such systems [8]. Therefore, the prototype was built from pre-established sizes from the respective material industry. The project took into account the proportions that allowed the use of these materials with the least possible losses based on the standard maximum dimensions of the insulating material manufacturers, MDF boards, profiles, photovoltaic panel, etc.
All the objects exposed to radiation from the sun heat up by absorbing the incident energy. That said, the heating process will be as fast as less reflective the surface exposed to solar radiation is. Subsequently, the structure has been painted black to absorb the maximum radiation, as shown in Figure 4. Of all the colors, matte black is characterized by absorbing large amounts of energy [8].
This prototype presents some peculiarities when compared to similar solar dryers. As for its size, the dryer was designed and built with 2.5 meters long, 1 meter wide and 3.5 meters high. At the top is characterized by having two circular chimneys with 120 mm in diameter that differ according to the drying method intended to operate. For natural convection is used the chimney with the butterfly valve to regulate the air flow. On the other hand, the remaining chimney has a fan inside intended for forced convection.
The process of food drying is made inside the drying chamber with the purpose of avoiding undesirable variations from solar radiation and therefore obtaining a final product of quality.

Figure 4 - Solar dryer before and after the painting

The developed prototype is considered a passive and indirect solar dryer operating in natural convection as shown in Figure 9. Although there's a chimney with a fan, it was not used in these experiments.

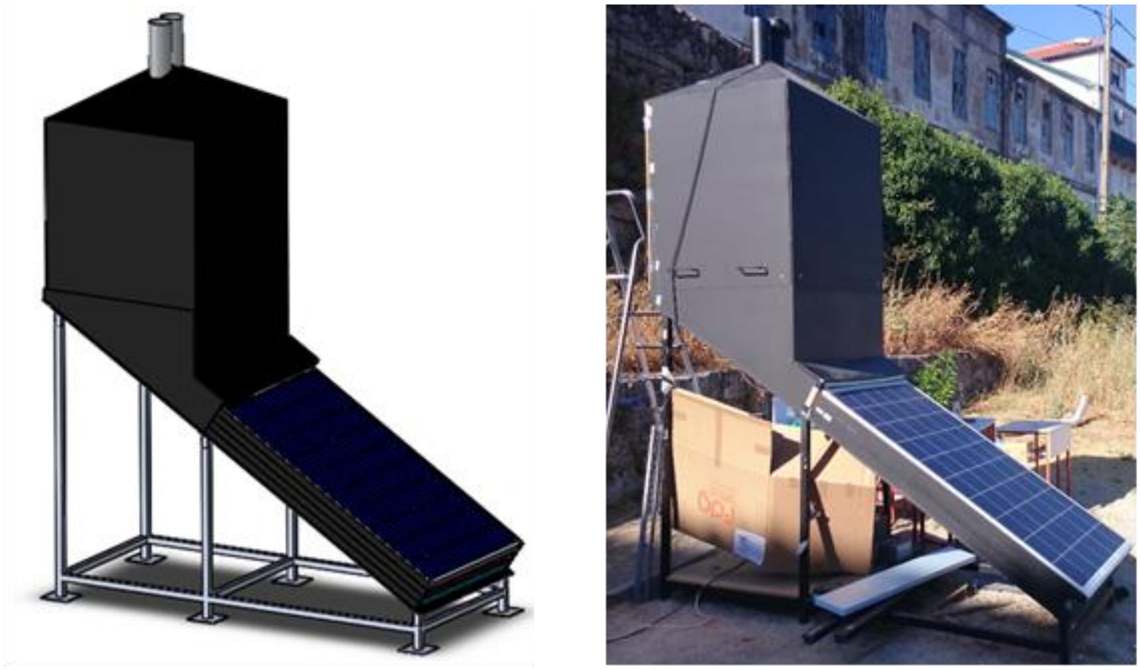

Figure 9 - Concept dimensioned in SolidWorks^{TM} and the final design of the solar dryer

III. Results and Discussion

The scope of the experimental study is to conduct experiments with different values of power in order to understand the behavior and the influence of different values applied to the electrical resistance and the respective role in heating the circulating air inside the solar dryer. Thus, the goal is to enhance the prototype through a range of operating conditions and study the energy behavior of the dryer.
Aiming to evaluate the behavior of electrical resistance depending on different values of power were performed four different types of experiments, designated by:

- Experiment 1 – 170W with no load restrictions;
- Experiment 2 – 100W;

- Experiment 3 – 125W;
- Experiment 4 – 150W.

