

**TECHNICAL AND TECHNOLOGICAL SUPPORT FOR FEED MATERIAL MIXING****Elchyn ALIIEV**, Doctor of Technical Sciences, Senior Researcher, Professor**Ruslan PONOMARENKO**, postgraduate student

Dnipro State Agrarian And Economic University

АЛІЄВ Ельчин Бахтияр огли, д.т.н., старший дослідник, професор**ПОНОМАРЕНКО Руслан Григорович**, аспірант

Дніпровський державний аграрно-економічний університет

The article presents the results of a review study of modern approaches to feed material mixing and structural and technological solutions for mixing equipment used in compound feed production. The importance of high-quality mixing of complete feed, premixes, and protein-mineral-vitamin supplements for ensuring stable nutritional value, safety, and efficiency of animal feeding is substantiated. The main mechanisms of bulk material mixing-convective, diffusive, and shear mixing-as well as the features of their interaction at different stages of the technological process are analyzed. It has been established that, alongside the positive effect of these mechanisms on mixture uniformity, the possibility of segregation, remixing-induced re-segregation, and local accumulation of individual components should be taken into account. The main groups of mixture uniformity indices are considered, including variance-based indices, contact indices, and distance-based indices. The feasibility of using relative standard deviation as a practical criterion for assessing the uniformity of compound feed component distribution is demonstrated. The main designs of feed material mixers are analyzed, and their advantages and disadvantages are identified with regard to material movement patterns, energy consumption, mixing intensity, and susceptibility of components to segregation. The prospects of using Y- and V-shaped mixers in batch production of compound feed and premixes are substantiated. A structural and technological design of a Y-shaped bulk material mixer with a stepper-motor drive, gate servomotors, a damping system, an accelerometer, a rhombus-shaped distributor, and an automated control system is proposed. The application of these technical solutions creates the prerequisites for improving mixture uniformity, reducing mixing time, expanding the range of controllable operating modes, and decreasing energy consumption. The review results can be used for further substantiation of the structural parameters and operating modes of mixing equipment.

Keywords: compound feed, feed materials, mixing, mixture uniformity, segregation, mixing index, relative standard deviation, Y-shaped mixer, V-shaped mixer, bulk materials, premixes, automation, structural and technological design.

Eq. 1. Fig. 8. Tabl. 1. Ref. 60.

1. Problem formulation

Modern production of complete feed involves the use of a wide range of feed materials, including grain components, protein products, mineral substances, vitamins, premixes, and other feed additives. The rational combination of these components ensures the required balance of nutrients and directly affects animal productivity, feed utilization efficiency, and the quality of products of animal origin [1–3].

One of the main technological operations in compound feed production (Fig. 1) is the mixing of feed materials, the quality of which determines the uniform distribution of nutrients and biologically active components throughout the entire volume of the finished mixture. This issue is particularly relevant when using premixes, minerals, and other additives introduced in small quantities. Their non-uniform distribution can result in localized deficiencies or excesses of individual components, reducing feed efficiency and adversely affecting animal productivity and health [4–7].

In accordance with the Law of Ukraine “On Safety and Hygiene of Feed” [8], feed materials and finished feeds must comply with established requirements for safety, quality, and traceability. Therefore, their preparation and mixing technology must ensure not only compliance with the prescribed formulation but also the required level of uniformity of the finished feed mixture.



The efficiency of the mixing process is determined by the physical and mechanical properties of the components and the structural and technological parameters of the equipment. The quality of the mixture is significantly affected by particle size distribution, density, moisture content, flowability, particle shape, coefficients of friction, component ratios, degree of working chamber filling, mixing duration, rotational speed of the working elements, and the nature of their interaction with the material. Differences in component properties can cause segregation, making it difficult to obtain a uniform mixture.

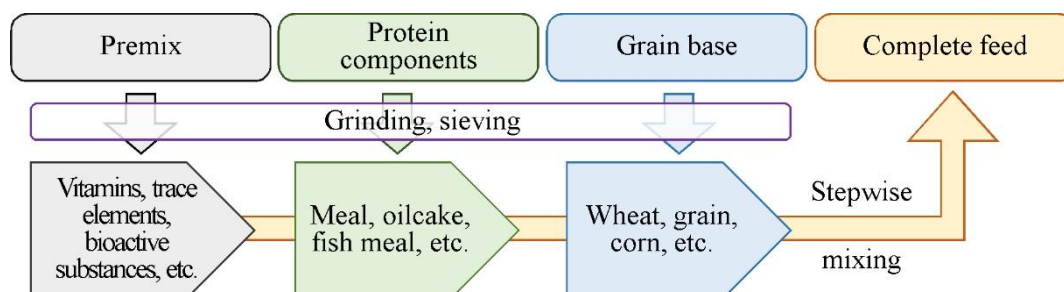


Fig. 1. Process flow diagram for the production of complete feed

Existing mixing equipment is characterized by a variety of structural designs and material movement patterns. Increasing mixing intensity generally requires greater mechanical action on the material, which may be accompanied by increased energy consumption. At the same time, excessive process duration does not always result in a proportional increase in mixture uniformity and may promote re-segregation of the components.

Therefore, improving the structural and technological solutions of mixing equipment and determining rational operating parameters that ensure intensive component movement, rapid achievement of the required degree of uniformity, and efficient energy use are highly relevant.

Thus, the problem lies in the need for a scientific substantiation of the technical and technological parameters of the feed material mixing process and improvement of the mixing equipment design to ensure the required uniformity of the feed mixture with minimum process duration and energy consumption.

2. Analysis of recent research and publications

Modern compound feed production technologies involve an integrated combination of operations for the storage, preparation, grinding, dosing, and mixing of feed materials. Technological lines (Fig. 2) may include separate sections for the preparation of grain, high-protein, mineral, and microcomponents due to differences in their physical and mechanical properties and the required dosing accuracy [1–9]. Studies of technological equipment used in compound feed production show that the efficiency of the entire production line largely depends on the coordinated operation of individual machines and, in particular, on the quality of component dosing and mixing.

Considerable attention in modern research is focused on the preparation of feed materials. Hammer and disc mills are used for grinding grain and protein raw materials, while the separation of grinding and classification operations is considered a promising approach to enable timely removal of the finished fraction from the working chamber and reduce energy consumption [10–13]. Recent studies of disc grain grinders, particularly those involving digital modeling of the particle fracture process, are aimed at substantiating the structural and operating parameters of working elements and improving the efficiency of raw material preparation [14–16]. At the same time, grinding quality has a direct effect on subsequent mixing, since differences in particle size and density can intensify segregation.

An important direction in improving technological lines is increasing dosing accuracy. Screw feeders are commonly used for the main feed components, whereas mineral components and premixes require considerably higher dosing accuracy and can be metered using specialized volumetric or vibratory devices [17–18]. Studies of modern dosing systems demonstrate the need to account for the physical and mechanical properties of the material, its flowability, and its tendency to form bridges or become suspended. This is particularly important for microcomponents, whose proportion in the formulation may be less than 1%, since dosing errors directly affect the stability of the nutritional composition of the feed.

A separate group of studies focuses on premix production (Fig. 3). It has been noted that, due to substantial differences in the mass fractions of individual ingredients, the mixing process should be considered as a sequence of micro- and macro-mixing stages. At the first stage, uniform distribution of the



microcomponents is ensured, after which the resulting premix is introduced into the main mass of the carrier and other components [19–21]. This approach makes it possible to reduce the non-uniform distribution of microingredients in the finished product.

