KnE Life Sciences

BRDEM-2019
International applied research conference
«Biological Resources Development and Environmental Management»
Volume 2020

Conference Paper

Formation of the Correct Mathematical Model of Grinding Raw Meat in Meat Mincer

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Abstract

Improvements of technological processes and equipment at modern meat-processing enterprises are challenging. It is especially important for the basic and widely used process of grinding raw meat material. Framework enhancements in meat grinding equipment allow one to significantly decrease power consumption and improve the quality of meat products and productivity of raw material processing. The grinding equipment for raw meat and meat products makes about a half of all the equipment used in meat industry. The generalized mathematical model presented is used to optimize the meat grinding process. Design and technology optimizationof mincers proves to be the most efficient only using correct mathematical models of extrusion processes. The influence of design and technological options on performance of mincers using EI is prioritized. The priority for further research is estimated. Both mathematical models of individual processes and results of computer simulations of mincers performance are presented. Mathematical equations, variables and algorithms are calculated using the "Delphi" program. The results of numerical calculations are illustrated by the corresponding graphical dependencies.

Keywords: mincer equipment, generalized mathematical model, grinding process, screw.

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Received: 24 December 2019
Accepted: 9 January 2020
Published: 15 January 2020

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the BRDEM-2019 Conference Committee.

1. Introduction

The existing variety of worm configurations of the cutting machine, their cutting units, different parameters of cutting tools, profiles, worms, structures, frames, grids and blades reveals the problem of optimization of meat processing equipment, such as meat grinders and mincers. Since the number of possible optimization parameters in modeling of the cutting process is more than 50, it is obvious that the analytical solution of such multiparameter optimization problem is difficult; its implementation requires the methodology of system analysis and mathematical modeling.

How to cite this article: Valery Pelenko, Vladimir Ivanenko, Elena Verboloz, Vera Demchenko, and Ilkhom Usmanov, (2020), ``Formation of the Correct Mathematical Model of Grinding Raw Meat in Meat Mincer'' in *International applied research conference «Biological Resources Development and Environmental Management»*, KnE Life Sciences, pages 12--26. DOI 10.18502/kls.v5i1.6013

To further improve the grinding equipment of raw meat materials, it is necessary to clarify and develop the theory of calculation, to find out new design solutions, the materials used, and modern technologies for manufacturing of equipment components. Theoretical research on improvements of meat mincer equipment will significantly reduce energy costs, improve the quality of meat products, energy efficiency and productivity of raw meat materials processing.

2. Methods and Equipment

The required pressure of raw meat in the contact plane of the knife with the plate was determined; the length of the screw line with a variable pitch was calculated in [1-4], as well as the problem of assessing the law of pressure distribution along its length. Based on this, the correct generalized mathematical model of the grinding process of raw food in the meat mincing is developed.

To mathematically describe the mincing process in worm mincing machines and to refine the existing analytical models [5-8] of the mincing process, we use the equation of energy conservation in a differential form.

In accordance with the analysis of force interaction of a food product with mincing structural elements, this equation is written as:

$$dA_{om} = dA^{sc}{}_{def} + dA^{r}{}_{def} + dA^{au}{}_{fr} + dA^{lm}{}_{fr} + dA^{fm}{}_{fr} + dA^{gp}{}_{fr} + dA^{j}{}_{fr} + dA_{cut} + dA^{p}{}_{cut} + dA^{is}{}_{fr}, \tag{1}$$

where: 1. dA$_{om}$ -- elementary operation of the mincer drive, J;

2. dA$^{sc}{}_{def}$ -- elementary operation of deformation of meat in the process of its movement in the screw channel, J;

3. dA$^{r}{}_{def}$ -- elementary operation of deformation of meat with knife blades in the rotational movement process, J;

4. dA$^{au}{}_{fr}$ -- elementary operation of friction forces of raw meat on the worm surface of the screw, J;

5. dA$^{lm}{}_{fr}$ -- elementary operation of friction forces of raw meat on the surface of the mincer hull in the forward motion, J;

6. dA$^{fm}{}_{fr}$ -- elementary operation of friction forces of the raw material on the framework surface of mincer in the rotational motion, J;

7. dA$^{gp}{}_{fr}$ -- elementary operation of friction forces of raw materials on the end of the output grinding plate, J;

8. d$A^{j}{}_{fr}$ -- elementary operation of friction forces in the junction of the surfaces of the knife and the plate during rotational motion, J;

9. dA_{cut} -- elementary operation of cutting meat with a knife blade, J;

10. d$A^{p}{}_{cut}$ -- elementary work of cutting meat on the edge of the holes in the output grid, J;

11. d$A^{is}{}_{fr}$ -- elementary operation of friction forces of raw meat on the inner surface of the grids of the output plate, J.

