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Experimental Investigation of the Solar Drying and Solar Collector Design for Drying Agricultural Product (Mint)

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Drying is basically a phenomenon of removal of liquid by evaporation from a solid. In the following section an attempt is made to provide a concise overview of the fundamental principles of drying process for agricultural product (Mint). Drying basically comprises of two fundamental and simultaneous processes: heat is transferred to evaporate liquid, and mass is transferred as a liquid or vapor within and the solid as a vapor from the surface. The experimental study is investigated in the Biskra city of Algeria for drying mint in the drying room which it integrated with a solar air collector (new design). We have to spread the produce on a suitable surface and let it dry in the drying room and added the study of thermal performance of solar air collector and trying with three different airflow rates, namely, 0.018, 0.028 and 0.034 kg/s are conducted. Finally, the results have been illustrated with mass water content, product temperature, drying room temperature, outlet temperature in both solar collector and drying room and enthalpy of solar collector and drying room.

1. Introduction

An improved technology in utilizing solar energy for drying agricultural is the use of solar dryers where the air is heated in a solar collector and then passed through products. There are two basic types of solar dryer appropriate for use with agricultural: natural convection dryers where the air flow is induced by thermal gradients; and forced convection dryers wherein air is forced through a solar collector. In this study the drying solar with forced convection. The forced convection solar dryer can be considered as a conventional mechanical drying system in which air is forced through a dried product holder but the air is heated by a flat plate solar collector rather than by more conventional means.
Most developing countries are unable to solve their food problems for then tire population because of the rapidly increasing number of people in their respective territories.
Some research effort to design and develop a forced convection solar dryer using evacuated tube air collector. Their performance was compared with natural sun drying. The results of the present study show that the proposed solar dryer has been greater efficiency, and the moisture content of bitter gourd is reduced from 91% to 6.25% in 6 hours as compared to 10 hours in natural sun drying.
Another work studies an experimental study was conducted to investigate the performance of a solely solar drying system and a system equipped with an auxiliary heater as a supplement to the solar heat (Khalifa et al., 2012). The performances of both are compared to that of natural drying. Beans and peas are dehydrated in a system that consists of two flat plate collectors, a blower, and a drying chamber. Tests with four different airflow rates, namely, 0.0383, 0.05104, 0.0638, and 0.07655 m3/s were conducted. The efficiency of the mixed drying system was found to increase by 25% to 40% compared to the solely solar drying. A best fit to the experimental data of peas and beans was obtained by six exponential equations for the various systems with a correlation coefficient in the range 0.933 and 0.997. Solar drying can be an effective means of food preservation since the product is completely protected during drying against rain, dust, insects and animals. There is a great diversity of designs and modes of operation: forced convection, (Ahmad et al., 2014), Indirect forced convection, (Bahlou et al., 2009), Direct cabinet and indirect cabinet solar dryers, (Banoult et al., 2010). Solar-biomass hybrid dryer enhanced by the Co-Gen technique, (Leon et al., 2008), Greenhouse solar dryers, (Abdullah 1997), Direct solar dryer, (Hii et al., 2006), Heat pumps, (Fadhel et al., 2010), Indirect natural

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convection solar dryer with chimney, solar dryer with greenhouse as collector, solar tunnel dryer (air collector), hybrid solar dryer assisted by evacuated tube collectors, (Jairaj et al., 2009; Chabane et al., 2013), presents a study of heat transfer in a solar air heater by using new design of solar collector. The collector efficiency in a single pass of solar air heater without, and with using fins attached under the absorbing plate has been investigated experimentally the maximum efficiency obtained for the 0.012 and 0.016 kg/s with, and without fins were 40.02, 51.50% and 34.92, 43.94%.

2. Characteristics of wet solids

The water-film solid adheres to its external surface by surface forces. A boundary layer at the periphery of the solid is constituted by air saturated with water, that is to say air containing water. Water vapor at a partial pressure equal to the vapor pressure of water that would be present in a chamber at the same temperature.
Let a mass Mh of wet material containing a mass Me of water and a mass Ms of dry matter:

$$Mh = Me + Ms \tag{1}$$

2.1 Absolute humidity

Authoritarian humidity or moisture content or content (Kgav / Kgas) in dry-based water, where more simply moisture is expressed by liquid contained in the product in relation to its dry mass.

$$X = \frac{M_e}{M_s} = \frac{M_h - M_s}{M_s} \tag{2}$$

2.2 Moisture-based water content

Relative humidity where water content (%), or moisture-based water content is expressed by the mass of liquid contained in the product relative to its wet mass.

