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Development of an intermittent drying process of onion

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Abstract

The aim of this work is to develop an intermittent energy-saving drying process that best preserves the quality attributes of the onion and is based on the knowledge of drying characteristics of the product. Onion slices, 5 mm thick were dried at 45°C, 55°C and 65°C under air flow rates of 20 dm³/s, 24 dm³/s and 28 dm³/s. The first critical drying time determined is between 0.75 and 3.5 hours and the second is between 3.25 and 14 hours. The most energy-efficient couple (temperature; air flow) is (65°C; 24 dm³/s). An intermittent drying process (step-down) has been developed which took into account these critical drying times and the most energy-efficient couple. The step-down process was compared to the most energy saving continuous drying (65°C; 24 dm³/s). The results showed an improvement of energy efficiency of 12.70 % of the intermittent process compared to the continuous drying. The nutritional quality in particular the fat content (166.04%), the vitamin C (53.85%) and proteins (2.50%) was significantly maintained by the intermittent process. The modeling of drying kinetics by four empirical models showed that the model Two term exponential and the model of Midilli described both the continuous drying and the intermittent process developed.

Keywords: Onion, critical drying time, energy efficiency, intermittent drying, continuous drying, food value.

1. Introduction

Drying is an important method widely used in the processing of agricultural products (Koyuncu *et al.*, 2007). Due to lack of timely and appropriate treatment, approximately one third of global agricultural production is lost each year (Gustavsson *et al.*, 2011). This loss is even greater in developing countries where 30 to 40% of fruits and vegetables are wasted (Karim and Hawlader, 2005a, b).

Drying is probably the most energy consuming operation of the agroindustrial process (Kudra, 2004; Hany *et al.*, 2014) and accounts for up to 15% of all industrial energy use (Chua *et al.*, 2001a). In an energy-consumption industry such as the drying industry, improving energy efficiency by 1% could result in a 10% increase in its profit (Beedie, 1995). Therefore, any small improvement in energy efficiency in the drying process of agricultural products would contribute to sustainable development (Kumar *et al.* 2014).

The drying air conditions have a great effect on the quality attributes of the dried product. The desire to reduce the energy consumption of the drying process and to improve the quality of the dry product has led to the development of several drying processes (Hany *et al.*, 2014) including the intermittent process which consists in varying the conditions of the drying air over time. This process has in many cases reduced energy consumption and significantly maintained product quality attributes. However, the variation in air conditions in relation to the specificity of the product has not been established.

The drying kinetics of agricultural products have three phases, mainly one phase at constant speed and one decay phase (Dissa *et al.*, 2011). Knowledge of the drying kinetics of a product and the determination of critical water contents (or critical times) would allow better regulation of the variation of the drying conditions during the different phases for a better energy efficiency and a good quality of the dried product. The modeling of the kinetics would make it possible to say whether the developed process can be described by a known empirical model.

Onion (*Allium cépa-L*) is a product containing a significant amount of bioactive components such as organo-sulfur compounds, vitamins and flavonoids (Belarbi-Ouarkoub *et al.*, 2008). It is widely used to flavor dishes but also for its nutritional and medicinal quality. Onion serves as a good medicinal compound for cataract, cardiovascular diseases and cancer thanks to its hypocholesterolemic, thrombolitic and antioxidant effects (Goudra, *et al.*, 2014). Its conservation poses enormous difficulties and the losses recorded during storage, despite the different methods used, reach 22% (Currah *et al.* 1990).

Dried onions, being increasingly incorporated in eating habits have become a standard ingredient used as an aromatic additive in many agro-industrial products such as sauces, soups, sausages, meats, fries, biscuits, etc., (Mazza *et al.*, 1980 ; Figen Kaymak-Ertekin *et al.*, 2005 ; Alam *et al.*, 2014).

This work aims to develop an energy-saving drying process that preserves the nutritional quality of the dry product. It is based on the couple (temperature; air flow) which brought best energy efficiency (quantity of water evaporated compared to provided energy) at the constant speed drying phase and on critical times for the various tested conditions.

2. Materials and methods

2.1. Material

2.1.1. Sample collection

The plant material consisted of onions of the variety "*violet de galmi*". These onions were purchased at the big market of Lomé in Togo.

2.1.2. Experimental Device and Measuring Devices

The device used (fig. 1) was a convective pilot dryer comprising a drying chamber coupled to an air heating chamber connected to each other by a centrifugal fan.

