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DESIGN AND ENGINEERING CALCULATION OF A SCREW PRESS FOR EXTRACTING JUICE FROM SEA BUCKTHORN

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ABSTRACT

This paper describes an experimental screw press for juice and cake separation. The constructive and structural schemes of the press are given, the characteristics of the main units of the equipment and the principle of its operation are presented. The algorithm of engineering calculation of juicer design is resulted, which is based on the calculation of pressing duration at different rates of screw rotation (ω = 14653 rad/s, ω = 12,56 rad/s, ω = 16,75 rad/s, ω = 18,84 rad/s) and studied influence of compression pressure by changing of diaphragm holes (δ=6·10-3 m; δ=10-3 m; δ=10·10-3 m; δ=12·10-3 m). The proposed method of engineering calculation of the pressing process makes it possible to determine the optimum parameters in advance and to develop a press of any capacity depending on production conditions.

Keywords: screw press, oilcake, sea buckthorn, pressing cage, flow-pressure characteristic.

INTRODUCTION

New technologies and equipment make it possible to fully process natural raw materials and produce products for the food, pharmaceutical, cosmetics and other sectors of the economy. These technologies and equipment are in high demand, with low energy costs, with preservation of the environmental cleanliness and very high quality. Innovative technologies increase the output of finished products due to complete processing of biologically active part of the plant, which until now has been a waste due to the lack of equipment that would allow them to be processed [1, 2].

Various technological methods (diffusion, extraction, pressing, etc.) are used to obtain juice and cake. The method of pressing allows obtaining high-quality juice from the pulp of fruits by mechanical way without extraction and chemical agents. In the process of pressing there is an additional destruction of the cellular structure, which is different for fruits of different species. As a result, processing losses, processing time and production costs are reduced [3, 4]. To study the pressing process (screw press) in the production of various food products, including juices, many scientists performed scientific works, as well as works on the study of screw presses [5-8].

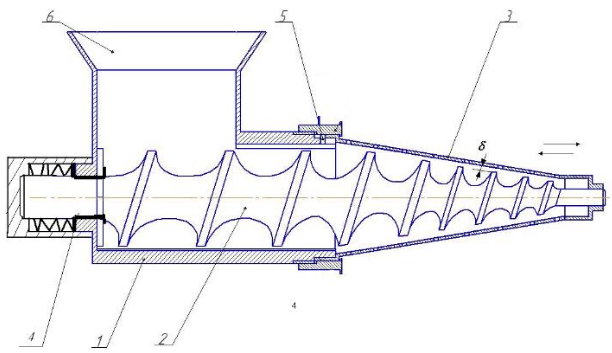
The experimental equipment designed by us with the help of the pressing process, will allow us to speed up the process of separating the juice of sea buckthorn seeds without using chemical methods and extraction, preserving its natural value, reducing the cost of inter-operational transportation and manpower, while increasing the efficiency of its use [9, 10].

There is no complete theory of screw presses operation until now and their creation is mainly based on experimental studies and empirical dependences obtained on the basis of experiments. This is due to the fact that in the screw channel of a screw press the properties of the raw material being pressed change: density, size and particle size distribution, amount of oil inside the particles and in the inter-particle pores, strength. These changes greatly complicate the analysis of pressing and squeezing processes, and do not allow to transfer the design of presses of new designs on a clear methodological basis [11, 12].

The purpose of the work is to develop an algorithm for engineering calculation of the screw press, which is based on the calculation of the duration of pressing at different screw speeds and the study of the effect of compression pressures by changing the diaphragm holes.

DESCRIPTION OF EXPERIMENTAL PRESS EQUIPMENT FOR JUICE PRODUCTION

In order to accelerate the pressing process, a prototype of juice separation equipment with a mechanism for uniform distribution of longitudinal axial screw load (Figures 1, 2) was designed [9].



1-housing; 2-screw; 3-cone grid; 4-mechanism of pressure adjustment; 5 - fastening nut; 6 - hopper

Figure-1. Schematic diagram of the press equipment for juice separation.

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Experimental press equipment is equipped with basic parts: a cylindrical tube, a cone-shaped press screw located inside the body (Figure-3), and a cone-shaped pressing cage (Figure-4), from which the product is discharged. It is also equipped with a pressure regulating mechanism.

