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EXPERIMENTAL INVESTIGATIONS OF THE PARAMETERS OF THE JET MILK HOMOGENIZER WITH SEPARATE CREAM SUPPLY

Визначено, що зменшення розміру жирових кульок до рівня клапанних гомогенізаторів забезпечується при діаметрі каналу подавання вершків 0,6 мм і розмірі центрального каналу 2 мм. Встановлено, що основним фактором, що визначає процес диспергування жирової фази молока, є швидкість потоку. Причому зменшення розмірів часток при зростанні швидкості потоку має прямо пропорційний характер.

Ключові слова: *струминний гомогенізатор, роздільна подача вершків, канал подавання вершків, діаметр жирової кульки.*

1. Introduction

Homogenization is a process of grinding of fat globules and their uniform distribution in the volume of the plasma of milk. This operation refers to one of the main regulatory processes for most products of the dairy industry. At the same time, it should be noted the high energy costs of the process for the most common designs of valve homogenizers acting on the principle of milk pushing into the narrow gap between the seat and the valve. Other designs of homogenizers, including known rotational, ultrasonic, electrohydraulic and vacuum, do not provide the necessary dispersion degree of fat globules and the necessary dispersed composition of the finished product [1, 2].

The general problems of increasing the effectiveness of homogenization include the lack of a single theoretical basis. There are 6 hypotheses of homogenization, on the basis of which more than 10 basic designs are made. The complexity of the study of the process lies in the high rate of movement, reaching several hundred meters per second and the small particle size fluctuates in the range of 0.8–1.2 μm. During more than a hundred-year history of using the operation, attempts were repeatedly made to investigate the processes leading to a decrease in the size of fat globules.

One of the known studies is investigation of the process using photographs obtained with a laser [3]. However, the current level of technology did not allow to draw a conclusion, which exhaustively explained the processes taking place in the zone of the valve slit. An attempt was made in [4] to investigate the process of grinding of fat globules in the complex field of a laminar flow. However, there were no significant conclusions about the mechanism of grinding. This is because the Weber numbers arising in this mode are more effective for grinding of fat globules in the air.

Another attempt using a transparent capacitance and a pulsating laser was made in [5], where it was claimed that grinding occurs under the influence of the difference in the gradient of the dispersion and dispersed phases. Recent research shows that the difference in the rates of dispersive and dispersed phases of the product plays a decisive role in the process of grinding of fat globules [6]. Therefore, studies in this direction are topical.

Laboratory unit has been created on the basis of the department of equipment of processing and food production of the Tavria State Agrotechnological University (Melitopol, Ukraine) with the purpose of researching the process of separating homogenization. This unit is based on the principle of creating the maximum difference in the rates of skim milk and cream. In this case, a hydrodynamic regime with Weber numbers greater than 50 is established in the homogenization chamber, as a result of which the size of fat globules in milk decreases.

2. The object of research and its technological audit

The object of research is the process of jet milk homogenization with a separate supply of the fat phase. The investigation of the process is carried out using developed laboratory unit for jet milk homogenization with a separate supply of the fat phase depicted in Fig. 1.

Fig. 1. Jet milk homogenizer with a separate supply of cream: 1 – pump НШ-10 (Ukraine) for skim milk supply; 2 – electric three-phase motor; 3 – connecting pipes; 4 – container for skim milk; 5 – homogenization chamber; 6 – manometer; 7 – throttled valve; 8 – pump control unit of cream supply; 9 – packet switch; 10 – container with cream with a centrifugal pump

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Skimmed milk from the container 4 under pressure of a pump 1, driven by an electric motor 2 through the connecting pipes 3, flows to the homogenization chamber 5. The supply rate of the dispersion phase is a function of the pressure regulated by throttled valve 7, the pressure value is controlled by a manometer 6. In the place of the maximal narrowing of the central channel of the homogenization chamber the amount of cream from the container with cream 10 is supplied by the pump with the help of the control unit of the supply pump 8. In order to ensure safety requirements in the unit, two packet switches 9 are provided.

The design solution for the homogenization chamber is shown in Fig. 2.

