ENGINEERING SOLUTION TO PROBLEM OF DOSING OF ULTRAFINE MATERIALS IN MIXED FEED PRODUCTION

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Abstract. The article is devoted to the problem of dosing and incorporation of ultrafine (nano) trace metals into mixed feed. Nanomaterials (in the form of ultrafine powders and suspensions) differ significantly in their properties and effects from substances in the form of macroscopic dispersions and continuous phases. The authors present the experimental findings of the impact of the operation conditions of mixed feed production on ultrafine powders of trace metal properties. A review of the dosing means used in feed preparation and analysis of their technical and technological parameters showed the need to develop the authors' design of a dispenser of ultrafine liquid-like materials. A hallmark of the presented dispenser is the availability of two isolated pneumatic chambers, a solenoid valve in the supply tank and a pneumatic shut-off valve at the end of the rod that provide increased operating speed, improved dosing accuracy and automatic introduction of ultrafine materials into the processed feed mixture. The article provides a dynamic analysis of a pneumatic actuator; for this purpose, the authors determined the operating effort on the rod when moving the membrane center to a predetermined setpoint, the response time of the pneumatic actuator, the time of filling the membrane chamber to a predetermined pressure, as well as estimated the working force stock on the membrane rod when it is deflected by the magnitude of the stroke. Based on the system of engineering analysis, the technical characteristics of the dispenser of ultrafine liquid-like materials were obtained, which allowed the authors to create a prototype that is being tested at the training and production facilities of the Orenburg State Agrarian University.

Keywords: feed, ultrafine powder, dispenser, membrane, air chamber.

Introduction

The competitiveness of enterprises engaged in the industrial production of combined feeds is achieved by increasing the efficiency of their activities based on the adoption of strategically sound decisions in a number of areas. One of these areas is improving the quality of products and improving the methods for their assessment [1; 2].

A significant part of modern research is aimed at exploring the possibilities of obtaining high-quality feeds by the joint use of bioadditives and trace elements in nano form [3]. World science has gained some experience in the development and application of ultrafine materials in agriculture. Recent studies have shown their effectiveness in feed production and animal husbandry [4; 5].

For the successful development of meat, dairy cattle and poultry farming in the Orenburg region, scientists were tasked with increasing the efficiency of the industrial production of combined feeds. One of the directions of its implementation was research in the use of ultrafine powders of trace metals in the production of animal feed for various groups of farm animals [6], which highlighted the need for an engineering solution to launch the industrial production of innovative feed. Membrane-type pneumatic drives have a number of additional advantages that can be used in the modernization of the industrial production of combined feeds: insensitivity to prolonged overloads, high response speed, the ability to reproduce translational motion without any transmission mechanisms. This article presents the results that solve the problem of dosing and introducing ultrafine (nano) materials in a liquid-like state into working feed mixture.

Materials and methods

Nano materials (in the form of ultrafine powders) contain structural elements, which geometrical dimensions do not exceed 100 nm, and radically differ in their properties and bioeffects from substances in the form of macroscopic dispersions and continuous phases.

An analysis of the actual technological processes in the industrial production of combined feeds allowed the authors to single out a set of conditions that significantly affect the physicochemical properties of ultrafine materials (Fig. 1). A series of laboratory experiments conducted by the team of authors showed the resistance of ultrafine powders of iron, zinc and copper oxides synthesized by electric explosion to oxidation and sintering at temperatures close to 25-27 ºC. However, a high chemical and diffusion activity was revealed, when heated to temperatures the working feed mixture

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significantly exceeding the boundary value of 27 ºC. The results obtained determined the main ideas of engineering solutions to the problem [7; 8].

The developed pneumatic dispenser for liquid-like ultrafine materials consists of a set of containers, two pneumatic chambers (a chamber for supplying a dose to the receiving tank and a chamber providing the drive of the distribution valve mechanism), as well as a control mechanism for the control valve.

