# MATHEMATICAL MODELING OF THE INULINE EXTRACTION PROCESS

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### Abstract

*In this study, a natural extract of Jerusalem artichoke was studied. The physicochemical properties of the concentrate obtained from the Jerusalem artichoke plant were studied. There are experimental statistical modeling methods in mathematical modeling. In this case, the results of experiments obtained at this facility are used to create a mathematical model of the technological process. Flow motion was studied for solution analysis. The importance of studying flow motion is to determine the parameters that need to be considered in modeling.*

**Key words:** *extraction, modeling, inulin, drying, solubility.*

**Introduction.** Due to the high growth of food industry and pharmaceutical production, many artificial extracts have been synthesized and these extracts are widely used in food products. Compared to natural extracts, their biological activity, taste and vitamins are insufficient [1].

Many natural food extracts contain biologically active substances, vitamins, amino acids, carbohydrates, aromatic substances and mineral salts. Pigments are composed of anthocyanins, carotenoids, chlorophyll and xanthophylls. Natural extracts are obtained mainly from plant raw materials, secondary raw materials from vegetables and fruits. Natural solutions are mainly obtained by extraction methods. Ethyl alcohol solution, water, vegetable oil, etc. are used as extractants [2,3].

Topinambour processing technology for the production of inulin. There are over 2,000 types of products containing inulin and oligofructose worldwide. In particular, in the Russian Federation the common inulin-containing products are: desugared "Russian chocolate", baby food "Heinz", coffee "For slimming" by "Leovit Nutrio", kefir "Biomax effective" by "Wimm-BillDann", drinking yoghurts "Ermigurt prebiotic" by "Ermann", etc. There are only three major inulin producers on the world market: Beneo-Orafti from Belgium has 70% of the market, while Cosucra, also from Belgium, and Sensus from Holland have a roughly equal share [3]. Inulin is predominantly produced in the industry from chicory, which is easier to process due to the regular shape of the root, although its content in topinambur is about the same. The molecular chain of inulin from chicory is longer [8], which is essential for the technological performance of the polysaccharide, for example for fat imitation. The solubility of inulin in water depends on the chain length, which decreases with increasing chain length, with improved gel-forming properties, and increased resistance to hydrolysis. In China, inulin is grown and produced from topinambour with a high maltodextrin content - up to 50%. In the Russian Federation, inulin production, particularly from topinambour, is only beginning to develop for the production of dietary supplements, with dried crushed topinambour or its juice being mainly used.

Promising ways of obtaining extracts from plant raw materials and their drying. In food processing, the main traditional dissolution and leaching methods include closed batch, continuous direct and counterflow, and filtration-flow or percolation processes with a fixed bed [9]. In closed batch processes mechanical or pneumatic agitation is used to intensify the process, in which gas is used not only for agitation but also as an oxidiser. In the case of intensive mixing the disperse particles move with a vector of velocity that changes its direction, and with a numerical value that is lower or higher than that of the washing stream. This is determined by the inertia of the dispersed particles and leads to the possibility of intensification of dissolution 38 and leaching, despite the reduction of the driving force of the processes in striving towards the equilibrium state [10]. In the case of low-intensity mixing, the dispersed particles hover in the fluid while in suspension, moving successively in the upward and downward flows of the fluid phase washing over them at a certain rate determined by gravitational and inertial forces, the latter being superior to the former in the inertial regime [11, 12]. These non-stationary processes are simple to implement but inefficient because of the well-known disadvantages of periodic processes. More common in industry are continuous dissolution and extraction processes. These processes may also be carried out in stirrers with continuous injection and withdrawal of contacting phases into the apparatus. In this method, the intensity is low, due to the contact between solid product and solution with a concentration that, due to agitation, approaches the concentration at saturation, which reduces the driving force and speed of the processes, relative to the average speed of a single batch operation, in which the equilibrium concentration is only reached when it is completed. In addition, it is possible for individual dispersed particles to "overshoot" in a single apparatus [12]. At the same time their residence time in the apparatus may not be sufficient to obtain a high degree of extraction of the extracted components. Therefore for a more significant intensification of the extraction process, the extraction process is conducted in cascade units, where the hydromodule is moved by gravity flow through series-connected apparatuses with agitators. In this organization of the process, the driving force is permanently reduced from one stage to another (the number of stages usually does not exceed 6) and, unlike the process in a single apparatus, when fresh solvent and the final concentrated solution come into contact, a relatively high degree of extraction can be achieved [12]. The effect can be strengthened by organizing countercurrent processes,

