Improvement of rotary disperser efficiency

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Abstract. The article describes the relevance of research. The experiment technique has been given. The experiment procedures have been described. The mathematical model of the dispergation process of the whole milk substitute has been obtained. The work presents the results of the experimental research of rotary disperser efficiency in production of the whole milk substitute for calf rearing in the prophylactorium period. Based on experimental researches optimum values of structural and operating parameters of the rotary disperser have been obtained. Comparison of theoretical and experimental researches and estimation of the homogeneity degree of the mixture obtained are given in the conclusion. The conclusions provide particular technical recommendations and research results obtained.

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Introduction

The modern stage of livestock farming development is based on production of new high-quality digestible polycomponent products with high nutritional and biological value.

Livestock rearing is a leading branch of livestock farming, and one of the key factors to obtain maximum number of quality products is maintaining and rearing healthy young cattle stock. Over recent years the animal feed science has accumulated a lot of experimental data on the effect of different nutrients as well as essential amino acids, vitamins, macronutrients and micronutrients, antibiotics, hormones, enzymes and other factors for metabolism and feed efficiency. These data are used for further improvement of the theory and practice of farm animal feeding [1, 2]. They ensure realization of genetic potential of animal productivity. The higher the feeding level is the higher the animal productivity is and the lower the efficiency of feed utilization is [3]. To improve the feed efficiency dispergation is used which together with the improved nutritional value of diary and combined products improves their quality, namely, consistency and taste. Improvement of product taste characteristics in dispergation is connected with decreased sizes of disperse particles and respective increased total area of their surface. As a result their influence on taste receptors is intensified which enhances taste perception [4, 5].

The dispergation process essence consists in crushing disperse particles to the sizes of several micrometers and their homogeneous distribution in space (stirring) [6].

The dispergation process efficiency can be estimated by settling or centrifuging the milk sample and by measuring fat of fractions obtained [7].

Method

The theoretical researches have been conducted using fundamentals, laws and methods of classical mechanics, physics and mathematics. The experimental researches have been conducted in laboratory conditions based on standard methods in accordance with applicable GOST standards and using the theory of designing the multiple-factor experiments. Basic calculations and processing of experiment results have been performed using mathematical statistics methods as well as MicrosoftExcel, Function Wizard and MathCAD12 software.

To verify theoretical researches and grounding of parameters the method of experimental researches has been developed which includes determination of process parameters: 1. Quality of mixture crushing; 2. Homogeneity degree of the mixture; 3. WMS concentration in 1 liter of water and structural parameters: 1. Rotary speed; 2. Processing time; 3. Number of windows of the internal stator shell.

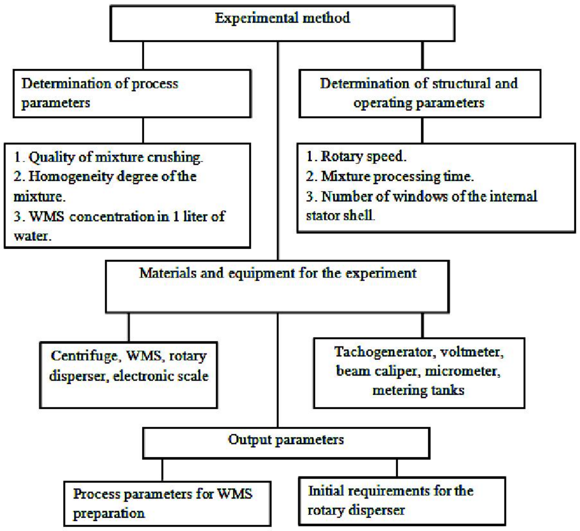

Figure 1. Experimental method

According to the experimental method used the experimental researches include: creation of the disperse system, generation of mechanical impacts on the WMS. The unit has been equipped with the devices for measuring the parameters of impacts generated.

Measurement results have been processed both manually and using a computer.

Certain directed liquid flows have been found in rotary disperser operation. The liquid is thoroughly stirred only as a result of formation of secondary flows and whirling motion. Under the influence of centrifugal forces the liquid is moved in the plane of rotary disperser spinning from the center to the walls. As a result of such movement the depression zone is formed in the center of the disperser and the swirl appears which sucks in the liquid from the layers above and below the rotary. Secondary flows and liquid circulation create a compound circulation circuit shown in the figure as a result of which mixture layers are stirred. The scheme of the experimental unit designed to achieve the objectives set is shown in figure 2.

The nonstructural Box–Behnken design for 4 factors varied at 4levels has been chosen as an experiment implementation design [8].

Dispergation efficiency has been determined using a mixture centrifugation method with measurement of mass fractions of fat in fractions obtained [9]. The criterion for the experiment response is the quality of mixture crushing which has been quantitatively measured by the thickness of the separated fat layer in centrifugation and has been measured in mm. Tending to zero is optimum for this parameter.

