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Preparation of liquid feed mixtures with continuous introduction of components

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Abstract. The article deals with the problem of increasing the efficiency of mechanization of forage harvesting in animal husbandry. According to the analysis of mixer designs and installations, a pilot project was proposed to cover the entire range of devices presented. A method for evaluating the quality of a mixture (degree of uniformity) with continuous introduction of components is proposed and a diagram of a laboratory installation is presented. Experimental studies have shown the feed range of the installation at different speeds of rotation of the impeller shaft. Mixing studies have confirmed the effectiveness of the plant design and its components: feeder, pump and mixer. Using experimental planning methods, the main factors influencing the mixing process were identified and the optimal parameters of the mixture quality were determined. When the unit was operating as a pump, a range of feeds in an open and closed loading chamber was obtained, and mixing quality indicators with continuous introduction of components, as well as water temperature t = 25...38 oC and the rotation speed is n= 1500...1600 min-1 reached the value of uniformity degree Θ=94.8%.

1 Introduction

The State Programme for Agricultural Development and Regulation of Markets of Agricultural Products, Raw Materials and Foodstuffs for 2013-2020 provides the main directions for the development of animal husbandry in our country. Measures for the development of dairy cattle breeding are aimed at increasing production and investment attractiveness of dairy cattle breeding. Thus, increasing the number of farm animals and increasing their productivity is impossible without the organisation of a full-fledged balanced feeding. The solution of livestock breeding problems at the present stage is possible only through the wide and active introduction of scientifically substantiated, modern resource-saving technologies into agricultural production.

Considering the problem of increasing the efficiency of livestock breeding, it should be borne in mind that the intensification of production at the current stage of development of the agricultural sector in the market economy implies not only the growth of additional investments per unit area and head of animal. It is necessary to develop and introduce new progressive technologies, to provide their improvement in accordance with the changed technique and technology of labour production organization. The decisive role in the

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technology of production of this or that final product or raw materials for further processing belongs to the means of mechanisation and automation [1,2,3].

Any mixture preparation involves mixing, which is widely used in agriculture and food industry to form emulsions and suspensions, homogeneous mixtures of bulk materials and other continuous media, as well as to intensify heat and mass transfer processes.

Thus, the first process step in mixing powdered components with a liquid is the creation of an intermediate surface between the components. This stage is necessary for the dissolution of the powder, and its properties such as wettability, dispersibility and solubility are of great importance here [4,5,6,7].

Dissolution of powdered components is carried out by one of the following methods:

- direct introduction of the component into a container with water and the use of a high-speed stirrer;
- using centrifugal pumps and rotary pulsation devices.

Accordingly, for mixing dry and powdered components with liquid medium there are two types of devices:

- with the introduction of components in the flow;
- batch introduction of components.

The analysis of designs of the installations used for dissolving dry, powdery products in dairy, food and other industries allows us to propose the following classification (Figure 1).

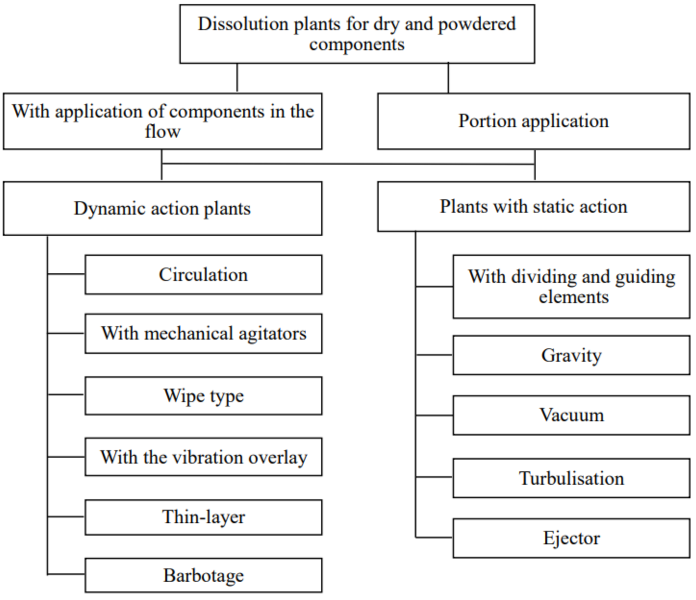


Fig. 1. Classification of plants for dissolving dry and powdered components.

