ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

TECHNICAL FEASIBILITY ASSESSMENT OF AN ELECTRICAL DRYER FOR BANANA DRYING

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Abstract. *Drying is an important process to food preservation, to reduce moisture content and to increase the shelf life of the agricultural products. Drying can either be done by traditional sun drying or using a dryer. The air in a dryer can be heated by using solar energy, electrical energy or a combination of both energy sources, in hybrid dryers. Solar dryers have their shortcomings, like the variety and unpredictability of the weather. Traditional sun drying, besides the aforementioned shortcomings, also is subject to birds and rodents. Artificial dryer promote a higher quality of the dried products, due to the control of the drying air properties. This work presents a study of the technical feasibility of an electrical dryer. Velocity, temperature, specific humidity and the total energy spent were measured. Experimental tests with and without load were performed inside the prototype. For different temperatures, thermal losses of 5% to 18% were found with no products inside the dryer. Drying tests of bananas showed thermal efficiencies from 69.5% to 76.8% and drying efficiencies from 16.3% to 18.3%.*

Keywords: *Food dryer, Electrical dryer, Efficiency analysis, Banana drying.*

1. INTRODUCTION

Drying is a unitary operation of moisture removal due to simultaneous heat and mass transfers. It is one of oldest methods of food preservation, which provides lighter weight for transportation, smaller space for storage, and longer shelf-life (Ertekin and Yaldiz, 2004; Doymaz, 2007). In natural sun drying, the solar radiation heat is used to evaporate the moisture present in the product. It requires little investment, but since the sunshine is intermittent and varying, the product may over/under dry (Murthy, 2009). Besides, it usually presents significant losses due to the reabsorption of humidity by the product during the rainy period; to contamination from pathogenic gems, rodents, birds and insects, and to enzymatic reactions, caused by heterogeneous and insufficient drying (Ertekin and Yaldiz, 2004; Raouzeos and Saravacos, 1986). Solar dryers are relatively simple devices. They range from very primitive ones used in small, desert or remote communities up to more sophisticated industrial installations, although the latter are still very few and under development (Belessiotis and Delyannis, 2011). They can be classified by various modes, as according to the type of dryer, to the operation temperature or the material to be dried, to type of operation, e.g., batch or continuous, etc. Leon et al. (2002) give a systematic classification based on design and mode of utilization of solar energy. Although solar drying can be considered as an elaboration of sun drying and an efficient system of utilizing solar energy, it has their shortcomings, like the dependence of the ambient conditions. Besides, solar drying systems must be properly designed in order to meet particular drying requirements of specific products and to give optimal performance. Designers should investigate the basic parameters such as dimensions, temperature, relative humidity, airflow rate and the characteristics of products to be dried (Janjai et al., 2009). In artificial dryers, velocity and temperature of the drying air are controlled, improving the final quality of the dried products. Electrical dryers can reduce food losses of natural sun dryers (Ertekin and Yaldiz, 2004; Doymaz, 2007). However, there is significant amount of energy consumption (fossil or electric) to heat and move the airflow.

In this way, it is necessary to develop efficient and low costs dryers. Recently, many studies present efficiency analysis of dryers by several researchers (Aghbashlo et al., 2009; Akpinar et al., 2005; Akpinar et al., 2006; Celma and Cuadros, 2009; Ceylan et al. 2007; Colak and Hepbasli, 2007, Midilli and Kucuk, 2003; Syahrul et al., 2002). This work proposes to study the technical feasibility of an electrical dryer to banana drying. Experimental tests with and without load were conducted in the prototype and the air velocity, the temperature, the humidity and the energy spent were monitored. In the tests without load, the airflow temperature was fixed (50°C, 55°C, 60°C, 65°C and 70°C), and the performance parameters were determined for each value. In the experimental runs for the drying of bananas, the airflow temperature was fixed (50^{o}C, 60^{o}C, 70^{o}C) and the maximum drying time was defined as 12 hours. The drying curves were obtained for each temperature.

2. MATERIALS AND METHODS

2.1. Design and construction of the system

An electrical dryer was designed, constructed and installed in Belo Horizonte, Brazil. The dryer consists mainly of a drying chamber with an electrical resistance. Figure 1 shows the corresponding scheme of the dryer. The prototype has a wood structure, with small weight and great mechanical resistance (Fig. 1). The dryer dimensions are 3 m (length), 1.1 m (height), and 0.9 m (width). A structure has been arranged in the drying chamber, in order to support six trays in which the products will be placed for drying. The dimensions of these trays are 0.7m x 0.5m, corresponding to an area of 2.1m^2 and useful area of 1.75m^2. As suggested by Leon et al. (2002), the drying capacity of a dryer is approximately 4kg of fresh product for each 1m^2 of tray area. Therefore, the drying capacity is estimated in 7kg.

The dryer wall is composed by a sheet of galvanized steel and an internal layer of glass wool. The air enters the device through a tubular inlet, induced by a fan, and is heated by an electrical resistance. The heated air crosses the galvanized wire grid tray with the products to be dried, removing moisture and leaves the dryer through a rectangular exit.

