ISSN:2321-1156

International Journal of Innovative Research in Technology & Science(IJIRTS)

MODELLING AND SIMULATION BANANA CONVECTIVE DRYING WITH A STEPWISE IN DRYING AIR TEMPERATURE

André Talla[1,2,*] , Yves Jannot[3], Jean Nganhou[1] and Cesar Kapseu[4]

[1]Energizing, Water and Environment Laboratory, National Advanced School of Engineering, University of Yaounde I, Po Box 8390, Yaounde, Cameroon

[2]Research Center, National Advanced School of Public Work, Po Box 510, Yaounde, Cameroon

[3] LEMTA, Nancy-Université, CNRS 2, Avenue de la forêt de la Haye, BP 160, 54504 Vandoeuvre Cedex France

[4]École Nationale des Sciences Agro-Industrielles, BP 455, Ngaoundéré, Cameroun

[*] Corresponding author: André Talla; Po Box 16 034, Yaounde - Cameroon; Fax : (+237) 22 22 18 16; E-mail: andre_talla@yahoo.fr

Abstract

An experimental study of banana convective drying with stepwise in drying air temperature has been carried out. Six tests have been realised: two tests at constant temperatures of 40°C and 60°C, then four tests beginning at 40°C with a temperature step to 60°C realised respectively 3h, 6h, 12h and 24h after the beginning. A model has been developed based on an empirical model for banana drying at constant air temperature and on the hypothesis that after a temperature step at a time t_c from θ_1 to θ_2, the drying goes on as if the water content at time t_c was reached by initial drying at temperature θ_2. This model leads to a quite satisfactorily representation of the experimental curves and may be used to simulate banana water content evolution in a drier where drying air temperature is not constant.

Keywords: convective drying; drying characteristic curve; banana; temperature step; drying rate

Nomenclature

a, b, c, d	Parameters of the DCC model	
e	Relative humidity	%
t	Time	s
θ	Temperature	°C
u	Air flow velocity	ms^{-1}
V	Drying rate	$kg_w.kg_{db}.h^{-1}$
x	Air absolute humidity	$kg_w.kg_{da}^{-1}$
X	Product water content (dry basis)	$kg_w.kg_{db}^{-1}$
A, α, β, γ	Parameters of reference drying rate model	
X_m, C, K	Parameters of the GAB model	

Subscripts

1	First drying period at temperature θ_1
2	Second drying period at temperature θ_2
c	Time of temperature stepwise
da	Dry air
db	Dry basis
eq	Equilibrium (relative to product sorption isotherm)
r	Reduced
ref	Reference
w	Water

Introduction

Banana drying has already been studied by many authors among them Jannot et al. [1], Boudhrioua et al [2], Dandamrongrak, Young and Mason [3], De Lima et al [4], Demirel and Turhan [5], Queiroz and Nera [6], Talla et al [7], Hameed et al. [8], Yan et al. [9], Achak et al. [10], Anwar et al. [11]. They generally test several theoretical model among those reviewed by Togrul and Pehlivan [12] to finally select the best fitted to their experimental drying curves. It can be noticed that all the drying tests presented were carried out with constant drying air temperature.

For energy savings in a drier, it could be interesting to begin the drying with a low air temperature to evacuate free water and to end with higher temperature to evacuate linked water in the phase of drying rate lowering. Furthermore, the air flowing in a drier does not remain at constant temperature since it is time variably humidified (and so refreshed) by water evaporation from the product. Thus, it is important to be able to predict the drying kinetics of a product under variable drying air temperature.

Chua et al [13, 14] have studied the effect of temperature step on banana drying but he mainly investigated experimentally the effect of temperature step on product quality (colour) and on drying time without proposing a simulation model.

Baini and Langrish [15] has developed a model to simulate drying with temperature step, it is based on a complete diffusion model leading to a quite complex resolution.

The aim of this paper is to propose a simple and accurate model to simulate the evolution of banana moisture content during its convective drying with a stepwise in drying air temperature. This model could be used to conceive a drier which could work with variable air temperature of drying. It is the case of dryers for organic products which shrinkage of volume during the drying is important and requires the progressive increase of the temperature during the operation of dehydration.