In both cases, centrifugal pumps and/or rotary pulsation devices are used to intensify the mixing process.

Devices with the introduction of components in the flow is advisable to install in high-capacity lines (up to 50 tonnes per hour on the finished product), and batch - at small enterprises.

The operation of the mixing plant must be subject to requirements determined by technological and technical and economic conditions:

- pumping and mixing of different types of substances;
- productivity, allowing to work in changing conditions under the necessary mode;

- the best quality of mixing and dissolution determined by the steady state of the mixture;
- easy access to the working parts of the plant for quick cleaning, rinsing and troubleshooting;
- the possibility of continuous loading of components to ensure uniform operation of the machine;
- minimum dimensions and weight;
- the lowest energy consumption for the machine drive.

In accordance with the above classification, let us consider the design and principle of operation of devices for dissolving dry and powdered components that can be used for preparation of whole milk replacer. Which is necessary for feeding young cattle if it is not profitable for the farm to use whole milk.

At present, farms are forced to use imported mechanised and automated units designed for preparation and distribution of liquid whole milk replacer. However, they are not widely used due to their high cost and significant operating costs.

On the other hand, violations of the technology of preparation of feed mixtures for young animals can lead to a decrease in live weight gain, body resistance and the appearance of a number of diseases of the gastrointestinal tract. Manual mixing of dry ingredients with water often does not ensure feed homogeneity, and improperly prepared liquid feed can cause diarrhoea.

In this case, the mixture of dry matter can be considered as a nutrient medium, which is nowadays very widespread in various types and fields of activity and is used to obtain the required composition and purpose of substances.

The constituent parts of nutrient media in our case are dry component and liquid, just as in the case of whole milk replacer, and they can be classified according to the following characteristics (Figure 2).

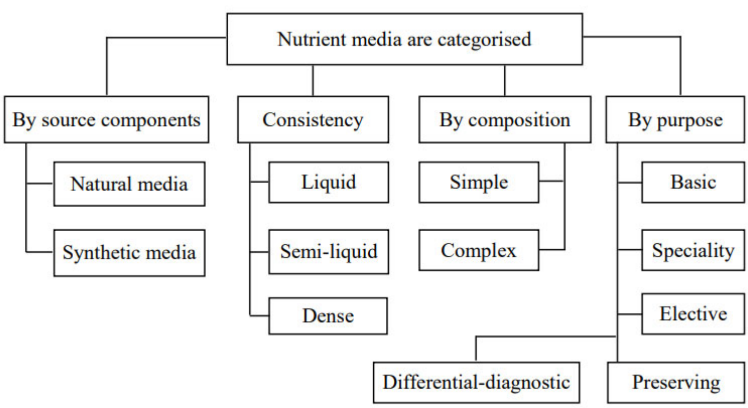


Fig. 2. Classification of nutrient media.

Of course, to obtain nutrient media are used installations (devices) for dissolving and mixing dry components with liquid. So two groups are distinguished: dynamic and static action. Classification of plants according to the principle of action is presented in Figure 3.

