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DESIGN OF SYSTEMS FOR INTEGRATED PROCESSING OF DAIRY RAW MATERIALS IN THE CHEESE INDUSTRY

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For the functioning of integrated systems for processing dairy raw materials in the cheesemaking industry, it is proposed to consider the basic concepts of synthesis of production systems. In order to implement the concept of waste minimization, it is proposed to separate the industrial wastewater into flows based on the concentration and values of the main parameters, as well as to protect the cheese whey from entering the water treatment facilities and direct it for disposal. The possibilities of implementing the concepts of deep raw materials processing into a target product have been analyzed, as well as the full utilization of raw and auxiliary materials. To this end, an experimental study was performed on the extraction of protein clots and adjusting the buffer capacity of infant dairy products using cheese whey. The study results indicate the insufficient effect of extracting the protein clot from whey (5–50 %) by combining the thermal and chemical processes. It was established that the redox conditions of the medium, in terms of the Eh indicator, can significantly affect the results, in close connection with the pH parameter and the estimated value of rH_2. It was found that the optimal conditions for the functioning of lactic acid microflora in the production of soft cheeses can be ensured by adjusting the Eh indicator through the introduction of whey of pH=4.4–4.6 units, Eh≤–0.1 V. Whey is introduced at the stage of dairy raw material fermentation, which creates optimal conditions for the formation of a clot until reaching rH_2 in the range from –5 to –7, and increases the product output by 1.5–7 %. The results of the experimental study indicate the high potential of using whey desalinated by ion exchange in order to reduce the buffer capacity in terms of acidity and adjust the redox conditions for infant milk mixtures until achieving rH_2=15.5–15.9. The research reported in this paper could be the basis for the further development of systems for the integrated processing of dairy raw materials in the cheesemaking industry

Keywords: whey, protein clot, redox conditions, buffer capacity, pH, Eh, rH_2

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1. Introduction

The production of various types of cheese requires special attention due to a large number of dairy enterprises, dairy raw materials, and generated waste.

The cheesemaking processes, in particular soft cheeses, may include three basic technological subsystems: the preparation of dairy raw materials, the extraction of protein clot, and the purification of waste. The main industrial waste is whey, which can account for more than 90 % of the total wastewater. Typically, the whey is mixed with water washed from the equipment and enters the treatment facilities, which leads to the loss of valuable components, disruption of the operation of treatment facilities, and subsequent environmental pollution. Whey is a biologically active liquid and the main source of whey protein and contains valuable components for the human body: lactose, milk fats, proteins, mineral salts, immunoglobulins, lactoferrin, and lactoperoxidase. This makes a given raw material a valuable material for further processing.

Therefore, it is a relevant task to design systems for the integrated processing of dairy raw materials in the cheesemaking industry, which could ensure the full utilization of valuable components, reduce the amount of waste, as well as its effective purification.

2. Literature review and problem statement

In order to ensure the functioning of systems for processing dairy raw materials in the cheese industry as integrated ones, it is proposed to consider the basic concepts of synthesis of production systems: the depth of raw materials processing into a target product; complete utilization of raw and auxiliary materials; minimization of waste [1].

Depth of raw materials processing into a target product. All cheese products can be divided on the basis of a technique for obtaining a clot: acid coagulation, rennet coagulation, acid-rennet coagulation. There is also a division by the type of clot obtained: solid/semi-hard with a high or low temperature of the second heating, soft, and brine, which are reflected by the relevant technologies [2–5]. Changing the values of technological parameters, in particular, a dosage of milk coagulating enzyme and lactic acid sourdough, temperature, the degree of clot grinding, as well as changing the type of cultures in sourdough provide for a wide range of products [6, 7].

However, the disadvantage of such technologies worth noting is a limited list of technological control parameters, which leads to the emergence of unadjusted factors influencing the qualitative and quantitative output of the product.

In the production of all types of cheese, a critical point is a subsystem for obtaining a protein clot, which determines not only the quality and quantity of the product obtained but also the amount of liquid waste, in particular whey and washing wastewater. The characteristic of the subsystem is that at each stage in the formation of a protein clot, the control parameter is the pH indicator. A given parameter characterizes the acid-basic equilibrium of the dispersed, phase structural transformations of proteins into complexes with phosphate [8, 9], and is closely related to the redox equilibrium of the medium (the indicator *Eh*). However, this connection is not reflected in the examined technologies as regards the technological control parameters. The *Eh* indicator is one of the determining ones for the quality of cheese products [6, 10]. Moreover, the sourdough of lactic acid streptococci used in the production of milk-protein products are anaerobes that are sensitive to *Eh* values and cannot develop at the values of a given parameter above a certain level [11]. As a result, the lack of control and the adjustment of this parameter can cause difficulties in ensuring the optimal conditions to form a clot and to promptly adjust detected violations in the technological process.

