USING A SOLAR CHIMNEY TO DRY AGRICULTURAL PRODUCTS

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Abstract. *Brazil produces an expressive amount of grains and fruits. However, inadequate drying processes are still used (mainly by small producers), causing a significant loss of products. This work proposes the use of solar chimneys to dry agricultural products. The solar chimneys consist of a tubular central tower, fixed to a radial greenhouse, open at the ends. The solar radiation incident on the ground is transformed in thermal energy, that heats the air under the greenhouse, generating a natural convection hot airflow. Ambient temperature air is admitted on the cover extremity, flowing radially and being heated towards the tower, where the airflow becomes axial. A solar chimney prototype was built at the Energy Alternatives Laboratory of the Mechanical Engineering Department of UFMG, in order to evaluate the technical viability of the device to be used as a dryer. On this prototype, the velocity, temperature and humidity distributions were measured, related to the incident solar radiation. It is fundamental to know the detailed behaviour of this distribution in the device to evaluate technical and economically the drying processes*

Keywords. *Solar Chimney, Solar Drying*

1. Introduction

Brazil is responsible for a considerable portion of the agricultural production of the world. Nevertheless, appropriate drying and storage systems of grains and fruit are not available to many producers, which results in great losses and reduction of food reserve (Silva, 2000). Most of the automatic drying systems require high initial investments, besides high operation and maintenance costs, making it difficult for Brazilian small producers to purchase it. Therefore, in order to allow these agriculturists to increase their production quality and to reduce their losses, the development of efficient and cheap devices and methods for drying food is necessary.

The dryers that use electrical energy or energy provided by the combustion of fossil fuel to heat the drying air are economically viable only when used in large plantations (Mühlbauer et al., 1996). The recent Brazilian energy crisis and the frequent variations of the petrol price in the national and international market stimulate the development of and strategic energy technology. Therefore, the use of solar dryers for drying agricultural products is a very promising alternative, presenting the advantage of using a renewable and non-polluting source of energy.

Throughout the last decades, a series of solar dryers for the drying of vegetal origin products have been developed. Muller et al. (1989) have performed a study about solar dryers greenhouse type for herbs and medical plants. In experiments conducted in Yugoslavia, the drying air reached the temperature of 60ºC. Schirmer et al. (1996) present an experimental study of a solar dryer tunnel type for bananas, built in Thailand. In this dryer, small axial fans drove by a photovoltaic panel force the airflow to the interior of the dryer. Bala et al. propose a dryer similar to the one proposed by Schirmer et. al. (1996), to dry pineaples. Bena e Fuller (2002) present a solar dryer for fruits that uses natural convection and a biomass back-up heater , with a capacity of 22 kg.

The objective of this paper is to propose a food radial solar dryer using a device known as solar chimney (Schlaich, 1995) and to evaluate its technical viability through experimental measurements of the flow temperature and velocity distribution regarding to the incident solar radiation.

2. Radial Solar Dryer

The radial solar dryer, object of this paper, is composed by a central tubular tower attached, on its base, to a translucent circular cover, which boundaries are opened (Fig. 1). During the insolation period, a portion of the incident solar radiation on the cover is absorbed by the ground and by the drying product (which is arranged over trays), being converted into thermal energy. The ground heats and transfers heat by convection to the air under the collector. The heated air flows upwards in the tower due to buoyancy forces, generated by the fluid density gradient. Ambient air temperature enters through the boarders and flows radially towards the center of the device, being heated by the absorbent ground, and removing humidity from the product. At night, part of the thermal energy stored by the ground during the insolation period is transferred to the airflow, allowing the continuous operation of the dryer.

