Iranian Journal of Chemical Engineering
Vol. 7, No. 3 (Summer), 2010, IAChE

Research note

Effect of Drying Conditions on Properties of Dried Sugar Beet

M. Mohammadzadeh, M. S. Hatamipour[*]

Department of Chemical Engineering, University of Isfahan, Isfahan, Iran

Abstract
Drying behavior of sugar beet was investigated in a bench scale fluidized bed dryer with an energy carrier (3 mm glass beads) and a freeze dryer. The effect of the type of dryer (fluidized bed dryer & freeze dryer) on the rate of drying and properties of dried sugar beet were studied. It was found that drying could be useful for the storage of sugar beet for a long time before processing, but the removal of more than 90% of its initial water content is necessary for the dried sugar beet to conserve its sugar content and other properties during storage. The results of experiments in two different dryers showed that drying time in a fluidized bed dryer with energy carriers is much less than that of a freeze dryer, but the dried matter obtained by the freeze dryer has a better appearance in comparison to fluidized bed dryer.
Also, the shrinkage of drying material with a change of moisture content was investigated and it was seen that a linear relation with reasonable error between these two variables was evaluated. The results are useful for mathematical modeling of the process.

Keywords: *Freeze Dryer, Fluidized Bed Hot Air Dryer, Sugar Beet, Heat Carrier, Shrinkage*

1- Introduction
Production of sugar from sugar beet has great economic importance due to the large usage of sugar in food industries. The nutritional value of sugar beet as supplier of minerals, dietary fiber and energy has been well recognized. However, this beet usually grows only during warm seasons and cannot be cultivated in all months of the year. Because of this, sugar beet should be stored for several months before processing [14].

Sugar beet is characterized by its sugar and initial moisture content at harvest. Non oxidized sugar beet has a perfectly white color, but if the peel was scraped and its surface has contact with air, it starts to oxidize, its color changes to black very quickly, and the sugar content will reduce rapidly. The decay of sugar beets during storage and the reduction of its sugar level is one of the most important barriers for sugar factories and they cannot operate continuously during the year.

An effective way to prevent this decay is reduction of water content by a drying process. Vaccarezza et al. [16] showed that

∗ Corresponding author: hatami@eng.ui.ac.ir

the main factors affecting the drying of sugar beet root slabs were the temperature of the drying, particle size and, to a lesser extent, the velocity of air flow. They also assert that Fick's law can be used for the prediction of drying behavior with reasonable accuracy. The article does not address the study of change in the sugar content of dried material.

There are numerous investigations on the air drying of agricultural root vegetables [1,6,11,12]. For sugar beet, oxidation causes a decrease in the sugar content and a change in its properties such as color. However, if the sugar content does not vary after drying, this method may be used for its preservation during storage. It should be noted that drying of foodstuffs has several aspects such as selecting the type of dryer, different mechanisms of moisture transport within the solid material, and shrinkage, and it should be investigated in a pilot or bench scale dryer before usage on a large scale.

Various methods have been developed for drying agricultural products, and each method has its own characteristics. Considering the thermal efficiency, fluidized bed dryers are among the most efficient, and are suitable for a variety of drying applications [15]. On the other hand, freeze drying as a new technology is suitable for obtaining dried matter with high quality [9]. It is often the only suitable drying process for the manufacture of dried products of high quality that cannot be obtained by any other drying method. Nevertheless, the operating costs are very high due to the slow sublimation rate at very low temperature and pressure. The optimization of the whole freeze-drying process relies on the study of complex interactions between the quality factors of the final freeze-dried material with a given product formulation and the coupled heat and mass transfer phenomena taking place during freezing and drying steps [4,9].

Foodstuffs are known to undergo volumetric changes upon water loss which are expressed as shrinkage. The physical parameters of the material such as shrinkage and density are necessary for the investigation of drying behavior and such modifications, occurring continuously during the drying process, affect the physical properties of the solids, as well as the transport properties [10]. Several studies have been done on the shrinkage of foods and vegetables [3, 5, 8, and 13], but no correlations have been reported for the shrinkage of sugar beet.

The main aim of this work is to investigate the drying behavior of a triangular based prism sugar beet particle in a fluidized bed dryer with energy carriers and a freeze dryer.

2- Materials and methods

In order to ensure reproducible results, all sugar beets were obtained from a single region ''Komishche'' (sugar beet farms near Isfahan) and kept in a refrigerator at 4 °C prior to experiments [2]. Sugar beets were thoroughly washed to remove soil and other debris. As we desired the shape of the drying samples be similar to the slices that were used in Isfahan sugar factory, the slices were cut in the form of a triangular based prism as shown in Fig. 1. The length of the equilateral triangle was 1.6 cm and the height of the prism was 4.6 cm.