The drying chamber comprised three superimposed trays of 0.34 m long and 0.32 m wide. The heating chamber equipped with a burner supplied with butane gas made it possible to raise the temperature of the drying air which could reach 115°C. The centrifugal fan (type HCAS 520-2 MONO) with a power (P) of 0.55 kW, with flow rates (D) up to 42.3 dm³/s sucked hot air from the heating enclosure and pushed it back into the drying chamber. It was linked with a frequency converter to regulate the flow of drying air. Aeration air duct homogenizing the flow of incoming air facilitated the measurement of the air drying air velocity.

The various measuring instruments used during the experiments are presented in Table 1.

2.2. Methods

2.2.1. Preparation of samples

The fresh onion was weighed and measured; then peeled, washed and cut into washer thickness 5 mm using a TOPAZ 195 slicer. The thickness of 5 mm has been also used by Sarsavadia (2007) which was based on the average thickness commonly used in the onion

flake industries. A part of sample was taken, weighed and placed in an oven at 105°C for 24 hours to determine the dry mass and then the initial water content (AFNOR, 1974). The empty trays were weighed after the drying chamber has been warmed up and the air flow has been adjusted. The onion slices were then regularly placed on the trays. These loaded trays were weighed and then introduced into the drying chamber. The drying time measurement was then switched on.

2.2.2. Experimental procedure

Firstly, onion slices, 5 mm thick were dried at temperatures of 65, 55 and 45°C and combined with air flow rates of 28, 24 and 20 dm³/s. The aim was to determine the critical times (times corresponding to the critical water contents), deduce the different drying phases and the most energy-saving drying condition (temperature, flow) during the drying phase at constant speed where drying is governed mainly by external conditions (Dissa et al., 2011). The selected temperatures were related to the maximum drying temperature of the onion reported in the literature as 55°C (Boroze et al., 2013).

Secondly, onion slices of the same thickness were dried in continuous at a temperature of 65°C and a flow rate of 24 dm³/s (couple, temperature and flow rate most energy efficient during the phase of drying at constant speed) and then in intermittent by varying the temperature as follows:

- first phase: 65 ° C for 2 hours (drying phase at constant speed);
- second phase: 55 ° C for 5 hours (first part of the deceleration phase);
- third phase: 45 ° C until equilibrium (second part of the phase of decrease).

The increase in temperature during the drying step at constant speed above the maximum drying temperature of the onion was explained by the fact that during this phase the product remained at the humid air temperature. The flow rate was kept constant and equal to 24 dm³/s because the influence of the flow rate on the drying kinetics was small and even negligible beyond the first critical time (Edoun et al., 2013).

2.2.3. *Drying curve*

During the drying process, the trays charged with products were removed and weighed every 15 min for 3 hours, then every 30 min until the equilibrium was established. The characteristics of the air (temperature, velocity and humidity) were recorded every 5 minutes using an Almemo 2980 station. The masses obtained through weighing were used to determine the reduced water content and draw the curve of the reduced water content depending on the drying time.

2.2.4. *Determination of critical water contents*

2.2.4.1. *First Critical Water and Critical Time*

The first critical water content X_{cr1} represents the transition point between the constant speed phase and the phase of decrease (Touré *et al.*, 2004). This transition is explained by the change in the phenomenon governing the rate of drying. From the stage where the drying is controlled mainly by the external convective transfers to that of the control by the internal diffusive transfers (Dissa *et al.*, 2011).

It was estimated from the tangent method at the origin (Derdour *et al.*, 1998). This method consisted in plotting the tangent at the origin of the curve representing the rate of drying as a function of the average water content of the product. It assumed that the curves of drying velocity as a function of the water content were comparable to two straight lines representing respectively the drying period at constant speed and the period of deceleration. This method is suitable only if during the period of slowing down the drying kinetics can be described by a diffusion law with a constant diffusivity (Moyné *et al.*, 1989). The critical point was then the point of intersection between the two straight lines. The critical time was then deduced from knowledge of the critical water content (Dissa *et al.*, 2010).

2.2.4.2. *Second Critical Water and Critical Time*

The second critical water content represents the transition water content between the first phase of decrease and the second phase of decrease. This is the water content at which the analytical solution of Fick diffusion equation passes from one simplified form to another (Dissa *et al.*, 2011).

The determination of this critical water content consisted in plotting the curve of the logarithm of the reduced water content as a function of the difference between the drying time t and the first critical time t_{cr1} ($t-t_{cr1}$). On this curve, a quasi-linear part could be observed, starting from

the first critical water content, corresponding to the first phase of decrease. The end of this linear part marked the point of second critical water content (*Dissa et al., 2010, Kibangou-Nkembo, 2013*).

