SOLAR DRYING OF BANANA USING A SOLAR CHIMNEY

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Abstract. *Drying is probably the oldest known method of fruits preservation. It is done by a process that uses thermal energy to remove part of the moisture content of the product. The first source of energy used for drying was the solar radiation, a renewable, non-pollutant and with low costs source. The solar dryers show stagnation of the drying air in low radiation periods. Because of this, there is a decrease in the quality of the products dried on most solar dryers operating in natural convection. The solar chimneys represent an interesting alternative to solar fruits drying, since they produce an ininterrupting flow of hot air. The solar chimney consists of a circular greenhouse open at the ends (inflow of air at ambient temperature), connected to a tubular central tower (outflow of the air heated on the greenhouse). It was done an experimental evaluation of the drying of bananas in a solar chimney. This paper presents the variation of the moisture content of bananas during time, related to measured values of drying air temperature and velocity, incident solar radiation and inflow temperature.*

Keywords. *Solar Chimney, Solar Drying of Bananas*

1. Introduction

Brazil is the world major fruits producer, with a production above 30 million of ton/year. Banana is the second most produced fruit (oranges are the most produced ones) and the most consumes fruit. Its annual average consumption is nearly 34,5kg/person (Alves, 1999). The banana culture represents a plantation of 500.000 ha. According to Silva (2000), about 40% of the brazilian production of fruits is wasted.

In order to reduce the high losses and to supply the national consumption of bananas, it is interesting to use preservation techniques. Drying is the oldest and one of the most suitable methods to food preservation. Schirmer et. al. (1996) presents an experimental study of a solar tunnel dryer built on Thailand, used to dry up to 300kg of ripe bananas. The temperature of the drying air from the collector varied between 40°C and 65°C during drying. The bananas samples were dried in 3.5 days (84 hours), compared to the 4.5 days (108 hours) needed for natural sun drying. The drier was protected from rain, insects and dust, and the dried bananas presented high quality.

Maskan (2000) dried slices of bananas Musa, using three distinct methods: convection (60°C and 1,45m/s), microwave and convection followed by microwave finish drying. Higher drying rates were observed for the microwave drying. The lowest drying rate ocurred for the convection drying. Although a high initial drying rate has been observed on the convection drying, the diffusion process becomes slower when the moisture content reaches low levels. The total times required to dry 4.3mm thickness banana samples were 482 minutes for convection drying and 172 minutes for the combined convection and microwave drying. The drying time for the microwave drying was reduced to 13 – 27 minutes, depending on the power level used.

Queiroz and Nebra (2001) present a theoretical and experimental study of the drying of bananas Musa acuminata, variety Nanicão, in an artificial dryer that allows to control the drying airflow parameters. Drying tests were performed with a drying airflow of 0.38m/s, in order to evaluate the time required for the products reach a 25% moisture content. The initial moisture content measured was 75%. To an airflow with relative humidity of 35,7% and temperature of

29,9°C, the required time was 121,8 hours. To an airflow with relative humidity of 7,37% and temperature of 68,4°C, the required time was 27,6 hours.

Chua et. al. (2001) present a study of the drying of slices of bananas Del Monte in a two-stage heat pump dryer capable of producing stepwise control of the inlet drying air temperature while keeping absolute humidity constant. The study consists on the comparison of the drying rate curves for step-down (35°C to 20°C) and step-up (20°C to 35°C) profile temperatures. The step-up temperature profile reduce significantly the drying time and reduced colour degradation in the order of 40%.

Boudhrioua et al. (2002) analyzed the changes on rheological properties of slices of Cavendish Grande naine bananas with the drying air temperature. The drying experiments were carried out at a constant air velocity (2m/s) without steam injection and at air temperatures of 40°C, 60°C and 80°C. The influence of initial ripeness was studied for drying at 80°C. It was observed that drying occurred faster when the product was ripe. The study showed that a radical change in the rheological behaviour of the slices occurred depending on the fruit ripeness after 4, 6 or 8h of drying at 80°C.

Dandamrongrak et. al. (2003) examined the thin-layer drying behaviour of bananas in a heat pump dehumidifier. Four pre-treatments (blanching, chilling, freezing and combined blanching and freezing) were applied to the bananas, exposed to a drying airflow at 50°C, at a constant velocity (3,1 m/s). The inlet air relative humidity was 10-35%. The freezing and the combined blanching and freezing were the most effective methods of improving the drying rate when drying bananas.

