# On the issue of substantiation of the mathematical model of the process of preparation of mixtures of protein-vitamin-mineral feed additives

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**Abstract.** The process of preparing feed mixtures using additives is a biotechnical system with deterministic relationships with technological and technical and economic characteristics, and a group of input, disturbing, control and output factors, taking into account which it is necessary to determine the rational machine technology, the structure of operations and the corresponding technical solutions that are embedded in the design of the unit. To describe the processes of mixing compound feeds, the main attention is paid to the analysis of energy parameters, the establishment by experimental means of rational parameters and modes of operation of mixers of different types, the determination of the speed of the product movement in the mixer, its performance and evaluation of the quality of mixing. The development of a general theory of the choice of rational modes and design features of mixers is carried out by compiling a system of equations that describes the functional behavior of individual elements, as well as the influence of connections with external factors imposed on their functioning.

## 1 Introduction

The solution of many problems that have arisen recently in the agro-industrial complex of the Russian Federation largely depends on the technical equipment of agricultural production, as well as the introduction of new promising technologies. Special attention should be paid to the livestock industry, the final products of which occupy the first place in the human nutritional diet [1].

The development of the livestock sector, in turn, is impossible without a stable feed base, which is able to provide enterprises and farms with the necessary feed components.

In this regard, there is an increasing interest in methods and technologies that allow state, farm and subsidiary agricultural production independently and with low material and financial costs, to receive balanced feed rations throughout the year.

One of such promising technologies is the hydroponic cultivation of green fodder. Hydroponic green food (HGF) contains the required nutrients and vitamins, is well eaten

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and absorbed. It should be noted that a common disadvantage of most of the existing equipment for the implementation of this technology is the low level of mechanization of sowing and harvesting operations [1-3].

The second promising technology of feed production is the preparation of full-fledged compound feeds based on protein-vitamin-mineral concentrates of additives (PVMA), which are a mixture of protein feeds enriched with vitamins, minerals, antibiotics and other substances [4-5].

Studies of the physiological role of feed components carried out by domestic and foreign scientists and specialists in the feeding of agricultural (agricultural) animals [4-5] allowed us to formulate three main conditions that formed the basis for the development of means of mechanization of animal feeding technologies:

- preparation of nutritionally balanced and quality feeds;
- giving animals a rationally necessary amount of feed;
- simultaneous intake of feed components into the animal's body.

The first condition indicates the need to feed agricultural animals with multicomponent diets that allow them to fully balance their nutritional needs. The realization of this condition was the development of a structure of mechanized technological operations aimed at giving raw materials new properties that improve the assimilation of feed and health, as well as reduce the unit costs of obtaining livestock products.

The second condition concerns the provision of agricultural animals with a sufficient amount of feed material and is solved by their normalized feeding. The recommended feed volumes are favorable conditions for the development of mechanization tools with a given productivity.

. The third condition is based on the formulated basics of balanced nutrition of agricultural animals and the organization of the feeding process, which ensures them. It has been established that feeding with full-fledged mixtures in comparison with component-by-component feeding allows reducing material costs by 15-20%. In addition, a number of mechanized feed preparation technologies have been developed for the main feed lines. The exception is the production of compound feeds, which in the form of concentrates or full-fledged compound feeds are an obligatory component of feed mixtures of a wider range. Due to the content of protein-mineral additives, vitamins, antibiotics, amino acids, etc. in the feed, a more efficient use of all other components of the feed ration and an increase in the productivity of agricultural animals is ensured.

The above conditions and their rational implementation are the basis of the development of resource-saving mechanized feed preparation technologies.

One of the main tasks of the production of compound feeds is to obtain a mixture that is uniform in composition. The quality of the mixing process ultimately determines the yield of livestock products, as well as the cost of material and energy resources for its production.

Currently, one of the aspects of the state economic policy of the Russian Federation is the decentralization of agricultural production. As for the livestock industry, there is a need to develop means of mechanization of the compound feeds preparation directly in farms and subsidiary farms. At the same time, the technological equipment of production is simplified, the metal and energy intensity of the process is reduced, as well as transportation costs. For the preparation of compound feeds, own raw materials can be used, which contributes to the rational and efficient use of feed resources of the farm and reduces feed consumption.

