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Justification of sedimentation stability of milk whey after electric spark processing

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Abstract

Introduction.The article focuses on the primary processing of milk whey, in particular, the prospect of its processing using electric spark discharges. Reasonability of the electric discharge application in whey processing technology is confirmed by experimental research as well as mathematical and statistical analysis.

Materials and methods. Mathematical modeling established a rational mode of electrohydraulic treatment of whey which is accompanied by a maximum dispersion of particles of precipitated casein dust.

Results and discussion. It has been confirmed that the average hydrodynamic diameter of milk whey particles decreased from 1697,5 ± 82,38 nanometer to 221,34 ± 0,3 nanometer after electric discharge processing with the peak voltage of 45 kV and discharge quantity of 25. The polydispersity index at that plummeted from 1,0 to 0,35...0,40, which characterizes the system as the one close to monodisperse state.

We have noticed that at the voltage of 30 and 35 kV and the discharge number of 5...15 the particle dispersion was insubstantial. The average particle size decreased only by 22...30%. It was also concluded that at the voltage growth as well as increase in a discharge number the peak values on the distribution curves shifted to the particle size of 500...1000 nm, while the average hydrodynamic diameter decreased. The best results during the electrohydraulic milk whey processing were achieved at the voltage of 45 kV and the discharge number amounting to 25.

The sediment volume in the processed whey decreased from 0,9…1,1 to 0,1...0,2 cm^3 at the voltage of 45 kV and the discharge number of 25.

Conclusions. It is proposed a technological scheme of primary milk whey processing using electro-hydraulic method.

Introduction

The plants having a small production volume in most cases return whey to agricultural commodity producers, which use it to feed the cattle. It is widely known that due to the fact it contains biologically valuable proteins of animal origin, milk whey is an irreplaceable product for feeding young cattle and swine. At that, nutritional value of 14 kg sweet or 17 kg sweet wheat equals to that of 1 kg of barley (12,5 megajoules of metabolizable energy and 11 % of cheese protein), however, the protein quality in whey due to a large amount of essential amino acid is considerably higher than in the case with barley [1, 2, 13]. That is why the maximum retaining of proteins in milk whey is topical.

Transporting and storing of organic whey which has not undergone preliminary preparation irrefutably leads to protein loss caused by deposition of casein dust particles. The latter, in their turn, impede heat exchange processes at heating to more than 65 °C. At that, protein intensively exudes on the surface of the heat-exchange apparatus, forming a burn-on which is hard to get rid of. It leads not only to the sharp decrease in the quantity of a valuable component, but also lowers the pasteurization efficiency, makes the equipment cleaning more difficult.

Unwanted denaturation of whey proteins and their aggregation with casein dust can be avoided provided that mild modes (such as thermisation) [3, 4] are used, but it will not prevent from the unwanted deposition.

That is why the research aimed at the search for the new ways of whey processing, which allow retaining all the valuable components, ensuring the sedimentation system stability is of a particular interest.

The ability of a system to resist the particle deposition is characterized by sedimentation stability. It is ensured with the help of a variety of factors, depending on which kinetic sedimentation stability (KSS) and thermodynamic sedimentation stability (TSS) are distinguished [5, 6].

Kinetic sedimentation stability (KSS) (Formula 1) is typical for disperse systems with comparatively coarse particles. It is measured with the help of a value which is inversely proportional to a sedimentation constant (Ssed). In its turn, sedimentation constant depends on the rate of sedimentation (u) (formula 2):

$$KSS = \frac{1}{S_{sed}} = \frac{9\eta}{2r^2(p - p_0)} \tag{1}$$

$$u = \frac{2g(p - p_0)r^2}{9\eta}, \tag{2}$$

in which g is free fall acceleration; p, p_0 are density values of a disperse phase and dispersive medium correspondingly; r is a particles' radius; η is the medium's viscosity.

For particles the size of which amounts to less than 0,1micrometer, thermal motion and diffusion are taken into account. During the process of the particles' deposition concentration changes according to the height of a liquid column – in higher layers it decreases, whereas in lower ones this value increases. These systems are characterized by thermodynamic sedimentation stability, which is directly connected to sedimentation and diffusion balance (formula 3).

$$TTS = \frac{k_B T}{\nu g(p - p_0)}, \qquad (3)$$

in which ν is the volume of particles, $\nu = \pi r^3 / 3$; T is temperature, k_B is a constant.

