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Experimental Study of the drying kinetics of the Pink Shrimps: Parapenaeus Longirostris Type

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Abstract: *Morocco has a diversity of marine species of great interest from the aquaculture standpoint. Their availability in space and time requires the development of conservation techniques ensuring the quantity and quality of these products. In this context, our work studies the kinetics of the drying and storage of shrimps as per the requirements for food products. Our work consists in an experimental protocol carried out in a partially thin film solar dryer operating in forced convection and provided with an auxiliary power source. Three drying temperatures were selected (50, 70 and 90 ° C) for a drying air flow rate of* $0{,}083\,m^3.s^{-1}$.

Keywords: *Drying kinetics, preservation, characteristic drying curve, modeling.*

I. Introduction

In order to contribute to the valuation of the seafood drying and storage process, we focused on the study of drying kinetics of the shrimps of the Parapenaeus longirostris type from the Agadir region. The experiments were performed in a thin film partially solar dryer operating in forced convection and equipped with a source of auxiliary [1]. In order to determine the influence of temperature on the drying rate, we conducted three experiments with a drying air flow at three temperatures (50, 70 and 90°C). The experimental results obtained have allowed us to determine the temporal evolution of the water content and profile of the drying rate in function of the water content for different aerothermal condictions of the drying air. We have also established a model of characteristic drying curve [2].

Nowadays, the aquaculture industry is experiencing a significant development in Morocco. Much research is conducted in the field biological, in particular the reproductive cycle. But few studies have focused on issues related to the conservation of these products. The fact is that if foodstuff is not dried in good conditions, it may degrade and therefore lose all of its nutrients and its organoleptic quality [3]. The drying can improve product quality, increase shelf life and facilitate their processing. This work aims to:

- Modernize the sector to improve the traceability of products, their taste and health quality;
- Improve the development of the national and international market: further processing;
- Reduce its energy costs and environmental the impact by using clean and abundant solar energy;
- Preserve the socioeconomic fabric.

The drying method used here is that of forced convection, it allows a simultaneous transfer of heat and mass (steam from the product). The drying fluid used is hot air.

II. Material and methods

The drying system used is an indirect convective dryer with a source of extra heat and a variable airflow fan (Fig. 1), this drying system controls the temperature and the drying air flow by control units incorporated in the drying chamber.

 

Figure 1. Partially solar dryer running in forced convection (EESPAM) with the control box.

Ambient air is preheated in a simple plane-, single glazing- solar collector. A centrifugal fan draws hot air from the solar collector unit and propels it through an air suction pipe. Electrical resistors provide in case of need extra energy to ensure a constant drying temperature at the inlet of the drying chamber.The mass of product to be dried is set at 50.0 g ± 0.1 g. The drying temperature is adjusted using the thermostat. One sets the input air flow in the drying chamber. At first, the time interval between two successive weights is three minutes. This interval increases as the product mass decreases. Each weighing gives the product wet mass $\mathrm{m_h(t)}$. The drying experiment is stopped when the product mass becomes constant. By stoving at 105 ° C for 24 hours, the dry weight on determines dry weight $\mathrm{m_s}$. Dry based moisture content $X(t)$ at time is defined by:

$$X(t) = \frac{m_h(t) - m_s}{m_s} \quad (1)$$

III. Results and Discussion

Shrimp drying conditions: The different experimental drying conditions are shown in Table 1. The fresh product, then dried at 50 ° C, is presented in Fig. 2.

Table 1: Shrimp drying conditions

Test	Drying temperature (° C)	Ambient air temperature (° C)	Relative humidity of the ambient air (%)	Drying time (min)
1	50	$17{,}5 \le \theta \le 30{,}4$	$27{,}3 \le \mathrm{Hr} \le 43{,}7$	170
2	70	$30 \le \theta \le 34{,}4$	$19{,}4 \le \mathrm{Hr} \le 24{,}7$	101
3	90	$27{,}9 \le \theta \le 35{,}1$	$22{,}2 \le \mathrm{Hr} \le 33{,}5$	60

The initial water content of the shrimp is of the order of 4% of dry matter and it was reduced to a final water content of 0.93% of dry matter. The final moisture content is a feature of each product. This is the optimal value for which the product does not deteriorate and keeps its nutritional and organoleptic qualities [4].

