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Modeling of Drying Curves of Food Products by *Thermofrigopump*

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Abstract

Drying is one of the main techniques for preserving agricultural and food products. It is also a process which is involved in the manufacture of many food products, as an integral stage of processing or as an accessory (freezing, cooking, etc.). Understanding the phenomena involved is based on a good knowledge of the balance between air and the product and on mastery of the kinetics of drying and transformation of the product. This article focuses on the drying of food products at low temperature (35˚C) by *thermofrigopum*. We were able to model the drying kinetics of banana[1] and *thiacry*[2] based on the numerical method proposed by Moyne (1984). The experimental curves obtained have similarities with correlation coefficients very close to 1 with the numerical Moyne model. Finally, the specificity of drying at low temperature is the conservation of the organoleptic properties of the dried products. A second article [F 2] will then describe the specificities of dryers used in the food industries (IAA) and the impact of the drying process on the quality of organic products.

Keywords

Thermofrigopump, Water Content, *Thiacry*, Modeling Drying Kinetics

1. Introduction

The aim of drying food products is to lower the water content of products to allow healthy storage while transformations (structural modification, degradation of organic constituents, etc.) can take place within the avoiding the development of mold and bacteria. During this operation, different physicochemical product. The

[1]Banana: Banana originating from Ivory Coast.
[2]*Thiacry*: Flour (millet) rolled and steamed widely used in Africa, particularly in Senegal.

study undertaken firstly presents an experimental aspect concerning the influence of different parameters such as temperature, relative humidity of the air, the initial water content of the product, the air speed, etc., on the kinetics of dehydration of the product during forced convection drying. From experiments carried out, we developed a model for drying kinetics based on the simultaneous transfers of material and heat inside the product and on the writing of overall material and heat balances over the entire of the dryer. This model adequately predicts changes in water content, temperature and product quality.

In practice, it is difficult or almost impossible to prevent stress during drying. Optimization of the drying process is naturally desired to ensure rapid drying while maintaining product quality and minimizing the energy consumption of the dryer. In terms of quality, we normally seek to ensure at least that the stresses developed during drying never exceed the breaking threshold, that is to say, to avoid excessive degradation in relation to structural behavior and the visual appearance of the product [1].

2. Methodologies for Obtaining Drying Curves

Obtaining the drying characteristic curve and calculating the mass flow of water require knowledge of the drying speed.

2.1. Calculation of Drying Speed

The acquisition of experimental data on the mass of the product makes it possible to represent the curve giving the loss of mass (kg) as a function of time (s). However, it is customary to use the water content of the product on a dry basis (X, kg of water/kg of dry mass) and not the mass, to trace the drying curve.

Depending on usage, this data is transformed in order to trace either the drying speed curve or the so-called Krischer curve [2] depending on whether the drying speed ($-\mathrm{d}X/\mathrm{d}t$) is represented as a function of time or water content on a dry basis.

Deriving the drying curve can be tricky when this curve is "noisy". In fact, this operation is sensitive to "noise" and accentuates it [3]. To eliminate or reduce this "noise", it is necessary to carry out smoothing or filtering operations.

There are many filtering methods including:

- the method of Lanczos (1956) which proposes a numerical derivation formula including filtering. This method sacrifices the first and last points of the curve according to the length of the filtering [4];
- another type of filtering is to use a finite impulse response or moving average filter. This filter belongs to the category of dynamic filters which constitute a subclass of linear filters;
- the more recent wavelet decomposition method was developed in the 1980s [5]. It is a non-stationary signal analysis method that allows analyzing the frequency content of a signal at a local level;
- another method is to lengthen the time step when diverting. To ensure noise reduction, long time steps are required, resulting in loss of some of the infor-

mation contained in the initial data;

- one of the simplest methods is the adjustment of a polynomial on the mass loss curve [3].

In this study our choice fell on the last method of adjusting a polynomial.

2.2. Method for Determining the Characteristic Curve of Drying

The interest of this curve is important, it is enough to know the values of the initial and equilibrium water content to be able to describe the kinetics of drying in any air condition.