Thus, achieving the maximum levels of the depth of raw materials processing into a target product is complicated, which can lead to a decrease in the output of the product and its quality. That predetermines the need to establish a relation between *Eh* and pH at each stage of protein clot extraction, to determine optimal values, and study possible ways to adjust these indicators.

The depth of utilization of raw and auxiliary materials. In order to implement a given concept, dairy enterprises process whey as the main waste, which can be presented as a system consisting of the following units: disposal, cyclical use, a combined production.

Disposal of whey. The production of lactose and lactulose, whey drinks, dry whey, and combined milk-fat dry concentrates is widespread. Typically, industrial processes include integrated technologies involving heat treatment, filtering at different levels, electrodialysis, evaporation, distillation, hydrolysis, reagent treatment, thickening, filling, etc. [12–14]. However, the most common way to dispose of whey is to produce protein products. There are several basic groups: whey-protein concentrate (protein content, 65–70 %); whey-protein isolate (protein content, >90 %); whey-protein hydrolysate (protein content, 70–80 %); individual protein fractions. In the production of protein products, heat treatment, reagent regulation, membrane filtration technologies of various levels, electrodialysis, ion exchange, etc. are widely used [15, 16]. It is worth noting that all these technologies of whey disposal imply its processing as secondary raw material in other industrial processes and sectors of the food industry. Given that whey is a rather unstable substance that changes its characteristics under the influence of storage time and temperature factors, a series of related problems arise, in particular in the field of logistics.

Cyclical use. Whey can be used to improve the quality and quantity of products in cheese and dairy products. Whey is added to milk as an additional source of protein formations at the pasteurization stage, and then, as part of the raw material mixture, it participates in the entire manufacturing process. Whey protein concentrate is also used in this way, in particular, it can be introduced at different stages of the process [16]. However, this practice is not common due to the insufficient number of studies conducted and the technologies implemented. Critical aspects are the properties and type of whey that can be used for this purpose, as well as the choice of the optimal stage in the technological process for the introduction of whey. The potential of this aspect is not fully disclosed and thus needs further research.

Combination of production. Whey can be used as a raw material in other industries as well. Whey parmeate is applied as a substitute for process water in the production of ethyl alcohol, in particular, at the fermentation stage [17, 18]. Whey was included in the list of the basic permitted substances in agriculture as a herbicide in the cultivation of cucumbers and zucchini to protect against powdery mildew [19]. Moreover, whey is rich in α-lactalbumin protein fraction, which predetermines its widespread use in the production of baby dairy products in order to adjust the protein composition of cow's milk and approximate it in properties to the maternal one. The technologies in such whey processing face the same challenges as in the disposal technique. It is also important to emphasize the problem of ensuring compliance of whey with regulated standards for use in the above industrial processes given its instability. That makes it possible to use only certain types of whey, from certain types of cheese products.

Thus, the most common technologies of processing whey involve its use in other manufacturing processes of dairy production, or in the production in other industries. The technique of cyclic use has not been widely used to date, which renders relevance to research into its development, in particular in the field of using whey in order to organize closed production.

Minimization of waste. Wastewater is the main liquid industrial waste, generated after washing the equipment and devices, as well as a result of the manufacturing process. Impurities in the wastewater from the cheesemaking industry are divided by chemical composition and origin into three main groups: organic live and non-living, inorganic.

The presence of live organic impurities in wastewater is associated with a possible presence in raw milk of vegetative pathogens, in particular, these are the bacteria *Campylobacter*, *Enterobacter sakazakii*, *Escherichia coli*, *Salmonella*, *Listeria monocytogenes*, etc. The organisms form stable bio-films on the tanks and equipment at dairy enterprises, from where they enter the raw materials and drains. Whey has many lactic acid bacteria that are used in fermentation – *Streptococcuslactis*, rods of the genus *Lactobacillus Leuconostoc*. Live organic impurities can also enter the waste during their storage and supply to treatment facilities [20, 21].

About 90 % of impurities in the wastewater from cheese-making enterprises are organic inanimate impurities: milk fats, proteins of different groups, and sugar. Therefore, the wastewater is characterized by high values of BSK and HSK indicators (an average of 580–3,000 mg/dm^3) [22]. Although literary sources outline a significant organic load on the waste from cheese-making enterprises, the decisive role of whey in this state of affairs remains unattended. The vast majority, both living and inanimate organic impurities, are contained in the composition of whey. The presence of whey in the wastewater significantly affects the indicators of BSK and HSK, which can reach up to 60,000 mg/dm^3. This indicates the importance of removing whey from the wastewater or separating it into individual flows. Organic impurities also penetrate wastewater as a result of washing the equipment, in particular, by surfactants.