Let us note some features of these energy costs components.

Elementary works dA_{om}, d$A^{gp}{}_{fr}$, d$A^{j}{}_{fr}$, dA_{cut} are performed in the mincer for the worm angular movement (dφ), while works d$A^{sc}{}_{def}$, d$A^{w}{}_{fr}$ are produced by an elementary linear actuator to move the product along the axis of the screw channel (dL). And elementary works d$A^{b}{}_{def}$, d$A^{lm}{}_{fr}$, d$A^{p}{}_{cut}$, d$A^{is}{}_{fr}$ are performed on the linear movement of the product along the longitudinal axis of the screw body (dx) or the axis of the mincing plate holes dx_h.

In this case, the elementary displacements interchangeare shown as:

$$dx = dLcos\alpha, dx_h = dL[4(R_{oa} - R_{ia})^2/d_0{}^2 n],$$

where: R_{oa}, R_{ia} are the radii of the cylinders forming the outer and inner worm surface, M.

Let us suppose that elementary work d$A^{fm}{}_{fr}$ is equal to zero, thus providing no turning of raw materials relative to the mincer framework.

Let us consider in detail every component of elementary works.

1. Elementary work of the mincer drive is expressed through the screw shaft torque M_{sh} and the differential of the angular coordinate dφ:

$$dA_{ot} = M_{sh} d\varphi, \tag{2}$$

where: φ is the angle of the worm rotation, rad.;

M_{sh} is the torque on the screw shaft, N*m.

2. The elementary work of meat deformation in the worm channel with a cross-section area S is determined by the pressure of the raw material P (L), variable in helix length L and the differential of this length dL:

$$dA^{sc}{}_{def} = P(L)SdL,$$

where: L is the length of the helix screw, m;

S -- the area of the worm channel passage section,which has the coordinate L, m;

P (L) is the pressure of raw meat in cross section of the worm channel,which has the coordinate L, PA.

The value of the elementary work of deformation according to the theory of elasticity is determined by the ratio of stress s, relative deformation of material ε and its specific volume:

$$a_1 = [P^2(L)/4E]\pi(R_{oa} - R_{ia})^2.$$

It is necessary to pay attention to the modulus of El of the deformable material E. Let us suppose the speed of raw meat moments along the axis of the grinder is about 0.01--0.1 m/s, then the modulus of elasticity is close to E=1,7*10^{5}PA [10]. As the stress relaxation in volumetric compression exceeds this boundary making σ_{rel}=1,6*10^6 PA, the calculated value is E=1,7*10^{5}PA [11].

3. The elementary work of meat deformation with knife blades at rotational movements, similarly to the elementary work of meat deformation in the worm channel, is expressed as:

$$dA^b{}_{def} = (\sigma\varepsilon/2)dw_m.$$

Expressing σ through ε and E, we get:

$$dA^b{}_{def} = E(\varepsilon^2/2)dw_m.$$

Given the average value of the relative meat deformation εis determined by the ratio of the knife blade thickness δ to half the length of the last worm turn, and the volume of the deformable material equals the volume of the interstitial space dw$_m$, we carry out simple and obvious transformations:

$$\varepsilon = \delta/(t/2); t = 2\pi R_{oa}tg\alpha_a; \varepsilon^2 = \delta^2/(\pi^2 R_{oa}{}^2 tg^2\alpha_a).$$

$$dw_m = S_m cos\alpha_a dL,$$

where: S$_m$ is the area of meat contact with the surface of the mincing plate sectors between the blades, m^2;

