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PHYSICAL AND MATHEMATICAL MODEL OF THE PROCESSES OF A DEVICE FOR PROCESSING WATERMELONS

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The knowledge of the grinding processes of the pulp of fruits and vegetables is not sufficient. In this article, we examined the processes of destruction, grinding, mixing the pulp of watermelon. The criterion equations of these processes are derived taking into account the indicators of the pulp and peel of the watermelon. The derivation of criteria equations for calculating the characteristics of the processes used in the processing of watermelon fruits is considered. The mechanic-technological basis for calculating and designing machines for processing watermelons for food purposes is outlined. The results of experimental studies to determine the optimal kinematic and structural parameters of these machines are presented. The basic physic mechanical and rheological properties of watermelon fruits are given. One of the tasks set for the researcher was to choose a physical model of the processes of separation of pulp from the crust, destruction, grinding of pulp and mixing of the pulp. The values of these quantities depend both on the kinematic parameters of the dynamic interaction and on the physic mechanical and rheological properties of the fruits of melons. The obtained criteria equations can be used to determine the technological parameters of machines where it is necessary to destroy the fetus with minimal energy costs.

Key words: watermelon, criteria equations, process calculation, cutting, piercing, disruption, flesh, pulp.

ФИЗИКО-МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ПРОЦЕССОВ УСТРОЙСТВА ДЛЯ ПЕРЕРАБОТКИ АРБУЗОВ

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Знание процессов измельчения мякоти фруктов и овощей недостаточно для создания базы данных по свойствам, характеристикам и сортовым особенностям плода. В этой статье мы рассмотрели процессы измельчения, перемешивания мякоти в полости арбуза для получения очищенной корки и однородной мякоти. Критериальные уравнения этих процессов выведены с учетом показателей мякоти и кожуры арбуза. Рассмотрен вывод критериальных уравнений для расчета характеристик процессов, используемых при переработке плодов арбуза. Изложены механо-технологические основы расчета и проектирования машин для обработки арбузов для пищевых целей. Приведены результаты экспериментальных исследований по определению оптимальных кинема-тических и конструктивных параметров этих машин. Приведены основные физико-механические и реологические свойства плодов арбуза. Одна из задач, поставленных перед исследователем, заключалась в выборе физической модели процессов отделения пульпы от корки (без разрушения), разрушения, измельчения пульпы и перемеши-

вания пульпы. От физико-механических и реологических свойств плодов арбуза зависит подбор пере-мешивающих и измельчающих органов установки. Полученные критериальные уравнения могут быть использованы для определения технологических параметров машин, в которых необходимо перерабо-тать плод с минимальными энергетическими затратами.

Ключевые слова: арбуз, критериальные уравнения, расчет процесса, резка, прошивка, разрушение, мякоть, мякоть.

ҚАРБЫЗДЫ ӨҢДЕУ ҚҰРЫЛҒЫНЫҢ ФИЗИКАЛЫҚ-МАТЕМАТИКАЛЫҚ МОДЕЛІ

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Жемістер мен көкөністердің целлюлозасын ұнтақтау процестерін білу жеткіліксіз. Бұл мақалада біз қарбыздың ортасын жою, кесу, араластыру процестерін қарастырдық. Бұл процестердің критериалды теңдеуі қарбыздың ортасындағы жұмсығы мен қабығының көрсеткіштерін ескере оты-рып шығарылады. Қарбыз жемістерін өңдеуде қолданылатын процестердің сипаттамаларын есептеу үшін критериалды теңдеулерді шығару қарастырылады. Азық-түліктік мақсаттағы қарбыздарды өңдеуге арналған машиналарды есептеу мен жобалаудың механикалық-технологиялық негіздері көрсетілген. Бұл машиналардың оңтайлы кинематикалық және конструктивтік параметрлерін анықтау бойынша экспериментталды зерттеулердің нәтижелері берілген. Қарбыз жемістерінің негізгі физикалық, механикалық және реологиялық қасиеттері келтірілген. Зерт-теушіге жүктелген міндеттердің бірі – целлюлозаны қыртыстан бөлу, деструкциялау, целлюлозаны ұнтақтау және мас-саны араластыру процестерінің физикалық моделін таңдау болды. Бұл шамалардың мәндері қауынның динамикалық әрекеттесуінің кинематикалық параметрлеріне де, физикалық-механикалық және рео-логиялық қасиеттеріне де байланысты. Алынған критериалды теңдеулерді ең аз энергия шығынымен ұрықты жою қажет болатын машиналардың технологиялық параметрлерін анықтау үшін пайдала-нуға болады.

