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PARAMETER OPTIMIZATION OF MILK PULSATION HOMOGENIZER

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Abstract

Homogenization is one of the normative processing stages in dairy foods production. One of the topical problems of the modern food industry is to design energy effective equipment for homogenization of milk emulsions. The perspective method to intensify milk fat phase dispersing is to improve pulsation homogenization. Such machines combine high energy efficiency and dispersion degree which exceed the indexes of valve homogenizer. The aim of researches is to decline power consumption of the process of milk pulsation homogenization by optimizing its parameters.

Experimental pulsation homogenizer has a piston with openings which performs sinusoidal oscillations in the cylindrical chamber and is driven by crank gear. The product is supplied into the homogenizer by the volumetric pump. Creating high velocity relative slip between a fat globule and milk plasma causes size reduction of the milk fat. To find out the optimal parameters of the process the graphic methods of the local optimization are used. Emulsion dispersion degree was determined by measuring fat globules sizes by optical microscope with digital camera.

Conducted researches on the pulsation homogenizer showed high correlation between the acceleration of emulsion and fat globules average size. The analytically got results are experimentally confirmed on increasing dispersion degree whereas the specific energy consumption declines and piston oscillation frequency increases. Using conical openings of the piston compared with cylindrical ones makes it possible to reduce energy consumption of the homogenizer. Decreasing coefficient of the piston open area negatively affects milk dispersion degree. Using piston with the conical openings at its oscillation amplitude of 10 mm and vibrations frequency of 150 s^{-1} and emulsion acceleration of about 105 m/s^2 it is possible to get milk emulsion with the average dispersion of the fat phase of 0.8 µm. Specific energy consumption here does not exceed 3400 J/kg.

The received results prove high potential of further research-and-developments of the industrial prototype of the pulsation homogenizer.

***Key words**: Homogenization, Dispersing, Milk dispersion, Pulsation homogenizer, Pulsation homogenization.*

1. Introduction

Homogenization is one of the normative processing stages in dairy foods production. Homogenization is used to: avoid sedimentation and layering of milk fat, increase stability in storage, advance consistency of protein clots, improve the taste, colour, increase viscosity etc.

One of the topical problems of the actual food industry is renovating energy effective equipment for homogenization of milk emulsions [1]. The most widespread in a milk processing line are valve homogenizers that are characterized by high specific energy consumption up to 26 J/kg. Other types of equipment for homogenization cannot produce the same high quality of emulsion [2].

The perspective method to intensify milk fat phase dispersing is the development of the pulsation homogenization. Such machines combine high energy efficiency with dispersion degree which exceeds the indexes of a valve homogenizer. An experimental pulsation homogenizer has a piston with openings which performs sinusoidal oscillations in the cylindrical chamber and is driven by the crank gear. The product is supplied into the homogenizer by the volumetric pump. Creating of high velocity relative slip between a fat globule and milk plasma causes size reduction of the milk fat.

The aim of researches is to reduce power consumption of the process of milk pulsation homogenization by optimizing its parameters.

2. Materials and Methods

In order to conduct experimental researches on milk pulsation homogenisation an experimental setup was developed. Its design is given in Figures 1, 2.

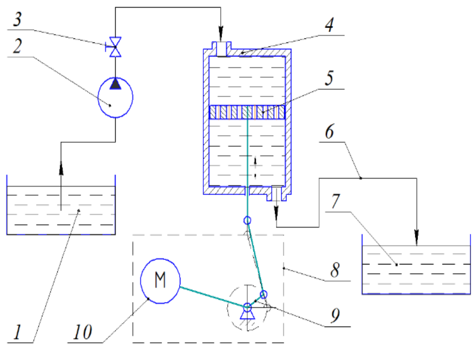

Figure 1. Design of the setup for researching pulsation homogenisation of milk: 1, 7 - process containers for feeding and discharging of milk accordingly; 2 - pump; 3 - valve; 4 - process chamber of the homogenizer; 5 - piston; 6 - piping; 8 - driving motion of the operating element; 9 - crank gear with an amplitude regulator; 10 - electric motor with a rotation frequency regulator

