Cleaning module of the sorting surface of a continuous processing unit for grinding and freeze drying of lumpy materials

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Abstract. The article considers the problem of improving the quality of semi-finished vegetables and the possibility of optimizing and automating this process. The processes of cleaning calibrated crushed lumpy materials are analyzed depending on the physomechanical and chemical properties of the processed materials, with elements of modeling the process modes of equipment operation, allowing improving the quality of the final product. The mathematical model is considered and presented in two parts: the mathematical model of a separate system and the mathematical model of the interaction between elements, the latter reflecting a new approach. The construction of a mathematical model of the individual elements of the system and the mathematical model of interaction is carried out inseparably from each other, as a single process. The method is effective because it is based on the use of the found response function equation. For a given value of one of the factors, such boundaries of change of another factor are determined that ensure that the optimization criterion does not go beyond the certain studied framework, due to the technological requirements of the process under consideration.

1. Introduction
Food security is the most important component of the country's security, an integral part of national security, and its problems, in particular include the preservation of public health through quality nutrition. In the system of measures aimed at improving the health of the population, the primary task is to ensure the safety of food products, including semi-finished products and fast food, from the process of industrial processing and production to their preparation at home [1].

2. Analysis of issues
The transition to market relations, the formation of a multi-level economy in the agro-industrial complex of the Russian Federation necessitate technical solutions aimed at improving the consumer properties and quality of food products.

As a result of exposure to environmental pollutants in violation of the technology of cultivation, processing or storage conditions, food products can accumulate toxic substances – so called "pollutants" - toxic elements, mycotoxins, pesticides, nitrates, nitrosamines, dyes, oxidants, etc. Hygienic regulations
experimentally justify the maximum permissible concentration (MPC), taking into account a large number of factors and combinations arising during production.

3. Results

The object of the study is the process of cleaning a vacuum sorting machine that forms a part of a continuous installation for grinding and freeze-drying the lump materials.

The plant additionally contains a device for cutting vegetables at the top of the vacuum dryer and a sorting device that allows calibrating the crushed lump material [2].

The use of such a design provides the following solutions:

- the percentage of sorting accuracy increases with a relatively small length of the drum, since the shape of the separation holes has a slit-like shape, and they are located in the direction of movement of the particles composing the pile, which ensures rapid sorting of scraps;
- the productivity of the line for processing of fruit and vegetable raw materials and the quality of the final product increases.

The device has the following advantages:

- small scraps are separated from the particle pile at the beginning of its movement in the sorting drum;
- it is possible to adjust the distance between the threads forming the sorting surface of the drum in a simple way which increases the range of use of the machine;

With the existing advantages in operation, a disadvantage was found, namely, a decrease in the separation clearance due to adhesion of starch and particles of the sorted heap, [3].

The study of this problem was carried out using a mathematical model of the dynamics of contamination (sticking) of starch particles and small particles of chopped potatoes on the inner surface of the sorting machine. Sizing threads and the mutual influence of product quality and process factors - machine performance and scheduled cleaning (washing) time, were modeled depending on the composition of the incoming raw materials, [4].

The relations of the mathematical model are built on the following assumptions:

- the growth of sticking per unit time is proportional to the first degree of its volume:
  \[ \Delta \tilde{O} = f \tilde{O} \Delta \tilde{t} \]  
  where \( \tilde{O} \) is the amount of adhering starch and small cut particles; \( \Delta \tilde{t} \) is the time interval for which a change in volume occurred; \( f \) is a coefficient of proportionality; \( \Delta \tilde{O} \) is an increment of volume.

Substituting in the right side of the dependence (1) instead of volume \( \tilde{O} \) composition \( \tilde{O}X(\tilde{O}) \), new variable \( X(\tilde{O}) \), which is a function \( \tilde{O} \), we obtain a complex volume growth in time taking the function \( X(\tilde{O}) \) linear \( X(\tilde{O}) = f_a \) we get the absolute increment \( \Delta \tilde{O}(\tilde{t}) \) the volume of adhering starch and small cut particles in an ideal technological mode for a period of time \( \Delta \tilde{t} \) kind of:

\[ \Delta \tilde{O}(\tilde{t}) = \bar{v}(\tilde{t}) \tilde{O}(\tilde{t}) \Delta \tilde{t}, \]  

\[ \bar{v} = f f_a, \]  

where \( \bar{v} = \bar{v}(\tilde{t}) \) is a variable rate of volume increment, referred to the square of the volume of adhering starch and particles.