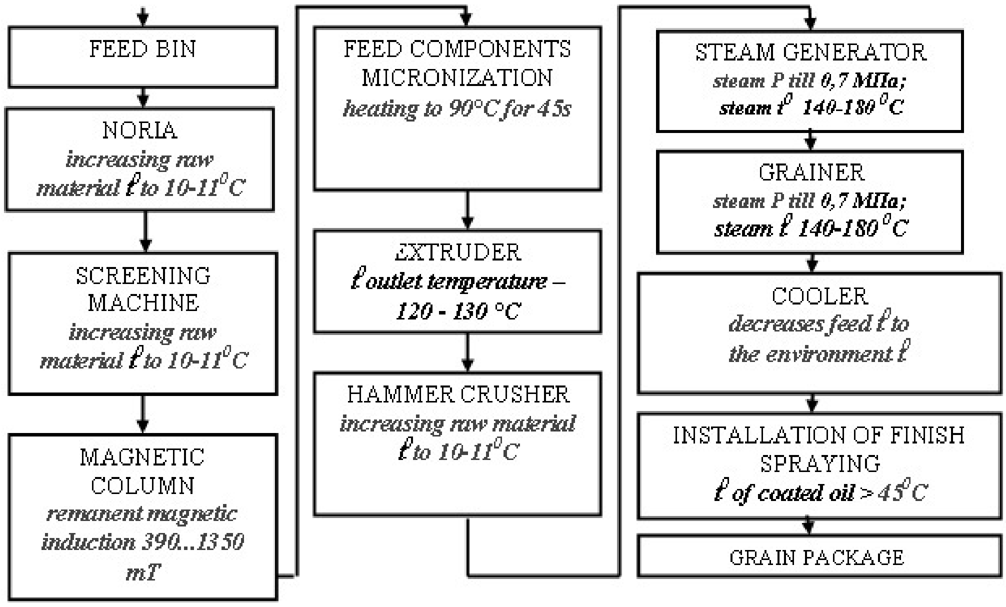

Fig. 1. **Operating conditions of technological equipment affecting ultrafine material**

The set of containers includes a supply tank 1, an accumulation tank 2, a dosing tank 3, a receiving tank 4 (Fig. 2). A distinctive feature of the presented dispenser is the presence of two isolated pneumatic chambers, which ensures an increase in the operating speed, an improvement in the dosing accuracy of ultrafine materials and the automatic introduction of ultrafine materials into the working feed mixture. The design of the control valve is a pair of steel shaft 27 with a bronze sleeve 30, forming a landing with a gap. The steel shaft in the dispenser workflow can take two positions in two mutually perpendicular planes, rotating as a result of the action of the control valve of the control valve around the longitudinal axis by 90 degrees.

The axial channel 26 of the steel shaft 27 is connected to a non-through radial channel of a cylindrical shape 31, and the axial channel 32 is connected to a non-through radial channel of a cylindrical shape 33. The radial channels 31 and 33, when the steel shaft 27 is rotated around its longitudinal axis by 90 degrees, can take horizontal or vertical position. The bronze sleeve of the control valve also has radial channels of cylindrical shape 34 and 35 located in one vertical plane coaxially with the channels 31 and 33.

Pneumatic dispenser operates as follows. In the “standby” state, the steel shaft of the control valve 27 is located relative to the bronze bushing 30 in such a way that the channels 31 and 33 are aligned coaxially with the radial channels 34 and 35. Compressed air through the axial channel 26 enters the consumable capacity of the pneumatic dispenser, passing sequentially radial channel 31 and radial channel 34.

At the same time, compressed air through the axial channel 32 enters the flow tank of the pneumatic dispenser, passes radially through the radial channel 33 and the radial channel 35, imparting a turbulent movement of the suspension to prevent caking or settling of ultrafine powder. Under the action of compressed air entering the supply chamber through the pipe 7, the membrane 8 is deformed (bends to the right) and moves the rod with a hollow channel 9 and the fitting 10 to the right. Dosing tank 3, located in the nozzle 10, also moves to the right and is blocked by the inner walls of the channel. The return spring 11 is compressed, the valve 12 allows compressed air to enter the stem with the hollow channel 9. The inlet shutoff valve 13 and the outlet shutoff valve 14 open and the dose of ultrafine material located in the tank 3 enters the receiving tank 4 for introduction into the feed mixture.