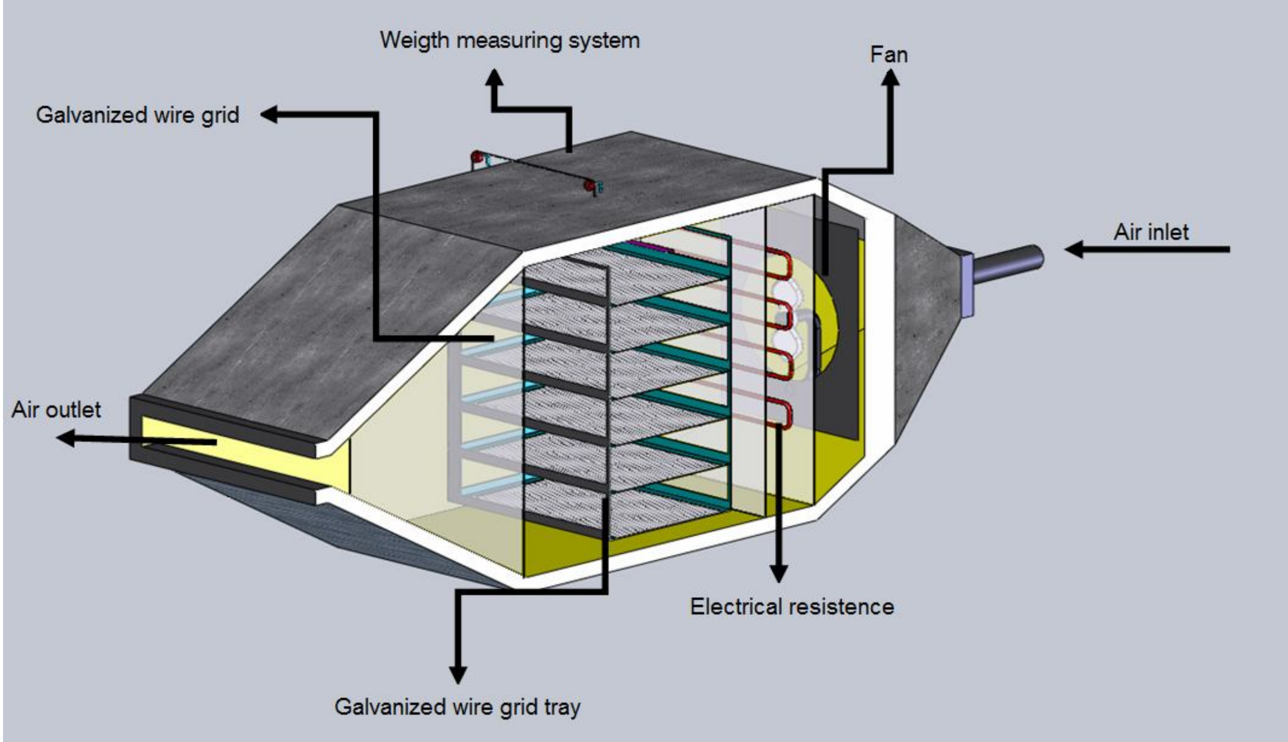

Figure 1. Schematic representation of the dryer

The dryer's geometric configuration and the presence of three vertical galvanized wire grid promote an uniform air velocity distribution. The drying trays are fixed in a suspended structure, connected to a load cell by a steel cable, for instantaneous moisture content measurement. The product is inserted and removed from the drier through a front door.

2.2. Instrumentation and experiments

To collect all data needed to evaluate the dryer's performance, several systems to perform measurements and data acquisition were utilized. A Wattmeter (ICEL AW-4700, with uncertainty of ±3%) was used to measure the total active energy used by the dryer. Thermometers (ICEL TD-880, with maximum uncertainty of ±0.8°C) were used to measure the ambient temperature and the drying air temperature inside the dryer. The air velocity at the inlet of the dryer was measured with a propeller thermal-anemometer (ICEL model AN-4870, with a global uncertainty of ±3%). The product weight loss during the drying process was measured with a digital analytical balance (with uncertainty of ±0.2g) and tension type load cell (uncertainty of ±3%). An uncertainty analysis in accordance with a 95 percent confidence interval was performed to estimate the errors in the experimental data (Moffat, 1988; ISO, 1998).

ISSN 2176-5480

The thermal tests were performed initially without load inside the dryer and in steady-state conditions. These first tests were carried out in order to adjust the internal airflow, temperature, and sensors position. The dryer's temperature was fixed in 50°C. The air flow velocity and temperatures at the inlet and the outlet of the dryer were measured at every 5 minutes, during a 1-hour period, as well as the total energy used in the dryer. In order to minimize the uncertainties, the test was repeated 5 times. The same procedure was adopted for temperatures of 55°C, 60°C, 65°C and 70°C. With the experimental data, the heat losses and the dryer's efficiency were determined.

In the drying tests, the sampling was of banana *Musa balbisiana*. All the samples presented the same size and maturation stage at the beginning of the drying process. The ripened products were submitted to a pre-treatment, according to Aguirre and Gasparino Filho (1999) considerations.

There are 6 trays in the dryer, each one subdivided in 4 smaller trays, resulting in 24 trays. An amount of approximately 7 kg of bananas were placed onto the 24 trays, corresponding to the maximum drying load capacity of the device. Three tests were performed, with temperatures of 50°C, 60°C, and 70°C. Each test lasted 12 hours. After the end of the test, the final moisture content was determined.

A banana sample was used in the determination of the initial moisture content. After measuring its weight, the product was placed in a muffle furnace with controlled temperature, and submitted to a 105°C temperature, during 24 hours. The products weight was periodically measured to have its instantaneous moisture content determined. The measurement of the electrical energy spent allowed an economic analysis to be performed, as a function of the temperature operation.

