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Water retention capacity of sugar beet pulp dried by various methods

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Abstract

Introduction. Dried sugar beet pulp should become one of the main ingredients of cattle forage in Ukraine, and so production of such pulp is a very important task, given the necessity of processing by-products of the sugar industry in the absence of large cattle-breeding complexes.

Materials and methods. Fresh sugar beet pulp has been used as a food product in a form of an extracted chopped straw of 50 micrometers to 1 mm, with the moisture content of 76 to 80 %. Researches with application of the convection drying method have been conducted in the DNG-9035A drying cabinet. The water retention capacity was determined as a ratio of the amount of water retained by the fibres and remaining in the test tube after centrifuging, and the corresponding amount of dry substances (accuracy ± 1 g of water/g of dry substances).

Results and discussion. Based on the conducted experiment analysis, it has been determined that the pulp dried by the low-temperature method mostly swells in the first 15 to 20 minutes. Within this time period, soaking up to the recovery coefficient $\beta = 0{,}84\ldots0{,}89$ takes place. The maximum value of the recovery coefficient amounts to 0,93 per 30 minutes for the pulp dried with hot air at the temperature of 100 °C.

As a result of conducted experiments, we have determined that the granulated pulp dried under such method swells within the first 20 minutes, whereas the pulp shreds swell within the first 80 minutes. Within this time period, soaking up to $\beta = 0{,}69$ takes place. The maximum value of the granulated pulp recovery coefficient amounts to 0,76 per 35 minutes. However, afterwards, due to mechanical damages in the process of granulation, the product loses its shape completely, and turns into a liquid powder concentrate. The maximum value of the pulp shreds recovery coefficient amounts to 0,78 per 105 minutes.

An excessive heat strain per each unit of the material causes considerable destruction of the capillary porous pulp structure, and formation of a crust on the surface, therefore moisture penetration into the material is complicated, and so the liquid interacts with the solid material structure quite slowly. Moisture does not penetrate into destructed cells, and fills open capillaries and pores of the material only.

Conclusions. More destructed structure of the pulp facilitates renewal of initial properties as a result of moisture absorption. However, the ability to absorb moisture after drying is one of the necessary conditions determining the quality of final product.

Introduction

By-products of sugar beet processing, i.e. pulp and molasses, are the principal forage for cattle feeding. Sugar beet pulp is effectively used for feeding ruminants due to the high dietary fibre content (up to 25 % of the dry matter) [3]. Sugar beet pulp may replace a significant share of cereals in concentrate mixtures for cattle cows. It is acceptable to replace up to 30 % of the dry matter of dairy breeds forage, and up to 50 % of the beef breeds forage [7]. Around 8,6 million tons of dried sugar beet pulp (in granules and shreds) are produced globally, and the product is mostly used as a separate component in cattle forage or as a compound feed ingredient [1].

Major countries producing granulated sugar beet pulp are Germany, France, the United Kingdom, Ukraine, the USA, Canada, Japan, China and Chile. In Germany, France, the UK and the USA, over 50 % (about 4,5 million tons) of the global dried granulated sugar beet pulp is produced on 96 sugar factories, whereas in total there are about 700 sugar factories in the world [2, 6].

The cattle forage composition is usually determined by means of the so-called Least Costing Program. If all ingredients (and corresponding digestibility) of the fodder products are known, the final and definitive composition of the cattle forage, depending on the nutrition needs (the life cycle and the production plan), is selected out of the available fodder products under the Least Costing Program. An optimal composition depends on the price of each fodder product, and is calculated with the account of the necessary product value amount, based on the minimal price. Dried sugar beet pulp should become one of the main ingredients of cattle forage in Ukraine, and so production of such pulp is a very important task, given the necessity of processing by-products of the sugar industry in the absence of large cattle-breeding complexes [3, 4].

The research objective is to determine the recovery of the sugar beet pulp dried by various methods, and under different temperature conditions.