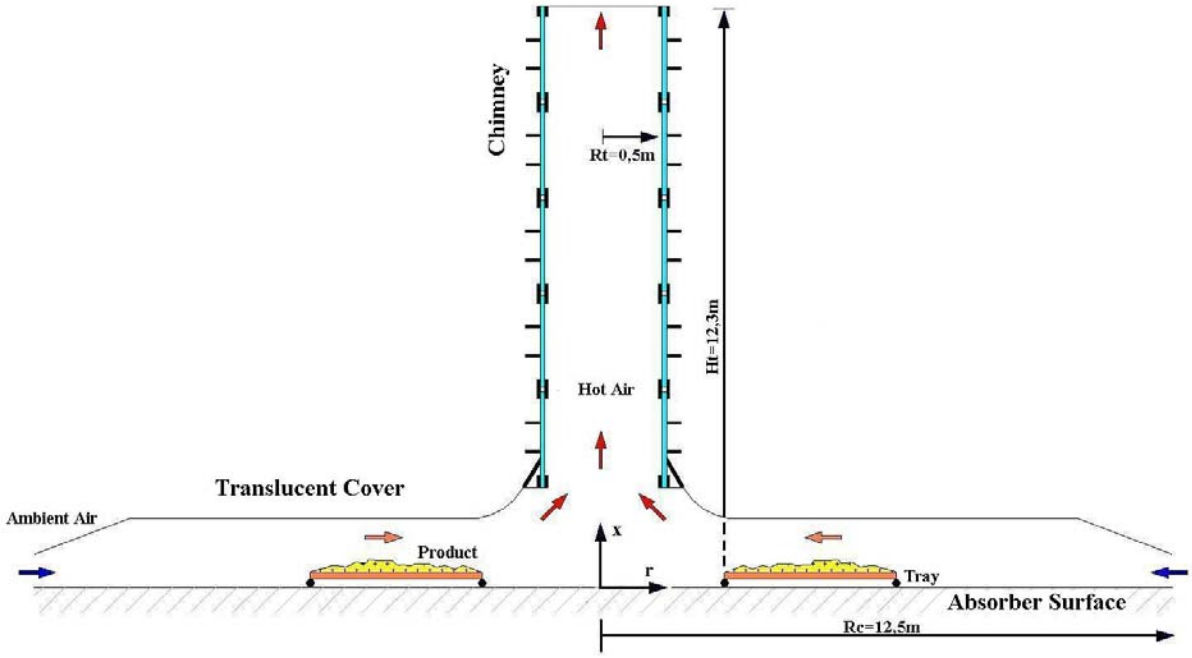

Figure 1 – Schematic diagram of the radial solar dryer

Figure 2 – Photography of the radial solar dryer

In order to evaluate the technical viability of the radial solar dryer, a prototype of a solar chimney (Fig. 2) was constructed at the Energy Alternatives Laboratory (LAE) of the Mechanical Engineering Department (DEMEC) of Universidade Federal de Minas Gerais (UFMG). The tubular tower, 11 m high and with a 0,5 m radius, was constructed in wood and covered with glass fiber, being 11 m high and having a 0,5 m radius (Rt). The tower was installed over a 1,3 m high metal base, reaching the height (Ht) of 12,3 m. A thermal-diffuser plastic film fixed to wooden frames was used to make the circular translucent cover. The cover, with a 12,5m radius, was fixed 0,5 m above the ground by a metal structure. The absorbent surface is a concrete layer painted in dull black, constructed above the ground. In order to minimize the heat losses caused by the motion of the wind under the cover, the air entrance height was reduced to 0,05 m and a black plastic film was placed all around the dryer (2,5 m away from its boundary). The laying and withdrawal of the products in the dryer are performed through the boundaries of the device, inside the trays. This device is the object of a preliminary study of the use of solar chimneys as food dryers. The geometric configuration adopted in the construction of this prototype can be modified to be better adjusted to the presented purpose.

3. Experimental Methodology

The intent of this paper is to determine the applicability of solar chimneys as food dryers. A prototype was constructed at the Energy Alternatives Laboratory of the Universidade Federal de Minas Gerais. In order to get a light and resistant structure, an aeronautic philosophy was used in the construction of the tower. It was made by assembling 5 circular modules, with 1 m diameter and 2,2 m length each, resulting on the total height of 11 m. The modules were coated in the interior and exterior with glass fiber, in order to increase its resistance, diminish its internal roughness and reduce the heat losses to the exterior. The tower is supported 1 m above the ground by 6 steel mechanic tubes. It is attached to the ground by steel cables. The solar collector is composed by concentric polygons sustained by steel columns (Fig. 3), 0,5 m high. The collector is composed by a translucent cover made of a plastic film and by an absorbent surface (the ground under the cover). The material used on the cover was a thermal-diffuser plastic for greenhouses fabricated by Nortène, which avoids the formation of shades in the collector and has protection against UV rays. A thin superficial concrete layer, painted in black, composes the ground.