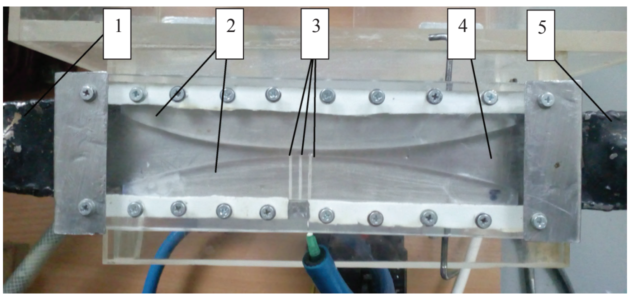

Fig. 2. Milk homogenizer chamber with separate cream supply: 1 – branch pipe for skim milk; 2 – guides; 3 – channels for fat phase supply; 4 – lid made of organic glass; 5 – branch pipe for homogenized milk

The chamber (Fig. 2) consists of branch pipe for skim milk (fat content up to 0.05 %), through which the product under required pressure is supplied to the neck, which is formed by two flow guides 2. Cream is supplied at the point of maximal narrowing to milk in the ratio calculated from the material equation balance through thin channels 3 [7].

This design allows to realize the principle of a separate cream supply, at which energy savings of about 70 % are achieved, which is achieved by reducing the amount of product that is homogenized. In addition, separating homogenization helps to limit the mechanical effect on the protein phase and provides greater stability of the emulsion [1]. Observation of the process progress makes it possible to carry out the lid 4 made of organic glass. The withdrawal of homogenized milk takes place through the branch pipe 5.

The laboratory unit of a jet milk homogenizer with a separate supply of the fat phase according to theoretical calculations is capable of providing a productivity of 1600–2000 kg/h, which is sufficient for most of the technological processes in the industry. Simultaneously with homogenization, the milk is normalized that reduces the energy costs of the process, but it is characterized by the need for preliminary separation of milk obtained from different manufacturers.

To the shortcomings of equipment should be attributed the possibility of the appearance of obliteration phenomenon of the cream supply channels. In order to eliminate this, periodic treatment of the equipment with a substance containing a solvent of mineral deposits is proposed. In addition, this unit does not allow maintaining the temperature of dispersive and dispersed phases of the product, the change of which from the level of the nominal value of 60 °C worsens the conditions for grinding of fat globules.

3. The aim and objectives of research

The aim of research is to determine the nature of the dependencies between the process factors and the average size of fat globules after homogenization. The obtained dependences will expand the scope of information on the practical application of a jet milk homogenizer with a separate supply of the fat phase. If energy costs are reduced at 70 % of the valve samples, the average particle size will be 0.85–1.1 μm [8].

To achieve this aim it is necessary to:

1. Identify the influential factors of the process and develop a methodology for conducting the research.
2. Carry out a study of the effect of supply rates of skimmed milk, the size of the canal at the point of maximal narrowing, and the channel for cream supply on the dispersion quality.
3. Determine the optimal values of the selected factors, based on the condition of ensuring the smallest size of fat globules.

4. Research of existing solutions of the problem

Recent trends in the industry claim the need to apply the principles of discrete-pulse [9], pulsate [10], frequency-pulsate [11] and intensify the homogenization process by creating an active turbulent regime [12]. Most of these principles, when implemented in the design of jet milk homogenizers, can provide a sufficiently high difference in the product phase rates [7]. Due to the difference in the phase velocities, critical values of Weber numbers occur that causes the droplet to collapse under the influence of tangential stresses and dynamic heads acting on it from the medium [13, 14].

In the course of the analysis of world periodicals, the following directions of reducing the energy intensity of jet milk homogenizers are revealed for the size of the fat globules is less than 1 μm:

- intensification of the grinding process due to changes in flow parameters;
- selection of the optimal shape of the working chamber;
- research and improvement of the design of the T-shaped mini mixer;
- creating a difference in the phase rates between the dispersed and dispersive medium.

The use of a T-shaped mini mixer ensures skimmed milk supply through two channels perpendicular to the flow of cream that moves at a higher speed [15], at a level approaching the valve samples. But at the same time, mixer design is characterized by high energy costs, which are necessary skim milk injection.

The study of the process of reducing the size of fat globules that is due to a change in the working cross-section of the mini mixer chamber [16, 17] does not provide a sufficient degree of particle refinement. The average particle size is more than 1 μm, which indicates that changing the shape of the working space without intensification of the process is not effective by reducing the size of the fat globules.

