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Drying time of maltodextrin in a spray dryer

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Abstract:
The work consists of a spray dryer applied to the drying of maltodextrin with the aim of predicting the drying time of drops that were atomized in the dryer.
Background*: Maltodextrins are, by definition, hydrolyzed starch build up by units of a-D-glucose bound together, mainly, by glycosidical (1→4) linkages. Maltodextrins are usually classified by their values of dextrose equivalent, ranging up to 20.*
Materials and Methods*: The spray dryer used in this study is from the Brand: NIRO-GEA, with a nominal evaporation capacity of 1200 kg.h⁻¹; outlet air flow of 46.4 m³.h⁻¹; production of 50 tons of maltodextrin/day. The dimensions of this equipment are 9600 mm in height and 6800 mm in diameter. Six industrial batches of maltodextrin produced in a starch processing plant were used for this study.*
Results*: It was found that the drying time of the drops was less than 3 seconds, mainly due to the significant influence of the small initial concentration of water in the drops dispersed in the dryer.*
Conclusion: *The drying time of the maltodextrin droplets atomized inside the spray dryer is less than 3 seconds. This is due to the solids content of the droplets being relatively large and therefore drying is facilitated due to the average size of 90% of the particles being up to 242 µm.*
Key Word*: Droplets atomized; Evaporation capacity; Starch slurry; Starch processing; Syrup drying.*

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I. Introduction

Maltodextrins are, by definition, hydrolyzed starch build up by units of a-D-glucose bound together, mainly, by glycosidical (1→4) linkages with a general formula [$(C_6H_{10}O_5)nH_2O$]. Maltodextrins are usually classified by their values of dextrose equivalent, ranging up to 20. Dextrose Equivalent (DE) expresses the number of reducing ends aldehyde groups relative to pure glucose at the same concentration, so that high DE indicates high hydrolytic conversion and lower average molecular mass [1]. Dextrose equivalent to maltodextrin manufactured by Cargill ranges from 17.0 to 19.9 [2].

The process for producing liquid maltodextrin having a DE between 5 and 20% begins by mixing starch with an amount of water sufficient to provide a starch solution around 50% DS (% dry solid). An amount of α-amylase sufficient to hydrolyze the starch is added to this solution. This starch slurry is evaporated to obtain a starch solution with DE between 0.5 and 5.0%. The enzymatic process involves two steps of α-amylase addition. In the first step, the solution is heated from 120 to 165°C for a period of 30 seconds to 10 minutes. It is then kept at a temperature between 101°C and 115°C, for up to 10 minutes in a pressure vessel. In the second step of adding α amylase, the solution is kept between temperatures of 93°C to 100°C for enough time to obtain the product with DE until 20% [3].

Figure 1 presents a scheme of the conversion of starch to maltodextrin ([4]; [5]).

The objective of this study was to verify the drying time of maltodextrin in an industrial spray dryer.

Drying concepts

Spray drying is a process where a liquid droplet is rapidly dried as it encounters a stream of hot air. Figure 2 is a schematic diagram of a spray drier. The small size of the liquid droplets allows very rapid drying and the residence time of the material inside the spray drier is in the order of seconds [6].