$$X_r = \frac{M_e}{M_e + M_s} \tag{3}$$

2.3 Drying speed

The drying rate is the mass of evaporated water per unit of time and per unit area of evaporation of the material. The expression of the drying speed is then written:

$$R = -\frac{dM_v}{s.dt} = \frac{M_s.dx}{s.dt} \tag{4}$$

$$M_v = M_s.dx \tag{5}$$

$$dx = X_e - X_s \tag{6}$$

3. Experimental study

In this study, we focused on agro-food drying, using a solar collector and a drying chamber, which we manually performed in the technological hall of the Department of Mechanical Engineering of the University of Biskra, carried out in the period from February to May 2018.

Figure 1: Experimental setup (solar collector with drying chamber) Figure 2: Holes of inlet solar collector

3.1 Description of the test bench

The experiment bench tests were carried out near the technological hall of the Department of mechanical engineering of the University of Biskra, which is located at the south-east of the Algerian Sahara at 34.5042 ° of latitude, at 5.4447 ° of longitude and at 105 meters of altitude. The experiment site is exposed to the sun.
In our case for the realization of the sensor we had recourse to the design of the following elements:
a. The box: is in the shape of wooden box of multiple type of thickness 15mm which will be used as base for the sensor, its dimensions are 153cm x 83cm x 10cm.
We placed holes 20 mm in diameter along the upper and lower front of the box to enter and exit the air. As can be seen Fig.2.
b. Insulation: Thermal insulation refers to all the techniques used to limit heat transfer between a hot environment and a cold environment, for this we used a good type of polystyrene with dimensions of 147cm x 77cm x 4cm.
c. Characteristic of polystyrene: The thickness of the polystyrene is 4 mm, which makes it solid and of high quality; It retains the temperature for a long time; It supports a temperature up to 100 ° C; It is flammable, with a self-ignition temperature of about 490 ° C.
d. Reflective Film: is a plywood type pad that separates the insulation from the absorber, to avoid affecting the insulation of sunlight concentrated in the absorber, its dimensions are 150cm x 80cm.
e. Characteristic of plywood: Good flexural strength and modulus of elasticity; Resist moisture; Resistant to high temperatures
f. The absorber: The solar absorber is the part of the solar heating system that captures the heat and transmits it to the air (for solar air heating). It acts as a heat exchanger that turns solar energy into heat. We made it in galvanized sheet with the same dimensions as the reflective film.
g. Glazing (Plexiglas): is a material with multiple applications. This thermoplastic, which can be molded by compression, injection, casting, blowing and extrusion, comes in many colors and in many forms (panels, blocks, pipes, bars). Feature of Plexiglas: This very clear material with a glossy appearance has a very high transparency and a higher light transmission than glass (its optical index is 1.49); It is resistant to UV rays, corrosion and atmospheric agents while being much lighter than glass (1.19 g/cm^3 density); Finally, it's very smooth and shiny surface appearance makes it an aesthetic material, even design, that can be used in the fields of construction and furnishing.

3.2 Manufacture of the drying chamber

The room is made of multiple type wood, protected on all sides with good quality insulation. Connect to the solar panel by a pipe, which passes air through holes to distribute this air on the dried product; its dimensions are 80cm x 50cm x 50cm.

Figure 3: Experimental setup of drying chamber

Figure 4: Orifices into drying chamber

Figure 5: Support of the product

Figure 6: Vacuum cleaner for air circulation control

-Orifices: We drilled holes in order to distribute the air on the product and avoid burning it. In our case, we put holes 10 mm in diameter in a square board, 30 cm by 30 cm. As show in Figure (4).
-The grate: Is a support on which the product is arranged, with holes for the removal of water, attached by four rods equilibrated to allow us to weigh the product without removing it (see Fig.5, This grid is characterized by its hardness and resistance to rust.