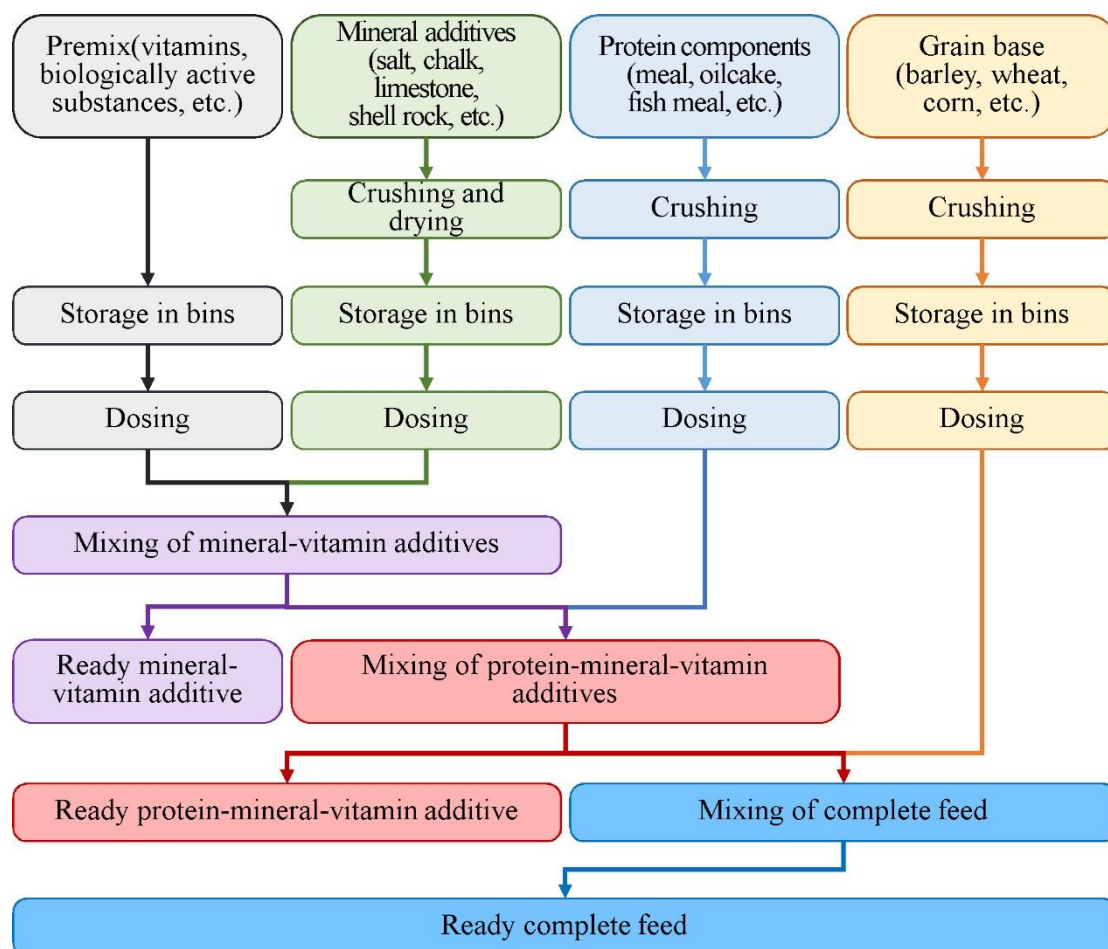


Fig. 2. Technological line for the production of compound feed supplemented with protein-mineral-vitamin additives

According to the results of studies [22–24], mixing quality depends on the type of mixer, process duration, and the sequence in which the components are loaded. Gravity and paddle mixers are used for mineral-vitamin mixtures, whereas screw and helical mixers are employed for the final mixing of feed components. However, the versatility of a mixer does not always ensure the required quality of the resulting mixture, particularly when there are significant differences in the physical and mechanical properties of the components.

Studies of mixture formation in paddle mixers show that the design of the working elements and their operating mode have a significant effect on material movement intensity and the final uniformity of the mixture [25]. Studies of two-section mixers have investigated the possibility of improving the efficiency of balanced feed mixture preparation through the rational combination of working zones [26]. Another research direction involves improving the working elements of dosing devices and ensuring a stable supply of components to the mixing chamber [28, 29].

The application of mathematical and numerical modeling makes it possible to investigate mixing processes in greater depth. In particular, discrete element method (DEM) modeling of feed mixture flow enables the trajectories of individual particles, their interactions, and the mechanisms of mixture formation to be studied [27–28]. This approach is promising for identifying insufficiently mixed zones, assessing the influence of the geometry of the working chamber and working elements, and substantiating the operating parameters of mixers.

Modern studies also consider ribbon-screw and other combined designs of bulk feed mixers. In particular, [29] investigated the structural and technological parameters of a ribbon-screw mixer, confirming

the relevance of searching for rational working-element geometry and operating modes. At the same time, studies of mixer-feeders indicate the need to ensure not only sufficient mixing intensity but also stable mixture quality over time and throughout the entire volume of the working chamber.

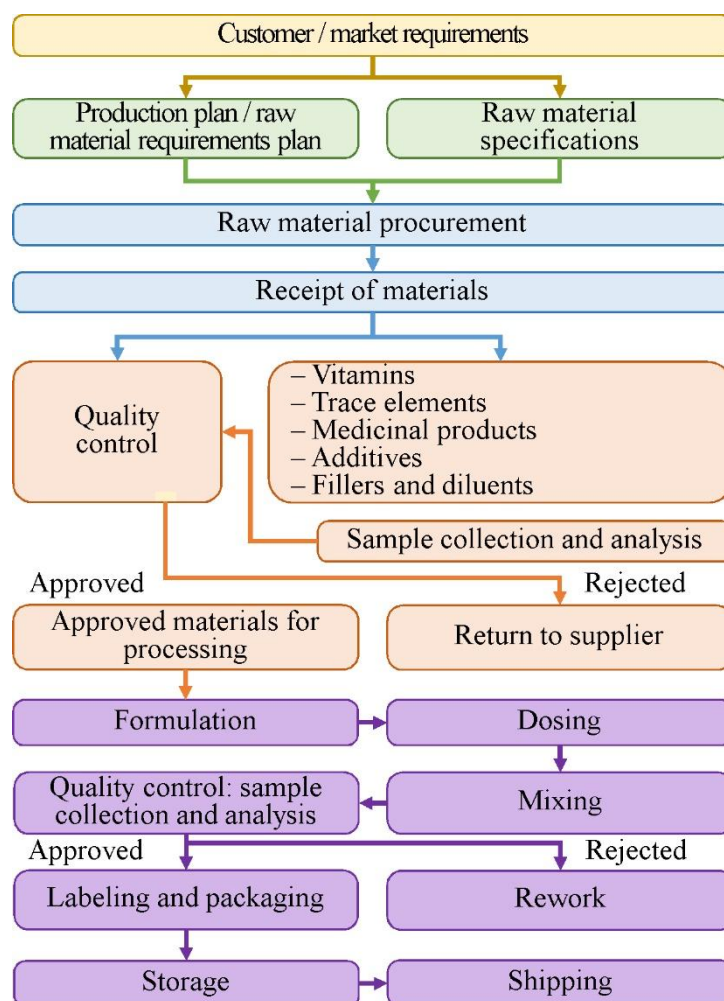


Fig. 3. Flowchart of the premix production process

One of the main indicators of mixing efficiency is the uniformity of the resulting mixture, which can be appropriately assessed using the coefficient of variation (CV). For high-quality premixes, a CV of less than 5% is generally considered desirable. However, an excessive increase in mixing duration does not always improve the result, since re-segregation of particles may occur after a certain level of uniformity has been achieved. Therefore, determining the optimal process duration is no less important than selecting the mixer design.

Analysis of the reviewed studies shows that existing technical solutions encompass a wide range of mixing equipment, from gravity and paddle mixers to screw, helical, and combined mixers. At the same time, most studies focus on individual designs or specific groups of feed materials. The relationship between the structural and operating parameters of mixers, the kinetics of achieving feed mixture uniformity, and the energy efficiency of the process remains insufficiently systematized.

Thus, an analysis of current scientific studies confirms the need for further investigation of feed material mixing processes, taking into account their physical and mechanical properties, working-element design, rotational speed, working chamber fill level, and process duration. A promising research direction is to establish the mechanisms governing the formation of a uniform mixture and determine rational technical and technological parameters of mixing equipment, which will make it possible to improve the quality of finished compound feed while simultaneously reducing process duration and energy consumption.

3. The purpose of the article

The aim of the article is to generalize and systematize modern scientific approaches to the study of

feed material mixing processes, the mechanisms governing the formation of uniformity in compound feed mixtures, and methods for its quantitative assessment, as well as to substantiate a promising structural and technological design of a Y-shaped bulk material mixer with automated control of operating modes.

4. Results and discussion

An in-depth study of the mechanisms of mixing and the efficiency of feed component blending is of great importance for optimizing technological processes in compound feed production and improving the design of mixing equipment. Despite the diversity of formulations and the intended use of feeds, the main mechanisms of mixing bulk feed materials remain common [30–32]. These include (Fig. 4): convective, diffusive, and shear mixing.

Convective mixing occurs as a result of the movement of individual masses (portions, “blocks”) of feed materials within the working volume of the mixer under the action of paddles, screws, or ribbon agitators. These volumes are repeatedly transferred from one zone to another, ensuring the redistribution of components throughout the working space and increasing the contact area between them. At the initial stage of the process, this mechanism is predominant, as it provides a rapid reduction in mixture heterogeneity at the macroscale. However, the size of the moving volumes depends not only on the mixer design but also on the flowability and particle-size distribution of the feed materials.

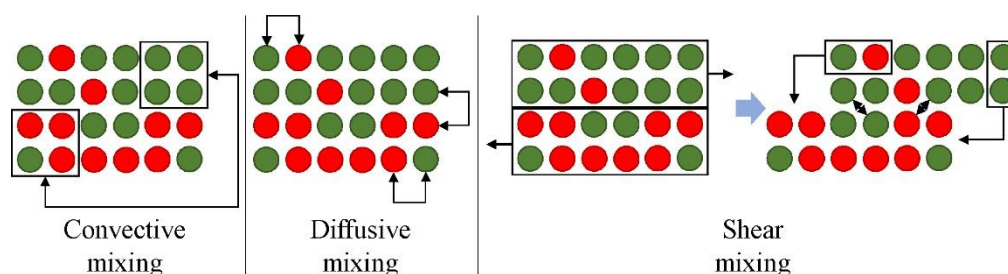


Fig. 4. Schematics of the mechanisms of convective, diffusive, and shear mixing

Diffusive mixing is associated with the random movement of individual particles within small local zones. In compound feed production, this mechanism is particularly important for the uniform distribution of microadditives, premixes, and vitamin-mineral components. The rate of diffusive mixing is significantly lower than that of convective mixing; however, it is precisely this mechanism that ensures the microscale homogeneity of the mixture. When the dimensions of heterogeneous zones become smaller than the characteristic dimensions of the moving masses, the role of convection decreases, and diffusion becomes the primary mechanism for achieving a high degree of mixing.