Several drying tests have been carried out with a temperature step from 40°C to 60°C occurring after various drying times. The simulated results have then be compared to the experimental ones to validate the model.

1. Material and methods

1.1. Experimental Device

The experimental device consists in a drying apparatus in which a sample of the product to be studied is submitted by leaching to an airflow whose temperature, humidity and velocity are controlled by a regulated system. This device is represented on figure 1. Masses are measured with a precision of 0.001 g, air temperature, humidity and velocity are measured with respective precisions of 0.5 °C, 2 % relative humidity and 0.1 m.s^{-1}. The dimensions of the test cross section are 150 x 150 mm^2. Product samples are set on a perforated tray which dimensions are 250 x 110 mm^2.

1.2. Procedures

Measurements and especially mass product are recorded every ten seconds during the first hour, then every minute during the following five hours and finally every ten minutes until the drying ends. The drying was stopped after 72 hours to ensure the complete drying (final water content less than 0.2) of the product whatever the drying conditions are.

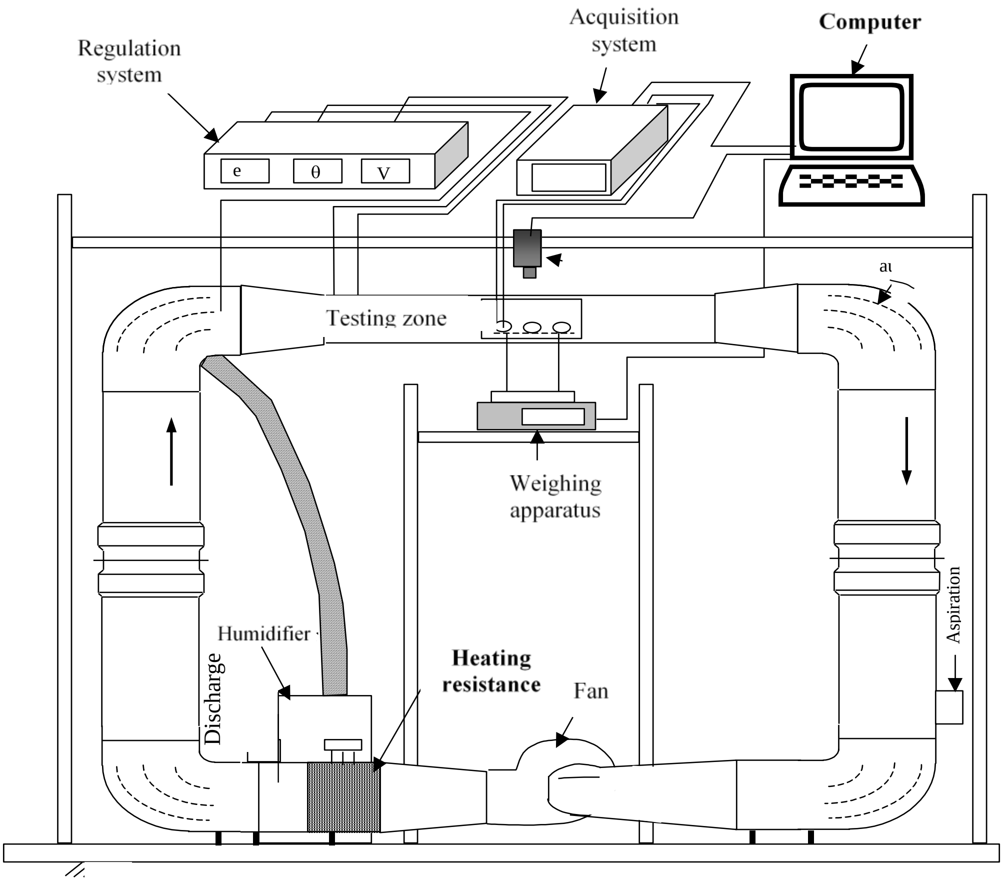


Figure 1: Experimental device

The products are first washed with water before being peeled and cut. Bananas used in these tests have a mean diameter of 30 mm. A banana was cut in two cylinders with 50 mm height then each cylinder is cut longitudinally to obtain four quarters of cylinder.