Under the action of compressed air entering the chamber providing the drive of the control valve mechanism through the pipe 17, the membrane 18 is deformed (bends to the right) compressing the return spring 20 and moving the stepped shaft 19 to the right. The rack gear 22 is rigidly fixed to the connecting shaft 23. The shaft 23 is rigidly fixed relative to the rack 21 and is located vertically. When moving the stepped shaft 19 together with the rack 21, the rack wheel 22 is rotated by a certain angle.

The opposite end of the shaft 23 is rigidly connected to the bevel gear 24, which in contact with the bevel gear 25 forms a gear train. When the rack wheel 22 is rotated, rotation is made to the steel shaft 27, i.e. the control valve is controlled. Calculation of the diameter and selection of the gear module of rack and pinion gears provides a 90-degree rotation of the control valve control shaft. The radial through channel 37 of the steel shaft 27 is combined with the through channel 38 of the bronze sleeve 30, which allows the suspension from the supply tank to move into the storage tank. This position of the radial channels of the steel shaft 27 and the bronze sleeve 30 of the control valve corresponds to the “dosing” state of liquid-like ultrafine materials (Fig. 2).

The housing 28 connecting the chamber for supplying the dose of the suspension to the receiving tank and the chamber providing the drive of the distribution valve mechanism has an opening 29, the purpose of which is to communicate the enclosed space of the housing with the atmosphere so as not to interfere with the movement of the stepped shaft by air concentration in the inter-chamber space. As soon as the supply of compressed air stops, then under the action of return springs 11 and 20, the rod with a hollow channel 9 and a stepped shaft 19 will move to the left, in the initial position.