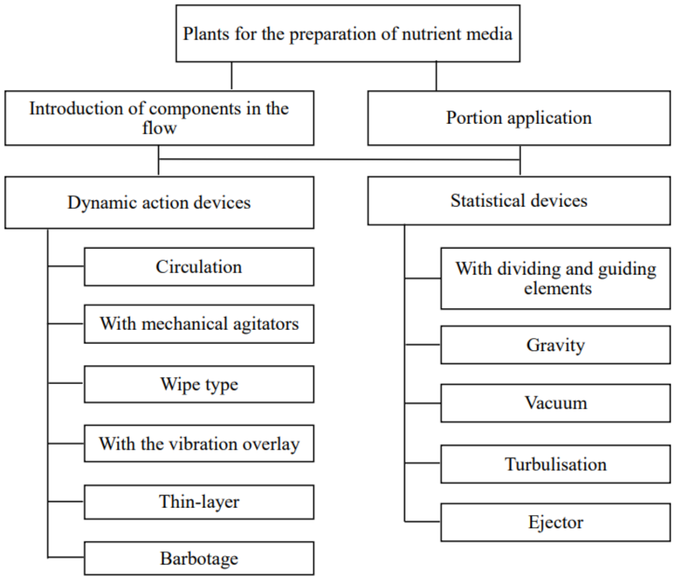


Fig. 3. Classification of plants by operating principle.

According to the organisational-technical feature, the plant designs (Figure 4) are subdivided into continuous-operating, which are expedient to install in high-productivity lines (up to 50 t/h by finished product) and periodic-operating, used in low-productivity lines (up to 1 t/h).

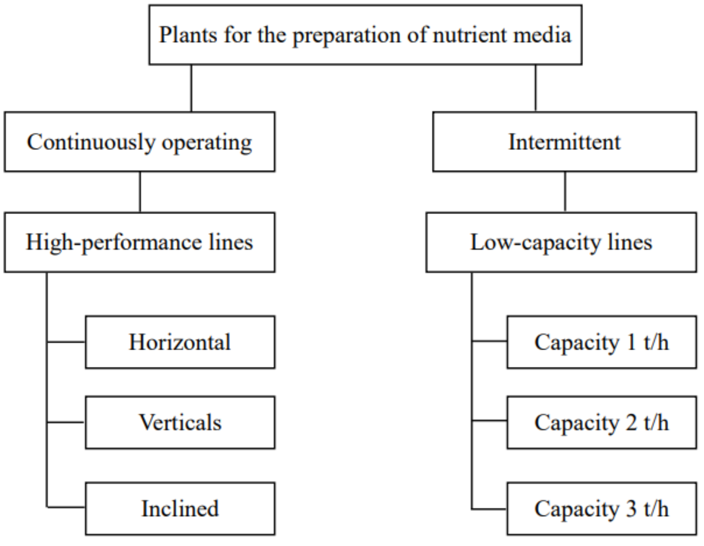


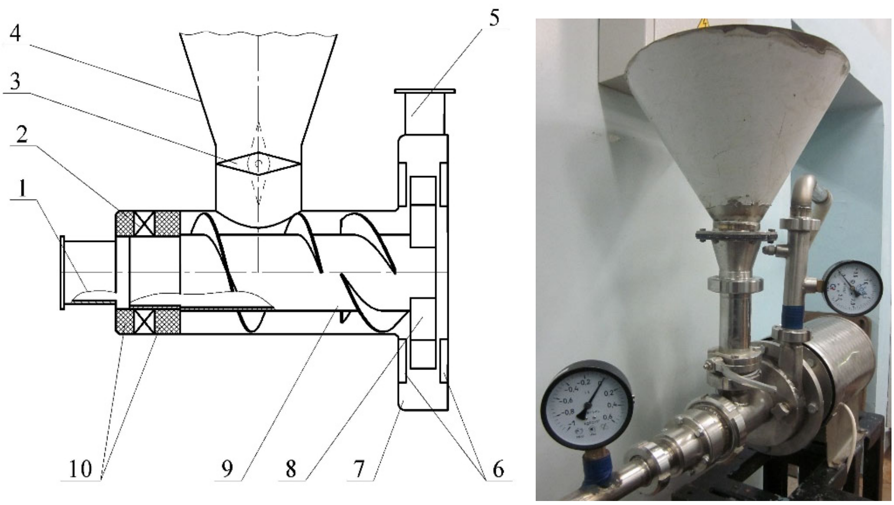
Fig. 4. Classification of plants by organisational and technical characteristics.