The research task is to draw attention to the increase of dried sugar beet pulp production, as well as to the improvement of the quality of this product; to give practical recommendations for the methods and conditions of sugar beet pulp drying.

Materials and methods

Fresh sugar beet pulp has been used as a food product in a form of an extracted chopped straw of 50 micrometers to 1 mm, with the moisture content of 76 to 80 %. Dried substances contained, in %: hemicelluloses — 25 to 33, cellulose — 20 to 27, lignin — 1 to 6, uronic acids — 21,5 to 23, protein — 7 to 12, residual sucrose — up to 0,5, ashes — 4. Pulp samples were frozen (–40 °C) for storage, and defrosted to the room temperature prior to every drying experiment.

Researches with application of the convection drying method have been conducted in the DNG-9035A drying cabinet (the drying chamber volume of 30 l, and the maximum power consumption of 850 W). Such dryer ensures the drying agent temperature within the range of 5 to 300 °C, with the temperature setting discreteness of 0,1 °C, and the temperature stability of ±1 °C.

For the purpose of determining the water retention capacity, the dry product sample (up to 2,0 g) was weighed and poured over with distilled water (20 °C) in a test tube [5]. The product was saturated with moisture at 20 °C temperature, and stirred every 5 minutes. Then, the product was centrifuged during 10 minutes. The water retention capacity was

determined as a ratio of the amount of water retained by the fibres and remaining in the test tube after centrifuging, and the corresponding amount of dry substances (accuracy ±1 g of water/g of dry substances).

The amounts of dry substances were measured by samples drying in the drying furnace at 105 °C temperature, until the mass of dry substances became constant. The method accuracy is ±0,1 %.

Results and discussions

Influence of the sugar beet pulp drying conditions over the pulp recovery capacity has been evaluated by the following methodology: a batch of fresh pulp taken from the diffusion machine was split into two groups. The first group of samples was dried to the moisture content $W = 14$ % in a AK-2-type pulp drying cylinder; the second group of samples was dried under the laboratory conditions, by the conductive and convention drying methods, to the moisture content $W = 28$ %.

In order to evaluate the recovery capacity of dried sugar beet pulp, it is appropriate to select an indicator which would quantitatively characterize the moisture absorbing capacity. In most cases, researchers use the relative swelling coefficient K as such indicator, and it represents the recovery of the sample mass m_2 after soak to the initial mass m_1:

$$K = m_2/m_1. \tag{1}$$

Figure 1 represents the dependence of the swelling coefficient K on the watering process duration for three types of sugar beet pulp: curves *1*, *2* — samples of industrially made granulated pulp and pulp shreds, curve *3* — samples of sugar beet pulp obtained by the conductive drying method. The highest coefficient K was that of the laboratory samples. In our opinion, this may be explained by the fact that the dewatering process took place under quite moderate temperature strains, while the osmotically retained moisture partially remained within the material (the final moisture content was 28 %). Development of a crust and further destruction of the crust created conditions for free moisture penetration into the material, and for the moisture interaction with the substance structure.
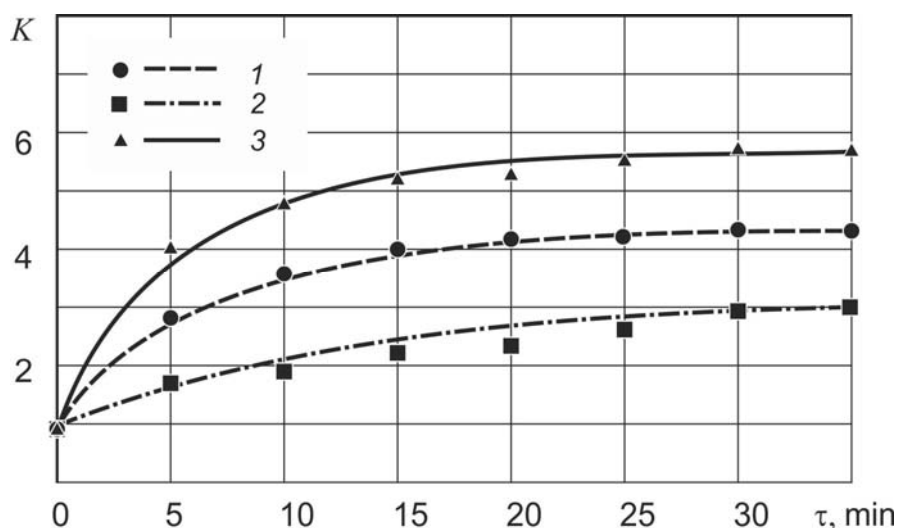
Figure 1. Alteration of the pulp relative swelling coefficient
For different types of pulp:
1 — granulated pulp; 2 — pulp shreds; 3 — pulp obtained by the method
of conductive hot air drying at t = 115 °C