The principle of the drying characteristic curve is to reduce all the experimental data so as to be able to put them into usable form not only by the experimenter himself; but also by the entire scientific community [6]. To achieve this, the approach followed consists of normalization by representing the ratio of the drying speed in an instant t ($-\mathrm{d}X/\mathrm{d}t$) to the first phase speed $(-\mathrm{d}X/\mathrm{d}t)_1$, under the same air conditions depending on the reduced water content X_r [7] [8]. The equilibrium water content X_{eq} is deduced from the sorption isotherm.

The drying kinetics are represented in the form:

$$\left(-\frac{\mathrm{d}X}{\mathrm{d}t}\right)=\left(-\frac{\mathrm{d}X}{\mathrm{d}t}\right)_1 f\left(X_r\right) \tag{1}$$

X_r is the reduced water content defined by:

$$X_r=\frac{X-X_{eq}}{X_{cr}-X_{eq}} \tag{2}$$

$\left(-\frac{\mathrm{d}X}{\mathrm{d}t}\right)_1$ is the constant phase speed occurring for: $X_i \le X_r \le X_{cr}$.

$f\left(X_r\right)$ is the drying speed reduced.

We arbitrarily impose a mathematical expression on the function $f(X_r)$; this function should check the following properties:

$$f\left(X_r\right)=0 \quad \text{for} \quad X_r=0$$

$$0 < f(X_r) < 1 \text{ for } 0 < X_r < 1$$

In general, polynomial type or power type functions are considered to represent the characteristic curves.

As part of this study, we used the degree 3 polynomial type functions represented in this form:

$$f\left(X_r\right)=A_1X_r+A_2X_r^2+A_3X_r^3 \tag{3}$$

HAS$_1$; HAS$_2$; HAS$_3$: parameters to be determined experimentally.

Function defined according to the wet base water content gives:

$$f\left(X_h\right)=B_1X_h+B_2X_h^2+B_3X_h^3+K \tag{4}$$

With:

B_1; B_2; B_3; K: parameters to be determined experimentally.

2.3. Determination of the First Phase and the Water Content Critical

The critical water content Xcr is generally a function of drying conditions. In the case of organic products, several authors note that it is difficult to locate a first drying phase even for products with a high initial water content [9]. They identify the critical water content Xcr at the initial content Xi. The explanation lies in the fact that cell walls disrupt the rapid migration of moisture towards the surface of products [7]. Thus the constant velocity phase can be determined using a correlation which includes external aerodynamic conditions and taking into account the deformability of biological products or using the analogy of heat and mass transfers through the boundary layer of a completely wetted surface (Equation (3)).

3. Material and Method

The dryer used is made up of keys arranged vertically so that air circulation is from bottom to top.

Figure 1 illustrates the type of dryer used.

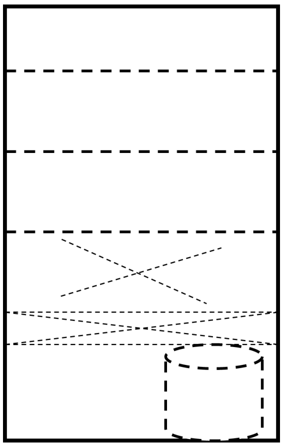

Figure 1. Dryer diagram.

The method used is convective drying of food products. The drying air is that coming from the condenser which is used to cool the compressor and the condenser at the same time. Air circulation is ensured by a centrifugal fan. A control device, a psychrometer thermometer, makes it possible to monitor the temperature and relative humidity of the air. This type of drying is also called air conditioning drying.

Heating the air increases its evaporative capacity. So for a coupling of drying conditions and product quality, we dried bananas and *thiacry* with air at 49% and 55% relative humidity at a constant temperature of 35˚C and a speed of 1.5 m/s measured by an anemometer.

The mass of the product to be dried is weighed every hour in order to follow the kinetics of drying until the mass remains constant. For this we used a digital display scale with sensitivity 1/10.