Figure-2. General view of the pilot press equipment.

Figure-3. Pressing screw.

Figure-4. Cone-shaped pressing cage.

The pressure regulating mechanism on the juice separation equipment maintains a consistent pressure distribution on the longitudinal growth of the screw due to the variation of the gap between the cone screws and the cone grid. This process is realized by the wiping motion of the cone screw.

Pressure regulating mechanism consists of spring, coupling nut, control nut and two tips of sliding and washer, rubber sealing rings (Figures 5-10).

Figure-5. Pressure regulating spring.

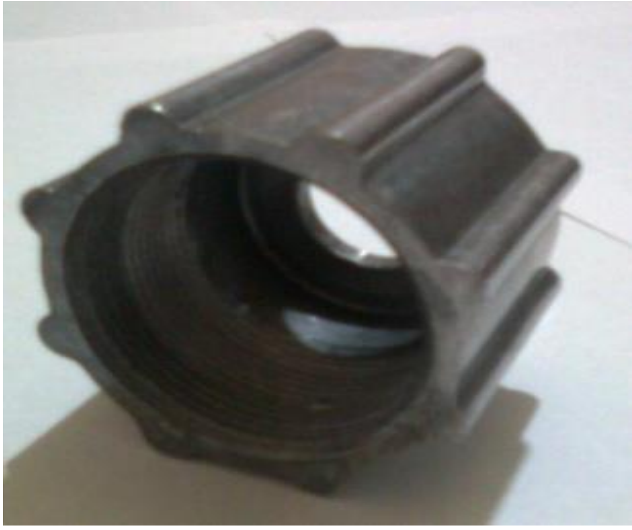

Figure-6. Coupling nut.

Figure-7. Slide tip.

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Figure-8. Check nut.

Figure-9. Washer.

Figure-10. Rubber O-ring seal.

Juicing equipment works in the following way: sea buckthorn is fed from the loading neck into the pressing chamber. The product is pressed as a result of the gradual reduction of the outer diameters of the pressing screw in the direction of the product flow and the juice is released through the holes of the cone-shaped grid. The pressure required to separate the juice is controlled by a specially designed pressure regulator (Figure-11).

Figure-11. Juice separation process.

As a result of installing a pressure control mechanism in the design of the improved equipment, providing holistic change in the gap between the cone screw and the cone-shaped grid, we achieve intensification of the process of juice separation, ensuring uniform pressure distribution on the longitudinal axis of the screw.

CALCULATION ALGORITHM FOR THE ENGINEERING DESIGN OF THE JUICER

Engineering calculations are obtained on the basis of the following experimental studies:

- to study the duration of pressing by changing velocities (ω = 14,653 rad/s, ω = 12.56 rad/s, ω = 16.75 rad/s, ω = 18.84 rad/s);
- study the influence of compression pressures by changing the holes of the diaphragm (δ=6·10-3 m; δ=10-3 m; δ=10·10-3 m; δ=12·10-3 m).

The method of engineering calculation of intensification of pressing process was obtained using computer mathematical programs MathCad 2000 (9.0) Rus and MATLAB 9.9 R2020b [13]. In the developed method of engineering calculation of intensification of pressing process, for uniform arrangement of determined values in one system, an algorithmic flowchart for entering computer mathematical programs is shown on Figure 12.

The proposed method of engineering calculation of the intensification of the pressing process makes it possible to determine the optimal parameters in advance and to develop a press equipment of any productivity, depending on the production conditions [14, 15].

Calculation of the diaphragm matrix cone

In our case, according to Figure 13, the shape of the matrix forming channel is cone-circular. At the section, which is a tapered plane and has the form of an ended oblique cylinder, we choose the arithmetic mean diameter between the initial and final diameters, then:

$$K_{\Phi} = \frac{3\pi d_a^3 d_b^3 (d_a - d_b)\cos\gamma_{\Phi}}{128 l_{\Phi} (d_a^3 - d_b^3)}$$

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where, $d_a = R_a + r_a$, $d_b = R_b + r_b$ - mean diameter;

$\dfrac{l_\Phi}{\cos\gamma_\Phi}$ - length of channel.