Figure 2. Fresh and dried shrimp at 50 ° C and with a drying air flow of $0{,}083\,\mathrm{m^3.s^{-1}}$ **.**

Profiles of the water content and of the drying rate: The drying curves of the experimentally obtained shrimp, describing the evolution of the water content as a function of time, are presented in Fig. 3. These curves described the evolution of the drying rate in function of time are shown in Fig. 4. The variation of moisture content versus drying time and the drying rate versus moisture content were given in Figs. 3 and 4 respectively. It is apparent that there is an absence of phase 0, the increasing drying rate period, where the temperature of the product is increased without any substantial loss of water and phase 1, the constant drying rate period. There is only the presence of the falling drying rate period (phase 2). These results are in agreement with the earlier observations [5] [6] [7].

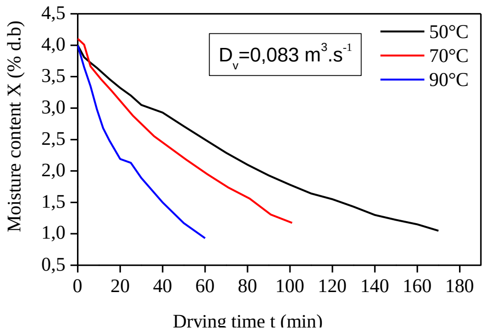

Figure 3. Profiles of the water content for different drying air temperatures.

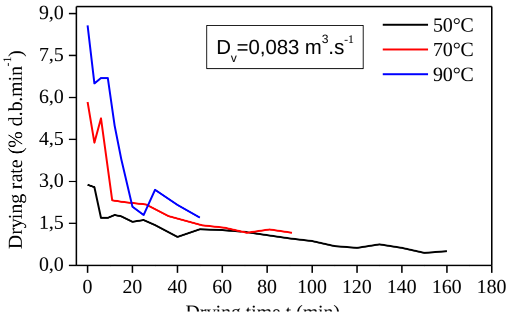

Figure 4. Profiles of the drying rate for different air drying conditions.

The versatile modular solar dryer installed at ENS allows for the control of two aerothermal settings: Temperature and drying airflow. For a same flow of drying air, the shrimp drying rate increases as the temperature of the drying air is growing and therefore the water content declines significantly (Fig. 5). This result is consistent with other work on solar drying of medicinal plants and food products : Karaaslan, 2016 [7]; Ertekin and Yaldiz 2004 [8] ; Lahsassniet al 2004 [1] ; Bimbenet 1978 [9].

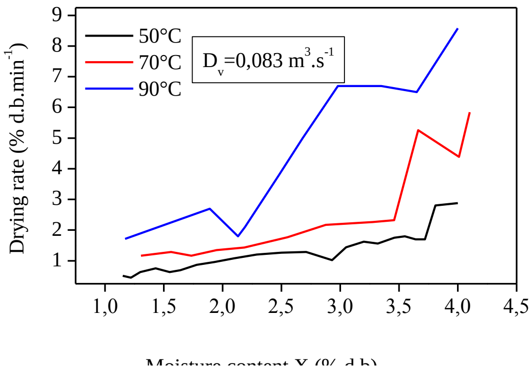

Figure 5. Influence of temperature on the shrimp drying rate.

Characteristic drying curve (CDC) of the shrimps: The principle of this method is to collect experimental results for various drying air conditions on a single so-called CDC curve that may be used by all scientists. The method developed by Van Meel (1958) [10] consists in representing the ratio of the drying rate at instant t at the drying rate of first phase, under the same conditions of air drying depending on the reduced water content X * , hence :

$$X \rightarrow X^{*} = \frac{X(t) - X_{eq}}{X_0 - X_{eq}} \quad (2)$$

$$\left(-\frac{dX}{dt}\right) \rightarrow f = \frac{\left(-\frac{dX}{dt}\right)_t}{\left(-\frac{dX}{dt}\right)_0} \quad (3)$$