3. MATHEMATICAL MODEL

The problem under investigation is based on forced convection of air over wet products inside a dryer. The airflow is heated using an electrical dryer. The thermal behavior of the airflow is described by mass and energy balances in the dryer. It should be stressed that in the balance equations the cumulative terms were neglected, considering that even if the thermodynamics properties change with time, its temporal derivatives are null. Equation (1) presents the general equation of energy conservation of drying air, for steady state conditions (Fox et al., 2010)

$$\dot{Q} - \dot{W} = \dot{m}\left(h_{out} + \frac{V_{out}^2}{2}\right) - \dot{m}\left(h_{in} + \frac{V_{in}^2}{2}\right) \tag{1}$$

Where $\dot{Q}$ is the heat transfer rate, $\dot{W}$ is the power used to operate the dryer, $\dot{m}$ is the air mass flow rate, h_{in} and h_{out} are the specific enthalpies of the airflow at the inlet and outlet, respectively, and V_{in} and V_{out} are the airflow average velocities at the inlet and outlet sections, respectively. Since the products were only heated by the electrical resistance, $\dot{Q}$ represents the thermal losses.

The useful energy used to raise the airflow temperature (Ec) when the dryer was empty, was determined based on the airflow mass, on the airflow specific heat at constant pressure (c_P) and on the ambient (T_{in}) and on the outlet (T_{out}) airflow temperatures.

$$E_C = \int \dot{m}\left(h_{out} - h_{in}\right)dt \tag{2}$$

The total energy (E_T) used to operate the dryer can be calculated by

$$E_T = \int \dot{W} dt \tag{3}$$

Finally, the thermal efficiency η_T can be defined by Leon at al. (2002)

$$\eta_T = \frac{E_C}{E_T} \tag{4}$$

In drying tests, experimental results are usually presented in the form of moisture ratio versus drying time. The moisture content expressed on wet basis is the weight of moisture per unit of wet material (Belessiotis and Delyannis, 2011)

$$W = \frac{m_w}{m_w + m_d} \tag{5}$$

In the previous equation, m_w represents the mass of wet material and m_d is the mass of dry material. The instantaneous moisture content was obtained by

$$W_i = 1 - \frac{m_w + m_d}{m_i} \tag{6}$$

m_i is the instantaneous mass of the products, measured using a load cell.

The drying efficiency is defined as the ratio of energy required to evaporate the moisture E_v to the energy supplied to the dryer E_T (Boughali et al., 2009)

$$\eta = \frac{E_V}{E_T} \tag{7}$$

The amount of energy required to evaporate the moisture is determined as the product between the water vaporization enthalpy (h_{lv}) and the mass of water removed from the products (m_{H2O}).

$$E_V = m_{H2O} . h_{lv} \tag{8}$$

4. RESULTS AND DISCUSSION

Figure 2 presents the results for the thermal test without load, for the temperature of 55ºC. It can be noticed that the inlet and outlet temperatures are approximately constants. There is a minor variation of the mass flow rate inside the dryer.