The use of installations for the preparation of feed milk mixtures allows to ensure compliance with the technology. The analysis shows that most of the equipment presented on the market has a design with a paddle stirrer. The equipment works batchwise, low intensity of mixing causes the need to increase the duration of the process, which increases energy costs for obtaining mixtures.

2 Materials and methods

At the Department of Technological and Power Equipment of the Vyatka State Agrotechnological University the design of the unit for the preparation of liquid fodder mixtures (Figure 5), consisting of a rotary-pulsation apparatus based on a centrifugal pump and a dosing device in the form of a screw has been developed. In contrast to units of similar purpose it has the following competitive advantages:

- automatic maintenance of the set ratio of dry components and liquid;
- possibility of providing high productivity with small dimensions;
- qualitative mixing of components: no sticking of material on the walls of the hopper, no clumping, qualitative final product.



a b

Fig. 5. Schematic diagram (a) and general view (b) of the plant for preparation of liquid feed mixtures.

The unit (Figure 5) consists of a loading chamber 4, working chamber 7, discharge 5 and suction nozzle 1, impeller 8, hollow sleeve with spiral winding 9.

The hollow sleeve 9 is fixed in the bearing 2, which is provided with seals 10 on both sides. The sleeve 9 is connected through the housing with the suction pipe 1. In the lower part of the feeding chamber 4 there is a flap 3, which closes off the supply of material in the feeding chamber 4 and prevents air from entering the impeller.

The proposed unit is able to operate both in lines with in-line and batch application of components.

3 Results and discussion

To determine the maximum feed rate at different modes, tests were carried out and the results are shown in Figure 6.

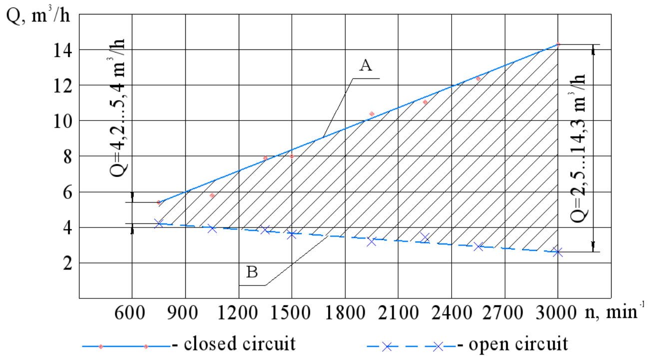
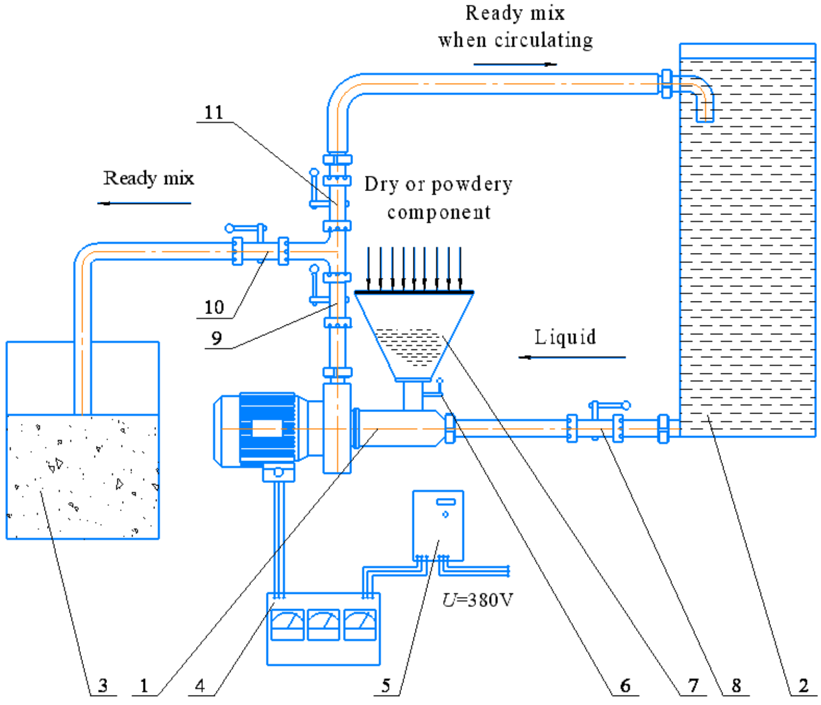