And finally, the water activity of the product is measured using a water activity meter.

4. Results

The evaporative capacity of the dryer is 1.54 kg of water/h for a drying temperature of 35˚C and a relative humidity of 45% for dried products leaving at the minimum temperature of 25˚C.

The evolution of the *thiacry* mass as a function of time and relative humidity is represented by **Figure 2**.

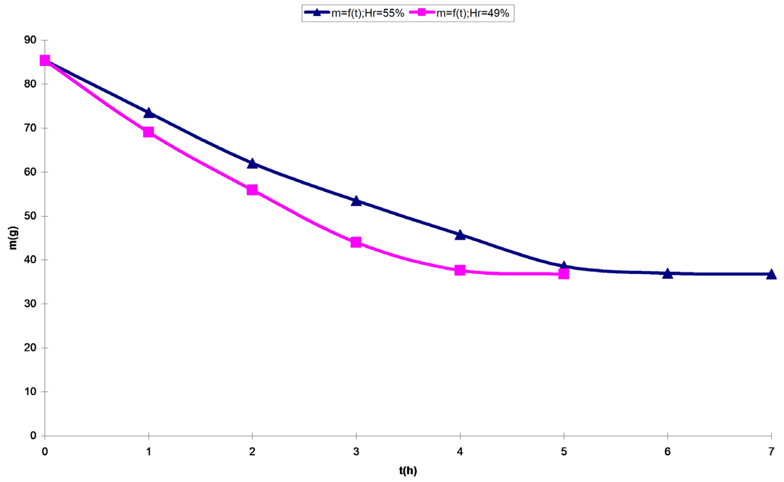

Figure 2. Evolution of the mass of *thiacry* for different humidity values.

The mass evolution curves of *thiacry* over time, there is a linear part during the first two drying phases and a curvature in the third and final phase where the product has lost almost all of the water involved in drying.

The curves are clearly separated and have the same appearance.

The representative banana drying curve is represented by **Figure 3**.

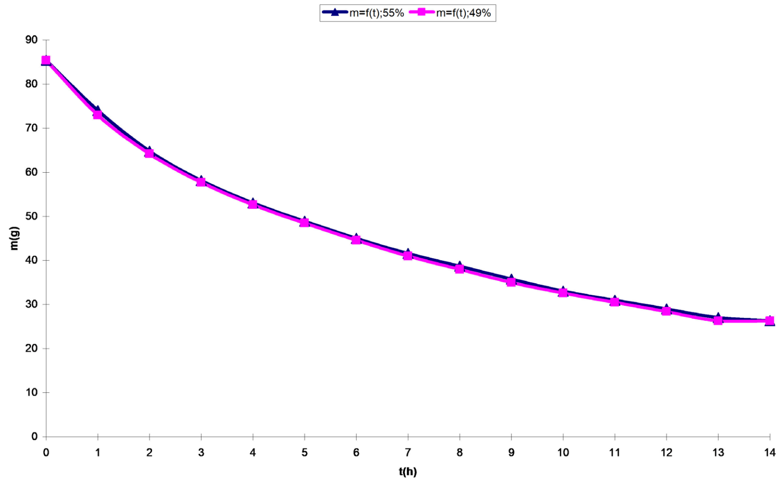

Figure 3. Evolution of banana mass for different humidity values.

The curves of mass evolution of the banana as a function of time have a very brief linear appearance at the start of drying and take on a hyperbolic appearance until the end of drying. Banana is a product very rich in sugar which inhibits bacteriological development processes.

The water present in the banana is physiologically linked to the latter unlike that present in the *thiacry* which consists mainly of open water.

5. Discussion

Analysis of the drying kinetics of *thiacry* shows that it is very sensitive to variation in humidity as shown in **Figure 4**.

