Device for batching of free-flowing preservatives for processing of feed grains when flattening

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Abstract. Among chemical preservatives, liquid organic acids are most often used to preserve grain, for which various dosing devices are used in the grain mass. However, the use of effective and cheaper dry products, such as sulphur powder, is constrained by the lack of application devices. In this regard, the purpose of our work was the development of a dosing device designed for the metered supply of powdered preservatives laid for storage of raw flattened feed grain. As a result of the research physical and mechanical properties of powdered sulfur were established, which allowed one to find a structural solution to the problem of dosing of such material. Production tests of the prototype of the developed device showed its energy and economic efficiency when preserving raw feed grain with powdered sulfur.

1. Introduction

To increase the efficiency of dairy cattle breeding, it should receive cheap and high-quality feed, including the most valuable of them-concentrated. In this regard, it is necessary to improve the technology of harvesting and storage in order to reduce costs and improve the quality of the main component of such feed-grain fodder.

Analysis of available literature data [1] allows us to conclude that in modern conditions the most popular method is preservation of flattened raw feed grain by various chemical or biological agents. Application of this method allows refusing such expensive operations on preparation for storage of grain mass as cleaning and drying [2].

The introduction of a preservative is used for the best preservation of feed grain, in which various chemical or biological preparations are made [3]. The nutritional value of barley treated with chemical preservatives is increased by 10% in comparison with feed grain, canned in the usual way (drying, silage) [4].

When using preservatives, special attention should be paid to the accuracy of dosing and uniform distribution of the preservative in the grain, a uniform flow passing through the flattening machine [5,6,7]. The introduction of a preservative less than the recommended dose does not provide the required preserving effect, and with an overdose there is a significant rise in the cost of the technological process [8]. Chemical or biological preservation gives a good effect only when a good spray of drugs is provided during spraying and almost every single grain is covered with a thin film of liquid. At the same time, work with acids requires compliance with special safety rules [9].
The analysis of scientific and technical literature and patent documentation showed that the most popular flattening machines are equipped with dispensers of liquid forms of preservative. There are also technical devices for spreading liquid preservatives by external spraying and injection methods [10].

A prerequisite for the use of powdered sulfur for preservation is its relative cheapness and availability. They are formed mainly by splitting amorphous sulfur powder in methyl and ethyl esters of lactic and acetic acids, as well as in aldehydes synthesized during lactic fermentation [11]. However, dispensers simply do not exist to make such preservatives.

2. Materials and methods
To determine the characteristics that allow working with ivy machines of different productivity, laboratory tests of the dosing device were carried out. To do this, the dispenser was installed canopies, brought to a stable mode of operation. Samples of bulk material were removed at intervals of 30, 60, 90 and 120 s. The cutoff time of collection of the material was controlled by a stopwatch, a mass of selected material measured on the scales. The accuracy of the time measurement was ±1s, the mass of the preservative was ±1G.

With the help of the computing program Maple, version 17 and the use of four standard packages: linear algebra, graphs, approximations of functions, extended graphics, we built graphs of the dependencies of the studied quantities [12]. The software designation of the applied packages is as follows: restart: with (linalg): with (plots): with (CurveFitting): with (plottools).

At the first stage, the approximation of experimental dependences of the mass of the given material m on time t, m(t), at different pressure values P was carried out = 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 3.5; 4.0; 4.5; 5.0 and 5.5 bar. A third-order polynomial was taken as an approximating polynomial:

\[ m = a \cdot t^3 + b \cdot t^2 + c \cdot t + d \]

The second phase was carried out approximation of the values of m(t) for various values of R, using a standard software system of analytical calculations Maple package Spline-approximation.

Definition of absolute economic indicators was conducted in accordance with the methods of economic evaluation (GOST R 53056-2008) [13].

The energy intensity of energy resources per hour of operation of the power machine (tractor, combine) was determined by the "Manual on agro-energy and economic assessment of technologies and systems of forage production" [14].

3. Results and Considerations
To establish the structural parameters of the dosing device, the physical and mechanical properties of powdered sulfur were first determined. As a result of the measurements, the bulk density of the powdered preservative was established. When changing the height of the bulk material from 5 to 15 cm, its bulk density increased from 0.58 to 0.80 g / cm$^3$.