The organic whey contains particles the size of which equals up to 50 nanometers, while the coagulated particles of casein dust amount to maximum 2–2,5 micrometers [1], that is why in the first place kinetic sedimentation stability has to be taken into account in this system.

As it can be seen from the formula 1, KSS value is higher for smaller particles. Thus, dispersion is viewed as an acceptable way to address the problem of unwanted coarse casein dust particles and the remnants of curd's sedimentation.

The majority of methods based on the range of mechanical and physical effects (cleavage, grinding, crushing of particles, super-high-speed flow of liquid through the narrow gap 'valve seat-valve', adiabatic boiling in the vacuum, disk dispersion, hydrodynamic cavitation, impact, pulse, ultrasonic medium disturbance etc.) ensure disintegration of particles to a medium diameter of 1–2 micrometers and larger.

The given rate of dispersion is not suitable for achieving our aim, since the size of coagulated casein dust particles remaining in whey after ripening or sedimentation of the basic product, which are able to form unwanted sediment, amounts to 2–2,5 micrometers [1].

Electrophysical methods are believed to be promising in this case, as they not only contribute to dispersing, but also decreasing the amount of microscopic flora in general [7–9]. High-voltage pulse in liquid, resulting in electrohydraulic effect, seems to be of particular interest to us. The essence of this method is in forming within a volume of liquid pulsed electric discharge, causing high hydraulic pressure as well a variety of physical and chemical phenomena to emerge. The latter include hydrodynamic shock, linear liquid flow at super-high-speed, impulse cavitation, polydisperse ultrasonic radiation, the effect of plasma in a spark channel, accompanied by infrared, ultraviolet radiation, impulse electromagnetic fields etc. [10, 12].

There is insufficient amount of data concerning the influence of this electrophysical method on the content and qualitative characteristics of milk whey, which is also true for prospect of its realization for dispersion of coagulated casein dust particles and decrease in the level of biological contamination.

Having taken into account all the facts given, we believe that the improvement of primary milk whey processing by using the hydraulic effect is bound to be a topical and promising line of research.

Materials and methods

The object of the research was milk whey with mass fraction of protein amounting to 1,0...1,5 %, received during the production of non-fat cottage cheese.

The milk whey processing with electric discharge was carried out in the experimental technological complex consisting of the surge current generator GIT50-5×1/4S, discharge chamber, measuring and auxiliary instruments [8].

Discharge circuit and processed medium parameters were as follows:

- voltage equaled 30–45 kV in increments of 5;
- the amount of discharge pulses 5–25 s in increments of 5;
- the energy in a discharge channel – 4,5–5,5 kilojoules;

- the volume of a discharge chamber amounted to 2700–3000 cm^3;
- temperature of the processed medium – 6 ± 2 °C, 20 ± 2 °C and 30 ± 2 °C.

Statistical distribution of the particle size in milk whey and its electrokinetic potential (*ζ-potential*) was researched using the method of dynamic light scattering in the analyzer *Malvern Zetasizer Nano ZS (Malvern Instruments Ltd.*, Great Britain) with the detection angle of 173 °, helium-neon laser with its power amounting to 4 mW and a wavelength of 633 nm.

All the measurements in the research were made at the temperature of 25 °C. In order to control the results' repetitiveness every sample was measured at least three times. The size distribution in the intensity units was received from the correlation function analysis using the *General purpose* algorithm in the analyzer's *Zetasizer Software 6.20.*

We have carried out the multifactorial experiment followed by statistical data manipulation and defining corresponding mathematical relations between the average hydrodynamic diameter, polydispersity index, voltage and the number of electric discharges. The mathematical relations were generally presented in such an equation:

$$D = f(U, n) \text{ and } PI = f(U, n),$$

where D is an average hydrodynamic diameter, PI is a polydispersity index, U is voltage, n is the number of discharges.