Inorganic impurities. Inorganic coagulants are used in the manufacturing processes of cheesemaking, in particular $CaCI_2$. In order to adjust environment conditions, different stages of the processes employ H_3PO_4, HCI, and H_2CO_3 for acidification, or NaOH and $Ca(OH)_2$ for leaching. NaCl, Na_2CO_3, and H_2O_2 can be used to₃ ensure high quality of products at different stages. Residual concentrations of these compounds enter the wastewater. Inorganic impurities also enter the wastewater as a result of washing the equipment, in particular, KOH and NaOH, H_3PO_4 and HNO_3, NaClO, etc.

There are a series of problems related to wastewater management at cheesemaking plants. The variability of wastewater concentrations is not compared with the design capacity of sewage treatment facilities. Wastewater is not divided into flows depending on the concentrations of impurities and the values of the basic parameters, which, in turn, can adversely affect the operational stability of treatment facilities and reduce the level of purification. The redox conditions in the medium affecting the biological purification technique due to the redox sensitivity of microorganisms [23] are not taken into consideration.

It is advisable to separate the wastewater based on its concentration into concentrated (high content of whey and brine after clot aging) and poorly concentrated (after washing the equipment); according to the values of the main parameters, into flows with acid-oxidation and alkaline-reduction environment, etc. That could make it possible to individually select the technology for each stream, which would ensure the high efficiency of purification, the operational stability of the facilities, and reduce running costs. It is necessary to ensure the recycling of sediments and eluates formed during the purification process.

It is necessary to make sure that whey does not penetrate the treatment facilities together with the main run-off, and, instead, to ensure that it is processed as a biologically active liquid. It is considered expedient to conduct experimental research into each of the three highlighted techniques related to processing cheese whey, in particular: disposal, reuse, a combined production. Although whey processing is considered above in the context of the complete utilization of raw materials, the expected research results could be extrapolated for the concepts related to the depth of raw materials processing and waste minimization, taking into consideration their inseparable connection.

3. The aim and objectives of the study

The purpose of this work is to study the possibilities of implementing the basic concepts for synthesizing manufacturing systems, in particular, the depth of raw materials processing into a target product, the completeness of the utilization of raw and auxiliary materials, and the minimization of waste. This would make it possible to obtain practical results that could become the basis for the further development of systems for the integrated processing of dairy raw materials in the cheesemaking industry.

To accomplish the aim, the following tasks have been set:

– to conduct an experimental study into the whey disposal technique involving the extraction of the whey-protein clot by means of thermal and chemical treatment in order to determine the effect of protein extraction and the main factors of influence;

– to conduct an experimental study into the cyclic use technique involving the extraction of the milk-protein clot with the repeated application of whey as a reagent in order to determine the optimal conditions for the extraction of protein clot and increase the yield of products;

– to conduct an experimental study into the technique of combined production to determine the buffer properties of cow's and breast milk, as well as to approximate the properties of infant milk mixtures to breast milk by using whey treated with ionites.

4. The study materials and methods

At the first stage of whey disposal, we conducted an experimental study on the extraction of whey protein clot by means of the thermal and chemical treatment of whey in order to determine the effect of protein extraction. The method used involves the following alternate stages: heating the whey up to 95 °C, aging for 30 minutes, the first application of reagents, cooling the mixture, and the separation of protein formations. Then the second application of reagents is performed, followed by the second heating of the whey to 95 °C, aging it for 30 minutes, and the final separation of protein formations after cooling the mixture. The specified control parameters include: temperature (t, °C), reagent dosage (V, ml), active acidity (pH, unit), redox potential (Eh, mV), processing time (τ, min) [24]. The experiments used fresh whey after the production of soft cheeses, as well as chemical reagents: HCI, Na_2CO_3, NaOH, $Ca(OH)_2$, $CaCI_2$, $FeCl_3$, Na_2HPO_4, CaO, Al_2O_3, H_3PO_4, as well as dolomite and fresh milk.

At the second stage related to the cyclic use, an experimental study was performed on the extraction of a milk-protein clot with the repeated use of whey as a reagent, according to two experimental strategies. The study's first strategy involves the normalization of milk and fermentation parameters at a temperature of 30–32 °C with the addition of 3–5 % of sourdough and coagulant at the rate of 40 g of the preparation per 100 liters of milk. After 3 hours, whey is added in the amount of 1–2 % of the volume of the milk mixture, after 6 hours – the formation and separation of a protein clot. The study's second strategy implies the normalization of milk and fermentation parameters at a temperature of 30–32 °C with the addition of 3–5 % of sourdough and whey in the amount of 1–2 % of the volume of the milk mixture. After 5 hours, a clot is formed, and its separation is carried out. In our experimental study, fresh farm milk, fresh whey were used after the production of soft cheeses, in particular homemade cheese, the ferment of lactic acid streptococci, and $CaCI_2$ solution.