For pulp shred samples, the K coefficient was the lowest at the end of the trial, at $\tau = 80$ min. and $K = 4{,}15$ (not indicated in the Figure above). An excessive heat strain per each unit of the material causes considerable destruction of the capillary porous pulp structure, and formation of a crust on the surface, therefore moisture penetration into the material is complicated, and so the liquid interacts with the solid material structure quite slowly. Moisture does not penetrate into destructed cells, and fills open capillaries and pores of the material only.

However, the K coefficient is not accurate enough to characterize the recovery, since it only determines a ratio of the final sample mass m_2 to the initial mass m_1. Researchers have recently started to apply another indicator which directly demonstrates how closely a moisture content of a material approximates to the initial moisture content, or how the overall material mass after the material watering approximates to the initial material mass which is deemed as 1 or 100 %. Such indicator is the recovery coefficient β:

$$\beta = W_2/W_1. \tag{2}$$

The moisture content in the recovered material may be estimated by the ratio

$$W_2 = (100 - W_0)/\beta, \tag{3}$$

where W_0 is the moisture content of the dried material, in %.

The subject of the research aimed at determining the recovery coefficient was pulp shreds dehydrated at various temperatures of the drying agent – 40, 60, 80 and 100 °C. The research results are shown on the Figure 2.
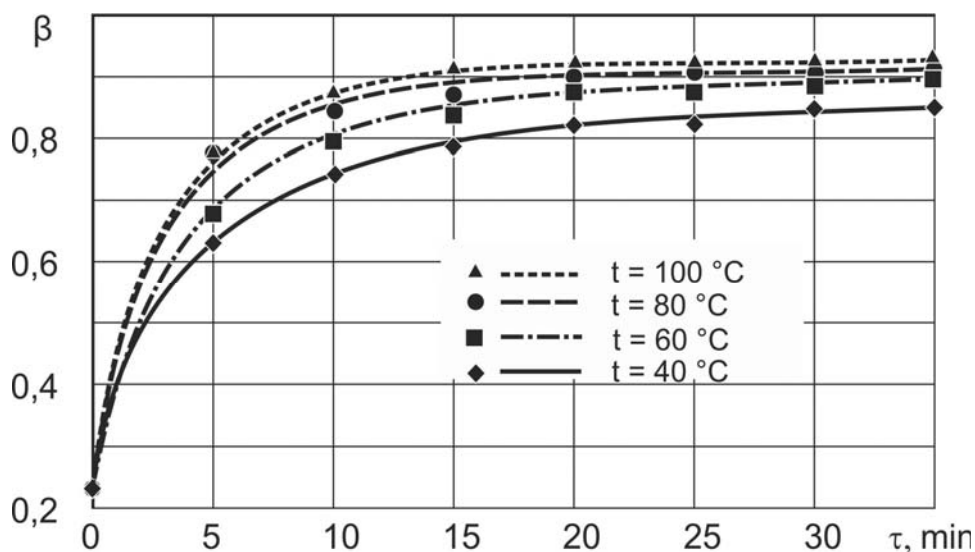
Figure 2. Recovery of pulp at different drying temperatures

Based on the conducted experiment analysis, it has been determined that the pulp dried by the low-temperature method mostly swells in the first 15 to 20 minutes. Within this time period, soaking up to $\beta = 0{,}84\ldots0{,}89$ takes place. The maximum value of the recovery coefficient amounts to 0,93 per 30 minutes for the pulp dried with hot air at the temperature of 100 °C.