The traditional open sun drying has some inherent limitations: high crop losses ensue from inadequate drying, fungal attacks, insects, birds and rodents encroachment, unexpected down pour of rain and other weathering (Ekechukwu et. al., 1999). An artificial dryer is more expensive than a solar dryer and requires high costs to heat the airflow. Solar dryers improve the quality of the dried products (related to sun drying) and have lower costs than artificial drying. The use of solar dryers is an interesting alternative, since they use a renewable and non-pollutant energy source and simple and non-expensive technology.

This paper presents an evaluation of the drying of bananas (variety nanica) in a solar chimney. Sun drying of the products was compared to the drying on the solar chimney. The nightly behaviour of the device was studied through the comparison of the drying of products continuously maintained in the dryer and of the products placed in a dessecant chamber during the night. The drying rate curves are presented. The incident solar radiation and the drying airflow parameters (velocity and temperature) were measured along the experimental test. The purpose of the present work was to study the drying of bananas in a solar chimney, evaluating its technical feasibility as a solar dryer.

2. The Dryer

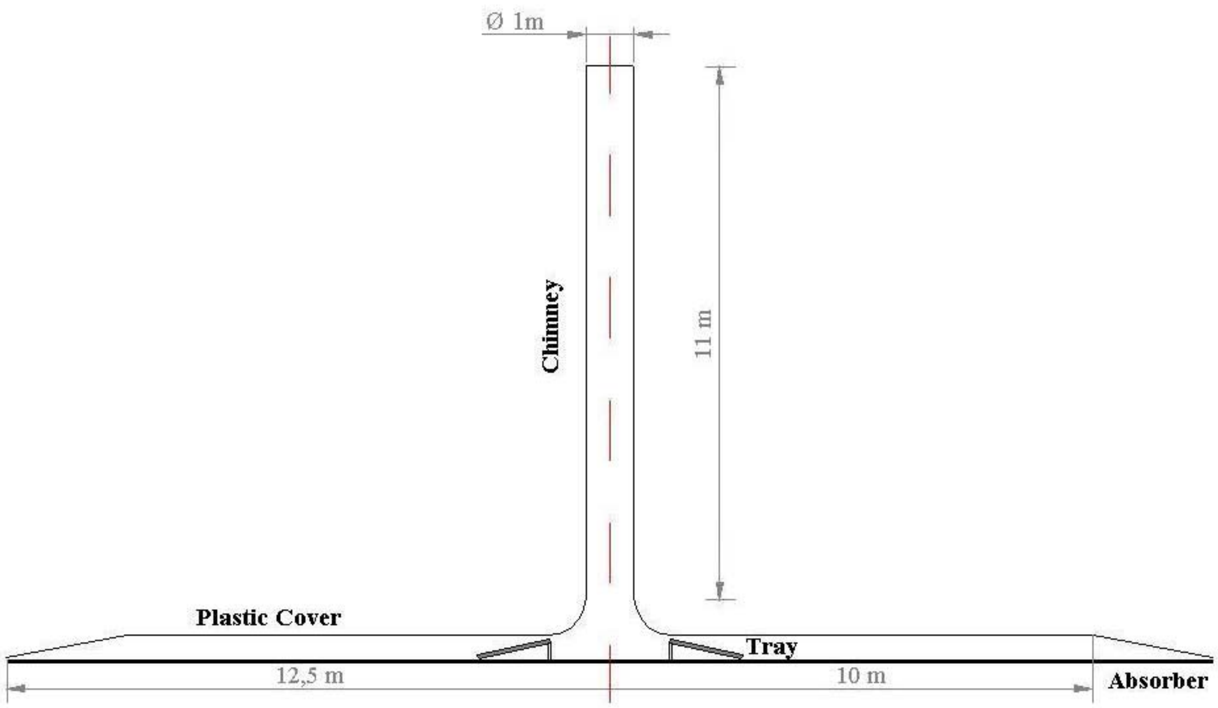

Figure 1 –Schematic representation of the solar chimney

Solar chimneys are devices generally used to produce electricity. However, they are economically viable only for large collector areas (Schlaich, 1995). The solar chimney used as a solar dryer was built on the Laboratório de

Alternativas Energéticas of Universidade Federal de Minas Gerais (Brazil). Its tower is 12,3 m high and his cover has a 25 m diameter (Fig. 1).

The solar chimney tower was built on five modules of 2,2 m high and 1,0 m diameter each. The modules were connected in order to obtain the total height of 11 m. The modules were built on wood and were covered, internally and externally, with fiberglass. This was intended to increase the mechanical resistance and to minimize thermal losses. The tower is supported by a basis made of 6 steel tubes and it is attached to the ground by steel cables. The 500 m^2 of the collector área were covered with a translucent plastic film (designed for greenhouses) with 150μm of thickness. The ground above the plastic film was covered with a black concrete layer. The height of the covering increases from the periphery (where it is 5 cm high) to a radial position r = 10 m (50cm high), and remains constant, equals 50cm (Fig. 2).