When airflow thermal conditions have reached the required values, the products to be dried are set on a tray in a single layer and then introduced in the testing zone parallel to the air flow. As the mass of the product is quite low (approximately 130 g) and the testing zone quite short (250 mm) the air temperature and relative humidity are supposed to be constant all along the support. The mass product evolution is deduced from the recorded measurements.

A set of five tests has been carried out with various air conditions as described in table 1: two tests were carried out with a constant temperature for respectively 40°C and 60°C then four other tests were carried out with a temperature step from 40°C to 60°C after a varying time t_c : 3 h, 6 h, 12 h and 24 h. The constant values of air water content and velocity were respectively 0.012 $kg_w.kg_{dm}^{-1}$ and 1.0 m.s^{-1}.

Mass measurement of a product set on a tray placed in a parallel airflow must take into account the force exerted by the airflow on the tray. This force may vary with the geometry of the support and with the projected area of the product on its support. In case of a highly shrinkable product as banana, this force may vary along the drying time but in our case, it was verified that it was constant and lead to a mean mass correction of 0.2 g all along the drying time. A more precise value was evaluated for each drying test.

Table 1:Values of the parameters of the model

b	c	d
2.648	0.447	-0.004

A	α	β	γ
0.0766	1.866	0.0753	-0.0091

2. Mathematical drying models

We expose first the mathematical models developed to feign the experimental results. The application of such a model in the conception of a drier, which would work with variable air temperature of drying, is major.

First, for modelling banana drying with constant drying air temperature, the empirical model of Jannot et al [1] was retained since the simulated curves were satisfactorily compared with experimental drying curves obtained with various representative air conditions (temperature, velocity, humidity). Using this model, the reduced drying rate V_r defined as:

$$V_r = \frac{\frac{dX}{dt}}{V_{ref}}$$

with X: product moisture content

V_{ref}: reference drying rate calculated by :

$$V_{ref} = A\,\theta^{\alpha} u^{\beta} x^{\gamma}$$

where A, α, β, γ: Parameters of the model

T: drying air temperature (°C)

u: drying air velocity ($m.s^{-1}$)

x: drying air water content ($kg_w.kg_{db}^{-1}$)

According to Jannot at al. work, reduced drying rate V_r can be expressed as :

- If $X_r \leq 0.2$ $\quad V_r = cX_r + d$
- If $0.2 \leq X_r \leq 1$ $\quad V_r = \frac{\exp(bX_r)}{\exp(b)}$

where X_r is the reduced water content defined as:

$$X_r = \frac{X - X_{eq}}{X_0 - X_{eq}}$$

with X_0: initial water content

X_{eq}: equilibrium product water content calculated by the GAB model established by Talla and al. (7) for banana:

$$X_{eq} = \frac{X_m CKe}{(1-Ke)\left[1+(C-1)Ke\right]}$$

where: $X_m = 0.108$; $C = 6531$; $K = 0.993$ for $\theta = 40°C$

$X_m = 0.083$; $C = 1828$; $K = 1.011$ for $\theta = 60°C$

e: air relative humidity

The aim is now to propose a model to simulate banana water content evolution during drying with air temperature equal to θ_1 from the beginning to time t_c and equal to θ_2 from time t_c to the end. In this case the formula presented by Jannot et al [1] obtained by integration of relations (3) and (4) can no longer be used to calculate $X_r(t)$ since V_{ref} is not constant during the drying. Using it may lead to bad representation of experimental data as found by Baini and Langrish [15].

Calling X_c the product water content reach after t_c drying time with air temperature θ_1, the proposed model is based on the following hypothesis : the drying will go on at temperature θ_2 after time t_c as if the water content X_c have been reached after a drying with a constant air temperature θ_2 since the beginning. This corresponds to the hypothesis that the product has « no memory ». This is not totally true since two products having the same mean water content after being dried at two different temperatures will not present the same internal water content gradient. Nevertheless, it may be an acceptable hypothesis for high water contents when the capillary effect leads to low water content gradient inside the product.