α_a is the helix angle of the last turn of the screw, rad:

$$S_m = \pi R_{oa}{}^2 - mbR_{oa} = \pi R_{oa}{}^2(1 - \frac{mb}{Roa}).$$

Thus, the ratio is:

$$dA^v{}_{def} = \frac{E^2 cos\sqcap}{2(tg\sqcap)^2}(1 - \frac{mb}{Roa})dL.$$

As ($\frac{E^2 cos\Pi}{2(tg\Pi)^2}$ (1 - $\frac{mb}{Roa}$) dL= a_2,

$$dA^b{}_{def} = a_2 dL. \tag{3}$$

Let us note that:

$$\Pi = \pi R_k = \pi(R_{oa} - -R_{ia}),$$

where: R_k is the equivalent radius of the worm channel, m (see Fig.1).

Thus, the equation (5) is written as:

$$dA^w{}_{fr} = \pi\mu\frac{\nu}{1-\nu}P(L)L_W(R_{oa} - R_{ia})dL = a_3 dL. \tag{4}$$

5. Elementary work of the friction forces of raw meat on a surface of the mincer framework in forward motion, given the constrained compression is:

$$dA^{lm}{}_{fr} = 2\pi R_{oa}\mu\frac{\nu}{1-\nu}P(L)L_m cos\alpha dL = a_4 dL, \tag{5}$$

where: L_m is the length of the mincer body, m.

6. Elementary work of the friction forces of raw material on the surface of the mincer framework in rotational motion is assumed to be zero, providing the condition of not turning, which is written in the form of the equilibrium equation of forces acting on meat, in the projection of the longitudinal axis of the framework:

6.1. In case of counter-rotation edge resistance to the crushing stresses σ_{cm} this equation is written as:

$$2\pi R_{oa}\mu\frac{\nu}{1-\nu}P(L)dx - \sigma_{cm}\Delta_B cos\alpha_b dx = 0.$$

Now it is possible to determine the minimum required height of the counter-rotation collar$\Delta_{Бmin}$ as:

$$\Delta_{Bmin} = 2\pi R_{oa}\mu\frac{\nu}{1-\nu}P_{max}/\sigma_{cm}cos\alpha_b, \tag{6}$$

where: P_{max} is the maximum pressure P (L), PA;

α is the helix angle of the counter-rotation collar to the axis of the mincer framework, rad.

6.2. With resistance of the counter-rotation edges to the compensatory voltage cutoff σ_{cp}, similarly get the minimum required width of the slot $\Delta_{W\,min}$:

$$\Delta_{W\,min} = 2\pi R_{oa}\mu\frac{\nu}{1-\nu}P_{max}/\sigma_{cp}cos\alpha_W,$$

where: α_w is the helix angle of the counter-rotation slot to the axis of the mincer framework, rad.

Presence of the worm equipment of the real product turning relative to themincer framework with an angular velocity of about 15% of the screw rotation angular velocity is indicated in [12]. In our case, this value is neglected, since the stabilizing effect of the guiding elements is not taken into account in this paper.

7. Friction forces of raw meat, located in the inter blade space of the knife, on the inner end of the output mincing plate is determined through the moment of friction M$_{fr}$ and differential angular displacement:

$$dA^{gp}{}_{fr} = M_{fr} d\varphi. \tag{7}$$

Let us note that the differential angular coordinate dφ is associated with the elementary movement of food material along the axis of the mincer framework dx:

$$dx = R_{oa} tg\alpha d\varphi. \tag{8}$$

Thus, if necessary, (9) can be expressed in terms of the coordinate "x".

The moment of friction forces defines M$_{fr}$ via the magnitude of the friction force F$_{fr}$ and the radius of the pressure center r$_c$:

$$M_{fr} = F_{fr} r_c.$$

The friction force is determined by the Coulomb-Amonton law:

$$F_{fr} = \mu S_x P_{max}.$$

The area of friction S$_x$ is equal to the area of the output mincing plate:

$$S_x = \pi (R_{oa} - R_{ia})^2. \tag{9}$$

Thus, we get:

$$F_{fr} = \mu \pi (R_{oa} - R_{ia})^2 P_{max},$$

where: P$_{max}$ is the maximum pressure in the cutting area, PA;

r$_c$ is the coordinate of the friction force pressure center.