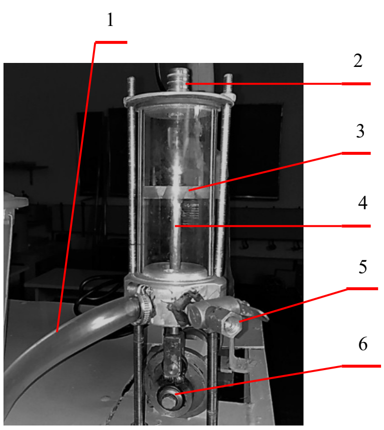

Figure 2. Process chamber of the homogenizer: 1 - emulsion discharge manifold; 2 - product feed manifold; 3 - piston; 4 - rod; 5 - pass valve; 6 - crank gear of vibration

To find out the optimal parameters of the process the graphic methods of the local optimization are used. Emulsion dispersion degree was determined by measuring fat globules sizes by optical microscope with a digital camera.

In order to determine correlation between acceleration and average fat globules diameter the coefficient of determination had been calculated according to the method of Pearson squares by means of Microsoft Excel was used.

3. Results and Discussion

3.1 Results of the theoretical research

In the theoretical researches conducted earlier we put forward a hypothesis about the decisive role of the emulsion acceleration in dispersing fat phase in a pulsation homogenizer [3]. According to the results of the analytical researches the connection was defined between the milk emulsion acceleration (and basic parameters of the pulsation homogenization) and average diameter of the fat globule d [4].

$$d = \frac{K_h}{\sqrt{a_0}} = \frac{K_h}{\pi n}\sqrt{\frac{K_o}{2\varphi s}} \qquad (1)$$

Where:

K_h- Coefficient of homogenization which defines energy efficiency;

a_0- Emulsion acceleration;

K_o- Daylight area ratio of the piston;

n - Frequency of the piston oscillation, s^{-1};

φ - Vlocity coefficient of the piston opening;

s - Amplitude of the piston oscillation, m.

3.2 Results of the experimental researches

In order to check the hypothesis consistency about the decisive role of the acceleration for our tested homogenizer an experiment had been carried out and its results are shown in Figure 3. For changing emulsion acceleration according to the formula (1) we varied frequency of the piston oscillation in the range of 3,000 - 10,000 min^{-1}, amplitude of oscillation (up to 30 mm), quantity and shape of the piston openings (for varying velocity coefficient and daylight area ratio).

The got data show high correlation ($R^2 > 0.96$) between acceleration and average fat globules diameter in the pulsation homogenizer according to the formula:

$$d = \frac{225}{\sqrt{a_0}}. \qquad (2)$$

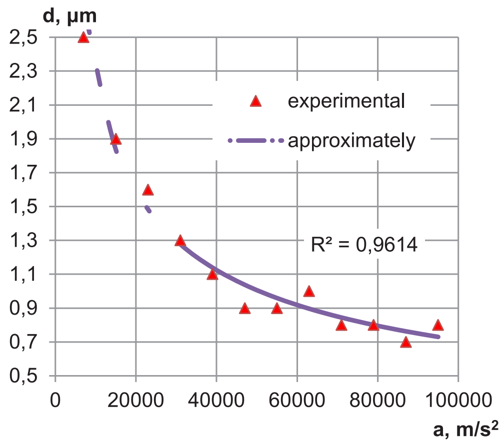

Figure 3. Dependence of the average fat globules diameter *d* on the emulsion flow acceleration in the piston openings a_o

Function is power relation, characteristic of valve, stream and rotor-pulsation homogenizers [5, 6, and 7]. With the impact intensity increase the rates of dispersion decrease. The homogenization coefficient for pulsation dispersing of milk fat equals 225. It proves the hypothesis about the main factor of milk fat globules disruption in the pulsation homogenizer.

When comparing dependences of dispersion on the emulsion acceleration for the pulsation homogenization and the pulsation machine with a vibrating rotor it is possible to see that in spite of different types of design, the dependence behavior is the same. Processing in a rotor-pulsation machine is more efficient ($K_h = 68$) due to the additional impact of vibration and resonance phenomena effecting the processing medium.

According to the results of the theoretical researches [8] we made pistons with cylindrical and conical openings. Parameters of the pistons with conical openings were: K_o = 0.04 (Figure 4 a) and K_o = 0.02 (Figure 4 c) φ = 0.98. Parameters of the pistons with cylindrical openings were: K_o = 0.48 (Figure 4 b) and K_o = 0.24 (Figure 4 d) φ = 0.82.

