Chapter 61

Production of maltodextrin in spray drying and srri: impacts of the glass transition temperature

Crossref doi https://doi.org/10.56238/methofocusinterv1-061

Siegrid Kopp Ikeda
University of Uberaba - PPGEQ, Brasil
E-mail: siegridkikeda @ gmail.com

José Roberto Delalibera Finzer
University of Uberaba - PPGEQ, Brasil
E-mail: jose.finzer@uniube.br

ABSTRACT
Incluir o resumo em inglês. Maltodextrins are products of the partial hydrolysis of starch. They are classified according to the degree of hydrolysis of the starch and have various functional properties such as sweetness, solubility and viscosity. The variation in the final density of the product may not meet the specification of consumer companies. The product will not be properly positioned on the pallets or there will be damage to the packaging, due to inadequate storage, generating financial losses or product returns. The decision to evaluate maltodextrin quality control has matured after the realization that final density has an impact on storage and customer service. This work aims to verify the influence of the spray dryer drying parameters on the apparent density of maltodextrin, using data from available processes and the glass transition temperature under the operating conditions of the spray dryer. The study showed that among the quantified parameters, the vacuum applied in the spray dryer influenced the apparent density of maltodextrin and the dryer must operate with an average vacuum of 44 mmCa, since the other drying parameters presented similar values and, therefore, without influencing the apparent density. The calculated glass transition temperature (Tg) value for this drying system is between 150.0°C to 150.8°C, the dryer chamber outlet temperature between 106.12°C to 107.00°C and at air inlet temperature in the dryer between 192.08°C to 196.43°C. The dryer's internal operating temperature is below the glass transition temperature of the product. This makes it possible to classify the product as vitreous.

Keywords: Maltodextrin, Glass transition temperature, Apparently density.

1 INTRODUCTION

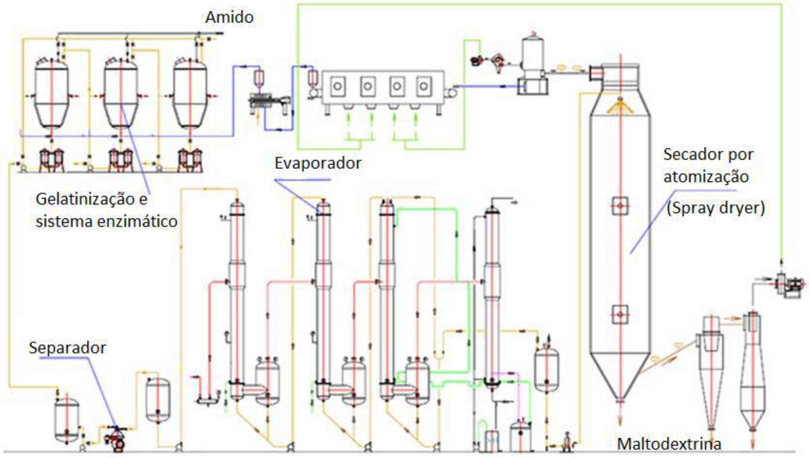
Maltodextrins are products of the partial hydrolysis of starch and have been widely used in many types of processed foods (Silva, 1995). They are classified according to the degree of starch hydrolysis and have several functional properties, such as sweetness, solubility and paste viscosity.

By definition, maltodextrin is hydrolyzed starch formed by α-D-glucose units joined mainly by α-glycosidic bonds (1→4). As the hydrolyzed product of starch, it is constituted by a mixture of saccharides, mainly D-glucose, maltose and a series of oligosaccharides and polysaccharides, presenting a wide distribution of molecular mass (Moretto et al., 2005).

Maltodextrin is water soluble, where it is used as a texture modifier, gelling agent, fat substitute, volume enhancers, cryoprotectants and to extend product shelf life, primarily as an encapsulation matrix.