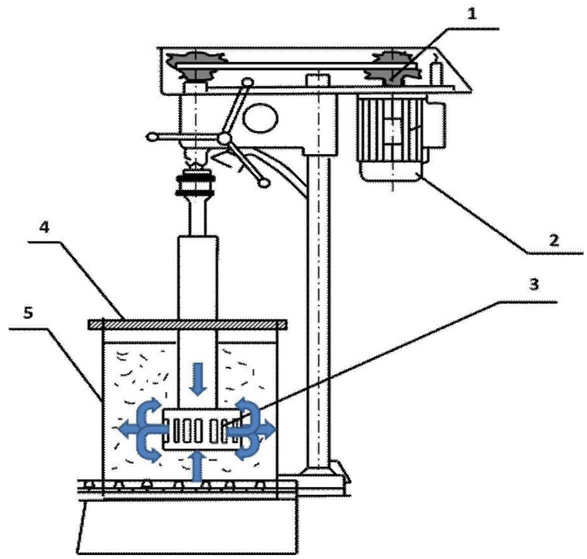

Figure 2 – Scheme of the experimental unit:
1– speed variator; 2– electric motor; 3–rotary disperser; 4–mount for the disperser housing; 5–tank.

Main part

To conduct the experiments the mixture prepared has been placed in 5 liter tank 5 of the unit (Figure 2) and they include electric motor 2 with parameters set. The mixture processing time has been recorded using a stopwatch. Upon completion of processing the mixture samples have been taken from six different tank parts with the capacity of 5mm3 and have been placed into the centrifuge. The centrifuging time has been recorded using an automatic circuit breaker with a stopwatch. Basic centrifuging time and centrifuge rundown time have been recorded in a log. After centrifuging the mixture samples the fat amount has been measured using a beam caliper. The measurement results have been recorded in a log. The rotary speed has changed in an electric motor by speed variator 1, the number of windows of the internal stator shell has changed by 2 additional rings of the overlap window of the internal stator shell. WMS concentration in 1 liter of water have been prepared in advance by adding the WMS dry powder in 1 liter of water with a temperature of not less than $+38^0$C, the WMS powder has been weighed using the electronic scale SF400 with the accuracy of ± 1 g.

When using the experiment design the parameters have been encrypted. We measure the quality of mixture fractionation through three replications for all experiments.

Based on the obtained results of the experiments conducted using the method the regression equation has been deduced which adequately describes the process of WMS movement in the laboratory unit housing depending on the rotary speed, processing time, number of windows of the internal stator shell and WMS concentration in 1 l. of water. The criterion for the experiment response is the quality of mixture crushing.

$$y=3,2-0,569X_1-0,093X_2+0,356X_3+0,10X_4-1,9875X_1X_2-0,595X_1X_4+0,195X_2X_3+0,18X_2X_4-0,309X_1^2-0,3315X_2^2+1,2335X_3^2 \quad (1)$$

Confidential intervals have been taken by the table value of the Student's criterion; adequacy has been checked by the table value of the Fisher's criterion. [10]. The adequacy of models is proven with a probability of P = 0.99 with $F_T > F_R$ (where $F_T = 19.42$; $F_R = 1.32$). The model is adequate.

The experiment conducted using the method and adequacy of the regression equation deduced have proved efficiency of the selected parameters of material crushing, i.e. formation of the WMS homogeneous mixture with processing parameters set.

To process the results obtained MathCAD12 software has been used which allows to achieve optimum values of the factors.

To analyze the influence of the factors on the mixture dispergation the process response surfaces have been formed. The experiment response criterion is the quality of mixture crushing.

Based on the analysis of data obtained when using the software program the encrypted values have been obtained.

$$Y_{mx} = \begin{bmatrix} 0,95 \\ 1,07 \\ 0,23 \\ 0,89 \end{bmatrix}$$

At that, the optimum value of the rotary speed optimization criterion is 258.5 s^{-1}, the processing time is 320 s, the number of windows of the internal stator shell is 12 pcs. and WMS concentration in 1 liter of water is 0.110 ±0.005 kg.

Conclusion

To compare theoretical and experimental researches the diagrams of influence of each particular factor on the mixture crushing quality have been made, thus, three factors have been substituted one by one in the regression equation deduced at the optimum (zero level), and one factor has been left at the varying level. Thus, the following system of equations has been deduced:

$$\begin{cases} y(x_1) = 3,2 - 0,569\,x_1 - 0,309\,x_1^2 \\ y(x_2) = 3,2 - 0,093\,x_2 - 0,3315\,x_2^2 \\ y(x_3) = 3,2 + 0,356\,x_3 + 1,2335\,x_3^2 \\ y(x_4) = 3,2 + 0,1x_4 \end{cases} \quad (2)$$

Comparison of the mixture crushing quality determined in the experiment with the similar ones measured in theoretical researches has shown that they are statistically indistinguishable, which proves the adequacy of the mathematical model obtained. Graphical implementation of experimental researches has confirmed the theoretical ones. The correlation coefficients are shown in Figure 1.

Table 1. Correlation coefficients

Correlation coefficients	
$y(x_1)$	0.99
$y(x_2)$	0.98
$y(x_3)$	0.80
$y(x_4)$	0.98

The mixture homogeneity degree [lambda] in the experiments conducted has been determined using the method of Kukhta G.M. [11].

In 93% of the experiment conducted the mixture homogeneity [lambda] is of satisfactory and good quality.

