DryEcoMate – An horticultural dehydrator, using solar thermal and photovoltaic energy, low cost production, modular and portable

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Abstract: *DryEcoMate is a horticultural dehydrator developed through a partnership between the Polytechnic Institute of Setúbal, Synege and Regipomo. It is an energy-efficient, low-cost, modular, and portable dehydrator that works exclusively with renewable energy, namely solar thermal and photovoltaic and can operate independently of the instant weather conditions. To optimize a dehydration process, it is essential to optimize the following factors: Time, Product Quality, Energy Efficiency, Cost and Flavor / Odour. DryEcoMate allows the optimization of these factors by effectively controlling dehydration air temperature and air circulation speed, depending on the type of product to be dehydrated, the solar radiation and outdoor temperature at each time. DryEcoMate allows the use of outdoor air conditions at each moment, optimizing the process by reading the temperature and relative humidity conditions of the outside air, the air at the entrance of the dehydration chamber and the air at the exit of the dehydration chamber as to allow, at each instant and through the recirculated air / air flow mix, the control system to optimize the operating conditions of the equipment. DryEcoMate is a lightweight mobile device that allows to be moved and placed in the position that best suits it and allows greater efficiency in operation at all times. This equipment allows its placement in the best orientation at all times depending on the solar time, but also on the location of the production of dehydration at each moment of production. For this, in addition to its lightweight construction, the implementation of 100% swivel wheels allows ease of orientation and placement location. DryEcoMate is equipped with a solar thermal panel, a photovoltaic solar panel, a dehydration chamber, an electric resistance, fans to force air circulation inside the chamber, motorized air dampers actuators / valves, temperature and RH probes and a control system, which allows the equipment to operate under optimized conditions in each instant.*

Keywords: Vegetables dehydration, Solar thermal energy, Photovoltaic solar energy, low cost dehydration.

1. INTRODUCTION

Dehydration is a simple and affordable food preservation method, which consists of removing enough water so that the food can be preserved for a long period of time. There are three key factors for food dehydration to be successful: temperature, relative humidity and air velocity. The temperature should be the most suitable so that the moisture of the food can be removed without running the risk of cooking it. The relative air humidity must be low in order to allow the absorption of the water released by the food. Air velocity shall allow saturated air to be released from the dehydration chamber. Food can be dehydrated using solar radiation, a furnace and also an electric dehydrator, always taking into account that the temperature, humidity and air velocity should be the most appropriate for the type of food. Table 1 shows the different dehydration temperature ranges according to the type of horticultural products

Table 1. Dehydration Temperatures [1]

	Temperature (°C)
Herbs	35
Vegetables	52
Fruits	57

Air velocity is not in itself a determining factor for the dehydration process. Different studies indicate that speeds up to 1.5 m/s are acceptable during the process [2]. However, the relative humidity of the air and the temperature inside the dehydration chamber are directly dependent on the air velocity and so it is a great advantage when there is the possibility of regulating the air velocity.

2. SOLAR DEHYDRATORS

2.1. Operation principle

Solar dehydrators use the energy of the sun to heat the air that will dehydrate the food. As the air is heated, its relative humidity decreases thereby, acquiring a greater capacity to absorb the moisture released by the food. The air circulation in the dehydrator allows the moisture released by the food to be transported out of it. Food dehydration can be divided into two phases: the first stage happens when the moisture that is in the outermost layers of food is evaporated. On a second stage the water in the inner layers of the food has to be transported to the outer layers so that it can be evaporated. Figure 1 relates the rate of the dehydration process to the amount of water present in the food.

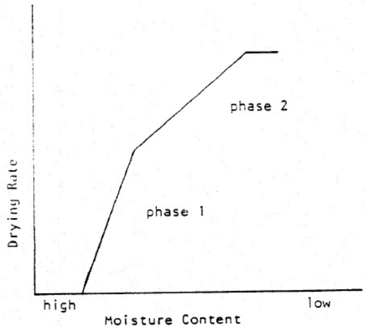

Figure 1. Relation between the rate of dehydration and the amount of water present in the food [3].