where in the countercurrent flow of solids and liquid in the battery apparatus the fresh solvent at the end of the unit is in contact with the leached material, and at the beginning the feed material interacts with the concentrated solution, which makes the unit operation more uniform [7]. With this arrangement of the process flow, fresh solvent is introduced at the end of the unit, which makes it possible to increase the degree of extraction of components from the pores of the solid product, and on the other side of the unit to use the solution for surface extraction more efficiently.

**Materials and Methods.**

Mathematical modelling of extraction and drying processes. The limiting factor for the extraction rate is the internal mass transfer in the solid phase, which it is advisable to model in order to calculate the concentration distribution in the volume of the starting product during extraction, which determines its duration and compliance with technological limits to ensure the quality of the finished product.

The task of mass transfer modelling is to determine the duration of phase contact determined by extraction kinetics.

Mass transfer is effected by the difference in content of the transferred component on the surface and inside the original product - crushed topinambour, which consists of particles whose shape is close to cylindrical, so the equivalent diameter calculated from the volume of the particle is taken as the characteristic size.

In order to find the unsteady concentration fields, a system of differential equations for heat and mass transfer must be solved.

The mass transfer equation for the one-dimensional problem is as follows:

$$\frac{\partial c}{\partial \tau} = \overline{D} \frac{\partial^2 c}{\partial x^2}$$
(1)

where c - is the concentration of the transferred component in the feed or raffinate, x - is the particle depth coordinate, $\tau$ is the current process time, $\overline{D}$ - is the average molecular diffusion coefficient in the solid phase.

When building the model, we assume that during the extraction of inulin from topinambour, internal and external mass transfer takes place equally over the entire outer surface of a cylindrical particle of small diameter dэкв = 4 mm internal and external mass transfer.

Hence, as the first coordinate x characterising the particle and on which the desired function depends c (x,$\tau$), one can take its radius r, mm, that is x = 0 … rэкв.

- The initial value of the x-coordinate corresponding to the surface of the particle: Xn = 0.

- The final value of the x-coordinate corresponding to the centre of the particle: Xk = rэкв

In this simulation option it is not necessary to carry out the calculation in polar coordinates, since the concentration changes in uniform surface mass transfer are not determined by its direction. As another coordinate in the finite-difference grid, when used to solve the mass transfer equation, we take the duration of the extraction process $\tau$,c. Coordinate $\tau$= 0 …$\tau$k

- Initial value of coordinate $\tau$ corresponding to the starting point of the process at the initial time at $\tau$= 0.

- End value of coordinate $\tau$, corresponding to the end of the process $\tau$= $\tau$k.

Equating the equations of process speed at the interface

and in the boundary layer of thickness $\delta$ we obtain, similar to heat transfer, boundary conditions of the second kind [58]:

$$-D\frac{dy}{dx} \approx D\frac{(y_{\text{нач}}-y_{\text{p}})}{\delta} = \beta_{\text{x}}(x_{\text{p}} - x_{\text{т}})$$
(2)

where $\beta_{\text{x}}$ - is the mass transfer coefficient in the liquid phase; $x_{\text{т}}$ , $x_{\text{p}}$ - current and equilibrium concentrations of inulin in the liquid phase, D - molecular diffusion coefficient, x - layer depth coordinate; y, $y_{\text{нач}}$, $y_{\text{p}}$ - current, initial and equilibrium concentrations of inulin in the starting product and the raffinate.

In mass transfer processes, given the well-known assumption of dynamic equilibrium at the interface, the concentration at the interface can be identified with the solution concentration at saturation, i.e. the equilibrium concentration $x_{\text{p}}$ in the extract or $y_{\text{p}}$ in the raffinate. This assumption allows to choose boundary conditions of the 1st kind when developing a mathematical model of mass-exchange process of extraction. When determining the initial conditions, the initial concentration is assumed to be a uniform inulin content over the volume of the product before the start of the process.

