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Experimental Analysis of the Thermal Behavior of a Dual Solar-Biomass Tunnel Dryer Type "Hohenheim" for Aromatic Plants

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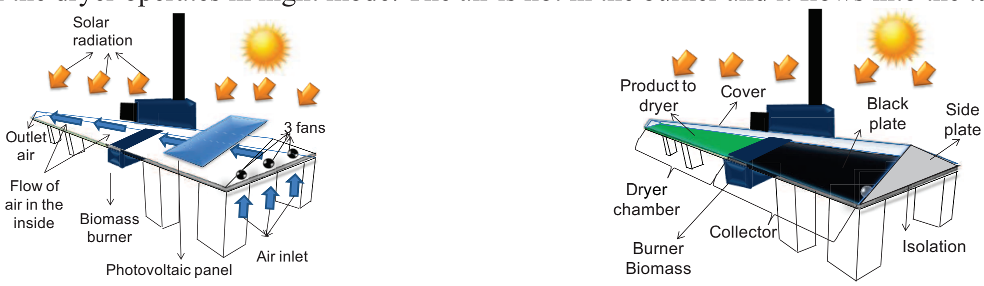
Introduction

The traditional way of reducing the moisture in a harvest is to dry it in the open sun, so it is expanded and dehydrated as it receives direct solar radiation. However, in this process the harvest is often exposed to dust, rodents, insects, birds, rain and wind that might damage the product. At the industry level, these problems are corrected by using solar dryers of chamber that protect the harvest of environmental phenomena and pests. They improve the quality of the harvest and reduce the moisture to lower levels that the ones achieved with the open sun method. In this paper we study a solar dryer type Hohenheim built in Colombia that preserves final product properties such as color, vitamins, fragrance and essential oils. The design was developed in Germany during 1980s and has been tested in over 30 countries (DONOGHUE ET AL., 2015).

Characteristics of the tunnel dryer type Hohenheim

The tunnel dryer is located in a town near Bogota, Colombia. It has four components: a) a photovoltaic panel that receives the solar radiation. It supplies energy to move three fans located in the inlet inside the plate (BALA ET AL., 2005). The air passes through the tunnel dryer and is expelled; b) a solar collector (Figure 1b) that has the function of increasing the air temperature over room temperature. The hot air outside the collector is used to dehydrate the product in the dryer chamber; c) a dryer chamber in which the product loses vapor water (Figure 1b); and d) a biomass burner that operates in periods of cloudiness or when the dryer operates in night mode. The air is hot in the burner and it flows into the tunnel dryer.



(a) Air flow. (b) Components.

Figure 1. Tunnel dryer type Hohenheim

Materials and methods

The tunnel dryer type Hohenheim with the modification of a burner biomass has the following features. The dryer chamber has an area of 20 m², the inlet air hot of the burner biomass has an area of 1 m², the collector has an area of 12.6 m² and there is a transition area of 2.4 m². Every fan and photovoltaic panel has a potential of 80 W. There are 3 fans and 3 photovoltaic panels.

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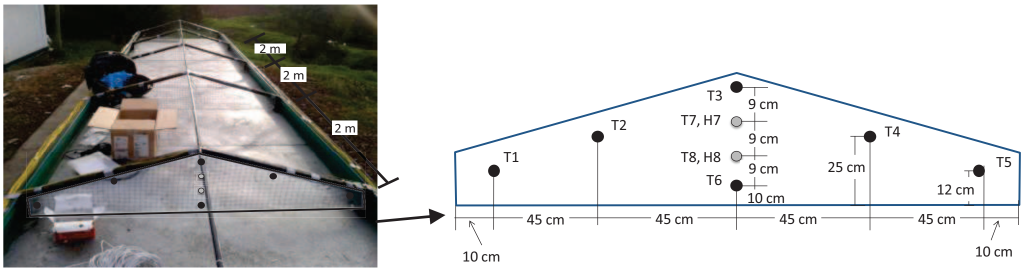
The following instrumentation was used to do the measurement; a module for Agilent 34970A data acquisition, connected to 60 type K thermocouples (accuracy 1 ± °C), a micro-controller board Arduino Uno, a Lenovo G470 laptop computer, a Samsung laptop computer, a solar radiation sensor SP Lite 2 (accuracy ± 0.2%), 5 sensiriom SHT71 sensors to measure humidity and temperature (accuracy ± 3% RH and 0.4 °C), a temperature and humidity sensor data logger (accuracy ± 3% RH and ± 0.5 °C), current clamp brand EXTECH EX 480 (accuracy 0.5±%), thermo anemometer brand Alnor AVM 440 (speed accuracy ± 3% and 0.3 °C temperature) and thermometer fluke 54-II (accuracy 0.5 ± %).

