Theory and practice of sucrose extraction from beet tissue

Kulneva Nadezhda Grigorievna

Doctor of Technical Sciences, Full Professor
Nozdrevatykh Yulia Alekseevna
Master

Voronezh State University of Engineering Technologies, Voronezh, Russia

Abstract. Sucrose is extracted from beet tissue by way of diffusion and it includes sucrose transfer from internal layers of chips to their surface following molecular diffusion laws and from the surface of chips to extractant. One of the ways to enhance efficiency of the diffusion process in beet sugar production is thermal action on beet chips with various heat carriers in order to destroy protoplasm that prevents sucrose release from vacuoles to the beet tissue periphery. The objective of this thesis is to ensure utmost performance of the diffusion process by choosing the most effective components of chemical heat treatment of beet chips. Rational conditions of solution electrochemical activation for beet chips chemical heat treatment prior to extraction have been selected experimentally.
Keywords: extraction, beet tissue, molecular diffusion coefficient, chemical heat treatment.

Extraction of one of multiple components from a compound raw material using a dissolvent is a fundamental stage of beet sugar production [1,2].

It is commonly supposed that sucrose extraction from beet proceeds under certain conditions (temperature of 72-75 °C) and comprises two most important stages: sucrose transfer (convective diffusion) from internal layers of chips to their surface following molecular diffusion laws and from the surface of chips to extractant (mass exchange). Sucrose is extracted from beet chips as a result of diffusion, which is spontaneous equalization of the matter concentration at the interface of two phases mediated by heat motion of molecules. Sucrose extraction in itself is a complex mass exchange process, during which the mass exchange rate is related to the mechanism of distributed matter transfer in the phases involved in mass exchange. Mass exchange is mainly affected by molecular diffusion, which is understood to be mass transfer from one part of the system to another one mediated by heat motion of molecules [3,4,5].

Reliable research data on matter diffusion from plant tissue cells in "pure" solutions is of high theoretical and practical relevance for the study of the mechanism of matter transfer from inside cells of the plant tissue to its surface as well as its mass transfer from the surface to the extractant. Analysis of reference data has yielded the following equation for the calculation of the sucrose diffusion coefficient in pure water at a temperature of 20-70 °C and sucrose concentration of C = 5-30 % w/w. The equation is as follows:

$$D = 0{,}422 \cdot 10^{-5} e^{-0{,}015e} e^{\frac{-2700}{T}} ,$$

where T is absolute temperature, K.

The process of sucrose diffuse extraction from beet chips is a fundamental mass exchange process in beet sugar production. Workmanship and technology of the diffusion department of a beet sugar factory predetermines operational efficiency of all downstream stations as well as quality and output of finished products [6,7].

Production of the diffusion juice with the best possible technology parameters throughout the production season is the most critical task of the sucrose extraction station. To solve this task, operational efficiency of this production area has to be maintained at the highest level possible, namely: the optimal diffusion process has to be ensured and problems occurring during sucrose extraction have to be promptly identified and eliminated.

One of the ways to enhance efficiency of the diffusion process in beet sugar production is thermal action on beet chips with various heat carriers. The main objective of thermal action is to destroy a complex system of barriers that prevent sucrose release from cell vacuoles to the beet tissue periphery. These barriers represent a cellular system comprising the cell membrane and many cell organelles of the beet tissue. According to researchers, [8] the most effective way to destroy the above barriers is heat treatment of beet chips with various heat carriers, the most effective of which is heating steam. However, some think that long-term heat treatment of beet chips is unfeasible.The objective of this thesis is to ensure utmost performance of the diffusion process by choosing the most effective components.

Results and their discussion

Diffusion with chemical heat treatment of beet chips with heating steam and solutions of the proposed saline reagents before extraction (figure 1) has been studied.

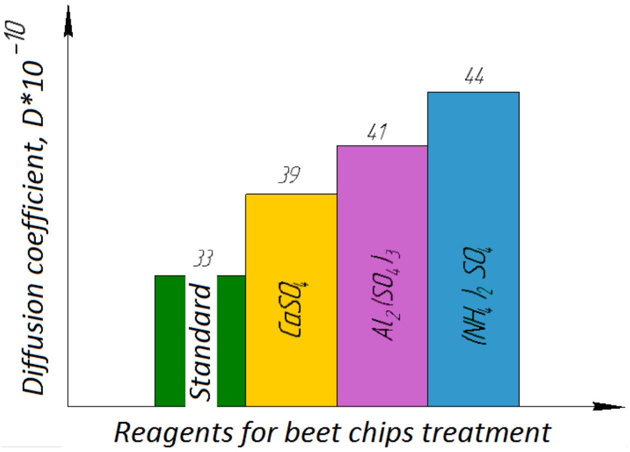

Figure 1 – Sucrose diffusion coefficient when various reagents are used

Analysis of diffusion coefficient values allows to draw a conclusion on the positive influence of beet tissue chemical heat treatment with solutions of the proposed reagents on the coefficient. The highest diffusion coefficient value is attained when the beet tissue is treated with the hot solution of ammonia sulphate $(NH_4)_2SO_4$ [9].