2.2. Types of solar dehydrators

Solar dehydrators can be divided into two families, depending on whether there is mechanical circulation or not. Dehydrators without mechanical circulation are referred to as passive dehydrators and those using circulating fans or pumps are called active dehydrators. In the family of passive dehydrators there are still two different types of dehydrators. Dehydrators where food is exposed directly to solar radiation are called direct passive dehydrators, and dehydrators where food is not directly exposed to solar radiation are indirect passive dehydrators. Figure 2 shows the different types of solar dehydrators [3].

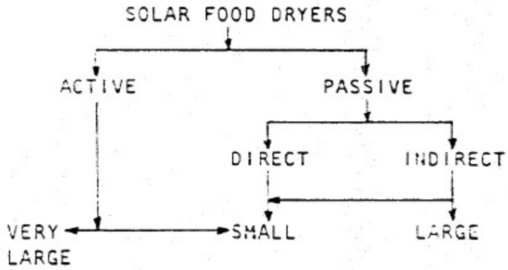

Figure 2. Relation between the dehydration rate and the amount of water present in the food. [3]

In direct solar dehydrators, foods are exposed to direct solar radiation. Typically these devices consist of a dehydration chamber covered by transparent glass or plastic and with openings allowing the entry and exit of air. In indirect passive solar dehydrators the dehydrated food is placed in a well-insulated dehydration chamber. Food dehydration of is ensured by a solar collector, which will allow the outside air to warm up and consequently its relative humidity will drop. In this case, the necessary air movement to the process is ensured by natural convection, and it is imperative that the intake of the outside air is performed at a lower height than the extraction of the indoor air. In active solar dehydrators the circulation of hot air is performed by a small fan, or in larger devices by an air circulation pump. These dehydrators are thermodynamically more efficient and the dehydration process is relatively faster [4]. Its main advantage is that it can be used to dehydrate large quantities of product.

2.3. Possible problems using Solar dehydrators

Dehydrating foods using exclusively and directly energy from the sun can be a time-consuming and unpredictable process as atmospheric conditions are an uncontrollable factor. There is also the "night" factor, since at night there is no solar radiation, the dehydration process can become very time consuming, thus putting at risk the quality of the food in the process of dehydration. So a dehydrator that combines the use of solar energy with another source of energy is the solution that is most interesting for people who want to dehydrate food and do not want to be exclusively dependent on the weather.

3. DRYECOMATE SOLAR DRYER

3.1. General description

DryEcoMate is a horticultural solar dehydrator, using solar thermal and photovoltaic energy, low cost production, modular and portable developed by IPS, Regipomo and Synege. The DryEcoMate Fruit and Vegetable Dehydrator is an energy-efficient, low-cost, modular, mobile dehydrator that works exclusively with renewable energies, namely solar thermal and photovoltaic and operating independently of the weather. However in special conditions it is possible, if the conditions do not allow it, to operate with conventional electric power. As mentioned previously, for an efficient dehydration the key factors to be controlled are Temperature T (ºC), Relative Humidity RH (%) and Air Velocity V (m/s). In this way DryEcoMate has the possibility to control these three factors, two in an active way (temperature and air speed) and another in a passive way (relative humidity).

3.2. Optimization of the dehydration process

To optimize the dehydration process, it is essential to optimize the following factors: Time, Product Quality, Energy Efficiency, Cost and Flavor/Odor. DryEcoMate allows the optimization of these factors by effectively controlling dehydration air Temperature and air circulation velocity depending on the type of product to be dehydrated, solar radiation and outdoor temperature. DryEco Mate allows the use of outdoor air conditions at any moment, optimizing the process by reading the temperature and relative humidity conditions of the outside air, the air at the entrance of the dehydration chamber and the air at the exit of the dehydration chamber so as to allow at each instant and through the recirculated air/air flow mix control system to optimize the operating conditions of the equipment.

3.3. Ecological design and construction

The design and construction of DryEcoMate is 100% ecological and only ecologically clean materials are used. In this way no type of glues, varnishes or toxic surface treatments are used. All types of tightening and fixing are completely mechanical.

3.4. Mobile equipment

DryEcoMate is a lightweight, mobile device that allows you to move and position it in the way that best suits you and allows you to be more efficient at all times. This equipment allows its placement in the best orientation at all times depending on the solar time, but also the location of the production of dehydration at each moment of production. For this in addition to its lightweight construction the implementation of wheels 100% orientable allows the ease its orientation and placement location.

