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HEAT AND MASS TRANSFER IN THE PROCESS OF ELECTROFRACTIONATION OF SECONDARY MILK PRODUCTS

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ABSTRACT

Complete and wasteless processing of milk envisages a complex utilization and recovery of raw products, including secondary resources, taking into account ecological factors due to high indices of biological and chemical oxygen demand of whey. Electrical activation of whey is one of the promising methods of processing of secondary milk raw products that we have studied and used for recovery of protein-mineral concentrate, inversion of lactose into lactulose and their subsequent application. The working regimes of heat and mass transfer, characteristics of the obtained products and advantages of electrophysical treatment are described.

INTRODUCTION

The complete and rational utilization of milk is a problem of great ecological influence associated with the traditional technologies of manufacturing foodstuffs. By-products of milk processing should be used with the greatest possible effectiveness especially if to take into account that immense amounts of them are produced [1]. Nowadays utilization of whey again goes through its vigorous renewal, though several decades ago is was considered to be a useless by-product. Whey spoils quickly because of a high content of lactose (milk sugar), which is a media favorable for the germination of bacteria. Factors that define the oxidation activity of a product are biological and chemical oxygen demands; these parameters are rather high for milk whey [2].

Principles of wasteless technology were formulated by the UN Comission, which envisage a reasonable activity taking into account the obligatory environment protection [3]. Therefore, development of wasteless and low-waste technologies of milk processing is a permanent and essential component of the research. One of the main problems consists in the utilization of milk by-products, the more especially as the whey amount increases with the continuous growth of the production of protein milk products [4]. At the same time, the milk consumption as an end product strongly varies dependent on the tradition of the country, its geographical position, the degree of the development of agriculture and industry in it [5]. A wasteless processing cycle of whey and degreased milk, returning back of immune proteins and other valuable whey components in foodstuffs as well as creation of new products and beverages may solve the existing problems [6]. Among the reasons, which hamper the process, one can mention a relatively low concentration of dry substances and high energy consumption related with this during the deep processing of whey, its instability at storage and relatively high transportation costs.

A dry whey contains 71.1% of lactose, 14% of protein fraction, 7.7% of mineral substances and 0.9% of other components (Figure 1). Lactose is a unique carbohydrate that contains only in milk products and plays an important physiological role in a human organism [7].

The chemical composition of whey is rich and various, and its processing in an industrial scale was and remains a vital problem. Utilization of whey proteins (lactalbumins, lactoglobulins, immunoglobulins), which possess the greatest decomposition rate among whole proteins, is promising.

Protein fractions refer by their composition to the most valuable proteins of animal origin (Table 1) and are a rich source of indispensable amino acids. Note that the composition of dry wheat strongly varies dependent on the season; the maximal content of dry substances in whey was observed in February – April and August – October [8].

It is difficult to choose a rational direction for whey utilization because it is defined by many factors, which are often contradictory. Analysis of the set of determinant factors will allow one to make a right choice, especially taking into account a growing awareness that whey contains all valuable milk components, such as vitamins, proteins, mineral substances at virtually complete lack of fats [9].

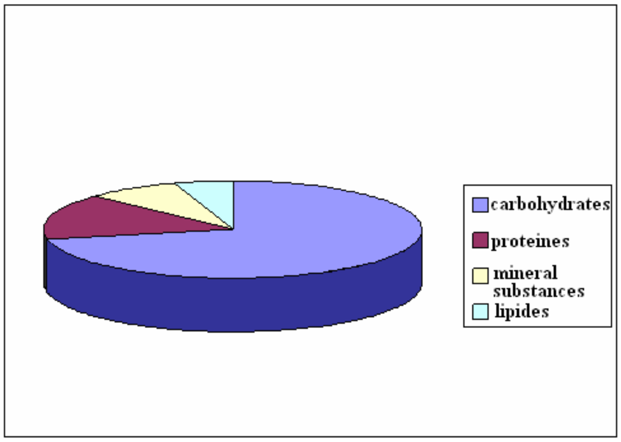

Figure 1 Dry initial whey (IW) composition

Table 1 Content of protein fractions in whey

Protein fraction	Content of dry substances, %	Isoelectric point (pH)	Denaturation temperature, ^{o}C
Lactalbumins:	7–12	5.3	60–90
β -lactoglobulins	2–5	4.2–4.5	60–100
α-lactalbumins			
Albumins	0.7–1.3	4.7	75–90
Immunoglobulins	1.9–3.3	5.5–6.8	75–90