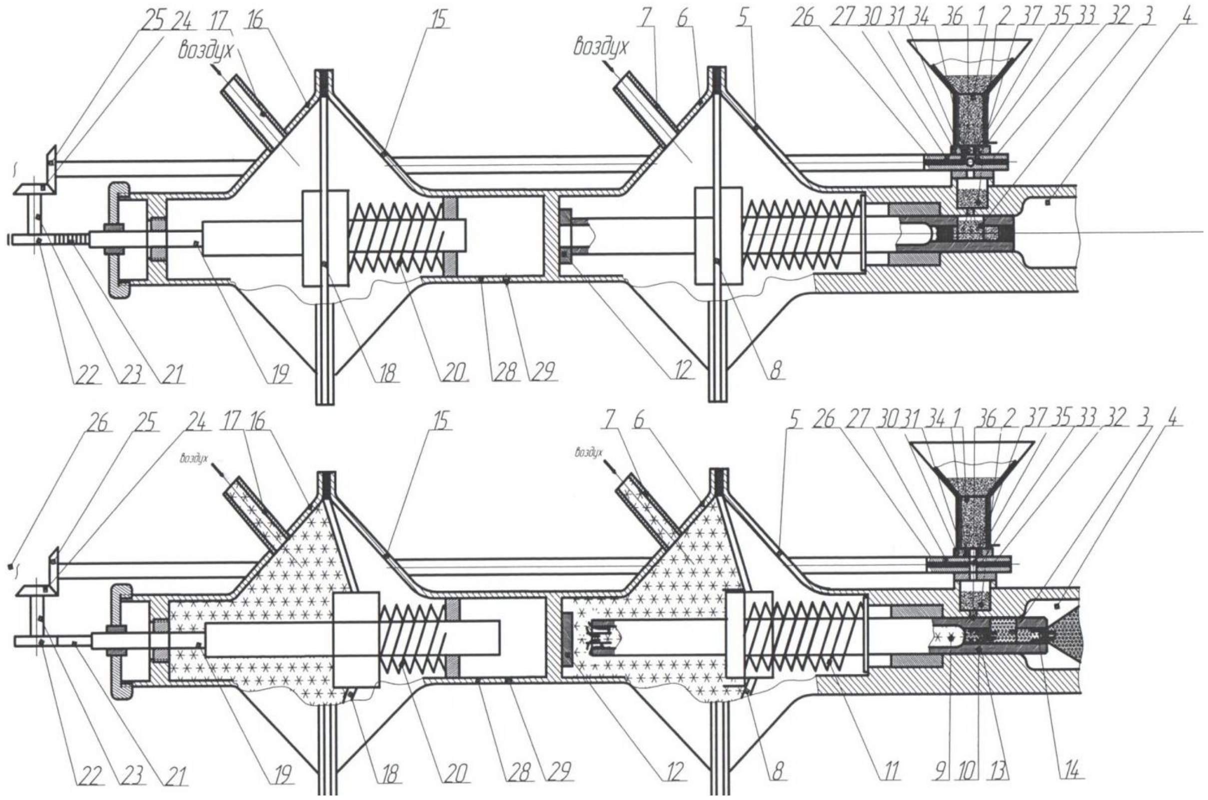

Fig. 2. **Pneumatic dispenser for liquid-like ultrafine materials (longitudinal section):**
“ready station” position, “dosing” position

As a result, the control mechanism will rotate the steel shaft 27 of the control valve 90 degrees to the “standby” position. The fitting 10 will return to its original position, in which the cumulative and dosing cameras will receive a message. The suspension of liquid-like ultrafine materials will move from the storage chamber to the metering chamber. When compressed air is supplied through the nozzles 7 and 17, the process is repeated.

Figure 3 shows a fragment of a standard industrial line for the production of animal feed with the inclusion of the authors’ batcher at the finish site.

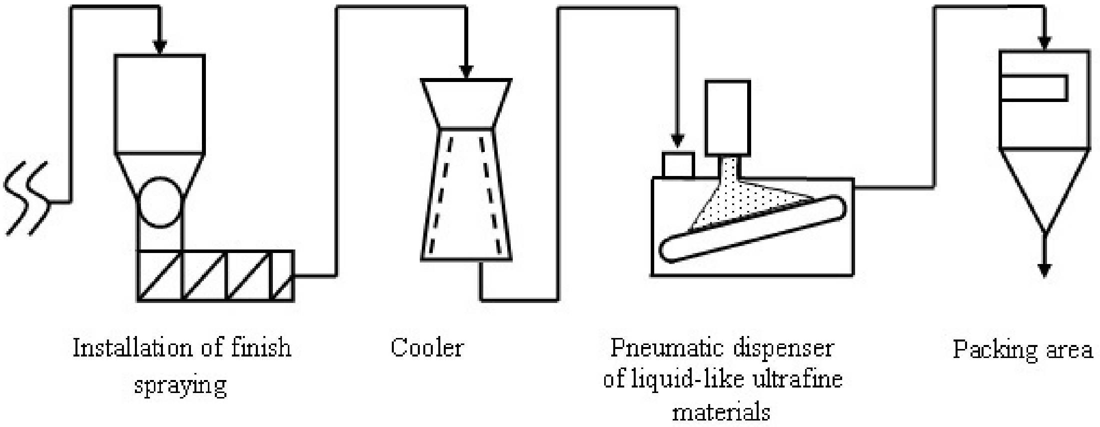

Fig. 3. **Fragment of a production line for production of animal feed with the inclusion of a dispenser of ultrafine materials**

Results and discussion

To perform a dynamic calculation of the membrane actuator of any of the isolated pneumatic chambers, we determine the working force on the rod F_{rod}, when moving the center of the membrane by a predetermined value $x = 3$ mm, the response time of the membrane actuator, the time of filling the membrane chamber to a given pressure and evaluate the working force on the membrane rod during its deflection by the value of the stroke of the rod.