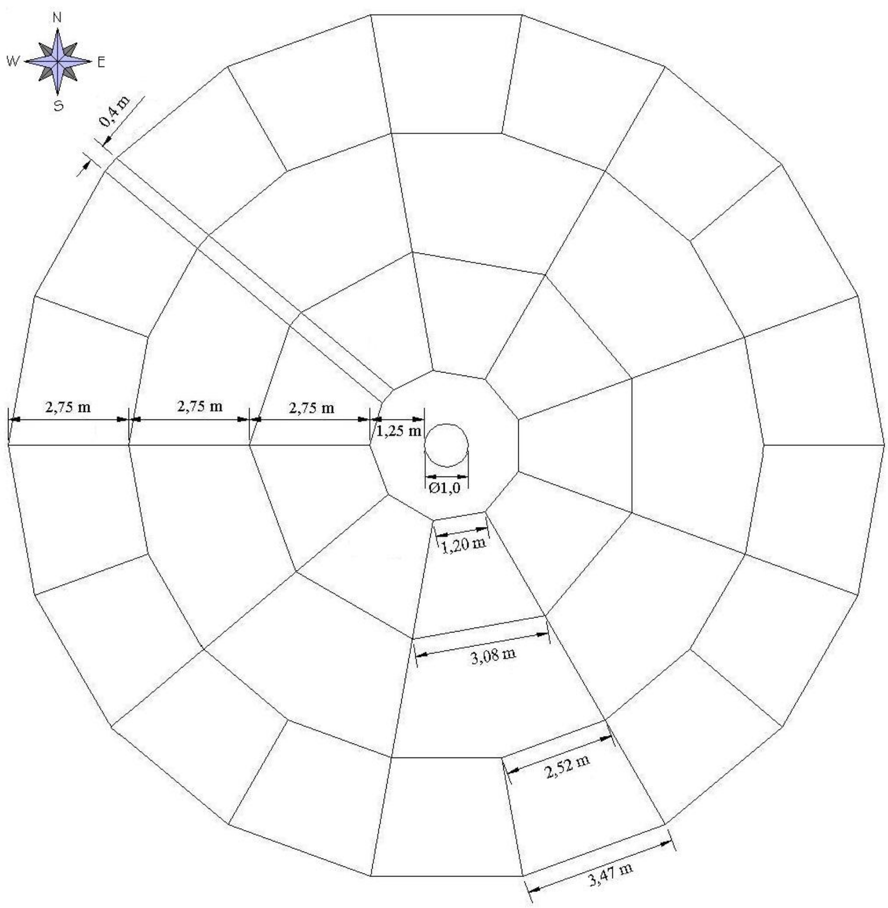

Figure 3 – Schematic diagram of the top view of the solar chimney

An experimental procedure was performed, which led to the determination of the thermal and aerodynamic features of the main parameters of the hot airflow (velocity and temperature) in strategic localizations, versus the solar radiation incident on the device cover.

In order to evaluate the balance of the solar radiation on the device, four Eppley Black and White 8-48 pyranometers were used, arranged as shown in Fig. (4). The measurement uncertainty of the system composed by the four sensors and by the data acquisition system is 5% of the read value, with a level of confidence of 95%. The relationship between the values read on the pyranometers allows the determination of the main optical properties of the ground and of the cover.

