XVII^th^ World Congress of the International Commission
of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

# EXPERIMENTAL STUDY OF BANANA DRYING ENERGY COSTS IN A PROTOTYPE ELECTRIC DRIER

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**CSBE101329 – Presented at Section VI: Postharvest Technology, Food and Process Engineering Conference**

**ABSTRACT** This work is devoted to the experimental study of banana drying energy cost. A prototype drier with a capacity of 120 kg of fresh produce, meeting the need of a producer, was designed and built. The system was then used to undertake an experimental study on energy costs of banana drying, taking into account the influence of aerodynamic settings within the drying enclosure. The results showed that the final sought water content, approximately 20% in dry base, is obtained in 35 hours when drying is performed at 60°C without air recirculation; the power consumption was 83 kWh. The power consumption was lower (only 30 kWh) when drying at lower temperatures combined with air recirculation during the process. The combination of the aerodynamic settings would therefore make it possible to divide the energy drying cost by three but would consequently increase operation time. These results offer an interesting indicator on energy constraints related to this type of processing for banana conservation, a strongly perishable product of great economic importance for the Subsaharan African countries in particular.

**Keywords:** Drying, banana, kinetics, electric drier, energy cost.

**INTRODUCTION.** Drying food products is a vital technique for developing countries whose food self-sufficiency rests primarily on agriculture. It consists in reducing the activity of water in these products up to a value which enables to preserve while respecting some related quality standards and guaranteeing, for the production chain, reasonable pace and cost (Bimbenet, 1978).

Tropical fruits, in this case banana, are extremely important for the economies of several Sub-Saharan African countries. In Cameroon for example, banana is produced industrially and traditionally throughout the year in the equatorial zone; 14 % of this production is directly intended for export. In primarily agricultural rural areas, after-harvest losses are estimated at up to 60 % (Ministry of Agriculture, 1986) due to the landlocked nature of most of these areas (absence of road infrastructures) and lack of preservation equipment. Initially, the main interest of this preservation technique was to make up for the seasonal gap between most food products and to spread out their consumption over the year. Increasingly, the revalorization of these products is continuing thanks to the opening towards foreign markets (European and African). Banana, in this case stabilized by a drying operation will have export outlets and constitute an opportunity for revalorizing production surpluses.

In most cases, the structure of food products is variable both in terms of space and time. During drying, their surface is reduced due to the contraction of tissues which partly compensates for water departure. As a result, all the parameters which depend on the internal dimensions change. For this reason, several authors have devoted their work to the concept of characteristic curve of drying to describe the behaviour of the drying kinetics of these products (Jannot et al, 2004; Talla et al, 2001; Ahouannou et al, 2000; Coutinho et al, 1997; Kiranouidis et al, 1997; Drouzas and Schubert, 1996; Queiroz and Nebra, 1996; Belahmidi et al, 1993; Desmorieux and Moyne, 1992). Sorption isotherms, one of the major problems of stabilization and preservation of these products by drying, constitute one of the preferred directions of research for some authors (Talla et al, 2005; Arogba, 2001; Vijayanand et al, 2000; Mir and Nath, 1995; Myhara et al, 1998; Tsami et al, 1999). Others focused their attention on the phenomenon of withdrawal and the diffusion coefficient during the fruit drying operation (Talla et al, 2004; Krokida and Maroulis, 1997; Mauro and Menegalli, 1995).

Concerning the energy cost of drying fruits, some authors were interested in the source of energy used for the drying operation (Schirmer et al, 1996; Drouzas and Schubert, 1996; Bowrey et al, 1980) but as far as we know, literature so far has no information concerning the energy cost of drying banana in particular. Such information on the energy constraints would constitute an interesting indicator of decision-making for such a stabilization approach of this product in view of preservation, taking into account its importance for the economy of Sub-Saharan African countries in particular.

The objective of this work is to determine the energy cost of drying banana in a prototype electric drier with a capacity corresponding to the need of a producer, designed and produced for this purpose. This study takes into account the influence of aerodynamic parameters, in the drying chamber, on this cost.