We got a pretty good combination of the drying paces despite variations of air and product properties (Fig. 6). This figure shows a perfect combination for low water content and a remarkable dispersion at high water contents. This dispersion is explained by the fact that in this area, the drying rates $\left(-\frac{dX}{dt}\right)$ do merge; and since the initial velocities $\left(-\frac{dX}{dt}\right)_0$ are not the same for all the tests, the dimensionless drying rate f is not unique; hence the bad combination of drying kinetics near the axis of the reduced water contents [11]

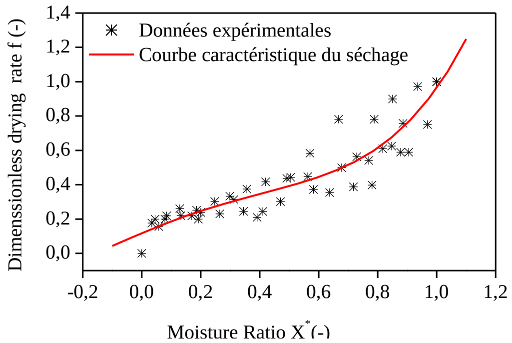

Figure 6. Characteristic drying curve (CDC) of shrimps

The determination of the drying kinetics is made by direct calculation of the derivative of the water content from the experimental points using appropriate software (Smoothing on DOS, Curve-Expert 3.1 and Origin 6.1). From the experimental data of the three temperatures, we established the correlation expressing the normalized drying rate of shrimps as a polynomial of order 4 in X *.

$$f = 2{,}15X^{*} - 5{,}255X^{*2} + 5{,}868X^{*3} + 1{,}025X^{*4}$$
$$r = 0{,}854 \text{ and } ESM = 0{,}1043 \qquad (4)$$

The characteristic drying curve can be regarded as independent from the process variables and a single curve is sufficient to characterize it in all cases. This curve allows the grouping of results obtained under different conditions of air speed, temperature and air humidity rate and would enable the dryers of similar food products to extract maximum information on the conditions of drying of the species studied, regardless of the proposed drying environment.

Smoothing of the shrimp drying curves: Several empirical or semi-empirical models are used to describe the drying kinetics and to predict the reduced water content X * in function of the drying time. To describe the drying pace of shrimps and seek the most adequate empirical equation, we used seven thin-layer drying models of food products. Table 2 summarizes the empirical drying equations used in the modeling.The model that is appropriate to the description of the pace of the shrimp drying kinetics is selected according to the following criteria: high correlation coefficient (r), minimal average bias (ESM), and a minimum reduced chi-square. These statistical parameters are defined by:

$$r = \sqrt{\frac{\sum_{i=1}^{N}\left(Xeq_{i,pre} - \overline{Xeq}_{i,exp}\right)^2}{\sum_{i=1}^{N}\left(Xeq_{i,exp} - \overline{Xeq}_{i,exp}\right)^2}} \qquad (5)$$

$$ESM = \frac{1}{N}\sum_{i=1}^{N}\left(X^{*}_{pre,i} - X^{*}_{exp,i}\right) \qquad (6)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(X^{*}_{pre,i} - X^{*}_{exp,i}\right)^2}{N-n} \qquad (7)$$

Table 2 : Drying models applied to the description of shrimp drying curves

Model Name	Model equation	References
Newton	$X^{*} = \exp(-kt)$	Bruce (1985)
logarithmic	$X^{*} = a\exp(-kt) + c$	Togrul & Pehlivan (2003)
Two-term	$X^{*} = a\exp(-k_0 t) + b\exp(-k_1 t)$	Henderson (1974)
Wang and Singh	$X^{*} = 1 + at + bt^2$	Wang & Singh (1978)

Approach to the dissemination	$X^* = a\exp(-kt) + (1-a)\exp(-kbt)$	Yaldiz et al. (2001)
Verma et coll.	$X^* = a\exp(-kt) + (1-a)\exp(-k_0 t)$	Verma et al. (1985)
Midilli-Kucuk	$X^* = a\exp(-kt^n) + bt$	Midilli, & Kucuk (2003)

Where a, b, c, k, k_0, k_1 and n are constants that can be temperature dependent.

The curves having the water content reduced in function of the drying time are described by seven models. The coefficients of each drying model were determined using the nonlinear optimization method based on the Levenberg-Marquard algorithm with software programs Curve-Expert 3.1 and Origin 6.1. The different models are compared based on their correlation coefficients (r) and their chi-square parameters chi-square statistics χ^2 and the average bias ESM (Table 3).

