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EXPERIMENTAL BANANA DRYING STUDY USING SOLAR DRYER

Alexandre Melo de Oliveira.
André Guimarães Ferreira.
Cefet-MG Centro Federal de Educação Tecnológica de Minas Gerais. Av. Amazonas, 7675 - Nova Gameleira, Belo Horizonte - MG
alexanoliveira@gmail.com; agferreira@deii.cefetmg.br

Cristiana Brasil Maia.
Puc-MG Pontifícia Universidade Católica de Minas Gerais. Av: Dom José Gaspar, 500 Coração Eucaristíco - Belo Horizonte – MG
cristiana@pucminas.br

Joyce Mattedi Gobbi.
Cefet-MG Centro Federal de Educação Tecnológica de Minas Gerais. Av. Amazonas, 7675 - Nova Gameleira, Belo Horizonte - MG
joycegobbi@yahoo.com.br

Breno Raphael Lourenço.
Cefet-MG Centro Federal de Educação Tecnológica de Minas Gerais. Av. Amazonas, 7675 - Nova Gameleira, Belo Horizonte - MG
breno.raphael@yahoo.com.br

Abstract. *Drying is a technique which has been used for a long time for the conservation of food. This single technique consists of removing water or any other type of liquid from a solid material, in the form of steam, through thermal vaporization. Drying of food products has as objective decreasing of humidity levels, an unfavorable environment for the growth of microorganisms, which increases conservation time. Drying can be classified depending on its heating source: solar, artificial or hybrid. Brazil is among the biggest producers of banana in the World, however, post-harvest losses are estimated around 40% of total production. The use of solar dryers for bananas constitutes an interesting alternative, because it uses a renewable source of energy. In addition, Brazil is geographically positioned in a region with excellent availability of solar radiation. The present paper made use of a solar cabin type dryer for the drying of bananas. The experimental analysis was carried varying the charge of the dryer and the convection of air from the drying process, aiming at determining the optimal relation between these parameters, through determination of thermal efficiency and drying efficiency. The thermal efficiency of the dryer without load ranged from 7.4% to 25.7%. The results allowed to define the ideal condition of dryer operation to the banana drying, is at maximum load and minimum mass flow rate of air drying. The highest value obtained for drying efficiency was 18.8%.*

Key words: *Solar drying; Drying of banana; Energy efficiency.*

INTRODUCTION

The use of solar radiation for drying is considered one of the oldest forms of application of solar energy. Drying was used mankind since ancient times, for food preservation and for drying textiles, construction materials, among others. Historically, the first installation of solar energy for drying found in the south of France and is dated about 8000 BC Until the discovery and use of wood and biomass, solar radiation was the only source of energy available to mankind, to the time when small isolated communities around the world started using solar radiation to dry and preserve small amounts of food.

Drying fruit is to reduce its moisture content, contributing to the creation of unfavorable conditions for the growth of microorganisms, reducing weight, increasing the shelf life, reducing the cost of packaging and transport, and energy savings as the final product does not require refrigeration. The dried bananas has commercial value larger than the banana in nature. When the product drying process takes place by means of solar equipment value added to the product is even greater. Brazil is geographically positioned in a region with excellent availability of solar energy, favoring the use of technologies based on this clean energy.

The drying fruit is an important factor to inhibit the growth of microorganisms and also various chemical reactions, allowing better preservation of these products at room temperature, minimizing the susceptibility to decay. Therefore, the final humidity is established with the purpose of obtaining a stable product, without disregarding the sensory quality, which determines the acceptance of the product by the consumer (STRINGHETA et al., 2003).

The process of drying fruits, based on free water withdrawal is one of the most ancient techniques of food preservation and is a technique widely used to preserve fruits, vegetables and even meat. Drying allows preserving food for long periods of time without refrigeration. Besides increasing the shelf life, dehydrated products add greater value to the end product, reduces transportation costs from the reduced mass when compared to the same product in natura.

In developing countries over 40% of food losses occur in steps and post-harvest processing. In these countries, control measures must be taken of the producer's perspective, through appropriate post-harvest techniques in this context solar drying shown an interesting alternative for reducing such losses (FAO, 2012).