The data acquisition module Agilent 34970A Data was used as the interface of the computer Benchlink Data Logger software in which the measurement intervals can be programmed and the readings can be checked in real time. This software was used to take readings of 60 type K thermocouples continuously for a period of 50 hours. The temperature profiles were measured using 9 nets placed along the tunnel dryer. There were 6 nets installed in the dryer camera (Figure 3), with 2 m distance from one to the other (Figure 4b). There were other 3 nets installed in the collector: one was 2.6 m long and the other was 3 m long. The sensor was located in the vertical net as presented in Figure 2.



a) Net installed every 2 m   b) Horizontal view of the tunnel dryer

Figure 2. Installation of temperature sensors in the dryer chamber.

Energy efficiency

One of the objectives of the energy efficiency is to reduce energy consumption to identify the variables of the process. The two main components of the dryer are calculated. They are the collector and dryer camera. The collector efficiency is defined as the relationship between the inlet and outlet energy. The energy input is calculated as the total solar radiation in the area collector (USUB ET AL., 2008 AND CHOWDHURY ET AL., 2011) and the photovoltaic module. The outlet energy is calculated as the gradient temperature generated by convection of the air, for the value of specific heat and the mass flow (USUB ET AL., 2008 AND CHOWDHURY ET AL., 2011), as it is presented in Table 1.

Table 1. Experimental results

Parametric	Equation	Parametric	Equation
η_{col}	$\dot{Q}_{u,sal}/(I_{col}A_{col} + I_{panel}A_{panel})$	η_{sec}	$\dot{Q}_{T,sal}/(I_{sec}A_{sec} + \dot{Q}_{u,sal})$
$I_{col}A_{col}$	$A_{col}\int Sr(t)dt$	$I_{sec}A_{sec}$	$A_{sec}\int Sr(t)dt$
$I_{panel}A_{panel}$	$A_{panel}\int Sr(t)dt$	$\dot{Q}_{T,sal}$	$\dot{m}_r L_g$
$\dot{Q}_{u,sal}$	$\frac{\int \dot{m}(t)C_p(T_{col,sal} - T_{col,ent})dt}{\Delta t}$	η_T	$\frac{\dot{Q}_{T,sal}}{I_{col}A_{col} + I_{panel}A_{panel} + I_{sec}A_{sec}}$

Results and discussion

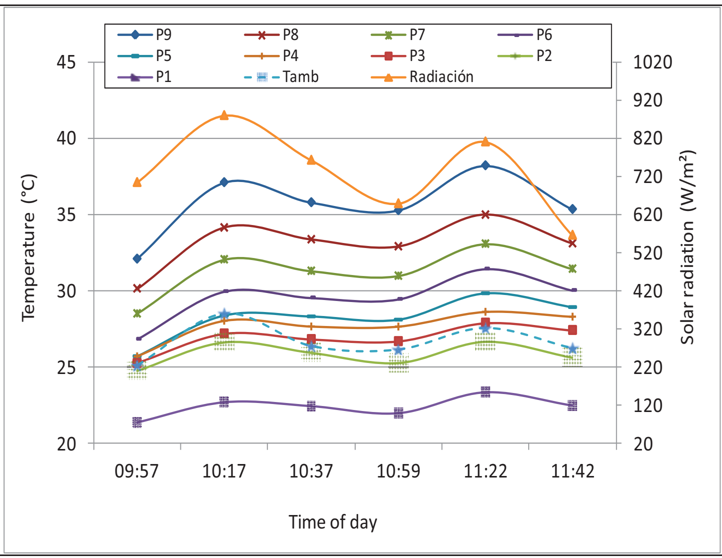
The anemometer measures the air velocity of the fans every 30 seconds as shown in Table 2. The velocity was adjusted according with solar radiation (Equation 1). The fan velocity ranged from 0 to 13.43 m / s. Solar radiation varied from 0-1164.18 W / m; relative humidity ranged from 6.5% to 81.5%; temperatures at the collector were between 11.69 ° C and 79.02 °C, and the drying chamber between 30 °C and 69.5 °C.

$$V = mR + b \tag{1}$$

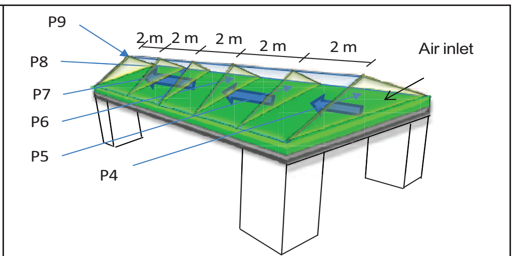
Table 2. Mathematical model of the velocity of the fans