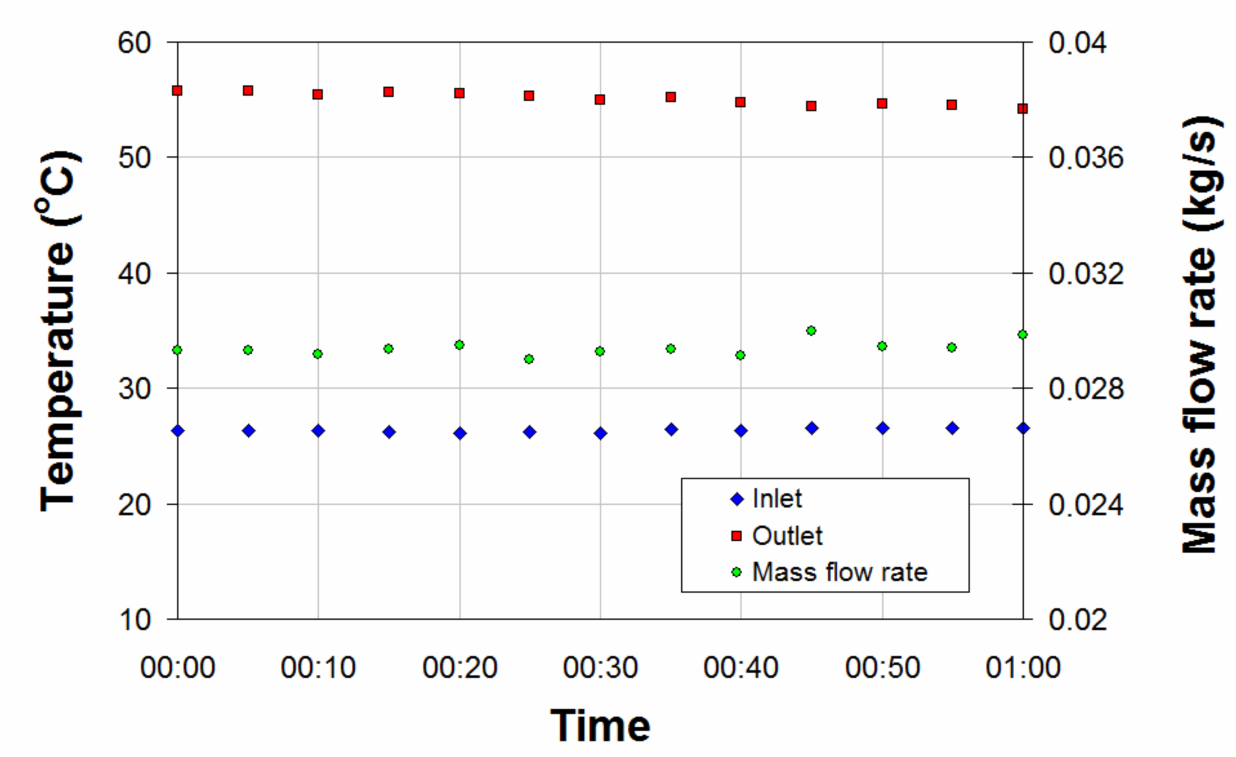

Figure 2. Parameters of the drying air for the 55°C thermal test

The thermal efficiency is a very useful parameter to evaluate the dryer. It is observed (Figs. 3-5) that it increases with mass flow rate and decreases with temperature rise and energy consumption. It is generally known that the collector efficiency increases with the mass flow rate (Boughali et al., 2009). The outlet airflow temperature is defined by the user. The increase of the airflow temperature increases the energy consumption, since more energy is required to heat the airflow. Also, as the outlet temperature increases, the wall temperature and the thermal losses to the surroundings also increase. As a consequence, the thermal efficiency decreases.

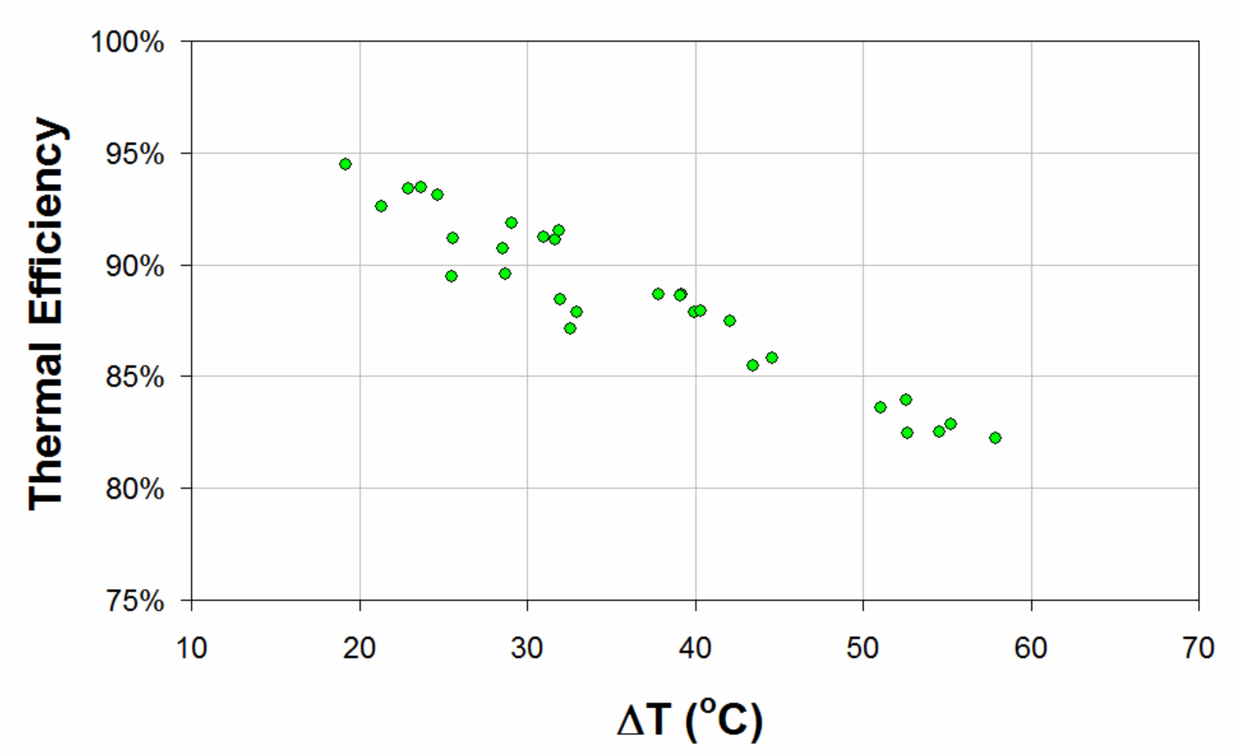

Figure 3. Thermal efficiency as function of temperature rise, with mass flow of (0.0290±0.0016)kg/s

