EFFICIENCY DETERMINATION OF METHODS FOR ELIMINATING THE POLARIZATION LAYER IN THE PROCESS OF MEMBRANE CONCENTRATION OF BUTTERMILK

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ABSTRACT

The object of research: the process of membrane concentration of buttermilk using methods of removing the polarizing layer on the membrane surface.

Investigated problem: determination of the effectiveness of methods for eliminating the polarization layer on the membrane surface during membrane concentration of buttermilk.

Main scientific results: The results of experimental studies on methods of removing the polarization layer to increase the productivity of ultrafiltration equipment in the process of membrane concentration of buttermilk are presented. Mathematical models are proposed based on the regression equation of a factorial experiment using the elimination of the polarization layer on the membrane to determine the rational operating parameters of the membrane concentration of buttermilk. These parameters were determined: pressure – 0.4…0.5 MPa, buttermilk temperature – 40…50 °C, speed of pulsating flows – 1.5…1.7 m/s, frequency of bubbling of raw materials – 0 , 10…0.15 min-1, bubbling pressure – 0.56…0.58 MPa. A comparative analysis of the application of the method of vibrational mixing and bubbling of separated non-fat dairy raw materials to eliminate the formation of a polarization layer on the surface of membranes in the process of membrane concentration is presented. Based on the obtained quantitative and qualitative characteristics of the ultrafiltration products, it can be seen that vibrational mixing and bubbling of the processed buttermilk equally intensify the process of membrane concentration of buttermilk.

The area of practical use of the research results: enterprises of the dairy industry of the food industry, engaged in waste-free processing of dairy raw materials and its by-products.

An innovative technological product: devices for reducing the polarization layer, allowing to increase the performance of membranes in the process of membrane concentration of buttermilk.

Scope of application of the innovative technological product: waste-free processing of dairy raw materials at dairies and dairy plants and other food industry enterprises.

1. Introduction

1. 1. The object of research

The object of this research is the process of membrane concentration of buttermilk using methods of eliminating the polarizing layer on the membrane surface.

1. 2. Problem description

During the production of butter at the stages of whipping or separating the cream, buttermilk is formed, which is the liquid part of the cream, which does not knock off. Buttermilk, especially the one obtained in the production of butter by churning high-fat cream, rich in biologically important phospholipids (lecithin, etc.), which have high emulsifying properties. All the main components of milk (except for fat) are contained in buttermilk in the same quantities, so that it can be used without restrictions by people of any age [1].

The trend of the dairy industry in the world today does not allow the full production of functional components in the complex processing of buttermilk. Although some products and technologies are nevertheless integrated into the dairy industry and the dairy market through foreign firms or through traders in the dairy market. This raises the need for appropriate research and development of new technologies and technical solutions for buttermilk processing [2, 3].

Recently, in the processing industry, the dairy processing industry is characterized by a high level of formation of secondary raw materials. One of the ways of processing this raw material is the use of membrane processes [3, 4].

The advantages of the membrane concentration process include the relatively low energy consumption of the process and its high efficiency. Such a process does not require the use of chemical reagents and contributes to the production of consumer valuable products. At the same time, simultaneously with the concentration of the food product, it is purified from low molecular weight fractions and bacteria, and a constant pH value of the solution is maintained [5, 6].

1. 3. Suggested solution to the problem

Along with this, the development of membrane technologies in the world has created different types and compositions in the development of new types of membrane elements. Such developments have received a wide range of applications, and not only in the dairy food industry. This, in turn, contributed to the creation of new technologies, including in the conditions of buttermilk processing [7, 8].

A clear limiting role in the widespread use of membrane methods of concentration, in particular, ultrafiltration of low-fat dairy raw materials, is the low specific performance of membranes due to insufficient technical support for its processing [9, 10]. This circumstance is due to the specific properties of high-molecular substances of low-fat dairy raw materials, in particular, buttermilk. The practical absence of methods for reducing and eliminating the polarization layer in ultrafiltration installations is explained by the insufficient amount of experimental data required to create new technologies and technical equipment for UV processing of buttermilk [10, 11].