Conventional technologies used at most today's beet sugar enterprises do not ensure high quality of diffusion juice. This brings about a need to improve the existing technical and manufacturing methods using the modern scientific approaches that secure high tech effect with minimum resource and power outlays [10,11].

Scientific progress has brought to life a prospective school based on the use of electrophysical and electrochemical impacts of high- and low-frequency electric fields on various semi-finished products of beet sugar production.

The most promising is electrophysical and electrochemical impact of electric field (electrochemical activation) on production solutions and process liquids of beet sugar production. Use of electric fields is enabled by the presence of electrically charged particles in process fluids that interact with the external electric field. It is important to note that harmful nonsugars (HMC, HOA, protein-pectic complex substances) carry electric charges of certain polarity, while sugars have no electric charge. In addition to its technology effect, electrochemical activation (ECA) features high controllability, full automation possibility and may be used to develop highly efficient and environmentally sound technologies [12].

Experimental studies have been conducted to describe feasibility of application of ECA reagent solutions for the enhancement of heat mass exchange parameters of extraction and to determine reasonable parameters of electrochemical action.

At the first stage, in order to justify feasibility of application of ECA reagent solutions for the enhancement of beet tissue permeability, aqueous solutions of ammonia and aluminium sulphate with reagent concentration of 0.05% were prepared and subjected to ECA for 60 s with electrode current density of 3 mA/cm^2 and electric field intensity of 1.2 V/cm. Reagent solutions thus electroactivated were heated to 72 °C and used for beet tissue chemical heat treatment. Diffusion coefficient was used as a criterion of beet tissue permeability; it was calculated in line with the method [13] (figure 2).

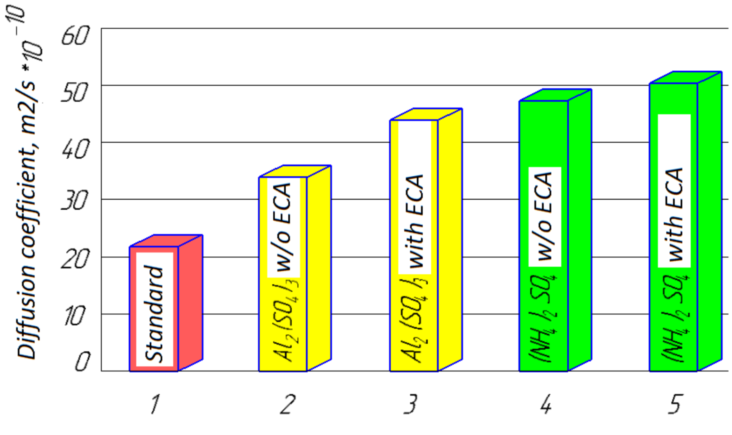

Figure 2 – Diffusion coefficient depending on the method of chemical heat treatment of chips

Analysis of the resulting sucrose diffusion coefficient values confirms feasibility of electrochemical action on aqueous solutions of the reagents used for chemical heat treatment of chips. This processing method enables fast denaturation of the protein-pectate membrane of cell walls, which results in its reduced stability that causes destruction and fragmentation. This brings about elevated permeability of the beet tissue.

Qualitative indicators of the semi-finished products obtained using the conventional technology and with prior chemical heat treatment of beet chips with electroactivated solution of ammonia sulphate are presented in table 1.

Table 1 – Qualitative indicators of diffusion and purified juices

Indicators of semi-finished products	Flowchart without treatment of beet chips before extraction	Prior treatment of beet chips with ECA $(NH_4)_2SO_4$ solution
Diffusion juice		
Purity, %	85.7	87.6
Protein content, mg/cm^3	0.38	0.21
Purified juice		
Purity, %	91.0	92.7
Color index, optical density units	216	178
Mass fraction of calcium salts, % CaO	0.031	0.025

Conclusion

Analytical study of the experimental data obtained has resulted in the elaboration of methods of diffusion juice production with chemical heat treatment of beet chips with steam and aluminium and ammonia sulphate solutions before extraction [14,15,16].