3.5. Equipment Components

The DryEcoMate is modular with a solar thermal panel, a photovoltaic solar panel, a dehydration

chamber, an electric resistance, fans to force air circulation inside the chamber, motorized air dampers actuators / valves, temperature and humidity probes and its control system that allows the system to operate under certain imposed conditions. The following is a brief description of the function of these accessories:
- The solar thermal panel - of its own design and built entirely from scratch guarantees, as long as the climatic conditions allow it, the heating of the air that circulates in the dehydration chamber for drying the products;
- The photovoltaic panel - has the function of charging the batteries that power the dehydrator support devices, namely, the system controller, air circulation fans, electric resistance and motorized actuators/valves;
- The dehydration chamber - consists of several shelves where the products are placed to be dehydrated. On these shelves, the dry and hot air passing through the fruit and vegetable products will dehydrate them;
- The PV fed electrical resistance - this equipment arises with the objective of giving support to the solar panel for heating the air inside the dehydrator. Thus, when the air is not at the set-point temperature, the electric resistance starts, heating the air in its passage;
- Air fans - these devices, which are connected to the control system, allow their speed to be variable. They have the function of forcing, with greater or less speed, the circulation of the air flow inside the dehydrator;
- Actuators/motorized valves - these devices have a coupled register and have as a function to regulate the admission and exit of circulating air in the dehydrator;
- Temperature and humidity probes - have the function of monitoring the temperature and humidity conditions inside the dehydrator, making the equipment devices work in order to guarantee an efficient product dehydration process;
- Control module - this device performs a wide variety of functions that are necessary to control the dehydration process, being the "brain" of the dehydrator. It monitors and controls the inlet, outlet, temperature, relative humidity and velocity of the circulating air.

3.6. Working principle

In order for the drying process to be as efficient as possible, it is necessary to control some variables associated with it, namely air temperature, relative humidity, air circulation velocity inside the equipment and air registers. For this there is the system controller. DryEcoMate's drying method is done by channelling heated air into the dehydration chamber. The renewable energy source used for air heating is the sun, which translates into significant energy savings. The climatic conditions necessary for the good performance of the equipment are relatively high temperatures, moderate wind and low relative humidity. The drying of the food consists of exposing the food in a closed chamber, which has several shelves, where the products are placed to be dehydrated and where there are suitable conditions for a good circulation of heated air with low relative humidity.
This dehydrator is a hybrid because it can operate using renewable energy, without recourse to any conventional energy source or, if the weather conditions are less favourable, to operate using conventional electricity, thus guaranteeing the adequate and necessary conditions for the process of dehydration. The innovation in this equipment consists in using new air circulation or recirculated air depending on the current weather conditions allowing the use of 100% new air circulation or the use of recirculated air depending on the position of the actuators/motorized valves which are positioned in the ideal conditions for the dehydrator to function (see figure 3). In addition to this position of the actuators/motorized valves to achieve the best operating conditions, the fans are also of a variable

speed, allowing the dehydration air velocity to be ideal to achieve the best dehydration conditions according to the user defined objectives: fast dehydration (dehydration time optimization) or slow dehydration (taste/odour optimization of the dehydrated product).