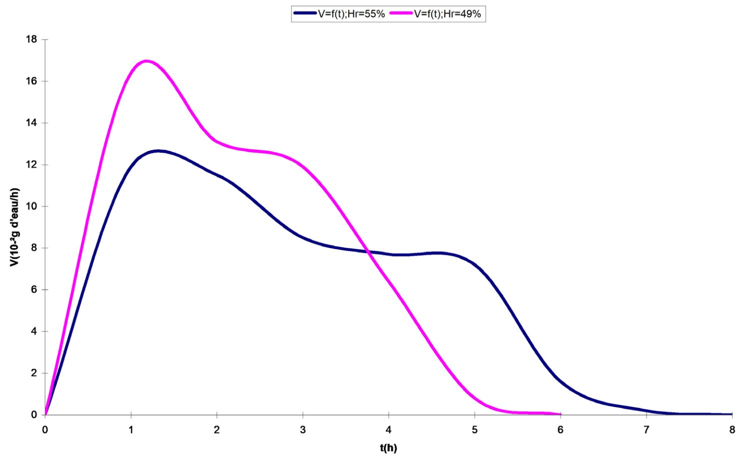

Figure 4. Drying kinetics of *thiacry*.

The drying time of these types of foodstuffs (couscous, *arraw*, etc.) whose water is not physiologically linked to the product has the same appearance. The lower the humidity of the drying air, the more the drying time becomes reduced.

Analysis of the drying curve of *thiacry* shows that its drying depends enormously on the characteristics of the drying air. **Figure 5** illustrates such behavior.

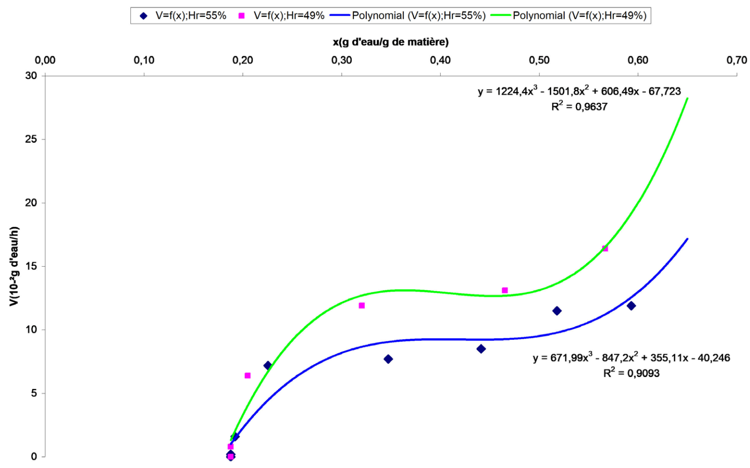

Figure 5. Drying curves of *thiacry* at 55% and 49% at 35˚C.

As for the banana, the results obtained revealed that the drying of the latter presents a wider zone in which the drying speed is not subject to the characteristics of the drying air. In other words, variations in temperature and relative humidity have little influence on the drying kinetics of the product unlike *thiacry* as shown in **Figure 6** and **Figure 7**.