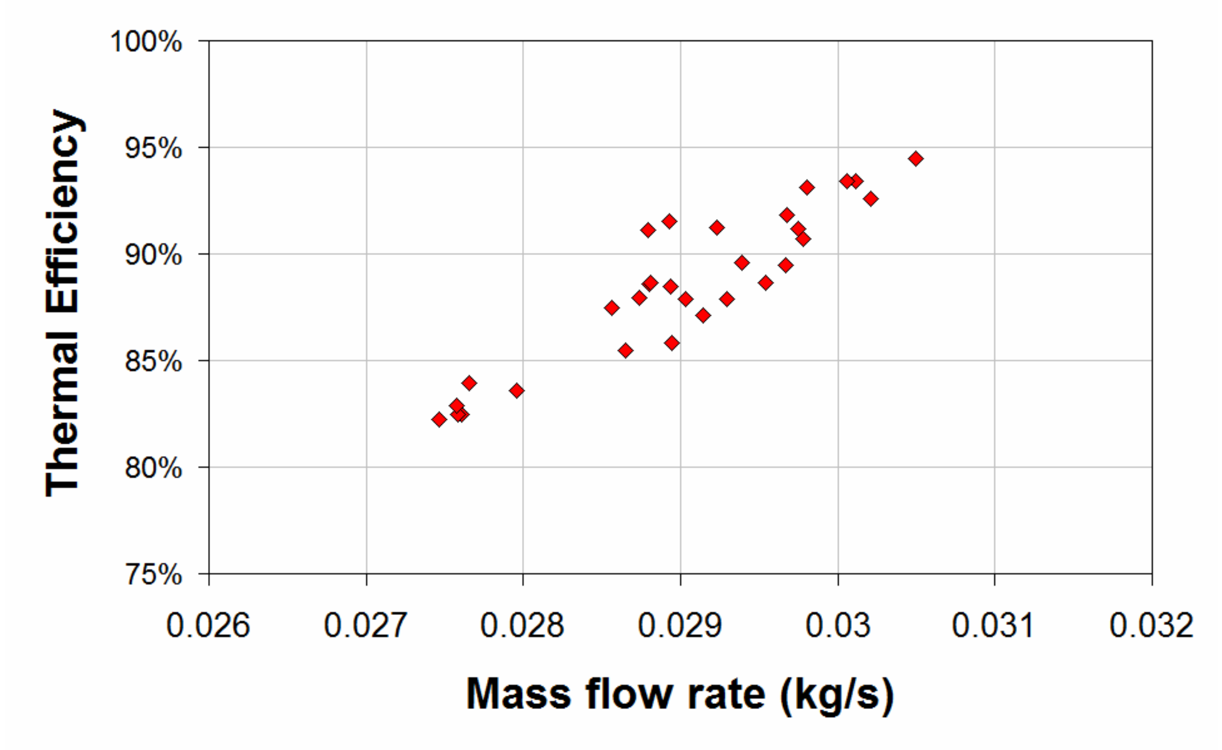

Figure 4. Thermal efficiency as function of mass flow rate, temperature rise, with temperature rise of 19°C until 58°C

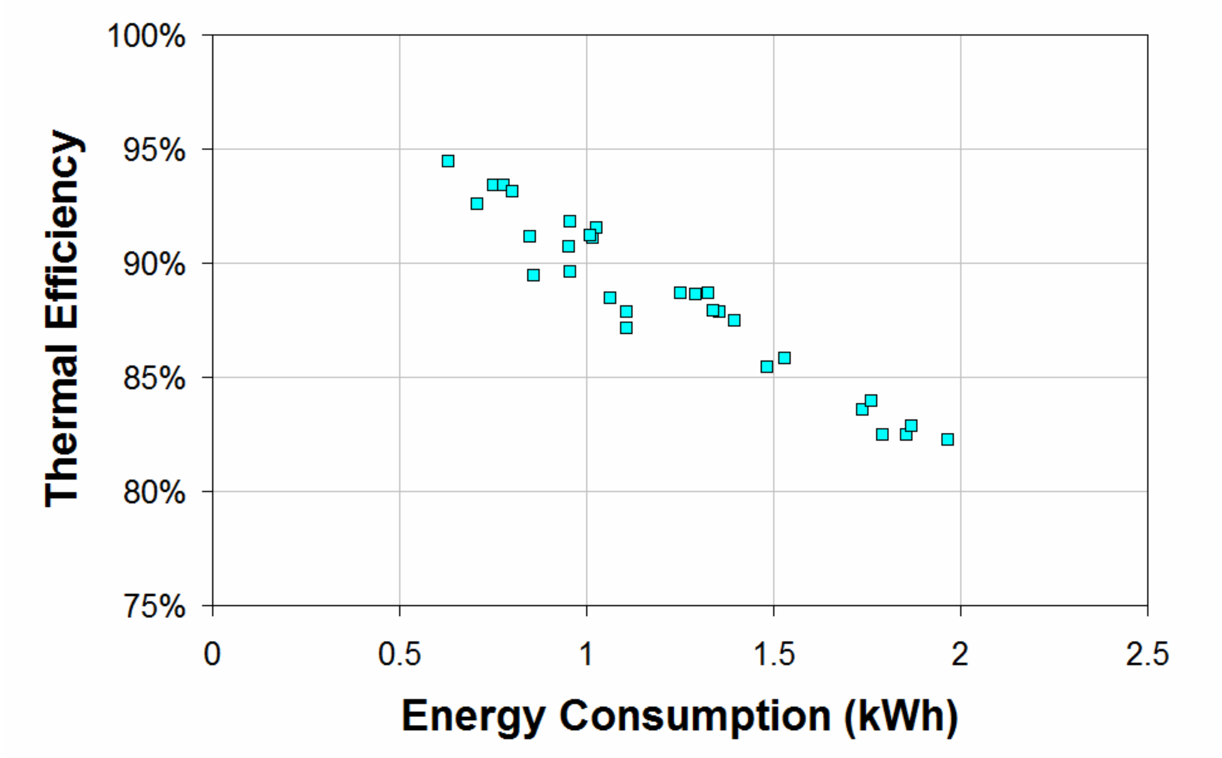

Figure 5. Thermal efficiency as function of energy consumption

Figure 6 presents the results for the drying tests. The air enters in the device at ambient temperature that ranged from (18.1±0.6)^{o}C to (31.9±0.6)^{o}C during the tests. The outlet temperature is a function of the temperature defined by the user, and varied around the set value. When compared to Fig. 2, a wider range of the outlet airflow temperature is observed, since a new variable was inserted (the wet products), making more difficult to control the operation of the electrical resistance.