Shear mixing occurs in narrow slip zones characterized by a high velocity gradient between material layers. In these zones, intensive deformation of the bulk material, breakdown of agglomerates, and an increase in the contact area between groups of particles take place. The shear mechanism is closely associated with convective movement; however, it provides additional breakdown of lumps and improves the uniformity of component distribution, particularly for materials with increased moisture content or a tendency to agglomerate.

Characteristic mixing process curve. The mixing process of feed materials in an industrial mixer occurs simultaneously through the action of all three mechanisms (Fig. 5). Its progression can be conventionally represented by a curve showing the dependence of the degree of mixing on time [33–35]:

- Stage I (initial) – convective mixing predominates, resulting in a sharp decrease in the mixture heterogeneity index;
- Stage II (intermediate) – convective and shear mechanisms act simultaneously; the rate of improvement in mixture homogeneity gradually decreases;
- Stage III (final) – diffusive mixing predominates; the minimum value of the coefficient of variation is reached, after which slight fluctuations in the parameter may occur.

It should be noted that the actual industrial process of compound feed mixing is considerably more complex than its simplified representation. In practice, segregation, re-segregation, or local accumulation of microcomponents may occur.

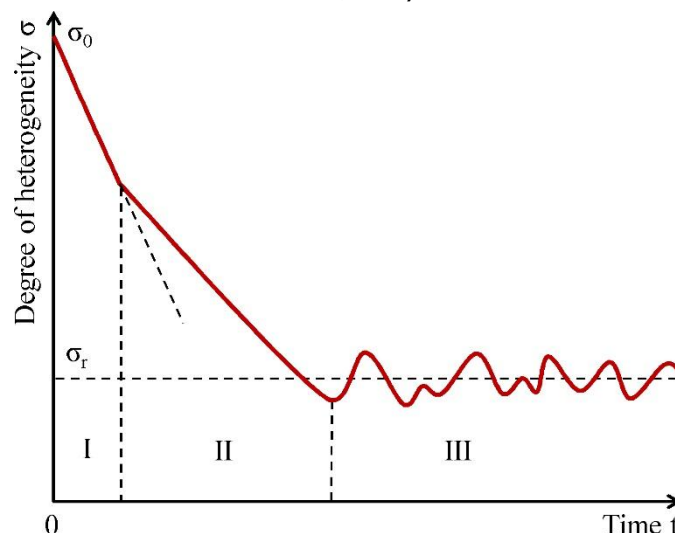


Fig. 5. Schematic representation of the characteristic curve of the mixing process

Evaluation of feed mixture homogeneity. One of the key tasks in compound feed production technology is determining the degree of homogeneity of the finished mixture. Although perfectly uniform mixing is desirable, it is practically unattainable due to the natural tendency of feed particles toward segregation, diffusion, and convective redistribution. Segregation occurs when there are differences in particle size, shape, or density, as well as under the influence of vibration, transportation, or material transfer [36–38].

For the quantitative assessment of compound feed homogeneity, mixing indices are used to characterize the uniformity of distribution of an individual component (often a tracer or microadditive) within the mixture. Typically, an index value of 1 corresponds to a completely mixed state, whereas 0 corresponds to a completely segregated state. An effective mixing index should be [39–41]:

- strongly correlated with the actual homogeneity of the finished product;
- independent of the type of mixer;
- simple to determine and statistically reliable.

Over the past several decades, numerous indicators have been proposed for assessing the mixing of bulk materials, including feed components. Most of them were developed for two-component systems and are based on statistical analysis of concentration variation in individual samples. Depending on the assessment approach, they can be divided into three main groups: variance-based indices, contact indices, and distance-based indices [42–44].

In compound feed production practice, variance-based methods, particularly RSD, are most commonly used because they are relatively simple, accessible, and demonstrate a good correlation with actual product quality indicators. However, in the following analysis, a modified RSD index will be used, which is determined as follows [27]:

$$h = 1 - \frac{1}{N} \sum_{i=1}^N \frac{|M_{1i} - M_{2i}|}{M_{1i} + M_{2i}}, \quad (1)$$

where M_{1i} is the mass of component 1 in sample container P_i ; M_{2i} is the mass of component 2 in sample container P_i ; N is the number of sample containers.

A comprehensive approach to evaluating mixture homogeneity makes it possible to optimize mixer operating conditions, reduce the risk of segregation, and ensure consistent compound feed quality.

When selecting a mixer for compound feed production, a number of technological factors should be taken into account, including: requirements for mixture homogeneity, the risk of particle segregation, possible changes in particle size during mixing, sensitivity of feed components to shear loads, energy consumption level (low- or high-energy mixing), temperature conditions, the number of process stages, batch or continuous operation, equipment cost, and ease of cleaning [45].

Mixers for bulk feed materials (grain, meal, oilcake, premixes, and mineral additives) are classified according to their operating mode as batch, continuous, and semi-continuous mixers.

According to the predominant mixing mechanism, the equipment can be conventionally divided into four main types: drum (gravity) mixers, convective mixers (with forced mixing), hopper mixers (mixing during gravity discharge), and fluidized-bed (fluidization) mixers.

Drum (gravity) mixers are among the simplest and most widely used types of equipment. Mixing takes place inside a sealed housing that rotates around an axis, causing the feed particles to roll and cascade over one another under the action of gravity.

The housing may have a cylindrical, double-cone, V-shaped, or Y-shaped configuration (Fig. 6). Such mixers are effective for free-flowing components with similar physical characteristics, for example, crushed grains of different crops [46–48].

Advantages: simple design, uniform mixing under properly selected operating conditions, and ease of cleaning due to the minimal number of internal components.

Disadvantages: insufficient efficiency for cohesive, moist, or dusty components; an increased risk of segregation when there are significant differences in particle size and density; and the possibility of stratification during discharge due to the formation of a funnel-shaped flow.

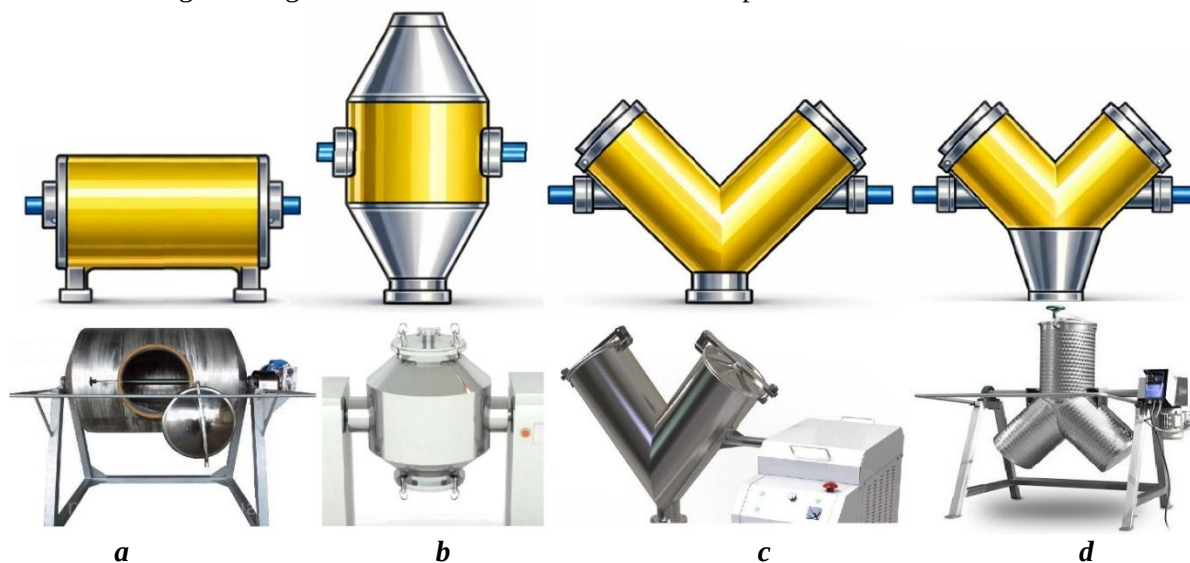


Fig. 6. Generalized schematics of drum (gravity) mixers:
a – horizontal mixer; b – double-cone mixer; c – V-shaped mixer; d – Y-shaped mixer

Convective mixers are widely used in the compound feed industry. Unlike drum mixers, mixing is performed through the forced transport of the material by a working element (ribbon, paddles, or screw). A typical design consists of a stationary housing (cylindrical, conical, or trough-shaped) and a rotating working element. The particles are transported from one zone to another, ensuring intensive convective mixing and reducing the risk of segregation. The main types (Fig. 7) include ribbon mixers, paddle mixers, orbital-screw mixers, and vertical screw mixers [49–53].

A ribbon mixer operates on the principle of opposing axial and radial material movement. Two helical ribbons (right- and left-handed) transport the feed mass in different directions, ensuring intensive mixing. Such mixers are widely used for dry compound feed mixtures and for introducing small amounts of liquid additives (oils, flavoring agents).