The study of changing the hydrodynamic mode of the mixer operation also does not reveal a significant reserve for reducing the energy costs of the process [18]. The use of a microchannel in a mixer is expedient in the opinion of the authors only if the influence on the central part of the jet providing pulsations [19].

The counterflow-jet milk homogenizer provides grinding to an average particle size of about 1 μm with a reduction in energy costs by 3 times compared to a valve homogenizer [6]. Along with this, it is characterized by such significant drawback as significant foaming, which occurs due to the destabilization of the protein phase when the flows collide.

There are patented designs, that are used the principles of ejecting cream to the flow of skim milk through the nozzles in a certain rate [7]. However, they are able to provide reducing the sizes of fat globules to only 1.1 microns that is more than technological requirements of 0.8–0.9 microns.

Thus, the most effective way to reduce energy costs while providing grinding to the level of valve structures is provided by a jet milk homogenizer with a separate supply of the fat phase. It combines the principles of ensuring the maximum difference in the rates of dispersion and disperse phases with simultaneous intensification of liquid in the chamber.

5. Methods of research

The following limits of factor variation are determined for the experiment [20]:

– the distance between the guides at the place of maximal narrowing (the lower limit is 1 mm, the upper limit is 3 mm, the step of the factor change is 1 mm);
– supply rate of skimmed milk (lower limit is 37 m/s, upper limit is 87 m/s, step of factor change – 25 m/s);
– diameter of the cream supply channel (the lower limit is 0.6 mm, the upper limit is 0.8 mm, the factor change step is 0.1 mm).

The input parameters of the process include the diameter of the cream supply channel, the supply rate of the skim milk and the distance between the guides at the point of maximal narrowing.

The output parameters of the process of jet homogenization of milk with a separate cream supply are the average size of fat globules and the uniformity of their distribution in the emulsion.

Each experiment was performed in three replicates. In the study of jet milk homogenization with a separate supply of the fat phase, several indicators were recorded. Thus, the temperature of cream and skimmed milk was 60 °C. Cream fat content of 40 % was fed to the flow of skim milk at the rate necessary to provide the original fat content at 3.5 %. The amount of cream and the rate of their supply were calculated from the equation of material balance for a jet milk homogenizer with a separate supply of the fat phase.

After each experiment, a carefully selected sample of the product was selected. Part of the sample was to be diluted 1:10 with water, from which a drop of sample was taken for study under a microscope. After settling for 15 minutes of the sample covered by a cover slip, the sample was examined on a MICROMED P-1-LED optical microscope (Russia) with a resolution of 1500 times and a connected digital camera. It is shown in Fig. 3.

For the study, the magnification was increased to 600 times, based on the conditions for providing a clear picture and taking into account the limitations of the digital camera. When the sample was moved in the longitudinal and transverse directions, the characteristic fields of vision were photographed. After this, the disperse characteristics of the fat globules were calculated. The scale was determined by a photo taken previously with an optical micrometer with a 0.01 mm dividing point.

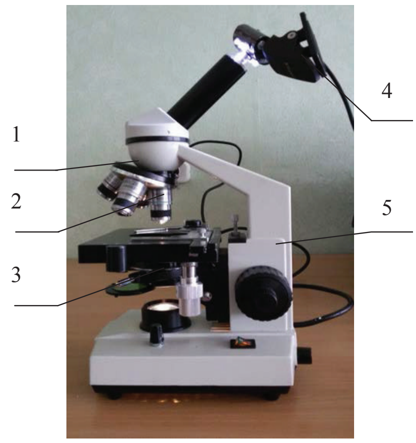

Fig. 3. Appearance of a microscope with a digital camera: 1 – lens; 2 – sample table with homogenized sample; 3 – lamp; 4 – digital camera; 5 – coarse adjustment screw

6. Research results

In order to choose the optimal values for the supply rate of skim milk and the diameter of the cream supply channel from the results of the experiments shown in Table 1, let's plot the graph shown in Fig. 4. From the fluctuation range of the experimental values, let's select the scale for each of the coordinate axes. After that, let's apply the values of the parameters to the resulting grid and approximate the closest known functional dependence of the parameters. It is the line.