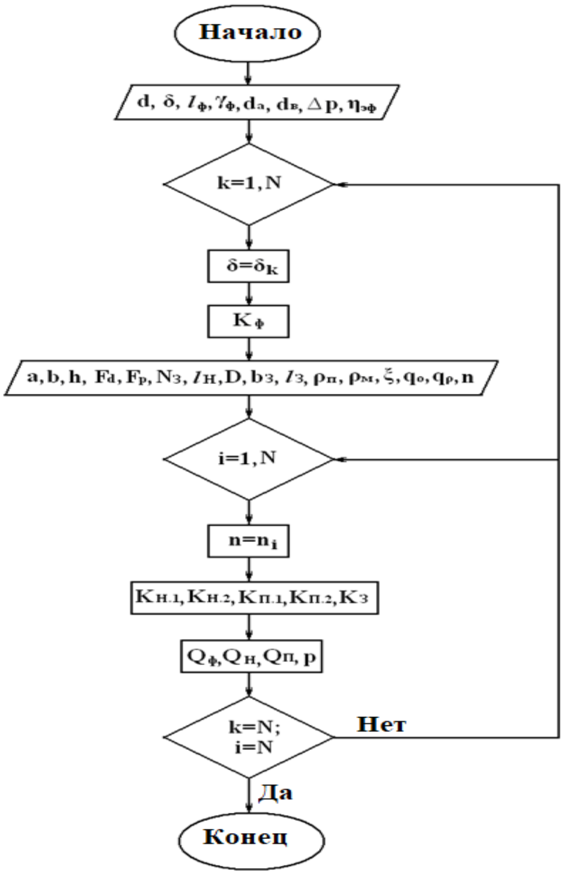


Figure-12. Block diagram of the engineering calculation.

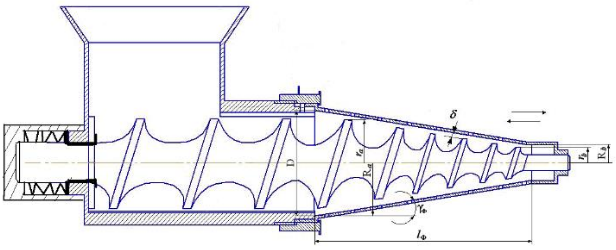


Figure-13. Matrix cone-ring forming channel.

In accordance with equation (2.18) the capacity (flow-pressure characteristic) of the matrix forming channel, m^3/s

$$Q_{\Phi.} = \frac{3\pi\, d_a^3 d_b^3 (d_a - d_b)\Delta p \cos\gamma_\Phi}{128\eta_{э\phi} l_\Phi (d_a^3 - d_b^3)} \tag{2}$$

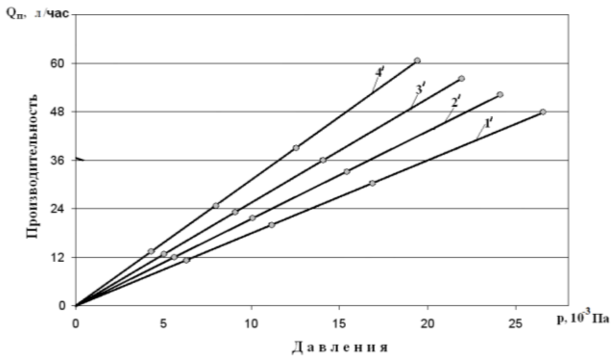
where, Δρ is the pressure drop in the matrix forming device, Pa.

Let's characterize the average diameters d_a, d_b, based on the values of the internal diameter d of the screw , the thickness of the product layer in the channel δ , the conical angle $\gamma_Ф$

$$d_a = d + \frac{\delta}{\cos\gamma_\Phi}, \quad d_b = d + \frac{\delta}{\cos\gamma_\Phi} + 2l_\Phi \cdot tg\alpha = d + \frac{(\delta + 2l_\Phi \sin\gamma_\Phi)}{\cos\gamma_\Phi}$$

Substituting the obtained values da, db into equation (2), the dependence of productivity QΦ and pressure drop p in the matrix forming channel on the layer thickness δ in the diaphragm gap is presented as a nomogram. The sloping curve showing dependence starts from the beginning of coordinates, specifically at zero motion.