Advanced methods of whey processing may be classified according the mains directions as thermal and chemical membrane methods, which have both definite advantages and disadvantages [10]. Thermal and chemical methods inevitably lead to denaturation of whey proteins at temperatures of 50 – 60 ^{o}C. Using membrane methods it is possible to recover up to 25 – 30% of proteins; however, when the pore size decreases, some problems arise. Methods involving an ion exchange are of periodic action and demand additional processes for regeneration of ion-exchange materials, which are rather time-consuming. The method of electrodialysis also needs regeneration of membranes and high energy expenditure. Hence, one may expect that the most effective treatment of whey can be performed by a combined action of two or several methods.

EXPERIMENTAL AND DISCUSSION OF RESULTS

In connection with this, electrophysical methods for processing of protein-carbohydrate milk raw materials are of great interest, which are based on the stimulation and new approach to the usage of internal resources of each product. With this aim the authors used electroactivation of whey in a flow-type membrane electrolyser with a subsequent recovey of a protein-mineral concentrate (PMC) in the field of mass forces as well as of deprotenized whey (DW) for further lactose processing [11].

The found regimes allowed the transfer of 60-65% of proteins, 94-96% of calcium- and phosphorus-containing ions of the initial whey (IW) into the protein-mineral concentrate (PMC) (Figure 2).

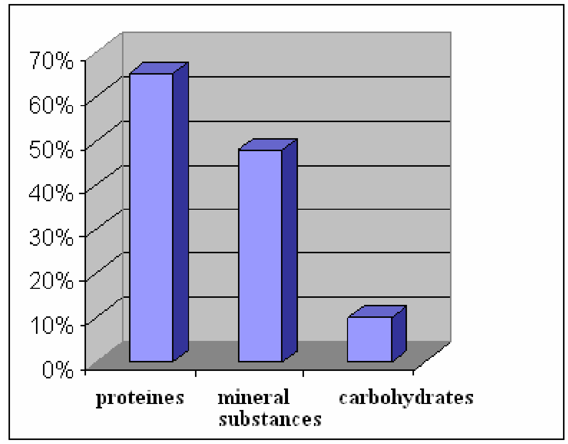

Figure 2 Quantity of main substances transferred into PMC (percents of IW)

At least 90% of carbohydrates and almost all potassium and sodium ions remain in the deprotenized whey (DW) (Figure 3), and it may be used for further lactose processing. The content of such nitrogen compounds as creatine, creatinine, urea, etc. in DW may favor, along with a residual protein, the increasing of external bifidogenity of further isomerised end lactulose product.

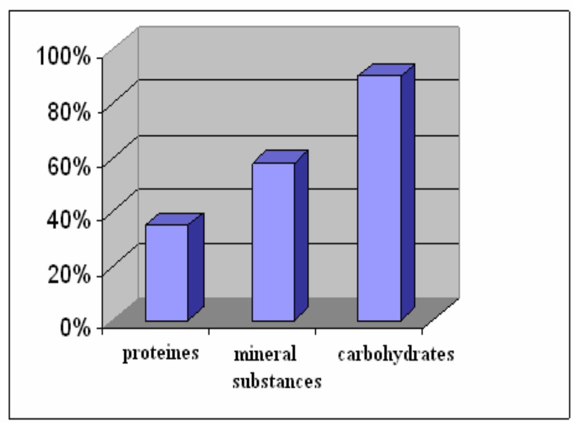

Figure 3 Quantity of main substances remained in DW (percents of IW)

The main parameters, which control the process, are the electric current density, the composition of anodic solution, the rate of flow of the liquid into the cell and the membrane type. Combination of these factors, which defines the degree of temperature increasing and the active acidity in the cathode cell, as well as the membrane state and electric voltage, influences the quantity and composition of the produced concentrate [12].