To increase the productivity of ultrafiltration membranes in the process of membrane concentration, it is necessary to jointly influence the polarization layer on the membrane surface of the hydrodynamic pressure of the method of turbulization of the flows of the processed raw materials and hydraulic shock of the liquid on the surface of the UV membrane [12, 13].

The aim of this research is to compare the effectiveness of vibrational mixing and bubbling methods to eliminate the polarization layer on the surface of ultrafiltration (UF) membranes during membrane concentration of buttermilk.

2. Materials and Methods

In order to eliminate and reduce the amount of the polarizing layer in the process of membrane concentration of buttermilk, methods of vibrational mixing and bubbling of processed low-fat dairy raw materials in the immediate vicinity of the surface of semi-permeable UF membranes have been proposed.

2. 1. Experimental procedures

A schematic diagram of an ultrafiltration unit for carrying out the membrane concentration process using vibrational mixing is shown in Fig. 1. To intensify the process of concentrating food liquids, each of the ultrafiltration modules is equipped with a perforated vibrating plate.

The membrane installation works as follows. The liquid to be separated is fed to the ultrafiltration module 4 with a perforated plate 5. During the ultrafiltration process, the permeate is removed from the recycle, and the formed concentrate through the heat exchanger 1 by pump 2 will enter the next two UF modules until it contains the required dry matter content, which is monitored using a refractometer 3 in Fig. 1.

The schematic diagram and description of the membrane module using the vibrational mixing method are presented in [14].

The schematic diagram and description of a membrane experimental setup with a bubbling device are presented in [15].

The appearance of the experimental membrane modules in the process of concentrating the pectin extract under laboratory conditions is shown in **Fig. 2.**

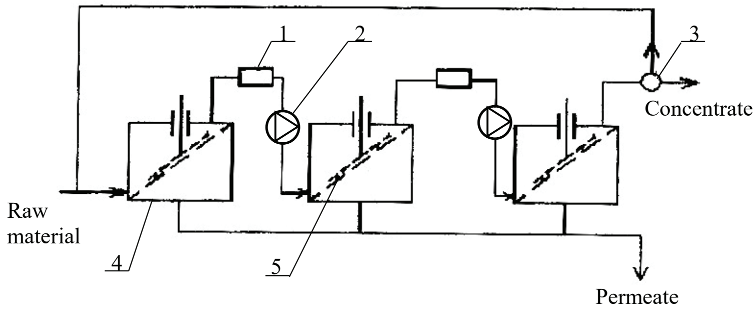


Fig. 1. Diagram of a membrane installation using the vibration concentration method: 1 – heat exchanger; 2 – peristaltic pump; 3 – refractometer; 4 – membrane module; 5 – perforated vibrating plate

Fig. 2. Experimental membrane plant for concentrating low-fat dairy raw materials

2. 2. Modeling the process of membrane concentration of buttermilk

In determining the rational parameters of the process of membrane concentration of buttermilk, the proposed mathematical model was used according to the method of experiment planning. Regression equations were obtained, obtained by modeling various parameters of membrane concentration of buttermilk (1), (2), which contribute to a more detailed study of the phenomena that occur on the surface of UF membranes during buttermilk UF [16].

As input parameters for the study of the concentration of buttermilk were selected: t – temperature of UF concentration, °C; P – filtration pressure, MPa; n_2 – bubbling frequency, min^{-1}; P_1 – bubbling pressure, MPa.