Coordinate r$_c$ is determined by the integral:

$$\int_{Ria}^{Roa} 2\mu\pi (r_c - r) r P_{max} dr = 0.$$

Simple transformations give the ratio:

$$R_c = \frac{2}{3}(R_{oa} - R_{ia}). \tag{10}$$

Solving the system of equations (9) - (12), we find the value of dA$^{gp}{}_{fr}$:

$$dA^{gp}{}_{fr} = \frac{2}{3} \mu \pi (R_{oa} - R_{ia})^3 P_{max} d\varphi = a_5 d\varphi. \tag{11}$$

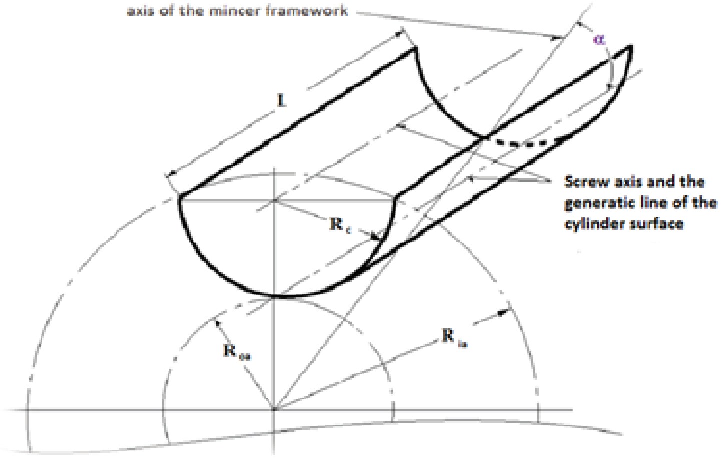

Figure 1: The equivalent perimeter and contact area of raw meat with the screw surface.

8. Elementary work of friction forces at the knife-plate junction with rotational motion [9, 10] is:

$$dA^j{}_{fr} = M^j{}_{fr} d\varphi.$$

The friction force F$^j{}_{fr}$ at the knife-platejunction is determined by the coefficient of metal knife friction μ$_j$ on the metal plate, the maximum pressure in the cutting zone P$_{max}$ and the contact surface mb (R$_{oa}$--R$_{ia}$):

$$F^j{}_{fr} = m\mu_j b(R_{oa} - R_{ia})P_{max}.$$

Taking into account the coordinate of the friction force pressure center similar to (12), we get:

$$Mjfr = (2m/3)\mu jb(Roa - Ria)2Pmax.$$

Thus, the final value of the knife friction on the plate is written as:

$$dAjfr = (2m/3)\mu H - pb(Roa - Ria)2Pmaxd\varphi = a6d\varphi \tag{12}$$

9. The elementary work of cutting meat with a knife blade dA$_{cut}$, is determined by the value of the shear stress meat σ_{cp}, the area of the output lattice with a hole diameter σ_{cp} and the number of holes n:

$$dAcut = \frac{\pi do^2}{4} n\sigma cprcd\varphi,$$

or taking into account (12):

$$dAcut = \frac{\pi do^2}{6} n\sigma cp(Roa - Ria)d\varphi = a7d\varphi, \tag{13}$$

where: n is the number of holes in the output mincing plate,

d_o is the hole diameter, m.

10. The elementary work of meat cuttingby the edge of the output plate dA^{p}_{cut} is determined by the ratio:

$$dApcut = \pi d0Pspncos\alpha dL = a8dL. \tag{14}$$

11. The elementary work of the raw meat friction force to the inner surface of the holes of the output plate is determined by:

$$dApcut = \mu\frac{\nu}{1-\nu}Pmax\delta p\pi d0ndxh,$$

where: dx_h is the differential movement of raw materials along the axis of the mincing plate hole, corresponding to the differential movement dL of the product, along the worm screw line, m;

δ_p is the thickness of the output mincing plate, m.