The results of the researches (Figure 5) indicate increasing fat globules sizes with respect to theoretical calculations according to the formula (1).

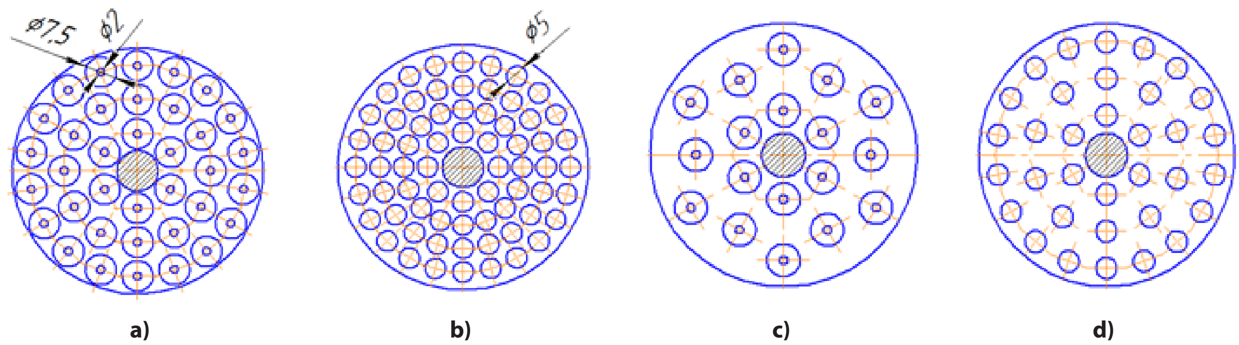

Figure 4. Parameters of the piston: a) with 36 conical openings, b) with 68 cylindrical openings, c) with 18 conical openings, d) with 34 cylindrical openings

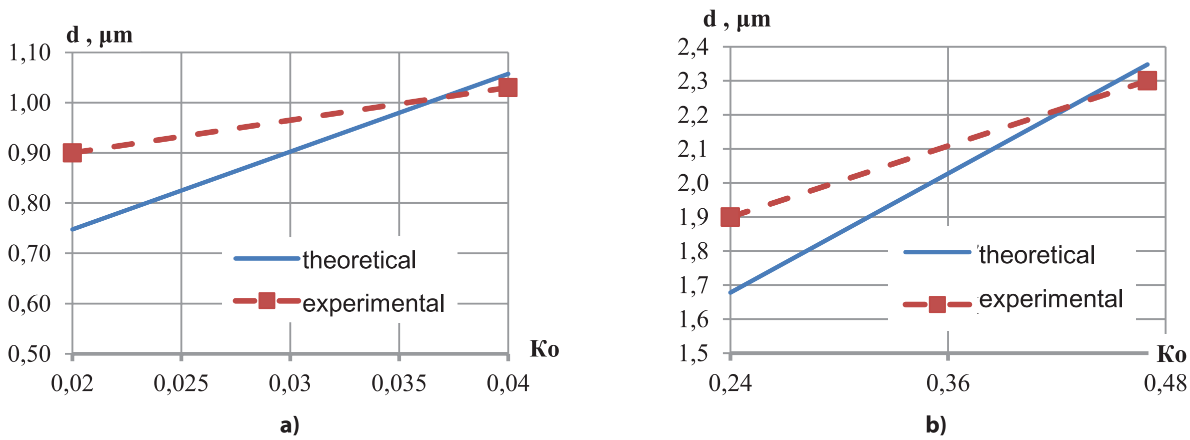

Figure 5. Dependence of the average fat globules diameter d on the coefficient of the piston daylight area ratio K_o for a) conical openings with n = 6,000 min^{-1}, s = 10 mm; b) cylindrical openings with n = 9,000 min^{-1}, s = 10 mm

At 2 times reduction of the number of the piston openings the difference between the theoretical and experimental values reaches 18% for cylindrical and 13% for conical openings. At 2 times decrease of K_0 the emulsion dispersion decreases for conical openings by 5% more than for cylindrical. Such difference can be explained with non-uniform position of the openings on the piston surface, hereupon the number of dead zones and local whirls between openings increases. The sizes of such zones grow at:

- Increasing diameter (for conical openings - a larger diameter) of the piston openings;
- Decreasing number of openings.