## 1. Material and methods

### 1.1. Experimental device

The experimental device is a drying chamber which enables to subject food products to air temperature, speed and moisture at values controlled by a control system. This parameter control would enable to better master the understanding of physical phenomena governing the evolution of heat and mass transfers during the drying of these products. It is a static device (supports of fixed products). Air circulation in the drier can be opened or recycled. This device schematized on figure 1 includes:

- A parallelepipedic structure (200 cm × 102 cm × 192 cm) made up of:
- Cross-section, two compartments: the lower compartment which is used as drying chamber and the top compartment which serves as housing for the sheath and its various accessories. At the level of the air distribution corridor there is a system for housing the valve guillotine which enables to operate half of the drier. The air

evacuation corridor on its part, has a valve guiding system which enables to adjust the ventilation rate;

- Seen from outside, the front presents the two flaps of the door leading to the drying chamber and a certain number of elements involved in starting and operating the drier (control panel, electric meter, speed variator). The left hand side includes two rectangular section openings, one enabling aspiration and the other one air exhaust. The back comprises twelve (12) small circular section openings per compartment, enabling to engage the probes for air speed and temperature measurement;

- A heating sheath which includes:

- two centrifugal fans with a power of 350 W, single phase each; each fan has a rated air flow of 1 500 $m^3h^{-1}$;
- a bank of resistant heaters with a total power of 16 kW operating on a three-phase current;
- a ventilation shaft made up of a concentrator which connects the fans to the resistance battery and a diffuser which adapts the outlet of the heater battery and the inlet of the air distribution corridor. To ease the homogeneous distribution of air layers on the trays, two horizontally tilted deflectors with an angle of 22.5° on both sides of the symmetry axis of the diffuser are fixed upstream the diffuser.

- An air distribution corridor made up of:
- a parallelepipedic corridor of a horizontal section of 12 cm x 86 cm and laid out on the right hand side of the drying chamber and receiving hot air coming from the heating system;
- air intake ports in the enclosure (rectangular section) whose dimensions 2 cm × 86 cm are performed throughout the left wall of the chamber of this corridor to the right of each tray;

- A drying chamber designed to ease parallel air flow on the products; it comprises two columns of 12 trays each separated from each other by full sheets. This arrangement aims at achieving homogeneous product drying, in the enclosure within a given time, without worrying about changing trays generally necessary in driers with perpendicular air flow in relation to the products;

- Trays designed to ease water evaporation throughout the entire surface of the product. The openings performed on each tray, on the front side in relation to air flow, enable the entire heat-transferring surface to be in contact with the entraining fluid;

- An air exhaust and recirculation corridor, of the same dimension as the distribution corridor, which collects air coming from the drying chamber. This air is released entirely or partially into the atmosphere via the exhaust opening located under. The recirculated air flow is adjusted by partially (or totally for a zero recirculation rate) resealing the exhaust corridor by a valve system;

- Aspiration of new air by forced convection, ensured by upper opening performed on the left hand side of the drier.

- An electric variator enables to readjust the air flow according to the desired value;

- An integrated control console associated with the heater battery for temperature control in the drying chamber, capable of bearing a maximum power of 22.8 kW; the console is equipped with a PID type regulator, a contactor serving as the power device and of a platinum probe of the "Pt100 ohms/0°C" type with a temperature range between 0 and 300°C;
- A three-phase electric meter of 60 amps for recording energy consumption.
- An electronic precision scale “Mettler” ± .001 g used for acquiring information relating to the mass of the products;
- Probes for measuring air temperature and hygrometry enabling the transmission of information to the acquisition system;
- A hot wire anemometer for controlling the rate of air flow in the drying chamber;
- A data acquisition unit connected to a microcomputer equipped with the appropriate software which enables visual acquisition in time, data storage and processing.

### 1. 2. Description of the Experimental Protocol

- Measurement of various sizes

Air is aspirated by two centrifugal fans of 350 W directed towards the heater battery using a concentrator element. It is then heated until the set temperature and directed towards the distribution corridor by an air vent where it is distributed in the drying chamber including 12 trays per compartment, i.e. 24 trays in all. These trays of .645 $m^2$ each are in woven "Nylon" wire, on which rests a screen made with glass fibre material to better resist high temperatures. From one level to another the trays are separated by galvanized full sheets. This arrangement eases, on the one hand, parallel air flow in relation to the product and, on the other hand, an almost uniform drying of the food products in the course of time. The average air speed measured during the tests using a hot wire anemometer is worth 2.06 $ms^{-1}$ for loading densities from 4.13 to 5.24 $kgm^{-2}$ of products. The temperature at the inlet of the drying chamber is maintained at the instructed value thanks to the PID control system.