Given the kinematic relationship between the elementary movement dx_h and dL, due to the equation of continuity of the raw material flow, we get:

$$\rho\pi d02ndxh/4dt = \rho\pi(Roa - Ria)2cos\alpha dL/dt$$

or

$$dxh = 4(Roa - Ria)2dL/d02n,$$

thus

$$dAhfr = 4\mu\frac{\nu}{do(1-\nu)}Pmax\delta p\pi cos\alpha(Roa - Ria)2dL.$$

We can write:

$$dAhfr = a9dL. \tag{15}$$

Thus, the energy conservation equation (1) in the differential form, taking into account (2), (3), (4), (6), (7), (13), (14), (15), (16) and (17), takes the form:

$$Mkrd\varphi = a1dL + a2dL + a3dL + a4dL + a5d\varphi + a6d\varphi + a7d\varphi + a8dL + a9dL, \tag{16}$$

or

[Mkr-$\frac{2}{3}\mu$(Roa -- Ria) 3Pmax -(2m/3)μH-pb(Roa -- Ria) 2Pmax - $\frac{\pi do^2}{6}$nσcp(Roa -- Ria)]dφ
= ={[P2(L)/4E]π (Roa -- Ria)2 +$\frac{E\delta^2 cos}{2\pi(tg\ \sqcap)^2}$ (1 - $\frac{mb}{\pi Roa}$) +πμ$\frac{\nu}{1-\nu}$ P(L)Lw(Roa -- Ria) +
+2πRoaμ$\frac{\nu}{1-\nu}$P(L)Lkcosα+πdoPspn cosα +4μ$\frac{\nu}{do(1-\nu)}$Pmaxδpπcosα(Roa -- Ria)2}dL.

Differentiating equation (18) in time, we get the dependence of the linear velocity V_L of raw meat movement along the axis L of the worm channel depending on the angular velocity "ω" of worm rotation:

$$V_L = [(M_{kr} - a_5 - a_6 - a_7)\omega/(a_1 + a_2 + a_3 + a_4 + a_8 + a_9)], \tag{17}$$

where: V_L=dL/dt is the linear speed of raw meat material movement of along the worm channel axis, m;

ω = dφ/dt is the angular speed of worm rotation, s^{-1}.

It should be considered that with the equation (18) differentiatedin time, the law of pressure change along the helix length is stationary and all design parameters together with physical and mechanical characteristics of the materials are time independent.

Let us consider the law of pressure distribution along the length of the screw channel line, as well as design parameters of grinder elements and physical and mechanical characteristics of the food material, we find the speed of raw meat movement along the axis L of the worm channel:

$$\begin{aligned}&\mathrm{VL}=\{[\mathrm{Mkr}\text{-}\tfrac{2}{3}\mu(\mathrm{Roa}\text{--}\mathrm{Ria})3\mathrm{Pmax}\text{-}(2\mathrm{m}/3)\mu\mathrm{H}\text{-}\mathrm{pb}(\mathrm{Roa}\text{--}\mathrm{Ria})2\mathrm{Pmax}\text{-}\tfrac{\pi do^2}{6}\mathrm{n}\sigma\mathrm{cp}(\mathrm{Roa}\text{--}\mathrm{Ria})]\omega\}/\\&/\{[\mathrm{P2cp/4E}]\ \pi\ (\mathrm{Roa}\text{--}\mathrm{Ria})2+\tfrac{E\delta^2 cos\alpha\pi}{2\pi(tg\ \ \alpha\pi)^2}(1\text{-}\tfrac{mb}{\pi Roa})+\pi\mu\tfrac{\nu}{1-\nu}\mathrm{PcpLw}(\mathrm{Roa}\text{--}\mathrm{Ria})+\\&+2\pi\mathrm{Roa}\mu\tfrac{\nu}{1-\nu}\mathrm{PcpLkcos}\alpha+\pi\mathrm{doPspncos}\alpha+4\mu\tfrac{\nu}{do(1-\nu)}\mathrm{Pmax}\delta\mathrm{p}\pi\mathrm{cos}\alpha(\mathrm{Roa}\text{--}\mathrm{Ria})2\}.\end{aligned}$$