Solar dryers have enough versatility being used to dry all kinds of products. Many solar dryers have been developed for drying of agricultural products (Al-Juamily et al. (2007); Sreekumar et al. (2008); Jairaj et al. (2009); Sethi e Arora (2009); Silva (2010); Amer et al. (2010); Singh (2011); Banout et al. (2011); Slama e Combarnous (2011); Maiti et al. (2011); López-Vidan et al. (2013); El-Sebaii e Shalby (2013); Ringeisen et al.(2014); Gomes et al. (2014); Fudholi et al. (2014).

GENERAL OBJECTIVE

This work aimed to experimentally evaluate the effect of varying the drying load and the flow of air flow inside the dryer in the operating conditions of a solar dryer for drying bananas in order to maximize efficiency drying and determining the optimum relationship between these parameters.

The specific objectives of the project:

- Theoretical and experimental definition of ideal drying capacity operation of the solar dryer;
- Experimental evaluation of environmental thermal conditions and runoff in the solar dryer;
- Lifting banana samples drying curves on the solar dryer, to different climatic conditions, flow of the air flow and load of bananas.
- Achievement of energy balance and definition of thermal losses and thermal efficiency and drying of the solar dryer from experimental tests.

EXPERIMENTAL PROCEDURE

The solar drier used in this work "Fig.1" shows the glass cover and the housing with low wooden structure density and high mechanical strength, coated internally and externally by galvanized steel plates painted matt black, with internal insulation glass wool. The solar drier booth type used in this research work, has 1.8m long, 1.0m wide, 0.35m high in air heating chamber and 0.55 m long in the drying chamber. The drying capacity is about 2 kg. The dryer was developed in Boiler Laboratory of the Department of CEFET-MG Materials Engineering.

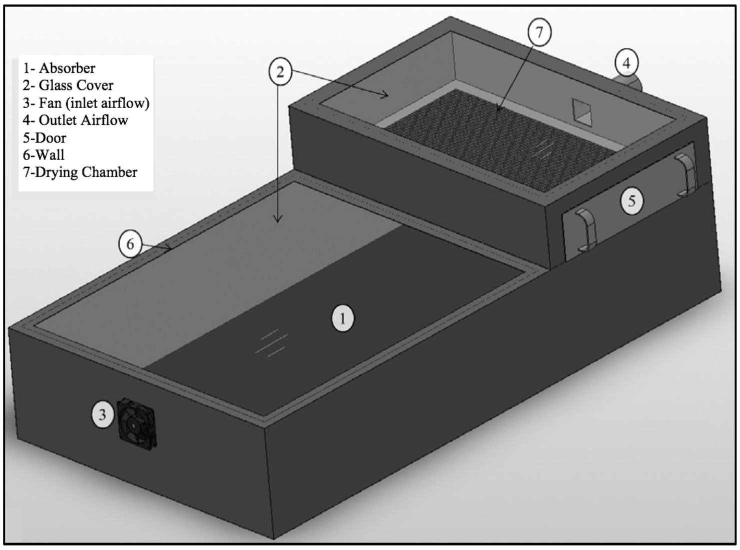

Figure 1. Schematic representation of the dryer cabin type

The dryer "Fig. 2" a portion of the incident solar radiation passes through the glass cover and reaches the absorber (painted matte black to increase absorption of solar radiation). The air flow enters the dryer at ambient temperature, is heated by absorption and through the drying chamber in which drying product is placed. The flow of hot air removes moisture from the product and leaves the dryer through a straight pipe section with screens. The product is introduced and removed through the side of the dryer door.

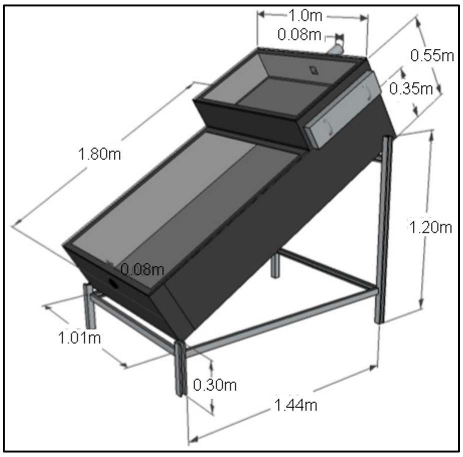

Figure 2. Dryer Solar and its dimensions

According to the "Eq. (1) "the thermal efficiency of solar dryer, the drying process (ηs), is given by the ratio between product water vaporization energy and the power drawn from dryer (LEON et al., 2002)

$$\eta_s = \frac{\int \dot{m}_{H_2 0} \cdot h_{lv} \cdot dt}{\int A \cdot G \cdot dt} \quad (1)$$