Figure 2 – Photography of the solar chimney

Part of the solar radiation incident on the plastic cover is absorbed by the ground under the collector and by the agricultural products (placed on drying trays), being converted on thermal energy. The hot ground heats the airflow under the cover. The inlet air, on ambient temperature, flows radially from the periphery to the center of the system, increasing its temperature and removing humidity from the products to be dried. As hot air is lighter than cold air, it rises up the chimney. Suction from the chimney then draws in more hot air from the collector and cold air comes in from the outer perimeter. At night, a portion of the thermal energy storaged by the ground (during the day) is transferred to the airflow, providing a continuous operation of the solar dryer.

3. Experimental Procedure

The bananas used on the experimental solar drying runs belong to the *Musa acuminata* species, Nanica variety. The bananas has the same ripeness level, characterized by the peel colour. The samples initial average diameter was 25 mm (with maximum variation of 3 mm) and the initial average lenght was 165 mm (with maximum variation of 16mm).

Each banana was immersed in a chlorine solution 50ppm concentration by 20 minutes. Then, they were immersed in a second chlorine solution 20 ppm by 10 minutes. The samples were washed in running water and peeled.

The initial moisture content was measured in a controlled temperature and humidity oven. The products were divided in 3 lots with approximate masses. The bananas were placed, as whole fruits, on drying trays.

The first sample was dried at open-sun. The tray was exposed directly to the sun, from 08:00h to 16:00h; after that, it was placed in a laboratory. On the next day, the procedure was repeated. The second sample was continuously maintained in the dryer. The third sample was maintained in a tray inside the dryer, from 08:00h to 16:00h. Then, it was placed in a dessecant chamber. During the day, the silica contained on the chamber was heated to lose the humidity absorbed on the nightly period.

The bananas moisture content was measured through the product weighting in a scale with measure uncertainty of 0,3g (determined to a confidence level of 95%). The moisture content was measured at least five times a day.

An Eppley Black and White solarimeter, model 8-48, was used to measure the solar radiation incident on the cover dryer. The system (sensor and data acquisition system) measure uncertainty was 5%.

The mass airflow was determined through the measurement of the airflow velocity in the tower, using 5 propeller anemometers. The sensors, with 8% of measure uncertainty, were distributed on a cross section of the tower (x/Ht = 0,5). The tower velocity profile and the average velocity of the airflow were then determined.

Three K-termocouples, with $2^{o}C$ of measure uncertainty, were used to evaluate the ambient air, the ground and the airflow temperatures. In order to minimize measure errors due on the sensor, the termocouple was protected of the solar radiation incident by a tubular support. The ambient air temperature was measured in a ventilated shelter, protected by solar radiation, located 1,5m from the ground.

4. Experimental Results

The drying runs were conducted from 03/31/2003 at 01:00 pm to 04/08/2003 04:00 pm, when the last sample reached the desired moisture content (25%). The initial moisture content was determined through the complete dehydration of the product in a temperature and humidity controlled oven. The obtained initial moisture content was 77,2% (wet basis). The sample remained 24 hours in the oven, with $110^{o}C$ temperature and relative humidity near zero.

The bananas were exposed to solar radiation until a 25% moisture content was reached. The final average diameter was 12 mm (with maximum variation of 2mm), resulting in a shrinking of 48% (related to an initial average diameter of 25 mm).

The extraterrestrial radiation for the tests location varies from 34 MJ/m^2 on 03/31 to 33 MJ/m^2 on 04/08, resulting in 300 MJ/m^2 of total energy. Figure (3) shows the amount of daily incident energy on the cover, with the daily extraterrestrial energy, for each test day. Due to atmospheric atenuation, the energy incident on the cover was 135 MJ/m^2, representing 45% of the extraterrestrial energy. The atmospheric atenuation was very significant, reducing the available energy on the device e increasing the drying time.