At the third stage related to combined production, an experimental study was carried out to determine the redox buffering and buffer capacity based on the acidity of cow and breast milk by the potentiometric titration with a 1N solution of HCI and a 1N solution of H_2SO_4. Fresh farm cow's milk and fresh breast milk of the second month of lactation, as well as a 1N solution of HCl, were used. In addition, a study was performed to reduce the buffer capacity and approximate the properties of infant milk mixtures to breast milk by introducing the whey pre-desalinated with ionites. Treatment with ionites was carried out statically for 20 minutes using them in the amount of 1 g/100 ml. Fresh whey was used after soft cheese production, the SMA baby milk mixture, the Purolite NRW100R cationite (UK), the Purolite A845 anionite (UK).

At each of the three stages of experimental research, we electrometrically determined the pH and *Eh* of the medium using the universal EB-74 ionomer.

The dimensionless estimation indicator rH_2 used at all stages combines the values of *Eh* and pH and makes it possible to adjust the redox properties of dairy raw materials regardless of pH. It is calculated from formula (1) [25]:

$$rH_2 = \frac{Eh}{0.029} + 2\text{pH}, \quad (1)$$

where *Eh* is the redox potential of the environment, V; 0.029 is the constant value, per pH, the hydrogen indicator of the environment, dimensionless.

5. Results of research into the whey processing technique

5. 1. Whey disposal technique

When extracting a whey-protein clot by the thermal and chemical treatment of cheese whey in order to determine the effect of extraction, we controlled the acid-alkaline and redox properties of the medium in accordance with the pH, Eh, and rH_2 parameters. The results are given in Table 1.

Fig. 1 demonstrates that at the slight fluctuations in pH (1.3–0.2), significant differences in the *Eh* values (0.53 V at the input, 0.19 V at the output) are observed. This indicates the imbalance of redox conditions in two whey samples identical in the main parameters.