In order to conduct the drying process in a rational manner, it is necessary to observe temperature limitations related to the hovering time of the particles and the duration of moisture removal, speed and temperature of the heat transfer medium, etc. It should be borne in mind that the results obtained in the experimental setups must be transferred to industrial apparatus, taking into account the principles of scale transition [13, 14].

Since it is difficult to determine experimentally the temperature change in the product volume during the drying process in case of chaotic fine particles with short duration of spray drying, it is advisable to simulate it and solve model equations taking into account the real conditions of dehydration.

In developing a mathematical model for the dewatering of small diameter suspended inulin particles, they can be likened to a "thin layer" characterized by small values of the mass and heat transfer criteria Bio (BiT <<1,BiM <<1).

In extraction and convective spray drying processes the shape of particles and droplets can be assumed to be cylindrical or spherical with a certain accuracy and the energy input to be uniform over the entire phase contact surface. In this regard, one of the coordinates for constructing the temperature functional dependence can be taken as the equivalent particle radius.

As already mentioned, in such modelling there is no need to carry out the calculation in polar coordinates as temperature changes at uniform surface energy input are not determined by its direction [4]. Often desorption shrinkage is neglected to simplify models of the dewatering process [3, 6], which is excluded when drying dispersed high-moisture particles where significant shrinkage is observed. When using numerical methods for solving the heat transfer equation, it is possible to take into account the change of particle size in steps with a given step, which is provided by finite difference method applied in this work, where differentials are replaced by finite differences. Due to the fact that the exact change of the particle size in time cannot be studied experimentally practically, in realization of the model it is assumed to change linearly from the initial to the final equivalent diameter determined empirically by disperse composition

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analysis [4, 6]. In the case under consideration, the finite temperature distribution along the particle radius of the previous zone will be the initial for the subsequent one. As another coordinate of the difference grid, instead of dewatering time, the associated current humidity of the treatment object determined in previous studies is used, whose change depending on the duration of the process is also divided into characteristic zones. By sequentially combining the temperature fields of the individual zones, a common temperature field is obtained.

Using a mathematical numerical finite difference method, the concentration and temperature fields for the extraction of inulin from topinambour and convective drying of the inulin solution in a spray state were obtained.

In the one-dimensional formulation of the problem, in its most general form, the energy transfer equation for volumetric energy input is as follows:

$$c_p(x, T, w)\frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x}\left(\lambda(w, x, T)\frac{\partial T}{\partial x}\right) +$$
$$+ \varepsilon \cdot r(w, x, T) \cdot \rho(w, x, T) \cdot \frac{\partial w}{\partial \tau} + W(w, x, T) \qquad (3)$$

Here r is the amount of energy for the vapour formation of 1 kg of moisture when the entropic component is taken into account:

$$r = 3118,4581 \cdot 10^3 - 2286.66 \cdot T - 55,5 \cdot$$
$$\cdot RT \cdot lnA_w + 55, (5)T\frac{\partial(\Delta S)}{\partial U_p} \qquad (4)$$

In the absence of an internal heat source W(w,x,T)=0, unlike infrared and microwave dehumidification. Let's replace $\frac{\partial w}{\partial \tau}$ to the change in moisture averaged over the diameter $\frac{\partial w}{\partial \tau}$ and assume a phase transformation coefficient of ε= 1, due to the high intensity of moisture transfer mainly in the vapor form at the conditional structural isotropy of the particle [3, 6]. This results in the independence of the thermophysical characteristics from x, which makes it possible to take $\bar{\lambda}$ (w T,) over the differential sign.

Dividing all terms of the equation by c·$\bar{\rho}$ (w,T) we obtain:

$$\frac{\partial T}{\partial \tau} = \bar{a}(w, T)\frac{\partial^2 c}{\partial x^2} + \frac{r(w,T)\bar{\rho}(w,T)\partial\bar{w}}{c_{\bar{\rho}}(w,T)} \cdot \frac{\partial\bar{w}}{\partial\tau} \qquad (5)$$

where $\bar{a}(w, T) = \frac{\bar{\lambda}(w,T)}{c \cdot \bar{\rho}(w,T)}$ - is the thermal conductivity coefficient.