With this hypothesis and using the empirical model of Jannot et al [1] based on the Drying Characteristic Curve concept, the banana drying rate with a temperature step from θ_1 to θ_2 at time t_c can be calculated as: (1)

- If $X_r(t_c) < 0.2$:
  - $t < t_c$:

$$\frac{dX}{dt} = V_{ref1}\frac{\exp(b\,X_{r1})}{\exp(b)} \quad \text{with} \quad X_{r1} = \frac{X - X_{eq1}}{X_0 - X_{eq1}} \qquad (2)$$

and $V_{ref1} = A\theta_1^{\alpha} u^{\beta} x^{\gamma}$

  - $t > t_c$ and $X_r > 0.2$:

$$\frac{dX}{dt} = V_{ref2}\frac{\exp(b\,X_{r2})}{\exp(b)} \quad \text{with} \quad X_{r2} = \frac{X - X_{eq2}}{X_0 - X_{eq2}} \qquad (3)$$

and $V_{ref2} = A\theta_2^{\alpha} u^{\beta} x^{\gamma}$

  - $t > t_c$ and $X_r < 0.2$: (4)

$$\frac{dX}{dt} = V_{ref2}\left(c\,X_{r2} + d\right) \quad \text{with} \quad X_{r2} = \frac{X - X_{eq2}}{X_0 - X_{eq2}} \qquad (5)$$

and $V_{ref2} = A\theta_2^{\alpha} u^{\beta} x^{\gamma}$

- If $X_r(t_c) > 0.2$:
  - $t < t_c$ and $X_r > 0.2$:

Drying rate calculated with relation (7)

  - $t < t_c$ et $X_r < 0.2$:

$$\frac{dX}{dt} = V_{ref1}\left(c\,X_{r1} + d\right) \text{ with } X_{r1} = \frac{X - X_{eq1}}{X_0 - X_{eq1}} \text{ and}$$

$$V_{ref1} = A\theta_1^{\alpha} u^{\beta} x^{\gamma} \qquad (10)$$

- $t > t_c$:

In this case, drying rate calculated with relation (9).

The banana water content can easily be calculated from these formula by integration with a fourth order Runge-Kutta method. The same calculation scheme could be used successively for several drying air temperature steps and thus could represent water content evolution in a drier where drying temperature may vary continuously.

3. Results and discussion

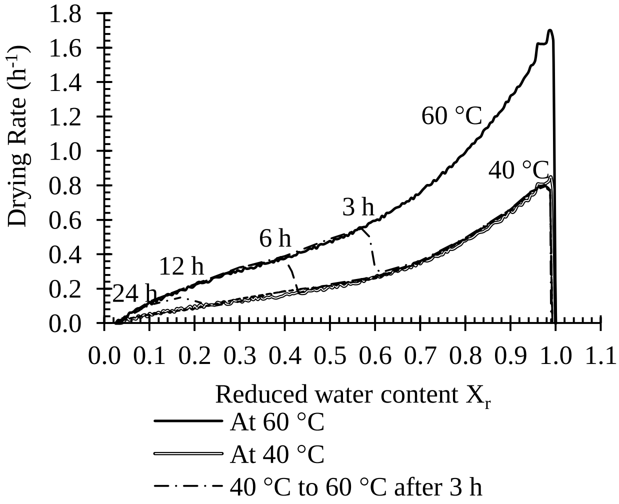
3.1. Effect of step time on drying rate

The values of the parameters b, c, d, A, α, β, γ of equations (2) to (4) are given in Table 1. The banana moisture content can be calculated by integration of formula (3) and (4) or by use of a fourth order Rung-Kutta integration method. Figure 2 (a) represents the drying rate $V = \frac{dX}{dt}$ as a function of the reduced water content X_r. It is remarkable that after the temperature step at respectively 3h, 6h, 12h and 24h, all the curves trends towards the curve obtained with a constant air temperature of 60°C. This seems to validate the hypothesis that drying goes on as if it has begun at 60°C. Meanwhile, it could be observed that the time needed to reach the drying rate at 60°C after the temperature step increases when the mean water content at the step decreases. This may be explained by a higher water content gradient (depending on temperature) inside the product when the liquid phase disappears.