3.3 Flow measurement

To measure the flow, we used (the vacuum cleaner sees Fig.6, the anemometer and the voltage regulator), to have a link between the voltage and the speed see Tab.1. Use of the debit law:

$$\dot{m} = \rho . V . S \tag{7}$$

Table 1: Adjusting the flow in terms of voltage

Voltage (Volt)	Speed (m/s)	Surface (m²)	Mass flow rate (kg/s)
50	0.72		0.0067824
56	1.12		0.0105504
60	2		0.01884
62	2.63	0.00785	0.0247746
64	3.1		0.029202
68	3.5		0.03297
70	3.7		0.034854

-Preparation for the test: •*Experimental determination:* The dimensions of the collector are: Dimensions (general): 1.53 m x 0.83 m.
-Dimensions (specific): 1.50 m x 0.80 m.
Calculation of the collector surface: -Total area: 1.27*;* -Area (specific): 1.20.
•Dimensions of the drying chamber: -Dimensions (general): 0.80 m x 0.50 m x0.50; -Dimensions (specific): 0.73m x 0.42m x0.39.
Calculation of the volume of the drying chamber: -Total volume: 0.20; -Characteristics of the drying process: We summarized the results of the drying process in the table 2 showing the state of the product before and after drying with a characteristic average, the results are as follows:

Table 2: Statistical results obtained from mint for different flows

m	0.018 kg/s	Before drying	0.029 kg/s	Before drying	0.034 kg/s	Before drying
G	928.43 W/m²		919 W/m²		882 W/m²	
V_{wind}	0.98 m/s		1.36 m/s		1.34 m/s	
T_{amb}	26.86 °C		28.04 °C		32.19 °C	
$T_{e,cham}$	60.69 °C		56.47 °C		57.49 °C	
$T_{s,cham}$	50.29 °C		45.51 °C		48.41 °C	
T_{pr}	41.98 °C	After drying	39.94 °C	After drying	43.34 °C	After drying
T_{cham}	44.47 °C		39.45 °C		43.91 °C	
$\Delta T_{Chambre}$	-10.40 °C		-10.95 °C		-9.07 °C	
M_t	168 g		105 g		120 g	
M_{an}	62 g		39 g		38 g	
M_w	106 g		66 g		82 g	

4. Results and discussion

Figure 7; show the variation of moisture content as a function to total time in minutes according to mass flow rate. We remark that variation its observation in the beginning operation to 150 min and then the curves it's approaching together to when the dry is stable. The dry product of mint doesn't depend of the total mass but relate of the time and the speed dry. Figure 8 show the variation of drying speed as a function of moisture content of the mint according to three mass flow rates with a different total mass of the mint used. We can see the drying speed begin with increase evolution to arrive in the point of deviation when the drying speed attains the values equal to ratio 0.00215, 0.0111 and 0.014 according to ratio moisture content 1.3, 1.7 and 2.17, respectively the total mass of the mint 168, 105 and 120 g. We conclude that mass flow rate of the air comes less versus the drying speed come fast. The global solar radiation it's begins with less power and increase to arrive a maximum value in median sun and then decrease to arrive a minimum value, see Fig.9. We can observe that the global solar radiation takes the maximum value with three days of the tests from 970 to 1025 W/m². This power used in the solar collector for heat air which gives the important temperature of drying chamber. The figure 10 show, the evolution of relative humidity which goes to inlet solar collector, according to three days of the test, we can be seen the maximum variation is in the second days of the test and come minimum with approach in the first and last day.

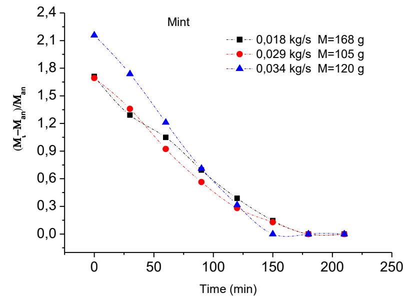


Figure 7: Moisture content of Mint;

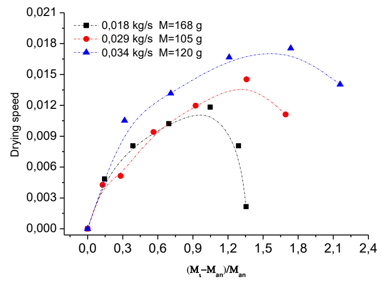


Figure 8: Drying speed versus moisture content of the Mint;

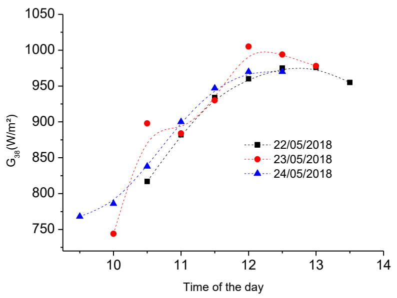


Figure 9: Global solar radiation according;