According Leon *et al.* (2002), the instantaneous thermal efficiency of a empty dryer can be obtained by:

$$\eta_T = \frac{\dot{m} \cdot (h_s - h_e)}{A \cdot G} \quad (2)$$

Where,
$\dot{m}_{H_2 0}$ is moisture instantaneous flow that is removed from the product in the dryer;
$\dot{m}$ it is the flow of drying air;
h_{lv} it is the latent heat of vaporization;
h_s is the enthalpy of the air at the outlet;
h_e is the enthalpy of the incoming air;
A é a área do secador solar;
G is hemispheric solar radiation.

The initial moisture content on a wet basis, m_i the initial sample mass m_f and the final mass of the dry sample.

The instant moisture content ($U_{x(BU)}$) of banana samples, on a wet basis, was determined according to "Eq. (3) ":

$$U_{X(B.U)} = 100\% - \left[\frac{m_i}{m_x} \left(100\% - U_{i(B.U)} \right) \right] \quad (3)$$

Where $U_{x(BU)}$ is the instant moisture content on a wet basis, m_i is the initial mass in (in grams), m_x is the instantaneous mass (in grams) in a given time and $U_{i(BU)}$ is the initial moisture content of the product at the base wet.

Following is a brief description made in topics of the procedures adopted during the drying tests.

During the drying tests of bananas in the solar dryer, the following procedures were followed:

- Preparation of banana samples cut in slices of about 1 cm thick;
- Mass Measurement of each empty tray;
- Uniform distribution of the samples in trays;
- Mass measurement of all samples bananas;
- Positioning of the trays in the drying chamber of the collector;
- Glass cover cleaning to remove any dust;
- Drive the two thermo-hygrometers and positioning them at the inlet and collector air outlet;
- Positioning and drive the thermo-hygro-anemometer in manifold air output;
- Data acquisition system operated Agilent;

- Measurement of the mass of the reference pan 15 min 15 min throughout the duration of the test;
- Mass measurement of all samples dried at the end of each assay;
- Shutdown of the collected equipment and storage of data in the *datalogger* and *Agilent*;
- Clean the trays in order to avoid the dried product residue buildup.
- Preparation of banana samples cut into slices of about 1 cm thick;

For the realization of experimental tests in this work the following instruments are used:

- drying and sterilization oven with microprocessor-controlled temperature control, digital display, 200 W heating power, NT522 model Nova Técnica;
- a digital scale, Toledo model 9094C; the measurement uncertainty ± 1g, used to evaluate the mass of the trays and banana samples before and during the drying process in oven and solar drying.
- a thermo-hygro-anemometer for measuring the speed, temperature and relative humidity of the air flow (Icel, AN-4870 model, measuring range air velocity of 0.1 m / s to 35m / s measurement uncertainty of 3% the read value, temperature measuring range from -20 ° C to 70 ° C with 0.6 ° uncertainty of measurement, and measuring humidity range of 0% relative to 100% with 3% measurement uncertainty for the measuring range 10-90% and 5% for other measuring ranges) "Fig.3";
- two thermo-hygrometers with *data logger* (Icel, HT 4400 model, 3% measurement uncertainty for relative humidity and 1 ° C for temperature) "Fig.3";
- • A pyranometer (Kipp & Zonen, model CMP21, measurement uncertainty <1% for temperatures between -20 ° C and 50 ° C) with the photothermal type sensor with internal temperature compensation circuit, sensitivity: 8.30 $\mu V/Wm^{-2}$, 5 seconds response time for measuring the incident solar radiation on the solar dryer "Fig.3";
- portable data acquisition system (Agilent Technologies, model 34972A);
- a thermostatic bath (HAAKE, modelo C35).

