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Theoretical substantiation parameters of the process for obtaining a soybean-grain substitute for dairy feed.

Sergei Viktorovich Varaksin*, Sergei Mikhailovich Dotsenko, Lyudmila Gennadievna Kryuchkova, Andrei Vladimirovich Burmaga, and Dmitrii Aleksandrovich Markin.

Far East State Agricultural University, Politechnical St. 86, Blagoveshchensk, 675005, Russia

ABSTRACT

The article presents the theoretical dependences obtained in the form of corresponding formulas that allow engineering calculations for the construction of multifunctional machines (MFM) intended for the preparation of a whole milk substitute. On the basis of the developed MFM scheme, calculation formulas were developed describing the processes of seed soaking, extraction of protein and separation of the resulting suspension. This will allow the calculation of multifunction machines.
Keywords: soybean-grain substitute for dairy feed, soybean-grain composition, multifunctional machine, dependence, soybean-grain residue, patent.

**Corresponding author*

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INTRODUCTION

The preparation of whole milk substitutes (WMS) for feeding young animals is one of the current problems of agricultural production [1]. This is due to the fact that a large amount of whole or low-fat cow milk is used for fodder purposes, which could be sold and used for human nutrition.

The classic WMS formula for calves is a mixture that includes whey, wheat flour, soy flour, and starch (TC 491216-85) [2].

This WMS has a high cost, and therefore virtually unavailable to the commodity producer.

MATERIALS AND METHODS

On the basis of the existing methods of mathematics and applied mechanics, calculation formulas for determining the parameters of a multifunctional machine of the corresponding productivity are obtained, characterized by a mass supply of the product in the production of a whole milk substitute for feeding young farm animals.

RESULTS AND DISCUSSION

According to the developed scheme for obtaining feed products (Figure 1), the seeds of the soybean-grain composition are soaked up to improve the efficiency of their destruction processes and subsequent extraction of protein and other substances from the particles obtained, by extracting them.

In this case, the process scheme provides for the subsequent separation of the liquid (protein phase) from the insoluble soybean-grain residue to obtain a soybean-grain substitute for dairy feed (SGSDF).

The model for assessing the functioning of this process can be represented by the following equation

$$M_p = f\left(\tau_s, \lambda, \eta_p\right) \rightarrow max, \quad (1)$$

where M_p – mass of protein substances in the liquid fraction;
τ_s - duration of soaking seeds of soybean-grain composition (SGC);
λ– degree of grinding SGC;
η_p- indicator of the efficiency separating the liquid fraction from an insoluble soybean-grain residue (ISGR).
The structural diagram of the SGSDF subsystem is shown in Figure 1.

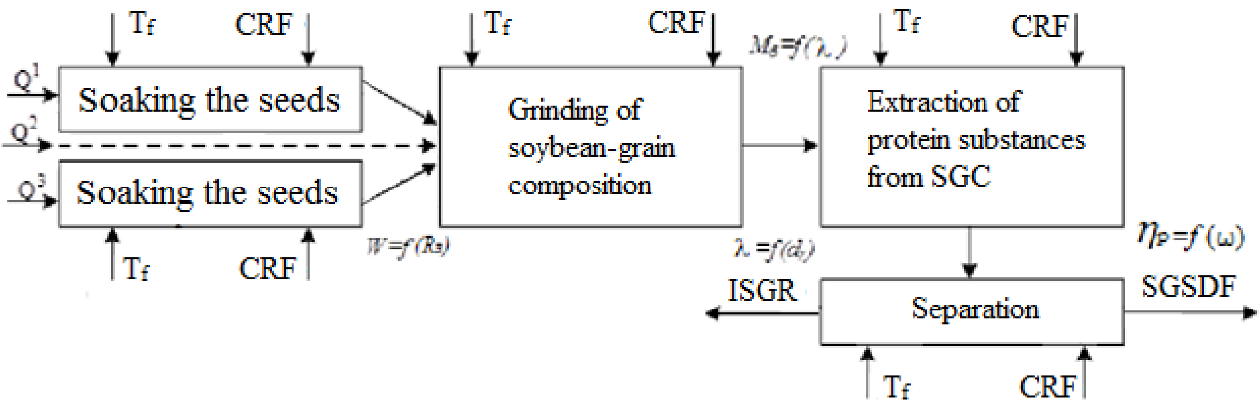

Figure 1: Block diagram of a subsystem for preparing a soybean-grain substitute for dairy feed using a multifunctional machine: T_f - technological factors; CRF – constructive-regime factors.