The share of recovered protein increases from 30 to 60% with the increase in the current density from 0.013 to 0.021 A/cm^2 (Figure 4).

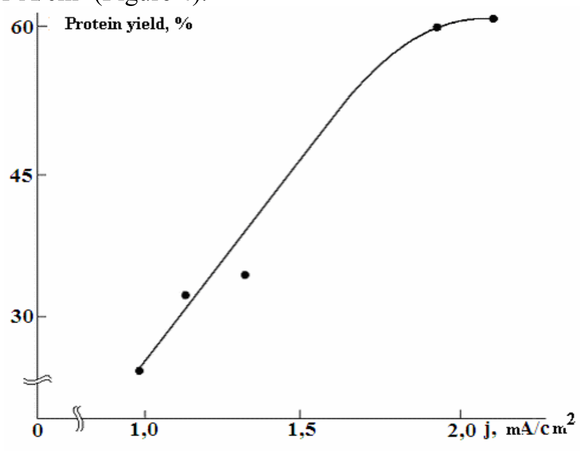

Figure 4 Dependence of the protein yield on the current density

A characteristic feature is the increase in pH of the clarified whey (CW) and the quantity of recovered protein with time and their asymptotic saturation. The quantity of the recovered protein-mineral concentrate is not the same at different processing stages. Investigations of the quantity and quality of protein fractions of PMC have shown that the optimum is in the range of pH=8.0–10.0 and amounts to about 50-60% at the current density of 0.019–0.021 A/cm^2.

The change in the whey pH during processing may be smooth or dramatic dependent on the combination of the initial parameters (Figure 5). The period during which the process reaches its optimum protein yield decreases virtually by a factor of two with the increase in the current density. Evidently, the increase in the current density favors not only the increase in the protein quantity in PMC, but also decreases the time of whey processing.

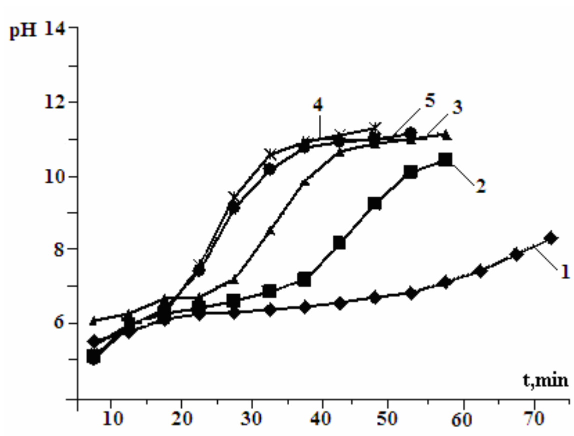

Figure 5 pH vs. time dependence for various values of current density j, mA/cm^2: 1 – 1, 2 – 1.2, 3 – 1.4, 4 – 2.0; 5 – 2.0 [ultrafiltration membrane (UFM)]

The increase in the current density is accompanied by the intensive heating of the whey being processed in the cathode camera. If for the current density of 0.013 A/cm^2 the rate of the temperature increasing amounts to 0.029, then at 0.021 A/cm^2 it amounts to 0.62 degrees per minute (Figure 6). The concomitant increase in temperature confines the further increase in the current density. If for j = 0.021 A/cm^2 the end temperature in the cathode cell amounts to 42 ^{o}C, then for j = 0.023 A/cm^2 the protein yield does not increase, and the temperature while increasing to 60 ^{o}C reaches the level of denaturation for protein molecules. Therefore, it is impossible to optimize the process only over the current density.