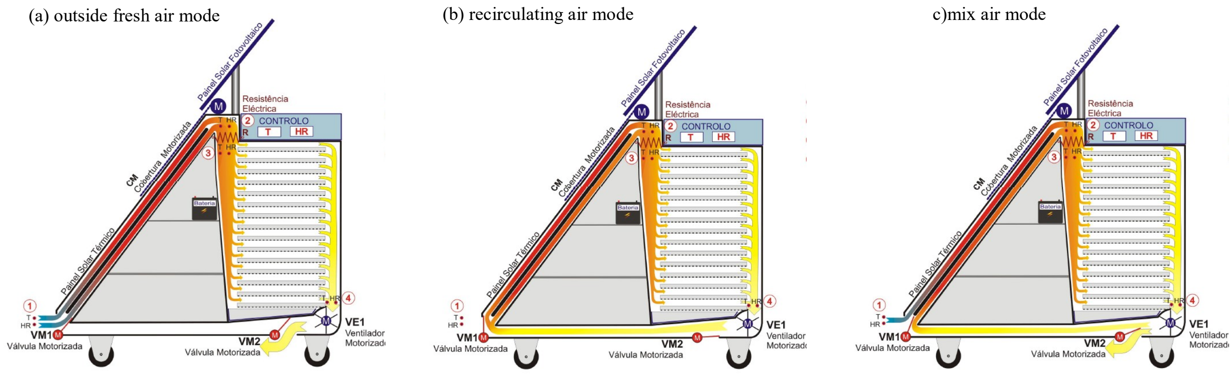

Figure 3 – Operation modes

Conditions for using fresh outside air

Under these conditions, where apparently the climatic conditions are most desirable for the operation of the machine, using only solar energy. Its operation consists of the outside air enters the opening on the lower zone of the solar panel and rises inside the solar panel, by the effect of natural convection, receiving heat from solar irradiation on the panel, and arrives at the entrance of the dehydration chamber. Here the air is forced to descend by the above mentioned effect and by the aid of air fans located in the lower zone of the dehydration chamber, where it is directed outwards. For this condition the air registers are positioned so as to allow air intake at the base of the solar panel and air exhaust (downstream of the air circulation fans). The dampers are driven by two motorized actuators/valves controlled by the system controller. With these conditions the inside air in the dehydration chamber is constantly renewed.

Conditions for using recirculation air

In these conditions there is no new air intake, due to the fact that the outside air temperature is not adequate, so the air recirculates inside the equipment and undergoes reheating when passing through the solar panel. Thus, the air recirculates inside the equipment, rising inside the solar panel, by the effect of the natural convection, receives heat originating from the solar irradiation on the panel, and arrives at the entrance of the dehydration chamber. Here the air is forced down by the aforesaid effect and by the aid of air fans located in the lower zone of the dehydration chamber until it returns again to the entrance zone of the solar panel. In this situation the air registers do not allow air inlet or outlet.

Conditions for using a mix of outside and recirculated air

Under these conditions part of the circulation air is reused, only part of the intake of new outside air being made. The new/circulated air mixture rises through the interior of the solar panel, by the effect of natural convection, receives heat from solar irradiation on the panel, and arrives at the entrance of the dehydration chamber. Here the air is forced down by the above mentioned effect and by the aid of air fans located in the lower zone of the dehydration chamber. In the lower zone the air register is in a position that allows part of the circulating air to be removed from the system, the rest being directed to the entrance zone of the solar panel where it will mix with the new outside air.

3.7. Control system

The dehydrator control system consists of several sensors that monitor the temperature and humidity inside and outside the dehydration chamber, as well as a set of motorized actuators/valves and fans that try to keep the parameters inside the dehydration chamber in optimal values for an efficient dehydration of food. These components are controlled by an Arduino control board, with microcontroller. The temperature and humidity sensors chosen are the DHT22 model. The fan module is composed of 4 associated 12V fans in a parallel serial connection so that they can be controlled by a 24V PWM signal. The heating resistor has a power of 50W with 24V supply. Motorized actuators/valves are powered at 24V with position control determined by a 0-10V analogue input, this control voltage is generated by PWM outputs used as DAC. The hardware control functions were developed using the open source software Arduino IDE 1.6.11. Figure 4 shows the principle scheme of the dehydrator with its main components.

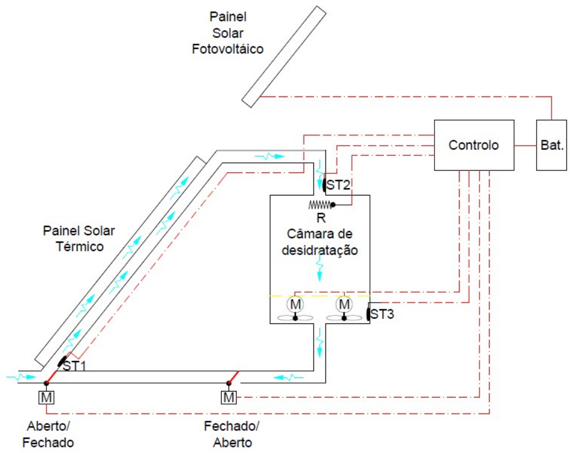

Figure 4 – DryEcoMate Drying Principle Scheme

4. CFD SIMULATIONS

4.1. Overall objective

In order to study and optimize the dehydration process as well as air flow inside the dehydration chamber, a CFD numerical simulation of the drying inside the DryEcoMate dehydration chamber was performed. For the numerical simulations, AnSys Fluent Software [10] was used in order to analyse and optimize the best airflow with in the dehydrating chamber.