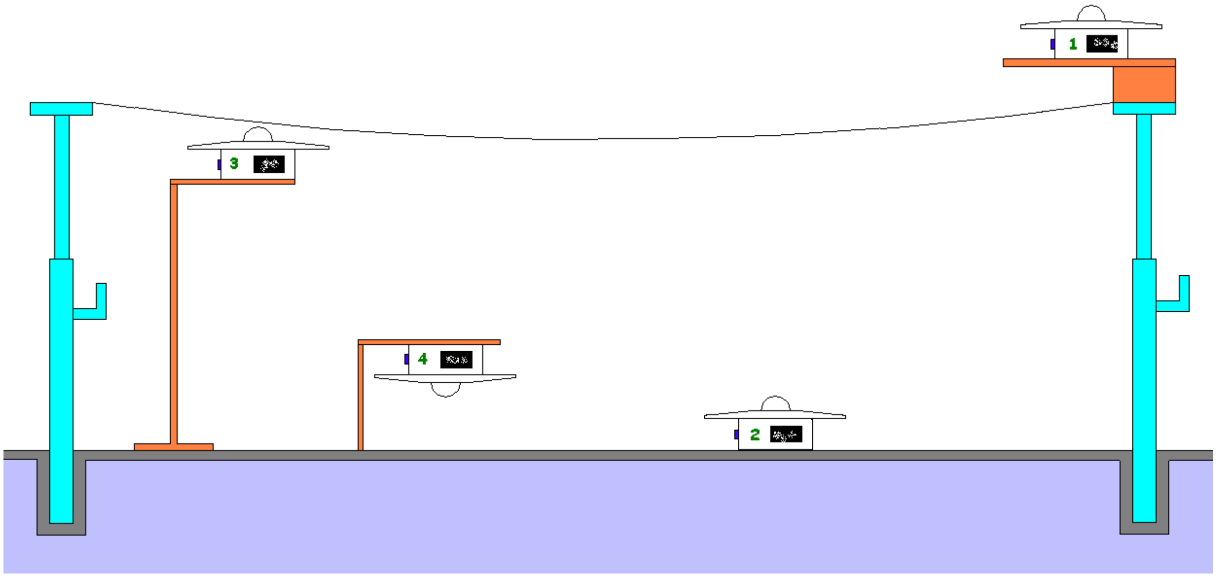

Figure 4 – Arrangement of the pyranometers under the cover

Three K type thermocouples, with total (sensors and data acquisition system) measurement uncertainty of 2ºC, with a level of confidence of 95%, were used to measure the temperatures. One thermocouple was maintained in the exterior of the device, in a shelter protected from the solar radiation, in order to measure the ambient air temperature. Two thermocouples were placed at the entrance of the junction (r/Rc = 0,16) so as to measure the temperatures of the ground surface and of the flow 25 cm above the ground (Fig. 5). A tubular support armored against solar radiation was constructed in order to reduce the thermocouple measurement errors.

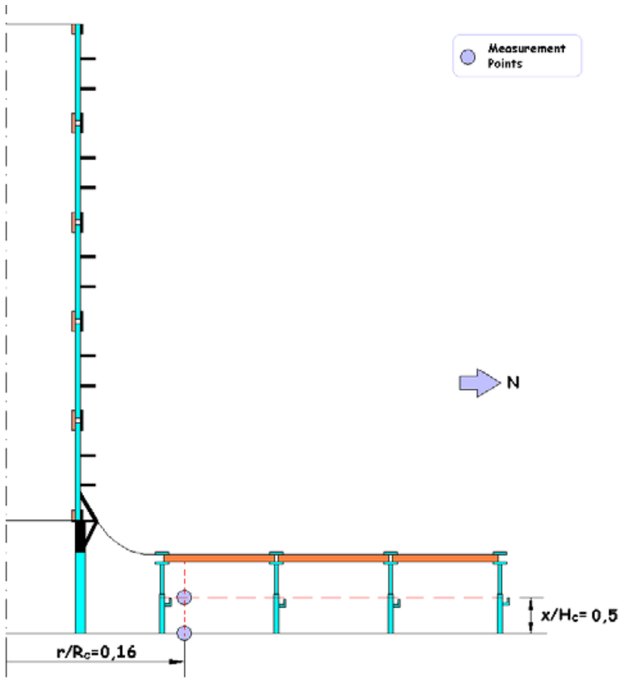

Figure 5 – Arrangement of the thermocouples under the cover

The flow velocity fields were monitored using three propeller anemometers, with measurement uncertainty equal to 8% of the read value (sensors and data acquisition system), with a level of confidence of 95%. The anemometers were distributed throughout a cross section of the tower (x/Ht = 0,5), in the positions r/Rt = 0, r/Rt = 0,4 and r/Rt = 0,8 (Fig.

6). Based on the velocity values measured, it was possible to determine a velocity profile for the cross section of the turbulent flow and to calculate the average velocity in the section. The data acquisition interval was 60 s.