2.2.5. Evaluation method of mass diffusivities during the phase of decrease

The transfer of humidity during the phase of drying decrease was controlled by the internal diffusion. By assuming this unidirectional diffusion (following z), the Fick diffusion law (Eq.1), linked the water content of the product (X), the mass diffusivity (D), the time (t) and the direction (z) used to describe the drying process for most products.

$$\frac{\delta X}{\delta t} = D \frac{\delta^2 X}{\delta z^2} \quad /1/$$

For a uniform distribution of the initial moisture, the external negligible resistors and an isothermal process, the analytical solution of Eq. 1 is Eq.2 (*Fahloul et al., 2009*):

$$\frac{X - X_{eq}}{X_0 - X_{eq}} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp \left[- (2n-1)^2 \frac{\pi^2 D t}{4 z^2} \right] \quad /2/$$

The solution took into account the initial water content (X_0), the water content at the equilibrium (X_{eq}) and the thickness of the sample. Eqn. 2 is simplified by taking the first term of the solution of the series and assuming X_{eq} equals 0:

$$X_r = \frac{X}{X_0} = \frac{8}{\pi^2} \exp \left[- \frac{\pi^2 D \cdot t}{4 e^2} \right] \quad /3/$$

Eqn. 3 can be written as Eqn. 4:

$$\ln(X_r) = \ln \left(\frac{8}{\pi^2} \right) - \frac{\pi^2 \cdot D \cdot t}{4 e^2} \quad /4/$$

Which is an equation of a straight line in the form $y = b + ax$ where:

$$b = \ln \left(\frac{8}{\pi^2} \right) \quad /5/$$

$$a = - \frac{\pi^2 \cdot D}{4 e^2} \quad /6/$$

By plotting the experimental curve $\ln(X_r) = f(t)$, the coefficient a is determined and the diffusivity D of the product is deduced from the Eqn. 6.

2.2.6. Method for evaluating the energy efficiency of the intermittent process versus continuous drying

The energy E_θ of a given quantity of air at a temperature θ , containing Y kg of water vapor per kg of dry air is given by the Eqn. 7 (Bimbenet 2002):

$$E_\theta = m_a (Cp_a + Y.Cp_v). \theta \quad /7/$$

Where m_a represents the mass of dry air, Cp_a et Cp_v the mass heat at constant pressure respectively of dry air and water vapor and θ the temperature of this air. Y is given by the Eqn. 8 (Bimbenet 2002):

$$Y = \frac{0,622.P'_\theta \cdot \varphi}{10132500 - P'_\theta \cdot \varphi} \quad /8/$$

Where φ is the relative humidity expressed in% and P'_θ is the saturated vapor pressure at a temperature θ expressed in Pascal (Pa). For a temperature $\theta > 45^\circ\text{C}$, this saturating vapor pressure is given by Eqn. 9 (Nadeau et Puiggali, 1995):

$$P'_\theta = \exp \left(23,1964 - \frac{3816,44}{\theta + 227,05} \right) \quad /9/$$

The mass of dry air was evaluated on the basis of the relation between the mass of water vapor (m_v) contained in the air considered and its mass of dry air as follows Eqns. 10 and 11:

$$m_v = Y.m_a \quad /10/$$

$$\frac{m_v}{M_v.M_a} = \frac{Y.m_a}{M_v.M_a} \quad /11/$$

Where M_v and M_a are the respective molar masses of water (water vapor) and dry air. So we have Eqns. 12, 13 and 14:

$$\frac{V_v}{M_a} = \frac{Y.V_a}{M_v} \quad /12/$$

$$V_v = Y \frac{M_a V_a}{M_v} \quad /13/$$

$$V_a + V_v = \left(1 + Y \frac{M_a}{M_v}\right) V_a \quad /14/$$

But $V_a + V_v = V = D.t$, where V_a , V_v , V , D and t are respectively the volume of dry air, volume of water vapor, total volume of air, air flow and the drying time. Eqn. 15 is then obtained:

$$m_a = \rho_a V_a = \frac{\rho_a M_v D.t}{M_v + Y.M_a} \quad /15/$$

ρ_a is the density of the dry air which results from the absolute temperature T , Eqn. 16:

$$\rho_a = 1,292 \frac{273,15}{T} \quad /16/$$

The energy actually supplied by the air heating chamber is given by Eqn. 17:

$$\Delta E = E_{\theta_s} - E_{\theta_{amb}} \quad /17/$$

θ_s and θ_{amb} are respectively the drying temperature and the ambient temperature.

The energy saving carried out from the intermittent process compared to the continuous drying is then evaluated by the Eqn. 18:

$$g = \frac{\Delta E_c - \Delta E_i}{\Delta E_c} \times 100 \quad /18/$$

Where the indicators c and i respectively represent the continuous and the intermittent.

