Evaluation of the process of pelleting for pre-sowing treatment of flax seeds

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Abstract. The paper presents a computational method that allows to predict the process of drainage of flax seeds with expanded perlite and biohumus for complex pre-sowing treatment with preliminary irradiation of seeds in the infrared range. From a methodological point of view, in the process of seed granulation, the efficiency depends on the adhesive bond arising in the process of rolling and dispersing. To solve this problem, the calculations of mathematical models of the process of granulation of seeds and the process of dispersion of perlite with biohumus on the surface of seeds were carried out in order to obtain a finished dragee with components of natural origin and improve the sowing qualities of treated seeds and the finished product. As a result of the developed models, analytical solutions of kinetic problems for the process of precipitation of particles of a draining mixture of perlite and biohumus on the surface of flax seeds are obtained. The described mathematical model allows to determine the technological parameters of the granulation process - particle size of the granulating mixture and granulation time, for the calculation of granulating components in the development of technological equipment for granulation. The approximation of the obtained data was made, which showed the prospects and effectiveness of the ongoing developments.

1. Introduction

To date, increasing the yield and quality of sowing qualities of field crops is one of the tasks of food security of the country and providing the population with quality food. Pre-sowing seed treatment is an important advantage, since properly and qualitatively prepared seeds for sowing are one of the main conditions for the formation of an optimal crop structure. One of the important solutions is a complex pre-sowing treatment of seeds, including irradiation of seeds with infrared radiation and pelleting using expanded perlite and vermicompost.

To increase the yield and germination of flax, a complex pre-sowing treatment of seeds, including electrophysical irradiation of seeds with infrared radiation and pelleting with biohumus and expanded perlite, was studied.

The article presents a study of the process of seed granulation, which ensures uniform sowing, facilitates the sowing of seeds with a small size, like flax seeds, helps to save seed material, improves plant growth conditions, increases productivity due to the components that make up the shell. Perlite in the form of an inert-sorbing agent, which is part of the mixture for drainage, provides additional nutrition with water resources of a moisture-loving linseed plant. Application in the composition of
perlite and biohumus, allows you to gradually give the necessary components to the roots of plants throughout the growing season, which will contribute to the growth and development of plants [1].

Prospects for the development of technological methods of pre-sowing seed treatment by creating an artificial shell are very diverse. However, the General principle of processing is reduced to a single technology, the seeds are consistently applied layers of different components, the bulk of which is inert. The only difference is in the components used. There are many designs, schemes and dehumidifiers that differ in processing methods, which arise from the diversity of the mixture components and the conditions in which they are applied to the seeds. The most appropriate solution for granulation of flax seed expanded perlite and vermicompost will be the installation of a pelletizing drum. The result is the development of technology of long-lived flax seed pelleting using environmentally friendly components of natural origin [2-4].

2. Materials and methods of research

The deposition of particles on the surface of seeds can be explained by the theory of adhesion bond, since the granulation process consists in the adhesion of particles to the surface of seeds with different physical and chemical origins. The cause of adhesion is the molecular attraction of the contacting phases or their chemical interaction. The main components of the adhesive composition are substrate-solid and adhesive-adhesive agent.

Soaked flax seeds sprinkle with fine vermicompost and expanded perlite. The granulation process is carried out in two stages of granulation: coating and dispersion of the liquid on the surface of the particles in suspension. Consider the kinetics of seed coating in a layer for pelleting.

2.1. Kinetics of the process of coating flax seeds with a loose layer for pelleting

Let, in the first approximation, the surface of the seeds is an ellipsoid with an average radius of half-axis length A and short B.

The scheme of the coating process is presented in the figure 1.

![Figure 1. The scheme of the process of rolling the seed in the layer for pelleting: 1 the seed; 2-the stuck layer for pelleting; 3-the mixture for pelleting; 4 – the conjugation line.](image)

Experimental studies show that the granulated seed in the process of coating acquires a shape close to the ball (figure 2). Without considering the physico-chemical cause of adhesion, we assume that it occurs due to the emerging stresses \( \sigma_z \) in the zone of contact interaction between the solid particle and the bulk material under the action of the mass \( P \) of the particle.