For comparison, we have carried out a series of similar researches on pulp shreds and granulated pulp samples industrially made at the Rokytnyanskiy and Dubnivskiy Sugar Factories. As a result of conducted experiments, we have determined that the granulated

pulp dried under such method swells within the first 20 minutes (curve *1* on the Figure 3), whereas the pulp shreds swell within the first 80 minutes (curve *2* on the Figure 3). Within this time period, soaking up to β = 0,69 takes place. The maximum value of the granulated pulp recovery coefficient amounts to 0,76 per 35 minutes. However, afterwards, due to mechanical damages in the process of granulation, the product loses its shape completely, and turns into a liquid powder concentrate. The maximum value of the pulp shreds recovery coefficient amounts to 0,78 per 105 minutes (not shown on the Figure 3).
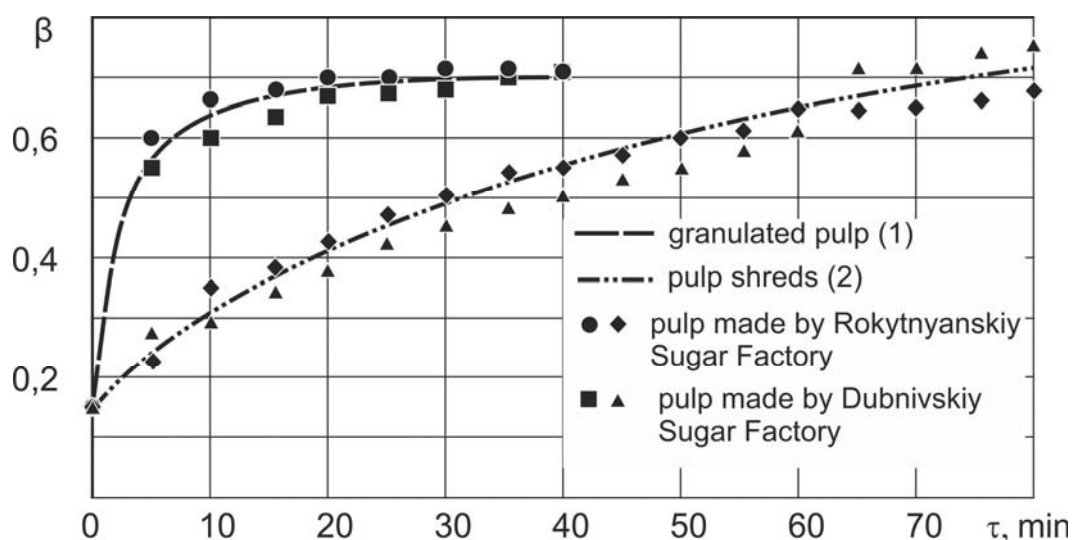

Figure 3. Recovery of industrially made pulp

As it can be seen, the absorption process takes place very intensively at the beginning of watering, approximately within the first 5 minutes. Later on, the process slows down and basically switches over to the saturation stage. The best recovery of pulp shreds is observed under the laboratory drying conditions, at temperatures over 100 °C. It may be explained by the fact that under such conditions shred cells are destroyed, and moisture gets free access to the middle of the product.

Evaluation of the Regression Equation Appropriateness.