A paddle mixer provides faster mixing due to the high mobility of particles. The mixing cycle is usually significantly shorter than that of ribbon models.

Screw mixers (orbital or vertical) lift the material from the lower part of the hopper upward, creating circulation. They are suitable for large-volume feed mixtures; however, when processing moist or cohesive components, “dead zones” may form.

Advantages of convective mixers: high mixing intensity, reduced risk of segregation, and the possibility of continuous operation.

Disadvantages of convective mixers: lower efficiency for very large volumes, poor mixing of materials with different densities or particle sizes, the presence of “dead zones” in the hopper, high energy consumption, and rapid wear of mechanical components when processing heavy or abrasive mixtures.

Hopper mixers

In feed production, hoppers or silos can be used not only for storage but also for mixing. During discharge, a velocity gradient develops within the hopper, which promotes partial mixing of the material [54–55].

Axial mixing is achieved by recirculating the discharged material. This method is economically feasible for large quantities of grain when it is necessary to equalize quality parameters such as moisture



content, bulk density, and impurity level, which may vary depending on harvesting conditions.

To reduce segregation, distribution devices or partitions are used to distribute the material flow uniformly over the surface. The conical section of the hopper should ensure a mass-flow regime to prevent the formation of stagnant zones.

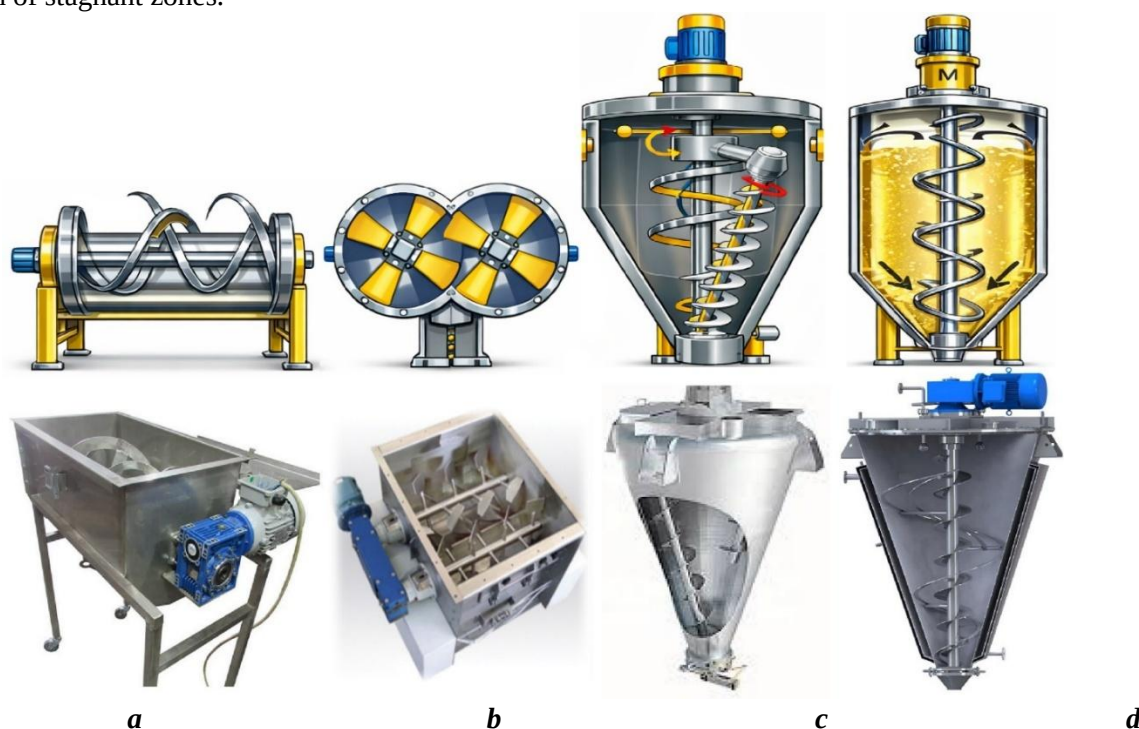


Fig. 7. Convective mixers:

a – ribbon mixer; b – paddle mixer; c – orbital screw mixer; d – vertical screw mixer

Disadvantages of hopper mixers: partial and non-uniform mixing, particularly in large volumes; the possibility of stagnant zones when the hopper lacks an appropriate conical shape or partitions; and material segregation when the components have different characteristics.

Fluidized-bed mixers

Mixing occurs by passing air through a layer of particles at a velocity sufficient to create a fluidized state. The particles acquire high mobility, which promotes intensive mixing [56–58].

Such units can simultaneously perform other technological operations, including drying, granulation, and coating. However, segregation may become a problem, particularly when there are significant differences in the size or density of the components.

Disadvantages of fluidized-bed mixers: segregation problems when particle size or density differs substantially; high requirements for airflow and energy consumption; and increased structural and maintenance complexity.

Features of mixer selection for compound feed production

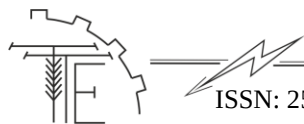
A comparison of different types of mixing equipment is presented in Table 1.

Selection according to process requirements. If additional grinding or breakdown of agglomerates is required, high-energy convective mixers with small clearances between the working elements and the housing are appropriate. For the production of premixes and protein-mineral additives, the following factors are particularly important: ease of cleaning, absence of material accumulation zones, minimal contact of the mixture with lubricants, and wear resistance when processing abrasive components.

When processing thermosensitive feed additives, heating of the mixture caused by mechanical energy should be taken into account, and a cooling system should be provided if necessary.

Batch mixers are appropriate for flexible production involving different formulations, whereas continuous mixers are more suitable for large volumes of uniform products.

Selection according to mixture quality. The primary criterion is achieving the required degree of homogeneity. Significant differences in particle size, density, and component proportions—for example, the addition of 0.5–1% premix to a grain-based mixture—create a risk of segregation. Mixers dominated by the convective mechanism, such as ribbon and screw mixers, are less prone to stratification than gravity mixers.



Selection according to economic indicators. Mixing costs include equipment depreciation, energy consumption, maintenance, and repair expenses.

In modern feed production, it is also important to consider the flexibility of the equipment in terms of changing formulations and the possibility of rapid transition between different types of compound feed.

Thus, the selection of a mixer type for feed materials should be based on a comprehensive analysis of the physical and mechanical properties of the components, requirements for finished-product quality, operating conditions of the enterprise, and economic feasibility.

Table 1.**Comparison of Different Mixing Equipment**

Mixer	Mixer Type	Main Mixing Mechanism	Segregation (Stratification)	Axial Mixing	Ease of Cleaning	Tendency to Segregation During Discharge
Horizontal drum mixer	Batch	Diffusive	Partial	Poor	Poor	Poor
Double-cone mixer	Batch	Diffusive	Partial	Poor	Good	Poor
V-shaped mixer	Batch	Diffusive	Poor	Poor	Good	Poor
Y-shaped mixer	Batch	Diffusive	Poor	Poor	Good	Poor
Ribbon mixer	Batch	Convective	Good	Good	Good	Partial
Paddle mixer	Continuous	Convective	Good	Partial	Poor	Good
Orbital screw mixer	Batch	Convective	Partial	Good	Poor	Good
Vertical screw mixer	Batch	Convective	Good	Good	Poor	Good
Hopper mixer	Batch	Shear	Partial	Poor	Good	Partial
Fluidized-bed mixer	Batch	Shear	Partial	Poor	Good	Partial

Note: P – batch mixer; B – continuous mixer; D – diffusive mixing; C – convective mixing; S – shear mixing.

Y- and V-shaped mixers are considered preferable for premix production due to a combination of several important advantages. First, they provide high mixture uniformity even when small amounts of premixes or protein-mineral supplements are introduced, reducing the risk of segregation compared with horizontal drum mixers. Second, the design of a Y(V)-shaped mixer allows for easy equipment cleaning and rapid emptying, which is particularly important when working with thermosensitive or abrasive components. Third, minimal contact of the mixture with lubricants reduces the risk of contamination of the finished product.

In addition, Y(V)-shaped mixers are well suited for batch production, providing flexibility in changing formulations and rapid transition between different types of feed. The economic feasibility of this type of mixer is reflected in lower energy consumption and maintenance costs compared with high-energy convective mixers while maintaining high mixture quality. Thus, a Y(V)-shaped mixer optimally combines mixing efficiency, ease of cleaning, low susceptibility to segregation, and cost-effectiveness, making it a highly suitable choice for batch production of feeds and premixes.

A known dynamically improved V-shaped mixer [59] comprises a frame on which a rotational drive is mounted (a DC electric motor or an induction motor with a gearbox). Its shaft is connected via a flexible coupling to a shaft mounted in housing bearings on supports. A V-shaped vessel is rigidly mounted on the shaft and consists of two inclined branches connected by means of a tee fitting. Gates are installed at the free ends of the branches. Loading nozzles are located in the upper part of the frame above the inclined branches, while a discharge nozzle is installed in the lower part of the frame beneath the tee fitting.