To organize the production of compound feeds in farms and subsidiary farms, reliable, easy-to-operate units and installations for grinding, dosing and mixing are needed, which would allow producing compound feed from their own raw materials, enriching it with the necessary additives of industrial production.

The purpose of the research is to determine the place of the operation of preparing feed mixtures in the general technology of feeding agricultural animals, to analyze the existing analytical dependencies of the mixing processes of materials, and to substantiate the directions of theoretical research of the parameters of the installation for obtaining a mixture of feed additives.

## 2 Results of research

*A systematic approach to the study of the processes of preparation and use of compound feeds.* Justification of rational parameters of the technological process of preparation of compound feeds and its component, in the form of mixtures of additives, as a certain type of subject-practical human activity, requires taking into account the totality of factors that affect the mixing process. The process under consideration can be presented in the form of a closed set of transformations of raw material components into a homogeneous feed mixture.

The estimated characteristics of the selected mixing process technology are influenced by four groups of parameters: incoming, disturbing, controlling and outgoing. At the entrance to this aggregate, the physical and mechanical properties of each of the components used, their quantitative ratio by weight according to the recommended feeding rations, feed nutrition, feed mixture costs per unit of livestock products, the cost of mechanization and deductions for their operation are added.

The disturbing factors include specific indicators of the cost of metal structures, the cost of grain components, purchased additives, received livestock products, energy sources and wages.

The controlling factors, as a rule, manifest themselves through the daily need of the farm for compound feed, the productivity of the feed unit, energy and labor costs.

The output parameters are the dimensional characteristics of the crushed product and its alignment, the uniformity of the mixtures obtained, the coefficient of increasing the nutritional value of the compound feed prepared according to the proposed technology and its technical equipment, as well as technical and economic parameters, which primarily include productivity, unit labor costs, energy intensity, annual economic effect [6]. In addition to these groups of parameters, the efficiency of using the obtained compound feed by assimilating it by the animal's body also has an inverse effect on the characteristics of the studied mixing process, which is associated with the properties of the resulting product and its feeding.

Due to the multifaceted dependencies of the mechanized process of mixing compound feeds, it is advisable to consider it as a complex multilevel dynamic system that has a hierarchical structure that is, it consists of a number of subsystems located at different levels [7]. The requirements of such a structure are most met by the mixed biotechnical system "man – components of feed raw materials (materials) – technology and technical means of mixing (machine) – the body of an agricultural animal". In general, this system consists of separate subsystems located at different levels of influence. The functioning of this system consists in performing a number of operations with feed raw materials, and its effectiveness is achieved through the most rational, high-quality and intensive conversion of feed components into livestock products. Therefore, the agricultural animal acts as the main link of the considered biotechnical system. In the sphere of agricultural production, an animal performs a dual role, being both a means and an object of labor. Another biological link is a person who is present in all subsystems as a direct producer of intermediate and final products, or an organizer of production. A person is the most active element of the system. The technical deterministic links of the system will be materials and machines (means of mechanization), which will represent, respectively, the subject and method of labor. They are also present in all subsystems of the hierarchical structure.

The subsystem of the first level is a set of technological mechanized processes of a deterministic nature (dosing of components of micro- and macro-additives, their preparation, preparation of mixtures of additives, organization of grain supply, grinding of grain components, formation of metered grain flows, preparation of feed mixtures). Most of the processes and operations in the first subsystem are carried out mainly with the help of mechanical technical means that are installed permanently, provided with the delivery of feed raw materials and the export of the processed product – compound feed. The mixing process can be considered as the main operation in obtaining mixtures, and it can be carried out at one-time or step-by-step levels. A significant influence on the results of work in the first subsystem is exerted by the applied machine technology, the structure of flows, the technical solutions embedded in the machines, the adaptability of machines and their components to operation and maintenance.