To study the contact stresses on the interface \( |x| \leq s, y = 0 \) in a quasi-stationary process, a special (singular) integral equation is used (tangential stresses in the contact zone are neglected) [5-9]:

\[
\sigma_z(x) = -\frac{B}{\pi t} \sqrt{s^2 - x^2} \int_{-s}^{+s} \frac{f(\xi)}{\sqrt{s^2 - \xi^2} (\xi - x)} d\xi, 
\]

where

\[
f(x) = -t \frac{dw(x)}{dx},
\]

\( w \) – vertical movement of points of the interface line; \( B \)-constant.
Figure 2. Design scheme of granulated seed at the end of the coating process

Here

\[ w = -(w_0 + z(x)) \]  

where \( w_0 \) – rigid movement of points of the interface line seed-loose mixture for pelleting \( z(x) \) - the shape of the interface line of the seed in the plane \( x, z \).

We decompose the ellipse equation for the half plane \( z \leq 0 \)

\[ z(x) = -\frac{b}{a}\sqrt{a^2 - x^2} \]  

in the Maclaurin series

\[ z(x) = -(z(0) + \sum_{n=1}^{\infty} \frac{x^n d^{(n)} z(0)}{n! dx^n}) \],

where \( z(0) = -b \), and, given only the first three nonzero terms of the series, we get:

\[ w \approx -(w_0 + b + \frac{b}{2a^2}x^2 + \frac{b}{8a^4}x^4) = -(w_0 + b + \frac{x^2}{2R} + \frac{x^4}{8Ra^2}) \]  

where \( R = a^2/b \) – the radius of curvature of the ellipse at point A (see figure 1).

Then

\[ f(x) = i\left(\frac{x}{R} + \frac{x^3}{2Ra^2}\right) \],

and equation (1) will take the form:

\[ \sigma_z(x) = -\frac{B}{\pi R}\sqrt{s^2 - x^2} \left[\left(\frac{x^3}{2a^2}\right)\left(\sqrt{s^2 - \xi^2} (\xi - x)\right)^{-1}\right] d\xi \].

Consider the integrals:

\[ \int_{-s}^{s} \frac{\xi}{\sqrt{s^2 - \xi^2} (\xi - x)} d\xi = \int_{-s}^{s} \frac{\xi - x + x}{\sqrt{s^2 - \xi^2} (\xi - x)} d\xi = \pi + x \int_{-s}^{s} \frac{d\xi}{\sqrt{s^2 - \xi^2} (\xi - x)} = \pi \].
in the solution of which, according to [5-9], the value of the integral

\[
\int_{-s}^{+s} \frac{d\xi}{\sqrt{s^2 - \xi^2}} = 0.
\]

Then equation (7) will take the form:

\[
\sigma_2(x) = -\frac{B}{R} \sqrt{s^2 - x^2} \left( 1 + \frac{s^2}{4a^2} + \frac{x^2}{2a^2} \right).
\]  

(8)

Find the constant \( B \) from the equilibrium condition:

\[
\int_{-s}^{+s} \sigma_2 dx = -P,
\]  

(9)

whence it follows that

\[
B = \frac{2PR}{\pi s^2 \left( 1 + \frac{3s^2}{8a^2} \right)}.
\]  

(10)

Substituting (10) in (8), we get the expression for the contact stress

\[
\sigma_2(x) = -\left\{ \left[ P \left( 1 - \left( \frac{x}{s} \right)^2 \right) \right]^{1/2} \left[ 2\pi s \left( 1 + \frac{3s^2}{8a^2} \right)^{1/2} \right]^{-1} \left( 4 + \frac{s^2}{a^2} + \frac{x^2}{a^2} \right) \right\}.
\]  

(11)

or in dimensionless values

\[
K_\sigma = \frac{2s\sigma_2(x)}{P} = -\left\{ \left( 1 - \left( \frac{x}{s} \right)^2 \right) \right\} \left[ \pi \left( 1 + \frac{3s^2}{8a^2} \right) \right]^{1/2} \left( 4 + \frac{s^2}{a^2} + \frac{x^2}{a^2} \right).
\]  

(12)

During the coating process, the length of the line \([-s; s]\) of the interface between the bulk dragee and the pellet changes. Take the linear law in the change in the length of the conjugation line in timer:

\[
s = s_{\text{max}} - h \frac{\omega}{2\pi} \tau,
\]  

(13)

where \( \omega \) – the angular velocity of rotation of the seed; \( h \) - linear parameter of the particle for pelleting depending on its geometry and adhesive properties..