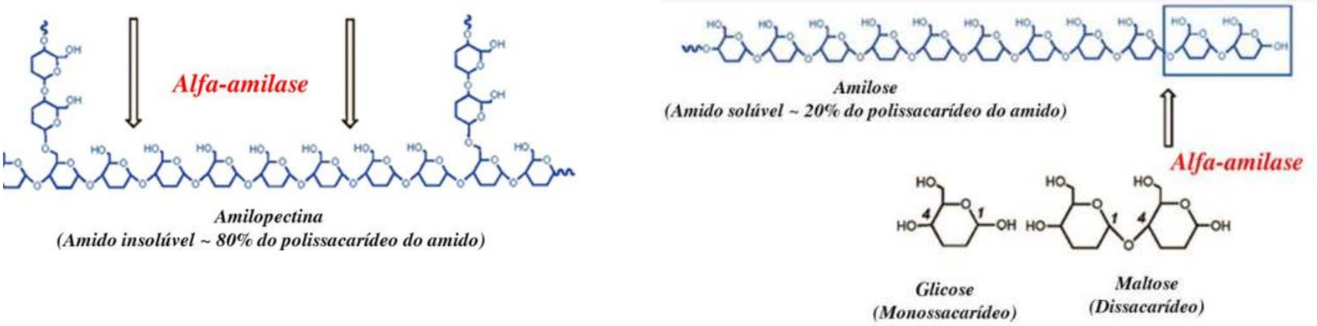
The enzyme amylase hydrolyses the α(1-4) bonds of the starch chains, producing glucose, maltose and oligosaccharides. Figure 1 is a flowchart of the process of converting starch to maltodextrin and Figure 2 shows how α-amylase works.

Figure 1. Schematic representation of the conversion process from starch to maltodextrin (Ikeda, 2021).



Source: Ikeda (2021).

Figure 2. Performance of the enzyme alpha-amylase in the conversion of starch.



Source: Ikeda (2021).

The rate equation for an enzymatically catalyzed reaction with a single substrate can be described by the Michaelis-Menten equation, see Equation (1), where vmax and Km are model constants and [S] the substrate concentration (Fogler, 1992).

$$v = \frac{v_{máx} \cdot S}{k_m + S} \quad (1)$$

The objective of this work was to verify the influence of the drying parameters in spray dryer, in the apparent density of the maltodextrin in six industrial batches, using the available process data and the glass transition temperature in the conditions of operation of the spray dryer, makes a comparison with results of maltodextrin drying in a rotary dryer filled with inerts in terms of the influence of the glass transition temperature.

2 METHODOLOGY

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 (2) is used to quantify dextrose-equivalent.

$$DE = \frac{Açúcares\ redutores}{Substância\ seca} \cdot 100$$

(2)

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 (3), with the determination of osmolality, measurement of the depression of the freezing point in an osmometer (Ikeda, 2021).

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

(3)

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 3.

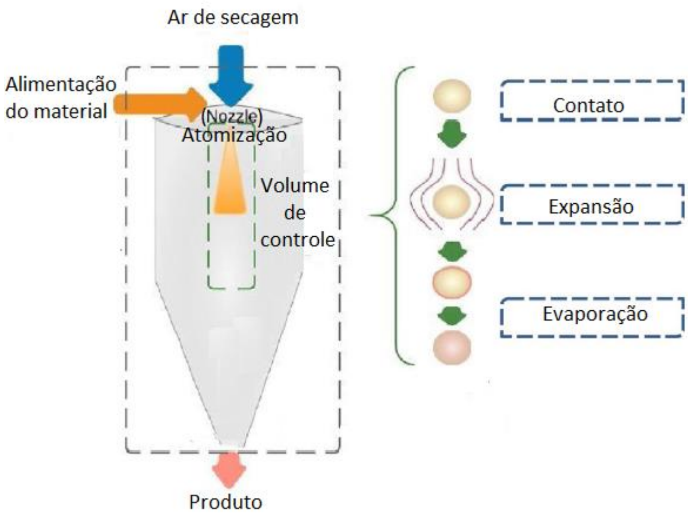
The feed liquid takes the form of droplets, which are quickly dried into particles with a diameter of about 30 to 500 μm by hot air in 5 ~ 30 s.

High power consumption and relatively low power utilization efficiency.

The energy efficiency of the spray dryer is about 25% to 60%.

The physical state of materials is related to changes between equilibrium and glassy states, see Figure 4.

Figure 3. Operation diagram of spray dryer (Ramos et al., 2019).



Source: Ramos et al., (2019).