Негізгі сөздер: қарбыз, критериалды теңдеулер, процесті есептеу, кесу, тесу, жою, ұнтақтау, целлюлоза.

Introduction

When analyzing the process of the de-struction of the fetus, it is necessary to take into account its physical and mechanical properties, which should be generalized by creating a mod-el of plant material that allows reflecting such fundamental properties of the material as elas-ticity, viscosity and ductility. The model for gourds is determined by the structure of the fetal cortex, consisting of a solid skeleton and a semi-liquid, liquid or gaseous substance filling the gaps between the solid elements of the cortex and the internal cavity of the fetus. Obviously, a more real model should contain a greater num-ber of simple elements, but practice shows that the use of more than three or four elements in models significantly complicates the possibility of visual observation of the behavior of bodies while changing so many of its properties.

Similarity theory allows, without integrat-ing differential equations, to establish a relation-ship between similarity criteria and to formulate a criteria equation that will be valid for all similar processes. Moreover, to derive the criterion equa-tions, it does not need any simplifications that are usually introduced in cases of analytical solutions of differential equations describing a complex phenomenon. Processes of the same physical na-ture are called similar if their criterion equations completely coincide.

Any of the technologies for processing fruits includes the operation of the destruction of the fetus.

Knowledge of the physical properties of food materials is necessary for the design and optimization of the processing process [1].

While Multipurpose Optimization (MOO) has provided many methods and tools for solving design problems, food processes have gained little benefit from them. MOO covers the definition of performance indicators, process modeling, integra-

tion of preferences, evaluating compromises and finding the best compromises [2].

Aremu, A. K., Ogunlade, C. A. studied the yield of juice on three fruits: orange, pineapple and watermelon. In their studies, the fetal juice constant (in decimal form) was also calculated and recorded. Each experiment was repeated three times for peeled and unpeeled pineapple, orange, and watermelon using four sets of sieves. The following indices are described by Oguntuyi (2013), Kasozi and Kasisira (2005), Abulude et al. (2007), Samaila et al. (2008), Aye, and Abugh (2012) were used to calculate juice yield, extraction efficiency and losses during machine extraction, while the juice constant was obtained from the ratio of the sum of the masses of extracted juice and chaff juice to the mass. The fruits fed the mass of juice in Chaff was determined using the ASAE method (1983), applied by Oje (1993), Oyeleke and Ollaniyan (2007), Aviara et al. (2008), Olaniyan (2010), Adebayo et al. (2014), Olaniyan and Obajemihi (2014)a) Juice yield,

$$JY, \% = \frac{w_{je} \times 100}{w_{je} + w_{rw}}$$

b) Extraction Efficiency, $\% = \frac{100 * W_{je}}{W_{fs} * X}$

c) Extraction Loss $\%$
$$= \frac{100 * (W_{fs} - (W_{je} + W_{rw})}{W_{fs}}$$

d) Juice Constant, $X = \frac{W_{je} + W_{jc}}{W_i}$

Where: WJE is Mass of juice extracted in grams, WRW is the Mass of residual waste in grams, WFS is

the Mass of fed sample in grams, X is the juice constant of fruits in decimal [3].

Methods

We studied two varieties of watermelon "Sweet Krimson", zoned in the Turkestan region, and "Dishim."

