DRYING CHARACTERISTICS OF TEXTURIZED SOY PROTEIN

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Abstract. Texturized soy proteins (TSP) are commonly used like a functional ingredient in several food applications and its process involves a drying step, which is necessary to decrease the product moisture content until the required level; the unit operation of drying is one of the most relevant and challenging processes in manufacturing food product. In this study, the drying curves of two commercial types of TSP (with different particle sizes) were determined in a pilot air-dryer operated at three different temperatures (90, 110 and 130°C), three different drying air velocities (100, 125 and 150 cm/s) and two different heights of product layer. The results showed that drying air temperature significantly influenced all the experimental drying curves. The height of product layer influenced only the drying curves of TSP Type I. The effect of drying air velocity was found to be lower. The experimental data were fitted to an exponential model of two constants and every combination of parameters showed a very good fit ($R^2 > 0,99$). In order to verify the general characteristics of the drying, the drying rate curve (R, in kg water/kg db x s) of each type of TSP was built: the drying rate decreased continuously throughout the drying period, indicating that drying of these types of TSP took place only during the falling rate period.

Keywords: Texturized Soy Protein, Drying, Process Parameters.

1. Introduction

Texturized soy protein is the most used vegetable protein in the human food due to the high protein content present in the soybean (soybean contains about 40% of vegetable protein) and the great nutritional value of its protein. The main functions of the use of TSP in a food product may include: increase water and protein content of this food, reduce product cost, enhance texture and hardness of the product and replace a portion of the meat keeping the original protein content of the product. As a consequence of these advantages, the range of food products that use soy protein as a functional ingredient are increasing day-by-day.

In the production of TSP, one of the principal steps is the drying process, which is necessary to decrease the product moisture content until the required level. The objective of dehydration in foods is diminishing its degradation caused by the growth of bacteria, yeasts and molds. Moreover, undesirable chemical and biochemical reactions – which also are responsible for product degradation and shelf life time reduction – are affected by moisture decrease (Geankoplis, 1993).

As the use of TSP as a functional ingredient is relatively new, a very few data of its drying characteristics are available in literature. Therefore, the objective of this study was the analysis of the drying characteristics of two commercial types of TSP and the development of a model capable to predict the drying curves of these products. The experimental drying curves of TSP types I and II were determined at three different drying air temperatures

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(90, 110 and 130°C), three different drying air velocities (100, 125 and 150 cm/s) and two different heights of product layer (2,5 and 5 cm for TSP Type I and 5 and 10 cm for TSP Type II).

2. Theoretical Fundaments

Drying is one of the most relevant and challenging processes of food industry, since a great number of food products are submitted to at least one drying step during its production (Barbosa & Vega, 1996).

Dehydration or drying of foods is described as any process that involves thermal removal of volatile substances (humidity) to obtain a dry solid (Mujumdar, 1995). The main purposes of drying products are to increase its shelf life, to better its quality, to simplify the handling, storage and transport of the products and also to prepare the product to subsequent processes.

Drying is a very complex process since it is a simultaneous heat, mass and movement transfer operation in which moisture is removed from food material and carried away by hot air. This operation may also be accompanied by chemical and biochemical reactions, phase change and shrinkage of the food product.

A typical curve of a drying process is the "drying-rate curve" which is a plot of the drying rate (R, in kg of water per kg of dry solid per unit of time) versus the moisture content (X, in kg of water per kg of dry solid) of the material. The drying-rate curve of a food product generally presents two distinct and well-defined phases: a constant drying-rate period (in the beginning of the drying process) and a falling-rate period, which starts at a certain moisture content known as the critical moisture content (XC).

In the first period, the product surface is completely wet and behaves as a surface of free water. As a consequence, the drying rate in this period is limited by the rate of water evaporation from the product surface. The rate of moisture migration from the interior of the product until its surface is greater than – or equal to – the rate of moisture evaporation from the surface to the external air, keeping constant the drying rate. Thus, the convective heat transfer exerts the main role during this period of the process and the external conditions (type of dryer, system pressure and drying air temperature, velocity and relative humidity) are the main factors that control the drying rate (Heldman & Hartel, 2000).