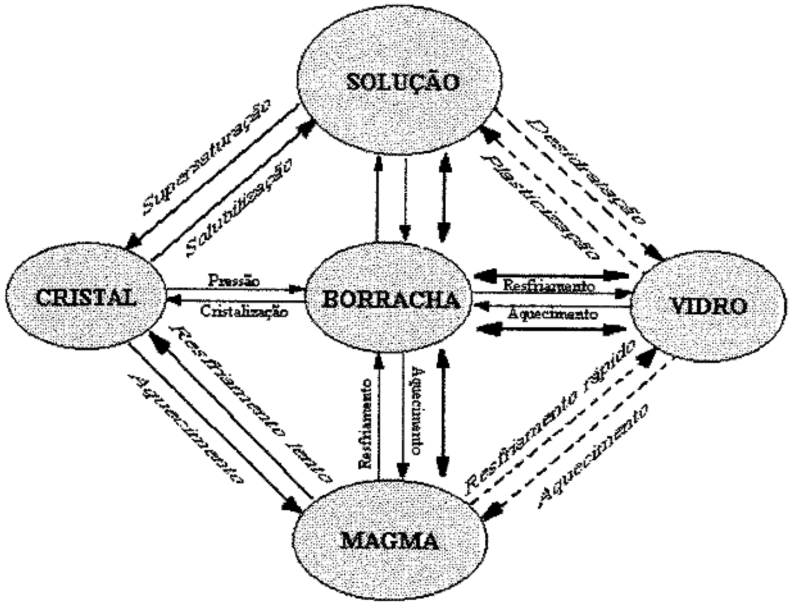
Below Tg a material is in a glassy state which is characterized by a rigid yet brittle solid. In glassy states, the mobility or diffusion of molecules is practically non-existent. When the material temperature is above the glass transition temperature, the material demonstrates increased mobility.

The sticky behavior depends on the composition, temperature and water content, about the glass transition phenomenon (Jouppila and Ross, 1994). The surface of the particles will be sticky at temperatures 10°C to 30°C higher than the glass transition temperature. Below the glass transition, the particles will look like stable glass. The glass transition temperature of maltodextrin was quantified by Equation (4): Busin, 1996; Collares, 2001; Schenz, (1995).

$$T_g = -1{,}4 \cdot DE + 1 \quad (4)$$

Depending on the material processed and the type of dryer, there are several phenomenological aspects cited by: Bucek, et al., 2020; Cavallaro, et al., 2020; Lourenço and Finzer, 2013; Sfredo, et al., 2005; Kachan, 1988; Strumillo et al., (1983).

Figure 4. Physical state of materials (Collares, 2001).



Source: Collares (2001).

The research developed is experimental and industrial data from maltodextrin processing are used and the experimental measurements are laboratory using industrial routine methodology. Other methodological details are described in (Ikeda, 2021) and (Ikeda et. al., 2022). Information on the operation of a rotary dryer with inert filling in the drying of matodextrin is described to exemplify the influence of the glass transition temperature on the drying performance. The SRRI consists of patented equipment used in the drying of pasty materials: Patent Letter No. PI8804812; inventors: Burjaili, M.M.; Limaverde, J.R.; Finzer, J.R.D.

3 RESULTS AND DISCUSSION

In the drying of the six batches of maltodextrin, the data collected in the study are: T_{ek} the entry temperature in the spray dryer drying chamber (ºC); V_{elr} the liquor inlet flow rate in the spray dryer ($m^3 \cdot h^{-1}$); $T_{e\ lr}$ the liquor inlet temperature in the spray dryer (ºC); R is the speed of the spray dryer atomizer (rpm); V_k the vacuum in the spray dryer drying chamber (mmCa) and T_{sk} the air outlet temperature of the spray dryer drying chamber (ºC).

Industrial batches of maltodextrin were sampled and analyzed to verify quality control parameters. Moisture (U), pH, total solids (DS), dextrose-equivalent (DE) and bulk density ($\rho_{r\ mtx}$) parameters were analyzed. The results are shown in Table 1.

Table 1 - Moisture analysis data, pH, total solids (%DS), dextrose equivalent (%DE) and apparent density of the six batches of maltodextrin.