The disadvantages of the dynamically improved V-shaped mixer include: insufficient mixture uniformity due to the absence of a central channel (straight branch) for uniform redistribution of the material; limited mixing efficiency when a large number of components are used due to the absence of an additional distributor inside the vessel; absence of sensors for monitoring the dynamic state of the vessel, which prevents optimization of mixing modes in real time; inability to provide automated and synchronized control of component feeding and discharge; and absence of dampers or vibration-control devices, which reduces mixing intensity.

A known Y-shaped mixer for bulk materials [60] comprises a frame on which a rotational drive is mounted (a DC electric motor or an induction motor with a gearbox). Its shaft is connected via a flexible coupling to a shaft mounted in housing bearings on supports. A Y-shaped vessel is rigidly mounted on the shaft and consists of two inclined branches and one straight branch connected by means of a tee fitting. Gates are installed at the free ends of the branches. Loading nozzles are located in the upper part of the frame above the inclined branches, while a

discharge nozzle is installed beneath the straight branch. A power supply unit is mounted on the frame and connected to the electrical mains through an ON/OFF button by means of electrical wires.

The disadvantages of the Y-shaped mixer include: lack of precise control over the angle and rotational speed of the vessel, which complicates process adaptation to different bulk materials; non-uniform mixing at high rotational speeds due to the absence of dampers for controlling vessel vibrations; limited integration with an automatic control system for the gates and material feeding; absence of real-time monitoring of the vessel's dynamic state for optimizing mixing modes; and insufficiently uniform distribution of bulk material due to the absence of a rhombus-shaped distributor inside the vessel.

The structural and technological scheme of the developed Y-shaped mixer for feed materials is shown in Fig. 8. The main structural element is frame 1, on which stepper motor 2 is installed. Torque transmission from the motor to the working vessel is provided by flexible coupling 3 and shaft 4. The shaft is mounted in housing bearings on supports 5, which are connected to frame 1 through rubber dampers 6.

Y-shaped vessel 7 is rigidly mounted on shaft 4 between the housing bearings. It consists of two inclined branches 8 and one vertical (straight) branch 9 connected by means of tee fitting 10. This configuration of the working vessel provides branching and subsequent convergence of bulk-material flows during rotation.

Servo drives 11 are installed at the free ends of branches 8 and 9, with their shafts kinematically connected to gates 12. They provide automated control of the mixture loading and discharge processes. Accelerometer 13 is installed on tee fitting 10 between inclined branches 8 to monitor the motion parameters and vibration state of the working vessel. A conductive slip ring 14 is provided on shaft 4 to transmit electrical signals between the stationary and rotating parts of the structure.

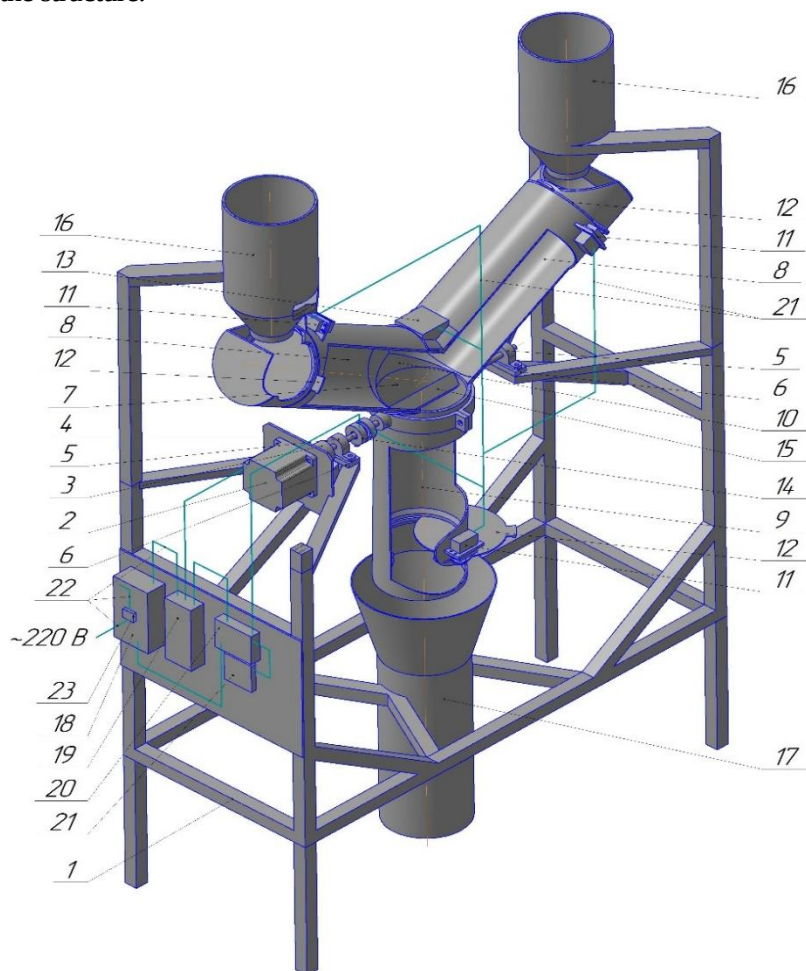
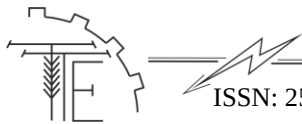


Fig. 8. Structural and technological scheme of the Y-shaped mixer for feed materials:

1 – frame; 2 – stepper motor; 3 – flexible coupling; 4 – shaft; 5 – housing bearings on supports; 6 – rubber dampers; 7 – Y-shaped vessel; 8 – inclined branches; 9 – straight branch; 10 – tee fitting; 11 – servo drives; 12 – gates; 13 – accelerometer; 14 – conductive slip ring; 15 – distributor; 16 – loading nozzles; 17 – discharge nozzle; 18 – power supply unit; 19 – stepper motor controller; 20 – control unit with display; 21 – keyboard; 22 – electrical wires; 23 – ON/OFF button



Inside tee fitting 10, a rhombus-shaped distributor 15 in cross-section is mounted on shaft 4. Its purpose is to change the trajectories of particle movement and redistribute material flows during rotation of the vessel.

The components are loaded through two loading nozzles 16 located in the upper part of the frame above inclined branches 8. The finished mixture is discharged through discharge nozzle 17 located beneath straight branch 9.

The mixer control system includes power supply unit 18, stepper motor controller 19, control unit with display 20, and keyboard 21. Electrical connection of the system components is provided by wires 22. Connection of the equipment to a 220 V AC mains supply is carried out using ON/OFF button 23. Power supply unit 18 provides electrical power to stepper motor controller 19 and control unit 20. Controller 19 controls the operation of stepper motor 2, while control unit 20 provides interaction with keyboard 21, servo drives 11, and accelerometer 13.

Before starting operation, the operator supplies electrical power to power supply unit 18 using ON/OFF button 23. The voltage is transmitted through electrical wires 22 to stepper motor controller 19 and control unit with display 20. Using keyboard 21, the operator sets the required technological process parameters, including the rotational speed of Y-shaped vessel 7, the duration of its rotation in the forward and reverse directions, and the total mixing time.

After the technological cycle is started, control unit 20 receives information on the spatial position and motion parameters of the vessel from accelerometer 13. Signals from the sensor are transmitted through electrical wires 22 and conductive slip ring 14. Based on the information received, the control system generates appropriate commands for stepper motor controller 19.

Controller 19 activates stepper motor 2, whose rotational motion is transmitted through flexible coupling 3 and shaft 4 to Y-shaped vessel 7. During the loading stage, the vessel is positioned so that inclined branches 8 are located at the top, while straight branch 9 is at the bottom. Servo drives 11 then open gates 12 on the inclined branches, allowing the components to enter the working vessel through loading nozzles 16. The material moves through inclined branches 8 to tee fitting 10 and then into straight branch 9. Filling is carried out to a predetermined level, after which the gates close automatically.

At the next stage, the stepper motor controller provides rotation of vessel 7 at the specified speed, direction, and duration. During movement, the feed components are displaced under the action of gravitational, inertial, and centrifugal forces and interact with the surfaces of the vessel and rhombus-shaped distributor 15. Changes in the direction of motion and the geometry of the Y-shaped vessel promote repeated redistribution of the material between its working zones.

Additional process intensification is provided by rubber dampers 6, which create an elastic connection between the housing bearings and frame. As a result, additional oscillatory movements of the working vessel occur during rotation, contributing to the disruption of stagnant zones and increasing the intensity of mutual particle movement. The current motion parameters are monitored by accelerometer 13, whose signals are transmitted to control unit 20 and can be used to adjust the specified operating mode.

After the preset mixing time has been reached, the control system generates a command to terminate the cycle. Stepper motor 2 rotates Y-shaped vessel 7 to a position in which straight branch 9 is located at the bottom. Servo drive 11 opens the gate of the straight branch, after which the finished mixture flows under gravity to discharge nozzle 17. Once unloading is completed, the gate closes, and the mixer is ready for the next technological cycle.

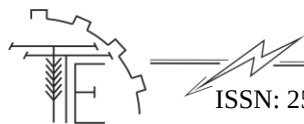
The proposed Y-shaped mixer provides controlled intensification of the mixing process through a combination of rotational motion of the working vessel, its additional oscillations, and changes in the direction of material movement. The use of a stepper motor enables precise control of the rotational speed, direction, and rotation angle of the vessel, creating the conditions for reproducible technological operating modes.