Sedimentation process of milk whey particles was researched with software package based on the finite volume method which is used for modeling of 3–D liquid stream and gas in technical and natural objects and also for visualization purposes of this stream by computer Figure ic.

An analytical model of milk whey particles sedimentation process is based on the following equations of Navier-Stokes flow continuity:

$$\frac{\partial V}{\partial t} + \nabla(V \otimes V) = -\frac{\nabla P}{\rho} + \frac{1}{\rho}(\mu + \mu_t)\left[\nabla V + (\nabla V)^T\right] + \left(1 - \frac{\rho_{hyd}}{\rho}\right)g$$

$$\nabla V = 0,$$

where V – vector of relative velocity, m/s;

t – time, s;

P – relative pressure, Pa;

ρ – density, kg/ m^3;

μ, μ_t – dynamic and turbulent viscosity, Pa·s;

ρ_{hyd} – hydrostatical density, kg/m^3;

g – gravitational vector, m/s^2.

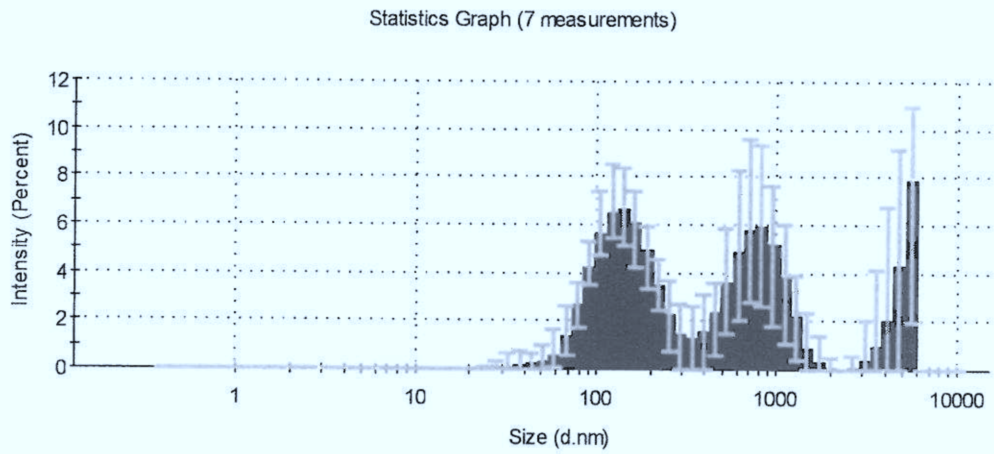
Results and discussion

The expediency of using the method offered in the technology of primary milk whey processing was supported by experimental research of particle size before and after processing, sedimentation system stability, microbiological whey readings and its storage life.

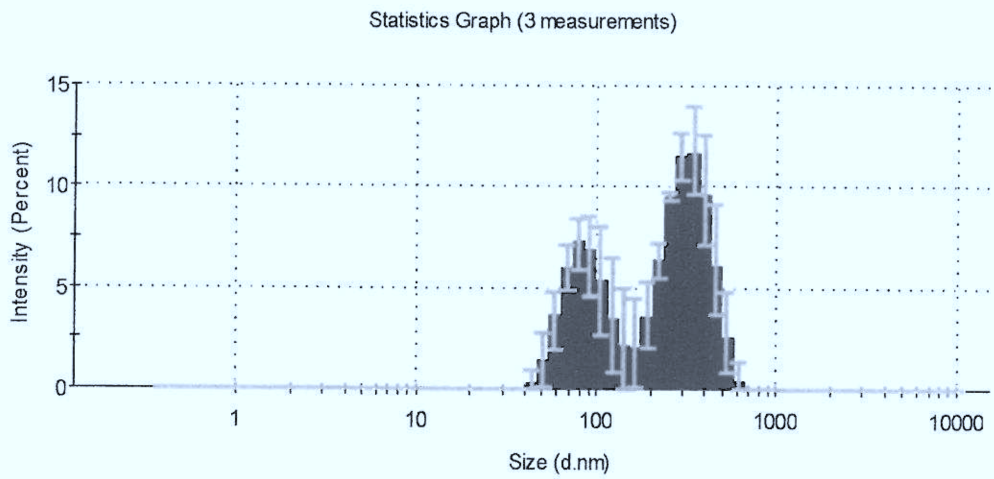
Having studied the dispersion phase whey transformations due to dispersion using the method given, we have defined the relation between the size of the particles and the processing parameters, namely voltage and the number of discharges.