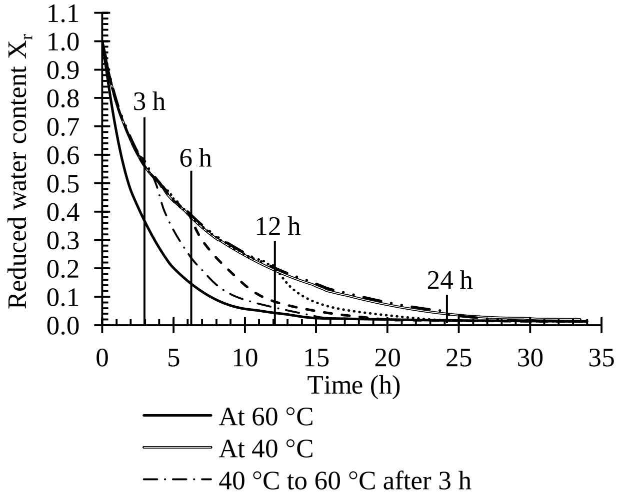
The same figure 2 (a) shows that the phase of stake in temperature of the product is very fast. This phase is expressed by the speed of drying which is supposed to be of a value almost null in its maximal value. This maximal value illustrates the beginning of the phase of drying with constant speed (first phase). We can note on the same figure that this phase is not detectable. The initial and critical moisture contents are thus practically merged. These results are in agreement with the works of Jannot and al [1] on the drying of the banana.

Figure 2 (b) represents the reduced water content X_r (to enable comparisons since the initial banana water content X_0 is not the same for all tests) as a function of time for the whole tests. It could be observed that all the drying curves (except for 60°C) are very close before temperature step and trends to the curve obtained at 60°C after the temperature step.

Besides, the same figure 2 (b) brings to light the influence of the stepwise in drying air temperature during the operation of drying of the banana. We can note that a stepwise of temperature realized at the end of time not overtaking 12 hours allows to affect a moisture content lower than 12 % (moisture content of preservation of this product) after a drying of this product for a duration of less than 24 hours. This important result shows that the drying of the banana with stepwise of temperature allows to avoid the phenomenon of crusting observed during the drying of this product with relatively high constant temperature (from 50°C). The works of Talla and al [16] shows that the duration of drying of the banana with weaker constant temperature until its moisture content of preservation requires a relatively long duration (at least 72 hours).



(a)

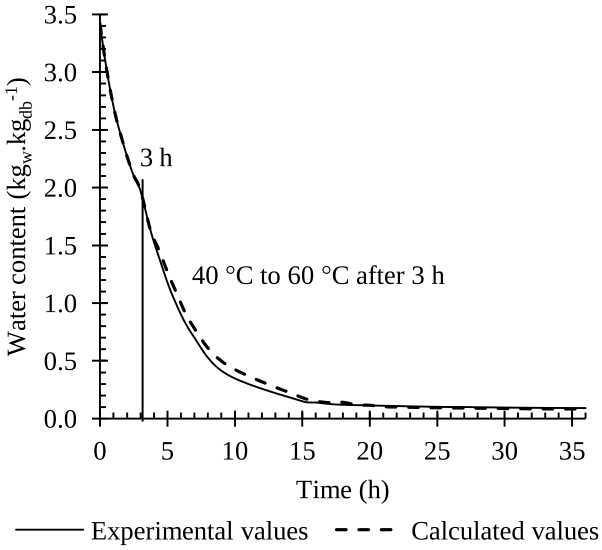


(b)

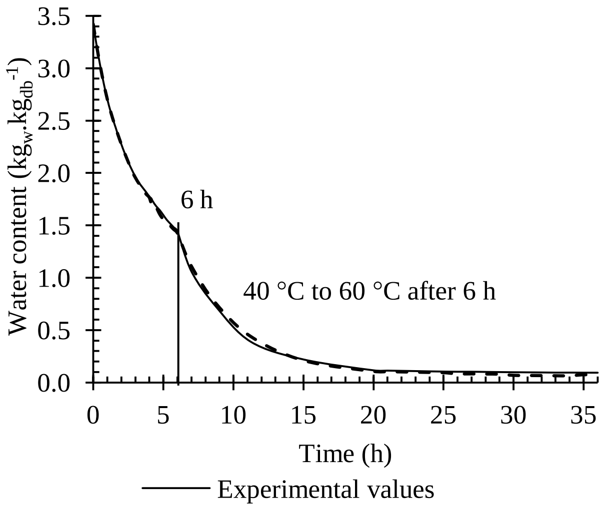
Figure 2: Drying rate vs reduced water content (a) and reduced water content vs time for constant drying air temperature (40 °C and 60 °C) and for stepwise in drying air temperature from 40 °C to 60 °C after 3 h, 6 h, 12 h and 24 h