The initial moisture content of the sugar beet root was measured by drying three different samples in an oven at 120 ^{o}C for more than 24 h -weighing the samples each hour until no further appreciable change in the weights of the samples- and averaging the results. It was found to be 74% on a wet basis (2.846 kg/kg dry solid). Their sugar content has been measured by saccharomat apparatus (Schmidt & Haensch Company).

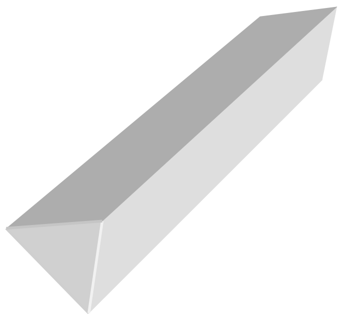

Figure 1. Shape of sugar beet samples

A laboratory scale fluidized bed dryer with glass particles as the energy carriers was used for performing the drying experiments. The schematic diagram of the experimental apparatus is shown in Fig. 2. The dryer was a 47 mm diameter and 60 cm length cylindrical pyrex column with a porous plate used in its bottom as the air distributor. Drying air was supplied from a high-pressure air source and a pressure regulator adjusted its pressure. Air was heated by an electrical heater and its temperature was controlled within ±1°C by use of a temperature controller. The humidity was determined by measuring the dry and wet bulb temperatures of the drying air. Drying air temperatures were 70-160^{o}C. The sample was suspended from a string in the fluidized bed. The rate of water loss from the sample was determined off-line. This was done by weighing the sample with the holding string on an electrical balance (Mettler) placed next to the dryer. The accuracy of the weighing was ±0.005 g. Measurements of temperature, weight loss, diameter, and length of sugar beet samples were recorded simultaneously.

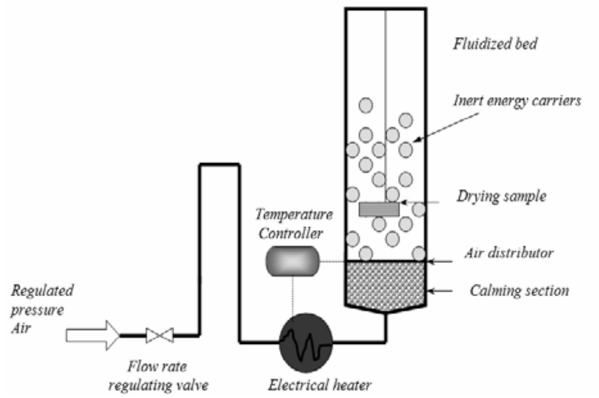

Figure 2. Schematic diagram of the experimental column

Several sets of experiments were carried out to show the effect of various parameters on the drying of sugar beet such as the maximum safe temperature which does not destroy the fibers, and the maximum water content that does not cause spoilage of dried matter during the storage period. The operating variables were air temperature, air velocity, the final moisture content of dried solids, the sugar content and drying time. It should be noted that the presence of inert particles facilitates the fluidization of the samples during drying and hence reduce the drying time of sugar beet slices. The flow rate of the drying air was fixed at a satisfactory bed fluidization state.

Samples of dried sugar beet with different levels of drying and various water contents were taken from the dryer and their sugar content was measured by the Karl Fischer method.

On the other hand, a freeze dryer (Operon, FDU-8612) was used for the freeze drying operation. For the purpose of drying, sugar beet samples were put on some trays. The apparatus was turned on at a specific set point temperature (near -70°C) and after running, the temperature started to fall to the set point. After reaching the set point, the vacuum operation was started automatically (till 10 mtorr) and the temperature fell again until -95°C. The released water from the samples was discharged from the bottom of the equipment. The drying process was continued until the samples reached the desired water content.

3- Results and discussion

In order to determine the effect of various parameters on the sugar content of dried matter, several sets of experiments were performed. In order to investigate the effect of the temperature of drying air on the sugar content of dried sugar beet, the required amount of dried beets (obtained at different temperatures) were rehydrated to the initial water content (by adding the required amount of water for 1 h) and after extraction according to the standard method of the sugar factory. Table 1 shows the effect of temperature on final sugar content and Table 2 shows the effect of the degree of drying of sugar beet in a fluidized bed at 150°C on its color change and hence sugar content.