2.2.7. Mathematical modeling of drying curves

Four empirical models (Table 2) were used to model the kinetics of continuous and intermittent drying in order to determine which model best describes each process. This would allow to know whether the developed process introduces a significant change or not in the kinetics of drying.

The adjustment between the experimental data and the predicted data for these models was determined using the coefficient of determination (R^2), the sum of squared errors (SSE) and

the root mean square error (RMSE) (Eqns. 19, 20 and 21). The choice of the best model is based on the highest R^2 , the lowest SSE and RMSE values.

$$R^2 = 1 - \frac{\sum_{i=1}^N (X_{r_{exp,i}} - X_{r_{cal,i}})^2}{\sum_{i=1}^N (\bar{X}_{r_{exp,i}} - X_{r_{cal,i}})^2} \quad /19/$$

$$SSE = \sum_{i=1}^N (X_{r_{exp,i}} - X_{r_{cal,i}})^2 \quad /20/$$

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^N (X_{r_{exp,i}} - X_{r_{cal,i}})^2 \right]^{\frac{1}{2}} \quad /21/$$

In the above Eqns. 19, 20 and 21, N is the number of observations, while $X_{r_{exp,i}}$ and $X_{r_{cal,i}}$ are the experimental and predicted values for the dependent variable at any observation i, respectively.

2.2.8. Methods of nutritional analysis

The water content of the fresh and dried onions was determined by drying at 105°C for 24 hours (AFNOR, 1974), the lipid content by the Soxhlet method (1879) and the protein content by the method of Kjeldahl (1883). The total reducing sugars were extracted in an aqueous medium and assayed by the method of Miller (1959). Vitamin C was assayed by a chemical method with iodine (Deymié *et al.*, 1981).

3. Results and Discussions

3.1. Evaluation of Critical Times and Critical Water Levels

The first and second critical times as well as the first and second critical water content for the different conditions tested are shown in Table 3.

It was noted that the first critical time was between 0.75 hours and 3.25 hours and the second critical time between 3.5 hours and 14 hours. These critical times decreased when the temperature and flow rate of the drying air increases except for the flow rate of 20 dm³/s for which the first critical time was the same at 55°C and at 65°C. The first reduced critical water content was between 0.56 and 0.73, it increases with air flow and is low for the temperature of 65 ° C. Kibangou-Nkembo (2013) found 0.71 for plantain and mango and 0.60 for cassava. Touré *et al.* (2004) found 0.91 and 0.89 for sweet banana, 0.89 for mango and 0.83 for cassava. The second critical water content is between 0.095 and 0.331 and obeys no tendency. For this parameter, Kibangou-Nkembo (2013) obtained 0.12 for mango, 0.24 for plantain and 0.36 for cassava.

3.2. Calculation of mass diffusivities during the phase of decrease

Table 4 shows the mass diffusivity of the onion for different drying conditions during the deceleration phase.

During drying phase of decrease, the variations between the mass diffusivities were too small, so it can be said that this phase is little bit influenced by the drying conditions. In the literature, similar values have been found for other food products (*Lewicki et al., 1998; Dissa et al., 2010*).

3.3. Evaluation of the energy efficiency of the intermittent process versus continuous drying

The evolution of the reduced water content during continuous drying and intermittent drying with reference to time is shown in figure 3. It can be seen that the products dried according to these two methods reached the same water content after 6.5 hours for continuous drying and 7 hours for intermittent drying. From these durations, the energies provided in the two processes were calculated and the energy gain obtained with the intermittent process was deduced and presented in Table 5.

It was noted that the intermittent process developed allows energy savings of 12.70% with an extension of the drying time of 0.5 hours, i.e. 7.69%. For intermittent drying on/off and an intermittency of 0.33, Jumah (1995) obtained for the drying of grain at 80°C during 20 min of effective drying, an energy saving of 19 % with an extension of drying time of 81.34% compared to continuous drying. Chin and Law (2010) obtained for the drying of *Ganoderma tsugae* at 40.6°C and effective drying time of 120 min an energy saving of 21 % with an extension of 76.86 % of drying time (Kumar et al. 2014).

3.4. Mathematical Modeling

Tables 6 and 7 present the results of the modeling of the reduced water contents as a function of time for continuous drying and intermittent drying, respectively. For continuous drying the two term exponential and Midilli et al. (2002) models had the same coefficient of determination (0,999). The sum of squared errors (SSE) and the root mean square error (RMSE) was respectively 0.001798 and 0.009995 for two term exponential and 0.001731 and 0.0104 for midilli et al. model. According to Hany and Gikuru (2014), the model of Midilli et al. is that one which better fit the continuous drying curve of onion.