Calculating the equation (2) for the limit at \( \Delta \tilde{t} \to 0 \), we derive a differential equation for the rate of change of volume at time \( \bar{t} \):

\[ \frac{d \tilde{O}}{d \bar{t}} = \bar{v}(\bar{t}) \tilde{O}(\bar{t}) \]  

By entering the factors of interest – the number of starch particles and small cut particles that pollute the surface of the machine, including sorting \( \tilde{K}(\bar{t}) \) and final products \( \tilde{P}(\bar{t}) \) – we obtain a generalized equation of the rate of change in the volume of adhering starch and small cut particles:
\[
\begin{align*}
\frac{d\bar{\delta}}{dt} &= \bar{v}(\bar{t})\bar{O}^2(\bar{t}) + \bar{\delta}(\bar{t})\bar{K}(\bar{t}) + \bar{\varphi}(\bar{t})\bar{P}(\bar{t}), \\
\bar{\delta} &= \bar{\delta}(\bar{t}), \\
\bar{\varphi} &= \bar{\varphi}(\bar{t})
\end{align*}
\]  

where \(\bar{\delta} = \bar{\delta}(\bar{t})\) is a variable rate of volume increment caused by a single amount of particles polluting the sorting machine; 
\(\bar{\varphi} = \bar{\varphi}(\bar{t})\) is a variable rate of volume increment caused by a single amount of particles contaminating the finished product, [5].

It is assumed that the parameters \(\bar{v}, \bar{\delta}, \bar{\varphi}\) change over time due to the natural causes of the process, and changes in the volume of pollution are explained by changes in the volume of production, increment in the number of particles that pollute the machine and products over time \(\Delta\bar{t}\), take the following form:

\[
\begin{align*}
\Delta\bar{K}(\bar{t}) &= \bar{d}(\bar{t})\bar{O}(\bar{t})\Delta\bar{t}, \\
\Delta\bar{P}(\bar{t}) &= \bar{\mu}(\bar{t})\bar{O}(\bar{t})\Delta\bar{t},
\end{align*}
\]

where \(\bar{d} = d(\bar{t})\) and \(\bar{\mu} = \bar{\mu}(\bar{t})\) are variable rates of increments in the quantities of particles polluting the technological equipment and the finished product, respectively, caused by one sort of raw material.

Passing to the limits a \(\Delta\bar{t} \to 0\), we have differential equations for the rate of change of the amount of polluting particles at a time \(\bar{t}\):

\[
\begin{align*}
\frac{d\bar{K}}{d\bar{t}} &= \bar{d}(\bar{t})\bar{O}(\bar{t}), \\
\frac{d\bar{P}}{d\bar{t}} &= \bar{\mu}(\bar{t})\bar{O}(\bar{t}),
\end{align*}
\]

By virtue of the assumptions made, dependencies (5), (8), (9) add up variables of different dimensions, introducing dimensionless variables and parameters, we transform them to a dimensionless form:

\[
\begin{align*}
t &= \frac{\bar{t}}{t_1}, \quad O = \frac{\bar{O}}{\bar{O}_1}, \quad K = \frac{\bar{K}}{\bar{K}_1}, \quad P = \frac{\bar{P}}{\bar{P}_1}, \\
\nu &= \bar{v}O_1t_1, \quad \delta = \frac{\bar{\delta}}{\bar{\delta}_1}, \quad \varphi = \frac{\bar{\varphi}}{\bar{\varphi}_1}, \quad d = \frac{\bar{d}}{\bar{d}_1}, \quad \mu = \frac{\bar{\mu}}{\bar{\mu}_1}, \quad t_1
\end{align*}
\]

Time scale \(t_1\) taken equal to one production cycle, then each unit of dimensionless time \(t\) corresponds to the duration of one cycle, \(t = 1\) means \(\bar{t} = 1\) cycle, \(t = n\) cycles, [5].

In further calculations, we take quadratic functions of time as coefficients of equations \(v(t), \delta(t), \varphi(t), d(t), \mu(t)\), containing model parameters. Finally, the system of equations (5), (8), (10-11) takes the form

\[
\begin{align*}
\frac{dO}{dt} &= (v_1t^2 + v_2t + v_3)O^2(t) + (\delta_1t^2 + \delta_2t + \delta_3)K(t) + (\varphi_1t^2 + \varphi_2t + \varphi_3)P(t) \\
\frac{dK}{dt} &= (d_1t^2 + d_2t + d_3)O(t) \\
\frac{dP}{dt} &= (\mu_1t^2 + \mu_2t + \mu_3)O(t)
\end{align*}
\]

The initial conditions in a dimensionless form take the following form

\[
O(1)=1, \quad K(1)=1, \quad P(1)=1
\]

Further work with the mathematical model is carried out according to the following scheme. Based on the analysis of statistical data of the technology under consideration, the time interval of variation is determined. For this interval, the initial time \(t_1=1\) for calculations and the values of the model variables corresponding to this interval are determined [6]. For the range of variation \(t_1÷ t_n\) \((n=1…10)\) by
processing the corresponding values, approximating power functions are constructed \( O(t) \), \( K(t) \), \( P(t) \). The constructed functions and their derivatives are substituted into the equations of system (12).