All the measured sizes are recorded every hour for 5 hours, then every 2 hours for 10 hours and finally every 5 hours for the remainder of the drying time estimated at 72 hours maximum for banana. The continuous acquisition of dry and wet temperature during the aspiration of the whole and along the trays located at the same level or not in the drying chamber is ensured by thermoelectric couples of the K type with a precision of ± .5°C connected to the data acquisition unit. Mass measurements are taken in a discontinuous manner by weighings using an electronic precision scale ± **.**001 g. The relative humidity of the ambient air are measured directly by means of a thermo-hygrometer with sensitive key and digital display. The air flow rate in the drying chamber is measured by placing the probe of the hot wire anemometer on each of the 12 cross-sections of air discharge within the test vein. We vary this speed by decreasing the air flow forced into the drying chamber by means of the speed variator operating the fan and assembled on the control panel on the front view of the drier.

The block test, intended essentially to measure the air distribution speed in the drying chamber and to carry out the readjustments necessary to achieve homogeneous distribution as much as possible, preceded the tests in performance test. Speed measurements are taken at three points midway each tray: at both ends and the middle. By readjusting the speed variator for an air flow rate of approximately 2.0 ms$^{-1}$ in the chamber, we measured in neutral, on the twelve trays, average speeds of 2.08, 2.04 and 2.05 ms-1 respectively at the first end, in the middle and at the second end of these trays. There are equally average differences **.**07 ms$^{-1}$ at the ends and **.**04 ms$^{-1}$ in the middle of the trays. Figure 2 gives the profiles of speeds obtained during block tests.

- Experimental Procedure

**a) Experimental Conditions**

The various set parameters (temperature, relative humidity and air speed) are displayed on the control console of the control system. The products meant for drying are laid out on the various trays in a thin layer then placed in the drying chamber, parallel to the hot air flow. The start buttons of air circulation, heating and humidification are then engaged. After ten minutes, steady operation is established. The third tray and the ninth of each compartment, representatives of the overall behaviour of the drying kinetics in the drier given their geometrical position, are model trays. The measurement enables to obtain the variation of mass of the samples of these model trays in the course of time. Drying is interrupted after 72 hours maximum, when the final water content of the product is between 10 and 20 % kg water (kg ms)$^{-1}$ as recommended in the literature (Collection « Le point sur », 1986).

**b) Presentation of the Samples**

The products undergo treatment by washing with water, before being peeled and cut up according to the desired size and form. The bananas used in all the tests have an average diameter of 30 metres. They are cut up transversely in pieces of 50 mm then each piece is split longitudinally in four equal cylindrical sectors.

## 2. Results and Discussion

### 2.1. Experimental Results

A whole of four tests in load were carried out on banana with an absolute humidity of the air practically constant and equal to **.**02 kg water (kg as)$^{-1}$ and an average speed of air circulation of 2.06 m.s$^{-1}$. Two tests were conducted respectively at fixed temperatures of 50 and 60°C without air recirculation. A test at 50°C with 50% opening of the air recirculation valve and a test with temperature surge from 40 to 50°C after 21 hours approximately (virtually no more free water in the product) including 50% opening of the air recirculation valve supplemented the series. Table 1 provides the main parameters of the results obtained. Figure 3 a) shows the paces of the drying kinetics for these various tests. Figure 3 b) shows the evolution of the corresponding energy consumptions according to the water content.