As the product dries, the rate of internal water migration decreases. When the critical moisture content is attained, the surface is no longer saturated with water and the drying rate begins to fall, starting the falling-rate period. From this moment and on, the drying rate is limited by the rate of water migration (or water diffusion) from inside the solid to its surface and, therefore, the product nature (superficial area, constitutes orientation, type and concentration of solutes) and the drying air temperature (that helps the water molecules migration) are the most significant parameters (Barbosa & Vega, 1996).

During the drying process, diffusion is the main mechanism of internal moisture migration (Van Arsdel & Copley, 1963). It occurs within the solid structure and/or within the capillaries, pores and small spaces saturated by vapor and may occur in different manners and under distinct drying conditions. Some of the internal migration mechanisms are the liquid-diffusion (due to moisture gradient), the vapor-diffusion (due to partial pressure gradient), the capillary flowing and the flowing due to pressure and temperature gradient. One or some of them may occur during the drying process and, moreover, the contribution of each mechanism in the moisture migration may vary during the process (Heldman & Hartel, 2000). As a consequence, the prediction of the drying rate in the falling-rate period is a very complex task.

3. References Review

Several researches have reported data about the drying characteristics of different food products; some of these works are briefly commented as follow. Abdelhaq and Labuza (1987) determined the effect of pretreatment method and drying temperature on the quality of dried apricots; Simal, Femenía, Llull and Rosselló (2000) evaluated the effect of drying air temperature on functional properties of dehydrated aloe vera and proposed a mathematical model to simulate the drying curves of the product. More recently, Park, Vohnikova and Brod (2002) studied the drying kinetics of garden mint leaves for three different temperatures and two different drying air velocities; Viollaz and Rovedo (2002) proposed a mathematical model to predict the drying kinetics of three-dimensional shrinking bodies; Doymaz and Pala (2002) studied the drying kinetics of red peppers under different pretreatment and air drying conditions; Sogi, Shivhare, Garg and Bawa (2003) studied the water sorption isotherms and drying characteristics of tomato seeds; Iguáz, San Martín, Maté, Fernández and Vírseda (2003) obtained the drying characteristics of the medium grain rough rice to apply in deep-bed drying simulation; Koyuncu, Serdar and Tosun (2004) reported the drying characteristics and energy requirement for drying of chestnuts. Concerning to drying characteristics of TSP, only one work was found in the literature: Romero (1988) determined the drying characteristics of two commercial types of TSP (in a static-bed dryer and in a moving-bed dryer) varying the air drying temperature between 50 and 91°C, the air drying flow rate between 0,13 and 0,18 kg/m^2*s and the height of product layer between 2 and 10 cm. The author observed that the drying of these products took place just under the falling rate period and the air drying temperature was the most influent parameter in the process.

4. Materials and methods

4.1. TSP Samples

The drying curves of two commercial types of TSP, provided by The Solae Company (Esteio, RS, Brazil), were determined. The studied samples were composed by 50% of protein, 20% of sugar, 0% of fat, 20% of fibers and 4% of ashes and the main difference between two types of TSP was the medium equivalent diameter of the samples (1,98 cm for TSP Type I and 15,26 cm for TSP Type II). The samples were collected directly from the process line (in the feeding of the industrial dryers).Thus, due to some desirable and/or necessary changes in the process parameters, they showed sensible variations in its characteristics of initial moisture content, density and porosity. The initial moisture content of TSP types I and II varied, respectively, between 20 and 35% and 22 and 28% db.

4.2. Drying experiments

The drying experiments were performed in a pilot static dryer, presented in Figure 1, composed by a centrifugal fan (2800/3400 rpm, 15 m^3/min), three electrical resistances in parallel (180°C at 330 m^3/min), a drying chamber with mobile sidewalls (that makes possible the inversion of the drying-air stream between ascendant and descendant) and a recipient for product disposal (area=0,04 m²), which is connected to an analytical scale (precision of 0,1 g). The input drying air flow rate and temperature were the controlled parameters.

Fig. 1. Pilot dryer used in the determination of the drying curves.

The following procedure was used during the drying experiments: the equipment was turned on and the desirable input drying air temperature and flow rate were set; when a constant condition was reached by the equipment, the samples were collected and disposed in the drying recipient until the set height of product layer was reached; the initial product mass was registered and the experiment was initiated. The product mass was registered each 90 seconds, quickly turning off the resistances and the fan (to provide scale stabilization). The drying air stream – always ascendant at the beginning – was inverted each 180 seconds to provide a more uniform drying. The experiment was finished when product moisture content reached less than 1% (dry basis). The moisture content of the samples before and after the drying experiment was determined using the standard method of moisture content determination (AOAC, 1990).