The digital oven was used to evaluate the initial moisture content of the samples. The anemometer with integrated data acquisition system was used to measure the velocity of the drying air flow. The temperature and humidity of the incoming and outgoing air flow were evaluated using two thermo-hygrometers sensors, both with integrated data storage system. The digital scale was used to measure the mass of the banana samples. The type K thermocouple was used to monitor the temperature of the cover glass. To measure the solar radiation collector in the plane incident to the solar dryer used a pyranometer coupled to a data acquisition system. The thermostatic bath was used on the K-type thermocouple calibration A "Fig.4" shows the positioning of the sensors in the dryer.

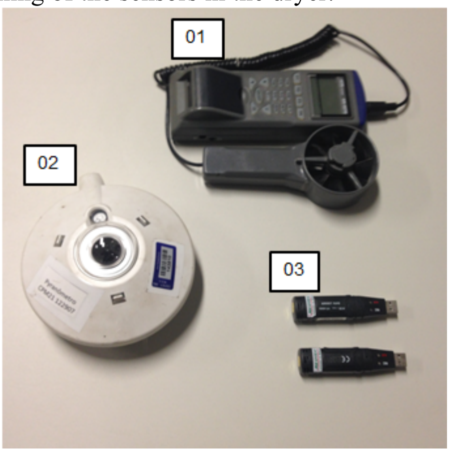

Figure 3. 01 - Thermo-hygro-anemometer; 02 - piranometer; 03 - Thermo-hygrometers

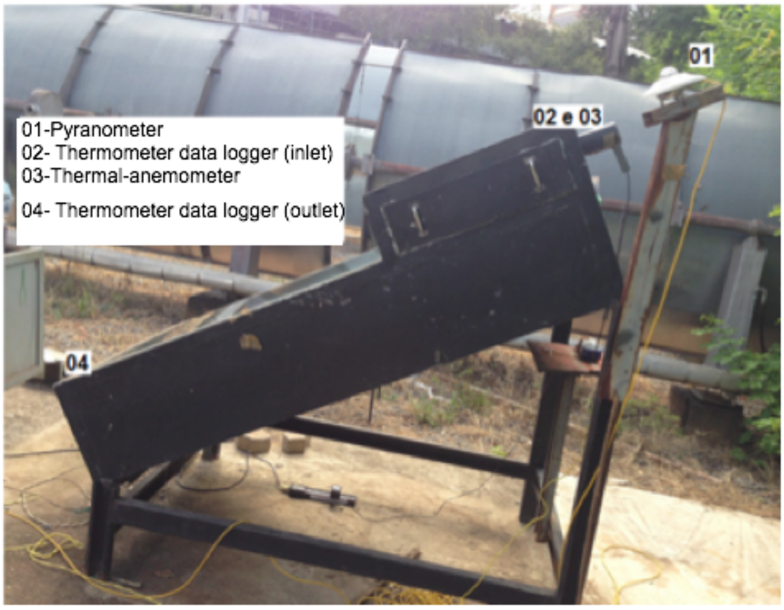

Figure 4. Positioning the sensors in the dryer

RESULTS AND DISCUSSION

This section presents the results of the data collected during the banana drying trials as well as the analysis and interpretation.

The influence of the charge capacity and the drying air flow rate was carried out a total of 11 (eleven) tests. And four (4) testing with no load dryer, two with maximum flow drying air about (0.0070 ± 0.0001) kg / s. And two with minimum flow about (0.0030 ± 0.0002) kg / s. The other seven (7) tests were carried out with the dryer loaded with load equal 0.5 kg, 1.0 kg and 1.5 kg. The "Tab.1" provides a summary of tests.

Table 1. Tests carried out

Date	Output	Charge
11/11/2013	Minimum	0.5 kg
11/22/2013	Minimum	1.0 kg
01/08/2014	Minimum	1.5 kg
10/25/2013	Maxim	0.5 kg
11/20/2013	Maxim	1.0 kg
01/09/2014	Maxim	1.5 kg
03/13/2014 and 03/14/2014	Minimum	3.36 kg

In order to better assess the influence of load capacity with the the drying efficiency was carried out another test in the days 03/13/2014 and 03/14/2014 with minimum flow for the drying air and the drier loaded with (3.36 ± 0.01) kg of banana. For the latter assay adapted from a screen at the bottom of profile "L" of the drying chamber was taken, banana samples were placed directly on the screened surface. We used if only one tray placed between the samples which served as a reference to measure the instantaneous mass, every 15 minutes throughout the drying test. The "Fig.5" shows the visual appearance of the banana samples at the beginning and the end of testing.