### 2.2. Interpretations

Table 1 shows that the final water content of preservation sought, approximately 20% in a dry base, is obtained after 35 hours when drying takes place at 60°C without air recirculation. Energy consumption is therefore 83 kWh. The energy consumed is only 30 kWh for 65 hours of drying at 40°C for approximately 21 hours before proceeding to 50°C then to 50% opening rate of the air recirculation valve. Also for a similar drying time (60 hours), drying at 50°C with air recirculation after 10 hours 30 minutes achieves energy gain of about 40%; the comparison referring to drying at the same temperature without air recirculation. Figure 3 a) shows the influence of various drying conditions on drying kinetics. On this figure, it can be noted that the drying speed evolves in the same direction as the temperature. The curves obtained at 50°C with and without air recirculation virtually merge. The same figure shows that temperature surge causes the curve to converge at 40°C towards the curve at 50°C. Figure 3b), representative of the paces of energy consumption curves (for various conditions of drying banana) according to the average water content, shows that the energy consumption evolves slowly and remains for all the testing conditions below 20 kWh for water content higher than 60 % kge.(kgms)$^{-1}$. In this area, draining free water remains predominant. Thereafter, energy consumption increases rapidly in the absence of air recirculation and owing to the fact that the product only has, essentially, dependent water which is difficult to evacuate.

On the other hand, one can note on the same figure the very significant positive effect of air recirculation and temperature surge on energy consumption: energy consumption during banana drying at 50°C without air recirculation is approximately double energy consumption at the same temperature with air recirculation and virtually triple when there is temperature surge from 40 to 50°C. Figure 4 represents the profiles of energy consumption in the course of time. These curves take almost linear forms with slopes which increase according to the temperature for drying without air recirculation (2.83 kW at 60°C and 1.84 kW at 50°C). One observes a change of slope of the consumption curve in the direction of reduction because of air recirculation (case of drying at 50°C with air recirculation). The association of temperature surge with air recirculation contributes to accelerate drying while leading to the weakest slope of the energy consumption curve (average slope of **.**48 kW for the case of drying with temperature surge and air recirculation from 40 to 50°C) for all the tests conducted.

**CONCLUSION.** The results presented above enable to affirm that the temperature and air recirculation have a very significant effect on energy consumption when drying banana. The drying speed and energy consumption evolve in the same direction as the temperature. Temperature surge therefore causes a decrease in energy consumption at the beginning of drying by a moderate temperature during the drainage phase of free water; at the end of the drying the dissociation of dependent water is supported by increase in temperature. Concerning air recirculation, its effect on the reduction of energy consumption results from the reduction of the thermal difference between air temperatures at the entry and the exit of the heater battery. The optimal operation of the drier would consist in drying the product at 40°C after 24 hours (limited energy consumption) then proceeding to 60°C at 50% of air recirculation for the next 20 hours (gain in time and energy).

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## APPENDIX A

Table 1: Duration of drying and power consumption according to temperature and the opening rate of the recirculation valve

| No. test | θ (°C) | Opening rate of the recirculation valve (%) | X f (% kge/kgms) | Duration drying (h) | E (kWh) | Observations |
|---|---|---|---|---|---|---|
| 1 | 50 | 0 | 19.87 | 60 | 106 | |
| 2 | 50 | 50 | 19.68 | 60 | 64 | Recirculation after 10h 30 |
| 3 | 60 | 0 | 18.99 | 35 | 83 | |
| 4 | 40/50 | 50 | 19.59 | 65 | 30 | Recirculation after 21h 25 |