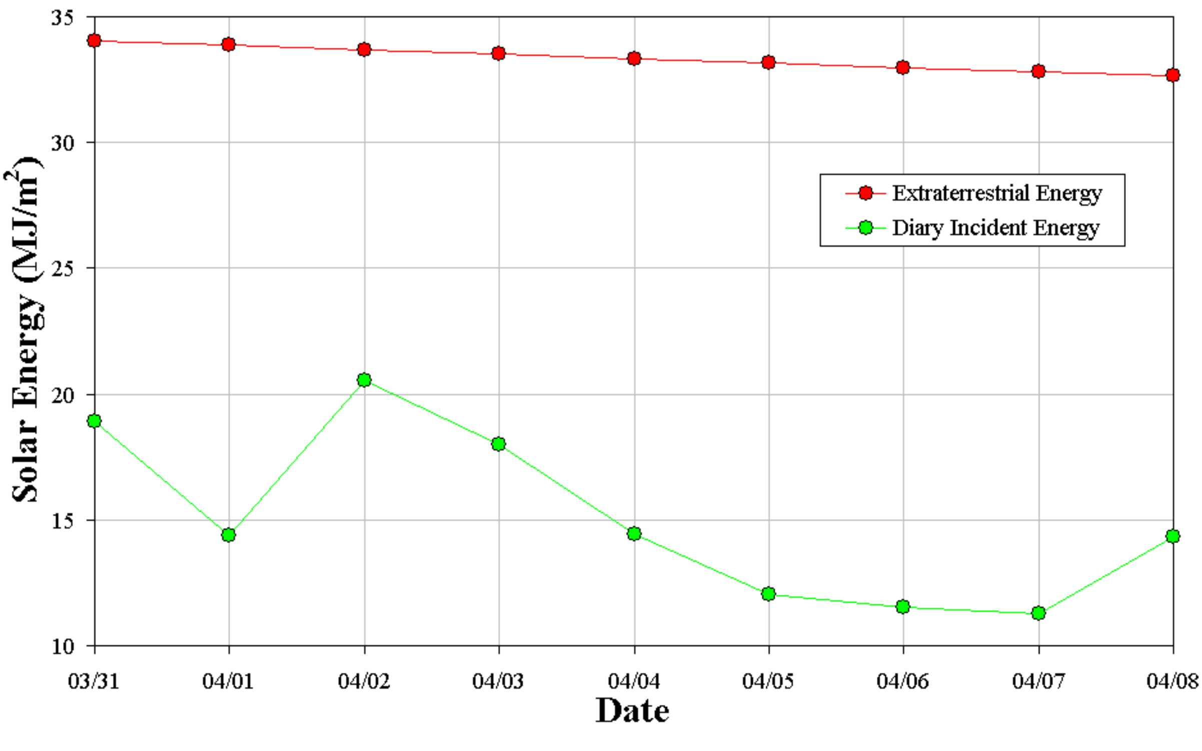

Figure 3 – Daily incident energy on the device cover

The extraterrestrial and incident global solar radiation are shown in Figures (4) and (5), for 04/02/2003 and 04/07/2003, that represents, respectively, the maximum and minimum daily incident energy values. Kt indicates the clearness index, defined as the ratio of a particular day´s radiation to the extraterrestrial radiation for that day. The differences between extraterrestrial solar radiation and incident solar radiation are due to atmospheric atenuation. At 04/02/2003, nearly 61% of the extraterrestrial solar radiation reached the device cover and, at 04/07/2003, only 34% of the extraterrestrial radiation reached the cover.