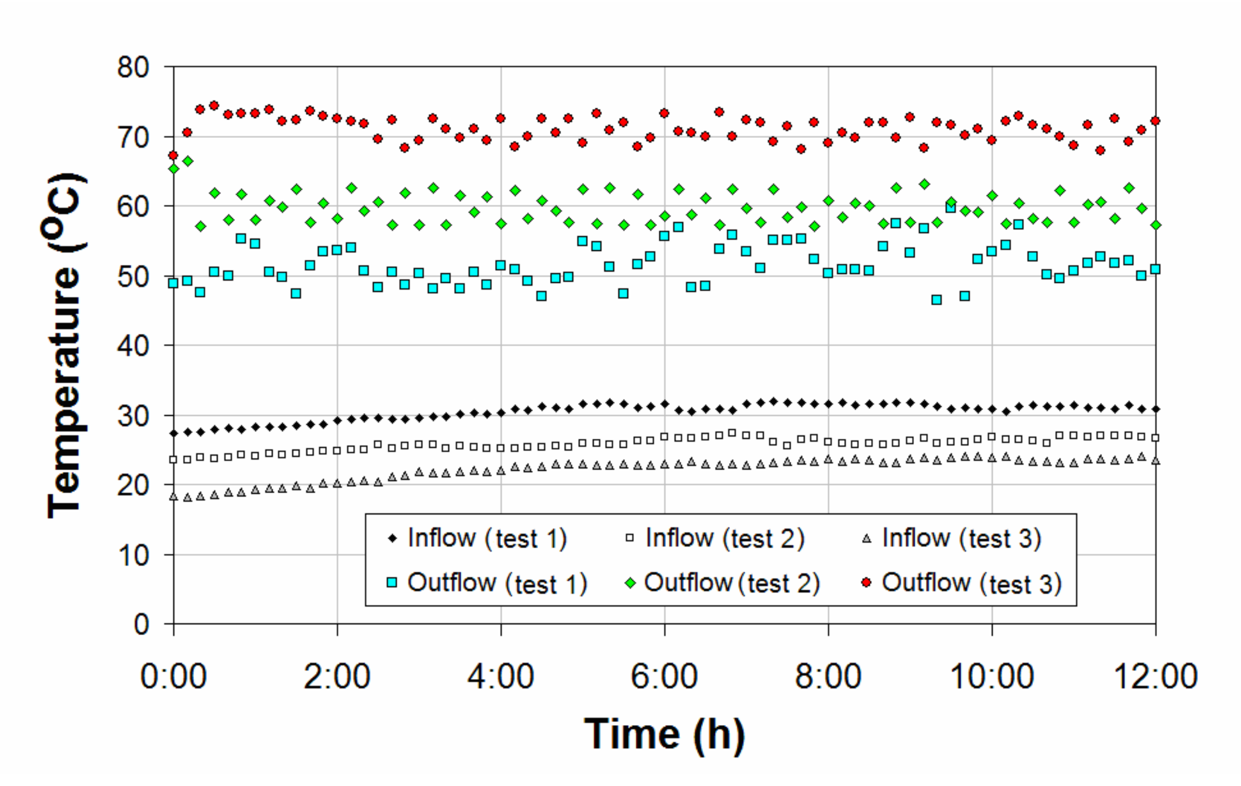

Figure 6. Temperature distribution: drying test

The banana's drying curves are presented in Fig. 7. The initial moisture content of the samples was 80.7%, 76.9% and 74.3% (wet basis) in the drying tests at 50°C, 60°C and 70°C, respectively. Since the tests did not occur simultaneously, the initial moisture content was different for each test. After 12 hours, the moisture content was reduced for 58.7% at 50°C, 43.9% at 60°C and 28.5% at 70°C. It can be seen that, as expected, a higher temperature leads to less drying times. In order to compare the results for the temperatures, a reference moisture content of 58.7% (relative to the higher temperature) was defined. The time required for the samples to achieve the reference moisture content was 12h, 6:50h and 3:30h for the temperatures of 50°C, 60°C, and 70°C, respectively.