All the samples were submitted to the experiments immediately after process sampling. Another important factor is that the equipment was placed inside the industrial area, where the temperature and the moisture content of the external air were basically constant.

In the determination of the TSP drying curves, the following parameters were varied: height of product layer (h, in cm), drying air temperature (T, in °C) and drying air velocity (v, in cm/s). In the experiments, for two types of TSP, three different drying air temperatures (90, 110 e 130°C) and velocities (100, 125 e 150 cm/s) were tested. Two different height of product layer were adopted, depending on the type of TSP used in each experiment (2,5 and 5 cm for TSP Type I; 5 and 10 cm for TSP Type II).

A complete factorial planning with three factors (T, v and h, the two firsts with three levels and the last one with two levels) was used to evaluate the influence of the studied parameters in the TSP drying process. This planning resulted in a minimum of 18 experiments (3 x 3 x 2) for each type of TSP; each parameters combination was tested, at least, in duplicate.

4.3. Data adjustment

In order to minimize the influence of the variation of initial moisture content in the results, the dimensionless moisture content (X_{adm}) was determined according to:

$$X_{adm} = \frac{X - X_{eq}}{X_0 - X_{eq}} \quad (1)$$

where X, X_0 e X_{eq} are, respectively, the moisture content at time t, the initial moisture content and the equilibrium moisture content of the sample.

In the fitting of the experimental drying data, a classic model, commonly found in literature, were used: a two constant exponential model (Eq. 2) were used to fit the dimensionless moisture data versus time.

$$X_{adm} = C_1 \exp(-C_2 t) \quad (2)$$

Where C_1 and C_2 are the constants of the exponential model.

A non-linear estimation package (Statistica ’98 Edition) was used to estimate the constants of the presented model. In order to check the veracity of the found solutions, the regressions were repeated using different initial guessed values (Peleg, 1993). The correlation coefficient (R^2) generated in each fit was used in the evaluation of quality of the fit.

In order to evaluate the influence of the studied parameters, as well the interaction effects among them, during the TSP drying process, a statistical analysis (ANOVA) was performed, using a program developed for Matlab 5.3 software. The F test, performed at the end of this analysis, indicated the studied parameter significance. According to Neto, Scarminio and Bruns (1995), if the calculated F is greater than the tabled F, the studied parameter is significant.

5. Results and Discussions

Figures 2 and 3 show some of the drying curves obtained for each type of TSP. Figure 2 shows the influence of the process parameters – height of product layer, drying air temperature and drying air velocity, respectively – in the moisture content variation of TSP Type I during drying time. Figure 3 shows the influence of the process parameters – height of product layer, drying air temperature and drying air velocity, respectively – in the moisture content variation of TSP Type II during drying time.

An important influence of height of product layer in the drying curves of TSP type I can be clearly observed in Fig. 2. The influence of drying air temperature is also significant for two types of TSP, as can be seen in Fig. 2 and 3; the drying air velocity, however, did not significantly influence the drying time of these types of TSP.

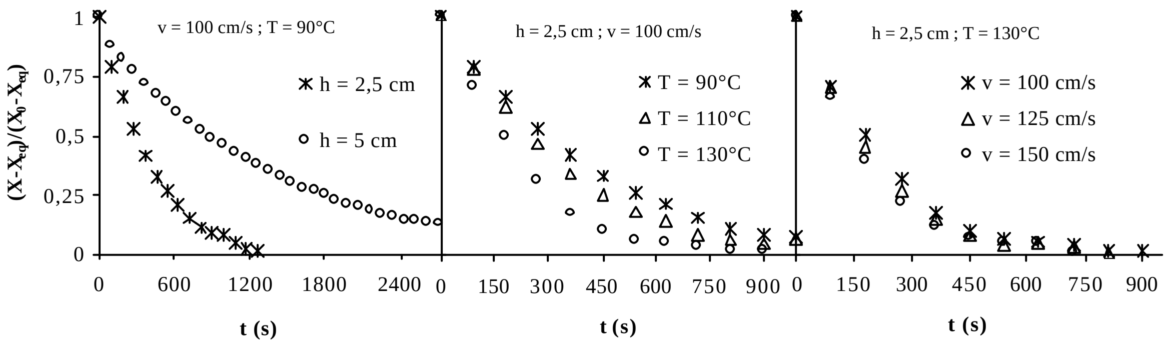

Fig. 2. Influence of height of product layer, drying air temperature and velocity in the drying of TSP Type I.