Parâmetros	Especificação	lote $_{mtx}$ 1	lote $_{mtx}$ 2	lote $_{mtx}$ 3	lote $_{mtx}$ 4	lote $_{mtx}$ 5	lote $_{mtx}$ 6
U (%)	< 5,00	4,93	4,48	4,22	4,75	4,24	4,37
pH	4,50- 5,50	4,94	4,80	4,90	4,97	4,92	4,91
DS (%)	> 95,00	95,07	95,52	95,78	95,25	95,76	95,64
DE (%)	17,0- 19,9	17,86	18,56	18,84	17,72	17,58	17,86
ρ_{rmtx} (kg·m^{-3})	470 (alvo)	446	419	434,1	482	477	469
Parâmetros	Especificação	lote $_{mtx}$ 1	lote $_{mtx}$ 2	lote $_{mtx}$ 3	lote $_{mtx}$ 4	lote $_{mtx}$ 5	lote $_{mtx}$ 6
U (%)	< 5,00	4,93	4,48	4,22	4,75	4,24	4,37
pH	4,50- 5,50	4,94	4,80	4,90	4,97	4,92	4,91
DS (%)	> 95,00	95,07	95,52	95,78	95,25	95,76	95,64
DE (%)	17,0- 19,9	17,86	18,56	18,84	17,72	17,58	17,86
ρ_{rmtx} (kg·m^{-3})	470 (alvo)	446	419	434,1	482	477	469

Source: Ikeda (2021).

Moisture (U), pH, total solids (DS) and dextrose-equivalent (DE) results are within the stated range of the product specification. The apparent density of lots 1,2 and 3 are with results below the target, and in lots 4,5 and 6 the data are close to the target value of 470 kg·m^{-3}.

The calculation of the mean temperatures for the admission of the drying air and the exit of the chamber and the inflow of the CSF showed that the variation in 25 hours, quantified every hour, were around an average value with low dispersion, as described in the Table 2.

Tabela 2 -: Valores médios e desvio padrão dos parâmetros de controle do *spray dryer* para os seis lotes de maltodextrina. Sendo: **M** o valor da média; σ o desvio padrão.

	Lote$_{mx}$1	Lote$_{mtx}$2	Lote$_{mtx}$3	Lote$_{mtx}$4	Lote$_{mtx}$5	Lote$_{mtx}$6
	M±σ	**M±σ**	**M±σ**	**M±σ**	**M±σ**	**M±σ**
T_{ek} (ºC)	192,08±16,64	195,4±3,77	196,43±3,09	193,35±2,52	194,5±1,54	194,85±1,67
V_{elr} (m³·h^{-1})	2,39±0,18	2,35±0,2	2,47±0,07	2,47±0,04	2,51±0,06	2,47±0,06
T_{elr} (ºC)	109,43±3,31	108,6±7,27	104,95±20,59	109,06±4,71	109,82±2,26	110,05±2,08
R (rpm)	11598±38	11480±0	11535±67	11480±0	11442±59	11480±0
V_k (mmCa)	34,72±5,4	30,21±4,26	33,57±2,57	42,61±3,76	44,45±3,04	-43,35±4,13
T_{sk} (ºC)	106,66±2,13	106,52±1,1	107,05±0,74	106,23±0,97	106,4±0,66	106,12±0,63

Source: Ikeda (2021).

However, the vacuum applied for batches 1 to 6 were: -34.72; -30.21; -33.57; -42.61; -44.45 and -43.35 mmCa, respectively. When a more pronounced vacuum is applied, keeping the flow rate and air temperature constant as well as the other average parameters, the moisture from the drops is eliminated more quickly and the particles contract more and, therefore, present less porosity when contained in containers . Despite the tendency towards greater internal porosity, which facilitates rehydration in terms of instantaneity, volumetric contraction (shrinkage) was probably dominant.

Applying Equation (3) and using the dextrose-equivalent value, the glass transition temperature in the system is determined for each of the batches produced (Table 3). The value of the glass transition temperature, Tg, is between 150.0 to 151.8°C and the maltodextrin outlet temperature in the dryer chamber, between 106.12 to 107.05 °C and the air inlet temperature in the dryer between 192.08 to 196.43°C. So that the internal operating temperature of the dryer is below the glass transition temperature of the product. This makes it possible to classify the product as vitreous.

Table 3: Dextrose-equivalent (DE) and glass transition temperature (Tg) data for maltodextrin batches.