Initial data: membrane diameter $D = 320$ mm, washer diameter $d = 224$ mm, rubber-fabric membrane thickness $h = 8$ mm, compressed air pressure $p = 5\cdot 10^4$ kgf·m^{-2}, elastic modulus of the material $E = 175$ kgf·sm^{-2}, initial tension force springs $P_0 = 10$ kgf, free deflection of an unloaded membrane $x_0 = 12$ mm (determined experimentally for the ratio $\rho = d/D = 0.7$ according to the known method [9]), the initial coordinate of the center of the membrane $x_c = 32$ mm.

To determine the working force on the rod, we use the well-known calculation formula, the conclusion of which is given in [9,10]:

$$F_{rod} = \frac{\pi p\left(\frac{D}{2}\right)^2}{3} a\left(1 - \frac{x\sqrt{b}}{\sqrt{(5a^2+b)(x_0)^2 - 5a^2x^2}}\right), \qquad (1)$$

where $a = 1 + \rho + \rho^2$, $b = (1-\rho)^2(4 + 7\rho + 4\rho^2)$.

When $a = 2.19$, $b = 0.9774$.

$$F_{rod} = \frac{3.14\cdot 5\cdot 10^4\cdot 256\cdot 10^{-4}\cdot 2.19}{3}\cdot\left(1 - \frac{3\cdot 10^{-3}\cdot\sqrt{0.9774}}{\sqrt{24.96\cdot 144\ 10^{-6} - 23.98\cdot 9\cdot 10^{-6}}}\right); F_{rod} \approx 2787\ \text{kgf}\ .$$

To calculate the response time of the membrane actuator, we use the initial data of formula (1), to which we add: the magnitude of the rod stroke $l = 11$ mm, the flow rate of the pneumatic system, by which we mean the ratio of the actual air flow during injection to theoretical $\mu = 0.35$, given the rigidity of the membrane with $c = 7000$ kgf·m^{-1} and the area of the supply pipe $S = 2\cdot 10^{-5}$ m^2.

The air pressure in the isolated pneumatic chambers at the beginning of the process is 10-11 kgf·m^{-2} (established experimentally), the effective membrane area is calculated by the formula

$$S_{eff} = \frac{\pi}{3}\left(\frac{D^2}{4} + \frac{D\cdot d}{4} + \frac{d^2}{4}\right) \approx 59\cdot 10^{-3}\ \text{m}^2.$$

The time of movement of the center of the membrane is determined as follows [9,10]:

$$t = \frac{5.06 l S_{м}}{\mu S p S_{eff}\cdot 10^3}\cdot\left[(0.857l + 0.714x_c)\cdot c + p_a S_{eff} + P_0\right]\ . \qquad (2)$$

$$t=\frac{5.06\cdot 11\cdot 10^{-3}\cdot 3.14\cdot 256\cdot 10^{-4}}{0.35\cdot 2\cdot 10^{-5}\cdot 5\cdot 10^{4}\cdot 59\cdot 10^{-3}\cdot 10^{3}}\cdot$$
$$\left[\left(0.857\cdot 11\cdot 10^{-3}+0.714\cdot 32\cdot 10^{-3}\right)\cdot 7000+10^{4}\cdot 59\cdot 10^{-3}+10\right]\approx 0.178\,\text{s}.$$

We calculate the time of filling the membrane chamber to a given pressure after stopping its center (for instance, up to 80 % of the compressed air pressure $0.8\cdot 5\cdot 10^4 = 4\cdot 10^4$ kgf·m^{-2}) [10]:

$$t=3.62\cdot 10^{-3}\cdot\frac{V_{min}}{\mu\ \ S}\left[\psi_1\left(4\cdot 10^4\right)-\psi_1\left(1.15\cdot 10^4\right)\right] \tag{3}$$

where $V_{min}=S_{м}\cdot x_c+S_{eff}\cdot l=3.14\cdot 256\cdot 32\cdot 10^{-7}+59\cdot 11\cdot 10^{-6}=3.219\cdot 10^{-3}\ \text{m}^3$,

the values of the preparatory time function ψ_1 are determined graphically from the experimental dependence after translating the arguments into dimensionless form:

$$t=3.62\cdot 10^{-3}\cdot\frac{3.219\cdot 10^{-3}}{0.35\cdot 2\,10^{-5}}\left[\psi_1(0.8)-\psi_1(0.24)\right]\approx 0.96\,\text{s}\,.$$