Figure 5. Visual appearance of banana samples.

The values of the inlet temperature (Tin) and output (Tout) of air drying are shown in "Fig 6", the maximum and minimum values for the inlet temperature (Tin) was (24.8 ± 0.6) ° C and (± 21.0 0.6) ° C, respectively. The maximum and minimum values for the outlet temperature (Tout) of the air drying was (70.7 ± 0.6) ° C and (25.2 ± 0.6) ° C, respectively. The greatest variation in temperature (47.2 ± 0.6) ° C occurred on 03/14/2014 at 13h20min.

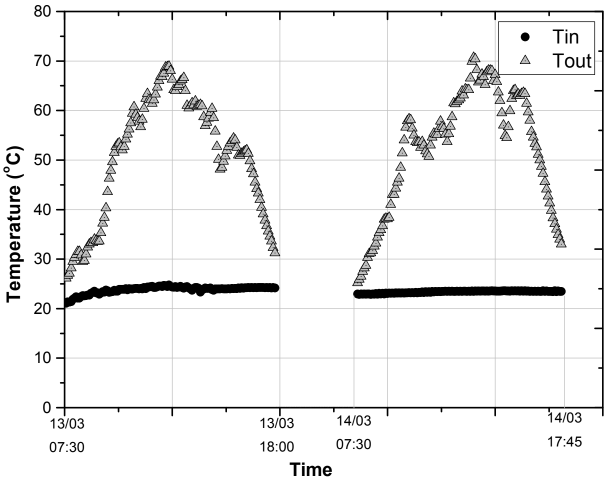

Figure 6. Air temperature in the drying days 03/13/2014 and 03/14/2014

It is presented in "Fig.7" after instant relative humidity of the air flow in the device input (URin) and output (URout). The inlet relative humidity (URin) ranged from (27.2 ± 0.8)% to (72.9 ± 2.2)%. The relative humidity in the output (URout) ranged from (12.7 ± 0.4)% and (74.2 ± 2.2)%. Except for the period corresponding to the beginning of the tests to 07:30, the output relative humidity of the air flow in the device is always less than moisture penetration. Increasing the air flow temperature promotes the reduction of the relative humidity, but the product moisture removal promotes increased absolute humidity.

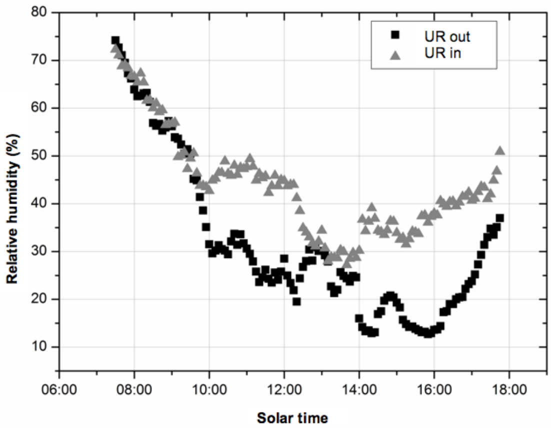

Figure 7. Relative humidity drying

The "Fig.8" shows the instantaneous thermal efficiency of the dryer. The instantaneous thermal efficiency ranged from 3.6% to 30.8% with a mean of 11.3%. The results show a very wide range results, though the dryer seems to have a slight tendency to increase the thermal efficiency by reducing solar radiation. The great dispersion presented is partly explained by the thermal inertia of the dryer. The instantaneous reduction of solar radiation does not cause a rapid reduction of ambient temperature and air flow. Consequently, there is an abrupt increase in thermal efficiency, causing large dispersion.