Let during the \( T \) technological cycle of granulation the surface of the pellet will acquire a spherical shape, and the half-length of the interface line will reach the value \( s_{\text{min}} \), then

\[
h_\frac{\omega}{2\pi} = \frac{s_{\text{max}} - s_{\text{min}}}{T}
\]

and equation (13) will take the form:

\[
s = s_{\text{max}} \left[ 1 - \left( 1 - \frac{s_{\text{min}}}{s_{\text{max}}} \right) \frac{\tau}{T} \right].
\]  

(14)

According to [10], the contact stress is proportional to the adhesive stress, therefore, the thickness of the coating layer can be defined as
where $|K_{\sigma}|$ is a function of the distribution of the granulation layer on the surface of the seed; $\phi_-$ is a function that depends only on the time of the granulation process.

Since with increasing layer thickness $\delta$ the rate of adhesion of $\partial \delta / \partial \tau$ reduced [10], we assume that:

\[ \phi(\tau) = C \left(1 - e^{-\beta \tau}\right), \quad (16) \]

where $C$, $\beta$ - constants.

To determine the constant $C$, we use the boundary condition: for $\tau = T$ and $x = 0$ -

\[ \delta = \delta_{\text{max}} = a - b, \quad (17) \]

then from (15), taking into account (16), (17) and (14), we find

\[ C = \frac{\pi(a - b)}{(1 - e^{-\beta T}) K}, \quad (18) \]

where

\[ K = \left[1 + \frac{3}{8}\left(\frac{s_{\text{min}}}{a}\right)^2\right]^2 \left[4 + \left(\frac{s_{\text{min}}}{a}\right)^2\right]^{-1}. \]

Thus, the thickness of the coating layer will be determined

\[ \delta(x, \tau) = \frac{(a - b)}{(1 - e^{-\beta T}) K} \left[1 - \left(\frac{x}{a}\right)^2\right]^{1/2} \left[1 + \frac{3s^2}{8a^2}\right]^{-1} \left(4 + \frac{s^2}{a^2} + 2\frac{x^2}{a^2}\right) \left(1 - e^{-\beta \tau}\right), \quad (19) \]

and the equation of the surface of the pellet will take the form:

\[ |z(x, \tau)| = \delta + b \left[1 - \left(\frac{x}{a}\right)^2\right]^{1/2} = \]

\[ = \frac{(a - b)}{(1 - e^{-\beta T}) K} \left[1 - \left(\frac{x}{a}\right)^2\right]^{1/2} \left[1 + \frac{3s^2}{8a^2}\right]^{-1} \left(4 + \frac{s^2}{a^2} + 2\frac{x^2}{a^2}\right) \left(1 - e^{-\beta \tau}\right) + \left[1 - \left(\frac{x}{a}\right)^2\right]^{1/2}, \quad (20) \]

where the parameter $s$ is given as (14).

Figures 3, 4, 5 show graphs of changes in the surface of the pellet at $b = 0.3a$, $s_{\text{min}} = 0.87a$, $s_{\text{max}} = 0.97a$, $\beta = 1$.

**Figure 3.** Schedule changes the surface of the pellets.

**Figure 4.** Changing the surface of the pellet over time at $x = 0$. 
Next consider the dispersion of the liquid and the deposition of the mixture for pelleting on the surface of spherical granules.

### 2.2. Kinetics of precipitation of sedimentary particles on the surface of seeds during dispersion

Due to the random orientation of the pellet in space, it can be assumed that on its spherical surface with radius $R$, the entire flow of particles of matter is uniformly deposited (figure 6).

![Figure 6. Scheme of particle deposition on the surface of the pellet.](image)

Neglecting hydraulic resistance, this process is described by the following expression [11]:

$$\frac{dm}{d\tau} = 4\pi R^2 \frac{d(Dc)}{d\rho},$$

(21)

where $m$ - the mass of particles deposited on the spherical surface of the draught, kg; $\tau$-time, s; $D$-adhesion coefficient, m2/s; c-particle concentration, kg / m3, $\rho$- the polar radius measured from the center of gravity of the pellet,m.