Thus, the response time of the membrane actuator is ≈1.14s. In the event that the membrane is made of a more flexible material, or is severely worn during operation, in the formula (4), V_{min} is replaced by V_{max}:

$$V_{max}=S_{м}\left(x_c+l\right)=3.14\cdot 256\cdot 10^{-4}\left(0.032+0.011\right)=3.45\cdot 10^{-3}\ \text{m}^3.$$

The response time of the membrane actuator increases lightly and will be ≈1.21 s.

We calculate the air pressure in the isolated pneumatic chambers at the end of the stroke [10]:

$$p_l=p_a+\frac{c\cdot l+P_0}{S_{eff}} \tag{4}$$

$$p_l=10^4+\frac{7000\cdot 11\cdot 10^{-3}+10}{59\cdot 10^{-3}}=1.15\cdot 10^4\ \text{kgf·m}^{-2}.$$

Let us determine the working force on the membrane rod during its deflection by the value of the stroke of the rod, taking into account the air pressure in the isolated pneumatic chambers at the end of the stroke according to the formula (1):

$$F_{rod}=\frac{3.14\cdot 1.15\cdot 10^4\cdot 256\cdot 10^{-4}\cdot 2.19}{3}\left(1-\frac{11\cdot 10^{-3}\cdot\sqrt{0.9774}}{\sqrt{24.96\cdot 144\cdot 10^{-6}-23.98\cdot 121\cdot 10^{-6}}}\right)-10\approx 44\,\text{kgf}\,\cdot$$

The greatest force on the rod occurs at the time of the inlet of compressed air into the chamber, then it decreases, since the pressure of the compressed air is gradually balanced by the elastic stretching of the membrane.

The main technical characteristics of the pneumatic dispenser of liquid-like ultrafine materials of the authors' design are presented in Table 1.

Table 1

Technical characteristics of the pneumatic dispenser for liquid-like ultrafine (nano) materials

Parameter		Value	
Dimensions		411X370X555 mm	
Weight		3,703 kg	
Air chamber		**Spray**	
Parameter	Value	Parameter	Value
Type of action	Straight	Suspension consumption	0.81 l·min^{-1}
Effective Membrane Area	590 cm^2	Pressure	0.2 MPa
Outside full diameter	370 mm	Material	Brass, stainless steel
Valve rod travel	11 mm	Drop size spectra	Extra fine
Membrane thickness	8 mm	SSpray pattern	Symmetrical torch with an angle of 120º

Laboratory experiments and engineering calculations were carried out on the basis of the Engineering Department of the Orenburg State Agrarian University, a prototype dispenser is tested during production experiments in the university's educational facilities. The design of the dispenser for liquid-like ultrafine materials was submitted for research to the Federal Institute of Industrial Property, where a positive decision on the grant of a patent of the Russian Federation was received on January 17, 2020 [11].

Conclusions

The studies conducted allowed the authors to develop a science-based approach to improving the efficiency of industrial production of combined feed based on the use of innovative components:

1. the influence of the conditions of formation of the working feed mixture on the properties of ultrafine metal powders was experimentally established;
2. we received engineering solutions to the problem of dosing nanopowders of metal-trace elements in the preparation of feed mixtures based on an analysis of the set of technological conditions and dynamics of the properties of ultrafine materials;
3. a system of engineering and technical calculations was completed, on the basis of which the main technical characteristics of the pneumatic dispenser of liquid-like ultrafine materials of the authors' design were determined;
4. dynamic calculation of the membrane drive allowed to determine: the working force on the rod $F_{rod} \approx 2787$ kgf, response time of the membrane actuator ≈ 0.178 s, time of filling the membrane chamber to a predetermined pressure ≈ 0.96 s and other parameters.

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