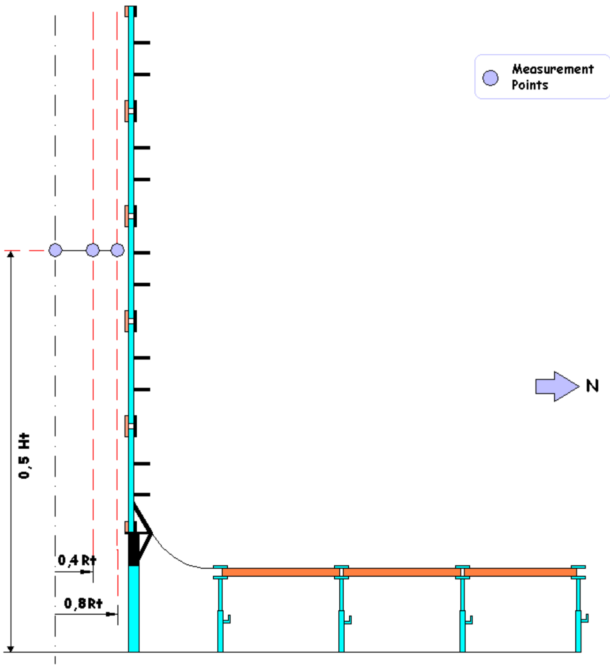

Figure 6 – Arrangement of the anemometers in the tower

4. Results

The experiments were conducted on the 2nd of March 2003. The global solar radiation incident in that period is shown in Fig. (7), as well as the extraterrestrial radiation. The difference between the two curves can be explained by the reflection e absorption of the solar radiation by the clouds, water vapor, dust and gases. The great drops observed in the global radiation are due to the presence of clouds in the sky, which partially block the passage of the solar radiation. Considering the presented data, the incident energy during the day represents 69% of the available solar energy (without atmospheric attenuation).

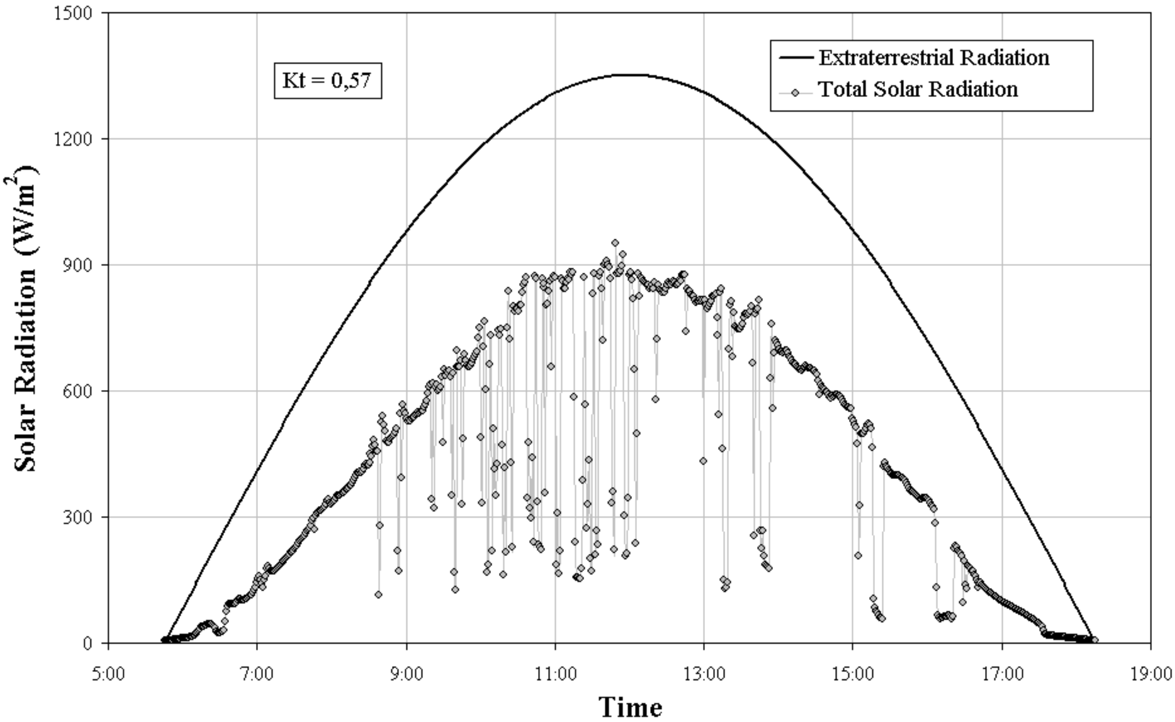

Figure 7 – Global incident solar radiation on the cover

A balance between the values measured by the pyranometers allows the determination of the optical properties of the materials used in the ground and in the cover of the dryer. The transmittance of the plastic film used in the cover varied from 50% to 80%, according to the solar radiation incidence angle (angle between the beam radiation on a surface and the normal to the surface), lower transmittance values corresponding to bigger incidence angles. An approximately constant absorptance of 90% was obtained to the ground material.