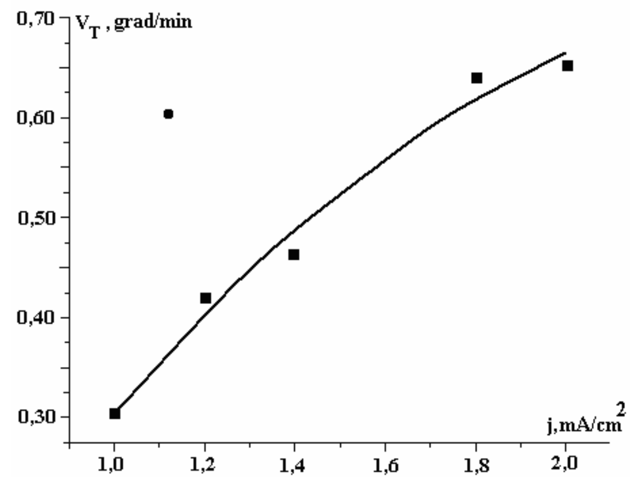

Figure 6 Increase in the whey temperature vs. current density. ● – UFM (ultrafiltration membrane)

The change in the salt balance of the whey being processed plays an important role in the process of protein recovery into PMC. Whey contains in average up to 0.85% of protein and 0.75% of ashes, whose main elements are as follows: Ca (0.04–0.11); P (0.04 –0.1); Mg (0.009–0.02); Na (0.03–0.05); K (0.09 –0.19) mol/l [13].

The change in the potassium and phosphorus content in the process of electrocontact processing of whey at various current densities was registered using colorimetry (Beckman analyzer) and X-ray electron probe spectral analysis. Their content was determined using colorimetry in IW and CW (a supernatant after PMC recovey) picked out at discrete pH values. During processing a continuous depletion of Ca and P content (table 2) in the whey and demineralization of IW with removal of the same elements by 94-96% occurred. The correlation in the increase of the protein quantity, which transfers into PMC, with the recovery of these elements is observed. At the complete demineralization of CW with removal of Ca and P, the further increase in the protein yield was not observed. While investigating the migration of calcium and phosphorus ions, it should be expected on the basis of materials balance that phosphorus ions mainly take part in the formation of a dense precipitate on the membrane surface.

Table 2 Comparative characteristics of the ion content in IW and DW

No.	pH	Ca	P	Na	K
IW	4.65	10.11	6.64	27.60	36.26
1	5.65	9.75	5.58	31.6	43.3
2	6.50	9.71	4.75	33.8	49.7
3	7.05	1.64	1.70	23.5	29.27
4	8.05	2.84	0.32	22.2	28.13
5	10.00	1.99	0.01	35.00	57.02
6	11.00	1.88	0.02	45.3	76.06
7	11.30	2.05	0.007	30.05	47.85
8	11.45	1.37	0.05	46.70	79.86
9	11.50	1.74	0.04	41.80	66.64
10	11.60	1.03	0.09	50.90	83.99
AC*	2.90	5.07	2.88	17.9	14.68
CC**	10.65	3.5	0.2	28.40	40.05

*) Anode cell
**) Cathode cell

Using colorimetry and X-ray electron probe spectral analysis we have determined that the Ca : P weight ratio in the PMC composition increased from 1.88 : 2.25 at the beginning of the process to 2.42 : 2.78 at the end of it, since their content was great in IW and was completely depleted by the end of the process. The Ca : P weight ration in the entire PMC produced at $j = 0.021$ A/cm^2 in the pH range of 4.6–11.5 amounted to 2 : 3; the spectrogram is shown in Figure 7. Application of the obtained results is of interest with regard to the optimization of the proposed method of whey treatment with the aim to increase the protein yield. To confirm the role of Ca and P in the recovery of protein in PMC we performed experiments with preliminary demineralization of the whey. It was found that PMC in minor degree separates as a foam in the cathode cell, but it mainly separates on the membrane leading to a dramatic increase in the electric voltage and temperature in both the cameras.