Table 1. Sugar content of dried sugar beet at various temperatures in the fluidized bed dryer

Exp.	T(c)	X_f (g/g, dry basis)	Sugar content
1	Fresh	2.846	18.60%
2	70	0.101	18.40%
3	100	0.015	18.60%
4	130	0.011	18.00%
5	160	0.0685	18.20%

Table 2. Change of color of dried sugar beet with various water contents, using fluidized bed dryer at 150˚C

Exp.	X_f(g/g, dry basis)	%of drying	color change
6	0.637	77.80%	Yes
7	0.511	82.10%	Yes
8	0.228	92%	No
9	0.0854	97%	No
10	0	100%	No

It was concluded that the removal of more than 90% of the initial water content of sugar beet is necessary for the dried sugar beet to conserve its sugar content and other properties during storage for a long time.

Fig. 3 shows the drying curve of sugar beet in a fluidized bed at 130 and 150°C. Drying temperatures of more than 130°C had no positive effect on the drying rate and only caused greater waste of energy. Drying at temperatures of less than 130°C decreases the rate of drying. Drying curves of sugar beet in the freeze dryer (data from three different runs) is shown in Fig. 4.

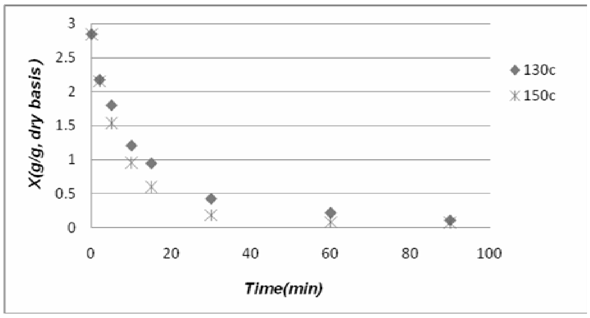

Figure 3. Experimental drying curve for sugar beet at 130 and 150˚C in a fluidized bed dryer

Several measurements of the dimensions of the length and height sample were made and recorded during drying using a micrometer. Since no meaningful relations were reported between shrinkage and the drying air temperature [5], all experiments were performed at 150°C.

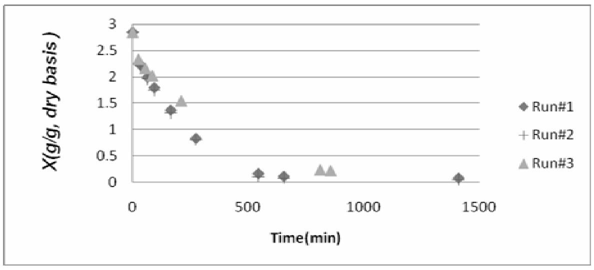

Figure 4. Experimental drying curve of sugar beet in the freeze dryer (at -95°C and 10 mtorr)

It was found that the overall trends of these functions were linear and should be correlated by Eq. 1.

$$\frac{d}{d_0} = AX + B \quad (1)$$

Where *d* can be height, length and volume of a triangular based prism and d_0 can also be the initial value of the mentioned variable.

The values of parameters A and B were obtained by non-linear regression, and are given in Table 3. In order to validate the proposed correlation, the predicted values of L/L_0, H/H_0 and V/V_0 were compared with a new set of experimental data.

The results could be predicted by an average accuracy of 98% by use of the proposed correlations. Data in Table 4 show a good agreement between the new experimental data and the calculated value of different parameters obtained by the proposed correlations.

Table 3. The calculated values of A and B (Eq. (1)) for 150˚c air temperature

	Air Temp.=150°C		
	A	**B**	**R^2**
L/L_0	0.097	0.728	0.954
H/H_0	0.073	0.79	0.938
V/V_0	0.196	0.393	0.94

Table 4. Comparison between correlation and another set of experimental data

Time (min)	X (g/g, dry basis)	Exp. L/L_0	Cal. L/L_0	Abs. relative error(%)	Exp. H/H_0	Cal. H/H_0	Abs. relative error(%)	Exp. V/V_0	Cal. V/V_0	Abs. relative error(%)
0	2.846	1	1.00	0.4062	1	1.00	0.2224	1	0.95	4.9184
2	2.151	0.96	0.94	2.4326	0.95	0.95	0.3133	0.79	0.81	3.1134
5	1.541	0.88	0.88	0.2867	0.91	0.90	0.8249	0.69	0.70	0.7299
10	0.953	0.85	0.82	3.4775	0.875	0.86	1.7635	0.56	0.58	3.5336
15	0.602	0.812	0.79	3.1534	0.836	0.83	0.2456	0.52	0.51	1.7323
30	0.182	0.748	0.75	0.3136	0.819	0.80	1.9168	0.44	0.43	2.5745
60	0.08							0.419	0.41	2.4630
90	0.071							0.409	0.41	0.5095

4- Conclusions

The following conclusions can be drawn from this work:

- By removing at least 90% of the moisture content of sugar beet, it can be stored for a long time with no considerable change in its sugar content and other properties.
- Drying can be performed at high temperatures till 170˚C without any damage to the fiber or decrease in the sugar content.
- Drying temperatures higher than 130˚C have no positive effect on the drying rate of sugar beet.
- Although the dried beets with freeze drying have higher qualities, the low rate and high operating costs are prohibitive, so this method is not economical in Iran.
- Some correlations for the shrinkage of sugar beet samples in fluidized bed dryer as a function of moisture content (X) were proposed.
- Experiments also showed that dried samples have high mass transfer rates for the rehydration and extraction of syrup and they can be used continuously in all periods of the year with high efficiency.

5- Acknowledgements

The sugar beet samples were supplied by Isfahan sugar factory and also measurements of the sugar content of dried sugar beet were carried out within this factory. The cooperation of the technicians is greatly acknowledged.

6- Nomenclature

t	Time (s)
Ta	Air temperature (˚c)
X	Moisture content of drying solid (g/g, dry basis)
X0	Initial moisture content of drying solid (g/g, dry basis)
Xf	Final state moisture content (g/g, dry basis)
ρs	Density of drying material (g/cm^3)
α	Sugar content
L	Average length of triangular based prism sugar beet sample (cm)
L_0	Initial average length of triangular based prism sugar beet sample(cm)
V	Volume of triangular based prism sugar beet sample (cm^3)
V_0	Initial volume of triangular based prism sugar beet sample(cm^3)
H	Height of triangular based prism sugar beet sample(cm)
H_0	Initial Height of triangular based prism sugar beet sample(cm)

References

[1] Adom, K.K., Dzogbefia, V.P. and Ellis, W.O., "Combined effect of drying time and slice thickness on the solar drying of Okra", J. Sci. Food, 73,315-320, (1997).

[2] Association of Official Chemists (AOAC), Official Methods of Analysis (Association of Official Chemists, Washington DC), (1980).

[3] Białobrzewski, I., "Simultaneous heat and mass transfer in shrinkable apple slab during drying", Drying Technology, 24:5, 551 – 559, (2006).

[4] Claussen ngrid C., Andresen, T. et.al, "Atmospheric freeze drying - modeling and simulation of a tunnel dryer", Drying Technol., 25:12, 1959 – 1965, (2007).

[5] Hatamipour, M.S. ,Mowla D., "Correlations for shrinkage, density and diffusivity for drying of maize and green peas in a fluidized bed with energy carrier", J. Food Eng., 59, 221–227, (2003).

[6] Hatamipour, M. S., Mowla,, D., "Drying behaviour of maize and green peas immersed in fluidized bed of inert energy carrier particles", food and bioproducts processing, 84(c3): 220–226, (2006).

[7] Hatamipour, M. S., Mowla, D., "Experimental and theoretical investigation of drying of carrots in a fluidized bed with energy carrier", Drying Technol., 21:1,83– 101, (2003).

[8] Hernandez, J. A., Pavon, G., Garcia, M. A., "Analytical solution of mass transfer equation considering shrinkage for modeling food-drying kinetics", J. Food Eng., 45, 1–10, (2000).

[9] Hottot, A., Peczalski, R., "Freeze-Drying of pharmaceutical proteins in vials: modeling of freezing and sublimation steps", Drying Technol., 24:5, 561 – 570, (2006).

[10] Katekawa, M. E., Silva, M. A., "The influence of glass transition on shrinkage in convective drying of fruits: A Case Study of Banana Drying", Drying Technol., 25:10, 1659 – 1666, (2007).

[11] McMinn, W.A.M., Magee, T.R.A., "Air drying kinetics of potato cylinders", Drying Technol. 14(9), 2025-2040, (1996).

[12] Miranda Bernardo, A. M., Dumoulin, E. D., Lebert, A. M., Bimbenet J. J., "Drying of sugar beet fiber with hot air or superheated steam", Drying Technol., 8:4, 767 – 779, (1990).

[13] Park, K. J., "Diffusion model with and without shrinkage during salted fish muscle drying". Drying Technol., 16(3–5), 889–905, (1998).

[14] Sablani Shyam, S., "Drying of fruits and vegetables: Retention of nutritional/ functional quality", Drying Technol., 24:2, 123 – 135, (2006).

[15] Strumillo, C., & Kudra, T., Drying: principles, applications, and design., USA, Gordon & Breach Science Publishers, (1996).

[16] Vaccarezza, L.M., Lombardi, J. L. Chirif J., "Kinetics of moisture movement during air drying of sugar beet root", J. Food Technol. 317-321, (1974).