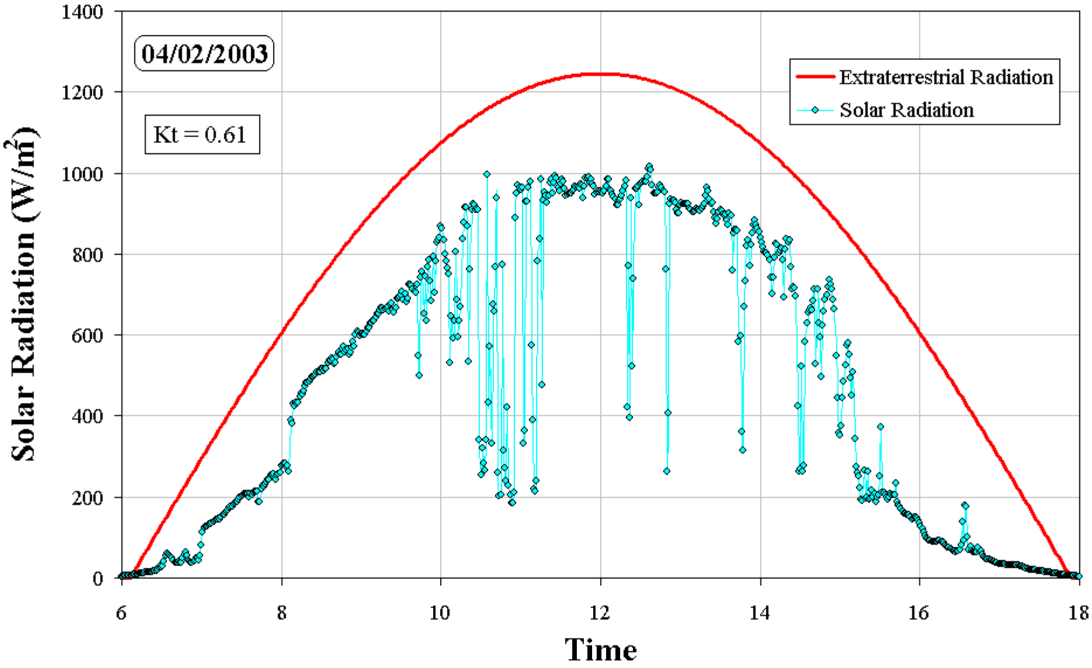

Figure 4 – Extraterrestrial and incident solar radiation on the device cover at 04/02/2003

The differences observed between extraterrestrial and incident solar radiation distribution for 04/02/2003 are less significant than those for 04/07/2003. The incident solar radiation follows the trends for the extraterrestrial radiation, reaching the maximum values near 12:00pm. For 04/07/2003, the incident solar radiation oscillated along the day, showing dissimilar behaviour due to significant clouds presence.

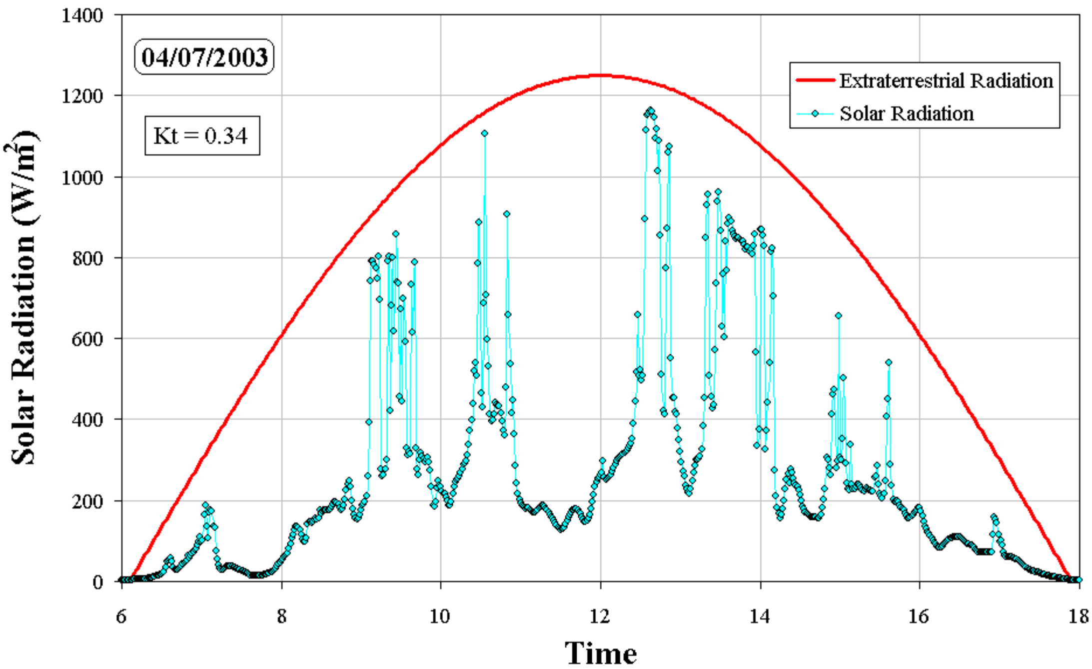

Figure 5 – Extraterrestrial and incident solar radiation on the device cover at 04/07/2003

Figure (6) shows the drying mass flow during the tests. It can be seen that the mass flow rised in the changes of (0.70 ± 0.06) kg/s to (2.7 ± 0.2) kg/s, the higher values ocurring when the incident solar radiations was higher (near sunset). It is interesting to notice that there is a significant mass airflow even in the nightly periods, when there is not incidence of solar radiation. Due to the reduction of the sectional cross area, the air velocity increases towards the device center.