The experimental research results shown on Figures 2 and 3 represent the dependence of dried pulp samples restorability on the watering duration and the drying temperature. For approximation of such kind of data by empirical dependences, we have used such equation as

$$\text{В} = \text{В}_0 + A_K \left(1 - e^{k\tau + k_1\tau^2}\right), \qquad (4)$$

where β_0 is the recovery coefficient at the initial moment in time; A_K is the maximal restorability coefficient value; and k, k_1 are the empirical equation coefficients at min.$^{-1}$, min.$^{-2}$ (respectively).

For estimation of the coefficients in the equation (4), the Statistica software has been used. The values of β_0, A_K, k, k_1 coefficients and the correlation coefficient r^2 are shown in the table below.

Table

Dried pulp recovery coefficients

Coeffi-cient	Industrially made dried pulp				Pulp dried under laboratory conditions			
	Rokytnyanskiy Sugar Factory		Dubnivskiy Sugar Factory		by the conductive method		by the convection method	
	granules	shreds	granules	shreds	60 °C	80 °C	60 °C	80°C
β_0	0,16	0,16	0,16	0,16	0,25	0,25	0,16	0,16
$A_K, \%$	0,71	0,69	0,72	0,76	0,91	0,88	0,93	0,91
k, хв$^{-1}$	−0,0269	−0,1612	−0,0177	−0,1302	−0,1385	−0,1207	−0,1672	−0,1525
k_1, хв$^{-2}$	0,00013	0,00349	−0,00003	0,00265	0,00345	0,00275	0,00353	0,0031
r^2	0,999	0,969	0,979	0,964	0,975	0,980	0,975	0,984

The diagrams *a* and *b* shown on the Figure 4 indicate the ratio between the experimental points $\beta_д$ and $\beta_р$, as approximated by the equation (4), for the samples of laboratory pulp shreds dried by the convection method, whereas the diagrams *a* and *b* on the Figure 5 represent the same ratio for the samples of laboratory pulp shreds dried by the conductive method.