4.2. Description of the numerical model

Two-equation turbulence models allow the determination of both, a turbulent length and time scale by solving two separate transport equations. The standard k-ε model in ANSYS Fluent falls within this class of models and has become the workhorse of practical engineering flow calculations in the time since it was proposed by Launder and Spalding [11]. Robustness, economy, and reasonable accuracy for a wide range of turbulent flows explain its popularity in industrial flow and heat transfer simulations. It is a semi-empirical model, and the derivation of the model equations relies on phenomenological considerations and empiricism. The standard - model [12] is a model based on model transport equations for the turbulence kinetic energy (k) and its dissipation rate (ε). The model transport equation for is derived from the exact equation, while the model transport equation for was obtained using physical reasoning and bears little resemblance to its mathematically exact counterpart. In the derivation of the - model, the assumption is that the flow is fully turbulent, and the effects of molecular viscosity are negligible. The standard - model is therefore valid only for fully turbulent flows. As the strengths and weaknesses of the standard - model have become known, modifications have been introduced to improve its performance namely the RNG model [13] -

4.3. Boundary conditions

Given the prototypical nature of the work being developed, the main focus of the numerical simulation was dedicated to the airflow inside the dehydration chamber, this is because, while the temperature is the driving force for the dehydration process to take place, the proper placement and airflow throughout the chamber is what will guarantee an uniform product treatment. This will provide a homogenous final consumable with all its parcels having the same properties and quality. With this in consideration the boundary conditions taken into account in the first set of simulation were Inlet velocity: 0,1 and 2.9m/s, for different cases and Outlet conditions: Outflow.

4.4. Simulation results

The CFD simulation results show the importance of the air flow in the dehydrating chamber and in the dehydrating process. Figure 5 shows some CFD simulation results on the velocity vectors, contours and streamlines in the dehydrating chamber. The results from the CFD simulation lead to some modifications and improvements in the dehydrating chamber, the shelves placement, geometry, in the airflow and in the dehydrating process.

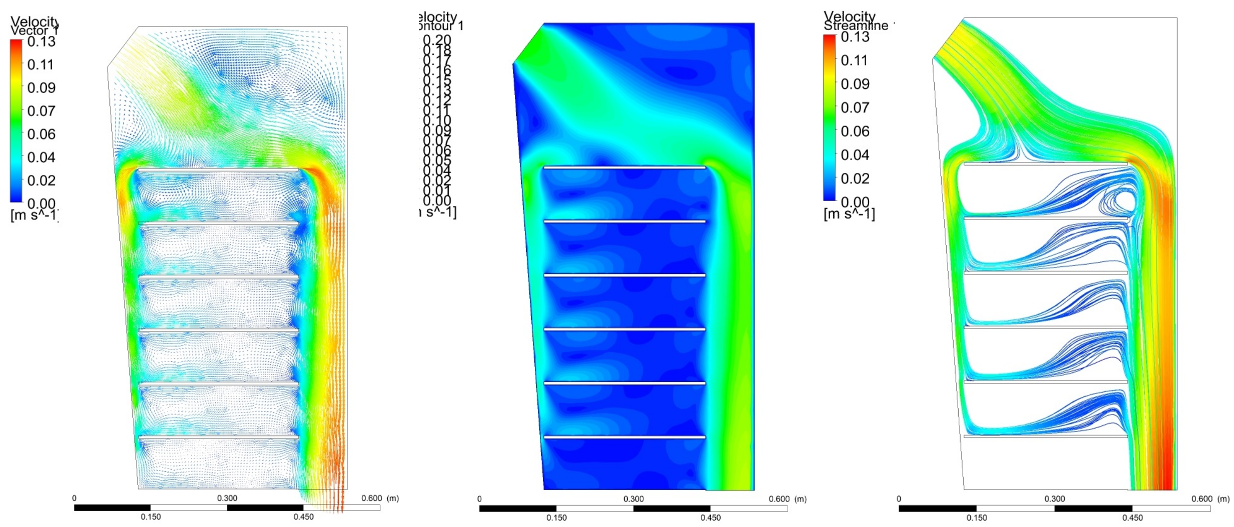

Figure 5. CFD simulation on velocity vectors, contours and streamlines in the dehydrating chamber.