In order to define parameter optimization of milk pulsation homogenizer it is necessary to compare the specific energy consumption [9] with the dispersion of milk emulsion. The curves of equal dispersion (Figures 6, 7) indicate decreasing specific energy consumption with increase in piston vibration frequency both for the pistons with cylindrical and conical openings. These results conform to the results of theoretical researches [10].

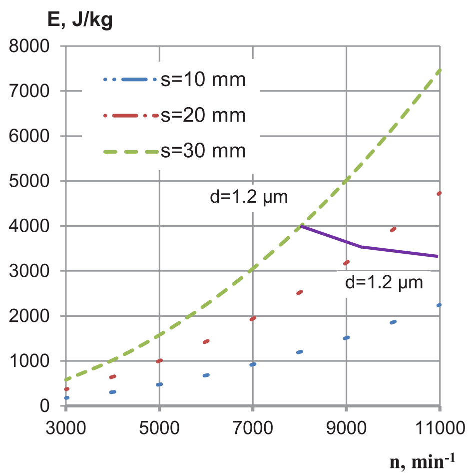

Figure 6. Dependence of the specific energy consumption and emulsion dispersion on the frequency *n* and amplitude *r* of piston oscillation for the cylindrical openings of the piston (K_o = 0.24)

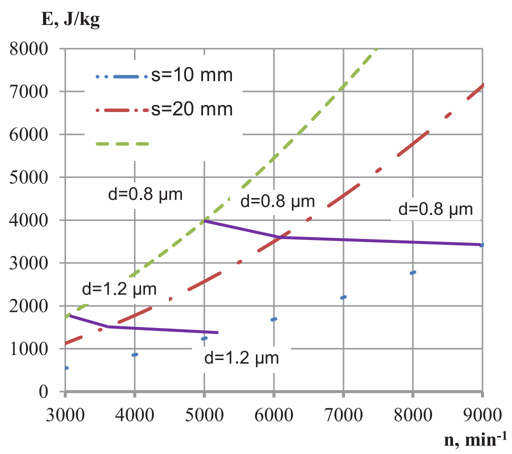

Figure 7. Dependence of the specific energy consumption and emulsion dispersion on the frequency *n* and amplitude *r* of piston oscillation for the conical openings of the piston (K_o = 0.04)

The average fat phase dispersion of 1.2 µm for the piston with cylindrical openings can be attained (Figure 6) with s = 30 mm and n = 8,000 min^{-1} and s = 10 mm and n = 9,600 min^{-1}, and in the last variant the specific energy consumption is lower by 10% and equals 3600 J/kg. The average fat phase dispersion of 0.8 µm for the piston with conical openings can be attained (Figure 7) with s = 20 mm and n = 6,000 min^{-1} and s = 10 mm and n = 9,000 min^{-1}, and in the last variant the specific energy consumption is lower by 5% and equals 3,400 J/kg. The specific energy consumption for the pulsation homogenizer with cylindrical openings of the piston for attaining emulsion dispersion of 1.2 µm is 3.3 times larger than for the pulsation homogenizer with conical openings of the piston (3,600 and 1,200 J/kg accordingly). It is explained with much smaller piston daylight area ratio with conical openings – 0.04 as compared with cylindrical ones - 0.24.

4. Conclusions

- Conducted researches on the pulsation homogenizer showed high correlation between the acceleration of emulsion and fat globules average size. This proves the hypothesis about the decisive role of acceleration in disruption of the fat globules of milk.

- The analytically got results are experimentally confirmed to increase the efficiency of the pulsation homogenizer (increasing dispersion degree and reducing specific energy consumption) at increasing piston oscillation frequency and decreasing amplitude of the piston oscillation.

- Using conical openings of the piston as compared to cylindrical ones makes it possible to reduce energy consumption of the homogenizer.

- Decreasing coefficient of the piston open area negatively affects milk dispersion degree.

- Using piston with the conical openings at its oscillation amplitude of 10 mm and vibrations frequency of 9000 min^{-1} (150 s^{-1}) and emulsion acceleration of about 10^5 m/s^2 it is possible to get milk emulsion with the average dispersion of the fat phase of 0.8 µm. Specific energy consumption here does not exceed 3400 J/kg.

5. References

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