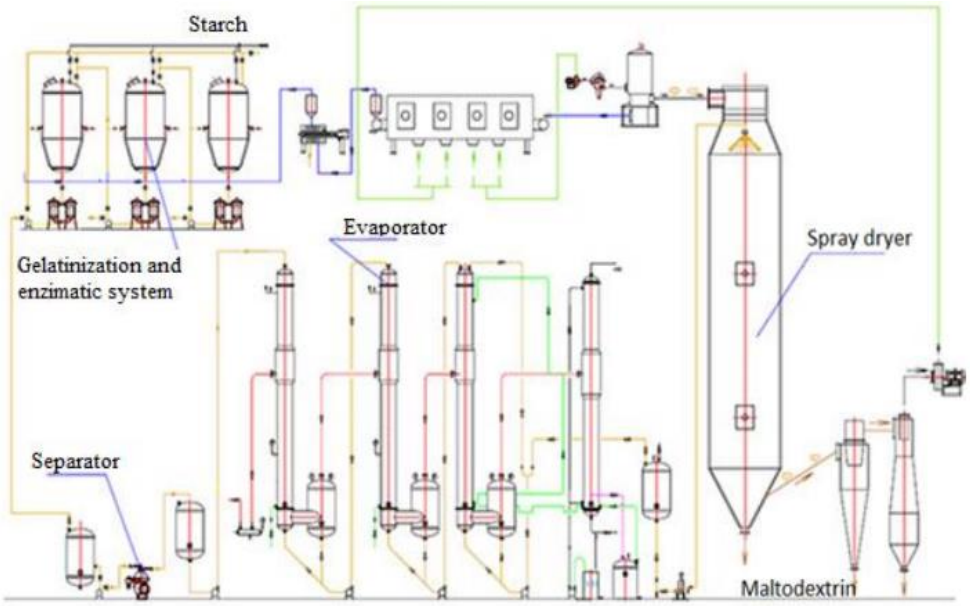

Figure 1: Schematic representation of the process of converting starch into maltodextrin.

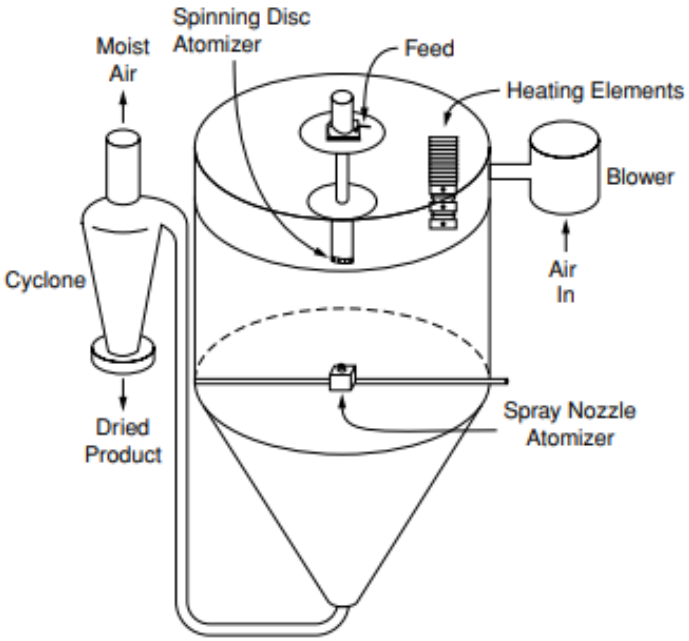

Figura 2: Schematic diagram of a spray drier.

The constant drying rate Rc or (dX/dt) is given by Equation (1).

$$\frac{dX}{dt} M_s \, h_{fg} = h \, A(T_a - T_s) \tag{1}$$

If ρL is the density of the liquid being dried, r is the radius of the droplet, and X_0 is the initial moisture content (dry basis, kg water/kg dry matter), we have Equation (2):

$$M_s = \frac{4\pi r^3(\rho_L)}{3(1 + X_0)} \tag{2}$$

and the Equation (1) becomes:

$$\frac{dX}{dt} \cdot \frac{4\pi r^3(\rho_L)(h_{fg})}{3(1+X_0)} = h(\pi r^2)(T_a - T_s) \tag{3}$$

Integrating the Equation (3):

$$t_c = \frac{4(X_0 - X_c)(r)(\rho_L)h_{fg}}{3(1+X_0)(h)(T_a - T_s)} \tag{4}$$

But, for water vaporization around small spherical particles, the relationship between the convective heat transfer, h, and the thermal conductivity of the saturated air, at the wet bulb temperature around the sphere of radius r, is given by the equation:

$$h = \frac{k_f}{r} \tag{5}$$

Therefore:

$$t_c = \frac{4(X_0 - X_c)(r^2)(\rho_L)h_{fg}}{3k_f(1+X_0)(T_a - T_s)} \tag{6}$$

The drying time in the falling rate period is [6].

$$t_f = \frac{h_{fg}(\rho_L)(r_c{}^2)(X_c - X)}{3k_f(\overline{\Delta T})} \tag{7}$$

The droplet size is a function of peripheral speed of a centrifugal atomizer, see Figure 3. A correction curve applies for water mass rates other than 20 lb/min.

The density values are obtained by equations presented in Table no1 [7].