The use of rubber dampers forms an elastic connection between the moving system and the frame and promotes the occurrence of additional oscillations. This activates particle movement, reduces the probability of stagnant zones, and increases mixing intensity.

The rhombus-shaped distributor provides additional separation and redistribution of feed-component flows in the branch-connection zone, increasing the number of cycles of mutual particle movement and contributing to the formation of a more homogeneous mixture.

Automated control of the gates using servo drives ensures synchronization of loading and unloading operations, while the accelerometer makes it possible to monitor the actual motion parameters of the working vessel. Collectively, these features enable adaptive control of the mixing process depending on the specified technological parameters and the actual dynamic state of the system.

Thus, the main structural features of the proposed mixer are the Y-shaped working vessel, controlled reversible motion, elastic mounting using dampers, an internal distributor, and an automated control system.



Their combined application is aimed at increasing mixing intensity, reducing the duration of the technological cycle, and improving the uniformity of the feed mixture.

5. Conclusion

Complete feed mixtures containing premixes and protein-mineral-vitamin supplements are a key element of rational animal feeding, ensuring optimal conversion of nutrients into animal products, increased productivity, and maintenance of animal health. Their effectiveness depends on the proper selection of components, accurate dosing, high-quality mixing, and compliance with safety and hygiene requirements regulated by legislation and international standards. The use of a quality control system at all stages of production and storage ensures stable nutritional value, product safety, and economic benefits for farms.

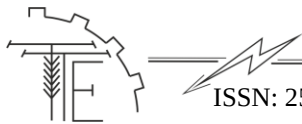
The mechanisms of feed material mixing—convective, diffusive, and shear—are interconnected and collectively ensure the achievement of mixture uniformity. Convective mixing rapidly reduces heterogeneity at the macroscopic level, the shear mechanism breaks up agglomerates and improves particle contact, while diffusion ensures uniform distribution of micro-additives and microscale homogeneity. The actual production process is complicated by segregation, re-segregation, and local accumulation of individual components. Various mixing indices are used to evaluate uniformity, including variance-based, contact, and distance-based indices, each having its own advantages and limitations. In feed production practice, variance-based methods, particularly relative standard deviation (RSD), are among the most convenient and best correlated with mixture quality. A comprehensive approach to the analysis and control of the mixing process makes it possible to optimize equipment operation, reduce undesirable phenomena, and ensure stable uniformity and quality of the finished feed.

Analysis of feed material mixer designs shows that mixing efficiency, mixture uniformity, and the risk of segregation largely depend on the mixer type, operating mechanism, and physicomachanical properties of the components. Drum (gravity) mixers are simple and easy to maintain; however, they are less effective for wet, cohesive, or components with substantially different densities. Convective mixers provide intensive mixing and reduce the risk of segregation, but they may have “dead zones,” high energy consumption, and increased wear of working components. Hopper and fluidized-bed mixers are suitable for partial or specialized mixing but are characterized by limited uniformity and increased design requirements. For batch production of premixes and complete feeds, Y- and V-shaped mixers are among the most effective. They provide high uniformity even with small component doses, a low risk of segregation, easy cleaning, and rapid emptying of the equipment. An additional advantage is their cost-effectiveness, including lower energy consumption and maintenance costs compared with high-energy convective mixers. Thus, Y(V)-shaped mixers optimally combine efficiency, reliability, and economic feasibility, making them a highly suitable choice for modern feed production.

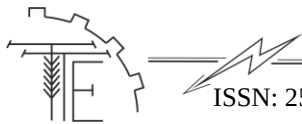
A structural and technological scheme of a Y-shaped mixer for bulk materials has been developed. The mixer is a highly efficient piece of equipment designed for accurate and uniform mixing of components. The design includes a rigidly mounted Y-shaped vessel consisting of three branches, a gate system with servo drives, dampers for reducing vibrations, and a stepper motor as the rotational drive. Additional equipment, including an accelerometer, conductive slip ring, rhombus-shaped distributor, and stepper motor controller, provides precise control of the mixing process. The control unit with a display and keyboard enables convenient adjustment of the mixer operating mode, while the optimized arrangement of the loading and discharge nozzles improves equipment ergonomics and productivity. This design ensures high mixture uniformity and process automation, making it suitable for industrial production of complete feeds and other bulk materials.

References

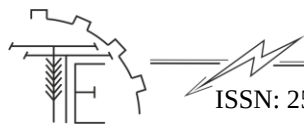
1. Azat, S., Mutushev, A., Yeszhanova, G., Tuleibayeva, A., Zhumakhan, K., & Nuraly, A. (2023). Development of a highly effective premix based on local plant raw materials to stimulate growth and development of growing calves. *Engineered Science*, 26, 994. <https://doi.org/10.30919/es994> [in English].
2. Perera, W. N. U., & Ravindran, V. (2025). Role of feed additives in poultry nutrition: Historical, current and future perspectives. *Animal Feed Science and Technology*, 326, 116371. <https://doi.org/10.1016/j.anifeedsci.2025.116371> [in English].
3. Dudarev, I., Uminsky, S., Moskalyuk, A., & Maslych, N. (2024). Increasing the stability of combined feed during its storage. *Agrarian Bulletin of the Black Sea Littoral*, (111), 98–102. <https://doi.org/10.37000/abbsl.2024.111.18> [in English].
4. Korobka, A. V., Rak, T. M., Bitlian, O. K., & Konks, T. M. (2018). Tekhnolohiya zastosuvannya premiksiv riznoho skladu u svynarstvi [Technology of using premixes of different composition in pig farming]. *Scientific Progress & Innovations*, (3), 122–126. <https://doi.org/10.31210/visnyk2018.03.18> [in Ukrainian].



5. Levytskyi, T. R. (2020). Vplyv tekhnolohichnoi kormovoi dobavky na peretrvnist pozhyvnykh rehovyn kormu u kurchat-broileriv [Effect of a technological feed additive on the digestibility of feed nutrients in broiler chickens]. *Scientific and Technical Bulletin of the State Scientific Research Control Institute of Veterinary Medicinal Products and Feed Additives and the Institute of Animal Biology*, 21(1), 130–134. <https://doi.org/10.36359/scivp.2020-21-1.16> [in Ukrainian].
6. Untea, A. E., Saracila, M., & Vlaicu, P. A. (2023). Feeding strategies and nutritional quality of animal products. *Agriculture*, 13(9), 1788. <https://doi.org/10.3390/agriculture13091788> [in English].
7. Rocha, A. G., Montanhini, R. N., Dilkin, P., Tamiosso, C. D., & Mallmann, C. A. (2015). Comparison of different indicators for the evaluation of feed mixing efficiency. *Animal Feed Science and Technology*, 209, 249–256. <https://doi.org/10.1016/j.anifeedsci.2015.09.005> [in English].
8. Verkhovna Rada of Ukraine. (2017). *Pro bezpechnist ta hihiienu kormiv [On the safety and hygiene of feed]* (Law of Ukraine No. 2264-VIII, December 21, 2017; amended March 2, 2026). <https://zakon.rada.gov.ua/laws/show/2264-19#Text> [in Ukrainian].
9. El-Deek, A. A., Abdel-Wareth, A. A. A., Osman, M., El-Shafey, M., Khalifah, A. M., Elkomy, A. E., & Lohakare, J. (2020). Alternative feed ingredients in the finisher diets for sustainable broiler production. *Scientific Reports*, 10(1), 17743. <https://doi.org/10.1038/s41598-020-74950-9> [in English].
10. Tewelde, K. G., Kiss, B., Csiszér, T., Pál, L., Such, N., Bartos, Á., & Dublec, K. (2026). Feeding low- and high-fibre sunflower meal to broiler chickens—Effects of inclusion rate and age of birds on the production traits, carcass composition, nutrient digestibility, gut viscosity, and caecal short-chain fatty acid content. *Animals*, 16(2), 162. <https://doi.org/10.3390/ani16020162> [in English].
11. den Hartog, J. (2003). Feed for food: HACCP in the animal feed industry. *Food Control*, 14(2), 95–99. [https://doi.org/10.1016/S0956-7135\(02\)00111-1](https://doi.org/10.1016/S0956-7135(02)00111-1) [in English].
12. DSTU 4120-2002. (2003). *Kombikormy povnoratsionni dlia silskohospodarskoi pytsi. Tekhnichni umovy. Z popravkoiu (IPS No. 5-2003) [Complete feed for poultry. Specifications. With amendment (IPS №. 5-2003)]*. National Standard of Ukraine. [in Ukrainian].
13. Sauvant, D., Perez, J.-M., & Tran, G. (Eds.). (2004). *Tables of composition and nutritional value of feed materials: Pigs, poultry, cattle, sheep, goats, rabbits, horses and fish*. Wageningen Academic Publishers. <https://appex-h.com/wp-content/uploads/2024/08/Tables-of-composition-of-feedstuffs.pdf> [in English].
14. Stas, E. B., DeRouchey, J. M., Goodband, R. D., Tokach, M. D., Woodworth, J. C., & Gebhardt, J. T. (2024). Nutritional guide to feeding wheat and wheat co-products to swine: A review. *Translational Animal Science*, 8, txae106. <https://doi.org/10.1093/tas/txae106> [in English].
15. Yang, P., Ni, J. J., Zhao, J. B., Zhang, G., & Huang, C. F. (2020). Regression equations of energy values of corn, soybean meal, and wheat bran developed by chemical composition for growing pigs. *Animals*, 10(9), 1490. <https://doi.org/10.3390/ani10091490> [in English].
16. Aliiev, E. B., & Linko, M. O. (2022). Analiz tekhniko-tekhnolohichnoho osnashchennia protsesiv ekspandovanoho pryhotuvannia kormiv [Analysis of technical and technological equipment for expanded feed preparation processes]. *Tekhnika, enerhetyka, transport APK*, 1(116), 51–57. <https://doi.org/10.37128/2520-6168-2022-1-6> [in Ukrainian].
17. Aliiev, E. B., Patsula, O. M., & Hrytsenko, V. T. (2017). *Tekhnolohiia kompleksnoi bezvidkhidnoi pererobky makukhy z nasinnia oliinykh kultur z oderzhanniam vysokoiakysnykh povnotsinnykh proteinovykh dobavok u vyhliadi pelet ta tverdoho biopalyva [Technology of comprehensive waste-free processing of oilseed press cake to obtain high-quality complete protein supplements in the form of pellets and solid biofuel]* [Scientific and methodological recommendations]. Institute of Oilseed Crops of the NAAS of Ukraine. [in Ukrainian].
18. Petrychenko, V. F., & Korniihuk, O. V. (Eds.). (2023). *Vyrobnytstvo, zahotivlia ta bezpeka kormiv [Production, harvesting and safety of feeds]*. Agrarna nauka. <https://doi.org/10.31073/978-966-540-580-1> [in Ukrainian].
19. Aliiev, E. B., Mykolenko, S. Yu., Sova, N. A., et al. (2022). *Tekhniko-tekhnolohichne zabezpechennia bezvidkhdnoi pererobky zernovoi syrovyny u kharchovi produkty i kormy [Technical and technological support for waste-free processing of grain raw materials into food products and feed]* [Collective monograph]. LIRA. [in Ukrainian].
20. Yehorov, B. V., Makarynska, A. V., & Vorona, N. V. (2014). Osoblyvosti tekhnolohii vyrobnytstva vysokoodnoridnykh kormovykh dobavok [Features of the technology for production of highly homogeneous feed additives]. *Grain Products and Mixed Feeds*, 2(54), 37–40. <https://doi.org/10.15673/2313-478x.54/2014.36425> [in Ukrainian].