On average, it was 0.72 g / cm$^3$ (table. 1).

This value of bulk density corresponds to the characteristics of the average bulk materials, the range of values of this indicator in which ranges from 0.6 to 1.1 g/cm$^3$.

Changes in the bulk density of powdered sulfur depending on the height of the embankment were uneven. Thus, with an increase in the height of the embankment from 5 to 10 cm, the bulk density of the powdered preservative increased by 35% and was equal to 0.78 g/cm$^3$, and a further increase in the height of the embankment from 10 to 15 cm increased it to 0.8 g/cm$^3$, i.e. by only 2.6%. For this reason, to continue to carry out measurements and further we considered it impractical.

According to the results of the measurements, a graph was constructed, which with a high degree of reliability (P=0.95) is described by the following regression equation:

\[ y = 0.257 + 0.21 \ln x \]

The above equation reflects the relationship of bulk density (y) with the height of the mound (x) of the powdered preservative.
To ensure the necessary duration of the dosing device, the height of the embankment in the bunker constructed by us should be 55 cm, so the indicators of the bulk density of the material were brought into line with this value using the obtained regression equation, which was displayed in figure 3. The graph presented on it shows that at the height of the embankment 55 cm the bulk density of the material will be 1.1 g/cm³.

To establish the flow ability of the material, the angle of natural slope was determined. According to the measurements, the angle of the natural slope was equal to 16.52°, and the coefficient of internal friction was 0.296. In further use of the data obtained, it was taken into account that to ensure complete emptying of the hopper, its walls should be positioned at an angle exceeding the angle of natural slope by 5-10 degrees. In our case, this meant that the minimum angle of inclination of the feeder hopper of the dosing device should be equal to 21°52'.

In determining dome formation it was found that after the material was absent (a set) when changing the hole diameter of the expiry from 1 to 4 mm. In diameter from 4 to 10 mm occurred short after, and then formed the arch, causing the expiration of the suspended material. This meant that the hole diameter had to be more than 10 mm to ensure a continuous flow of material.

In our opinion, the most suitable design of the powdered sulfur dispenser can be a pneumatic dispenser. Its advantages include the simplicity of design and maintenance of pneumatic mechanisms, and, consequently, low cost and time of cost recovery. This dispenser can operate in a wide range of temperatures and dust environment. Energy carrier (compressed air) for such a device is easy to obtain and relatively easy to transmit.

![Figure 1. The device of the dosed giving of powdered preservative for preservation of forages.](image)

To ensure reliable and complete introduction of a powdered preservative that does not require preliminary dissolution in water, a device for its introduction into raw feed grain with a Deposit for storage is developed (Fig. 4). In addition to the hopper, the dispenser design includes two pressure regulators (3, 7), the first (3) - with a dehumidifier, two pneumatic fittings (4, 12), an air dispersion device (8) and a pipeline system (2, 5, 6, 11). The dehumidifier is used to separate the incoming air from moisture, fittings – to separate the air flow, a device for air dispersion – to give the material at the bottom of the hopper when mixed with the air of a pseudo – liquefied state, a pipeline system-for supplying compressed air and transporting the working material (preservative). The ejector (10) allows the suction of the dosed material at a pressure difference inside it.

The device of the dosed supply of powdered preservative for the preservation of feed works as follows (Figure 1). The air coming through the air duct 5, passing through the pressure regulator 7 and through the breathing valve 8, enters the tank 9. The air flows leaving the breathing valve 8 are directed...
towards the bottom of the container. At the same time, the bottom part of the container is made tapering, which creates turbulences of air flows that perform intensive and uniform mixing of the preservative with air. Then, with the ejector 10, the suspension of the preservative from the tank 9 is sucked into the pipeline 11 and sent through it to the output channels 12, through which it is sprayed onto the flattened grain.