For more clearness, the diagrams contain auxiliary lines +10 % and –10 % indicating that the experimental data deviation from the approximated data is lower than the acceptable 10 %.
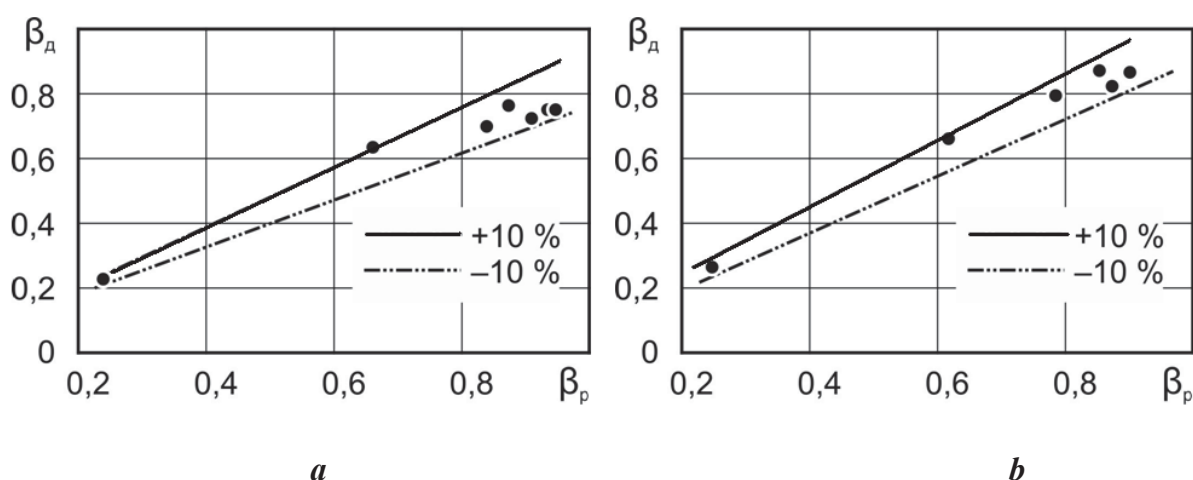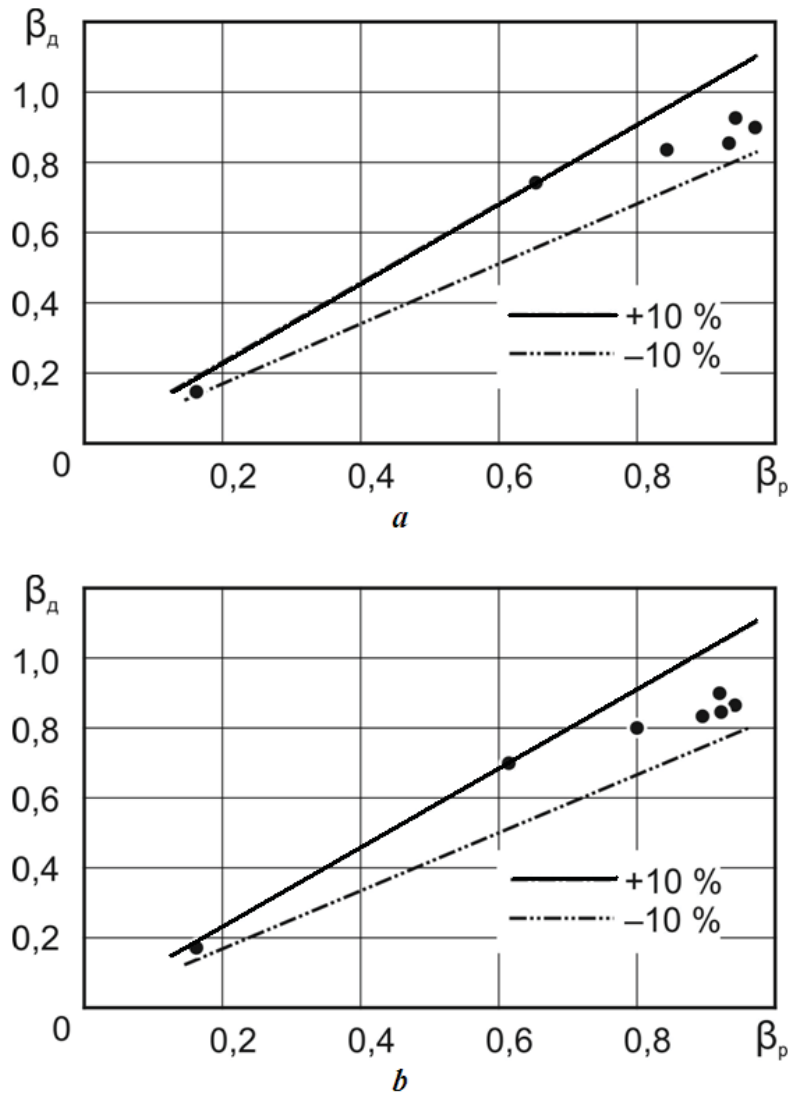

a *b*

Figure 4. Ratio of $\beta_д$ Experimental Data and $\beta_р$ Estimated Values
for Pulp Laboratory Samples Dried by the Convection Method:
a – under t = 60 °C; b – under t = 80 °C

Figure 5. Ratio of $\beta_\text{д}$ experimental data and β_p estimated values for pulp laboratory samples dried by the conductive method: *a* – under *t* = 60 °c; *b* – under *t* = 80 °c

Conclusion

Hence, we may conclude that, the more the structure of a vegetative material is destroyed, the better opportunities such material has for recovery of its initial properties, owing to moisture absorption. However, the moisture absorption capacity after drying is only one of a number of necessary conditions that determine the final product quality: at excessive temperature strains, vitamin complexes decay, and the jelly-generating capacity of sugar beet pectin declines. Taking into account all the factors, one or another drying method gains priority in terms of the finished product ultimate utilization purpose.

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