21. Piskun, V., Yatsenko, Y., Antonenko, S., & Zolotarov, A. (2024). Production of compound feeds in the conditions of farms with loaded reservation of dosing and mixing. *Scientific and Technical Bulletin of Livestock Farming Institute of NAAS of Ukraine*, (132), 124–139. <https://doi.org/10.32900/2312-8402-2024-132-124-139> [in English].
22. Yehorov, B. V., Shapovalenko, O. I., & Makarynska, A. V. (2021). *Tekhnolohiia vyrobnytstva premiksiv [Technology of premix production]*. TsUL. [in Ukrainian].
23. Iskakov, R., & Gulyarenko, A. (2025). Grinding and mixing uniformity in a feed preparation device with four-sided jagged hammers and impact-mixing mechanisms. *AgriEngineering*, 7(6), 183. <https://doi.org/10.3390/agriengineering7060183> [in English].
24. Makarynska, A., & Iegorov, B. (2019). Production technologies of formed premixes. *Grain Products and Mixed Fodder's*, 19(2), 38–46. <https://doi.org/10.15673/gpmf.v19i2.1446> [in English].
25. Luts, P. M., Babyn, I. A., Hovorukha, V. B., & Pavlichenko, V. M. (2025). Rezultaty eksperymentalnykh doslidzhen kavitatsiinoho dysperhatora kormiv bilkovo-vitaminnoho kontsentratu rosllynnoho pokhodzhennia [Results of experimental studies of a cavitation disperser for feeds based on plant-derived protein-vitamin concentrate]. *Central Ukrainian Scientific Bulletin. Technical Sciences*, 11(42), 139–147. [https://doi.org/10.32515/2664-262X.2025.11\(42\).1.139-147](https://doi.org/10.32515/2664-262X.2025.11(42).1.139-147) [in Ukrainian].
26. Aliiev, E. B., Koshulko, V. S., & Kocherezhko, N. V. (2023). Obgruntuvannia konstruktyvno-tekhnolohichnykh parametriv rotornoho zmishuvacha kombikormiv periodychnoi dii [Substantiation of the design and technological parameters of a batch-type rotary feed mixer]. *Tekhnika, enerhetyka, transport APK*, 3(122), 5–13. <https://doi.org/10.37128/2520-6168-2023-3-1> [in Ukrainian].
27. Brone, D., & Muzzio, F. (2000). Enhanced mixing in double-cone blenders. *Powder Technology*, 110, 179–189. [https://doi.org/10.1016/S0032-5910\(99\)00204-1](https://doi.org/10.1016/S0032-5910(99)00204-1) [in English].
28. Lee, S. J., & Hwang, S.-Y. (2025). Comparative study to evaluate mixing efficiency of very fine particles. *Applied Sciences*, 15(15), 8712. <https://doi.org/10.3390/app15158712> [in English].
29. Muzzio, F. J., Alexander, A., Goodridge, C., Shen, E., Shinbrot, T., Manjunath, K., Dhodapkar, S., & Jacob, K. (2004). *Solids mixing*. In Handbook of industrial mixing: Science and practice (pp. 887–985). Wiley. <https://doi.org/10.1002/0471451452.ch15> [in English].
30. Shi, Q. (2023). Quantifying the contributions of powder mixing mechanisms using a combined proper orthogonal decomposition and analysis of variance approach. *Physics of Fluids*, 35(11), 113333. <https://doi.org/10.1063/5.0172784> [in English].
31. Premi, M., & Sharma, V. (2022). *Mixing and forming*. In H. K. Sharma & N. Kumar (Eds.), *Agro-processing and food engineering* (pp. 123–145). Springer. https://doi.org/10.1007/978-981-16-7289-7_7 [in English].
32. Chaudhuri, P. K., & Fuerstenau, D. W. (1971). The effect of mixing aids on the kinetics of mixing in a rotating drum. *Powder Technology*, 4(3), 146–150. [https://doi.org/10.1016/0032-5910\(71\)80023-2](https://doi.org/10.1016/0032-5910(71)80023-2) [in English].
33. Massol-Chaudeur, S., Berthiaux, H., & Dodds, J. A. (2002). *Experimental study of the mixing kinetics of binary pharmaceutical powder mixtures in a laboratory hoop mixer*. Chemical Engineering Science. [https://doi.org/10.1016/S0009-2509\(02\)00262-2](https://doi.org/10.1016/S0009-2509(02)00262-2) [in English].
34. Villermaux, E. (2001). Mixing: Kinetics and geometry. In H. Aref & J. W. Phillips (Eds.), *Mechanics for a new millennium* (pp. 201–214). Springer. https://doi.org/10.1007/0-306-46956-1_11 [in English].
35. Marigo, M., Cairns, D., Davies, M., Ingram, A., & Stitt, E. (2012). A numerical comparison of mixing efficiencies of solids in a cylindrical vessel subject to a range of motions. *Powder Technology*, 217, 540–547. <https://doi.org/10.1016/j.powtec.2011.11.016> [in English].
36. Chaikittisilp, W., Taenumtrakul, T., Boonsuwan, P., Tanthapanichakoon, W., & Charinpanitkul, T. (2006). Analysis of solid particle mixing in inclined fluidized beds using DEM simulation. *Chemical Engineering Journal*, 122, 21–29. <https://doi.org/10.1016/j.cej.2006.05.006> [in English].
37. Park, C., Kim, J., Landon, R. S., Lyu, B., Cho, H., & Moon, I. (2019). Novel evaluation method for the continuous mixing process of bimodal particles. *Powder Technology*, 344, 636–646. <https://doi.org/10.1016/j.powtec.2018.12.052> [in English].
38. Chou, S.-H., Song, Y.-L., & Hsiao, S.-S. (2017). A study of the mixing index in solid particles. *KONA Powder and Particle Journal*, 34, 275–281. <https://doi.org/10.14356/kona.2017018> [in English].
39. Cho, M., Dutta, P., & Shim, J. (2017). A non-sampling mixing index for multicomponent mixtures. *Powder Technology*, 319, 434–444. <https://doi.org/10.1016/j.powtec.2017.07.011> [in English].
40. Chandratilleke, G. R., Yu, A., Bridgwater, J., & Shinohara, K. (2012). A particle-scale index in the quantification of mixing of particles. *AIChE Journal*, 58, 1099–1118. <https://doi.org/10.1002/aic.12654> [in English].