Productivity of UV membrane for membrane concentration of buttermilk in dead-end mode:

$$G_b = 2.078 + 0.136 \cdot t + 31.969 \cdot P - 1.442 \cdot \tau - 5.202 \cdot 10^{-4} \cdot t^2 - 39.575 \cdot P^2 + 0.223 \cdot \tau^2 - \\ - 3.333 \cdot 10^{-3} \cdot t \cdot P - 0.014 \cdot t \cdot \tau + 1.467 \cdot P \cdot \tau. \quad (1)$$

Productivity of the UV membrane for membrane concentration of buttermilk using the turbulization method:

$$G_b^m = -36.803 + 0.069 \cdot t + 42.708 \cdot P + 116.559 \cdot P_1 + 24.698 \cdot n + 3.323 \cdot 10^{-4} \cdot t^2 - \\ - 53.807 \cdot P^2 - 97.917 \cdot P_1^2 - 43.482 \cdot n^2 + 8.042 \cdot 10^{-3} \cdot t \cdot P + 7.158 \cdot 10^{-3} \cdot t \cdot P_1 + \\ + 0.012 \cdot t \cdot n + 13.64 \cdot P \cdot P_1 + 2.016 \cdot P \cdot n - 12.439 \cdot P_1 \cdot n. \quad (2)$$

3. Results and Discussion

First, the influence of the method of vibratory mixing of buttermilk on the process of its ultrafiltration was investigated.

Optimization of the technological modes of the UF process of the studied buttermilk in a dead-end mode and using the turbulization method made it possible to obtain volumetric graphical dependences characterizing these processes (**Fig. 3**).

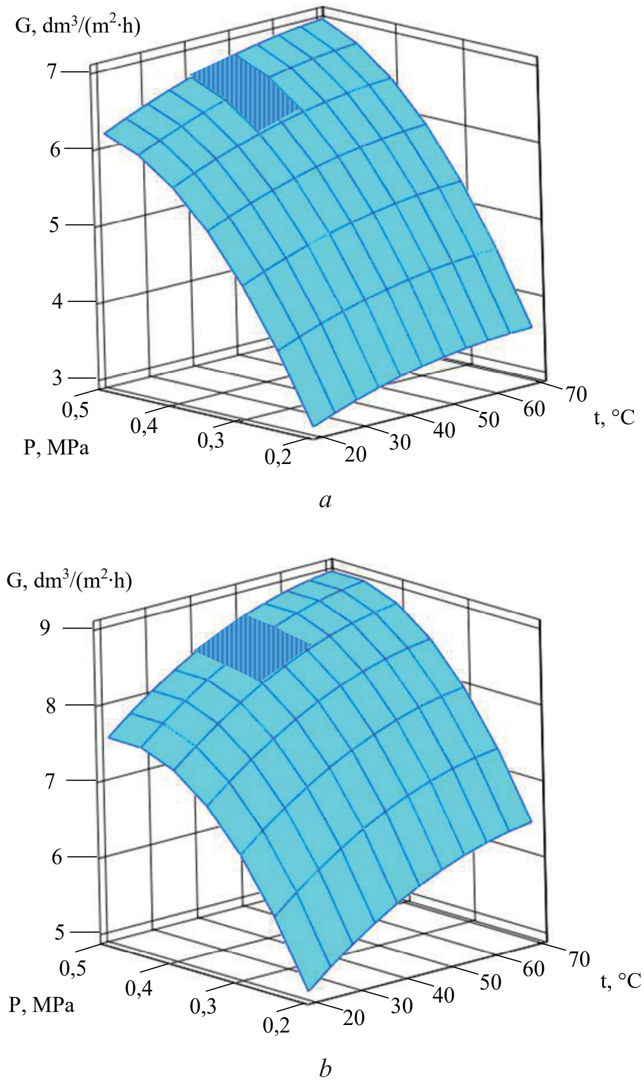
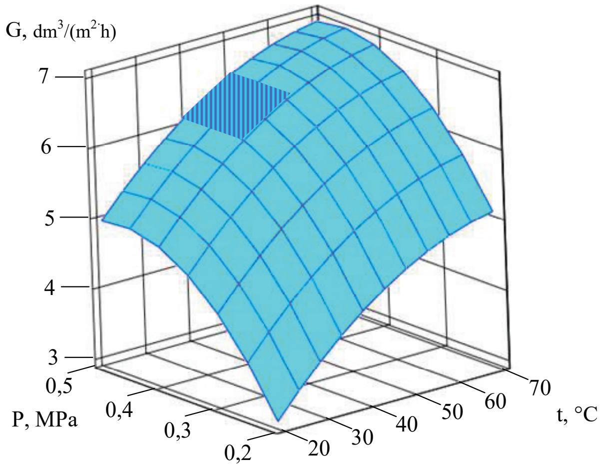