Taking into account time invariance of the considered process, the average pressure of food material, variable along the length of the worm surface, is defined as an average integral:

$$Pcp=(1/Lvl)\int_0^{Lvl}P(L)dL.$$

Along the axis of the mincer framework the speed V_X of the raw material is:

$$\begin{aligned}VX\ &=[Mkr-\tfrac{2}{3}\mu(Roa-Ria)3Pmax-(2m/3)\mu H-pb(Roa-Ria)2Pmax\\&-\tfrac{\pi do^2}{6}n\sigma cp(Roa-Ria)]\omega/\{[P2cp/4E]\pi(Roa-Ria)2/cos\alpha+\tfrac{E\delta^2}{2\pi(tg\alpha\pi)^2}(1-\tfrac{mb}{\pi D})\\&+\pi\mu\tfrac{\nu}{1-\nu}PcpLw(Roa-Ria)/cos\alpha+2\pi Roa\mu\tfrac{\nu}{1-\nu}PcpLk+\pi d0Pspn\\&+4\mu\tfrac{\nu}{do(1-\nu)}Pmax\delta p\pi(Roa-Ria)2\}.\end{aligned}\tag{18}$$

In this case, the mass productivity of the grinder is presented as:

$$Q=\rho V_L S\quad or\quad Q=\rho V_X S_X.\tag{19}$$

We can write for the generalized coordinate «L» using (3):

$$\begin{aligned}Q\ &=\{\rho\pi[(Roa-Ria)2/2,Mkr-\tfrac{2}{3}\mu(Roa-Ria)3Pmax-(2m)\mu H\\&-pb(Roa-Ria)2Pmax-\tfrac{\pi(do)^2}{6}n\sigma cp(Roa-Ria)]\omega\}/\\&/\{[P2cp/4E]\pi(Roa-Ria)2+\tfrac{E\delta^2 cos\alpha\pi}{8\pi(tg\alpha\pi)^2}(1-\tfrac{2mb}{\pi Roa})+\\&+\pi\mu\tfrac{\nu}{1-\nu}PcpLw(Roa-Ria)+2\pi Roa\mu\tfrac{\nu}{1-\nu}PcpLkcos\alpha+\\&+\pi doPspncos\alpha+4\mu\tfrac{\nu}{do(1-\nu)}Pmax\delta p\pi cos\alpha(Roa-Ria)2\}.\end{aligned}\tag{20}$$

We can write for the axis of the mincer framework «x» (21):

$$
\begin{aligned}
Q \ &= \pi(Roa - Ria)2\rho[Mkr - \tfrac{2}{3}\mu(Roa - Ria)3Pmax - (8/3)\mu H - pb(Roa - Ria)2Pmax \\
&\quad - \tfrac{\pi do^2}{6} n\sigma cp(Roa - Ria)]\omega/\{[P2cp/4E]\pi \\
&\qquad (Roa - Ria)2/cos\alpha + \tfrac{E\delta^2}{8\pi(tg\alpha\pi)^2}(1 - \tfrac{4mb}{\pi D}) \\
&\qquad\ +\pi\mu\tfrac{\nu}{1-\nu}PcpL\omega(Roa - Ria)/cos\alpha + 2\pi Roa\mu\tfrac{\nu}{1-\nu}PcpLk + \pi d0Pspn+ \\
&\qquad\ +4\mu\tfrac{\nu}{do(1-\nu)}Pmax\delta p\pi(Roa - Ria)2\}.
\end{aligned}
\tag{21}
$$

3. Results and Discussions

The mathematical model of the mincing process represents the dependence of the mincer performance Q on 21 parameters, 10 of which are constructive ((R_{oa}, R_{ia}, b, n, d_o, $\alpha_{п}$, α, L_k, δ, δ_p), 7 offer physical and mechanical characteristics of the material ρ, μ, ν, μ_{H-p}, P_{sp}, σ_{cp}, E), and 4 show technological parameters of the process (ω, P_{cp},P_{max}, M_{kr}).

To construct a grinder, its productivity can be easily calculated by the given ratio.

In order to analyze the influence of specific equipment parameters on performance, we conducted numerical experiments.

To implement numerical experiments and construct graphs, the program was written by "Delphi" to show the dependence of the grinding equipment performance on the influencing factors. Major dependencies are shown in Figures 2-7. Data analysis allows us to determine the most significant parameters and priorities to further refine the modeling and improve the specific components and processes of worm mincing equipment.