In many real systems, including milk whey, the particle form is not spherical, that is why to the particles of this kind the notion of hydrodynamic radius is applied (diameter).

We have noticed that at the voltage of 30 and 35 kV and the discharge number of 5...15 the particle dispersion was insubstantial. The average particle size decreased only by 22...30%. It was also concluded that at the voltage growth as well as increase in a discharge number the peak values on the distribution curves shifted to the particle size of 500...1000 nm, while the average hydrodynamic diameter decreased. The best results during the electrohydraulic milk whey processing were achieved at the voltage of 45 kV and the discharge number amounting to 25. The distribution curves of the particle size in the unprocessed whey and the whey after electrohydraulic processing at the given parameters are shown on the Figure 1 (a, b).



a



b

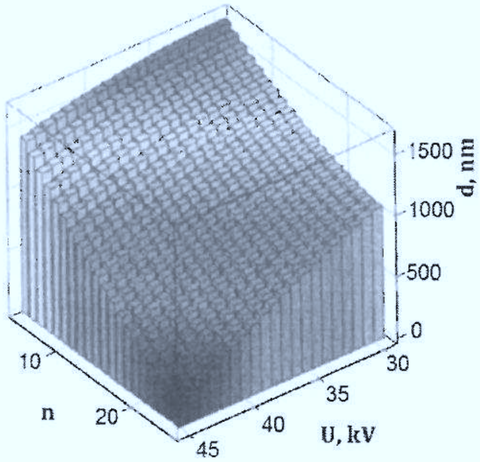
Figure 1. The distribution according to the milk whey particle size before (a) and after electrohydraulic processing at the voltage of 45 kV and the discharge number of 25 (b)

It was stated that the original whey contained the particles of a size amounting to more than 500 nm; their volume took up 89 %. The average hydrodynamic diameter of the particles was (1697,5 ± 82,38) nm, the polydispersity index equaled 1,0.

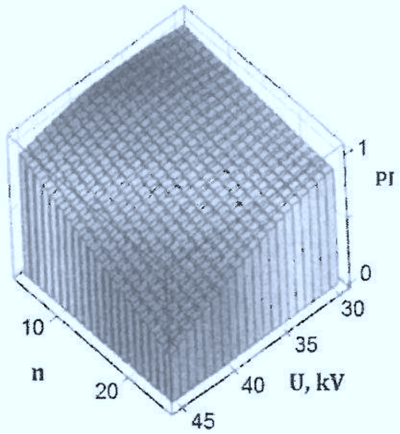
It has been found that after processing the average hydrodynamic diameter decreased from (1697,5 ± 82,38) nm to (221,34 ± 10,3) nm at maximum voltage and discharge number. The polydispersity index at that plummeted from 1,0 to 0,35...0,40, which characterizes the system as the one close to monodisperse state. The particles larger than 500 nm have not been found.

As the result of statistical data processing after the conducted research we have received the regression equations describing the influence of electrohydraulic processing parameters on the system dispersion degree characteristics – the average hydrodynamic diameter and polydispersity index. The Figure ical depiction of the received equations is shown in the form of a response surface (Figure 2).

Mathematical and statistical data processing confirmed that voltage *U* and the discharge number *n* substantially influence the particles' dispersion, providing us with the ability to define the rational parameters of electrohydraulic processing: the voltage amounts to 45 kV, whereas the discharge number equals 25.



a



b

Figure 2. The response surfaces depicting the influence of voltage and discharge number during electrohydraulic processing on the average hydrodynamic particle diameter in milk whey (a) and polydispersity index (b)

Table 1

The results of statistical research data processing

No	Regulated index	Regression equation
1	The average hydrodynamic diameter	$D(U,n) = 71.4116 \cdot U - 2.167 \cdot U \cdot n - 1.01036 \cdot U^2 + 0.8817 \cdot n^2 + 9.283 \cdot n + 681.1$
2	The polydispersity index	$PI(U,n) = 0.1092 \cdot U - 0.00149 \cdot U \cdot n - 0.0014 \cdot U^2 + 0.000068 \cdot n^2 + 0.03685 \cdot n - 0.947$

We carried out mathematical modeling of sedimentation process of casein particles before and after electric spark processing. This model was prepared for the justification of preservation term for the processed whey without sedimentation and protein losses.