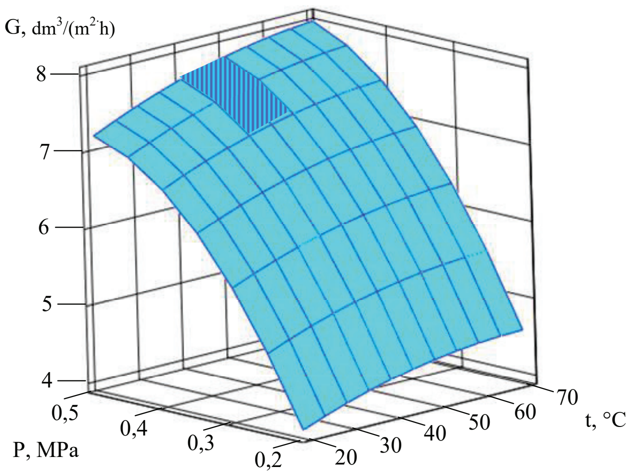
Fig. 3. Optimization of technological parameters of semi-permeable membranes of the GR type during UF concentration of buttermilk: *a* – in the dead-end mode; *b* – in the mode with vibration mixing of the raw material at a speed n_1=90 min^{-1}

The second stage of the study was to determine the effect of the method of bubbling on the membrane surface with inert gas bubbles (air) on the performance of PAN-type membranes in the process of membrane concentration of buttermilk.

Optimization of the operating modes of the UF buttermilk process (in a dead-end mode and using the method of reducing the polarization layer made it possible to construct three-dimensional graphical dependencies (**Fig. 4**).



a



b

Fig. 4. Optimization of technological parameters of semi-permeable membranes of the PAN type during UV concentration of buttermilk: *a* – in the dead-end mode; *b* – in the bubbling mode at a bubbling frequency n_2=0.15 min^{-1}; bubbling pressure P_1=0.58 MPa

The most rational modes of pressure P and temperature t of membrane concentration are highlighted on the graphical dependencies with special shading.

Studies of the performance of GR-type UF membranes have shown that the use of vibrational mixing of buttermilk leads to an increase in the productivity of semi-permeable membranes and can significantly increase the duration of the UF concentration of buttermilk.

The increase in the performance of UF membranes when using vibratory stirring of buttermilk is explained by the periodic discharge of pressure in the working chamber and the hydraulic shock of the liquid against the membrane surface. This leads to a partial removal of the polarizing layer from the membrane surface and to an increase in its performance. But unlike the previous method, this performance is lower.

Analysis of studies of the process of UF concentration using the method of bubbling buttermilk indicates that an increase in the frequency and pressure of bubbling leads to an increase in productivity both for the UF membrane PAN-50 (Bilorus) and for the UF membrane PAN-100 (Bilorus). This can be explained by the turbulization of buttermilk by the flow of bubbling air, as well as by the presence of a hydraulic shock of the liquid on the membrane surface, as in the case of vibrational mixing.

Analysis of the obtained data of mathematical modeling indicates that with an increase in temperature to 40...50 °C, an increase in the speed of movement of permeate occurs during UF concentration of buttermilk due to a decrease in their viscosity. With a further increase in temperature, the UF rate remains almost unchanged, which can be explained by the latent coagulation of the protein and the compaction of the polarization layer [17].