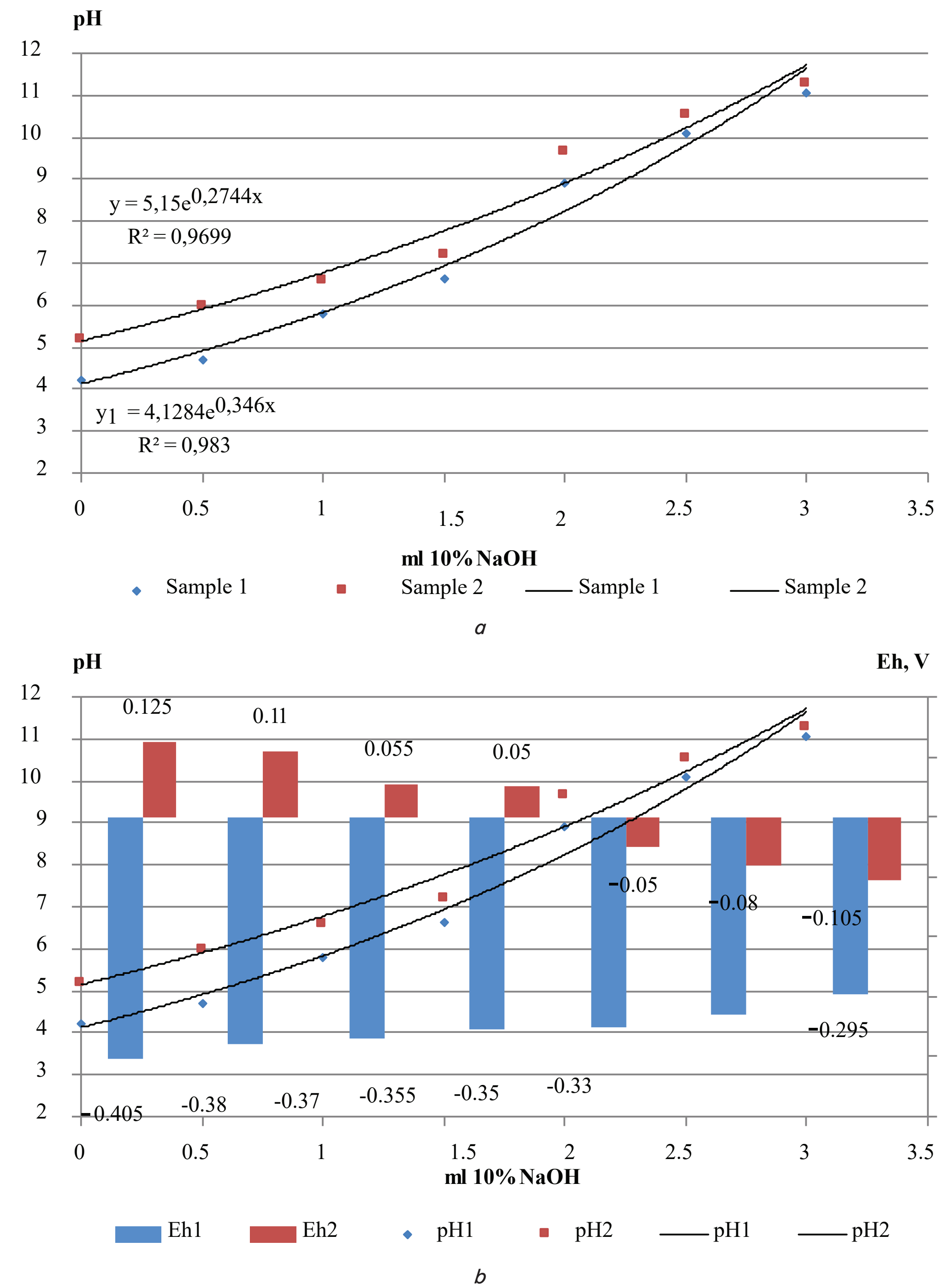


Fig. 1. Examining the redox conditions for two different whey samples: *a* – pH change, *b* – pH and *Eh* change

Table 1

Results of research into the extraction of whey-protein clot

No. of entry	Technological operation	pH	*Eh*, B	rH_2	Protein clot extraction effect, %	
					Expected	Actual
1	Heat treatment only	4.6	+0.16	14.7	20–34	Absent
2	Heat treatment with the addition of acids (HCl)	4.1	+0.19	14.8	40	To 5
3	Heat treatment with alkaline agents (Na_2CO_3, NaOH, $Ca(OH)_2$)	11	+0.1	25.4	55	Absent
4	Heat treatment with added coagulants:					
4. 1	$CaCl_2$	4.15	+0.18	14.5	≤65	Absent
4. 2	Dolomite	6	0.06	9.9	≤65	Absent
4. 3	Fresh milk	4.3	+0.17	14.5	≤65	20
4. 4	Acid whey	4.2	0.07	6	≤65	20
4. 5	$Ca(OH)_2$	11	0.08	19.2	≤65	50
4. 6	$FeCl_3$ (after alkalization)	5.5	+0.05	12.7	≤65	50
4. 7	$CaCl_2$+ +Na_2HPO_4	3.9	+0.11	11.6	≤65	Absent
4. 8	Na_2CO_3 (after fermentation)	5	+0.07	12.4	≤65	20–30
4. 9	CaO+Al_2O_3+ +H_3PO_4	4.35	+0.09	11.8	≤65	Absent
4. 10	Na_2CO_3 (after treatment with lactic acid)	4.8	+0.11	13.4	≤65	20–30

5. 2. Circular use technique

Given the importance of whey non-penetrating the wastewater, its biological activity, properties, and high protein content, it is advisable to study possible ways to increase the yield of products by reusing it. Whey recycling is carried out in order to ensure optimal conditions for the functioning of lactic acid microflora and adjust the redox properties of the medium during the technological process of soft cheese production.

Two experiments were carried out on the extraction of the milk-protein clot. The first used sourdough and $CaCl_2$ for fermentation, and whey to adjust the *Eh* parameter. In the second, sourdough and whey were used for fermentation (Table 2).

Experiment No. 1 (Fig. 2, 3). After 3 hours of fermentation, the milk mixture is characterized by high redox buffering, which does not correspond to the optimal conditions for the functioning of lactic acid microflora and the formation of a clot. To adjust *Eh*, the whey of pH=4.4–4.6, *Eh*≤–0.1 V was added to the milk mixture, in the amount of 1–2 % of the volume of the milk mixture. As a result, a redox medium is formed, which ensures optimal conditions for the formation of a clot. The output of products increases by 7 %.

Experiment No. 2 (Fig. 2, 3). Simultaneously with fermentation, the whey of pH=4.4–4.6, *Eh*≤–0.1 V was introduced into the dairy raw materials, in the amount of 1–2 % of the volume of the milk mixture. That could ensure optimal conditions for the functioning of lactic acid microflora and the formation of a clot, namely the redox medium. As a result, the clot is formed with a lower pH value and over a shorter period of time. The output of the product increases by 1.5 %.