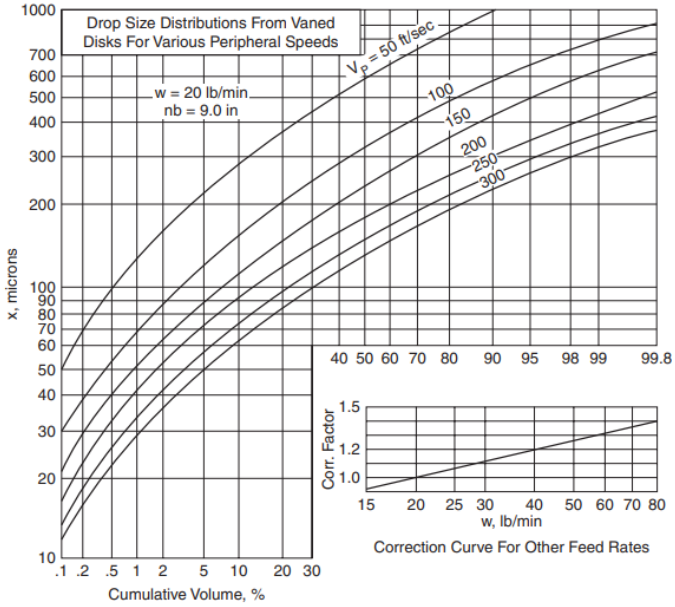

Figure 3: Doplet size as a function of pheriferical speed of a centrifugal atomizer [6].

II. Material And Methods

The density values are obtained by equations presented in Table no1 [7].

Table no 1: Equations for determination of density for foods components.

Component	Temperature relationship
Protein	$\rho = 1.3299 \times 10^{3} - 5.184 \times 10^{-1}T$
Carbohydrate	$\rho = 1.59919 \times 10^{3} - 3.1046 \times 10^{-1}T$
Fat	$\rho = 9.2559 \times 10^{2} - 4.1757 \times 10^{-1}T$
Ash	$\rho = 2.4238 \times 10^{3} - 2.8063 \times 10^{-1}T$
Water	$\rho = 9.9718 \times 10^{2} + 3.1439 \times 10^{-3}T - 3.7574 \times 10^{-3}T^{2}$
Ice	$\rho = 9.1689 \times 10^{2} - 1.3071 \times 10^{-1}T$

The density of the solution fed into the dryer is obtained by Equation (8).

$$\rho = 1/\sum(X_i/\rho_i) \quad 8)$$

ρ = density ($kg \cdot m^{-3}$); X_i is the mass fraction of component i; ρ_i = Component i density ($kg \cdot m^{-3}$).

The spray dryer used in this study is from the Brand: NIRO-GEA, with a nominal evaporation capacity of 1200 $kg.h^{-1}$; outlet air flow of 46.4 $m^3.h^{-1}$; production of 50 tons of maltodextrin/day. The dimensions of this equipment are 9600 mm in height and 6800 mm in diameter.

Six industrial batches of maltodextrin produced in a starch processing plant were used for this study. From the choice of batches, a traceability of these batches was carried out, identifying the drying process conditions in spray dryer and the characteristics of the syrup obtained after evaporation for concentration of solids content. The syrup was dried in a spray dryer. For the characterization of the finished powdered product, samples were collected during the bagging of the powdered material. Samples were analyzed in the laboratory using routine techniques. The drying operation data of the syrup batches were collected every hour, using the reading of the data available in the spray dryer operation control instruments.

The operating conditions of the spray dryer were monitored every hour during the drying process of six batches of maltodextrin. Initially the starch concentration is adjusted between 30% and 40% solids on a dry basis, and the addition of amylase of microbial origin. The gelatinized starch goes to the liquefaction reactor at a temperature of 90ºC to 95ºC, where the starch is hydrolyzed. The slurry is pumped into a tank at 140ºC for up to 10 minutes for enzymatic inactivation. Dextrose-equivalent (DE) expresses the number of aldehyde groups of reducing ends concerning pure glucose at the same concentration so that high dextrose-equivalent (DE) indicates high hydrolytic conversion and low molecular weight. Equation (9) is used to quantify dextrose-equivalent.