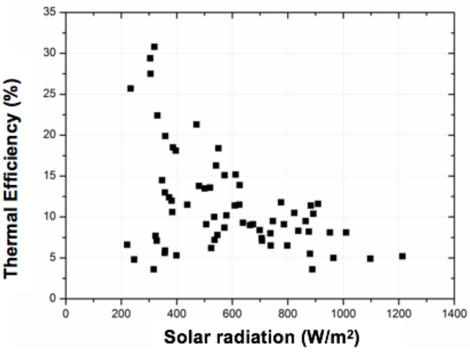

Figure 8. Instantaneous Thermal Efficiency

In "Fig.9" is shown drying curve of the banana samples, for tests carried out on 13 and 14 March 2014. The moisture content on a wet basis (BU) is shown in duration of the function assay. The moisture content (BU) of banana samples started with a value of 80% and reached value of 23% after 23 hours of drying. As mentioned above, for purposes of comparison with the previous tests was performed truncation when the moisture content reaches value of 57.7%, corresponding to a drying time equal to 12 hours.

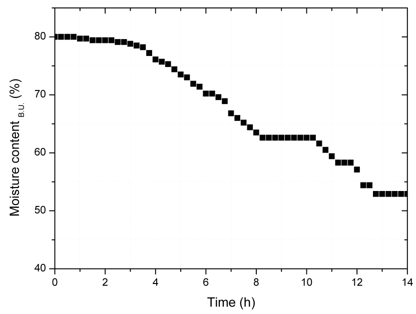

Figure 9. Moisture content and drying time function

The "Tab.2" shows the values of some measured and calculated parameters for testing at full load (3360 ± 1) g, where (G) is the global hemispheric solar radiation, (M_{H20}) is the water mass removed and ($\dot{m}$) is the mass flow rate of air drying. The dewatered mass is 72% of the initial mass banana, so that this test was the largest amount of water removed. The calculated value for the drying efficiency of 18.8% is about three times higher than the best drying efficiency calculated for the previous tests, demonstrated that the drying efficiency of the device rises significantly to increased load capacity.

Table 2. The test drying parameters with maximum load

Date	G(1) (W/m^2)	Tin (1) (°C)	UR_{in} (1) (%)	T_{out} (1) (°C)	$\dot{m}$ (1) (kg/s)	Banana initial mass (kg)	Water mass removed M_{H20} (kg)	Drying efficiency
03/13/2014 e 03/14/2014	495±15	23.6±0.6	43.6±1.3	37.5±0.6	0.0022±0.0001	3.360±0.001	2.431±0.001	18.8%

(1) average value

As the solar dryer has a fan (12V / 6W), ie, in every hour of operation there is a consumption of electricity equal to 0.006kWh. Taking into account the last test performed, the initial mass was 3360 kg fresh banana and banana final mass passes after 23h test corresponded to 0.929 kilograms and dewatered mass was 2.431kg. In this test were 0.138 kWh consumed, therefore, consumption was 0.04 kWh / kg of bananas in nature or 0.15kWh / kg Banana passes. In recent work (Fonseca, 2012) used an artificial dryer to pass banana production, the value calculated for the consumed energy was 1.17 kWh / kg of banana in natura and 4 kWh / kg of banana passes. Even using a small fan solar dryer, the solar dryer can be considered more sustainable than the artificial. The main source of energy in the solar dryer is renewable (solar radiation) electricity during the drying process is much lower compared to the energy consumed by an artificial dryer.

CONCLUSIONS

For tests with dryer unloaded thermal efficiency ranged from 7.4% to 25.7%. In tests conducted with the uploaded dryer, the device showed better drying efficiency in tests with lower values for mass flow rate of air drying and increased loading. The device was initially sized for 2 kg load, however, as previously said adaptation in the drying chamber allowed to charge the dryer 3.36kg banana in nature. From the results it was possible to define the ideal condition of dryer operation to the banana drying, it is at peak load and minimum mass flow rate of air drying. The highest value obtained for drying efficiency was 18.8%, higher than that obtained by (Ferreira, 2012) who obtained approximately equal drying efficiency 3% when using the same device of this paper to dry solid waste wire drawing. Finally it can be concluded that the equipment is technically and economically feasible for banana drying as it is fed sole energy that is abundant and free, especially in tropical regions that is where are the largest producers of bananas.

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