Figure (8) presents the dimensionless velocity profiles encountered for the chimney for several times during the day. The Reynolds number in the interior of the tubular tower varied between $7{,}0 \times 10^4$ and $1{,}7 \times 10^5$, characterizing the flow as turbulent for all tests. The velocity profile for a fully developed turbulent flow in a tube can be modeled by the equation (White, 2002)

$$\frac{u}{u_{\text{máx}}} = \left[1 - \frac{r}{Rt}\right]^n \tag{1}$$

The experimental results made possible the determination of the empirical factor ***n*** as 1/8. The maximum difference between the dimensionless velocities calculated by Eq. (1) and the dimensionless velocities obtained experimentally was 7%, which is inside the measurement uncertainty zone of the anemometers (8%).

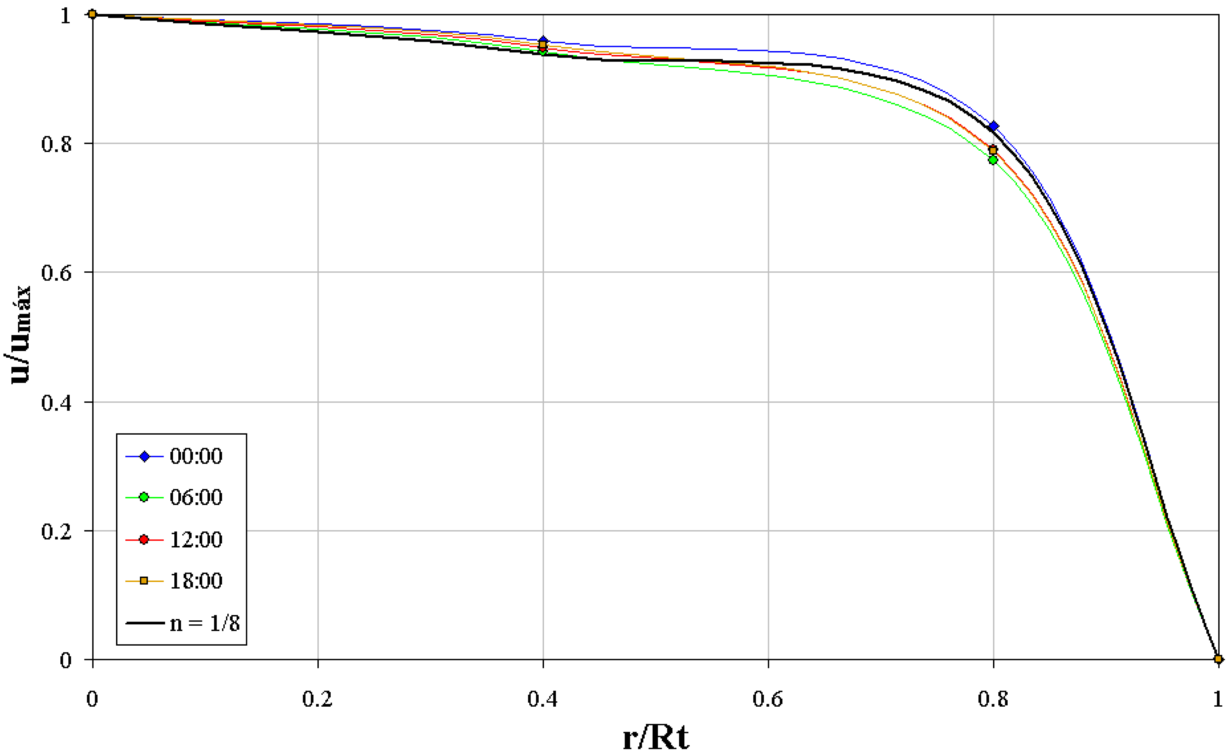

Figure 8 – Dimensionless velocity profile in the tower

Figure (8) presents the dimensionless velocity profiles encountered through Eq. (1) and through the experimental data. It can be noticed that the found velocity profile is able to represent the airflow in the tower, for the whole period of the test.