By minimizing the residuals:

\[
R_1(t) = v(t)O^2(t) + \delta(t)K(t) + \varphi(t)P(t) - \frac{dO}{dt};
\]

\[
R_2(t) = d(t)O(t) - \frac{dK}{dt};
\]

\[
R_3(t) = \mu(t)O(t) - \frac{dP}{dt};
\]

where 
\( v(t) = v_1t^2 + v_2t + v_3; \delta(t) = \delta_1t^2 + \delta_2t + \delta_3; \varphi(t) = \varphi_1t^2 + \varphi_2t + \varphi_3; \)
\( d(t) = d_1t^2 + dt + d_3; \mu(t) = \mu_1t^2 + \mu_2t + \mu_3; \)

Model parameters \( v_i, \delta_i, \varphi_i, d_i, \mu_i \) (i=1,2,3) are determined based on the first actual 10-cycle data of the technology under study. For this, the trends of factors \( O(t), K(t), P(t) \) are built. Figure 1 shows the correlation fields, the corresponding lines and equations of trends, as well as the approximation value.

Accordingly, equations with dimensionless variables and their constants take the form:

\[
O(t) = -0.4394t^2 + 5.1121t - 4.4 \quad O(t) = -0.8788t + 5.1121
\]

\[
K(t) = -0.2955t^2 + 3.25t - 2.5 \quad K(t) = -0.591t^2 + 3.25
\]

\[
P(t) = -0.0558t^2 + 0.9253t + 4.4 \quad P(t) = -0.1116t + 0.9253
\]

![Figure 1. Trend lines of the function O(t) K(t) P(t) for the period from 1 to 10 cycle.](image)

Then, by solving the inverse problem, the program determines the coefficients of the differential equations (12) on a 10 cycle time interval.
Estimated trend $O(t)$ predicts a monotonous increase in the volume of pollution, which is consistent with known statistics.

To solve this problem, a cleaning module is developed, which is a device consisting of a spray-nozzle collector controlled by a clogging sensor of the inter-flow space and a time relay of the cleaning module, figure 2.

![Diagram](image)

**Figure 2.** Schematic diagram with cleaning module: 1,3,10-shut-off valve; 2,4-water and air supply pumps: 5-pressure gauge-vacuum meter; 6-vacuum line; 7-leak detector; 8,9,19-rotary sluice gate; 11-drain line with overflow neck; 12-desublimator; 13-mass spectrometer; 14-vacuum meter; 15-pressure switch; 16-vacuum pump water ring; 17-vacuum chamber sorting and drying; 18-spray nozzle collector ultrasonic water and air purification.

4. **Discussion**

1. The change of the technological process according to the considered variant increases the quality of the finished product and the productivity of the line as a whole.

2. Savings (EC) from improving product quality and reducing waste are calculated when products are evaluated with certain quality indicators, in particular on the basis of grades or yield of suitable products, when waste is present in production (in our case, trimming and cleaning waste solutions). Savings from improving the varietal structure of output is formed as a result of a relative reduction in the level of costs per 1 ruble of the cost of production and is calculated by the formula:

   \[ EC = \left( \frac{C}{S} - \frac{C}{S_A} \right) S_A, \]  

   \[ (17) \]

   where $C$ is the cost of production; $S$ and $S_A$ are production costs before and after module implementation.

3. The progressive sorting structure of the output is determined by the values of specific weights of individual varieties, which are better than the average values for the calculation period, [6].

Savings in raw material EM costs with increased output or more complete extraction of useful components are calculated by the formula:

\[ EM = \sum_{i=1}^{K} S_i \left( \frac{M_i}{B} - \frac{M_i}{B_A} \right) B_A, \]  

\[ (18) \]

where $M_i$ is the volume of raw materials processing.

4. The volume of production of BA is defined as the sum of output B before introduction of the improvement and its possible increase of $\Delta B$ after introduction.

\[ BA = B + \Delta B, \]  

\[ (19) \]

5. **Conclusion**

When changing the technology, it is predicted to increase output at existing production facilities as a result of optimization of the technological process, increase productivity by reducing the loss of working
time and downtime of equipment, improve the quality of products (reducing marriage, improving the quality of products), [7].

The main sources of increasing the efficiency of operation of modified processes include: more complete use of technological equipment in time and power by reducing downtime for organizational and technical reasons, reducing the complexity of the production of units, direct release of production workers, improving product quality [8].

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