According to Figure-14 from the nomogram it is visible, that with increase of resistance of matrix forming device productivity decreases and pressure increases. Using the nomogram on the basis of practical mathematical modeling system it is possible to define necessary productivity (flow-pressure characteristic) and pressure equal to change of aperture gap for optimum juice separation.



$1^/$ - $\delta=4\cdot10^{-3}$ m; $2^/$- $\delta=6\cdot10^{-3}$ m; $3^/$- $\delta=8\cdot10^{-3}$ m; $4^/$- $\delta=10\cdot10^{-3}$ m

Figure-14. Nomogram for selecting the required optimum flow-pressure characteristics and pressure for juice separation depending on the diaphragm gaps.

Calculation of the Press and Squeeze Screw

Let's determine the geometric coefficient in the equation of the screw channel

$$\upsilon_z = \pi \cdot D \cdot n \cdot \cos\alpha$$

$$K_{H1} = \frac{\pi D \cos\alpha_{op.}}{2} \cdot h \cdot \frac{(a+b)}{2} \cdot F_d \cdot \psi \tag{4}$$

$$K_{H.2} = \frac{(a+b)\cdot h^3}{24 \cdot l_H} \cdot F_p \tag{5}$$

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where, ψ - coefficient considering the shear of non-Newtonian masses;
F_d, F_p - coefficients in the formulas that account for internal ratios $\frac{h}{\left(\frac{a+b}{2}\right)}$, in some literature [7] numerical values are determined from nomograms, we will define them according to Table-1 [8].

Table-1. Numerical values considering internal ratios.

$\frac{h}{\left(\frac{a+b}{2}\right)}$	**F_d,**	**F_p**	**ψ**	$\frac{h}{\left(\frac{a+b}{2}\right)}$	**F_d,**	**F_p**	**ψ**
0,1	0,92	0,91	0,707	0,5	0,72	0,69	0,695
0,2	0,87	0,87	0,702	0,6	0,67	0,63	0,672
0,3	0,83	0,83	0,699	0,7	0,63	0,57	0,667
0,4	0,78	0,74	0,697	0,8	0,59	0,51	0,647

Effective viscosity of mass, Pa·s

$$\eta_{эф} = \eta_{ж} + \frac{\theta_0}{\dot{\gamma}} \tag{6}$$

where, $\dot{\gamma} = \frac{\pi D n}{60(D-d)}$ - shear rate, 1/s
d - internal diameter of the screw, m;
θ_0 - yield stress, Pa.

According to formulas (3), (4), let's determine the capacity of the press and squeeze screw in the following form

$$Q_H = \frac{\pi D\cos\alpha \cdot h \cdot \frac{a+b}{2}}{2} \cdot F_\alpha \cdot \psi \cdot n - \frac{\frac{a+b}{2} \cdot h^3}{12 l_H} \cdot F_p \cdot \frac{\Delta p}{\eta_{эф}} = K_{H1} \cdot n - \frac{K_{H2}}{\eta_{эф.}} \cdot \Delta p \tag{7}$$

Substituting the values of K_{H1}, $K_{H.2}$ and K_Φ into the equation, we determine the first and second geometric coefficient

$$K_{П1.} = \frac{K_{H.1}}{K_{H..2} + K_\Phi} \tag{8}$$

$$K_{П2.} = \frac{K_{H.1} \cdot K_\Phi}{K_{H..2} + K_\Phi} \tag{9}$$

From equation (8) in equation (2) determine the pressure drop in the matrix forming device, Pa

$$\Delta p = K_{П.1} \cdot \eta_{эф.} \cdot n \tag{10}$$

From this we determine the total capacity of the press, kg/sec

$$Q_П = K_{П.2} \cdot n \cdot \rho_П \tag{11}$$

where, ρ_n - density of the pressed product, kg/m^3.

Equation (10) determines the pressure at the press output

$$p = \frac{K_{H.1} \cdot K_\Phi}{K_3 (K_{H..2} + K_\Phi)} q_\rho \cdot n \cdot \eta_{эф} \tag{12}$$

where, $q_\rho = q_0 \frac{\rho_П}{\rho_M}$ - quality indicator when separating the optimum juice content.