The average velocity in the tower of the dryer, calculated according to the determined velocity profile, is presented in Fig. (9). The pattern of the velocity indicates that the average velocity increases when the incident solar radiation on the device increases. The higher value (3,2 m/s) occurred at 12:30 p.m. The resulting mass flow values varied from (1.0 ± 0.1) to (2.6 ± 0.2) kg/s.

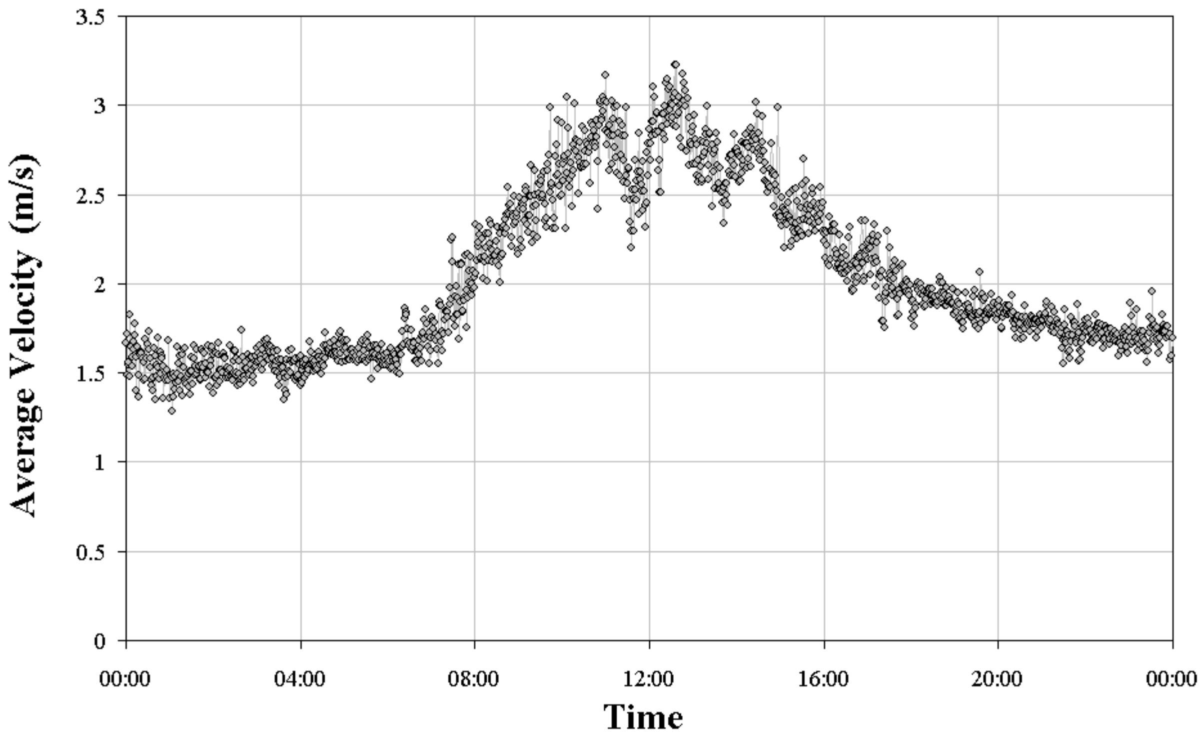

Figure 9 – Average velocity in the tower of the dryer

Figure (10) presents a comparison between the instantaneous values of the ground temperature, the ambient air temperature and the temperature of the flow, measured 25 cm above the ground, in the same radial position r/Rc = 0,16. The flow temperature varied from 23ºC (at 6:00 a.m.) to 52ºC (at 12:40 p.m.). The greatest rise in the flow temperature related to the ambient air temperature (18ºC) occurred at 12:40 p.m. During the simulation period, the ambient air temperature varied between 21ºC and 34ºC. It is important to notice that ground temperature surface always surpasses the flow temperature, since the ground absorbs part of the solar radiation available to the device (converting it into thermal energy) and heats the airflow, by convection. The drops of the values of the ground and flow temperatures occur simultaneously to the drops of the incident solar radiation values (Fig. 7).