In turn, the quality of the separated liquid fraction, in the form of SGSDF, is characterized by the following functional dependence:

$$M_p = f[\tau_s = f(k_g), \lambda = f(d_r)] \to max, \qquad (2)$$

where k_g – coefficient characterizing the properties of grain;
d_r - particle diameter of ground SGC.
In addition, the amount of liquid fraction obtained during the separation process, and hence the separation efficiency Π_p, characterized by the following functional dependence:

$$\Pi_p = \left(1 - \frac{Q_{sf}}{Q_{lf}}\right) \to max, \qquad (3)$$

где Q_{sf}- performance of the separation process by ISGR;
Q_{lf}- capacity of the liquid fractionation process.

According to the adopted scheme of soaking the seeds of soybean-grain composition, water with a seed in it is filled with water with a certain level h.

This level h will decrease to a value of h0 due to the absorption of water by the seeds of the soybean-grain composition.

The rate of change of this level over the soybean-grain composition:

$$\frac{dh}{d\tau_s} = -k_g \cdot h_0 \cdot e^{-k_g \tau_g}, \qquad (4)$$

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$$\tau_s = \frac{2{,}3}{k_g} \cdot \ln\left(\frac{h}{h_0}\right). \qquad (5)$$

Having adopted as its characteristic particle size its equivalent diameter - d_r, and likewise the seed of the composition - D_e, taking into account the degree of their grinding λ we get:

$$d_r = \frac{D_e}{\lambda} = \frac{1{,}24 \cdot \sqrt[3]{\left(\frac{4\pi}{3} \cdot a \cdot b^2\right)}}{\lambda} \le [d_r], \qquad (6)$$

where a and b – axis of the ellipsoid, for which the shape of the seed is adopted.

Taking these assumptions and assumptions into account, for the case of internal diffusion, we obtain:

$$M_p = \frac{5{,}06 \cdot D_{id} \cdot F \cdot \lambda \cdot (C - c)}{\omega \cdot \sqrt[3]{1{,}33 \cdot a \cdot b^2}}, \qquad (7)$$

where C – average protein concentration inside a seed particle;
c - average protein concentration in the aqueous solution surrounding the particle;
F – contact surface area;
D_{id} – coefficient of internal diffusion;
ω – angular velocity of the working body.

According to this expression, the degree of grinding λ, which determines the final particle size d_r.
In this connection, it is assumed that the yield of protein M_p, when it is extracted into the aqueous medium, the following dependence:

$$M_p = M_p^{max} - k_p \cdot d_r, \qquad (8)$$

where k_p – empirical coefficient.

When the rates of external and internal diffusion are commensurable, then neither external nor internal diffusion can be neglected, and then

$$M_p = \frac{D_{id}}{1{,}24\cdot\sqrt[3]{\left(\frac{4\pi}{3}\cdot a\cdot b^2\right)}}\cdot\tau_e\cdot F\cdot(C_1 - C_2), \quad (9)$$

$$M_p = \frac{D_{ви}}{\Delta}\cdot\tau_e\cdot F\cdot(C_2 - C_3), \quad (10)$$

where C_1 – average concentration of extracted protein in particles;
C_2 – concentration at the boundary of a particle and a liquid;
C_3 – average concentration of extracted protein in the liquid.
From equations (9) and (10) we have that

$$C_1 - C_2 = \frac{1{,}24\cdot M_p\cdot\sqrt[3]{(4{,}18\cdot a\cdot b^2)}}{D_{id}\cdot\tau_e\cdot F\cdot\lambda}, \quad (11)$$

$$C_1 - C_2 = \frac{M_\Delta}{D_{id}\cdot\tau_e\cdot F}. \quad (12)$$

Adding these two equalities term by term:

$$C_1 - C_3 = \frac{M_p}{F\cdot\tau_e}\left[\frac{1{,}24\cdot\sqrt[3]{4{,}18\cdot a\cdot b^2}}{D_{id}\cdot\lambda}\right] + \frac{\Delta}{D_{id}}, \quad (13)$$

where $\frac{D_{id}}{\Delta} = \beta$- mass-transfer coefficient, and $\tau_e = {2\pi}/{\omega}$ and then, ultimately, we have:

$$M_p = \frac{6{,}28\cdot(C_1 - C_3)\cdot F}{\left[\frac{1{,}24\cdot\sqrt[3]{4{,}18\cdot a\cdot b^2}}{D_{id}\cdot\lambda} + \frac{1}{\beta}\right]\cdot\omega}. \quad (14)$$