3.2. Simulation

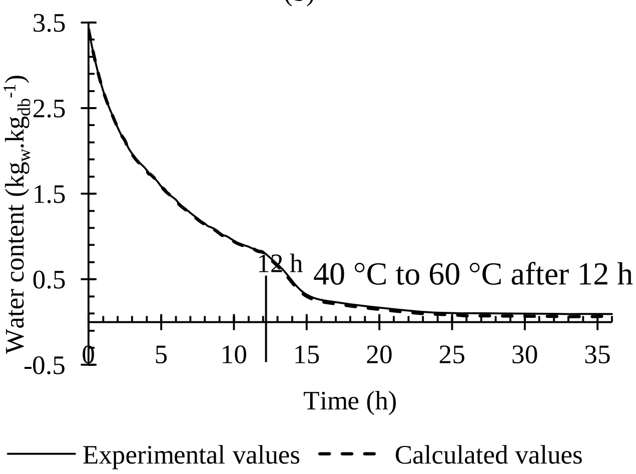
The above described model was used to simulate the evolution of the drying rate for the six different air conditions among which four with a temperature step from 40°C to 60°C. The simulated and experimental drying curves with temperature step are represented on figure 3. The agreement is fairly good since the outside banana diameter was not always constant on the whole length and not exactly equal to 30 mm that may lead to some difference between simulated and experimental results. The proposed model seems to be valid for simulating banana drying with varying air temperature and may be used to simulate banana water content evolution in a drier.



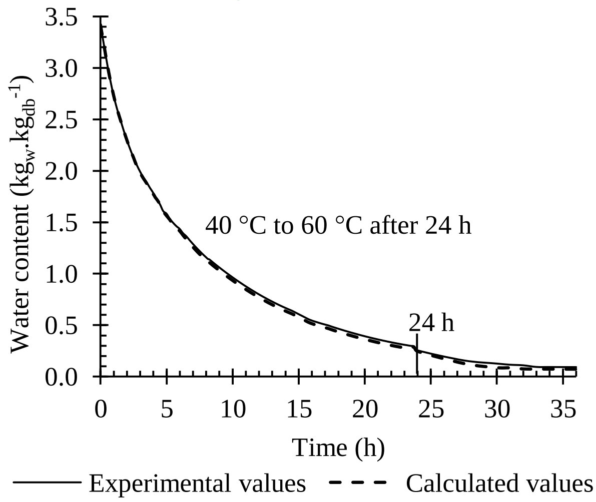
(a)



(b)



(c)



(d)

Figure 3: Experimental and simulated drying curves with stepwise in drying air temperature from 40 °C to 60 °C after 3 h (a), 6 h (b), 12 h (c) and 24 h (d)

4. Conclusion

A simple model for banana water content evolution during drying with air temperature stepwise has been developed. It is based on the use of the empirical model of Jannot et al [1] and the hypothesis that after a temperature step from θ_1 to θ_2, the drying goes on as if it has begun at temperature θ_2. This model fits quite satisfactorily with experimental drying curves with temperature step from 40°C to 60°C realised respectively 3h, 6h, 12h and 24h after the beginning of the drying. Its simplicity makes it well suited for modelling water content evolution in a drier where drying air temperature is not constant, as it is particularly the case in a solar drier.*

Acknowledgements

This work was partly supported by TREFLE Laboratory of the University of Bordeaux I, France.

References

[1] Jannot Y., Talla A., Nganhou J., Puiggali J.R., 2004, Modelling of banana convective drying by the drying characteristic curve (DCC) method, Drying Technology, 22 (8), 1949-1968.

[2] Boudhrioua N., Michon C., Cuvelier G., Bonazzi C., 2002, Influence of ripeness and air temperature on changes in banana texture during drying, Journal of Food Engineering, 55 (2), 115-121.