Table 3. Statistical parameters for each model

Model	Coefficients	ESM	r	χ^2
Newton	k = 0.0427	0.0265	0.9958	$7.0356\ 10^{-4}$
Logarithmic	a = 1.3327 k = 0.0077 c = -0.3616	0.0120	0.9993	$2.3074\ 10^{-4}$
Two term	a = 2.4489 k_0 = 0.0115 b = -1.4626 k_1 = 0.0069	0.0238	0.9982	$5.6546\ 10^{-4}$
Wang et Singh	a = -0.0104 b = $2.7837\ 10^{-5}$	0.0225	0.9977	$5.0536\ 10^{-4}$
Approximation de la diffusion	a = 5.2840 k = 0.0062 b = 0.8086	0.0236	0.9985	$3.4675\ 10^{-4}$
Verma *et al.*	a = 5.4518 k = 0.0062 k_0 = 0.0050	0.0186	0.9985	$3.461\ 10^{-4}$
Midilli-Kucuk	a = 0.9835 k = 0.0127 n = 0.9243 b = -0.0014	0.0119	0.9994	$1.4146\ 10^{-4}$

The model that provides the highest value of r and the lowest values of χ^2 and ESM is considered as the best to describe the kinetics of drying shrimp. The Kucuk Midilli model showed good correlation with the experimental curves. Indeed, the Fig. 7 and 8 show a perfect correlation between the experimentally reduced water content and the reduced water contents calculated by the Midilli Kucuk model. Therefore, the Midilli-Kucuk equation is selected for the modeling of the solar drying shrimp law [12] [13] [14].

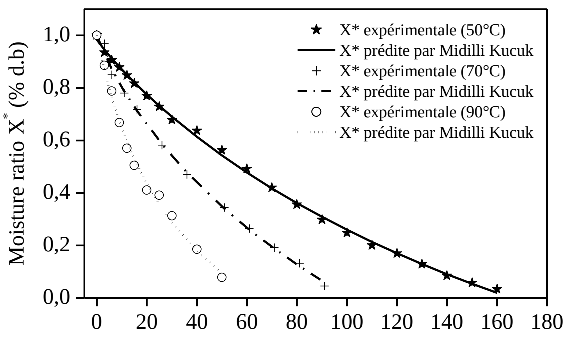

Figure 7. Experimentally reduced water content and predicted by the Midilli-Kucuk model for each temperature and for the rate of 0.083 $m^3.s^{-1}$

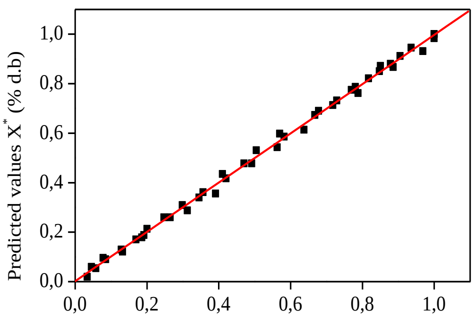

Figure 8. Reduced water content predicted by the Midilli-Kucuk model according to the experimentally reduced water content of shrimp

IV. Conclusion

Solar drying shrimp is studied in a solar dryer convective including an auxiliary heat source. From the experiments carried out at different drying air conditions, drying curves show the decreasing drying rate (Phase II), the absence of Phase 0 (warm-up) and Phase I (constant pace) . The temperature of the drying air is the factor that influences most the drying kinetics. The drying curve obtained allows us to generalize the shrimp drying kinetics data. It seems therefore interesting from the solar driers sizing standpoint to well determine this curve considered as a simplified approach allowing systematic procedures for calculation and can be used for the analysis of several similar cases. The main factor affecting the shrimp drying kinetics is the temperature of the drying air. The characteristic drying curve is obtained and the equation of the drying rate is determined empirically. Statistical analysis of experimental results in reduced coordinates X * (t), smoothed by the best-known models in the field of food processes engineering, allowed us to conclude that the Midilli Kucuk model is most appropriate for describing the kinetics of thin-layer convective solar drying of shrimps.

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