One of the objectives in relation to the performed experimental tests was starting them with similar climate conditions: ambient temperature, solar radiation and wind speed. By extension, it would also be ideal to start the experiments with the same voltage in the battery so that all tests are more credible, making possible a better comparison between the results of the various experiments. The period required for those experiments was initially twelve hours in order to take full advantage of the available solar radiation. However, that was not the case since the battery reached a point in which kept interrupting the power supply to the inverter. Interruptions in the experiments took place between 12h45m and 13:30, lasting forty-five minutes. As one of the objectives of experiments was to study the behavior of the battery depending on the system in low radiation situations, the chosen interval was optimal due to the daily peak of sunlight during this period. Within the range of all the collected data, only the most relevant and pertinent are presented and analyzed. In particular, the ambient temperature, the temperature inside the drying chamber, the battery voltage on different experiments, the values of power applied to the load and the estimated solar radiation on site.

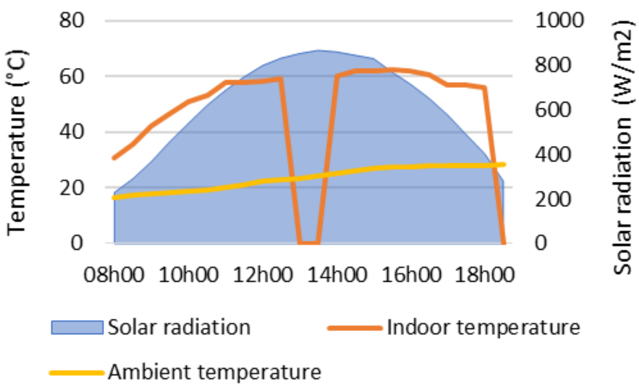

Figure 5 - Experiment 1 – 170W with no load restrictions

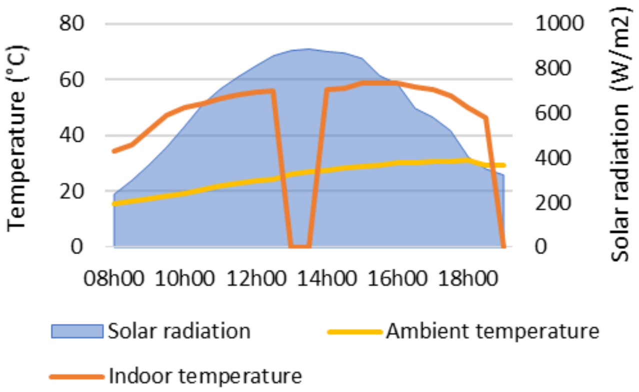

Figure 6 - Experiment 2 – 100W

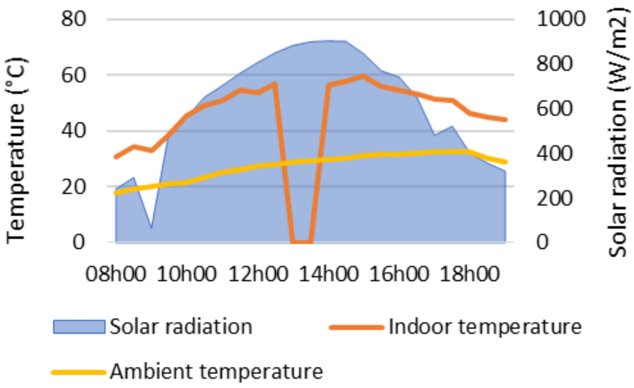

Figure 7 - Experiment 3 – 125W

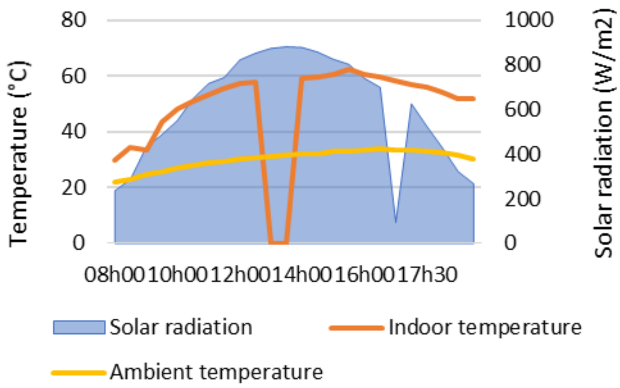

Figure 8 - Experiment 4 – 150W

Regarding to the experimental results, as expected, different values were obtained according on the daily climate conditions and depending on the value of the power applied to the load. Therefore, by analyzing the results, the conditions for the first experiment are ideals and best suited to, for example, dry cherries - a maximum temperature of 63°C was obtained inside the drying chamber.

IV. Conclusion

Different experimental studies made with different methods to dry agricultural products allow to evaluate the differences between them with the purpose to optimize the process of solar drying. However, these four different experiments demonstrate the same conclusion: nowadays, there's no specific solar dryer model without disadvantages regarding to the desired type of drying.