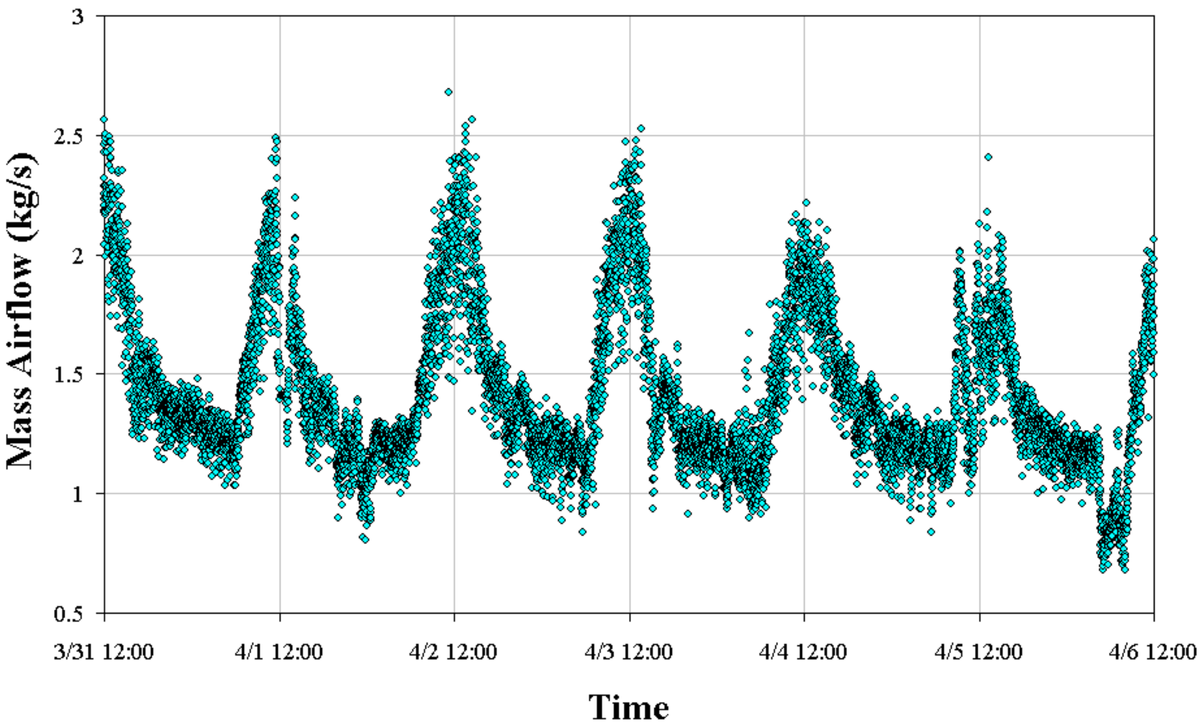

Figure 6 – Mass airflow in the dryer

The termocouples were placed on the same radial position of the drying trays. The temperatures on the ground, on the flow and ambient are shown in Figure (7), versus the time. The ground temperature rised in the changes of (23.2 ± 2.0)^{o}C to (61.3 ± 2.0)^{o}C and the airflow temperature, of (20.4 ± 2.0)^{o}C to (48.9 ± 2.0)^{o}C for a change in ambient air temperature from (18.5 ± 2.0)^{o}C to (32.6 ± 2.0)^{o}C. The maximum drop between the airflow and the air ambient temperatures (17.5 ± 2.8)^{o}C occurred at 04/03/2003, 02:00 pm. The maximum flow temperatures correspond to the times when the ground temperature reached its maximum value. The ground temperature always surpasses ambient temperature, ensuring the continuous operation of the solar chimney.