Here, the $Dc$ product is the specific flux of precipitated particles, referred to the unit of their motion in the radial direction of the pellet. Let's imagine it as

$$Dc = \frac{4\gamma D(R_0 - \rho)^2}{s^2},$$

(22)

where $R_0$ – radius of the sphere where the adhesion process stops ($c = 0$), $m$; $s$ – linear parameter of particles (size),m.

Then
The left side of equation (21) can be represented by

\[ d(Dc) = -\frac{8\gamma D (R_0 - \rho)}{s^2} \, d\rho. \]  

(23)

The left side of equation (21) can be represented by

\[ \frac{dm}{d\tau} = 4\pi\gamma M \rho^2 \frac{d\rho}{d\tau}, \]  

(24)

where \( \gamma \) – particle density of the mixture for pelleting, kg/m³; \( M \) – porosity of the layer for pelleting on the surface of the pellet.

Substituting (23), (24) in (21) and separating the variables, we obtain the equation

\[ \frac{d\rho}{(R_0 - \rho)} = -\frac{8\gamma D}{MS^2} \, d\tau, \]  

(25)

the solution of which has the form:

\[ \ln(R_0 - \rho) = -\frac{8\gamma D}{MS^2} \tau + C_1. \]  

(26)

To determine the constant \( C_1 \), we use the initial condition: for \( \tau = 0 \) – \( \rho = R \). We obtain

\[ \ln\left(\frac{R_0 - R - \delta}{R_0 - R}\right) = -\frac{8\gamma D}{MS^2} \tau, \]  

(27)

Where \( \delta = \rho - R \) – the thickness of the layer for pelleting on the surface of the pellet.

Where we have:

\[ \delta = R\theta \left[1 - \exp\left(-\frac{8\gamma D}{MS^2} \tau\right)\right], \]  

(28)

where

\[ \theta = \left(\frac{R_0}{R} - 1\right). \]  

(29)

Let the technological period of time \( \tau = T \) the thickness of the layer for pelleting on the surface of the pellet reaches the value \( \delta = \delta_T \), then equation (28) can be rewritten

\[ \delta = R\theta \left(1 - e^{-\beta T}\right), \]  

(30)

where

\[ \beta = \ln\left[\theta \left(\theta - \frac{\delta_T}{R}\right)^{-1}\right]. \]  

(31)

Figure 7 shows the dependence of the thickness of the deposited particles layer on the time at \( \theta = 0.5, \delta_T/R = 0.25 \).
The presented graph shows that the particle deposition process slows down over time \((\frac{d^2 \delta}{dt^2} < 0)\) due to the limited amount of the mixture for pelleting in a dispersed medium.

3. Results and discussion

As a result, the proposed computational model of the process of pelleting allows us to analytically describe the kinetics of deposition of particles of the mixture for drainage of expanded perlite and vermicompost on the surface of flax seeds.

The calculated dependences showing the change of the dragged surface over time and the dependence of the layer thickness on time are determined.

The obtained computational model allows to determine the necessary technological parameters of the processing time and the optimal particle size of the components for the process of pelleting during pre-sowing treatment of flax seeds.

4. Conclusion

The developed mathematical models determine the main technological parameters for complex pre-sowing treatment of flax seeds in the process of pelleting. The optimal processing time is 3…4 min. and the optimal particle size of expanded perlite and vermicompost—50…100 microns, allowing to obtain the necessary properties of the finished dragee from components of natural origin. The use of perlite will provide additional conditions for plant nutrition due to its hydrophobic properties. The process of electrophysical treatment of seeds with IR radiation in the C-wave range 3…4 microns, promotes the activation of biochemical processes and increase seed germination [12]. Combining all processes and used natural components of pre-sowing seed treatment involves a technology that eliminates harmful effects on the environment. Field studies conducted with treated flax seeds of the Voskhod variety at the pre-sowing treatment plant (UPO-01) showed the results of increasing the yield of fiber by 5.7 C/ha and seeds by 1.6 C/ha.

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