In this equation (13) the geometric coefficient of the pressing cage $K_з$

$$K_з = \frac{N_з L_з b_з^3 \xi}{24 l_з} \tag{13}$$

$b_з$ - width of the pressing cage gap, m;
$L_з$ - length of the pressing cage gap, m;
$l_з$ - wall thickness of the pressing cage gap, m;
ξ - side pressure coefficient;
$N_з$ - number of the pressing cage gaps.

Using the obtained mathematical expressions, according to Figure-14, we plot the dependence of changes in velocity on productivity Q_H and pressure of the pressing and squeezing screw p. In this figure we can see that with increasing velocity, productivity and pressure increase.

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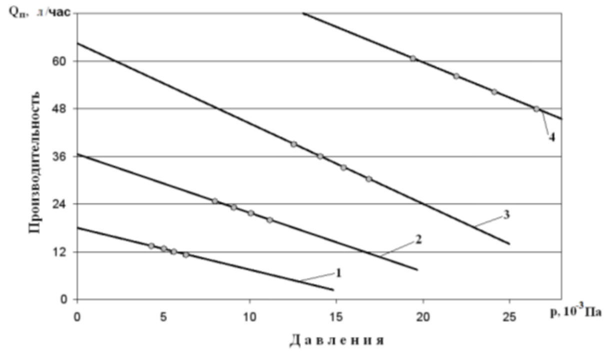


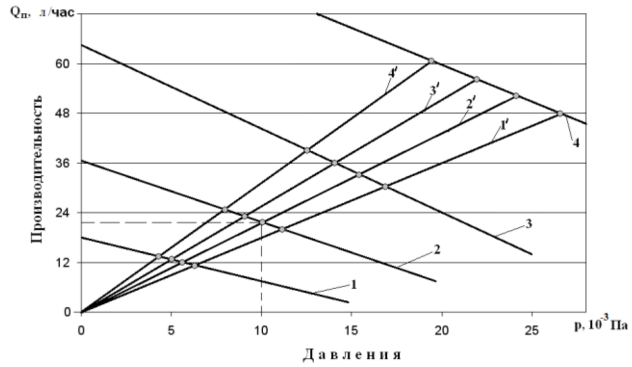
1-ω=14,653 rad/s; 2 - ω=12,56 rad/s; 3 - ω=16,75 rad/s; 4 - ω=18,84 rad/s

Figure-15. Nomogram for choosing the appropriate capacity and pressure required for optimum juice separation, relative to speeds.

According to Figures 14, 15, combining nomograms characterizing the diaphragm gaps of the press and velocities, from the changes of inclined sections we will select appropriate capacities and pressures necessary for optimum juice separation.

A mathematical modeling analysis system developed for the matrix forming device and press-and-pressure screw designs helps determine performance and pressure variations for optimum juice separation, using the relationship between velocities and diaphragm gaps along a given circumference of the juicer.

According to Figure-16 from inclined changes of diaphragm gaps and speeds it is possible to notice that the received results of the experiments correspond to results of analytical system of mathematical modeling on the basis of the shown dashed line. The productivity and pressure are defined at optimum juice separation on the basis of the presented discontinuous line received at the inclined crossing of parameters of speed ω=12,56 rad/s and diaphragm gap δ=6·10-3 m, satisfying requirements of process of pressing. The deviation between the obtained results of the experiments and the results of the analytical system of mathematical modeling does not exceed 4,3 %.



$1^{/}$ - $\delta=4\cdot10^{-3}$ m; $2^{/}$- $\delta=6\cdot10^{-3}$ m; $3^{/}$- $\delta=8\cdot10^{-3}$ m; $4^{/}$- $\delta=10\cdot10^{-3}$ m; 1 - ω=14,653 rad/s; 2 - ω=12,56 rad/s; 3 - ω=16,75 rad/s; 4 - ω=18,84 rad/s

Figure-16. Nomogram for determining the appropriate capacity and pressure required for optimum juice separation in relation to diaphragm gaps and velocities.

The correspondence of the results of the system of mathematical modeling and experiments is confirmed by nomogram solutions in accordance with Figure-16. The method of engineering calculation of intensification of pressing process is proposed.