5. RESULTS

Based on the CFD simulations and on the test made on the pre-prototype some improvements on the dehydration chamber were made. The final configuration of the DryEcoMate hybrid solar horticultural dehydrator is shown in figure 6. This figure show a photo of the actual pre-prototype and the correspondent design.

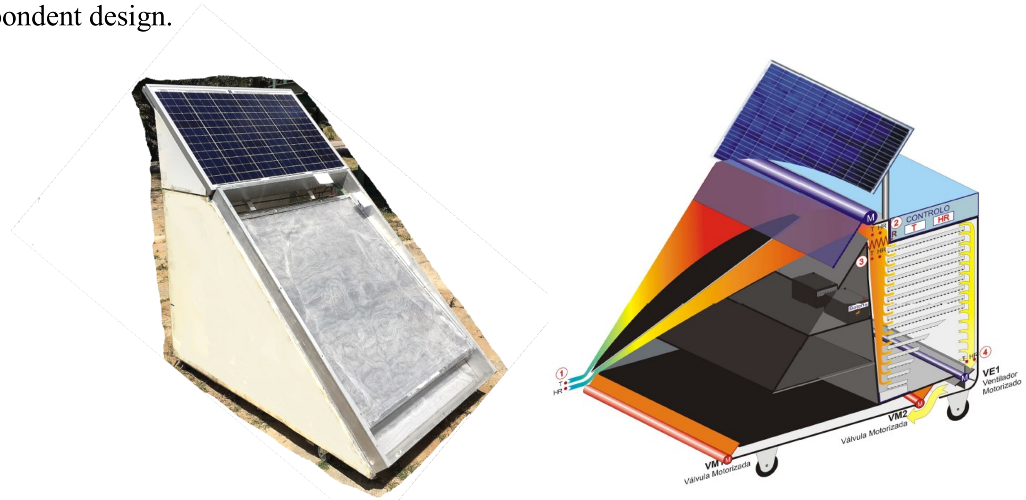

Figure 6. DryEcoMate hybrid solar horticultural dehydrator (photo and design).

After the construction of the DryEcoMate pre-prototype, some tests were carried out on this equipment and horticultural products were dehydrated on it. The dehydrated horticultural products in DryEcoMate have generally presented excellent taste and consistency, and the dehydration time being considerably lower compared to equivalent dehydration made in conventional electric equipment. Figure 7 show some eggplants dehydrated in DryEcoMate

Figure 7 – Eggplants dehydrated in DryEcoMate

6. CONCLUSIONS

The horticultural dehydrator DryEcoMate developed through a partnership between the Polytechnic Institute of Setúbal, Synege and Regipomo was presented. The objective was to develop an energy-efficient, low-cost, modular, and portable dehydrator that works exclusively with renewable energy, namely solar thermal and photovoltaic and can operate independently of the instant weather conditions.

It was verified that to optimize a dehydration process, it is essential to optimize the following factors: Time, Product Quality, Energy Efficiency, Cost and Flavor / Odour. DryEcoMate allows the optimization of these factors by effectively controlling dehydration air temperature and air circulation speed, depending on the type of product to be dehydrated, the solar radiation and outdoor temperature at each time.
The develop of DryEcoMate allows to use of outdoor air conditions at each moment, optimizing the process by reading the temperature and relative humidity conditions of the outside air, the air at the entrance of the dehydration chamber and the air at the exit of the dehydration chamber of so as to allow at each instant and through the recirculated air / air flow mix control system to optimize the operating conditions of the equipment.
DryEcoMate is a lightweight mobile device that allows to be moved and placed in the position that best suits it and allows greater efficiency in operation at all times. This equipment allows its placement in the best orientation at all times depending on the solar time, but also on the location of the production of dehydration at each moment of production. For this, in addition to its lightweight construction, the implementation of 100% swivel wheels allows ease of orientation and placement location.
The performance of CFD numerical simulation using Fluent Ansys permitted to optimize the design configuration, especially the dehydration chamber, based on the best air flow and heat transfer.

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