$Lote_{mtx}$	DE (%)	T_g (°C)
1	17,86	151,4
2	18,56	150,4
3	18,84	150,0
4	17,72	151,6
5	17,58	151,8
6	17,86	151,4

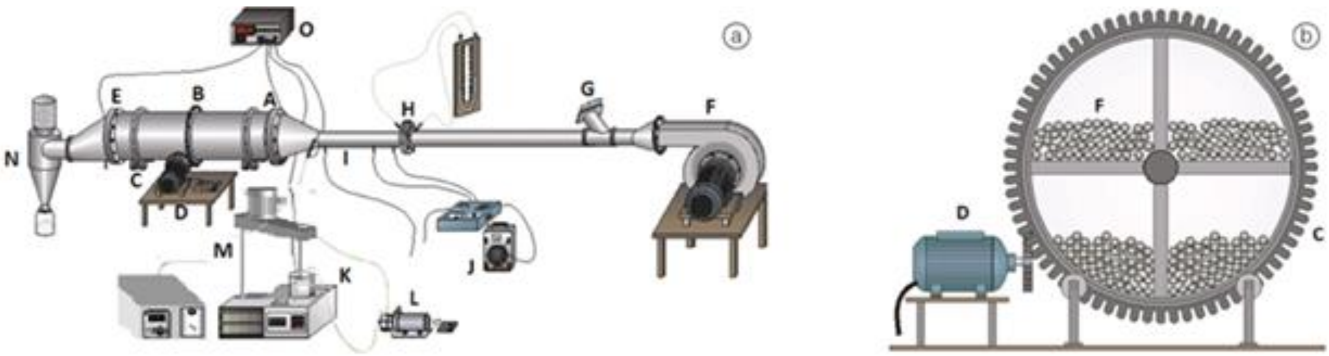
Fonte: Ikeda (2021)

Figure 5 consists of an image of the packaging of a form of maltodextrin commercialization, parameters such as the apparent density are relevant to maintain the uniformity of the product in the commercialization, both in the form of the packaging and internally when handled.

Figure 5. Appearance of maltodextrin sold in 25 kg packages.

A maltodextrina pode ser seca em secadores rotativos com recheio de inertes, Figura 6 (Collares, 2001); Burjaili, (1996), contudo os secadores por atomização são a opção comercial.

Figure 6. Schematic design of the experimental pulp drying unit. Rotary dryer filled with inert materials; Dust separation and collection system; (F) Centrifugal blower; Asbestos cement tube containing electrical resistors; Differential manometer in U; peristaltic pump; Water bath; Voltage variators; Air heater with electrical resistances; Temperature indicator (Limaverde Júnior et al., 2000)



Source: Limaverde Júnior et al., (2000).

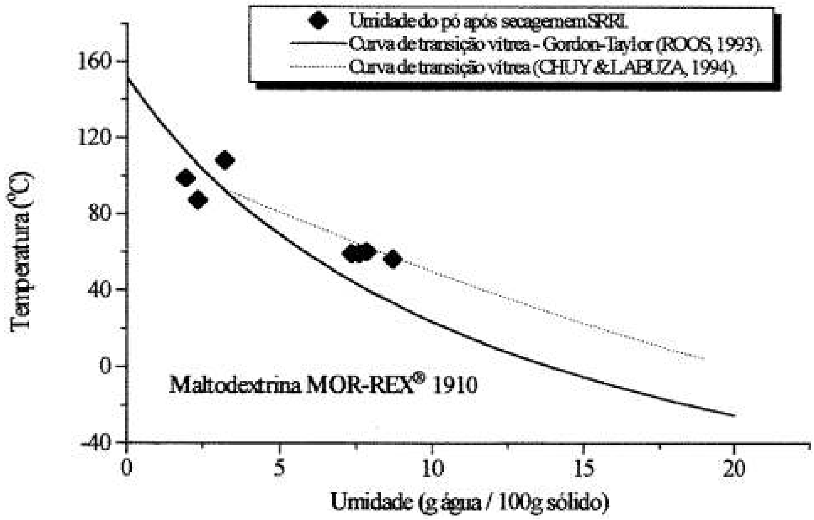
The SRRI (Figure 6) shows a cylindrical stainless steel drying tunnel, 25 cm in diameter and 60 cm long, divided into four longitudinal chambers. The pasty material is fed into the first half of the drying tunnel, through a hollow cylinder (diameter of 1.3 cm) arranged axially in its center, which has 30 perforations (diameter of 2.0 mm) in each chamber, evenly distributed along the feed section, where the paste is admitted. To prevent inert solids from escaping from the drying chambers, perforated plates were placed at the ends of the tunnel (Limaverde Júnior et al., 1998).