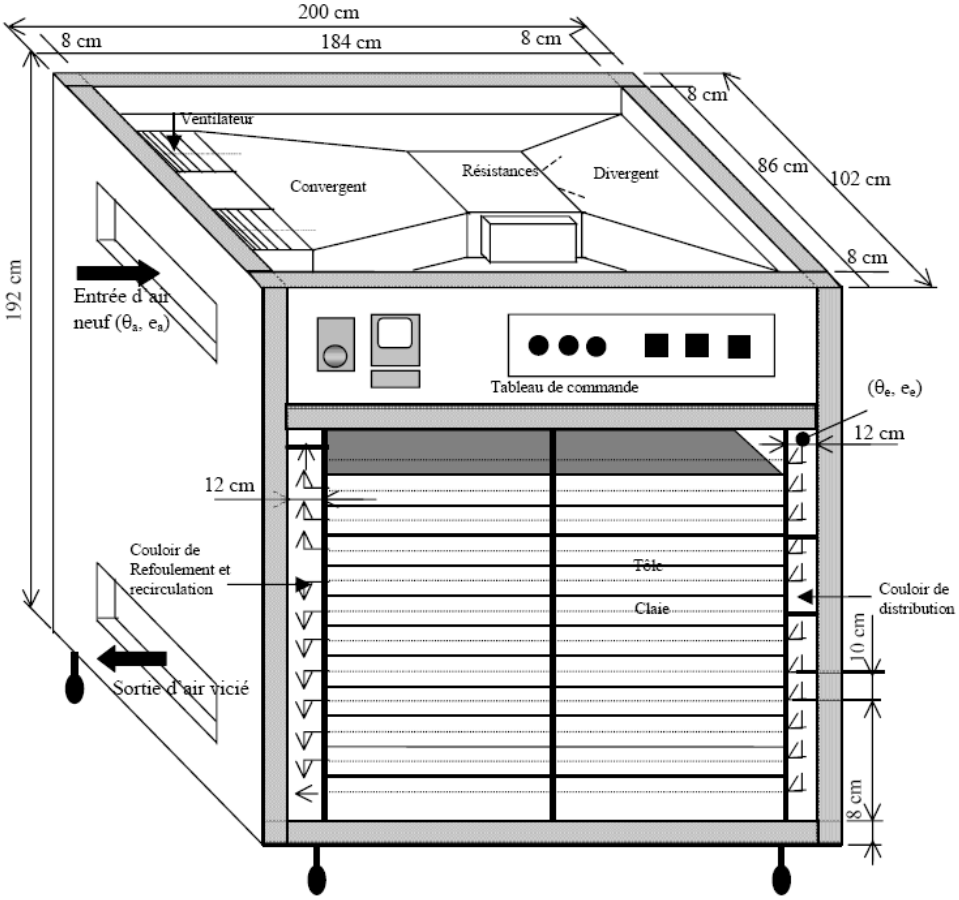


Figure 1: Experimental design

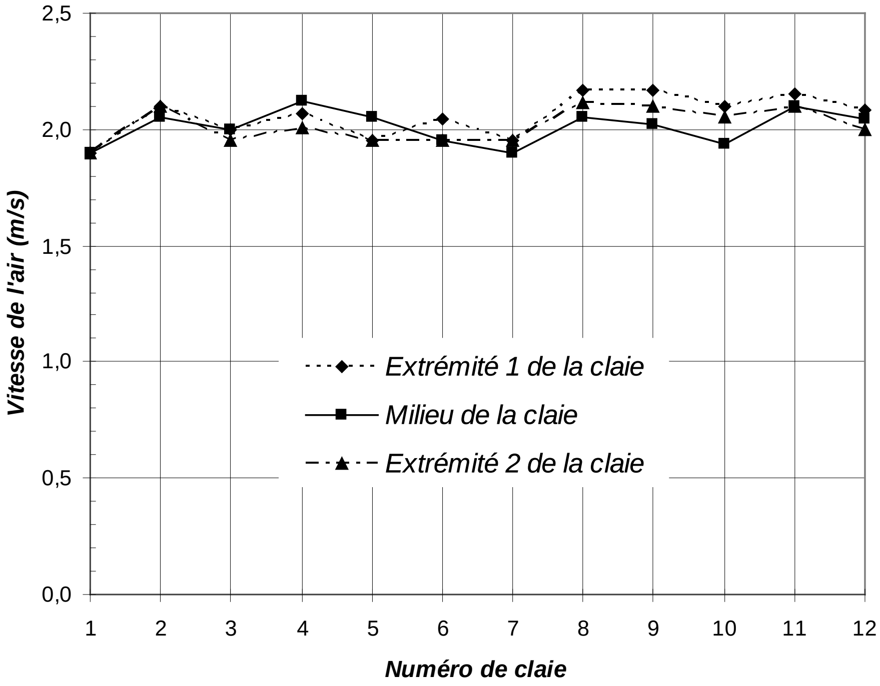
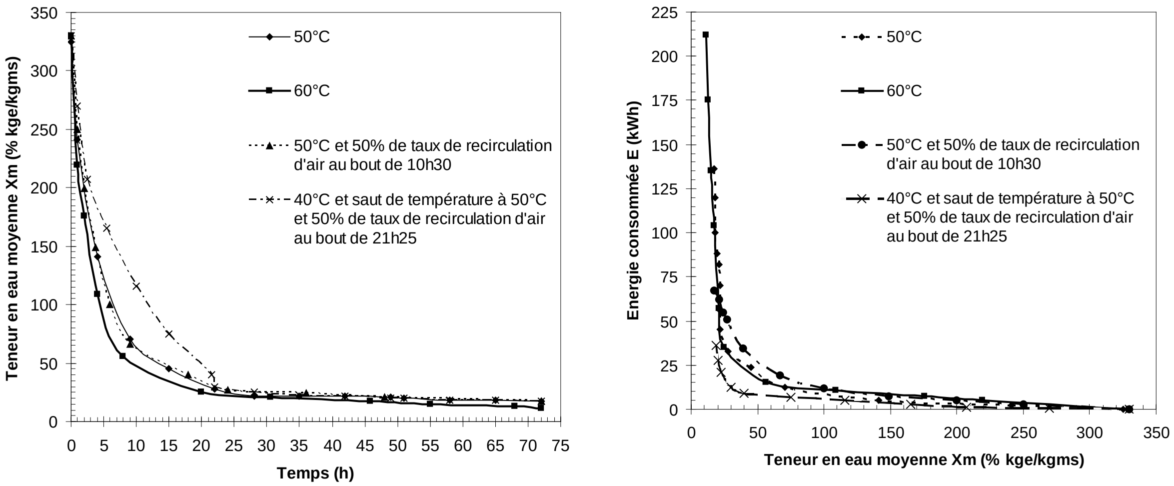