In the case of intermittent drying, the Two-term exponential model has the highest coefficient of determination and the lowest sum of squared errors and root mean square error (R^2 : 0.999, SSE: 0.001798, RMSE: 0.009995), followed by the Midilli *et al.* model (R^2 : 0.9999, SSE: 0.0002487, RMSE: 0.003717).

It can be noted from the above analysis that the two term exponential model described very well the intermittent drying developed. The intermittent drying could therefore be described by an empirical model according to whether the process definition took into account the characteristics of the product in order to minimize changes in the drying kinetics. Two term exponential was the same one that best described continuous drying. This confirms that the changes in the drying kinetics caused by the variation of the drying conditions of the developed process were negligible.

3.5. Nutritional analysis results

Table 8 shows the nutritional composition of onions dried continuously and intermittently. It was noted that the intermittent process allowed a retention of 166.04% fat, 2.50% protein and 53.84% vitamin C compared to continuous drying. Reduction sugars, on the other hand, were better retained by continuous drying with a retention of 15.60% more than intermittent drying. The developed intermittent drying process had therefore significantly maintained the nutritional composition of dried onions except for reducing sugars.

4. Conclusion

This work has developed an intermittent method of onion drying based on the determination of critical water contents, critical times and diffusivity. The first critical time determined for the various conditions tested was between 0.75 hours and 3.25 hours and the second between 3.5 hours and 14 hours. The diffusivities during the phase of decrease were very low and vary from $8.58 \cdot 10^{-10}$ to $2.19 \cdot 10^{-9}$ m²/s. The intermittent process developed showed an energy saving of 12.70%, better retention of fat, protein and vitamin C, respectively 166.04%, 2.50% and 53.84%. However, an extension of the drying time of 0.5 hours and a loss of reducing sugars of 16.50% in relation to the continuous drying carried out at 65 ° C with an air flow rate of 24 dm³/s was recorded.

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Engineer in agricultural mechanization, DEA in Material Sciences, PhD in Industrial Engineering, Postdoc in Logistics engineering, Associate Professor, **AZOUMA Yaovi Ouézou** is in charge of the Research Team on Agricultural Mechanization and Process Engineering (ERMAP) at “Ecole supérieure d’agronomie” of “Université de Lomé” in Togo (West Africa). This paper is related to our research project which goal is to carry out “Energy and quality saving in tropical high value crops drying”.

Public interest Statement

The loss of crops is greater in developing countries where 30 to 40% of fruits and vegetables are wasted. Drying process can help solve this problem but it is a high energy consuming operation in agro-industrial process. Besides, poor food quality can lead to diseases and nutritional deficiencies. In order to provide a solution to this problem, our research team designed a pilot dryer which makes it possible to dry products under various temperature and air flow. So, this work has developed an intermittent energy-saving drying process that best preserves the quality attributes of the onion, a high value crop in West Africa. Finally, the mastery of kinetics and energy performances of drying processes will help to design best dryers for tropical crops.

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Nomenclature

<i>Symbole</i>	<i>Désignation</i>	<i>ymbole</i>	<i>Désignation</i>
h	Hour (h)	P_o'	Saturating vapor pressure (Pa)
X_{ms}	dry matter content (kg dry matter / kg wet material)	φ	Relative humidity (%)
X_0	initial moisture content (kg water / kg d.b)	m_a	Dry air mass (kg)
X	moisture content at the instant t (kg water / kg d.b)	m_v	Water vapor mass (kg)
X_{eq}	equilibrium moisture content (kg water / kg d.b)	M_a	Mass molar of dry air (g/mol)
X_r	reduced moisture content	M_v	Mass molar of water (g/mol)
m_s	dry mass (kg)	V	Volume of drying air (m^3)
m_h	initial mass (kg)	V_a	Volume of dry air (m^3)
m	mass at time t (kg)	V_v	Volume of water vapeur (m^3)
$-\frac{dX}{dt}$	Drying rate (kg water / kg d.b / h)	ρ_a	Density of the dry air (kg/m^3)
$-\frac{\Delta X}{\Delta t}$	Variation of the moisture content reported to the duration (kg water / kg d.b / h)	ΔE	Energy provided by the enclosure of heating (J)
e	Thickness (mm)	E_θ	Energy of the air at the temperature θ (J)

Indice :

a : dry air
 v : water vapor
 amb : ambient
 s : drying (dry)
 c : continuous
 i : intermittent
 exp : experimental
 cal : calculated or predicted

θ : temperature
 eq : équilibre
 r : reduced
 h : wet
 ms : dry matter
 vs : saturating vapor
 0 : initial