A mathematical model of the dosing process can be constructed to determine the dose depending on the pressure in the pneumatic system of the dispenser and the time of grain processing on the basis of a logistic function that takes into account the physical and mechanical properties of the preservative and the structural features of the device. For its construction, the first approximation for the values of $P$ was carried out: 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 3.5; 4.0; 4.5; 5.0 and 5.5 bar. According to the obtained experimental data, a matrix equation for each pressure level was formed to determine four unknown parameters $(a, b, c, d)$. For example, for the pressure $P=0.5$ bar it was as follows:

$$
\begin{pmatrix}
6.3 \\
14.6 \\
20.6 \\
29.6
\end{pmatrix}
= 
\begin{pmatrix}
30^2 & 30^2 & 30 & 1 \\
60^2 & 60^2 & 60 & 1 \\
90^2 & 90^2 & 90 & 1 \\
120^2 & 120^2 & 120 & 1
\end{pmatrix}
\begin{pmatrix}
a \\
b \\
c \\
d
\end{pmatrix}
$$

In matrix form this dependence took the following form:

$$
M = A \cdot X 
$$

The column vector of unknown coefficients was determined from the ratio: $X = A^{-1} \cdot M$.

The type of the mass dependence polynomial of the material issued by the dispenser on time $(t)$ for the pressure value $(P)$ of 0.5 bar is given below:

$$
m_{P=0.5} = 0.0000327160494t^3 - 0.00716666667t^2 + 0.715555555t - 9.6
$$

Similar polynomials have also been derived for pressure values $P = 1.0; 1.5; 2.0; 2.5; 3.0; 3.5; 4.0; 4.5; 5.0$ and 5.5 bar.

A graphical representation of the above dependencies is shown in figure 2.

![Figure 2. Change in performance of the dispenser depending on the time of expiration of the](image-url)
material.

The obtained dependences show that with an increase in the incoming pressure, the output mass of the material increases and it reaches the highest value of 938.6 g at a pressure of 5.5 bar.

In figure 3, using the results of the multivariate experiment, the dependence of the dispenser performance on the pressure and the material expiration time is built.

![Figure 3. Changing the dispenser capacity depending on the pressure and the material expiration time.](image)

The established dependences are described by the regression equation.

\[
m = 34.225 - 83.4767 \times P - 0.380278 \times t + 14.7653xP^2 + 1.63233 \times P \times t
\]

The next stage of the study was the approximation of the parameters of the dependence of the mass of the material issued by the dispenser on the time \(m(t)\) for different pressure values \((P)\) at fixed intervals of time \((t = 120)\). The obtained dependences have a complex piecewise nonlinear character:

\[
m = \begin{cases} 6.2+46.8p+66.2(p-0.5)^3 & p(1) \\ -35.2+96.5p+99.3(p-1)^2-35.2(p-1)^3 & p(1.5) \\ -124+169p+46.6(p-1.5)^2-11.2(p-1.5)^3 & p(2) \\ -191+208p+29.8(p-2)^2+37.6(p-2)^3 & p(2.5) \\ -323+266p+86.2(p-2.5)^2-51.1(p-2.5)^3 & p(3) \\ -453+314p+9.56(p-3)^2-41.3(p-3)^3 & p(3.5) \\ -377+292p+52.4(p-3.5)^2-7.71(p-3.5)^3 & p(4) \\ -161+234p+64(p-4)^2+0.148(p-4)^3 & p(4.5) \\ 111+170p-63.7(p-4.5)^2-64.9(p-4.5)^3 & p(5) \\ 649+57.7p-161(p-5)^2+107(p-5)^3 & otherwise \end{cases}
\]

With the use of derived functions, we have considered the possibility of using a device for dosed supply of powdered preservative on the Murska series of flattening machines when operating from the MTZ 82.1 type A29 tractor compressor.01. It was found that the device can provide the required dosing of powdered preservative at a maximum performance of Murska flattening machines brands 220; 350; 700 and 1000. For its use on machines of greater productivity requires the installation of an additional compressor and ejector greater performance.

Based on the analysis of the graphical representation of the experimental data obtained, it was assumed that the analytical expression of the dependence function corresponds to the logistic function of the form

\[
m(t) = \frac{L}{1 + e^{-k(t-t_0)}},
\]

where \(L\) is the limiting value, \(k\) is the growth rate, and \(t_0\) is the time when the value of \(m(t)\) is half of the limiting value.