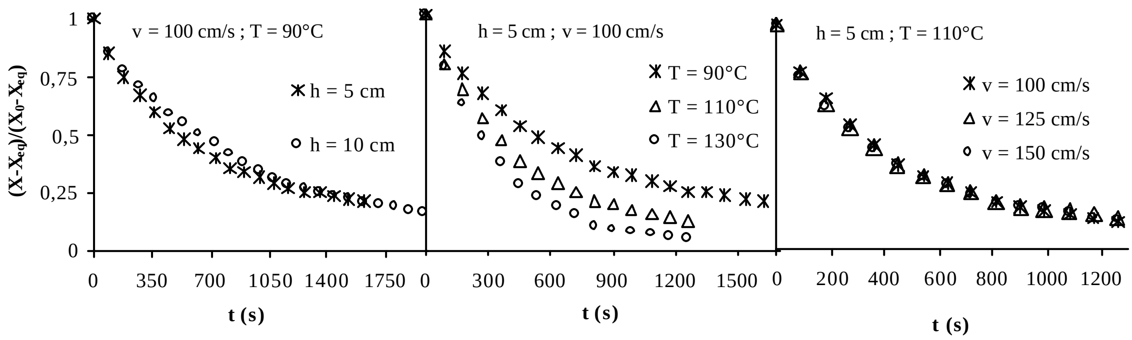

Fig. 3. Influence of height of product layer, drying air temperature and velocity in the drying of TSP Type II.

The experimental curves were then fitted using the exponential model of two constants (Eq. 2). Table 1 shows the correlation coefficients estimated in these fittings, were h_1 and h_2 are the height of product layer of 2,5 and 5 cm for TSP Type I and 5 and 10 cm for TSP Type II.

Table 1. Correlation coefficients estimated in the fitting of the experimental data to exponential model.

Parameters			*Correlation coefficient, R^2*	
T (°C)	*v (cm/s)*	*h (cm)*	*TSP I*	*TSP II*
90	100	h_1	0,999	0,990
90	125	h_1	0,999	0,991
90	150	h_1	0,998	0,987
110	100	h_1	0,998	0,995
110	125	h_1	0,999	0,993
110	150	h_1	0,999	0,992
130	100	h_1	0,997	0,999
130	125	h_1	0,997	0,999
130	150	h_1	0,998	0,997
90	100	h_2	0,998	0,996
90	125	h_2	0,998	0,992
90	150	h_2	0,998	0,992
110	100	h_2	0,998	0,995
110	125	h_2	0,998	1,000
110	150	h_2	0,998	0,999
130	100	h_2	0,999	0,999
130	125	h_2	0,995	0,995
130	150	h_2	0,996	0,998

It can be observed in this table that every combination of parameters, for two types of TSP, showed a very good fit with correlations coefficients over 0.99.

The values obtained for C_1 constant varied little and were very close to the unity. The values estimated for C_2 constant, however, varied significantly with the process parameters. Thus, the constant C_1 for the two types of TSP was considered independent of the studied parameters and equal to unity and a statistical analysis was carried out to identify the significance of these parameters in the estimation of the constant C_2.

Table 2 shows the result of the statistical analysis for each type of TSP, where F calc are the estimated F values and F tab are the F values got from F table.

Table 2. Result of the statistical analysis for TSP types I and II.