Calculation of the extraction process and extractors provides for a material balance, in which the amount of soybean-grain composition seeds received for extraction is equal to M_{sg}, amount of water - M_w, amount of outgoing protein extract -M_e^w and the amount of insoluble soybean-grain residue M_0.

In this case, the content of the extracted protein in the SGC seeds is $X_p\,(\%)$, and the liquid phase leaving - $X_e\,(\%)$, in water, the content of the extracted protein - Y_p and $Y_e\,(\%)$.

Equations of material balance have the following form [2]:

$$\left.\begin{aligned} M_{sg} + M_w &= M_e^w + M_0 \\ M_{sg}\cdot X_p + M_w\cdot Y_p &= M_e^w\cdot Y_e + M_0\cdot X_e \end{aligned}\right\} \quad (15)$$

Expressing M_0 through M_{sg} as $M_0 = \alpha\cdot M_{sg}$, where $\alpha = \frac{M_0}{M_{sg}}$ and we get that

$$M_{sg}\cdot X_p + M_w\cdot Y_p = M_e^w\cdot Y_e + M_0\cdot X_e. \quad (16)$$

From expression (16) we have:

$$M_{sg}\cdot(X_p - \alpha\cdot X_e) = M_e^w\cdot Y_e + M_w\cdot Y_p \quad (17)$$

M_w expressed through M_{sg} equally

$$M_w = M_{sg}\cdot\beta \quad (18)$$

and, when $M_{sg}\cdot(X_p - \alpha\cdot X_e) = M_e^w\cdot Y_e + M_{sg}\cdot\beta\cdot Y_p$.

When water enters the extraction $Y_p = 0$, then

$$M_{sg}\cdot(X_p - \alpha\cdot X_e) = M_e^w\cdot Y_e.$$

To apply this equation for M_e^w, you need to know the quantities M_{sg}, α, X_p, X_e, Y_e. With a known value M_{sg} the amount of extract is

$$M_e^w = \frac{M_{sg} \cdot (X_p - \alpha \cdot X_e)}{Y_e}. \quad (19)$$

With this expression in mind:
- productivity of the multifunctional machine for liquid fraction:

$$Q_{lf} = \frac{M_e^w}{\rho_l \cdot \tau_0}, \quad (20)$$

where ρ_l - density of the liquid fraction;
τ_0 - time of rotation of the operating element of the filtering centrifuge.
- productivity of the filtering centrifuge for an insoluble soybean-grain residue:

$$Q_{sf} = \frac{M_0}{\rho_0 \cdot \tau_0}, \quad (21)$$

where ρ_0 - density ISGR.

According to the first equation of the system (15), the amount of the incoming solvent is determined M_w (water). The relation M_{sg}/M_w = η – gives the value of the hydromodule.

Under the assumptions made above, in equation (6) it is necessary to observe condition $d_r \approx S$,

where S - gap between abrasive surfaces of the working body of the MFM.

When,

$$S \leq \frac{1{,}24 \cdot \sqrt[3]{V_g}}{\lambda} \leq D_e/\lambda, \quad (22)$$

where V_g - average volume of soaked seeds SGC.

The theoretical analysis of protein extraction from SGC seeds allowed to consider it in combination with the process of their grinding, as well as to establish factors linking these two processes.

Such factors are: initial SGC seed sizes characterized by a factor - D_e, degree of grinding - λ and the final particle size d_r.

The efficiency of the separation of the liquid fraction η_p, in turn, is characterized by the amount of the remaining liquid fraction in the soybean-grain insoluble residue and depends on the performance of the separator in the liquid phase:

$$\Delta W = a \cdot e^{b \cdot Q_{lf}},$$

where a and b – empirical coefficients.

This relationship is valid only if the soybean-grain composition is uniformly fed to the conical perforated rotor in time.