Fan 1		Fan 2		Fan 3		Location
m	6,40e-03	m	0,0183	m	0,0186	
b	4,688	b	2,226	b	2,845	
R-squared	0,941	R-squared	0,921	R-squared	0,778	

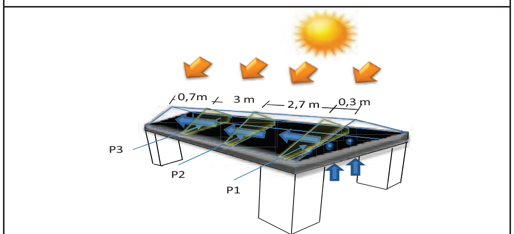
The temperature profiles measured made it possible to observe the variations in solar radiation. Temperature values were averaged to 6 sensors in each net (Figure 3b). In the drying chamber, the aromatic plants received the flow of air passing parallel to the product; the Figure 3b shows that the solar radiation received is more significant than the covered temperature that is lost by evaporation effects of aromatic plants. The outlet temperature of the solar dryer increased at an average of 8 °C for a distance of 10 m (Figure 3a). The same time interval values were averaged for temperature. Figure 3c shows the location of each net in which the measurements were taken. It was found that the average temperature decrease was 4.26 °C; this was due to the assumption that the air volume in the transversal area is about 3 times major than the volume entered by the fans. In the first section of the collector, temperature increases at an average up to 3.45 °C (P1 and P2 sensors) and in the second part temperature increases at an average of 1.03 °C (sensors P2 and P3) but the temperature is lower because in this section there is a shadow projected in the biomass burner.



a) Temperature inside



b) Temperature profile of the drying chamber



c) Temperature profile of the collector

Figura 3. Solar dryer tunnel.

In Table 3, the summary of the parameters of dryer when the dryer tunnel operates with solar energy is presented. The water vapor removed is 3.81 kg/h. The total power produced is 2567,96 W. The total useful power is 2335.58 W. The power absorbed by the collector was 9258.1 W. The power absorbed by the dryer chamber was 14 695.4 W. The power absorbed by the photovoltaic panel was 1430.6 W. The collector efficiency was 21.85 %. The chamber dryer efficiency was 15.1%; and the total efficiency was 10.11 %. The efficiency collectors found in the literature vary between 27.5% and 61.62% (BANOUT ET AL., 2011), and the chamber dryer efficiency varies between 32 y 65.3%. The comparison between this dryer with others found in the literature let us state that this dryer can be improved.

Tabla 3. Tunnel dryer experimental values

Parameters	Value	Unit	Parameters	Value	Unit	Parameters	Value	Unit
m_r	3.81	kg/h	$I_{col}A_{col}$	9258.1	W	η_{col}	21.85	%
$Q_{T,sal}$	2567.96	W	$I_{sec}A_{sec}$	14695.4	W	η_{sec}	15.1	%
$Q_{u,sal}$	2335.58	W	$I_{panel}A_{panel}$	1430.6	W	η_T	10.11	%

Nomenclature

Símb.	Term	SI	Símb.	Term	SI
$\dot{Q}_{T,out}$	Total power produced	W	$\dot{m}$	Air mass flow	kg/h
$I_{col}A_{col}$	Input power collector	W	t	Time	S
$I_{panel}A_{panel}$	Input power of the solar panel	W	T_{out}	Outlet temperature	K
$Sr(t)$	Radiación solar	$W\ m^{-2}$	T_{int}	Inlet temperature	K
$I_{dry}A_{dry}$	Input power of the drying chamber	$\frac{\text{kg}}{\text{s}}$	C_p	Specific heat of air	$\frac{\text{J}}{\text{kgK}}$
$\dot{Q}_{u,out}$	Useful power produce	W			

Conclusions and Recommendations

The temperature increment by solar radiation absorbed for the cover in the dryer chamber is more significant than the lost hot by evaporation in the dryer chamber. The model adjusted allowed to calculate the velocity change in terms of solar radiation. It was found a temperature decrease to the collector inlet, and therefore a recommendation is to install a fan at the exit of the dryer in order to reduce heat losses. There was a shadow over the biomass burner and the dryer chamber and they could not be moved for their size and the transport costs. For the next experimental work, it is recommended to place the dryer tunnel from east to west in order to avoid this. Besides, the biomass burner and tunnel dryer are supported in a foundation that was built based on their dimensions which makes measurements more difficult to obtain. The trays in the drying chamber are recommended to be relocated for better heat absorption. It is also recommended to install a thermal barrier to reduce the loss of temperature as well as the bracing system around the tunnel dryer to prevent the loss of energy for convection. It should not interfere with solar radiation.

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