Knowing $\frac{\partial w}{\partial \tau}$ =f(w) и $\bar{w} = f(\tau)$ and omitting the sign of the mean and the arguments of the functions, we obtain

$$\frac{\partial T}{\partial w} = \frac{a}{\partial w/\partial\tau}\frac{\partial^2 c}{\partial x^2} + \frac{r}{c_p} \qquad (6)$$

The initial conditions are given with respect to the uniform temperature distribution at $W_H$, in the form: at w=$w_H$, T=$T_0$, i.e.

$$T(x, w_H) = T_0$$

Since between surfaces of neighboring particles with the same temperature there is a mutual reflection of thermal energy, the radiant heat transfer between the particles can be neglected with sufficient accuracy. For the heat transfer at the phase contact boundary we assume the boundary conditions of the 2nd kind:

$$-\lambda(w)\frac{\partial T}{\partial x} = \alpha\left(T_{envir.} - T_{x=0 (sur)}\right) \qquad (7)$$

where $\alpha$- heat transfer coefficient, W/(mK²) x - particle depth, m; $T_{envir.}$ - temperature of drying agent, K; $T_{x=0}$ (sur) - temperature at the surface of the particle, K.

**Results and discussion.** Solving equation (6) under the above boundary conditions, we obtain the functional

dependence t=f(w,x). Then, by substituting in it w=f($\tau$,$W_H$,T) we define the function t=f(x,$\tau$,$W_H$,T). To increase both arguments in the drying process we will carry out the replacement of moisture w into dry matter content c.

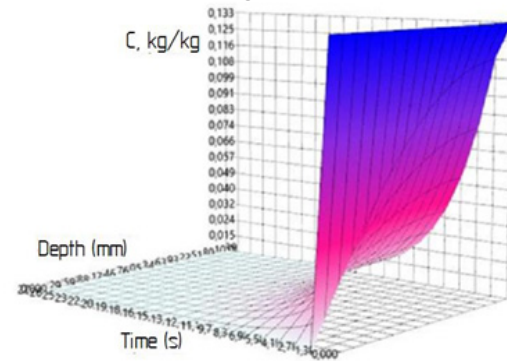Figure 1 shows a graphical interpretation of the concentration fields during inulin extraction.



**Figure 1. Concentration field using ultrasonic exposure at $T$ = 343 K.**

Considering the calculated temperature fields (Fig. 2), it can be concluded that insignificant temperature gradients exist, which result in uniform volumetric heating and 'gentle' moisture removal, as the material temperature during drying did not exceed $T$= 328 K. Periodic temperature
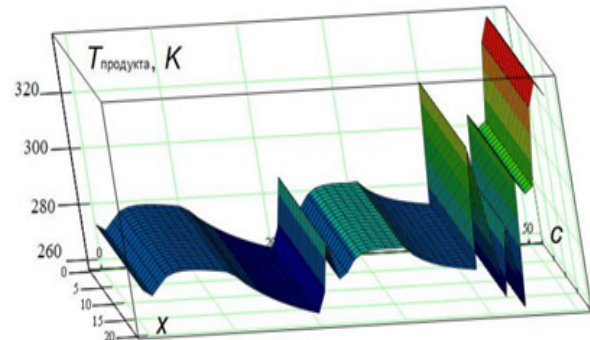


**Figure 2. Temperature field at Wn = 0.95 kg/kg; $T$ = 383 K; c, x are the order numbers of the steps (Δc, Δx)**

peaks, corresponding to jumps in the drying rate curves, are observed. In sections with approximately constant temperature the removal of free moisture occurs [8, 5]. An increase in temperature is caused by the expansion of structural moisture confined in closed cells and capillaries, blocked by liquid meniscuses, which leads to the so-called "greenhouse" effect and a decrease in the rate of moisture removal.