The second-level subsystem displays the connections within individual processes and the nature of work operations, the combination of mechanical methods of preparing feed mixtures with thermal, chemical or biological methods. The issues of the influence of external factors on the state of technical means, the impact of technological processes on the environment, as well as ergonomic requirements are considered.

The subsystem of the third level takes into account the delivery, accumulation and storage of an operational stock of raw materials; the use of compound feed as an integral part of mixtures of a wider range – wet bags and bulk mixtures with the introduction of stem and succulent feeds into them; the structural connections of biological and technical links of the system with engineering structures and communications are determined; the organization of waste disposal measures is taken into account production and their disposal.

The subsystem of the fourth level displays the connections of incoming and final elements that take part in the process of preparing compound feeds. This subsystem includes the physical and mechanical characteristics of the components of grain materials and additives used, the quality indicators of intermediate and end products, as well as the properties of the materials embedded in the machine design. In the subsystem, the biotechnical link (grain, processed products and additives) and the technical link (structural materials used in machines [7] are considered separately.

After a detailed review and description of the subsystems, the main task of the study can be formulated – consideration of the process of preparing mixtures of feed additives to simplify the structure of constructing mathematical models. As a result, it can be concluded that analytical research, for the implementation of the task, is sufficient to perform within the first subsystem, which can be displayed by processes of a deterministic nature. But taking into account the previously mentioned versatility of the connections of the mixing process with other factors that operate in subsystems of higher levels, it is necessary to perform an analysis and take into account the influence of these factors on the choice of optimal parameters of the mixing process.

To compile a rational structure of a mathematical model of the process of mixing feed additives, it is advisable to pre-analyze the existing analytical dependencies and identify the presence in them of connections between design parameters, as well as outgoing and incoming factors.

*Analysis of existing mixing models*. Issues of mixing different materials are given great attention in various industries and agriculture. The complexity and variety of phenomena that occur during mixing eliminated the need for a complete analytical description of this process, and reoriented researchers to develop simplified models of mechanisms and means of mechanization for the preparation of mixtures that more or less meet real conditions.

Наиболее распространенными модели смешивания являются:

The most common mixing models are:

- convective mixing – transfer of relatively large portions of material from one part of the volume of the working chamber to another ("macro mixing");
- diffusion mixing – redistribution of individual particles of material in micro volumes ("micro mixing");
- shear mixing as a process that occurs due to the formation of sliding areas between layers of material that move relative to each other in the presence of a velocity gradient;
- mixing as a probability is a statistical process as a result of the distribution of material particles in the volume of the working chamber;
- mixing as a set of "elementary" processes, each of which displays the properties of some class of phenomena and obeys the laws that are described by certain ratios.

The convective mixing model has not found widespread use due to the fact that it describes the movement of relatively large volumes of material, in which a sufficiently high mixing quality is not provided. In addition, there is a practical difficulty in calculating the parameters included in the equations and dependencies describing this process model.

The diffusion mixing model, which is analogous to the diffusion of gases that do not react with one another, has become more widespread. "Micro-mixing" through diffusion makes it possible to obtain a more complete redistribution of particles in the micro-volumes of the mixture.

The basis of such a model is Fick's second law for diffusion:

$$\frac{dc(x,t)}{dt} = \frac{d}{dx} \cdot \left[D' \cdot \frac{dc(x,t)}{dt}\right], \tag{1}$$

where $c(x,t)$ – the relative concentration of the control component in the mixture during time t at a distance x from the initial separation surface;

$D'$ – diffusion coefficient, $m^2/min$.

The practical application of dependence (1) is complicated by finding the coefficient D^'. Based on the fact that diffusion is a kinetic process, the formula can be used as the basis for further calculations

$$J = 1 - e^{-c\tau}, \tag{2}$$

where $J$ –an indicator characterizing the degree of mixing;

$c$ – mixing rate constant;

$\tau$ – mixing time, min

Considering equation (2), it follows that its practical application will also be complicated due to the unknown constant c. The constant c takes into account the dependence of the mixing process on many factors, including the physical and mechanical properties of the components being mixed, the geometry of the working bodies, the operating mode of the mixer, etc. Thus, solving equation (2), it is possible to find only the empirical dependence of the mixing process in a certain range of its parameters, with specific values for each case under consideration.