Analysis of the obtained data (Fig. 4) indicates the presence of a directly proportional relationship between the supply rate of skim milk and the average size of fat globules. As the rate increases, the value of the Weber number increases, causing the fatty phase to be reduced to smaller sizes. From the point of view of saving energy, the optimal rate is 60 m/s. As the pressure rises above this value, the quality of grinding continues to increase, but the energy costs of the process, according to theoretical studies, grow by almost a third.

Table 1

Experimental data on the relationship between the supply rate of skimmed milk υ, the diameter of the cream supply channel d_c and the average size of the fat globules after dispersing d_{av}

υ \ d_c	d_{av}		
	0.8	0.7	0.6
37	0.96	0.91	0.86
50	0.935	0.89	0.85
65	0.91	0.87	0.835
75	0.895	0.855	0.825
83	0.88	0.845	0.815

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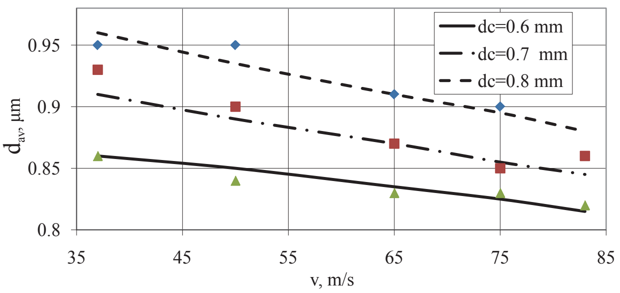


Fig. 4. Graph of the dependence of the skimmed milk rate υ and the diameter of the supply channel of the fat phase d_c on the average diameter of the fat globules d_{av} with the distance between the guides a=2 mm

The rational size of the cream supply channel from the point of view of technologically feasible conditions for the laboratory sample is 0.6 mm, at which grinding is achieved at a level of 0.83–0.86 μm. This is explained by the fact that the flow of skimmed milk acts more evenly on the jet of smaller diameter, while the central and peripheral parts of the jet are under the influence.

In order to select the optimal values of the central channel at the point of maximal narrowing, let's investigate the relationship between it, the diameter of the cream supply channel and the average diameter of the beads after homogenization, the experimental data of which are given in Table 2.

Table 2

Experimental data of the diameter of the cream supply channel d_c, the distances between the guides a and the average size of the fat globules after dispersing d_{av}

d_c \ *a*	d_{av}		
	1	2	3
0.6	0.81	0.835	1.05
0.65	0.83	0.85	1.1
0.7	0.85	0.87	1.15
0.75	0.87	0.9	1.2
0.8	0.9	0.92	1.25

The obtained data (Fig. 5) indicate that grinding at the level of valve homogenizers in the range of 0.8–0.9 μm provides the distance at the site of the maximal narrowing of – 1 and 2 mm. The optimal value of the parameter should be considered as 2 mm, because a slight decrease in the size of fat globules at a distance of 1 mm increases the energy costs per 1 kW. The studies confirmed the data obtained by modeling the process in the software complex ANSYS (USA) [20].

The obtained results indicate that the localization zone of the maximum velocities is scattered at a central channel distance of 3 mm. This phenomenon will worsen the conditions of grinding and lead to an increase in the size of fat globules.

The microphotos on the basis of which the average size of fat globules was calculated is shown in Fig. 6.

Microphotos of homogenized milk samples (Fig. 6) clearly demonstrate the advantage of reasonable optimal regimes.

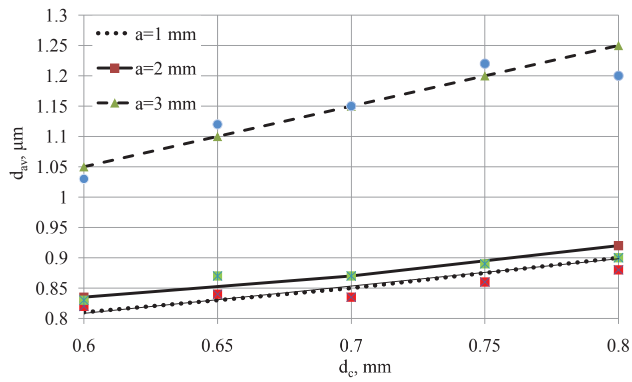
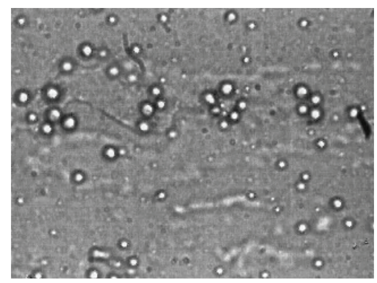
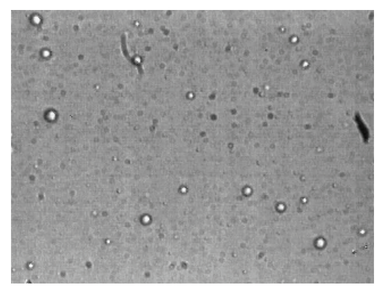