Fig. 6. Dependence of maximum flow rate on impeller speed of the unit for mixing bulk components with liquid.

Section A shows the feed rate of the device when the feed chamber is closed, here we can see that the characteristic has a straight-line dependence.

When the characteristic is taken at open feed chamber (section B) we have a falling characteristic of feeding. This circumstance is connected with the fact that at low rotational speed the loading chamber is partially overfilled, and then with increasing rotational speed air enters the system, which reduces the feed.

To study the mixing processes, the plant was assembled with an open circuit by flow and circulation scheme (Figure 7).



1 - installation; 2,3,4,5 - ball valves; 6 - tank with water; 7 - tank with ready mixture; 8 - multimeter DMK-20; 9 - frequency converter; 10 - tachometer; 11 – thermometers.

Fig. 7. Schematic diagram of the open circuit plant.

According to the flow scheme the unit works as follows (Figure 7): before the start of operation, valves 4,5 are closed, and valves 2,3 are opened. After starting the electric motor, tap 5 is opened and dry components are poured into the loading chamber. The resulting mixture flows into the tank 5.

The quality of the resulting mixture was previously assessed by the quantitative content of components. Water was used as a liquid component and chalk as a dry component. The final criterion was chosen the degree of homogeneity, which reflects some degree of approximation of the actual concentration of the component in the mixture to the ideal distribution. Therefore, the degree of homogeneity, which is the ratio of the content of the control component in the analysed sample to the content of the same component in the mixture, is the completion of the mixing process. To estimate the mixing error, the coefficient of heterogeneity (variation) expressed in % was used.

When chalk was used, the mass of the mixture was weighed and then settled for 24 hours. After that the settled chalk sediment was dried for 24 hours at room temperature. After measuring the mass of the dry residue, the container was washed and weighed. The tare mass was subtracted from the readings.

When assessing quality is much easier to consider the mixture two-component. To do this, allocate from the mixture of one component, called the control (key), and all the rest are combined in the second conditional component. The degree of distribution of the control component in the mass is used to judge the quality of the mixture. To assess the quality of a 2-component mixture, the dry component was chosen as the control component.

Quantitative characteristic of the completion of the mixing process is the degree of homogeneity, which was determined by the formula:

$$\theta = \frac{F_O(z_i)}{F(z-3)} = \frac{F_O(z_i)}{0{,}9973} \quad (1)$$

Where F_o - normalised Laplace function.

The proportion of particles of the control component in the mixture is within the specified limits; $0 < \Theta < 1$. The limiting case of complete mixing corresponds to the value $\Theta = 1$.

The study of the working process of the installation for the preparation of liquid feed mixtures was carried out using the methods of experiment planning. For the best description of the process flow when determining the degree of homogeneity for the flow scheme, the plan on Box-Benkin (Table 1) was implemented.

Table 1. Experimental design.