Table 2

Experimental study on the extraction of milk-protein clot

No. of entry	Process stage	pH	*Eh*, B	rH_2
Experiment 1				
1	Milk acceptance	6.9	+0.225	21.5
2	Milk normalization	6.6	+0.18	19.4
3	Introduction of whey after 3 hours of fermentation	6.35	–0.13	8.2
4	Clot formation after 6 hours	4.8	–0.46	–6.3
Experiment 2				
1	Milk acceptance	6.9	+0.225	21.5
2	Milk normalization	6.6	+0.18	19.4
3	Fermentation after 3 hours	6.3	–0.3	2.3
4	Clot formation after 6 hours	4.8	–0.49	–7.3

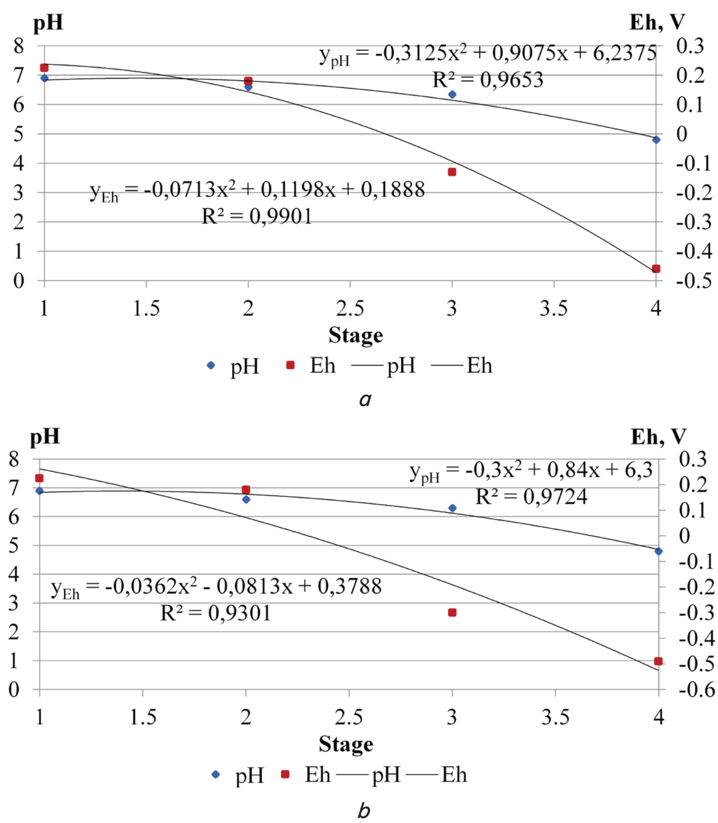


Fig. 2. Change in pH and *Eh*: *a* — experiment 1; *b* — experiment 2

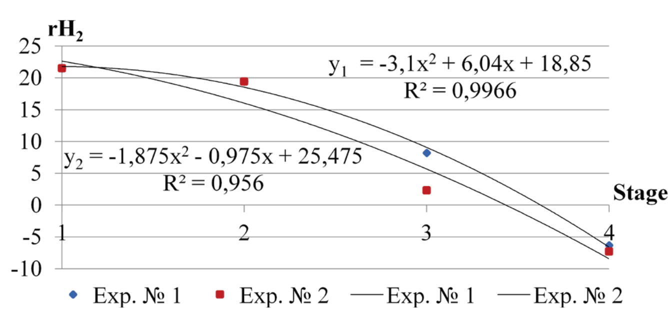


Fig. 3. Change in rH_2 during experiments 1 and 2

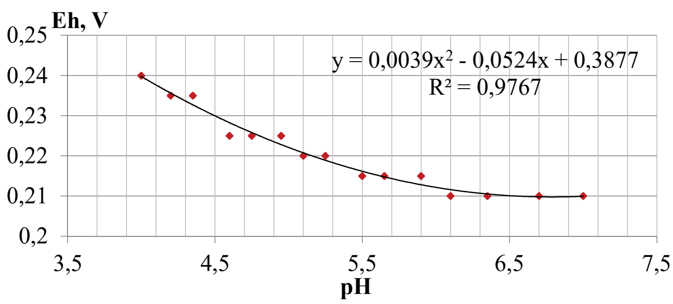
Based on the experimental data, it was established that the process of extracting a milk-protein clot and its completion is carried out under the redox medium conditions, which corresponds to rH_2 in the range from −5.5 to −7 (Fig. 3).