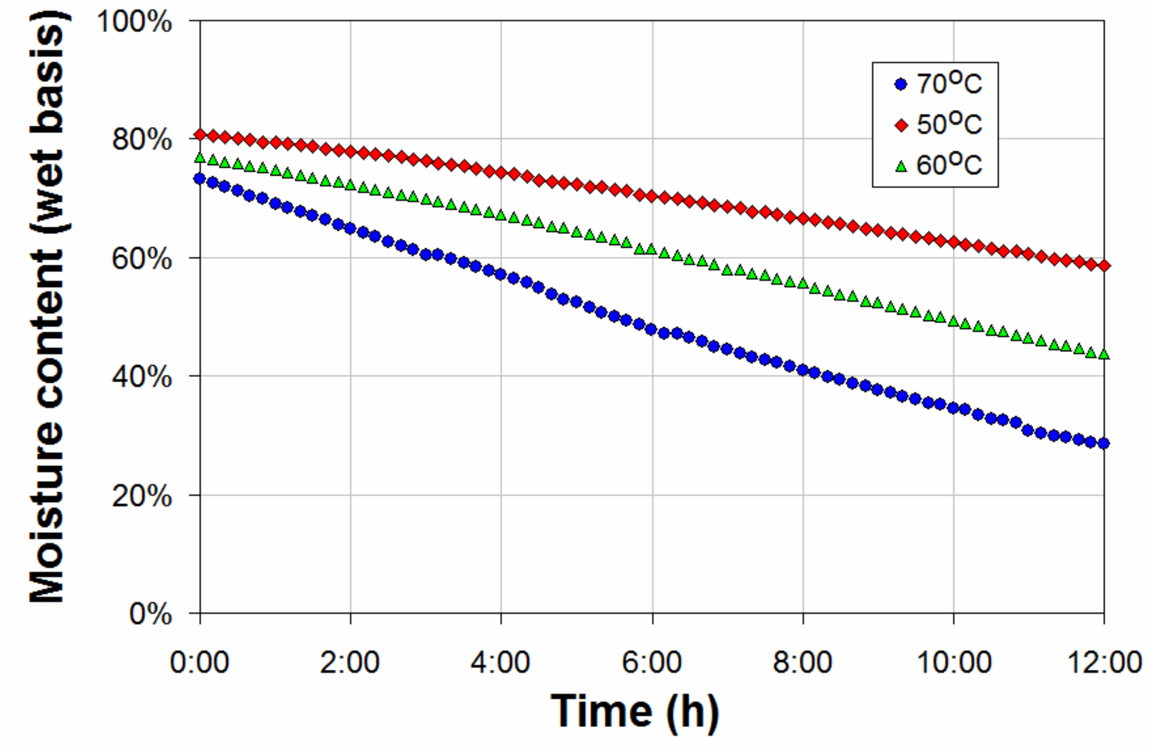

Figure 7. Banana drying curves

The total energy used during the drying tests can be observed in Fig. 8. The energy consumption after 12 hours was (10.4±0.3) kWh at 50°C, (15.4±0.5) kWh at 60°C and (21.7±0.7) kWh at 70°C. It can be noticed that the power consumption increases with the air temperature. Nevertheless, the energy consumption required to achieve the moisture content reference was (10.4±0.3) kWh at 50°C, (9.3±0.3) at 60°C and (7.3±0.2) kWh at 70°C. When these values are taken into account, the higher drying temperature seems more feasible.

The efficiency was obtained for the tests with and without load. It is an integral value, instead of an instantaneous value, since it is obtained after the determination of the total amount of electrical energy used in the dryer during the test.

The drying efficiencies obtained for 50°C, 60°C and 70°C were, respectively, 18.1%, 18.3% and 16.3%, showing that higher efficiencies were obtained for lower temperatures. This behavior is explained by the fact that all the drying tests were performed for the same time period (12 hours). The drying rate is a very important parameter used to evaluate the drying process. It is a measure of the velocity of the drying, defined as the temporal derivative of the moisture content (Boughali et al., 2009). The drying rate is determined by the temperature and moisture content of the product, as well as the temperature, relative humidity and velocity of the drying air. Usually, the drying rate has three different phases. In the first, the temperature of the material is heated until the drying temperature is achieved; it is a phase of increasing drying rate. The second phase is a constant-rate drying, and the third phase is a falling rate drying, where flow of moisture from mass interior decreases continuously (Belessiotis; Delyannis, 2011). Using a higher temperature, the second phase is reduced, and lower moisture content is reached in a lower time. Therefore, the falling rate drying starts, reducing the efficiency of the process.

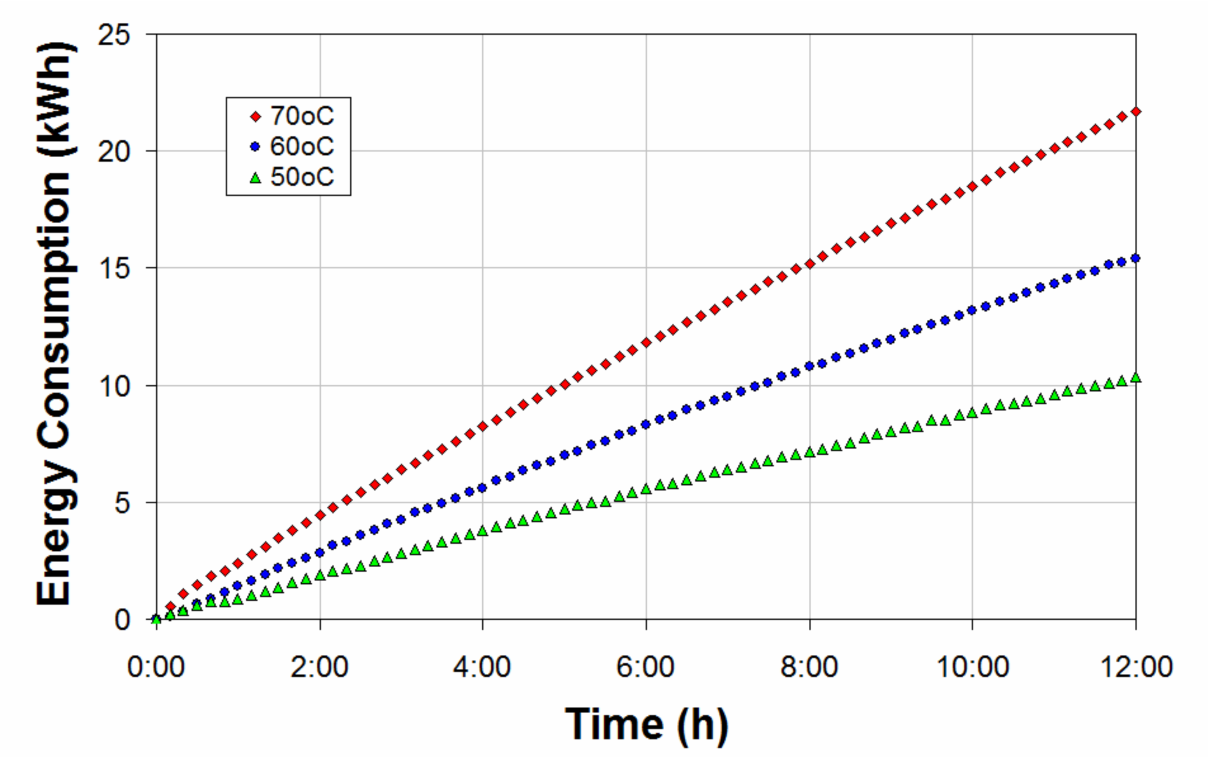

Figure 8. Total energy used: drying test

5. CONCLUSIONS

In this work an electrical dryer was designed and constructed for the drying of bananas. The construction of the prototype was made in wood, presenting small weight, low cost and good mechanical resistance. The dryer was tested with and without load, with the measurement of velocity, temperature, humidity and energy spent. The influence of the airflow temperature in the behavior of the dryer was analyzed.