To estimate the effect of the unevenness of the density of the isolated flux of the insoluble soybean-grain residue on the separation of the liquid fraction, we assume that the unevenness of the ISGR flux has a significant effect on the value ΔW for a time t, irregularity of the flow has the character of a normal distribution, and the function $\Delta W = f(Q_{lf})$ is continuous and differentiable.

In the neighborhood of the mathematical expectation $m = M(Q_{lf})$, in the interval from $-\infty$ to $+\infty$ the binomial series has the form:

$$\Delta W = a \cdot e^{b \cdot Q_{lf}} = f(m) + \frac{f'(m)}{1!}(Q_{lf} - m) + \frac{f''(m)}{2!}(Q_{lf} - m)^2 + \frac{f'''(m)}{3!}(Q_{lf} - m)^3 + \dots = a \cdot e^{bm} + + \frac{a \cdot b \cdot e^{am}}{1!}(Q_{lf} - m) + \frac{a \cdot b^2 \cdot e^{bm}}{2!}(Q_{lf} - m)^2 + \frac{a \cdot b^3 \cdot e^{bm}}{3!}(Q_{lf} - m)^3 + \dots = a \cdot e^{bm} \cdot \left[1 + \frac{b \cdot (Q_{lf} - m)}{1!} + \frac{b^2 \cdot (Q_{lf} - m)^2}{2!} + + \frac{b^3 \cdot (Q_{lf} - m)^3}{3!} + \frac{b^4 \cdot (Q_{lf} - m)^4}{4!} + \dots\right] \quad (23)$$

The average probable value of the undivided liquid fraction $M(\Delta W)$ obtained the corresponding transformations (2) and assumed that

$$\left(\frac{b \cdot D_{Q_{lf}}^{0,5}}{2^{0,5}}\right)^2 = K,$$

where $D_{Q_{lf}}$ - moisture dispersion.

$$M(\Delta W) = a \cdot e^{bm} \cdot \left(1 + \frac{K}{1!} + \frac{K^2}{2!} + \frac{K^3}{3!} + \dots\right) = a \cdot e^{bm} \cdot e^{K} = a \cdot e^{bm} \cdot e^{0,5 \cdot D_{Q_{lf}}} = a \cdot e^{bm + 0,5b^2 D_{Q_{lf}}}, \quad (24)$$

Equation (24) shows that by ensuring that the average density of the layer on the conical rotor of the separator is constant, the yield of the liquid fraction from the insoluble soybean-grain residue in $e^{bm + 0,5b^2 D_{Q_{lf}}}$ time.

This analysis allows to determine the approach to creating MFM structures with the location of the lower rubbing working disk flush with the inner wall of the conical separator (Fig. 2) or with a peak on the upper rim of the cone. This design feature ensures a smooth and uniform output of the ISGR mass from the interdisk space, as well as its distribution by a uniform layer along the inner wall of the rotor (Figure 2). Due to this, under the influence of centrifugal force, the liquid fraction, as far as possible, will separate from the ISGR. Finally, a greater value of the indicator will be achieved η_p determined by the equation (3).