**Conclusions.** The adequacy of the developed mathematical model of the drying process was evaluated by the final temperature in the powder layer of the dried inulin extract particles (particle surface temperature). On the basis of comparison of indications of the multimeter during testing with results of modeling it was shown that the average temperature of the powder at the outlet of the dryer at three repetitions made 322 K that guarantees maintenance of quality during drying. The relative error of the model temperature in relation to the experimentally determined temperature of the powder at the outlet of the dryer did not exceed 6%, which indicates the adequacy of the developed model and the possibility of its implementation in industry.

**References:**

1.Usenov A.B., Sultanova Sh.A., Safarov J.E., Azimov A.T. (2021) Experimental-statistic modelling of temperature dependence of solubility in the extraction of ocimum basilicum plants // IOP Conference Series: Earth and Environmental Sciencethis link is disabled, 2021, 868(1), doi:10.1088/1755-1315/868/1/012047

2.Sultanova Sh., Safarov J., Usenov A., Raxmanova T. (2020) Definitions of useful energy and temperature at the outlet of solar collectors. // E3S Web of Conferences: Rudenko International Conference "Methodological problems in reliability study of large energy systems". Vol. 216, P.1-5. https://doi.org/10.1051/e3sconf/202021601094

3.Korotkova E. I., Karbainov Y. A., Shevchuk A. V. (2002) Study of antioxidant properties by voltammetry. Journal of Electroanalytical Chemistry, no. 1, pp. 56-60.

4.Kitanovic, S. (2008) Empirical kinetic models for the resinoid extraction from aerial parts of St. John's wort (Hypericum perforatum L.). Biochemical Engineering Journal. V. 41. P. 1.

5.Veloso, G.O., Krioukov G.O. (2005) Mathematical modeling of vegetable oil extraction in counter current crossed flow in horizontal extractor. Journal of Food Engineering. V.66. P. 477-486.

6.Berk Z. (2013) Food Process Engineering and Technology: Second Edition (Book) / Z. Berk // Elsevier Inc. P. 690.

7.Laitinen A. (1999) Supercritical Fluid Extraction of Organic Compounds From Solids and Aqueous Solutions / A. Laitinen // Espoo.

8.Acosta-Esquijarosa J. Jáuregui-Haza U., Amaro-González D., Sordo-Martínez L. (2009) Spray Drying of Aqueous Extract of Mangiferaindica L (Vimang): Scale up for the Process. World Applied Sciences Journal. N 6 (3). P.408 – 412.

9.Gaafar A. M., El-Din F. Serag, Boudy A., El-Gazar H. H., (2010) Extraction Conditions of Inulin from Jerusalem Artichoke Tubers and its Effects on Blood Glucose and Lipid Profile in Diabetic Rats. Journal of American Science, 6(5), P.36 – 43.

10.May B.K., Perré P. (2002) The importance of considering exchange surface area reduction to exhibit a constant drying flux period in foodstuffs. Journal of Food Eng. Vol. 54, № 4. P. 271 – 282.

11.Cachim P. (2011). Using artificial neural networks for calculation of temperatures in timber under fire loading. Construction and Building Materials - CONSTR BUILD MATER, 25, 4175–4180. https://doi.org/10.1016/j.conbuildmat.2011.04.054

12.Singh D., Febbo P., Ross, K., G Jackson D., Manola J., Ladd C., Tamayo P., A Renshaw A., V D'Amico A., P Richie J., S Lander E., Loda M., Kantoff P., R Golub T., Sellers W. (2002). Gene Expression Correlates of Clinical Prostate Cancer Behavior. Cancer Cell, 1, 203–209. https://doi.org/10.1016/S1535-6108(02)00030-2

13.Golub T. R., Slonim D. K., Tamayo P., Huard C., Gaasenbeek M., Mesirov J. P., Coller H., Loh M., Downing J. R., Caligiuri M., Bloomfield C., Lander E. (1999). Molecular classification of cancer: Class discovery and class prediction by gene monitoring. Science (New York, N.Y.), 286, 531–537.

14.Westermann F., Wei J. S., Ringner M., Saal L., Berthold F., Schwab M., Peterson C., Meltzer P., Khan J. (2002). Classification and diagnostic prediction of cancers using gene expression profiling and artificial neural networks. GBM Annual Fall Meeting Halle 2002, 2002. https://doi.org/10.1240/sav_gbm_2002_h_000061