From the experimental data, the following parameters were determined:

- \(L = 938.6\) g
- \(k = 0.5\) bar
- \(t_0 = 120\) sec
Further, using the program Statistica 10 on the basis of the Levenberg-Marquardt method were obtained estimates of the parameters $a$, $b$, $C$, $d$ for different values of the analyzed data. A graphical representation of the obtained dependence and its coincidence with the experimental data is shown in figure 4.

![Figure 4. Dependences of the approximated and experimental mass on the air pressure in the pneumatic system for $t=120$ c.](image)

The obtained dependences indicate a good agreement between the experimental data and the function $f(m,p)$ (the coefficient of determination is $99.93\%$).

$$f(x) = \frac{abe^{Cx}}{a + b(e^{Cx} - 1)}.$$

Production tests of the new dispenser were carried out in the SEC "Berezniki" Gaginsky district of Nizhny Novgorod region. The technological process of preserving wet feed grain was carried out according to the following scheme: threshing grain, transportation to the storage site, loading into the flattening machine, flattening with processing of grain with preservative, unloading into a concrete trench, distribution along the trench, ramming, and sealing feed with polymer film.

Loading of the grain heap into the hopper of the Murska 1000 HD flattener was carried out by a front loader mounted on the MTZ 82.1 tractor and operating from the drive of its power take-off shaft.

The introduction of preservative was carried out simultaneously with the flattening of grain. In this case, the introduction of a powdered preservative was carried out by a new dosing device.

This device was operated from a compressed air source. Passing through the pressure regulator and the dispersion device, the air through the air duct fell into the hopper-dispenser storage. From the air dispersal device air flows rushed towards the bottom of the bunker. Intensive and uniform mixing of the preservative with air was provided by the design of the bottom of the hopper, which was made tapering, which provided turbulence of air flows.

From the storage hopper, the preservative is sucked in by the ejector and through the pneumatic duct was directed to the output channels through which it fell on the flattened grain.
Further, the preservative was evenly distributed over the surface of the grain mass coming out from under the rollers, and then the screw conveyor of the flattening machine was thoroughly mixed with the feed.

A comparative analysis of the energy performance of conservation technologies and preparation for feeding feed grain showed that the energy efficiency of the developed dispenser is 1.6 times higher than that of the dispenser used to make a liquid preservative. Due to this, the total energy intensity and energy consumption in the new version were reduced by 0.3%.

In terms of 1 ton of dry grain, this method in comparison with the grain laid for storage without drying, allowed to reduce the cost of 265.65 RUB. or 3.5%, and compared with the dried grain-1500.55 RUB. or 19.8%. Savings in comparison with dry grain is associated with a decrease in technological costs associated with its preparation for feeding, and when preserving raw grain, it is due to the low cost of powdered sulfur and the device for its application.

4. Conclusion
Preservative material-powdery sulfur-by dispersion composition refers to the powdery, the maximum particle size does not exceed 0.5 mm, the bulk density (0.72 g/cm³) – to the average, the angle of natural slope (16.52 deg.) – materials, not having or having a slight traction to the free-formative content when the diameter of the holes of the expiration of up to 4 mm. Built based on the logistic function, a mathematical model of the process of dispensing a preservative, taking into account the physic-mechanical properties and structural features of the device of a new dispenser, with a high degree of confidence (coefficient of determination = of 99.93%) allows to determine the application dose of the preservative depending on the pressure in the pneumatic system of the dispenser and the processing time of grain. The angle of the spray torch of the powdered preservative at the end of the dosing device from the pipeline without the sprayer is 11°19′, which corresponds to the parameters of the Murska 220 flattening machine. On the Murska 350, 700 and 1000 series, the required spray torch angles (25°, 95° and 110° respectively) are provided by the use of atomizers. The application of the developed device allows reducing energy costs for preservation of powdered sulfur and grain storage in comparison with the preservation of its propionic acid and the use of a standard centrifugal dosing pump. Techno-economic evaluation of the proposed design of the metering device during the laying of the storage 613 tons of raw feed grains with powdered sulfur in SPK "Berezniki" Gaginskiy district of Nizhny Novgorod region has shown a reduction in the cost 352,6 thousand RUB compared to the processing of propionic acid.

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