For experiments, together with KazNIIPO Institute for Potato and Melon Growing, 60 pieces were randomly involved. Fruits were taken after checking for defects with a thorough visual inspection, during laboratory tests and studies at $5 \pm 1\,^{\circ}$ C, $90 \pm 5\%$ relative humidity before use.

Also, the shape index was used to calibrate the watermelon fruit. The shape index was calculated. During the experiment, a relationship was found between a weighty watermelon and a watermelon shape index. The average weight of wa-

termelons was 8 kg, while the circumference of such watermelons was 78 ± 2.1 cm.

Mechanical Characteristics Watermelon is also designed to design appropriate machines. For further research, watermelons with the same shape index are discarded. 5 unit of watermelon are made (peel, mechanical armor, pulp parenchyma, etc.). the same size 3cm x 3cm, each experiment was carried out 5 times according to the following methods.

1.Determination of ultimate shear stress of food products

This technique is based on determining the ultimate shear stress in determining the parameters: Fost - residual loading force, g; h - penetration depth, m; δ is the ultimate shear stress, Pa.

The final result can be taken as the arithmetic mean of the values of the results of three determinations:

$\delta = K_{con}F_{ost} / h_2$, Pa

where: K_{con} - coefficient of the cone (1.1 - according to the passport of the device); F_{ost} - the residual loading force on the indenter "cone", N, - is determined according to the schedule as a constant value of the load value stress after relaxation of mechanical stresses; h - penetration depth, m, - corresponds to the value of the steady-state residual loading force.

2.Method for determining loading force

The method is based on determining the parameter of the loading force Fн. The final result was the arithmetic mean of the results of three determinations. Change in loading force on the indenter depending on the depth of its introduction into fresh, frozen and thawed fruits.

After uniformly slicing into different parts of the fetus, pieces of the fetus 10 mm thick were placed on the apparatus table close to the indenter, after which the apparatus conducted research and plotted.

3.The study of the strength characteristics of watermelon fruit

The experimental research program includes the determination of the strength characteristics of a watermelon and its parts. For research, winter varieties of watermelons with a thick crust and a dark color of the cuticle were taken. To register the data, the ST-2 structure-meter device was used.

4.Method for determining the strength characteristics on Reotest RN4.0

Raw materials are cut with a thickness of not more than 1 mm, samples are taken from three slices of watermelon, sliced into 2 cm

wide slices. From the prepared sliced slices, take the same sections of the slice, parallel to each other. We measure raw materials in shear, plate-plate. We determine the fracture strength, then identically prepare three more samples from the same sections of the segments and conduct oscillation tests. The results of the analyzes are presented in the form of a graph and table.
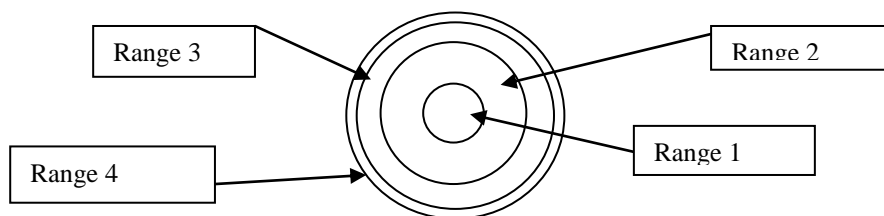

Figure 1 - areas of sampling, watermelon in the context

In Figure 1, the region 1 is the core of the watermelon, approximately 5 cm in diameter, the region 2 of the pulp parenchyma is the main part where the seeds are located, approximately 15-20 cm, region 3 is the mechanical armor, the cortical zone, from 23 cm in diameter, then region 4 - white peel (epidermis + cuticle)

The strength of the crust is determined first with the cuticle, then without the cuticle in different directions.