In the tests without load, it was observed a maximum increase of temperature (corresponding to the difference between the airflow temperatures at the outlet and inlet) of 58°C. Also, there was a small temporal variation of the airflow parameters, indicating a good response of the control system.

In the drying tests, it was fixed a period of drying of 12 hours. Since the higher airflow temperature promoted a lower drying time, it was defined a reference moisture content. It was observed that the time required for the samples to achieve this reference moisture content was higher for the lower airflow temperature.

When compared the energy spent in the dryer for the different airflow temperatures, it was observed that the higher temperature consumed a larger amount of energy; nevertheless, the energy spent to achieve the reference moisture content was lower for the higher temperature.

The thermal efficiency was higher for the higher temperature, but the drying efficiency was lower for the higher temperature. This behavior can be explained due to the constant period of time of the drying tests. The higher temperature promoted a faster reduction of the moisture content of the products; reducing the velocity of drying and the drying efficiency.

6. ACKNOWLEDGEMENTS

The authors are thankful to FAPEMIG and CEFET-MG for the financial and structure support.

7. REFERENCES

Aghbashlo, M.; Kianmehr, M. H.; Arabhosseini, A., 2009. “Performance analysis of drying of carrot slices in a semi-industrial continuous band dryer”. *Journal of Food Engineering*, Vol. 91, pp. 99–108.

Aguirre, J. M.; Gasparino Filho, J., 1999. “Desidratação de Frutas e Hortaliças: Manual Técnico do Instituto de Tecnologia de Alimentos”. *Campinas: ITAL.*

Akpinar, E. K. et al., 2005. “Energy and exergy of potato drying process via cyclone type dryer”. *Energy Conversion and Management*, Vol. 46, pp. 2530–2552.

Akpinar, E. K. et al., 2006. “The first and second law analyses of thermodynamic of pumpkin drying process”. *Journal of Food Engineering*, Vol. 72, pp. 320–331.

Belessiotis, V.; Delyannis, E., 2011. “Solar drying”. *Solar Energy*, Vol. 85, pp. 1665–1691.

Boughali, S. et al., 2009. “Crop drying by indirect active hybrid solar – Electrical dryer in the eastern Algerian Septentrional Sahara”. *Solar Energy*, Vol. 83, pp. 2223–2232.

Celma, A.R. and Cuadros, F.,2009. “Energy and exergy analyses of OMW solar drying process”. *Renewable Energy*, Vol. 34, pp. 660–666.

Ceylan, I.; Aktas, M.; Dogan. H., 2007. “Energy and exergy analysis of timber dryer assisted heat pump”. *Applied Thermal Engineering*, Vol. 27, pp. 216–222.

Colak, N.; Hepbasli A., 2007. “Performance analysis of drying of green olive in a tray dryer”. *Journal of Food Engineering*, Vol. 80, pp. 1188–1193.

Doymaz, I., 2007. “Air-drying characteristics of tomatoes”. *Journal of Food Engineering*, Vol. 78, pp. 1291–1297.

Ertekin, C.; Yaldiz, O., 2004. “Drying of eggplant and selection of a suitable thin layer drying model”. *Journal of Food Engineering*, Vol. 63(3), pp. 349–359.

Fox, R. W.; McDonald, A. T.; Pritchard, P. J., 2010. “Introduction to Fluid Mechanics”, *John Wiley & Sons Inc*.

ISO (International Organization for Standardization), 1998. “Guide to the Expression of Uncertainty in Measurement, GUM”, Geneva, Switzerland.

Janjai, S. et al., 2009. “Experimental and simulated performance of a PV-ventilated solar greenhouse dryer for drying of peeled longan and banana”. *Solar Energy*, Vol. 83, pp. 1550–1565.

Leon, M. A.; Kumar, S.; Bhattacharya, S. C., 2002. “A Comprehensive Procedure for Performance Evaluation of Solar Food Dryers”. *Renewable and Sustainable Energy Reviews*, Vol. 6, pp. 367-393.

Midilli, A.; Kucuk, H., 2003. “Energy and exergy analyses of solar drying process of pistachio”. *Energy*, Vol. 28, pp. 539–556.

Moffat, R. J. 1988. “Describing the uncertainties in experimental results”. *Experimental thermal and fluid science*, Vol. 1(1), pp. 3-17.

Ramana Murthy, M.V., 2009. “Areview of new technologies, models and experimental investigations of solar driers”. *Renewable and Sustainable Energy Reviews*, Vol. 13, pp. 835–844.

Raouzeos, G.S.; Saravacos, G. D., 1986. “Solar drying of raisins”. *Drying Technology*, Vol. 4, pp. 633–649.

Syahrul, S.; Hamdullahpur, F.; Dincer, I., 2002. “Energy analysis in fluidized bed drying of wet particles”. *International Journal of Energy Research*, Vol. 26(6), pp. 507–525.

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