Regarding the types of charge controllers, it's perceptible that the PWM type must be used in systems whose PV panel voltage is similar to the battery voltage. However, that's not the case with the PV panel used and hence the MPPT charge controller was chosen. This charge controller is more sophisticated but more expensive.
The two types of controllers are distinguished by the process they seek the maximum power point of the PV module. The MPPT charge controller does it by adjusting the input voltage in order to collect the maximum energy from the PV panel and then this energy is automatically monitored with the purpose of charging the battery according to the controller algorithm.

Essentially separates the voltage of the battery from the PV panel voltage, so that a 12V battery can be connected to the MPPT charge controller and simultaneously to the panel to produce 36V.

In all scenarios, the production of electricity through the sun will continue to rise. The increase in energy consumption worldwide leads to the indispensability of using renewable energies. The use of technologies related to renewable energy contributes to the production of clean, safe and affordable electricity. The need to achieve the goals imposed by international agreements regarding emission reductions and the increasing of environmental concerns should propel this technology to become more established as a marketable and economically viable product.

References

[1] Benito, T. P., *Práticas de Energia Solar Fotovoltaica*, Engebook, 2009.
[2] Ferreira, J., *Agricultura e ambiente - A agricultura biológica*, Agricultura e Ambiente - O Futuro, Direção Regional de Agricultura e Pescas do Centro, 1995. http://www.drapc.min-agricultura.pt/base/documentos/agricultura_ambiente.htm (25/02/2016).
[3] Morais, J., *Sistemas Fotovoltaicos da Teoria à Prática*. Engebook, 2009.
[4] Kumar, A., et al., "A Survey on the Design, Fabrication and Utilization of Different Types of Foods and Vegetables Dryer," IOSR J. Agric. Vet. Sci. Ver. I, vol. 8, no. 8 (2015), pp. 2319–2372.
[5] Belessiotis, V., Delyannis,E., "Solar drying," Sol. Energy, vol. 85, no. 8 (2011), pp. 1665–1691.
[6] Sharma, A., et al., "Solar-energy drying systems: A review," Renew. Sustain. Energy Rev., vol. 13, no. 6–7 (2009), pp. 1185–1210.
[7] Eswara, A. R., Ramakrishnarao, M., "Solar energy in food processing—a critical appraisal," J. Food Sci. Technol., vol. 50, no. April (2012), pp. 209–227.
[8] A. Bezerra, *Aplicações Práticas da Energia Solar*, Brasil, 1990.