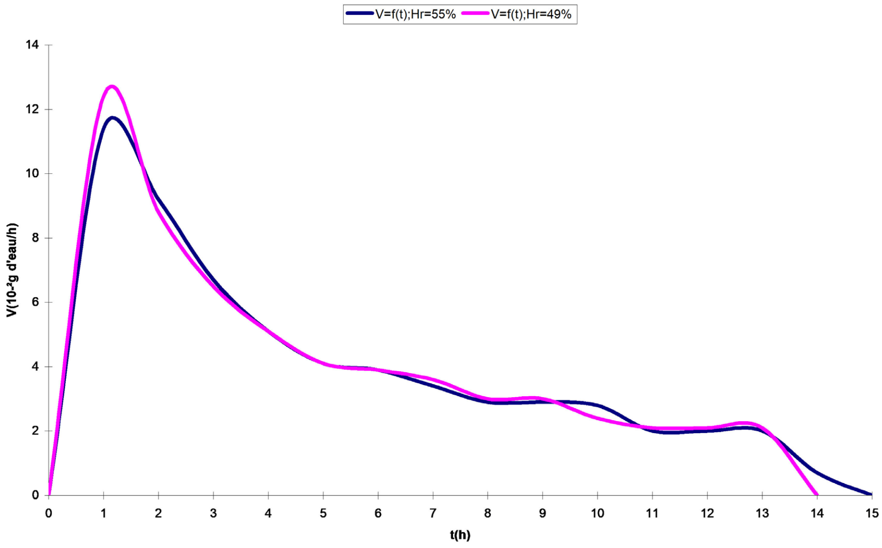

Figure 6. Banana drying kinetics.

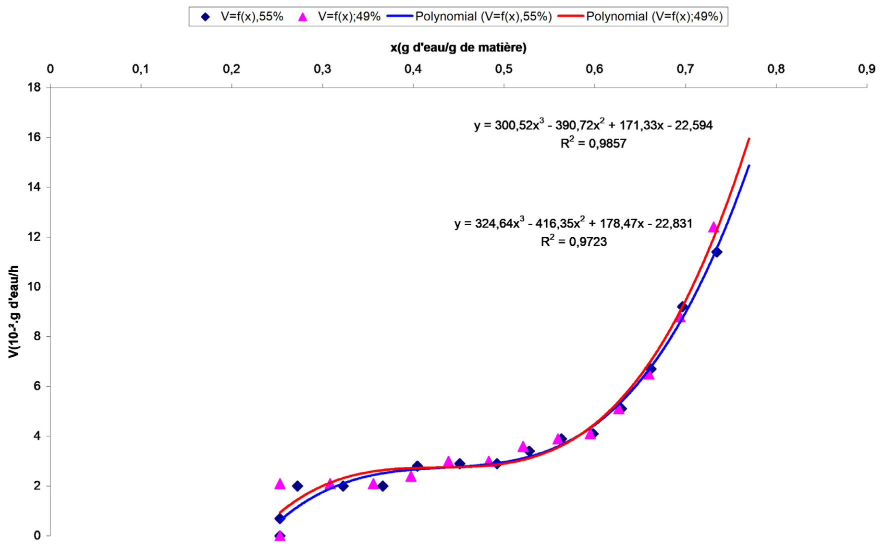

Figure 7. Banana drying curves at 55% and 49% at 35˚C.

Studies carried out on banana drying kinetics revealed a near constancy of banana drying curves between 35˚C and 60˚C [9]; which corroborates with our results.

The combined drying process by dehydration, impregnation by DII immersion and drying of the banana allows a weight reduction of 60.2% for relative humidity below 60% [10] in a reduced time.

Comparing these results with ours, we see that our method allows more advanced desiccation of the banana because the percentage of weight reduction obtained is 69.2%, a value significantly higher than that obtained by the DII and drying method.

Certainly the method we used takes more time but also allows us to keep the color of the product like the DII and drying method, which keeps the natural color of the food.

Finally, the drying curves thus obtained have correlation coefficients very close to 1, which allows us to affirm that the experimental conduct adopted is very effective and that the dryer, from an energy point of view, it allows food products to be dried while maintaining good quality because the drying air temperatures are very low (below 50˚C).

Figure 8 and Figure 9 show the drying curves at 49% and 55% at a temperature of 35˚C as well as the corresponding trend curves.