In 2005, foreign colleagues from India investigated the fruits of a watermelon with red pulp on an Instron plant manufactured in Great Britain, shown in Figure 2 (Instron, Canton, MA) [4], we conducted similar studies on a Structometer ST 2 and obtained the following data.
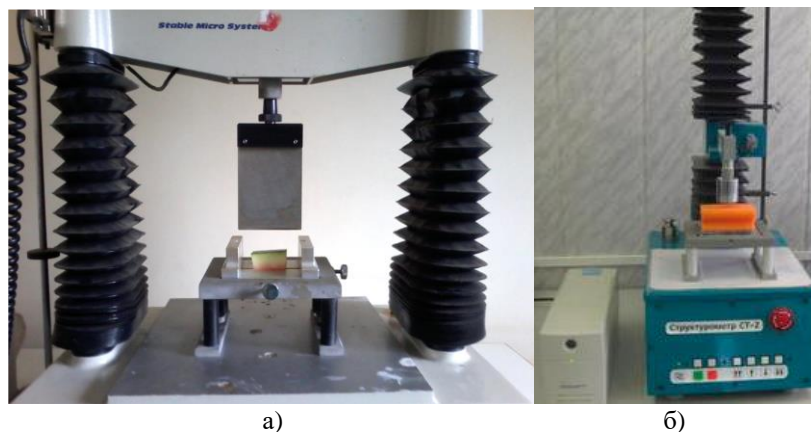

Figure 2 – Texturometers: a - Instron, Canton, MA, b- Structurometer CT 2

Results and their Discussions

Russian scientists Shaprov M.N., Semin D.V. et al. also conducted similar studies, the results of which on the Volga watermelon are given in the sources [5,6]. Also, experiments were conducted according to the methodology of the scientific consultant of the Doctor of Technical Sciences, Professor M. Shaprov, who did research on the installation they assembled, we conducted research on the CT 2 structureometer and the following data were obtained, presented in table 1. Our results in table 2

Table 1 - Difference in maximum shear stress depending on the cut-off area of the watermelon

Watermelon area	Maximum Shear Strength (N)	Maximum shear stress (N/мм^2)
Range 1	4±0,2	0,048±0,009
Range 2	5,5±0,1	0,069±0,002
Range 3	10±0,2	0,0139±0,003
Range 4	50±0,2	0,070±0,007

Table 2 - Strength characteristics of watermelon

Region	Fracture force, N	Puncture Force, N	Hardness, kg / mm^2	Cutting force with a flat knife N / cm	
				along	across
Watermelon bark					
Stalk of watermelon	470,4±2,7	131,0±1,5	0,91±0,1	28,5±0,3	36,9±0,62
Watermelon equator	432,5±6,8	109,1±0,72		36,9±0,4	37,1±0,5
receptacle	440,9±5,3	106,8±2		26,8±0,52	39,5±0,5
Watermelon pulp					
peduncle	176,9±2,7			13,0±0,2	10,6±0,15
equator	102,8±0,73			12,6±0,15	12,1±0,13
receptacle	166,4±2,7			9,33±0,14	8,6±0,14

The obtained research data was used to calculate and design a device for cleaning a watermelon from a cuticle, chopping and extracting pulp, and slicing a peeled peel into even cubes for making candied fruit.

The elastic modulus of watermelon amounted to 9.79 ± 0.94 × 100 Pa and vertical compression to 8.92 ± 0.78 × 100 Pa under vertical compression.

The efficiency of juice extraction and losses are calculated by the following formulas:

a) Juice yield, JY, % = $\frac{w_{je} \times 100}{w_{je} + w_{rw}}$ =31,6±0,23

b) Extraction Efficiency, % = $\frac{100 * W_{je}}{W_{fs} * X}$ =38,3±1,4

c) Extraction Loss % =$\frac{100 * (W_{fs} - (W_{je} + W_{rw})}{W_{fs}}$=6,4±1,2

Separation of pulp from the peel

The separation of pulp from the walls of the peel occurs by sliding cutting of the pulp from the inner walls of the peel

Elementary energy (work) *dA* (Дж), put it:

$$dA = dA_1 + dA_2 + dA_3 \qquad (1.1)$$

Where dA1 is the elementary work spent on volumetric plastic deformation, J.

dA2 - elementary work spent on the formation of an element of a new surface (at the limit of molecular forces or surface energy), J;

dA3 — elementary energy spent on compensation for losses associated with the friction process and heat generation, respectively, J.