Maltodextrin MOR-RE:x® 1910 corn starch hydrolyzate from Corn Products Brasil), with average dextrose-equivalent (DE) equal to 10 according to the manufacturer, was processed in the SSRI.

Two drying tests of MOR-REX® 1910 maltodextrin were carried out, in the SRRI, at air intake temperatures of 60 °C and 120 °C. The production of dry maltodextrin powder occurs in the region of transformation of the material from the "gummy" state to the glassy state (Ruan et al., 1999). It can be noted in Figure 7 that the points are located below the glass transition temperature, where the material is in the glassy state.

The total processing time was much higher for the drying test than operating at a temperature of 60°C (Test S2). Maltodextrin drying at a temperature of 100°C was approximately 57% faster than the test at a temperature of 60°C. The average moisture content of the powder obtained was 2.52 ± 0.60% for the test at a temperature of 100 °C and 7.88 ± 0.55% for the test at 60 °C.

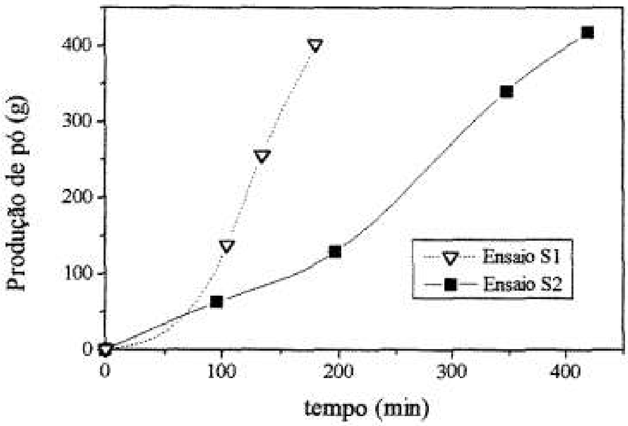
Figure 7. Correlation between the final moisture content of the high dextrin powder obtained by drying at 60 °C and 100 °C in the SRRI and the glass transition curve obtained by the Gordon-Taylor equation (Roos, 1993) data from Chuy and Labuza (1994)).



Source: Chuy e Labuza (1994).

Figure 8 shows the amount of powder produced in the two tests, it can be seen that it was around 400 g.

Figure 8. Production of MOR-RE:x® 1910 maltodextrin powder in Tests Sl(100oC) and S2 (60°C) in the SRR



Source: Collares (2021).

4 CONCLUSION

The study showed that among the quantified parameters, the vacuum applied in the spray dryer influenced the apparent density of maltodextrin, whose standard value is 470 kg·m⁻³. Therefore, when operating the dryer, an average vacuum of 44 mmCa should be operated, which made it possible to obtain the product at the specified density. Apparent density values of 433 kg·m⁻³ were below the specification value. The other parameters showed similar values and, therefore, no influence on the bulk density.

The average porosity of the malto dextrin was 0.7018±0.017 compared to the desired standard for the product. product.

The value of the glass transition temperature (Tg), calculated for this drying system, is between 150.0°C to 151.8°C, the dryer chamber outlet temperature between 106.12°C to 107°C and the air inlet temperature in the dryer between 192.08°C to 196.43°C. As a conclusion, the product obtained is at a temperature below the glass transition and, therefore, in the glassy state, not adhering phenomenologically to the internal surfaces of the dryer due to this condition. This condition also applies to the operation of the rotary dryer.

Future Studies using industrial installation: Enzymatic Processing and Evaporation of Maltodextrin Broth obtained by enzymatic processing, verify influences on the quality of the dry product.

ACKNOWLEDGMENT

The authors would like to thank the Fundação de Amparo à Pesquisa de Minas Gerais – FAPEMIG and UNIUBE for the support given to the development of this research.

REFERENCES

Bucek, E. U.; Finzer, J. R. D; Cavallaro, R. J. (2020). Mathematical Model for Determining the Coffee Leaf Area. *American Scientific Research Journal for Engineering, Technology, and Sciences*, 71, 11-19.