[3] Dandamrongrak R., Young G., Mason R., 2002, Evaluation of various pre-treatments for the dehydration of banana and selection of suitable drying models, Journal of Food Engineering, (55) 2, 139-146.

[4] De Lima A.G.B., Quieroz M.R., Nebra S.A., 2002, Simultaneous moisture transport and shrinkage during drying of solids with ellipsoidal configuration, Chemical Engineering Journal, (86), 85-93.

[5] Demirel D., Turhan M., 2003, Air-drying behavior of Dwarf Cavendish and Gros Michel banana slices, Journal of Food Engineering, (59) 1, 1-11.

[6] Queiroz M. R., Nebra S.A., 2001, Theoretical and experimental analysis of the drying kinetics of bananas, Journal of Food Engineering, (47) 2, 127-132.

[7] Talla A., Jannot Y., Nkeng G. E., Puiggali J.R., 2005, Experimental determination and modelling of sorption isotherms of tropical fruits: banana, mango and pineapple, Drying Technology, 23, 1477-1498.

[8] Hameed B.H., Mahmoud D.K., Ahmad A.L., 2008, Sorption equilibrium and kinetics of basic dye from aqueous solution using banana stalk waste, Journal of Hazardous Materials, (158) 2-3, 499-506.

[9] Yan Z., Sousa-Gallagher M.J., Oliveira F.A.R., 2008, Sorption isotherms and moisture sorption hysteresis of intermediate moisture content banana, Journal of Food Engineering, (86) 3, 342–348.

[10] Achaka M., Hafidib A., Ouazzania N., Sayadic S., Mandia L., 2009, Low cost biosorbent "banana peel" for the removal of phenolic compounds from olive mill wastewater: Kinetic and equilibrium studies, Journal of Hazardous Materials, (166) 1, 117–125.

[11] Anwara J., Shafiquea U., Waheed-uz-Zamana, Salmana M., Dara A., Anwarb S., 2010, Removal of Pb(II) and Cd(II) from water by adsorption on peels of banana, Bioresource Technology, (101) 6, 1752–1755.

[12] Toğrul I.T., Pehlivan D., 2003, Modelling of drying kinetics of single apricot, Journal of Food Engineering, 58, 23-32.

[13] Chua K. J., Mujumdar A. S., Hawlader M. N. A., Chou S. K. and Ho J. C., 2001, Convective drying of agricultural products. Effects of continuous and stepwise change in drying air temperature, Drying technology, 19 (8), 1949-1960.

[14] Chua K. J., Mujumdar A. S., Hawlader M. N. A., Chou S. K. and Ho J. C, 2001, Batch drying of banana pieces - effect of stepwise change in drying air temperature on drying kinetics and product colour, Food Research International, 34 (8), 721-731.

[15] Baini R., Langrish T.A.G., 2007, Choosing an appropriate drying model for intermittent and continuous drying of bananas, Journal of Food Engineering, 79, 330-343.

[16] Talla A., Jannot Y., Kapseu C., Nganhou J., 2001, Étude expérimentale et modélisation de la cinétique de séchage des fruits tropicaux – application à la banane et à la mangue, Sience des Aliments, 21, 499-518.

Biographies

André Talla (Corresponding Author) received the B.S. degree in Physics Sciences, in 1988 and the M.S. degree in Physics Sciences, in 1989, from University of Yaounde, Cameroon; then Master in Engineering, in 1992 and Specialized Master in Energy and Industrial Cold, in 1993, from 2IE of Ouagadougou, Burkina Faso; thereafter Master Research in Energizing, in 1998, from National Advanced School of Engineering, University of Yaounde I, Cameroon and the Ph.D. degree in Industrial and Mechanic Sciences from National Advanced School of Engineering, University of Yaounde I, Cameroon with alternation at the University of Bordeaux I, France. He is a senior lecturer of Engineering science at National Advanced School of Engineering, University of Yaounde I, an associate Professor of Engineering science respectively at National Advanced School of Publics Works of Yaounde city, Coast University of Douala city and Mountains University of West Region, Cameroon. His research areas include Thermal and Physical Characterization of Building Materials, Drying of the Tropical Products and Pollution of the Physical and Atmospheric environment. Dr André Talla may be reached at andre_talla@yahoo.fr.