Parameter	*TSP Type I*		*TSP Type II*	
	F calc	F tab	F calc	F tab
T	51,3	3,6	81,5	3,6
v	31,3	3,6	6	3,6
h	929,1	4,4	1,7	4,4
T + v	4,4	3,6	1,2	3,6
T + h	15,4	3,6	< 0,1	3,6
v + h	4,5	3,6	6,5	3,6
T + v + h	4,5	3,6	5	3,6

Observing the F calc and F tab values obtained for TSP Type I, it can be seen that all the parameters and interactions effects showed a statistical significance. For TSP Type II, however, only the temperature and velocity of drying air, as well as two of the interaction effects, showed a statistical significance. This analysis may confirm the results that could be observed in the drying curves: the height of product layer is a very influent parameter in the estimation of C_2 constant for TSP Type I but shows no influence in the drying process of TSP type II; the drying air temperature is a very important parameter for the drying process of these two types of TSP in the conditions studied and the influence of the drying air velocity is small but could not be neglected. Therefore, it can be observed that, in the conditions that the experiments were carried out, the drying of these two types of TSP is mainly dependent on the internal conditions and the drying air temperature and slightly affected by the surrounding conditions (as drying air velocity).

In order to verify the general characteristics of the drying, the drying rate curve (R, in kg water/kg db x s) of these two types of TSP during the different drying conditions was built. All the curves obtained showed a very similar behavior and some of them can be seen in Figure 4. This figure shows the influence of drying air temperature in the drying rate of TSP types I and II versus the moisture content to the following conditions: drying air velocity of 150 cm/s and height of product layer of 2,5 cm and 5 cm, respectively.

It can be observed from the figure that a drying constant rate period was not detected and the drying rate decreased continuously throughout the drying period, indicating that drying of these types of TSP took place during the falling rate period. Thus, the drying process of these types of TSP, in the studied conditions, can be considered as a diffusion-controlled process in which the rate of moisture removal is limited by diffusion of moisture from inside to the surface of the product. This result explains the great influence of drying air temperature in the drying curves of these types of TSP, since the increase of this parameter facilitates the moisture internal diffusion. In the same way, external factors have little influence in the drying rate. Therefore, the slight influence of the drying air velocity, which takes action mainly in the convective heat transfer, is explained.

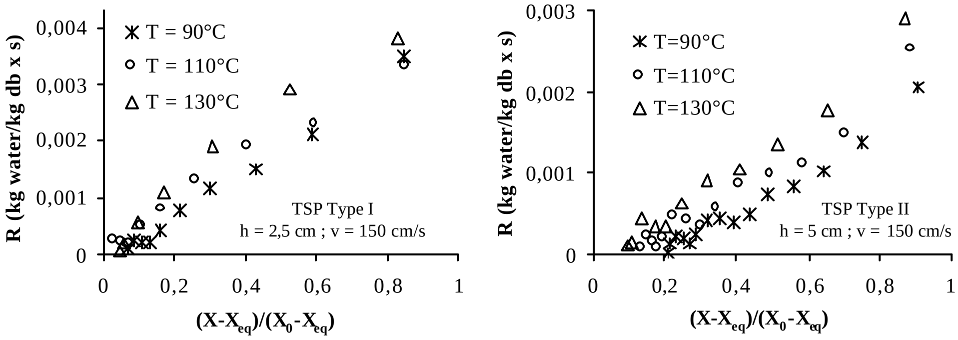

Fig. 4. Influence of drying air temperature in the drying rate curve of TSP types I and II.

The great influence of height of product layer in the drying curve of TSP Type I and its insignificance for TSP Type II may be explained by the product bed compactness, which is determined by the particle sizes and, consequently, by the height of product layer. The particle sizes of TSP Type I are much smaller than the particle sizes of TSP Type II and, thus, these particles form a bed whose compactness varies with the product layer height; the higher the bed compactness, the more difficult is for the drying air to cross the product layer and slower is the drying process. In addition, if the product layer is too compact, the drying air tends to flow, primarily, through preferential ways, which maintains some areas of the product bed moist for a long period of time, slowing, as a consequence, the drying process. On the other hand, the particle size of TSP type II (equivalent diameter of about 15.26 cm) do not permit the formation of a compact bed, but is responsible by the formation of a bed with large interstitial spaces that are not influenced by the height of product.

6. Conclusions

Two commercial types of TSP were dried in a pilot static dryer at different heights of product layer, drying air temperatures and velocities. The results show that the height of product layer were decisive for drying time of TSP Type I but not important for the drying process of TSP Type II and the drying air temperature has a great influence in the drying curves of these two types of TSP. Also, it was observed that the influence of the drying air velocity is small but could not be neglected. Observing the drying rate curves it was possible to conclude that the drying process of these types of TSP, in the studied conditions, can be considered as a diffusion-controlled process, being limited by the diffusion of moisture from inside to the surface of the product.

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