Visualization of sedimentation process is carried out with computer graph is presented on Figure 3.

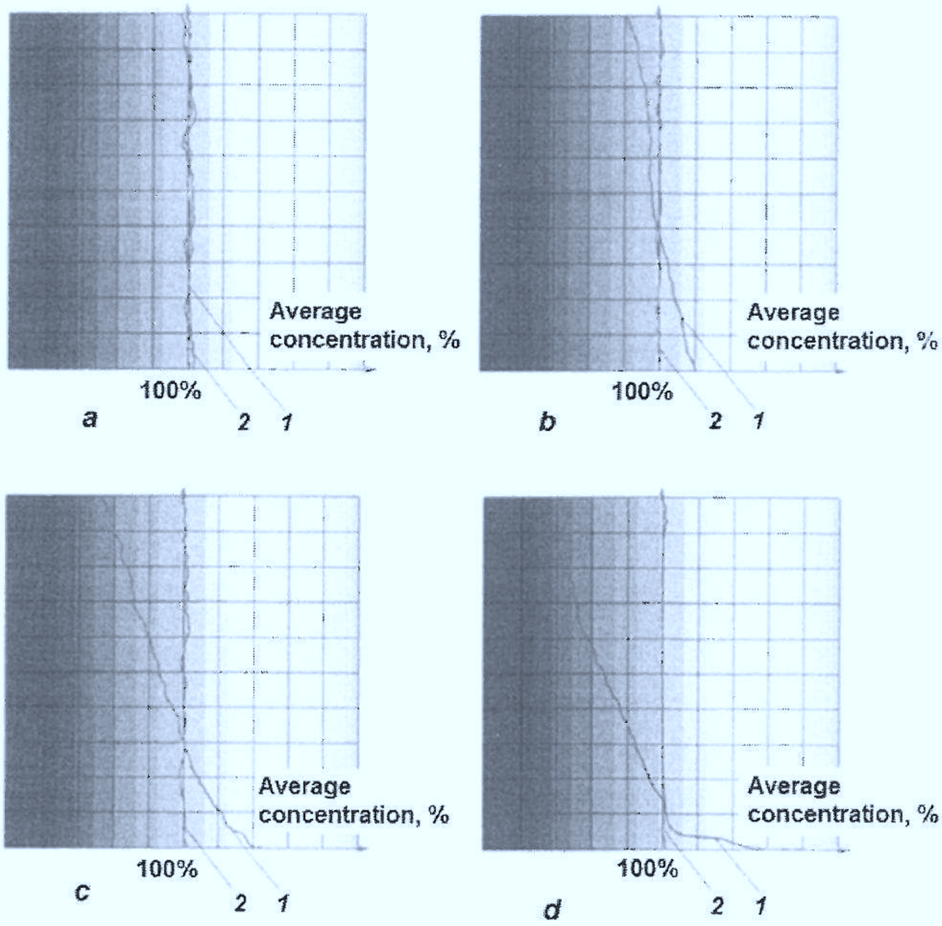


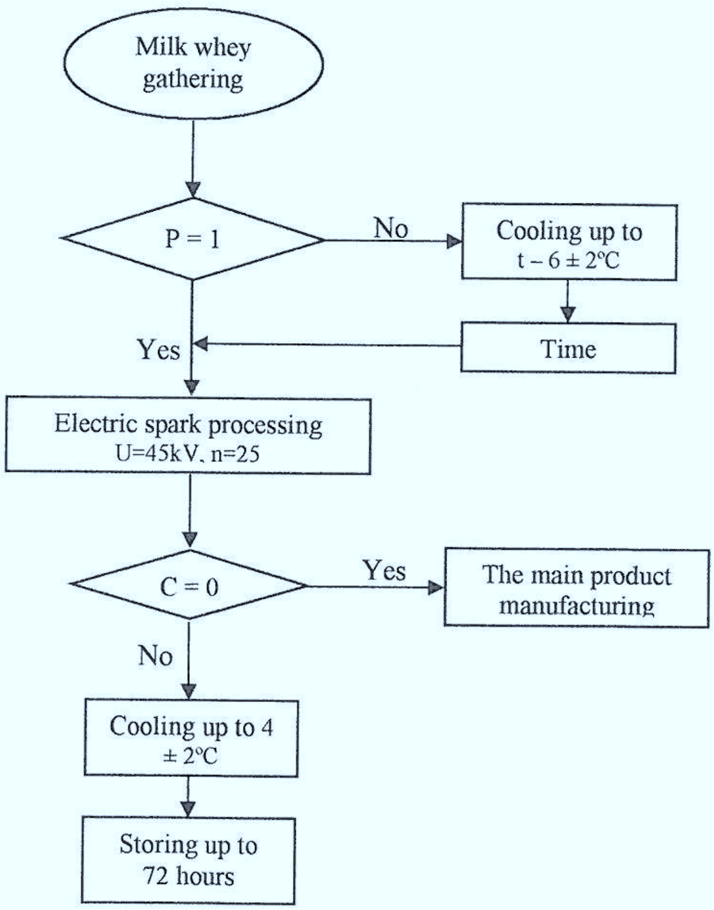
Figure 3. Change in particles concentration in milk whey during: a – 2 hours, b – 24 hours, c – 48 hours, d – 72 hours

The results provide a basis for conclusion for preservation of sedimentation stability in the processed whey as long as 72 hours.

In order to measure the sedimentation stability of the whey particles before and after processing, we defined the rate of particle sedimentation and KSS (formulae 1 and 2), as well as the sediment volume, which parted as a result of forcible deposition in the gravitational field. It was concluded that resulting from the decrease in size of protein particles caused by electrohydraulic processing the rate of sedimentation became several times slower, whereas KSS increased. The sediment volume in the processed whey decreased from 0,9...1,1 to 0,1...0,2 cm^3 at the voltage of 45 kV and the discharge number of 25. In the processed whey the visible protein deposit appeared only after 3 days of storing; conversely, the unprocessed whey contained deposited protein particles after just a few hours after it was put away.

The results concerning the electrokinetic potential indicate that system stabilizes and the process of whey particles' sedimentation slows down after electrohydraulic processing. In this way, at voltage of 45 kV, as the discharge number increases, the absolute value of ζ-potential of the processed whey particles increased from $-0{,}06 \pm 0{,}002$ up to $-4{,}02 \pm 0{,}26$ mV, illustrating that sedimentation stability in the processed milk whey rises.

On the basis of the conducted research we have created a flow chart of milk whey primary processing algorithm using electrohydraulic method (Figure 4).



P=1 – checking whether it is possible to process milk whey after it was received;
C = 0 – defining whether milk whey will undergo further processing or storing.

Figure 4. The flow chart of milk whey primary processing algorithm using electrohydraulic method

The processing may be carried out right after milk whey receiving or interim reservation. After electric spark processing whey is used for further technological purposes depending on the type of the manufactured product.

According to the results of this research, after such processing milk whey may be stored for 48 hours retaining its sedimentation stability, organoleptic, physical, chemical and microbiological properties.

Thus, after a series of experiments we have come to a conclusion that electrohydraulic processing of cottage cheese whey ensures increase in its sedimentation stability due to dispersion of casein dust particles to the average hydrodynamic diameter (221,34 ± 10,3) nm. The rational mode of cottage cheese processing was defined, namely voltage amounting to 45 kV, the discharge number equaling 25. It was proved that the given processing mode leads to a slowdown in sedimentation of particles and decrease in protein losses after primary processing.

Finally, the given technological scheme of milk whey primary processing using electrohydraulic method will allow stabilizing and retaining the quality of whey, as well as prolonging its storage life.

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