Name of factors and their units of measurement	Coded designation of factors	Factor levels			Variation interval
		Lower -1	Average 0	Upper +1	
Rotational speed of impeller n, min^{-1}	X_1	1500	2250	3000	500
Water temperature t °C	X_2	20	30	40	10

After realisation of experiments, calculation of estimates of regression coefficients, the following models of working process were obtained:

$$\theta = 91.28 - 1.83 \cdot x_1 + 2.6 \cdot x_2 + 2.56 \cdot x_1^2 + 1.87 \cdot x_1 \cdot x_2 - 2.29 \cdot x_2^2 \quad (2)$$

Using the software applications Microsoft Office Excel and Statgraphics Plus 5.0. for Windows in accordance with the methods outlined in, the estimates of regression coefficients were calculated, their significance was assessed, and the adequacy of the obtained models was checked. The calculations carried out to determine the mean value of the response and the estimated value of the optimisation criterion were determined in the Microsoft Office Excel environment.

Estimates of regression coefficients were considered significant with 95% confidence probability with the value of P-Value given in the table of analysis of variance not exceeding 0.05.

Table 2. Experimental results for the flow scheme.

Levels of variation	**Factors**		**Optimisation criteria**				
	Rotational speed of impeller n, min^{-1}	**Water temperature t °C**	**Degree of homogeneity, %**				
			Θ'	Θ''	Θ'''	Θ''''	Θ_{cp}
	x_1	x_2	y'	y''	y'''	y''''	y_{cp}
Upper +1	3000	40	–	–	–	–	–
Basic 0	2250	30	–	–	–	–	–
Nizhny –1	1500	20	–	–	–	–	–
1	–1	–1	95.47	91.2	92.7	90.7	92.52
2	0	–1	84.25	87.65	85.45	88.46	86.45
3	+1	–1	80.85	88.49	86.89	84.89	85.28
4	–1	0	97.28	92.42	97.28	91.44	94.61
5	0	0	89.5	93.98	98.45	93.08	93.75
6	+1	0	86.5	90.83	95.15	89.96	90.61
7	–1	+1	98.0	93.1	98.0	92.12	95.31
8	0	+1	85.0	89.25	93.5	88.4	89.04
9	+1	+1	98.25	93.34	98.25	92.36	95.55

Analysing two-dimensional cross-section (Figure 8), we can conclude that at water temperature t=25...38 °C and rotational speed n=1500...1600 min^{-1} reached the value of homogeneity degree Θ=94,8%.

Studies of mixing processes have shown that in all experiments the temperature of the initial liquid has the greatest influence on the quality of the mixture, and the rotational speed of the impeller does not affect significantly, but has a contribution when its value increases. As can be seen from the obtained cross-section, with a change in temperature, which can change during the experiment at a lower concentration of powdery component goes into the mixture and the plant begins to switch to a mode of operation with a higher feed rate.

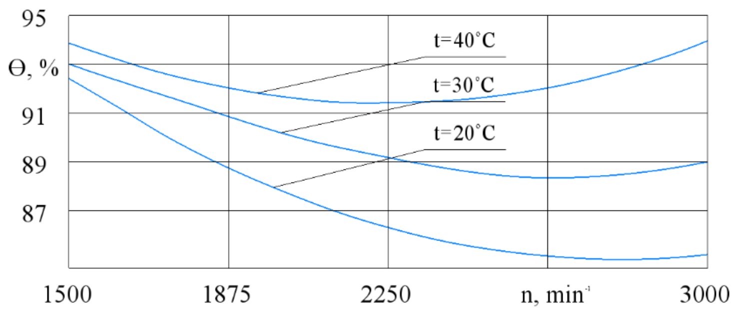


Fig. 8. Influence of rotation speed n and water temperature t on the degree of homogeneity of the mixture Θ, %.

4 Conclusion

The use of the proposed installation for the preparation of nutrient media will allow qualitatively and quickly mix dry components with liquid directly in the process of its movement. At the same time, no sludge and clumps of the dissolved component are formed:

- the developed design will meet the needs of a large number of consumers, as the presented device can be used in various fields of activity: biotechnological, food, medical industry and others.
- At continuous introduction of components, at water temperature t=25...38 ºC and rotational speed n=1500...1600 min-1 the homogeneity degree Θ=94,8% was achieved.

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