Figure 2: Profiles of speeds of the block tests in the prototype electric drier.



a) Average water content according to duration for various drying conditions

b) Energy consumption according to the water content for various drying conditions

Figure 3: Evolution of the average water content and energy consumption for various conditions of banana drying in the prototype electric drier at the air speed of 2.35 m/s

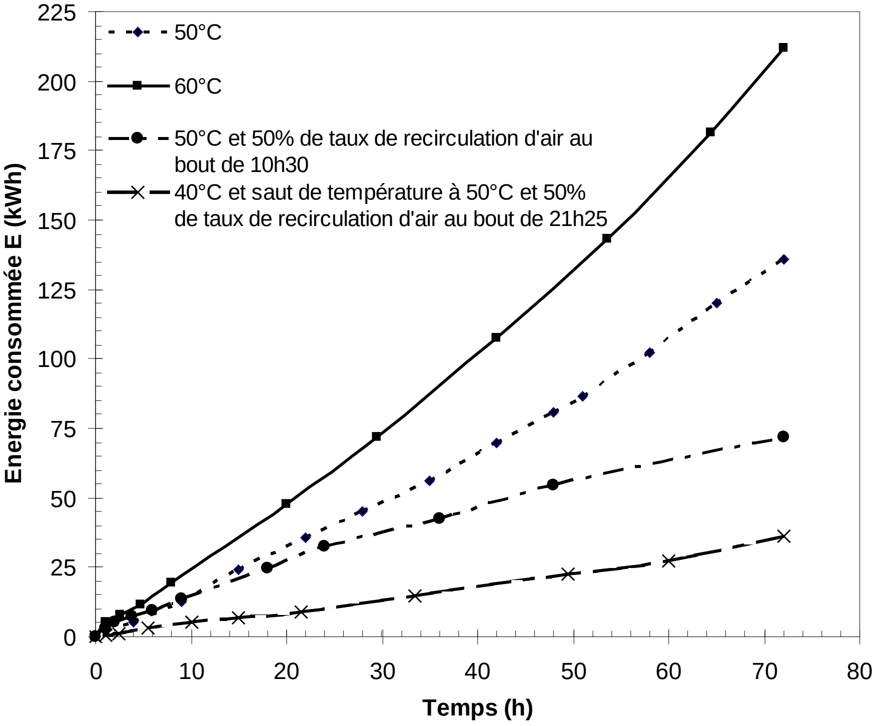


Figure 4: Evolution of energy consumption in the course of time for various banana drying conditions in the prototype electric drier at the air speed of 2.35 m/s