The terms dA1, dA3 are negligible in comparison with the value of dA2

We take into account only the value dA2 for cutting with sharp edges of the blades:

$$dA_2 = H_F \cdot 2dF \qquad (1.2)$$

where HF is a constant for a given material, characterizing its surface-active properties or otherwise specific work (energy) spent on the formation of a unit area of the material being cut, J / m^2;

dF - elementary surface increment during cutting deformation, m².

Total energy (work) spent on cutting:

$$A_2 = 2H_F \int dF \tag{1.3}$$

dF - elementary cut surface area, m²

F is the internal surface area of the slice, m².

2F - the newly formed surface is equal to the double sectional area of the section, m².

With a constant with a known configuration of the cutting area, the work will be expressed:

$$A = 2H_F \cdot F$$

The speed of the cutting process, as the most important kinetic factor is expressed:

$$v_p = \frac{dT}{F \cdot d\tau} \tag{1.4}$$

Where dT is the elemental cutting force when separating the pulp from the inner surface of the watermelon;

vp - cutting process speed;

Fp - cutting area.

The mathematical model of the process of cutting the flesh is presented in the form of a system of equations:

$$\begin{cases} v_p = \dfrac{dT}{F \cdot d\tau} \\ A = 2H_F \int dF \end{cases} \tag{1.5}$$

or otherwise:

$$\begin{cases} dT = v_p \cdot Fd\tau \\ dA = H_F \cdot 2dF \end{cases} \tag{1.6}$$

Grinding pulp inside the cavity

Grinding occurs in the cavity of a watermelon, after the introduction of a working organ. The fragile structure of the pulp of watermelon is destroyed. Destruction occurs as a result of compression deformations (mainly) and cutting.

Arguing in a similar way to (1.1), we obtain:

$$dA = dA_1 + dA_2 + dA_3$$

We neglect only the value dA_3

$$dA = dA_1 + dA_2$$

The elementary work dA_1 spent on volumetric deformation is expressed by:

$$dA_1 = \frac{\sigma^2 \cdot dV}{2E} \tag{1.7}$$

Where σ – fracture stress with pressure blades, Pa;

dV – elementary volume increment during deformation, м³;

E – the elastic modulus of the second kind, characterize the strength properties of this material (pulp of the product), Pa.

Total energy (work) spent on volumetric deformation:

We neglect only dA_3

$$dA = dA_1 + dA_2$$

Total energy (work) spent on cutting:

$$A_2 = 2H_F \int dF$$

The speed of the process is determined by the combined effect of crushing and cutting strains:

$$v_p = \frac{dR}{F \cdot d\tau} \tag{1.8}$$

Where $dR = dR_1 + dR_2$ is the elementary crushing and cutting force; F is the processing area.

The mathematical model of the process of destruction of the pulp will be present in the form of a system of equations:

$$\begin{cases} v_p = \dfrac{dR}{F \cdot d\tau} \\ A_1 = \dfrac{\sigma^2}{2E} \int dV \\ A_2 = 2H_F \int dF \end{cases} \tag{1.9}$$

or otherwise:

$$\begin{cases} v_p = \dfrac{dR}{F \cdot d\tau} \\ dA_1 = \dfrac{\sigma^2 \cdot dV}{2E} \\ dA_2 = 2H_F \cdot dF \end{cases} \tag{1.10}$$

Mixing pulp inside the cavity

The process of mixing the liquid is characterized by a complex distribution of velocities in its volume, which depends on the shape, size of the tank and mixer, as well as on the speed of rotation of the mixer blades.