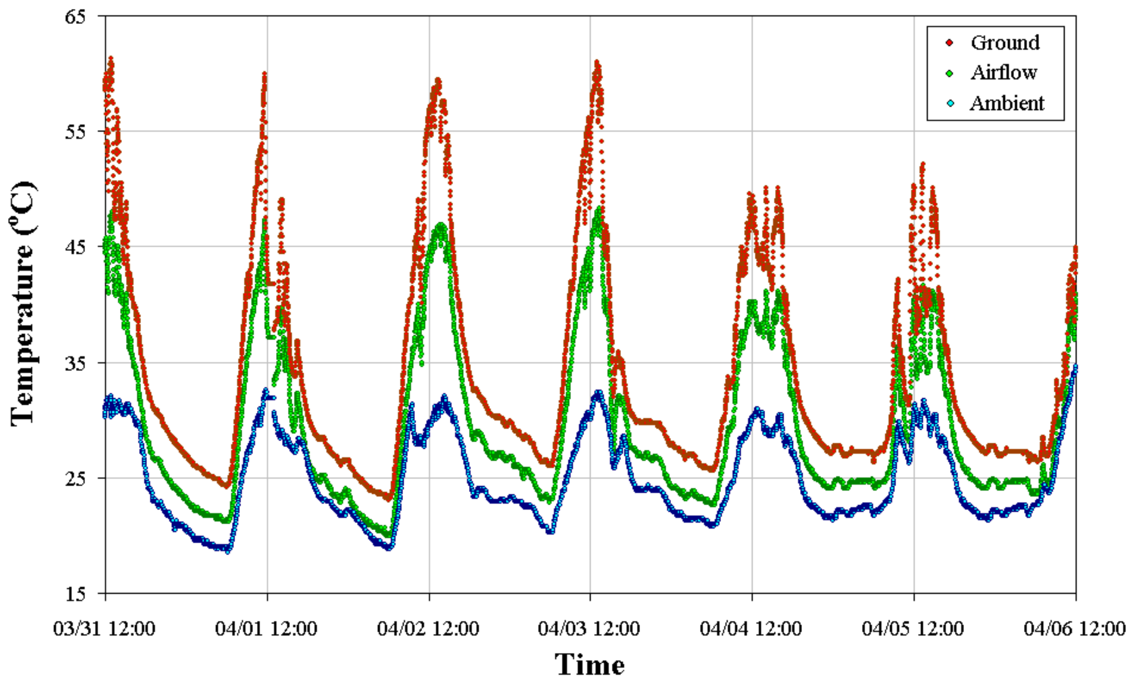

Figure 7 – Ground, airflow and ambient temperatures

The drying rate curves for banana samples are shown in Figure (8). The bananas maintained in a dessecant chamber at night required 125 hours to reach a moisture content of 25% (wet basis), the continuous drying of bananas in the solar chimney required 139 hours and the open sun drying took 193 hours. Taking the drying time of the sun drying as the basis for comparison, it can be observed that the continuous drying in the solar chimney was able to reduce in 28% the drying time and the maintanance of the products in a dessecant chamber, in 35%. For the climatic conditions of the drying runs, the most efficient method to dry bananas was to keep the products in a dessecant chamber in the period with low incidence of solar radiation.

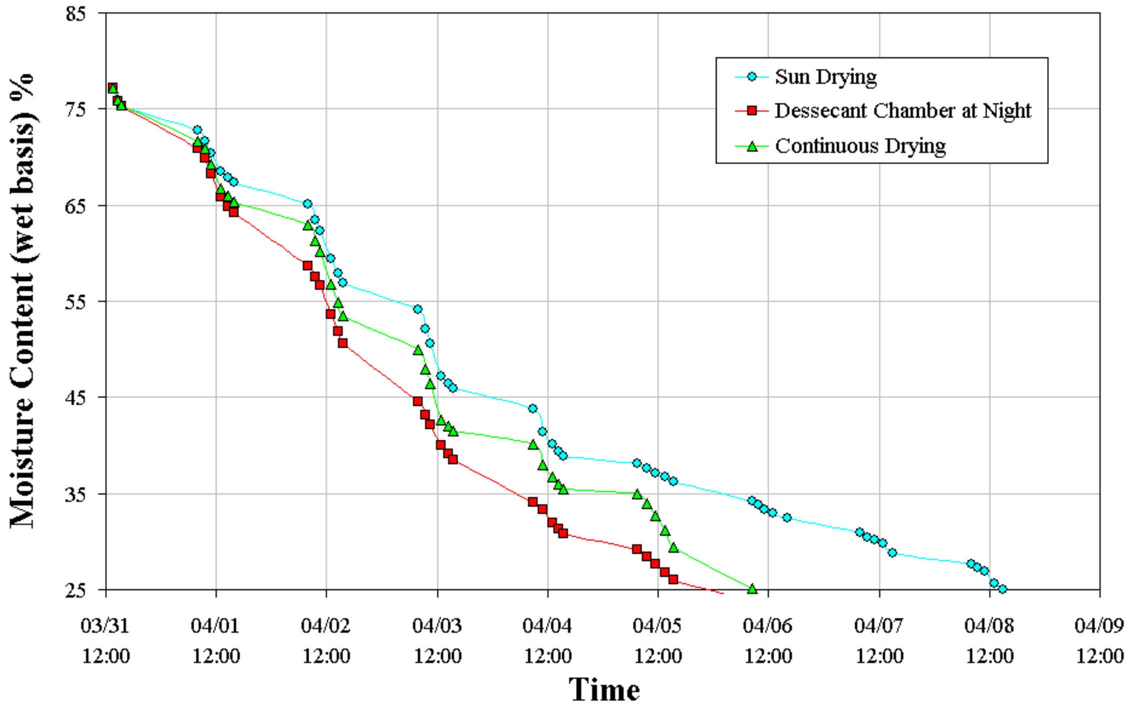

Figure 8 – Comparison of the drying curves

Figure (9) shows the dimensionless drying rate curves for the products, defined as the ratio of the moisture content (dry basis) and of the initial moisture content (dry basis) of the product. Notice that the water mass removed from the samples becomes lower with the time, since its more difficult to remove water from the products when its moisture content becomes lower.