While the current density increases, the growth of the share of soluble protein (from 373 mg% of protein at 0.009 A/cm^2 to 543 mg% at 0.021 A/cm^2) at the end stages of the process was registered. Taking into account the relative solubility of proteins in the concentrate (the ratio of their absolute solubility to the protein quantity in PMC), note, that the increase in the current density lowers the relative solubility of proteins in the concentrate, but does not influence their nutritive value. The pepsin-pancreatic index (PPI) value for PMC simulated *in vitro* under the action of proteolitic ferments (pepsin, tripsin and chemotripsin) amounts to 58 [14, 15].

The change in the curve slope with the increase in the current density is shown in Figure 8. The rate of pH increase and accompanied processes, which enhance with the current density increase, may be also supposed to play an important role.

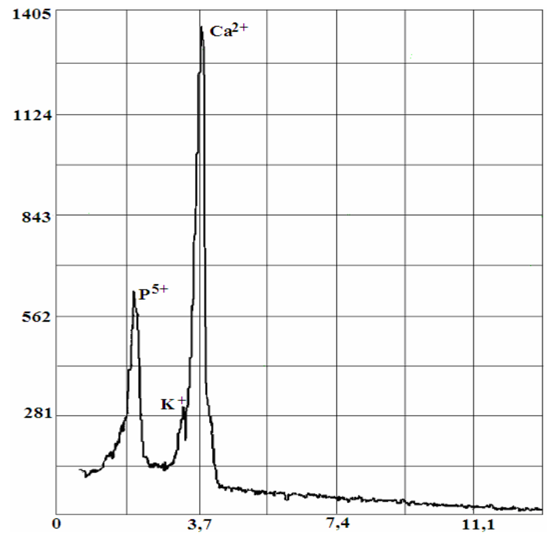

Figure 7 Summarized PMC spectrogram obtained by X-ray electron probe analysis

Potassium and sodium ions do not take part in the PMC formation (table 2). According the results of materials balance they transfer from the anode to cathode cell and enrich the deprotenized whey by these ions. These experiments give an additional evidence that mineral salts take part in the PMC formation, and salt ions should present in the process of electric activation of whey with the aim to lower energy expenditures.

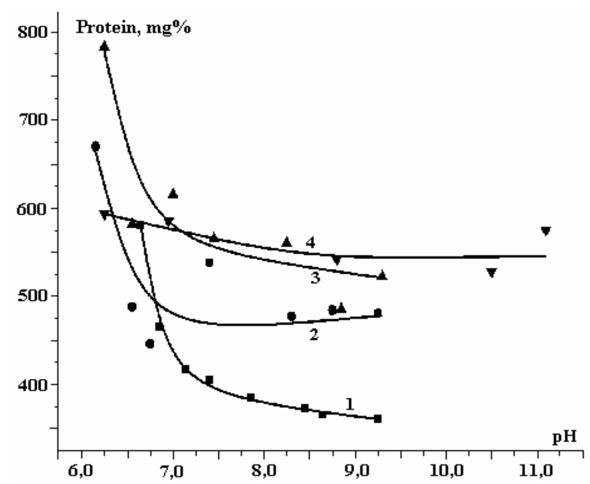

Figure 8 Variation of PMC protein solubility during the electroactivation at different current densities j, мA/cm^2: 1 – 9; 2 – 10, 3 – 13, 4 – 21

CONCLUSION

Thus, it was determined that the increase in the current density, with other constant regulated parameters in the process of whey treatment, leads to increase of the protein yield in PMC and lowers its relative solubility. The role of calcium and phosphorus in the process of whey protein recovery by the proposed method was shown.

On the basis of experimental results we can conclude that heat and mass processes were studied during electric fractioning of milk by-products.

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