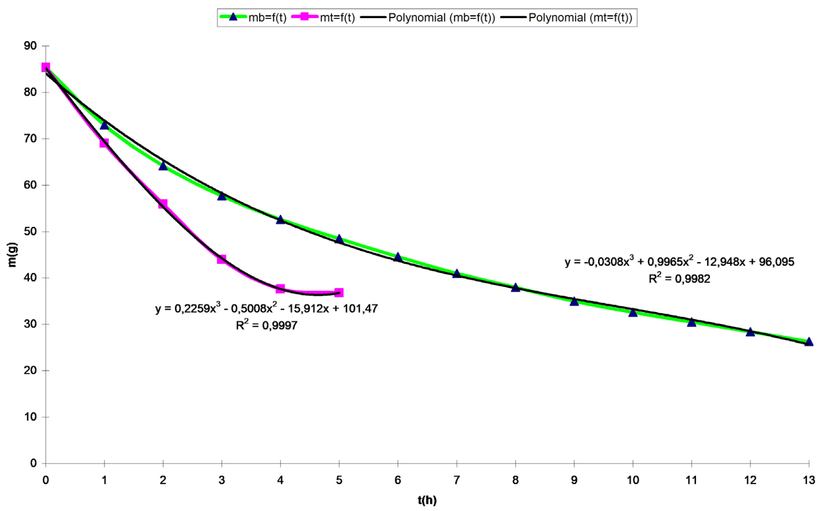

Figure 8. Drying curves of banana and *thiacry* at 35˚C and 49%.

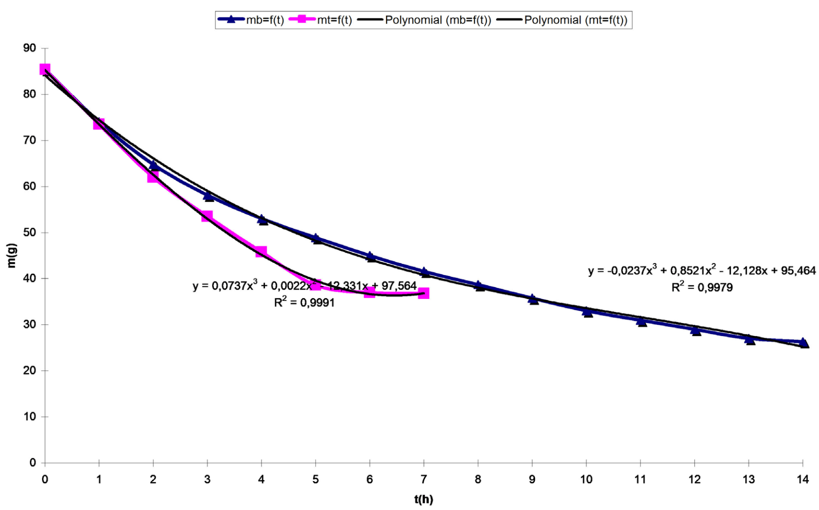

Figure 9. Drying curves of banana and *thiacry* at 35˚C and 55%.

The drying curves thus drawn verify the drying equation IV with correlation coefficients very close to 1 (0.99); which allows us to conclude that the method used corroborates with the numerical method cited above.

Sweet fruits like banana, mango, papaya do not need to be dried completely; unlike vegetables, because their high sugar content acts as a preservative.

The machine being placed in a dark place, sheltered from the sun, the dried products better retain their natural color and thus the vitamins and mineral salts are preserved [B1].

Finally, the drying time of the banana is included in the range allowed for drying the fruits which is from 10 a.m. to 3 p.m. and that of *thiacry* (cereals) is less than 10 hours.

To this, it must be added that low drying temperatures do not allow the destruction of vitamins A and C necessary for the proper functioning of our body, this is what justifies the interest in drying food products at low temperatures.

6. Conclusions

The *thermofrigopump* designed and tested for food preservation by lowering temperature and drying has given positive results.

The use of the energy released by the machine's condenser made it possible to carry out drying tests on food products in a dryer designed and produced as part of this study. The results obtained show that the dried products are of good quality. Indeed, the drying conditions of our dryer preserve the nutrients in the food and do not favor the Maillard reactions which are at the origin of the coloring of dehydrated products while respecting the drying times and a weight reduction of 69.2% unlike the DII method which is 60.2%.

This study showed that a *thermofrigopump* is a reliable means of saving energy in the food industries. From a cold room with a refrigeration machine with an air condenser, it is relatively easy to use the heat of condensation as an energy source to dry food products.

The *thermofrigopump* can be recommended for food industries using cold and drying food preservation.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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