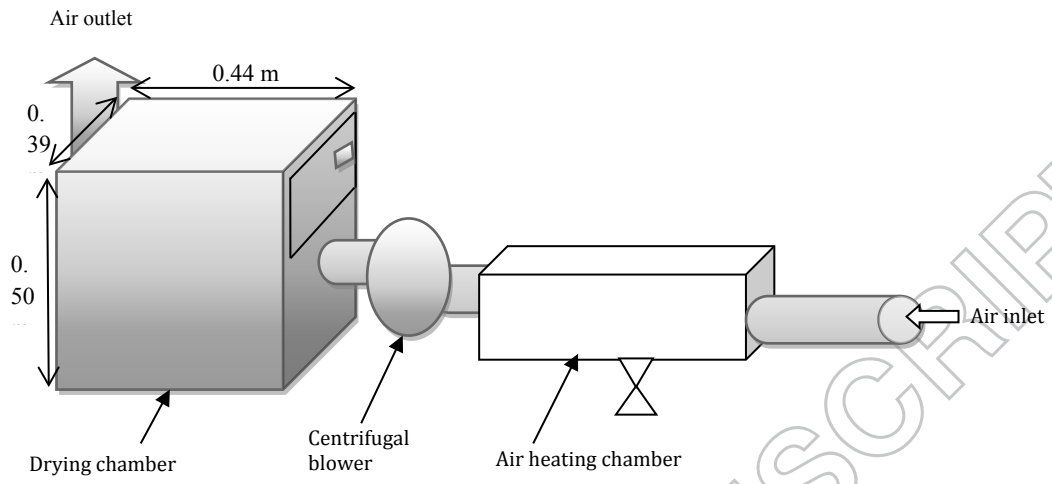


Figure 1 : Experimental dryer

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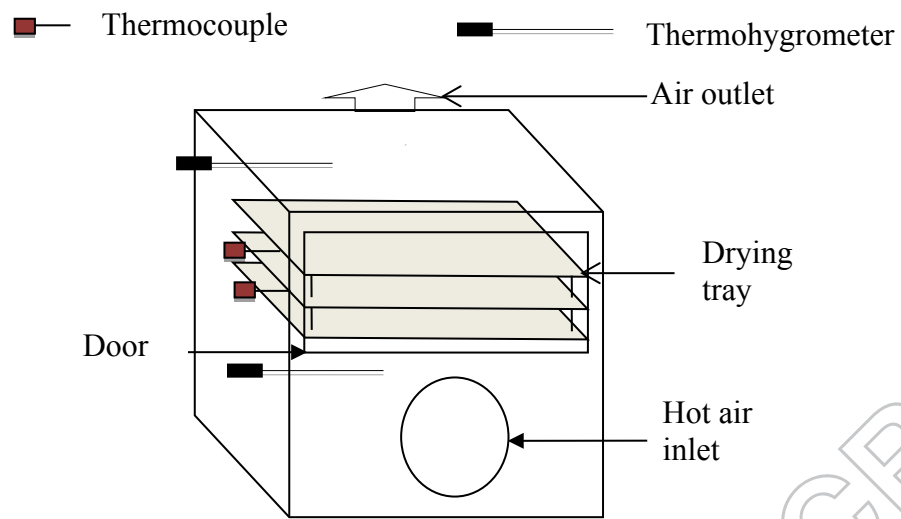