According to the Stokes theorem, in a closed loop (with stirring Fig. 3), the circulation of the vector

$$\Gamma_c = \oint_c \vec{a} \cdot \delta\vec{r} \tag{1.11}$$

Figure 3- closed loop mixing circuit
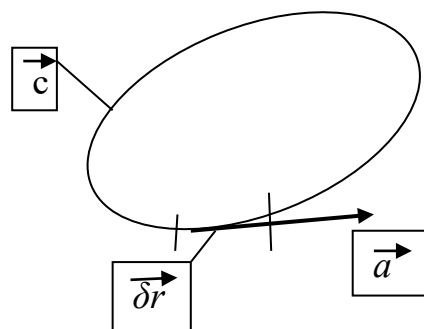
Where, c - closed loop; a - circulation vector (peripheral speed);

Γ_c- circulation vector a по with closd loop with (in a particular case around the circumference with stirring);δr - elementary movement (elementary path)

In this case, the work (Ac) of the closed-loop motion force expressed:

$$A_c = \oint_c \vec{R} \cdot \vec{\delta r} \tag{1.12}$$

R - force overcoming resistance of fluid layers, H.

For a unit of time, closed-loop operation is the power expended in mixing in an unsteady mode.

$$N = \oint_c \frac{dA}{\tau} \tag{1.13}$$

According to the first Helmholtz theorem, the angular velocity vector is determined by:

$$\vec{\omega} = \frac{1}{2} \cdot rot\vec{V} \tag{1.14}$$

$rotV$ - circumferential speed rotor, characterizing the intensity of the circular motion and equal to twice the angular velocity:

$rot\vec{V} = \vec{\Omega}$

$\Omega = rot\vec{V} = 2 \cdot \vec{\omega}$

The rotor is the spatial derivative of the velocity, or else the rotor is a vortex equal to twice the angular velocity. If the circulation Tc> 0, then this means that there is a vorticity in the fluid. Thus, mixing of the individual fluid layers and the whole as a whole occurs.

When mixing the liquid, the kinetic energy E in J is reported:

$$dE = \frac{\rho \cdot (\omega_0 \cdot x)^2}{2} \cdot h \cdot \omega_0 \cdot xdx \tag{1.15}$$

where dE is the elementary kinetic energy communicated to the mixer blades;

ρ is the density of the liquid system, kg / m3;

$\omega0$ is the constant angular velocity of rotation of the mixer, s-1;

x - distance from the axis of rotation (rotor axis), m;

h is the height of the blade, m;

dx - elementary blade length, m;

$$E = \frac{\rho \cdot \omega_0^3 \cdot h}{2} \int_{r_1}^{r_2} x^3 \cdot dx = \frac{\rho \cdot \omega_0^3 \cdot h}{8} \cdot \left(r_1^4 - r_2^4 \right) \tag{1.16}$$

Where r₁ is the radius of the inner edge of the blades, m;

r2 is the radius of the outer edge of the blades, m

The elementary friction force (dP) acting on the blade is expressed according to Newton's law:

$$dP = \frac{\xi \cdot \rho \cdot (\omega \cdot r_0)^2}{8} dF \tag{1.17}$$

Total force (P) of friction N (hydrodynamic resistance) is determined by:

$$P = \frac{\xi \cdot F \cdot \rho \cdot (\omega \cdot r_0)^2}{8} \qquad (1.18)$$

F - blade area, m².
ξ is the drag coefficient of the blade, depending on its shape and the mode of fluid movement.
r_0 is the radius of the blades, m
ω - working angular speed of rotation of the mixer, c⁻¹
Moment of friction M_f:

$$M_f = \frac{\xi \cdot F \cdot \rho \cdot \omega^2 \cdot r_0^{\,2}}{8} \qquad (1.19)$$

Operating Torque $M_к$

$$M_к = \frac{h \cdot \rho \cdot \omega^2 \cdot \left(r_2^{\,4} - r_1^{\,4}\right)}{8} \qquad (1.20)$$

Where μ is the dynamic coefficient of viscosity of the liquid system, Pa · s

Working power (N in W) on the shaft of the mixer is determined:

$$N = M_к \cdot \omega$$

$$N = \frac{h \cdot \rho \cdot \omega^3 \cdot \left(r_2^{\,4} - r_1^{\,4}\right)}{8} \qquad (1.21)$$

At a rotational speed of the agitator blades n in rev / s, the angular velocity
$\omega = 2\pi n$ and r = d / 2. d is the diameter of the mixer blades.
Criteria equation for the pulp mixing process.