CONCLUSIONS

The results of the research work allowed to make the following conclusions:

a) Different technological methods (diffusion, extraction, pressing, etc.) for obtaining sea buckthorn juice and cake were considered. The dependence of obtaining sea buckthorn juice on velocities (14,653 rad/s) and diaphragm holes (δ=6·10-3 m) was studied in the process of pressing.

b) The design of the juicer was developed, which allows to speed up the process of juice extraction and reduce specific power losses.

c) The dependence of the intensification of the pressing process is characterized by the ratio of various defined parameters. As a result the optimal parameters satisfying the purpose of work were determined ω=2,093 velocity rad/s and diaphragm gap δ=6·10-3 m.

REFERENCES

[1] Mizanbekova S. K., Bogomolova I. P., Shatohina N. M. 2020. Prospects for digital and innovative technologies in management competitiveness of enterprises. Food Processing: Techniques and Technology. 50(2): 372-382. DOI: 10.21603/2074-9414-2020-2-372-382

[2] Wilczyński K., Kobus Z., Dziki D. 2019. Effect of press construction on yield and quality of apple juice. Sustainability. 11(13): 3630.

[3] Wu C., Ge F., Shang G., Wang G., Zhao M., Wu L., Guo H. 2021. Design of Screw Type Automatic Apple Juicer. Journal of Physics: Conference Series. 1750(1): 012042. DOI: 10.1088/1742-6596/1750/1/012042

[4] Wilczyński K., Kobus Z., Guz T. 2018. Analysis of efficiency and particles size distribution in apple juice obtained with different methods. Journal of Research and Applications in Agricultural Engineering. 63: 140-143.

[5] Nnamdi U. B., Onyejiuwa C.T., Ogbuke C.R. 2020. Review of Orange Juice Extractor Machines. Advances in Science, Technology and Engineering Systems Journal. 5(5): 485-492.

[6] Donaldson M. 2020. Household Juice Extractor Comparison and Optimization. Journal of Food Processing and Technology. 11: 819. DOI: 10.35248/2157-7110.20.11.819

[7] Raghunath D., Unakal P. V., Gopinath C. 2011. Design of conceptual citrus fruit juicer for hawkers in India. SASTech-Technical Journal of RUAS. 10(2): 112-120.

[8] Omoregie M. J., Francis-Akilaki T. I., Okojie, T. O. 2018. Design and fabrication of a juice extractor. Journal of Applied Sciences and Environmental Management. 22(2): 207-212.

[9] Muratzhankyzy N., Kasenov A. L., Amirkhanov K. J., Moldabayeva Z. K., Kakimov M. M., Orynbekov D. R., Tokhtarov Z. K. A screw press for extracting juice from vegetable raw materials. Patent #3690 Republic of Kazakhstan, Published 24.05.2018.

[10] Kassenov A., Orynbekov D., Kakimov M., Tokhtarova S., Moldabayeva Z., Tokhtarov Z. 2019. Nutritive and biological value of sea buckthorn grown in east Kazakhstan region and its beneficial effects to human health. International Journal of Pharmaceutical Research. 11(1): 754-757.

[11] Sobolev S. N. 2007. Development of a method for obtaining amaranth oil by pressing on a single screw press. PhD-thesis, Voronezh.

[12] Fantino V. M., Bodoira R. M., Penci M. C., Ribotta P. D., Martínez M. L. 2020. Effect of screw-press extraction process parameters on the recovery and quality of pistachio oil. Grasas y Aceites. 71(2): e360. DOI: 10.3989/GYA.0107191

[13] Mateyev Y. Z., Shalginbayev D. B., Mateyeva S. Z., Kopylov M. V., Ostrikov A. N., Vasilenko V. N. 2019. Mathematical modeling of the extracting process of vegetable oil on auger equipment. EurAsian Journal of BioSciences. 13(2): 1875-1880.

[14] Kakimov M. M., Tokhtarov Z. K., Iskakov B. M. 2016. Intensification of the process of pressure treatment in order to develop equipment for pressing. Proceedings of the 19th International Scientific and Practical Conference Practical and theoretical aspects of complex processing of food raw materials and creation of competitive food - the basis of import substitution and food security of Russia. FGBNU VNIIMP named after V.M. Gorbatov Moscow. pp. 149-152.

[15] Dvoretsky D. S., Dvoretsky S. I., Peshkova E. V., Temnov M. S. 2014. Mathematical Modeling of Processes and Equipment of Chemical and Food Industries: A Training Manual Tambov: Publishing House of FSBEI HPE “TSTU”.