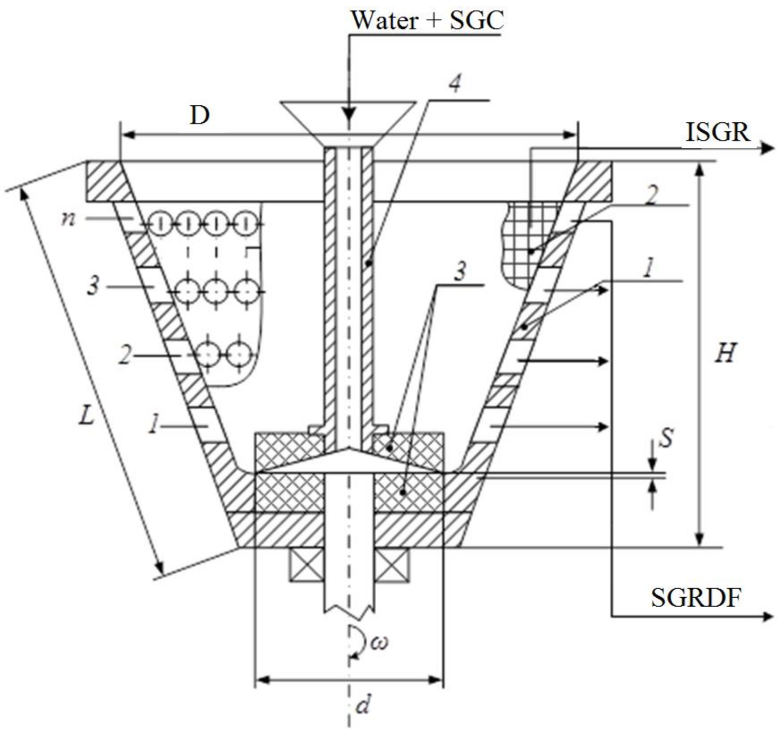

Figure 2: Scheme for calculating the separator parameters MFM
1 - perforated rotor, 2-screen filter, 3 - abrasive working elements; 4 - inlet branch pipe.

At the same time, according to the equation of material balance (15), we have that

$$Q_{lf} = \sum_{i=1}^{n} \frac{M_s \cdot \omega \cdot R_i}{\rho_{lf} \cdot h_i} = \sum_{i=1}^{n} \left[\left(\frac{M_{sg}}{\rho_{sg}} - \frac{M_0}{\rho_0} \right) \cdot \frac{\omega \cdot R_i}{h_i} \right], \quad (25)$$

where ω - angular velocity of the rotor of a centrifuge;

R_i- radius of the conical rotor, in the corresponding elementary cross section;
h_i- thickness of the residue layer, in the corresponding elementary cross section for height - H of the conical rotor (Figure 2).

The productivity of a centrifuge for an insoluble soybean-grain residue is defined as:

$$Q_0 = [Q_{sg} + Q_w] - Q_{lf}, \quad (26)$$

where Q_{sg}- receipt of soaked seeds SGC;
Q_w- water supply.

Taking into account the technological requirements:

$$Q_0 = k \cdot Q_{sg} - Q_{lf}, \quad (27)$$

where k - coefficient that takes into account the total moisture of the system "soaked seeds + water", k=10.

Feeding for grinding and extraction by soaked SGC seeds is presented as

$$Q_{sg}^{g} = \frac{[M_{sg} + M_w] \cdot \left[\left(\frac{R_{at}}{r} \right)^2 - 1 \right] \cdot v_r}{\left(R_{at}/r_{at} \right)^3 \cdot S_r}, \quad (28)$$

where $[M_{sg} + M_w]$- load density on abrasion unit;

R_{at} - radius of attrition;
r - adius of inoperative part of abrasion organ;
v_r- velocity of a particle moving along the abrasion body;
S_r- length of the trajectory along which the particle moves.
In the process of grinding, extraction and separation of ISGR, it is necessary that the condition:

$$k \cdot Q_{sg} \leq Q_{sg}^{g} \quad (29)$$

Taking this condition into account, we can write down that $Q = Q_{sg}^{g} - Q_{lf}$ and ultimately we have:

$$Q_0 = \frac{[M_{sg} + M_w] \cdot \left[\left(\frac{R_{at}}{r_{ou}} \right)^2 - 1 \right] \cdot v_p}{\left(R_{at}/r_{at} \right)^3 \cdot S_p}, \quad (30)$$

where v_p- speed of soybean pulp flow in the gap;
S_p- length of the trajectory of the soybean-cereal pulp.

Power spent on grinding and extraction processes – N_{ge}, as well as for separation ISGR – N_0 is determined:

$$N = N_{ge} + N_0 \quad (31)$$

In this case, the power used for grinding and extraction is:

$$N_{ge} = 0{,}01 \cdot k_1 \cdot Q \cdot S_r, \quad (32)$$

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but on separation ISGR:

$$N_0 = 0{,}01 \cdot k_2 \cdot Q_0 \cdot L, \quad (33)$$

where k_1 and k_2- empirical coefficients.

The approaches developed above made it possible to justify the schemes, parameters and corresponding MFM designs that are protected by the patents of the Russian Federation for inventions [3-11].

CONCLUSION

With the use of accepted mathematical methods and approaches, analytical expressions are obtained theoretically, allowing to make the necessary engineering calculations in the design of MFM for the production of SGSDF in young animals of farm animals.

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