Combination of heat and chemical treatment allows to heat up beet chips to the optimal diffusion temperature of 72 °C outside of the beet diffuser. Heated chips are fed to the beet diffuser, which helps decrease the process time. Steaming period is 30-60 s. Temperature of chips after steaming is 72 °C.

Qualitative indicators of the semi-finished products obtained using the method with prior chemical heat treatment of chips before sucrose extraction are much better than those of conventionally obtained juices. This evidences feasibility of the proposed method with thermal and chemical preparation of beet chips prior to sucrose extraction.

References

[1] Chawhuaymak, J. Efficient extraction method to collect sugar from sugar beet / J. Chawhuaymak, M. R Riley, W. Zimmt, K. Ogden // Journal of Biological Engineering. 2013. No. 2. P. 1748-1765.

[2] Rabhi Z. Kinetic model of sugar diffusion from sugar beet tissue treated by pulsed electric field / Z. Rabhi, K. El-Belghiti // Journal of the Science of Food and Agriculture. 2015. No. 8. P. 1213-1218.

[3] Bagherzadeh A. Effects of alkaline extraction of electroporated sugar beet to sugar manufacturing / A. Bagherzadeh, St. Frenzel, R. Schick, T. Michelberger // The international journal for the sugar. 2016. No. 3. P. 633-648.

[4] Bruniche-Olsen, H. Judging Coll - Divided Continuous Diffusers / H. Bruniche-Olsen // Sugar. 2010. No. 3. P.346-359.

[5] Goddertz, L. Developments in tower extraction: a new dimension / L. Goddertz // Zucker Industrie. 2013. No. 10. P. 812-826.

[6] Kulneva N. G. Improving the efficiency of the extraction of sucrose from beet chips / N. G. Kulneva, M. V. Zhyravlev // Materiály IX mezinárodní vědecko - praktická konference «Vědecký průmysl evropského kontinentu zemědělství» // Díl Publishing House «Education and Science» Zvěrolékařství.: Praha. 2013. P. 31-34.

[7] Wong D.S. Sucrose Extraction From Beet By Methanolic Calcium Chloride / D. S. Wong, J. M. Randall, R. H. Edwards // Journal USDA-Agricultural Research Service. 2009. No. 8. P. 1358-1366.

[8] Karpovich N.S. Heat treatment of beet chips [Teplovaya obrabotka sveklovichnoy struzhki] / Karpovich N.S., Totkaylo M.A. // Sugar industry. 1985. No. 1. P. 25-27.

[9] Kulneva N.G. Г. Influence of various reagents on the molecular diffusion index of beet sucrose / Г. Kulneva N.G., Zhuravlev M.V. // Bulletin of the Voronezh State University of Engineering Technologies. No. 1. 2015. P. 191-194.

[10] Kulneva N.G. Г. Application of electrochemical activation for the processing of beet chips in the sugar production / Kulneva N.G., Zhuravlev M.V., Г. Selezneva I.G. // Food industry and service innovations: Materials of the I International Scientific and Practical Conference. / FSBEI HPE Kuban State Technological University. Stavropol, 2014. P. 340-345.

[11] Kamal, E. Effect of centrifugal force on the aqueous extraction of solute from sugar beet tissue pretreated by a pulsed electric field / E. Kamal, Z. Rabhi // Journal of Food Process Engineering. 2015. No. 11. P. 1346-1358.

[12] Kulneva N.G. Г. Electrical technologies in the sugar production: Monograph. / Kulneva N.G., Golybin V.A., Fedoruk V.A. / VGTA, Voronezh. 2007. P. 237.

[13] Patent No. 1270698 of the Russian Federation. Method for determining the diffusion coefficient of sucrose in sugar beet / Karmayev V.N., Korniyenko T.S.; published 15.11.1986, Bulletin No. 42.

[14] Patent No. 2553234 of the Russian Federation. Method for the production of diffusion juice / Kulneva N.G., Zhuravlev M.V.; published 10.06.2015, Bulletin No. 12.

[15] Patent No. 2551551 of the Russian Federation. Method for the production of diffusion juice / Kulneva N.G., Zhuravlev M.V.; published 27.05.2015, Bulletin No. 34.

[16] Patent No. 2603829 of the Russian Federation. Method for the production of diffusion juice / Kulneva N.G., Zhuravlev M.V., Belyayeva L.A.; published 04.11.2016, Bulletin No. 26.