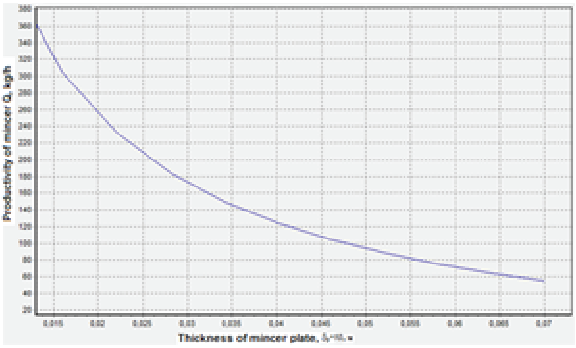

Figure 2: Influence of the output mincing plate thickness on the worm shredder performance (E_1).

The priority of the influence of factors on performance is assessed by determining the elasticity of the output parameter for each factor considering (E_1, E_2, E_3, E_4, E_5, E_6).

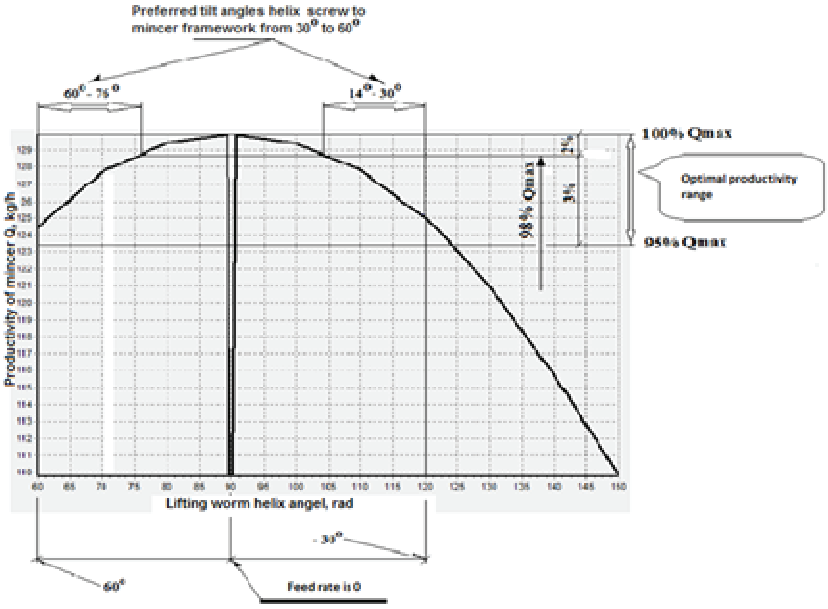

Figure 3: Dependence of the mincer productivity on the helix angle of the worm screw line (E2).

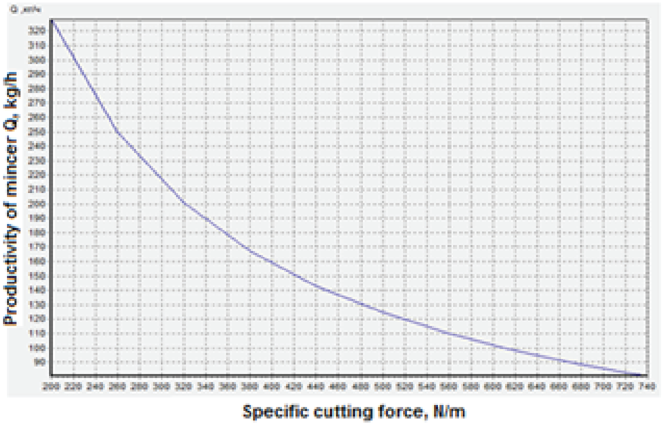

Figure 4: Dependence of the mincer productivity on the strength characteristics of raw food materials (E_3).

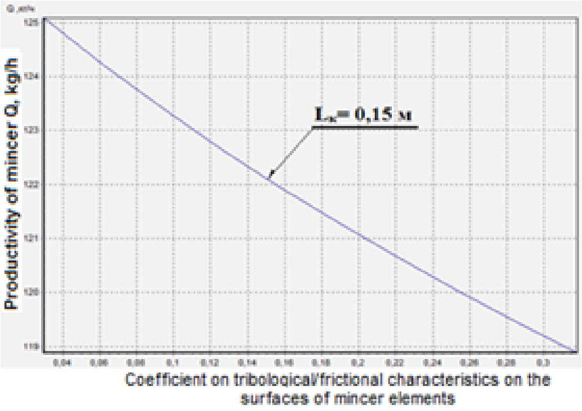

Figure 5: Dependence of productivity on tribological/frictional characteristics of the milled raw materials (E_4).