5. 3. Combined production technique

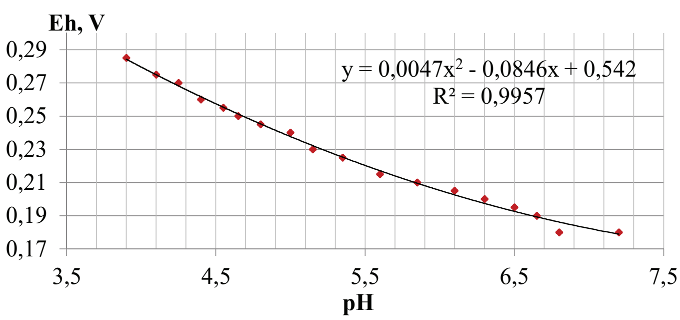
Whey has a high potential as a secondary raw material for the production of baby dairy products because the high content of the protein fraction of α-lactalbumin makes it close to the protein composition of breast milk. It is advisable to conduct research into determining the buffer capacity, for acidity and redox-buffering, of cow's and breast milk, as well as on the possibility of adjusting these parameters using whey.

To determine the buffer capacity for acidity and redox buffering, titration was carried out until pH=4 (gastric acidity level). When investigating the buffer capacity for acidity, the titration of cow's milk used 25/100 ml, and breast milk – 8/100 ml, that is, three times more. It was established that the maximum buffer capacity for the acidity of cow's milk is in the range of pH=6.0–5.4, which is caused by the buffer action of proteins.

When studying the redox buffering (Fig. 4), it was established that the pH interval of 7.0–6.1 corresponds to the buffering threshold. The maximum is in the pH interval of 6.0–5.4, which coincides with the maximum buffer capacity for acidity.



a



b

Fig. 4. Redox buffering: *a* – cow's milk; *b* – breast milk

It is known that in the production of baby milk mixtures it is necessary to reduce the buffer capacity of cow's milk because this indicator is important in the physiology of digestive processes. To this end, in order to change the quantitative and qualitative composition of proteins and reduce minerals in the product, one can use whey, both standard or desalinated by the methods of ion exchange and electrodialysis (the degree of desalination is 50–90 %).

The milk mixture "SMA", which was used in our study, contains the whey desalinated with electrodialysis to correct the protein composition. The study reported here showed that this mixture is close, in terms of buffer capacity for acidity, to breast milk (Table 3). Titration was carried out to the pH=4 – the optimal value of the action of gastric proteases.

Table 3

Reducing the buffering capacity of cow's milk with desalinated whey

Sample	Buffering capacity, ml/100 ml	pH	*Eh*, B	rH_2
Breast milk	18	4	+0.217	15.5
Baby mixture "SMA"	24	4	+0.105	11.6
Cow's milk	56	4	+0.182	14.3
Whey	20	4	+0.167	13.8
Whey after cationization	20	4	+0.223	15.7
Whey after anionization	24	4	+0.219	15.6
Milk:whey (50 cat./50 an.), 2:1	38	4	+0.230	15.9

Data from Table 3 indicate that the milk mixture has significantly lower values of *Eh* and rH_2, compared to women's and cow's milk. It should be noted that these indicators determine the activity of enzymes, microorganisms, as well as bacterial safety. Thus, there is a need to adjust the redox conditions of infant mixtures in order to bring them closer to breast milk. For this purpose, the whey was used in this work that was desalinated with ionites treatment (the degree of desalination for Ca is 20 %). Samples of the desalinated whey have the rH_2 values of 15.7 and 15.6, which are close to the values of breast milk (15.5), so this whey can be used to increase *Eh* and rH_2 of children's dairy products. A sample of the mixture of cow's milk and mixed whey from the previous study (1:1) in the ratio 2:1 indicates that the whey desalinated with ion-exchange also helps reduce the buffer capacity for the acidity of cow's milk. In order to further reduce this parameter, it is recommended to ensure the required degree of desalination of 50–90 % using ion exchange.

6. Discussion of results of developing the systems of integrated processing of dairy raw materials in the cheesemaking industry

Whey disposal technique. The results of our study into the effect of extraction of whey-protein clot from different samples do not correspond to the expected values based on the literary sources and are insufficient (5–50 %). The reason for such results was determined by the additional study of the acid-basic and redox medium conditions for the two samples of whey used in the main experiment. Fig. 1 shows that the input and output *Eh* values of the samples at unchanged values of other basic parameters are completely different, which are inherent in the opposite types of the medium – oxidizing and highly reducing. In addition, the dynamics of change in *Eh* during titration are also the opposite. This is a consequence of several factors, in particular: the whey samples are from different types of dairy acid cultures used in the production of cheese products from milk; the raw milk raw materials differed in the basic parameters; the technologies for the production of dairy cheese products were different. Since the redox medium conditions determine the direction and kinetics of transformations in protein systems, the differences in their properties for the starting whey, and the lack of adjustment, had a decisive effect on the resulting insufficient effect of extracting the whey-protein clot.