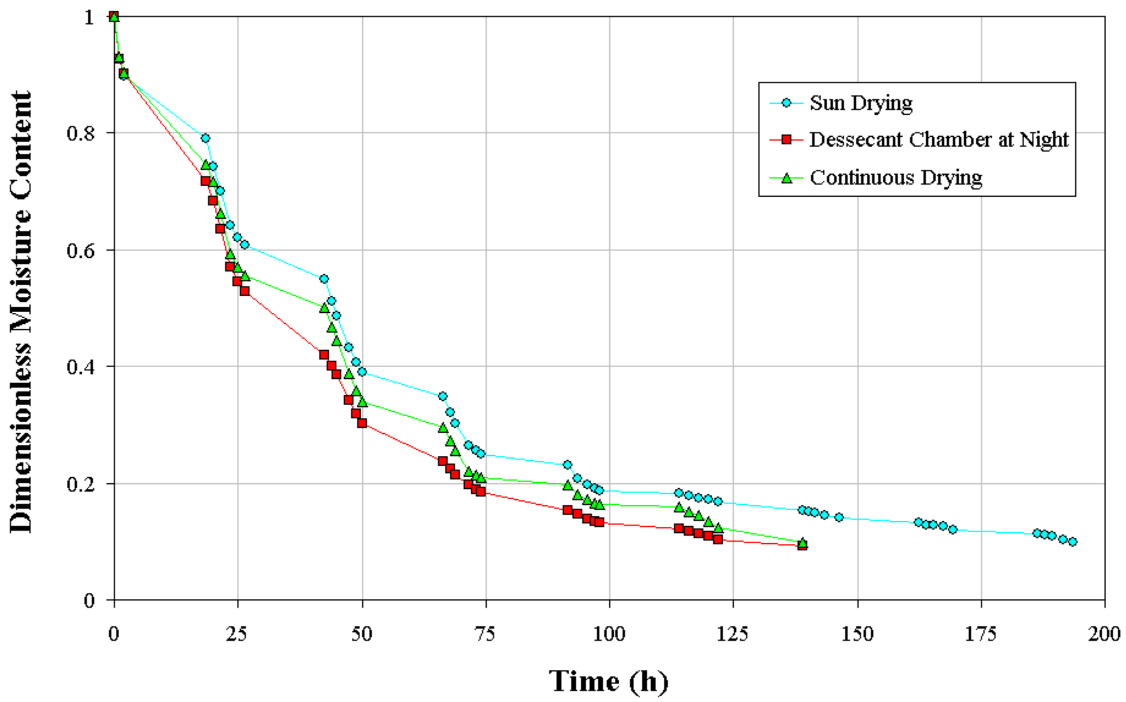

Figure 9 – Comparison of the dimensionless drying rate curves

The solar tunnel dryer used by Schirmer et. al. (1996) spent 84 hours to dry bananas up to 25% of moisture content (wet basis), while the solar chimney drying occurred in 139 hours. The solar chimney was submitted to worst climatic conditions, increasing the drying time. It can be seen on the time required to the open-sun drying, 108 hours for the solar tunnel dryer and 193 hours for the solar chimney. Nevertheless, the solar chimney reduced to 70% the drying time related to the open-sun drying, while the tunnel dryer reduced this time to only 77%.

5. Conclusions

A solar chimney was used to dry bananas. The drying ability of the device was evaluated, regarding to the ambient conditions (incident solar radiation and external ambient air temperature), through the airflow parameters (temperature and mass flow).

The use of a solar chimney reduced the time required to dry bananas in 30%, when compared to the open-sun drying, to the same climatic conditions. The nightly ability of the solar chimney was evaluated, comparing the drying rate curves for the products maintained continuously in the device with those for the products maintained in a dessecant chamber from 16:00h to 08:00h. On the nightly period, the drying rate of the bananas maintained in the device was lower than the drying rate of the bananas maintained in a dessecant chamber. This can be explained by the low temperatures reached in the device at night, that result in high airflow relative humidities and reduce the drying ability of the solar chimney.

The dried bananas were of suitable quality in terms of flavour, colour and texture. They did not present signs of being attacked by insects or little animals.

The solar chimney is an interesting alternative to dry agricultural products, allying a simple and not expensive technology with the use of a renewable and non-pollutant energy source for the generation of the drying airflow.

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