Figure 2: Drying chamber

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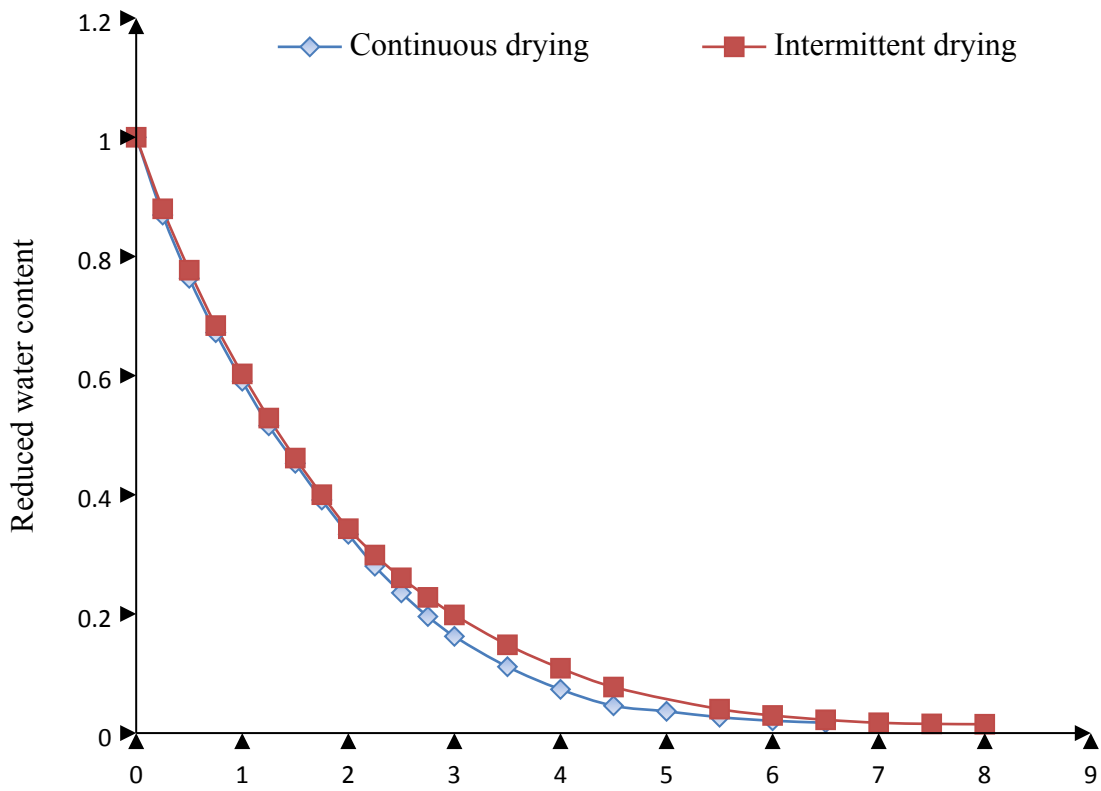


Figure 3: Water content according to time
Drying time (h)

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Table 1: Summary of the measurement instruments and physical parameters measured

Physical parameters measured	Measuring instrument	Precision
Temperature	K-type thermocouple	± 0.05 K
Air relative humidity	Capacitive humidity sensor type thermohygrometer A646 FH-E2C	$\pm 1,8$ %
Air flow rate	Thermo-anemometer FVA935-TH5	± 0.2 m/s
Mass	OHAUS electronic digital display	$\pm 0,1$ g
Thickness	Slide Caliper	$\pm 0,1$ mm
Drying time	Stopwatch	± 1 s

Table 2: Empirical mathematical models of the reduced water content

Name of the model	Equation of the model	Reference
Page	$X_r = \exp(-kt^n)$	Agrawal and Singh (1977)
Two term exponentiel	$X_r = a \exp(-kt) + (1-a) \exp(-kat)$	Henderson (1974)
Approximation of diffusion	$X_r = a \exp(-kt) + (1-a) \exp(-kbt)$	Kassem (1998)
Midilli et al.	$X_r = a \exp(-kt^n) + bt$	Midilli et al. (2002)

Table 3: Critical times and water contents

Temperature (°C)	Air flow (dm ³ /s)	tcr ₁ * (h)	Xrcr ₁ *	tcr ₂ * (h)	Xrcr ₂ *
45	20	3,25	0,64	14	0,095
	24	2	0,7	12	0,128
	28	1,5	0,73	10	0,131
55	20	2	0,66	7	0,202
	24	1,4	0,71	6	0,237
	28	1,1	0,72	4	0,331
65	20	2	0,56	5	0,206
	24	1	0,67	4	0,196
	28	0,75	0,72	3,5	0,271

*tcr₁: first critical drying time; tcr₂: second critical drying time;
Xrcr₁: first critical reduced water content; Xrcr₂: second critical reduced water content

Table 4: Mass diffusivities during the phase of decrease of drying

Temperature (°C)	Air flow (dm ³ /s)	Diffusivity (m ² /s)
45	20	8,58.10 ⁻¹⁰
	24	9,47.10 ⁻¹⁰
	28	1,02.10 ⁻⁹
55	20	1,33.10 ⁻⁹
	24	1,35.10 ⁻⁹
	28	1,46.10 ⁻⁹
65	20	1,80.10 ⁻⁹
	24	2,19.10 ⁻⁹
	28	2,05.10 ⁻⁹

Table 5: Energy effectiveness of the intermittent process compared to continuous drying

	θ (°C)	Y (kg d'eau/kg d'air sec)	t (h)	ma (kg)	E_0 (kJ)	ΔE (kJ)	g (%)
Continuous drying	65	0,02	6,5	567,21	38711,8 3	20844,8 3	
	30		6,5		17867,0 0		
Intermittent drying	65	0,02	2	175,52	11899,1 0	18197,3 2	12,7 0
	55		5	452,16	25938,2 4		
	30		7	627,67	19640,0 2		