Fig. 5. Graph of the dependence of the average diameter of the fat globules d_{av} on the diameter of the cream supply channel d_c and the distance between the guides at a skim milk rate of 60 m/s



a



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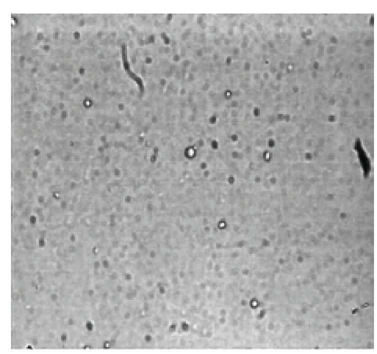

c

Fig. 6. Microphotos: *a* – non-homogenized sample; *b* – homogenized milk sample at a rate of 83 m/s, the distance of the central channel at the place of maximal narrowing of 1 mm and the diameter of the cream supply channel of 0.8 mm; *c* – homogenized milk sample at a rate of 60 m/s, the distance of the central channel at the point of maximal narrowing of 2 mm and the diameter of the cream supply channel of 0.6 mm

7. SWOT analysis of research results

Strengths. The strengths of research include the identification of the nature of the relationship between the diameter of the cream supply channel, the rate of skim milk and the average size of fat globules. The study is carried out under optimal temperature conditions, substantiated by the work of other authors. Cream supply at a constant rate ensures a uniform effect of the flow of skim milk on the cream. The cream supply in quantity that is determined using equation of material balance ensures the normalization of the emulsion to the fat content of drinking milk (3.5 %).

Using the method of direct measurement of fat globules under a microscope using a digital camera with the determination of the scale with precise scaling with an optical micrometer allows the dispersion characteristics of the milk emulsion to be determined with high accuracy. The sedimentation of the sample after dilution on the slide facilitates the emergence of small fat globules and their entry into the clear field of view of the microscope to improve the accuracy of determining the average diameter of the fat globules. The applied method of microphotographs allows not only to determine the average diameter of fat globules after homogenization, but also to study the uniformity of the distribution of fat particles in the volume of the milk plasma.

In comparison with analogues, for example, countercurrent-jet milk homogenizer, the laboratory sample is distinguished by the absence of destabilization of the protein phase of the emulsion. Compared with this homogenizer in a laboratory sample with a separate supply of cream, energy costs are reduced by almost a third. This is explained by the use of the principle of separate feeding of the fat phase with the possibility of simultaneous normalization of the product.

Weaknesses. The weaknesses of research include the lack of consideration for the effect on the average size of fat globules after homogenization of the cream supply and the effect of the fat content of the dispersed phase. The ability to fix smaller fat globules is limited by the low resolution of the microscope and the digital camera. The lack of investigation of the cream supply and the fat content of the disperse phase on the average size of the fat globules after homogenization does not make it possible to determine the empirical coefficient. This indicator takes into account the shape and dimensions of the fat feed channel and the conditions under which the product is normalized.

The short duration of the experiment, which is 10 seconds, can influence the results of the study at the initial and final stages of each experiment.

To negative moments of research it is necessary to attribute its high laboriousness at the stage of sample research and counting the number of fat globules. The drawbacks of the unit include the need for preliminary separation of cream, but this operation is used without this in most of the industry's technological processes.

Opportunities. Additional factors that will contribute to the realization of the research objectives include the following factors. Valve-type homogenizers are used in most regulatory processes in high-capacity milk processing plants. However, high energy costs and low rates of economy, when the limit is reached, encourage manufacturers to search for new promising areas of energy conservation. Among the most promising designs, from the viewpoint of reducing energy costs and condition of quality assurance on the level of valve samples, jet-type homogenizers are outlined. A significant part of them is based on the principle of creating a difference between the dispersed and dispersed phases of the product. Technical realization of this principle provides a reduction in the average size of fat globules from 3–4 in the non-degraded product to 0.85–1.1 μm in milk after homogenization.