BURJAILI, M.M. (1996). Desenvolvimento de um Secador Rotatório com Recheios de Inertes. Campinas: Universidade Estadual de Campinas, .218 p. Tese (Doutorado).

Burjaili, M.M.; Limaverde, J.R.; Finzer, J.R.D. (1988). Secador rotatório com recheio de inertes. Carta Patente. Nº PI8804812.

Busin, L.; Buisson, P.; Bimbenet, J. J. (1996). Notion de transition vitreuse appliquée au sechge par pulvérisation de solutions glucidiques. *Sciences des Aliments*. 16, 443-459.

Cavallaro, R. J.; Bucek, E.; Finzer, J. R. D. (2020). Enzymatic Inactivation of Coffee Leaves for Use in Beverage (in portuguese). *Research, Society and Development*, 9, 1-17, DOI: http://dx.doi.org/10.33448/rsd-v9i7.4598.

Chuy, L.E., Labuza, T.P. (1994). Caking and stickiness of dairy-based food powders as related to glass transition. *J. Food Sei*., 59 (1), 43-46.

COLLARES, F. P. (2001). Despendimento de filmes de pastas alimentícias durante a secagem sobre superfícies de sólidos e sua relação com a relação com a transição vítrea. Tese de Doutorado. UNICAMP – FEA. 205 p.

FOGLER, H. S. (1992). Elements of Chemical Reaction Engineering. Prentice Hall International Series. 2. ed. 1992.

Ikeda, S. K. Estudo das variáveis de secagem na produção de maltodextrina e os impactos no desempenho do secador e no produto. (2021). Universidade de Uberaba - PPGEQ. 77 p. Dissertação de Mestrado.

Ikeda, S. K.; Finzer, J. R. D.; Teixeira, E. P. (2022). Industrial Maltodextrin Production and Impacts on Dryer and Product Performance. *American Academic Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)*. 85 (1), 23-40.

Jouppila, K., Roos, Y.H. (1994). Glass transitions and crystallization in milk powders. *J. Daíry Sei*., 77 (10), 2907-2915.

Kachan, G.C. (1988). Contribuição da desidratação da pasta de tomate em secador de leito de jorro. EPUSP, 209 p. Tese (Livre Docência).

Limaverde Júnior, J.R., Collares, F.P., Limaverde, J.R., Finzer, J.R.D. (2000). Secagem de melaço e maltodextrina em secador rotatório com recheio de inertes. In CONGRESSO BRASILEIRO DE ENGENHARIA QUÍMICA, XIII, Anais, Águas de São Pedro- SP, CD.

Lourenço, G. A.; Finzer, J.R.D. (2013). Partial Drying of Cherry Tomatoes in Vibrating Tray Dryer with Recycle (in portuguese). *Brazilian Journal of Food Technology* (Online), 16, 334-345.

Moretto, E.; Fett, R.; Gonzaga, L.V.; Kuskoski, E.M.¨ Introduction to Food Science (in portuguese). *American Academic Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)* (2022) 85 (1),23-40.

Ramos, F.M; Ubbrink, J; Silveira, V; Prata, A.S. (2019). Drying of maltodextrin solution in a vacum spray dryer. *Chemical Engineering Research and Design*, 2019. 78-86.

Roos, Y. (1993). Melting and transitions oflow molecular weight carbohydrates. *Carbohydr. Res*.,238, 39-48.

Ruan, R., Long, Z., Chen, P., Huang, V., Almaer, S. & Taub, I. (1999). Pulse NMR study o f glass transition in maltodextrin. *J. of Food Science*, 64 (1), 6-9.

Silva, D. J. (1995). Production of Low Glucose Maltodextrin (in Portuguese). Dissertation, Universidade Estadual de Maringá. Brazil.

Schenz, T.W. (1995). Glass transitions and product stability- an overview. *Food Hydrocolloids*, 9 (4), 307-315.

Sfredo, M. A.; Finzer, J. R.D. ; Limaverde, J. R. (2005.). Heat and mass transfer in coffee fruits drying. *Journal of Food Engineering*, 70, 15-25.

Strumillo, C., Markowski, A, Kaminski, W. (1983). Modem developments in drying of pastelike materiais. In: Mujumdar A S. *Advances in Drying*. 1 ed. Montreal: McGraw-Hill,.2, 193-232.