41. Siiriä, S., & Yliruusi, J. (2009). Determining a value for mixing: Mixing degree. *Powder Technology*, 196(3), 309–317. <https://doi.org/10.1016/j.powtec.2009.08.009> [in English].
42. Arntz, M., den Otter, W. K., Briels, W. J., Bussmann, P., Beertink, H., & Boom, R. (2008). Granular mixing and segregation in a horizontal rotating drum: A simulation study on the impact of rotational speed and fill level. *AIChE Journal*, 54, 3133–3146. <https://doi.org/10.1002/aic.11622> [in English].
43. Chandratilleke, G. R., Jin, X., & Shen, Y. S. (2021). DEM study of effects of particle size and density on mixing behaviour in a ribbon mixer. *Powder Technology*, 392, 93–107. <https://doi.org/10.1016/j.powtec.2021.06.058> [in English].
44. Poux, M., Fayolle, P., Bertrand, J., Bridoux, D., & Bousquet, J. (1991). Powder mixing: Some practical rules applied to agitated systems. *Powder Technology*, 68, 213–234. [https://doi.org/10.1016/0032-5910\(91\)80047-M](https://doi.org/10.1016/0032-5910(91)80047-M) [in English].
45. Chang, R.-K., Chang, S.-I., & Robinson, J. R. (1992). A study of the performance of a modified V-shaped solids mixer using segregating materials. *International Journal of Pharmaceutics*, 80(1–3), 171–178. [https://doi.org/10.1016/0378-5173\(92\)90275-7](https://doi.org/10.1016/0378-5173(92)90275-7) [in English].
46. Lemieux, M., Bertrand, F., Chaouki, J., & Gosselin, P. (2007). Comparative study of the mixing of free-flowing particles in a V-blender and a bin-blender. *Chemical Engineering Science*, 62(6), 1783–1802. <https://doi.org/10.1016/j.ces.2006.12.012> [in English].
47. Bouhaouche, A., Kaoua, S., & Daoud, K. (2019). Numerical simulation of free flowing particles mixing in V-blender. *Granular Matter*, 21, 35. <https://doi.org/10.1007/s10035-019-0885-7> [in English].
48. Halidan, M., Chandratilleke, G. R., Dong, K. J., & Yu, A. B. (2018). Mixing performance of ribbon mixers: Effects of operational parameters. *Powder Technology*, 325, 92–106. <https://doi.org/10.1016/j.powtec.2017.11.009> [in English].
49. Yeow, S. T., Shahar, A., Abdul Aziz, N., Anuar, M. S., Yusof, Y. A., & Taip, F. S. (2011). The influence of operational parameters and feed preparation in a convective batch ribbon powder mixer. *Drug Design, Development and Therapy*, 5, 465–469. <https://doi.org/10.2147/DDDT.S25047> [in English].
50. Senda, S. P., Renanto, R., Roesyadi, A., Sumaryono, W., & Bindar, Y. (2012). The power consumption performance of an orbiting screw solid-solid mixer. *ITB Journal of Engineering Science*, 44B(3), 287–302. <https://doi.org/10.5614/itbj.eng.sci.2012.44.3.6> [in English].
51. Marczuk, A., Misztal, W., Savinykh, P., Turubanov, N., Isupov, A., & Zyryanov, D. (2019). Improving efficiency of horizontal ribbon mixer by optimizing its constructional and operational parameters. *Eksplotacja i Niezawodność – Maintenance and Reliability*, 21(2), 220–225. <https://doi.org/10.17531/ein.2019.2.5> [in English].
52. Kamath, S., Kunte, A., Doshi, P., & Orpe, A. V. (2014). Flow of granular matter in a silo with multiple exit orifices: Jamming to mixing. *Physical Review E*, 90(6), 062206. <https://doi.org/10.1103/PhysRevE.90.062206> [in English].
53. Petre, A. A., Stanciu, M. M., Mihalache, D. B., & Dumitru, D. (2021). Research regarding the common problems of design of the bunkers – A review. *E3S Web of Conferences*, 286, 03024. <https://doi.org/10.1051/e3sconf/202128603024> [in English].
54. Li, H., Huang, J., Liu, Z., Lv, M., & Ji, C. (2021). Experimental quantification of the lateral mixing of binary solids in bubbling fluidized beds. *Energies*, 14(22), 7796. <https://doi.org/10.3390/en14227796> [in English].
55. Oliveira, H. B., & Franklin, E. de M. (2024). Bidisperse micro fluidized beds: Effect of bed inclination on mixing. *Physics of Fluids*, 36(1), 013303. <https://doi.org/10.1063/5.0179153> [in English].
56. Jabbari, E., Mardanloo, P., Sarafan, K., & Molaei Dehkordi, A. (2024). Solids mixing intensification in tapered fluidized beds with an inlet jet: Experimental validation and CFD simulation. *Korean Journal of Chemical Engineering*, 41(1), 357–374. <https://doi.org/10.1007/s11814-023-00011-2> [in English].
57. Robinson, P. A., Muzzio, F. J., Brone, D., Connor, K., & Wightman, C. (1999). *Dynamically enhanced V-blender* (U.S. Patent №. 5,938,330). U.S. Patent and Trademark Office. <https://patents.google.com/patent/US5938330> [in English].
58. Jo, H., Kong, C., Nam, D. S., & Kim, B. G. (2015). Mixing performance of a novel flat-bottom vertical feed mixer. *International Journal of Poultry Science*, 14(11), 625–627. <https://doi.org/10.3923/ijps.2015.625.627> [in English].
59. Axe, D. E. (1995). Factors affecting uniformity of a mix. *Animal Feed Science and Technology*, 53(2), 211–220. [https://doi.org/10.1016/0377-8401\(95\)02011-N](https://doi.org/10.1016/0377-8401(95)02011-N) [in English].
60. FoodTechProcess. (n.d.). *Y mixer 150*. <https://foodtechprocess.com/en/mixers/206-y-mixer-150.html> [in English].

ТЕХНІКО-ТЕХНОЛОГІЧНЕ ЗАБЕЗПЕЧЕННЯ ЗМІШУВАННЯ КОРМОВИХ МАТЕРІАЛІВ

У статті наведено результати оглядового дослідження сучасних підходів до змішування кормових матеріалів та конструктивно-технологічних рішень змішувального обладнання для виробництва комбікормів. Обґрунтовано значення якісного змішування повнораціонних комбікормів, преміксів і білково-мінерально-вітамінних добавок для забезпечення стабільної поживної цінності, безпечності та ефективності годівлі тварин. Проаналізовано основні механізми перемішування сипких матеріалів: конвективний, дифузійний та зсувний, а також особливості їх взаємодії на різних стадіях технологічного процесу. Встановлено, що поряд із позитивним впливом зазначених механізмів на однорідність суміші необхідно враховувати можливість виникнення сегрегації, повторного розширювання та локального накопичення окремих компонентів. Розглянуто основні групи індексів оцінювання однорідності суміші, зокрема показники на основі дисперсії, контактні індекси та індекси на основі відстаней між частинками. Показано доцільність використання відносного стандартного відхилення як практичного критерію оцінювання рівномірності розподілу компонентів комбікорму. Проведено аналіз основних конструкцій змішувачів кормових матеріалів та визначено їх переваги й недоліки з урахуванням характеру руху матеріалу, енергоємності, інтенсивності перемішування та схильності компонентів до сегрегації. Обґрунтовано перспективність використання Y- та V-подібних змішувачів у порційному виробництві комбікормів і преміксів. Запропоновано конструктивно-технологічну схему Y-подібного змішувача сипких матеріалів із кроковим приводом, сервоприводами заслінок, системою демпфування, акселерометром, ромбоподібним розподільником та автоматизованою системою керування. Застосування зазначених технічних рішень створює передумови для підвищення однорідності суміші, скорочення тривалості змішування, розширення діапазону керованих режимів та зниження енергетичних витрат. Результати огляду можуть бути використані для подальшого обґрунтування конструктивних параметрів та режимів роботи змішувального обладнання.

Ключові слова: комбікорм, кормові матеріали, змішування, однорідність суміші, сегрегація, індекс змішування, відносне стандартне відхилення, Y-подібний змішувач, V-подібний змішувач, сипкі матеріали, премікси, автоматизація, конструктивно-технологічна схема.

Ф. 1. Рис. 8. Табл. 1. Літ. 60.

INFORMATION ABOUT THE AUTHORS

Elchyn ALIEV – Doctor of Technical Sciences, Senior Researcher, Professor of the Department of Technical Systems Engineering of Dnipro State Agrarian and Economic University (St. S. Efremova, 25, Dnipro, Ukraine, 49000, e-mail: aliev@meta.ua, <https://orcid.org/0000-0003-4006-8803>)

Ruslan PONOMARENKO – postgraduate student of Dnipro State Agrarian and Economic University (Dnipro, Serhiy Efremov St., 25, e-mail: Ponomarenko240314@gmail.com, <https://orcid.org/0009-0002-0282-8285>)

АЛІЄВ Ельчин Бахтияр огли – доктор технічних наук, старший дослідник, професор кафедри інжинірингу технічних систем Дніпровського державного аграрно-економічного університету (м. Дніпро, вул. Сергія Єфремова, 25, e-mail: aliev@meta.ua, <https://orcid.org/0000-0003-4006-8803>)

ПОНОМАРЕНКО Руслан Григорович – аспірант Дніпровського державного аграрно-економічного університету (м. Дніпро, вул. Сергія Єфремова, 25, e-mail: Ponomarenko240314@gmail.com, <https://orcid.org/0009-0002-0282-8285>)