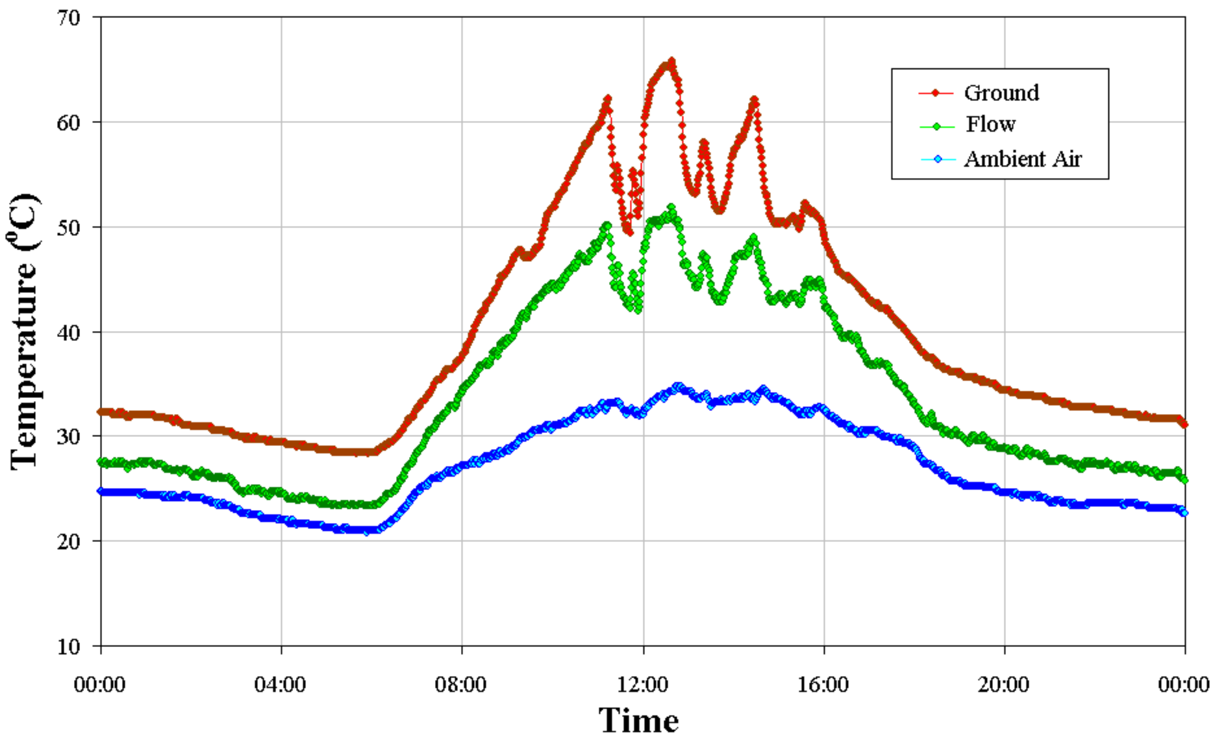

Figure 10 – Distribution of the temperatures at the external environment and at the cover of the dryer during the day

The most important parameters in a drying process are velocity and temperature. The values encountered for the airflow velocity in the interior of the prototype and for the rise temperature of the flow (in relation to the ambient air temperature) make the solar chimney an interesting device to dry food. It is important to emphasize that the parameters of the airflow generated in the solar chimney can be modified through changes in the geometry of the chimney, in order to adequate them to the type and amount of the drying products. Higher flow velocities are achieved using higher chimneys, and higher temperatures are achieved when the solar collector has a larger area.

A capacity of drying of 6,5 m^3 of products (arranged in layers with thickness of 5 cm) is expected for the solar chimney with the dimensions of the built prototype, if the drying trays were placed between the junction and the middle of the cover radius, using the peripheral area as an air collector.

5. Conclusion

This paper proposes the use of a solar chimney as a radial food dryer. A prototype was constructed in order to evaluate the viability of the device through the characteristic parameters of the flow. The prototype, with a collect area of approximately 500 m^2 and a tower 12,3 m high, has the capacity of drying approximately 6,5 m^3 of products.

The airflow velocities and temperatures were monitored during 24 hours (on the 2nd of March 2003), as well as the incident solar radiation and the ambient air temperature.

The airflow in the interior of the prototype presents a temperature rise of 18ºC at most, related to the external environment temperature, reaching 52ºC. The values encountered for the flow rates varied from 1,0 kg/s to 2,6 kg/s. These values enable the solar chimney to generate airflows with mass flow and temperature values suitable to dry food. Nevertheless, it is necessary to define the most suitable geometry for drying different kinds and amounts of products.

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