The initial requirements for designing and manufacturing the rotary disperser have been developed.

Resume

1. The performed analysis of existing researches on preparation of dispersed structured mixtures and the developed classification of technical solutions allow to prove the new design of the rotary disperser for preparation of the whole milk substitute. Such a device and technology based on it have an advantage over the existing ones and are relevant for modern agriculture in young stock breeding.
2. Theoretical researches have established that from among the known mechanisms of fat globule destruction the real one for our dispergation process is only the mechanism with pulling out of disperse particles and their crushing as a result of the velocity gradient, rupture of liquid disperse particles by means of relative speed of moving and fixed parts and crushing as a result of wear.
3. Study of the rotary disperser

operating process allows to obtain analytic dependence of the mixture preparation quality from the frequency of rotary revolution, mixture processing time, number of windows of the internal stator shell, WMS concentration in the mixture. It has been established that fundamental forces in the rotary disperser operating process are centrifugal forces and surface tension forces. Their correlation allows to establish that rotary disperser simulation is subjected to the Weber criterion (We ≥17) beyond which fat globule particles are destructed.

4. Based on theoretical calculations of parameters, namely: performance, capacity, coefficient of WMS mixture crushing quality and the innovative patent of Kurmanov, A.K., T.I. Isintaev and K.S. Ryspaev, 2006, “Rotary disperser”, A4 (11) 27141, IPC B01F 7/28 (2006/.01), B06B 1/16 (2006.01), application #2012/0719.1, application date 18.06.2012, publication date 15.07.2013, official patent bulletin, 2013, № 7; positive opinion to issue the patent for the invention of Kurmanov, A.K., T.I. Isintaev and K.S. Ryspaev, 2006, “Rotary emulsifier”, A4 (11) 27141, IPC B01F 11/02 (2006/.01), B01F 7/18 (2006.01), B06B1/16 (2006.01), A01J 11/06 (2006.01), A23L 1/035 (2006.01), application #2012/0840.1, application date 18.07.2012; positive opinion to issue the patent for the invention of Nametov, A.M., A.K. Kurmanov, T.I. Isintaev and K.S. Ryspaev, 2006, “Rotary emulsifier-disperser”, A4 (11) 27141, IPC B01F 7/00 (2006/.01), B06B 1/16 (2006.01), A01J 11/06 (2006.01), A23L 1/035 (2006.01), application #2013/0188, application date 14.02.2013, the experimental model of the rotary disperser with the diameter of 50 mm and 12 windows of the internal stator shell has been made.

5. The method developed allows to determine the following process parameters: mixture crushing quality, homogeneity degree of the mixture and WMS concentration in 1 l. of water and structural and operating parameters: frequency of rotary revolution, mixture processing time, number of windows of the internal stator shell in any values of the factors taken from the variability interval.

6. The initial requirements developed for preparing and designing the rotary disperser allows to manufacture the rotary disperser with the following parameters: rotary mean diameter of 50 mm, clearance between cutting edges of not more than 0.5 mm, width of holes of not more than 4 mm, height of holes of 12 mm, the number of holes 12 pcs., wall and edge thickness of not more than 2 mm.

7. The explorary researches conducted allow to achieve optimum centrifuge operation: rotary speed 628 s^{-1}, centrifuging time – 300 s ensure the most qualitative determination of the WMS mixture preparation quality in experimental researches.

8. To conduct researches in laboratory conditions the following has been developed:

- experimental unit which consists of the rotary disperser with the speed variator and the drive which allows to set different variation levels, i.e. experiments in accordance with the nonstructural Box–Behnken design.

9. The selected nonstructural Box–Behnken design at four levels allows to obtain the mathematical model – regression equation, mixture crushing quality depending on the frequency of rotary revolution, mixture processing time, number of windows of the internal stator shell, WMS concentration in 1 liter of water. Optimum values have been obtained with the rotary speed of 258.5 s^{-1}, mixture processing time of 320 s, 12 windows of the internal stator shell and WMS concentration in 1 liter of water of 0.110 ± 0.005 kg.

10. The homogeneity degree of the WMS mixture obtained as a result of experimental researches proves the stated hypothesis of uniform distribution of particles in the product tested. Uniformity of their distribution has been observed in 93% experiments conducted. Comparison of the mixture crushing quality determined in the experiment with the similar ones measured in the theoretical research shows that they are statistically indistinguishable, which proves the adequacy of the mathematical model obtained.

11. The annual economic benefit from introduction of the rotary disperser is 27 120 roubles per WMS ton due to reduction of total costs by 31.3 %, operating costs by 31,5% with a high quality of the mixture prepared. The payback period is 1.7 years.

Gratitudes

This work has been performed in accordance with the topics of the research work “ Development of recommendations on improving the efficiency of machine technologies in the agricultural sector for the conditions of the Kostanay region” approved by the National Centre for Scientific and Technical Information of the Republic of Kazakhstan on 13.02.12., state registration #0112 RK00946 and “Hazard analysis and critical control points in agricultural products in accordance with the HACCP system”, state registration #0112 RK00929 of 13.02.12.

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