The model of preparation of the mixture by shifting allows the formation of a number of layers from the mass of the material during its mixing, which move relative to each other at different speeds. Mixing occurs due to the precipitation of particles under the influence of gravity from one layer into the cavity of another. Such a model gives only a qualitative assessment of the mixing process.

Based on the analysis of scientific papers published by domestic and foreign researchers in the field of mixing of bulk and viscous media, it can be concluded that most of them consider this process as probabilistic. At the same time, according to one theory, the mixing process is most fully consistent with the alternative recovery process. According to another theory (Markov theory []), mixing is a homogeneous stationary "Markov" process, and the Kolmogorov equation with respect to the Markov process is used to describe it, which can be presented in the following simplified form

$$\frac{dq(x,t)}{dt} = -\frac{d}{dt}[T(x,t)\cdot q(x,t)] + \frac{d^2}{dx^2}[D(x,t)\cdot q(x,t)], \quad (3)$$

Where $x$ – the coordinate of the point of its movement in the axial direction;
$t$ – time, min;
$q(x,t)$ – probable density of control component particle distribution;
$T(x,t), D(x,t)$ – respectively, the transport and diffusion coefficients.

Equation (3) describes the mixing process as a combination of convective and diffusion processes. But the complexity of finding the coefficients T(x,t) and D(x,t) complicates its practical use.

A complete description of the process of mixing materials leads to complex analytical dependencies that only describe the process qualitatively, but cannot be used for its quantitative expression, due to the complexity of determining a number of constituent parameters.

The results of experimental and theoretical studies of the influence of numerous variable factors on the mixing process, which described a number of important aspects of this technological operation, are also of great importance. One of these aspects is the study of the influence of the rotation frequency of the mixer working body on the quality of the finished product [8].

Based on the above, it can be concluded that the main attention should be paid to solving the following tasks:

- analysis of the energy parameters of the mixing process [6, 7, 9];
- establishment by experimental means of rational parameters and modes of operation of mixers of different types [6, 8-11];
- determination of the product movement speed in the mixer and its performance [7, 9];
- determination of the mixing quality assessment [7 - 9].

To solve the tasks set, methods for calculating mixing equipment of various types that are not related to feed production can be used on the basis of previously obtained empirical data. Consequently, the initial data and experimental conditions may have significant discrepancies. As a rule, the results of these experiments are partial and do not reflect the basic laws of the mixing processes of bulk media. Поэтому предложенные методики не имеют общего назначения. Therefore, the proposed methods do not have a general purpose. For example, in [11], based on the analysis of the work of asphalt mixers, it is proposed to take the output value – the volume of the working chamber, depending on the specified performance, and then determine all other design dimensions. This method, based only on experimental data, is not suitable for practical calculations, since it does not establish the calculated dependencies of the mixer parameters with the technological process and mixing efficiency.

Another method of research is the choice as an output value for the calculation and design of feed mixers – productivity, which is determined by the daily need for feed preparation [9]. The required volume of the mixer is determined by the formula

$$V_{\text{см}} = \frac{Q\cdot T_{\text{см}}}{u\cdot j}, \quad (4)$$

where $Q$ – mixer capacity, kg/h;
$T_{cm}$ – mixing time of components, h;
$j$ – volume mass of the mixture, kg/m$^3$ ;
$u$ – efficiency index u=0.8-1.0.

For single - shaft cylindrical mixers , the required volume $V_{cm}$ of the working chamber is determined by the formula

$$V_{\text{см}} = \frac{\pi\cdot D_{\text{см}}}{4}\cdot L. \quad (5)$$

The diameter of the working chamber $D_{cm}$ will be determined by solving (4) and (5) together, relative to the desired value

$$D_{\text{см}} = \sqrt{\frac{Q \cdot T_{\text{см}}}{4 \cdot u \cdot j \cdot V_{\text{см}} \cdot L}}, \quad (6)$$

where $L$ – length of the mixer, m.