This equation is well known and is used to calculate the working power of the mixing process.

$$N = K_N \cdot \rho \cdot n^3 \cdot d^5 \qquad (1.22)$$

N is the working power spent on the mixing process, W;
KN - power criterion or otherwise modified Euler criterion for mixers;
ρ is the density of the liquid system, kg / m3;
d is the diameter of the stirrer blades, m;
n is the frequency of rotation of the blades of the mixer, c-1.
The criteria equation presented in several forms:

$$\frac{N}{\rho \cdot n^3 \cdot d^5} = C \cdot \mathrm{Re}_{\,м}^{\,k} \quad \text{Where} \qquad \frac{N}{\rho \cdot n^3 \cdot d^5} = Eu_{\,м}$$

$$N = Eu_{\,м} \cdot \rho \cdot n^3 \cdot d^5$$

The quality of mixing affected by a correctly selected and calculated angular velocity ω (c-1). It is associated with the so-called relative mixing speed. The final information on the calculations is summarized in table 3.

Table 3- Calculation results

	significative	Meaning
N,W	Total power on the agitator shaft	722
N,W	Starting power taking into account overcoming inertial forces	794,2
$M_{кр}$, N·m	Torque for the selection of the stirrer electric drive	46,7
$P_{1рез}$, N	Total cutting force including frictional forces	29,4
N_1, W	Cutting power of the pulp from the bark	230,8
N_2, W	Pulp cutting power	94,2
n, s^{-1}	Optimum speed	25
Re_M	Modified Reynolds criterion (for mixing)	129274
N_3, W	Working power on the agitator shaft	397
J_p	Cutting intensity criterion	$0,4 \cdot 10^{-3}$
σ, N / mm	Crumple stress	0,17
R_D	Criterion for the intensity of the action of the shear deformation force	$0,11 \cdot 10^{-4}$
V, kg / s	Installation performance	8,4

Criterion equations are derived that help to calculate complex processes in the processing of watermelon fruits. Processing difficulties are related to the purpose of the study. The aim of the study is to develop equipment for obtaining a homogeneous watermelon pulp and obtaining a cleaned and undamaged watermelon rind. The peel is processed into candied fruits, and the homogeneous pulp is processed into other types of sweet products. The difficulty lies in the fact that the process of grinding and mixing takes place in the cavity of the watermelon.

Conclusions

The knowledge of the grinding processes of the pulp of fruits and vegetables is not sufficient. Such aspects as loss of food product quality during prolonged exposure, when cutting the quality of sliced slices, chemical properties of the product, etc. are not taken into account. In this case, we examined the processes of pulp destruction, pulp grinding, pulp mixing, and the exposure time was minimal. The criterion equations of these processes are derived taking into account the indicators of the pulp and peel of the watermelon. One of the tasks set for the researcher was to choose a physical model of the processes of separation of pulp from the crust, destruction, grinding of pulp and mixing of the pulp.

The article presents our proposed models, which allow us to calculate the effective dimensions of the working body with a minimum exposure time to the pulp, taking into account the density of raw materials.

The values of these quantities depend both on the kinematic parameters of the dynamic interaction and on the physic mechanical and rheological properties of the fruits of melons. A formula for calculating the effective speed of mixing the pulp taking into account the reduction of energy consumption

They are described by specific criteria equations obtained on the basis of the similarity theory using the dimensional analysis method. The derived equations are new and are specific to this device. In the above equations, the obtained characteristics of the pulp are used (density, breaking force, etc.) The obtained criterion equations can be used to determine the technological parameters of machines where it is necessary to destroy the fetus with minimal energy costs.

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