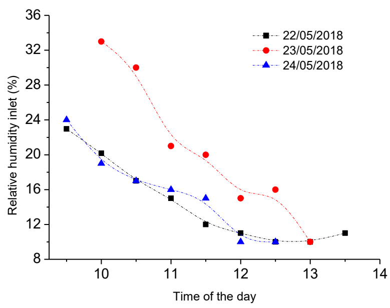
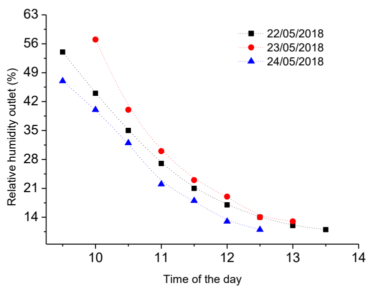


Figure 10: Relative humidity in to three days, respectively the inlet solar collector



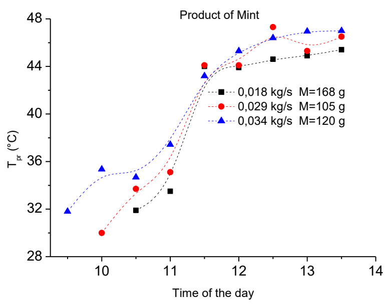
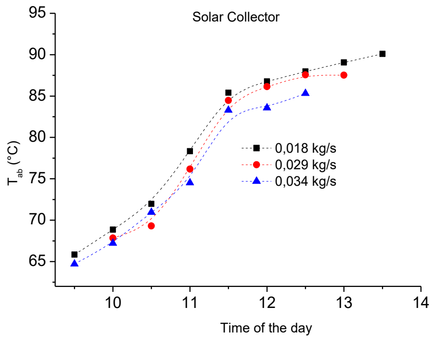


Figure 11: relative humidity in the outlet drying chamber; Figure 12: Temperature of the product of mint in the drying chamber

The figure 11 show, the progression of relative humidity which goes to outlet drying chamber, according to three days of the test, we can be remarked that values come much of the inlet solar collector which means the product out much the wet content and that what I needed to come. In the second days the relative humidity is going with a maximum value which begin with it 59% and the median in the first day with 54%, and a last variation in the last day with a minimum attain 47%. A during the heat air with solar collector which gives this temperature to drying chamber when the product put it inside on the support, under all this we create the source of distribution under the form of orifices in favor of homogenate the heat inside all chamber. In the figure 12, show the variation of temperature of the mint according to time of the day, we can see all the evolution curves begin with a less temperature and then take a more in the median sun time and for after that is stable with fixe temperature. When the mass flow rate takes a much is associating that the product gets a much the heat from air. In this study the heat air come from the absorber plate of a solar collector design see Fig.13, about this point we illustrate the curves of temperature an absorber plate for determinate the action with evacuated air in the streaming of collector to the drying chamber it's necessity for this part. When the temperature an absorber is high implicate that the temperature enters of the drying chamber come much it is important in this test see Fig.14. The evolutions come parallel with variation of global solar radiation effect see Fig.9. The drying chamber receives the temperature from the solar collector which absorbed from sun. The figure 14, show the variation of temperature of drying chamber sensor situated in the centre of the chamber. We remark that the temperature started with low temperature and finish with high temperature according to environment weather outside the experimental setup. The evolution come in versus varying with mass flow rate when lower implicate higher temperature in against come correct.



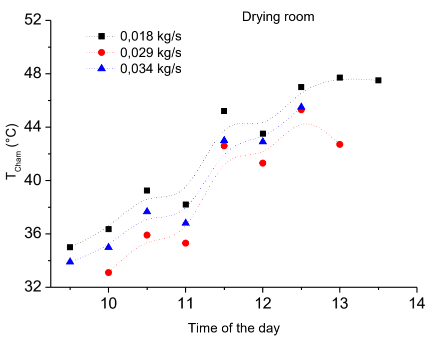


Figure 13: Temperature of the absorber plate of solar collector; Figure 14: Temperature of the drying chamber

5. Conclusions

This work allowed us to study the effects of some parameters on drying and specify the most influential.
It is necessary to indicate that the results obtained and represented by the different curves according to the studied model, are built on real experiments. The increase of the drying air temperature and the decrease of the flow rate, which is the most influential parameter, leads to the increase of humidity levels within the dryer and consequently the reduction of the drying time. For the capture surface, the increase of this factor makes it possible to increase the solar power captured. This leads to the elevation of the air temperature within the sensor allowing a short drying time. Thus, the drying air temperature, the flow rate, the mass of the product, and the solar radiation are important factors in increasing the efficiency of the dryer.

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