Calculation of the main parameters of the feed mixer (diameter $D_{n\ cm}$ and rotation speed n_(n cm)) it can also be carried out according to the methodology of similarity theory [7], by switching from a model to nature, in the form of

$$D_{n\ cm} = D_{m\ cm} \sqrt{\frac{Q_{n\ cm}}{Q_{m\ cm}}}, \quad (7)$$

$$n_{n\ cm} = n_{m\ cm} \sqrt{\frac{d_{m\ cm}}{d_{n\ cm}}}, \quad (8)$$

where $Q_{n\ cm}, Q_{m\ cm}$ – productivity, respectively, of the nature and model, kg/h; $D_{n\ cm}, D_{m\ cm}$ – diameters of the nature and model, respectively, m.

The disadvantage of this technique is that it does not determine the rational parameters of the model.

According to the volume-mass theory [10], the output values for determining the main parameters of the mixer are its mass (W) or volume (V) capacity, which are determined depending on the specified performance Q in the form

$$W = Q \cdot T_{cm}; \qquad V = \frac{W}{j}. \quad (9)$$

The considered methods concern only the issues of obtaining a homogeneous mixture directly in the mixer and do not take into account the impact on the mixing process, the quality of the finished product and the characteristics of the flows of individual components included in the mixture. Consequently, these techniques can be applied to batch mixers.

The methods that can be applied to determine the parameters of continuous mixers should establish the dependence of the mixing quality on the degree of unevenness of the incoming flows of components. For example, the volume of the mixer $V_{cm}$, subject to a sinusoidal change in the incoming concentration of any component relative to the dispersed concentration at the outlet and inlet of the ideal mixer, is determined as

$$V_{cm} = \frac{qT_p}{2n} \sqrt{\frac{1}{G_0^2/G_1^2} - 1}, \quad (10)$$

Where $q$ – volumetric feed of the material into the mixer;

$T_p$ – the average value of the period of the sinusoid concentration of the control component;

$G_0^2, G_1^2$ – dispersion of concentrations at the outlet and inlet of the mixer.

The main condition for the production of feed is to ensure zootechnical requirements for the quality of the finished mixture, which is characterized by its degree of uniformity and compliance with the composition specified in the diet recipe. The latter depends not only on the processes that occur in the mixer itself, but also on the nature of the dosing of the output components. At the moment they are in the mixer, due to the probabilistic nature of the output streams, there are some deviations in the ratio of components from the norms set by the diet. Therefore, to obtain a given ratio of components in the finished mixture, the mixer must provide smoothing of uneven flows.

Thus, the conducted analytical study showed that the theoretical and experimental studies of the mixing process of various materials, including feed materials, carried out to date, are not enough to fundamentally solve the issue of determining the design parameters and operating modes of mixers for a specific purpose. This defines a new range of tasks for conducting analytical studies, in which it is necessary to take into account not only the functional dependencies between the parameters of the installation and the modes of the mixing workflow, but also to take into account the action of incoming, disturbing, controlling and exiting factors. Therefore, the structure of the mathematical model, in addition to the dynamics equations that describe the process of moving the feed mass itself, should be supplemented with coupling equations that will characterize the influence of the biotechnological properties of raw materials and the resulting feed, as well as the technical and economic performance of the mixing plant.

## 3 Conclusion

1. The process of preparing feed mixtures using additives is a biotechnical system with deterministic relationships with technological and technical and economic characteristics, and a group of incoming, disturbing, controlling and exiting factors, taking into account which it is necessary to determine a rational machine technology, the structure of operations and appropriate technical solutions that are embedded in the design of the unit.
2. The results of the analytical study showed that in order to describe the processes of mixing compound feeds, the main attention is paid to the analysis of energy parameters, the establishment of rational parameters and modes of operation of mixers of different types experimentally, the determination of the speed of movement of the product in the mixer, its performance and evaluation of the quality of mixing.
3. The development of a general theory of the choice of rational modes and design features of mixers is carried out by compiling a system of equations that describes the functional behavior of individual elements, as well as the influence of the links imposed on their functioning with external factors.

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