$$DE = \frac{Açúcares\ redutores}{Substância\ seca} \cdot 100 \quad (9)$$

Unhydrolyzed starch has a DE value of zero, while anhydrous glucose has a DE value of 100. The analytical method used consists of weighing 12 to 13 g of sample, diluting the sample to 13% solids in the sample. Pipette 25 µl of the sample into the osmometer (brand: Adjanced Instruments, Inc. model: 3250 and read). The dextrose-equivalent value is calculated by Equation (10), with the determination of osmolality, measurement of the depression of the freezing point in an osmometer [7].

$$DE = 0{,}14 \cdot mOSm - 1{,}18\ (\%) \quad (10)$$

Maltodextrin is usually marketed in a solid state, therefore it must be dried. Spray drying is suitable for processing solutions, suspensions, and pasty materials, see Figure 4.

The feed liquid takes the form of droplets, which are quickly dried into particles with a diameter of about 30 to 500 µm by hot air in 5 ~ 30 s. High power consumption and relatively low power utilization efficiency. The energy efficiency of the spray dryer is about 25% to 60%.

III. Result

For a peripheral speed of the liquid at the atomizer exit of 300 ft/s, considering that 90% of the droplets are larger than dp, using Figure 3, we have: dp = 220 µm. However, the maximum rate of water evaporated in the dryer is: 876.66 kg/h (32.2 lb/min). Using Figure 3, the drop size must be corrected with a factor of 1.1. Therefore: effective dp is 242 µm.

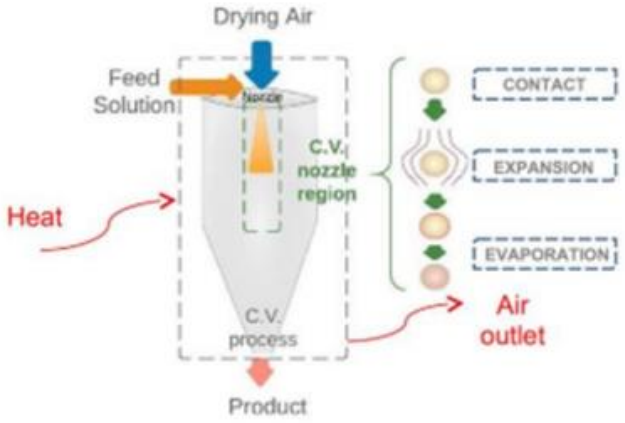

Figure 4: Operation diagram of spray dryer [8].

The moisture content of maltodextrin from evaporation was on average 30% (wet basis), 0.43 kg water/kg ds and after drying 0.05 kg water/kg ds.

Other data: The average drying air supply temperature was 194ºC and the wet bulb temperature was 106ºC. The vacuum applied to the drying chamber is 6 mmHg, pressure inside the chamber is 91.4 kPa. The latent heat of vaporization of water at the wet bulb temperature of air 2.245.106 J/kg. The average density of the maltodextrin feed in the dryer was 1311 kg/m^3.

For the condition of constant drying throughout the period, the drying time of maltodextin can be predicted.

Using Equation (6), we have:

$$t_{c=} = \frac{4 \cdot (0{,}43 - 0{,}05)(121 \cdot 10^{-6})^2 \cdot 1331 \cdot 2 \cdot 245 \cdot 10^6}{3 \cdot 0.063 \cdot (1 + 0.43) \cdot (194 - 106)}$$

$$t_c = 2.8\ s$$

Now using Equation (7), considering that the entire drying period occurs at a decreasing rate.

The logarithmic mean temperature difference consists of:

$$\overline{\Delta T} = \frac{(194{,}0 - 106{,}0) - (116{,}6 - 106{,}0)}{ln\frac{(194{,}0 - 106{,}0)}{(116{,}6 - 106{,}0)}} = 36{,}5°C$$

and we have: $t_f = 2.4\ s$

As the moisture of the maltodextrin when fed to the dryer is not significant, the drying time for small droplets is also short. In terms of the material moving inside the dryer, the possibility of the material that reaches the dryer wall becoming sticky and adhering to the wall is small. Mainly because the glass transition temperature of the material is higher than the exit temperature of the solids [3].

IV. Conclusion

The drying time of the maltodextrin droplets atomized inside the spray dryer is less than 3 seconds. This is due to the solids content of the droplets being relatively large and therefore drying is facilitated due to the average size of 90% of the particles being up to 242 µm.

Acknowledgment

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