Additional opportunities of the introduction of a jet homogenizer with a separate supply of cream will provide savings through simultaneous homogenization and normalization. In addition, the reduction in energy costs for it with respect to valve samples is 4 to 5 times, and for a countercurrent-jet homogenizer is about 30 %.

Threats. The threats associated with the introduction of research results of the jet milk homogenizer include the insufficient study of the processes taking place in a jet homogenizer with a separate cream supply. The main obstacle to the introduction of this type of jet homogenizer is the high financial costs of upgrading the equipment for homogenization in the milk processing industry. And when modernization is carried out, its main direction is not the replacement of morally and physically obsolete designs of valve homogenizers, but the replacement of their separate units. Since the possibilities of modernization of valve-type homogenizers have reached the limits of the technical capabilities of the design, it can be noted that there is no significant effect in terms of saving energy costs.

On the other hand, small enterprises, due to their flexibility, are more inclined to introduce new models of equipment, prefer less valuable designs to mixers and dispersants. The problems of these designs include the insufficient degree of grinding of fat globules, which for most structures after homogenization does not exceed 1.3–1.6 microns. Therefore, the possibility of introducing a jet milk homogenizer with separate cream supply at these enterprises exists at a cost reduction of the equipment.

Thus, SWOT analysis of research results allows to determine such problems in achieving the research objectives:

– reducing the cost of the unit that make it attractive for manufacturers of small and medium-sized enterprises;
– conducting a study of the relationship between the cream supply, its fat content and the average size of the fat globules after homogenization for a more perfect and universal design of the jet homogenizer;
– use digital camera with a high resolution for research, which will allow obtaining more accurate results for the smallest fat particles distributed in the volume of the plasma milk.

8. Conclusions

1. The research method is developed. The size of the central canal at the point of maximal narrowing, the rate of skim milk supply and the diameter of the cream supply channel are determined as influential factors. The distance between the guides at the site of maximal narrowing has a significant effect on the average size of the fat globules at sizes exceeding 2 mm. Reducing the distance to 1 mm slightly improves the quality of homogenization, but is characterized by an increase in energy costs of about 1 kW/t.

2. The nature of the relationship between the supply rate of skim milk, the size of the channel at the point of maximal narrowing and the channel of cream supply on the dispersion quality is determined. It is established that the main factor determining the process of dispersing the fat phase of milk is the flow rate. The relationship between the average size of fat globules and the supply

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rate of skim milk is directly proportional. However, using the operating mode at a rate exceeding 60 m/s significantly increases the energy costs of the process, but at the same time it ensures a further reduction in the size of the fat globules.

3. It is found that the optimum dimensions of the central supply channel for the fat phase are 0.6 mm. At the same time, it is ensured that the fat globules are milled to an average size of 0.83–0.86 μm. A smaller value of the indicator helps to facilitate the rapid obliteration of the cream supply channels, but the degree of grinding of the fat particles is predicted to be even more predictable. In this connection, in the conditions of production in the presence of the technological possibility of implementation, it is advisable to use several channels for supply the fat phase with dimensions of 0.2–0.3 mm.

The optimum value of the distance of the central channel at the point of maximal narrowing is 2 mm. Considering this, if it is necessary to increase the performance of the unit, it is possible to change the size of the unit, but at the same time the ratio of the parameters remains, and the recommended distance must be scaled.

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ПАРАМЕТРОВ СТРУЙНОГО ГОМОГЕНИЗАТОРА МОЛОКА С РАЗДЕЛЬНОЙ ПОДАЧЕЙ СЛИВОК

Определенно, что уменьшение размера жировых шариков до уровня клапанных гомогенизаторов обеспечивается при диаметре канала подачи сливок 0,6 мм и размере центрального канала 2 мм. Установлено, что основным фактором, который определяет процесс диспергирования жировой фазы молока, является скорость потока. Причем уменьшение размеров частиц при увеличении скорости потока носит прямо пропорциональный характер.

Ключевые слова: струйный гомогенизатор, раздельная подача сливок, канал подачи сливок, диаметр жирового шарика.

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