Our research results only indicate the problem identified but do not make it possible to determine the exact patterns of influence of possible rH_2 values of the whey medium on protein resistance factors. That may be interpreted as a limitation of the research but, at the same time, identifies the area of further studies. It is necessary to conduct experiments that would make it possible to categorize the types of whey from different technologies of cheese production according to the medium conditions, as well as to determine how to adjust them.

Cyclic use technique. The increased yield of the product obtained in the first experiment is primarily associated with a joint action to enhance the protein coagulation of $CaCl_2$ residues and lactic acid in the whey. The introduction of whey provided for an acid-reducing medium, that is, the optimal conditions for the functioning of the milk-acid microflora.

In the second experiment, $CaCl_2$ was not used to coagulate proteins, only milk-acid culture, and we added whey that contains coagulant residues in insufficient quantities for a maximum effect. That has made it possible to partially increase the output of the product due to the formation of protein complexes of casein dust and whey proteins and the formation of an acid-reducing medium.

Our experimental results indicate the possibility of ensuring optimal redox conditions for the functioning of milk-acid microflora in the production of soft cheeses. This is carried out by adjusting *Eh* by adding whey in the amount of 1–2 % of the volume of the milk mixture at pH=4.4–4.6, $Eh \leq -0.1$ V, containing lactic acid and $CaCl_2$. The introduction of whey at the stage of fermentation of dairy raw materials would create optimal conditions for the formation of a protein clot by reaching rH_2 in the range from −5 to –7, and increase the output of products by 1.5–7 %.

In the experiments, whey with fixed parameter values was used, which imposes certain restrictions on using the results and is an obvious drawback of the study. It is necessary to determine ways to adjust the main parameters that would make it possible to provide the necessary values for any type of whey, which is the main direction of our further research.

Combined production technique. The study results indicate that the maxima of the buffer capacity for acidity and redox buffering coincide and correspond to the pH range of 6.0–5.4. This suggests that these two quantities have a stable relationship and are predetermined by common factors, in particular the buffer action of protein systems. That indicates the need to adjust the protein composition of cow's milk in the production of baby dairy products, which can be carried out using whey whose protein composition is close to breast milk.

Moreover, the study results testify to the importance of pre-desalination of whey. This is due to the fact that the dominating salts in whey, citrates and phosphates, are the stabilizers of protein systems and cause their resistance to denaturation, and, as a result, a high level of buffer action.

Thus, adjusting the protein composition of cow's milk with the use of whey desalinated by ionic exchange makes it possible to bring baby dairy products closer in properties to breast milk, ensuring the regulation of redox conditions until rH_2=15.5–15.9 is achieved.

The degree of desalination of whey in our experiments was somewhat different from the degree of desalination, which the whey is subjected to in the production of children's mixtures according to known technologies. This discrepancy indicates the shortcomings of our research and possible limitations in the use of the obtained results. Thus, the need for further research has been identified, into the impact of the use of various types of ion-exchange resins and providing for various degrees of whey de-desalination to adjust the buffer capacity of raw materials.

In general, our study has shown the possibility of implementing the basic concepts of synthesizing industrial systems and could become the basis for the further development of systems for the integrated processing of dairy raw materials in the cheesemaking industry.

7. Conclusions

1. The results of the experimental study related to whey disposal technique indicate an insufficient effect of extracting the protein clot from whey (5–50 %) through the combination of thermal and chemical processes. It was established that the main factor of influence is the redox medium conditions, which determine the direction and kinetics of transformations in the protein system and are defined on the basis of the indicator *Eh* in close connection with the pH and rH_2.

2. The results of the experimental study related to the cyclic use technique indicate the possibility of ensuring the optimal redox conditions for the functioning of lactic acid microflora in the production of soft cheeses. This is carried out by adjusting the *Eh* indicator due to the introduction of whey at pH=4.4–4.6 units, $Eh \leq -0.1$ V, in the amount of 1–2 % of the volume of the milk mixture. Whey is introduced at the stage of fermentation of dairy raw materials, which creates the optimal conditions for the formation of a clot until reaching rH_2 in the range from −5 to −7 and increases the product output by 1.5–7 %.

3. The results of the experimental study related to the combined production technique indicate that the buffer capacity of cow's milk is almost three times the buffer capacity of breast milk. It was established that the use of whey, desalinated by ion exchange, ensures a decrease in buffer capacity in terms of acidity and the adjustment of redox conditions of cow's milk until rH_2=15.5–15.9 is achieved. Our results indicate the high potential of using whey as secondary raw material in the production of baby dairy products to adjust the protein composition and to approximate their properties to breast milk. In general, the study reported here has demonstrated the possibility of implementing the basic concepts of synthesizing industrial systems and could become the basis for the further development of systems for the integrated processing of dairy raw materials in the cheesemaking industry.

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