Table 6: Results of the modeling of continuous drying

N°	Name of the model	Constant of the model	Statistical Parameters
1	Page	k = 0.5286 n = 1.103	R ² : 0.9987 SSE: 0.002355 RMSE: 0.01144
2	Two term exponentiel	a = 1.588 k = 0.71	R ² : 0.999 SSE: 0.001798 RMSE: 0.009995
3	Approximation of diffusion	a = 2.482 b = 0.8036 k = 0.4082	R ² : 0.9989 SSE: 0.0019 RMSE: 0.01057
4	Midilli et al.	a = 0.9854 b = -0.001645 k = 0.5105 n = 1.11	R ² : 0.999 SSE: 0.001731 RMSE: 0.0104

Table 7: Results of the modeling of intermittent drying

N°	Name of the model	Constant of the model	Statistical Parameters
1	Page	k = 0.5108 n = 1.056	R ² : 0.9999 SSE: 0.0002901 RMSE: 0.003808
2	Two term exponentiel	a = 1.48 k = 0.6275	R ² : 0.9999 SSE: 0.0001686 RMSE: 0.002904
3	Approximation of diffusion	a = 4.382 b = 0.9321 k = 0.4172	R ² : 0.9997 SSE: 0.0004974 RMSE: 0.005116
4	Midilli et <i>al.</i>	a = 0.9949 b = -0.0001267 k = 0.5051 n = 1.062	R ² : 0.9999 SSE: 0.0002487 RMSE: 0.003717

Table 8: Nutritional composition of intermittent and continuous dried onion

	Continuous dried onion	Intermittent dried onion
Total reducing sugar (g/100g d.b)	6,52±0,12	5,64±0,4
Fat (g/100g d.b)	0,53±0,03	1,41±0,30
Protein (g/100g d.b)	8,39±0,22	8,60±0,21
Vitamin C (mg/100g d.b)	80,82±3,82	124,34±3,83

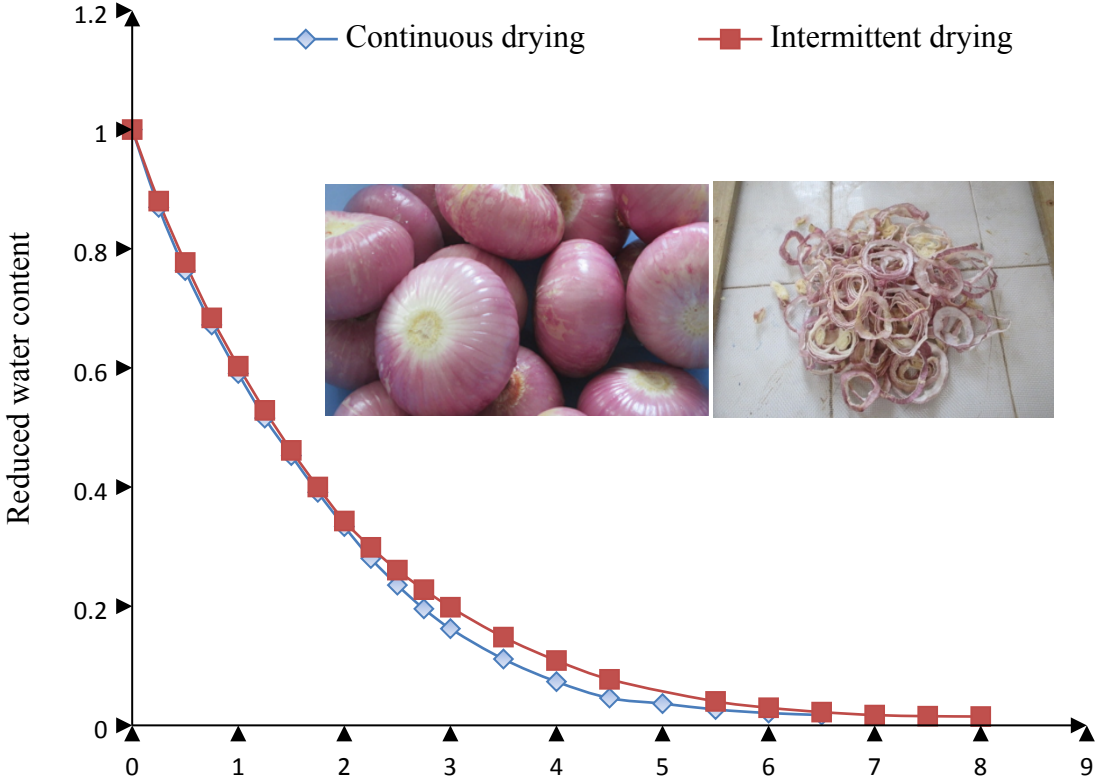


Figure 3: Water content according to time
Drying time (h)

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