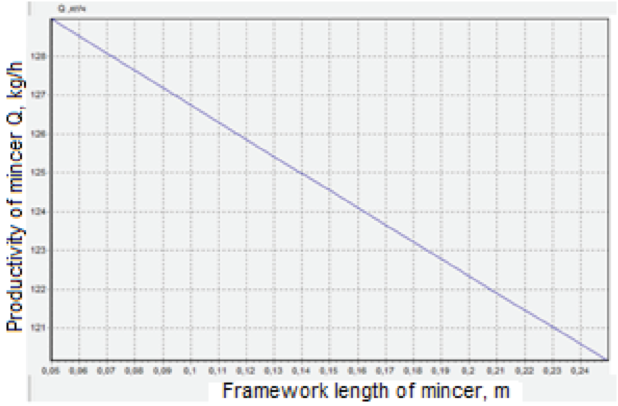

Figure 6: The dependence of the productivity on the framework length (E_5).

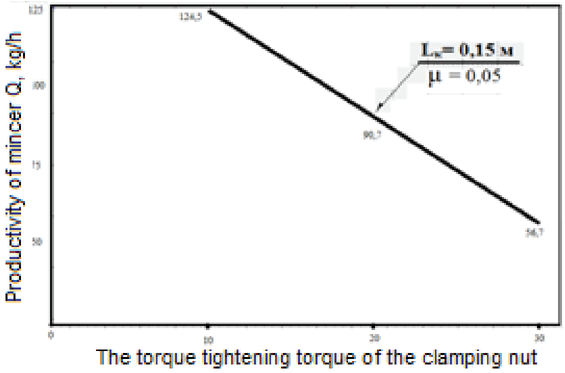

Figure 7: The dependence of the productivity on the torque (E_6) tightening torque of the clamping nut.

At the same time, we use a given ratio:

$$Ei = (\Delta Qi/Qi)/\Delta\Phi i/\Phi i),$$

where Qi, ΔQi are productivity and its increment under the influence of factor i;

Φi, ΔΦi are factor i and its increment (i=1,2,3,4,5,6).

The elasticity is calculated based on graphs:

E1= 1,028; E2= 0,127; E3= 1,038; E4= 0,054; E5= 0,087; E6= 0,817.

4. Conclusion

The results obtained show that the most important parameter is the specific cutting force of the material E_3= 1,038. Thus, it is necessary to provide defrosting of raw materials before the grinding process.

The second in importance to influence the mincer productivity is a change in thickness of the output mincing plate (E_1= 1,028). With the increase in thickness from $4*10^{-3}$m to $7*10^{-3}$m, the productivity of the mincer decreases from 125 kg/h to 55 kg/h, that is more than twice. Thus, the object of further study should be the possibility to minimize the thickness of the output mincing plate. In this case, it is necessary to solve the problem of joint deformation and strength of the knife-platepair and to investigate the patterns and wear rate of their contact surfaces.

The tightening torque of the clamping nut (E_6= 0,817) is ranked as the third in importance. It increases the mechanical load at the junction of the knife-plate, significantly increasing the energy intensity of the process in Figure 7. This brings to the fore the question of mathematical description of the process of the clamping nut tightening and the possibility of its optimization and regulation.

At the fourth position in importance is the helix angle of the screw line to the axis of the worm framework (E_2= 0,127). The necessity to optimize the helix angle disappears, as in a wide range of values (from 14^o to76^o) the productivity of the mincer is maintained at 95-98% of the maximum. A further increase in the mincer productivity due to a possible increase in the number of worm turnover will lead to significant increase in power consumption, since in accordance with equation (23) the performance is linearly dependent on the angular velocity.

The next factor is the length of the top framework (E_5= 0,087) and the worm respectively. The problem of determination of the length of the screw surface is solved in [2] for a variable pitch screw.

Acknowledgement

The authors would like to thank their colleague for their contribution and support of the research. They are also thankful to all the reviewers who gave their valuable inputs to the manuscript and helped in completing the paper.

Conflict of Interest

The authors have no conflict of interest to declare.

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