In the case of an increase in the UF pressure, it can be observed that the productivity of the G GR-type UF membranes increases intensively up to pressure values of 0.3…0.4 MPa for the dead-end mode and 0.4 ... 0.5 MPa for the method of vibrational mixing of the feedstock, after which the rate of its increase slows down. Similar results were obtained for PAN UF membranes in the bubbling mode.

To determine the effectiveness of using a particular membrane in the process of membrane concentration of buttermilk, it is necessary to study the qualitative composition of the feedstock and the final product. The results of studying the qualitative composition of the products of membrane concentration of buttermilk – concentrate and permeate – for both methods of turbulization of the process are presented in **Tables 1, 2**.

Table 1

Chemical composition of the products of membrane concentration of buttermilk with the method of vibration mixing

Indicator	Buttermilk	Concentrate			Permeate		
Content, %:							
dry matter	8.5	9.5	11.9	15.3	5.4	5.6	5.7
Protein	3.2	6.4	9.6	12.8	0.19	0.23	0.29
Fat	0.43	0.8	1.21	1.7	–	–	–
Lactose	4.84	2.22	1.03	0.70	4.27	4.18	4.09
Phospholipids, mg%	126.8	243.0	271.8	367.0	14.0	21.08	38.50
Cholesterol, mg	44.0	78.0	81.0	125.0	26.0	18.9	22.6

Table 2

The chemical composition of the products of membrane concentration of buttermilk with the bubbling method

Indicator	Butter-milk	Concentration factor value					
		1.5		2.0		3.0	
		concentrate	permeate	concentrate	permeate	concentrate	permeate
Content%: dry matter	9.01	10.11	5.1	12.00	5.3	15.82	5.7
Protein	3.10	4.65	0.19	6.20	0.21	9.30	0.26
Fat	0.60	0.91	res.	1.20	res.	1.80	res.
Lactose	4.5	4.15	4.27	4.05	4.31	3.92	4.37
Ash	0.7	0.47	0.51	0.45	0.53	0.42	0.57

Note: res. – minor component residues

As evidenced by the data in **Tables 1, 2**, buttermilk UF concentrate contains all the nutrients found in buttermilk output. At the same time, at different values of the solids content, the protein: fat ratio in the concentrate remains at the level of the original buttermilk. The lactose content in the UF concentrate decreases as the dry matter content increases due to its transition to the permeate. At the same time, the use of PAN-type UF membranes allows to preserve a greater amount of buttermilk nutrients, in contrast to the GR-type membranes. The obtained data on the chemical composition of the products of UF separation of buttermilk can be recommended for use in the development of new technologies for food products using derivatives of the membrane concentration of buttermilk.

The research results are limited in the use of only secondary milk-protein raw materials, as well as the use of only flat-type polymer membrane elements. In the future, further research will continue in determining the parameters of membrane processing of other types of food liquids, as well as improving the technical equipment of the process.

4. Conclusions

1. The prospects of using methods for eliminating the polarization layer on the surface of UV membranes in the process of membrane concentration of buttermilk have been determined, which predetermined the need for research in this direction.

2. Determined by the most rational operating parameters of the process of membrane concentration of buttermilk using UF membranes such as GR and PAN using methods of reducing the polarization layer. The following parameters are recommended: pressure – 0.4…0.5 MPa, buttermilk temperature – 40…50 °C, pulsating flow velocity – 1.5…1.7 m/s, buttermilk bubbling frequency – 0, 10…0.15 min $^{-1}$, the bubbling pressure should be equal to 0.56…0.58 MPa.

3. Based on the obtained quantitative and qualitative characteristics of the ultrafiltration products, it can be seen that vibrational mixing and bubbling of the processed buttermilk equally intensify the process of membrane concentration of buttermilk. The results obtained can be used in the study of other parameters of the membrane concentration process of low-fat dairy raw materials, which will make it possible to introduce the obtained technologies into industry at facilities for processing secondary dairy raw materials.

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