Розглянуто питання щодо нового методу боротьби з поляризаційним шаром на поверхні мембран у процесі ультрафільтрації знежиреного молока. Наведено результати експериментальних досліджень щодо впливу нового методу боротьби з поляризаційним шаром на продуктивність ультрафільтраційних мембран. Визначено раціональні робочі параметри проведення процесу ультрафільтраційного концентрування знежиреного молока з використанням барботування вихідної сировини біля поверхні мембрани

Ключові слова: знежирене молоко, мембранна обробка, поляризаційний шар, ультрафільтраційне концентрування, барботування

Рассмотрен вопрос относительно нового метода борьбы с поляризационным слоем на поверхности мембран в процессе ультрафильтрации обезжиренного молока. Приведены результаты экспериментальных исследований относительно влияния нового метода борьбы с поляризационным слоем на производительность ультрафильтрационных мембран. Определены рациональные рабочие параметры проведения процесса ультрафильтрационного концентрирования обезжиренного молока с использованием барботирования исходного сырья у поверхности мембраны

Ключевые слова: обезжиренное молоко, мембранная обработка, поляризационный слой, ультрафильтрационное концентрирование, барботирование

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STUDYING A NEW ANTI-POLARIZATION METHOD IN THE PROCESS OF ULTRAFILTRATION OF SKIMMED MILK

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1. Introduction

Since the dairy production is characterized by a high level of waste, it largely uses ultrafiltration. Traditionally, ultrafiltration (UF) is used to isolate proteins from skimmed milk material, such as milk, buttermilk, and whey; UF also concentrates milk in order to increase the yield of cheese and curd cheese, as well as reduce manufacturing costs [1, 2].

At present, the easiest way to apply UF in the dairy industry is protein normalization of drinking milk. The whole milk ultrafiltration turns 45.1 % of solids, including 96.5 % of lactose and 60.6 % of mineral salts, into filtrates. Similar results are obtained by ultrafiltration of skimmed milk [3, 4].

In addition to normalizing the protein and fat, UF processing of skimmed milk helps to:

– pre-concentrate milk [4, 5];

– extract/isolate a complex of milk proteins and, simultaneously, separate lactose and mineral substances [6, 7];

– regulate the content of colloidal calcium phosphate (CCP) [8, 9];

– remove microorganisms [10, 11];

– remove antibiotics from milk [12, 13].

Among all the known membrane processes of the treatment of low-fat raw milk, the most suitable is ultrafiltration, since the process of UF has advantages such as high efficiency, low energy consumption, and absence of the protein phase transformations. Unlike reverse osmosis and nanofiltration, UF proceeds at a much lower pressure and simultaneously provides a much higher selectivity than microfiltration [14]. Alongside the concentration of edible solutions, UF removes the low molecular weight substances and bacteria, maintaining a constant pH. All of the above factors promote an extensive use of ultrafiltration in the processing of raw milk and in the dairy technologies [15].

Therefore, it is relevant and timely to study the raw milk ultrafiltration processes that involve new anti-polarization methods.

2. Literature review and problem statement

Nowadays skimmed raw milk is extensively used as an object of baromembrane separation. The products of UF-processing of the skimmed milk material have a clear set of functional properties of a wide-range application in the dairy industry, which makes their choice as the object of research reasonable and expedient [16].

Despite the fact that membrane treatment processes have been successfully used in the food industry, the dairy production currently experiences certain difficulties with the engineering support of ultrafiltration processing of skimmed milk [17].

Modern development of membrane technologies allows creating a series of new generation of membranes, which leads to their wider use in the food industry. This requires a new engineering support, particularly in the processing of skimmed milk [18].

The development of ultrafiltration methods of the processing of skimmed raw milk is moderated by a low specific productivity of UF-membranes that is determined by the specific properties of macromolecular substances inherent in the skimmed milk material [19]. This is accompanied by the virtual absence of advanced low-efficiency ultrafiltration plants, which is due to the insufficient amount of experimental data required to calculate UF-concentration and specify the necessary equipment to implement the former [20].

An extensive introduction of baromembrane processes is impeded by a decrease in the membrane permeability during separation, which is caused by the formation of a precipitate layer on the membrane surface, i.e. concentrated polarization [21]. To prevent the formation of a polarization layer, it is necessary to provide a device capable of turbulizing the separable polydisperse system flow in the new membrane module designs [22].

Among all the methods of active influence on the formation of a concentrated polarization layer, the most acceptable, from the point of view of preserving the native properties of the separable raw material components, are hydromechanical methods [23]. Despite the large number of methods and hydromechanical devices to prevent the formation of a polarization layer on the membrane surface that were suggested in the previous studies, their potential is far from exhausted [24]. In particular, the use of bubbling in the separable system flow with the aim of further turbulence appears promising and, therefore, makes the research relevant.

3. The purpose and objectives of the study

The aim of the study is to use the bubbling method to prevent a polarization layer on the membrane surface in the process of UF-concentration.

To achieve the goal it is necessary to solve the following tasks:

– to characterize the current methods of preventing a polarization layer on the surface of the membrane;

– to use the bubbling method in identifying the factors that affect the process of the UF-concentration of skimmed milk;

– to use the research findings in determining the rational parameters of the UF-concentration of skimmed milk.

4. Materials and methods of studying the effectiveness of bubbling in preventing a polarization layer during the UF concentration of skimmed milk

The research laboratory "Nanotechnology in Food" of Kharkiv State University of Food Technology and Trade (Ukraine) hosted the research on the selection of optimal parameters of the UF-concentration of skimmed milk. In order to improve the membrane processing of skimmed milk, there was chosen a method of eliminating the polarization layer that can involve both physical phenomena and hydromechanical processes.

A detailed figure of the ultrafiltration laboratory plant based on the membrane module with a bubbling device, its principle of operation, and modeling of the UF-concentration of skimmed milk are shown in [25].

5. The research findings on the bubbling method for the UF-concentration of skimmed milk

An important factor that significantly affects the process of the UF-concentration of skimmed milk with the use of the feedstock bubbling over the membrane surface is the frequency of bubbling (n). Therefore, we studied how the requency of bubbling affects the performance of the UF-membranes of separable skimmed milk when the temperature is 20 °C and the UF-concentration pressure – 0.4 MPa, which is shown in Fig. 1.

Fig. 1 shows that the performances of both membranes are intensified due to increasing the bubbling frequencies to 0.10–0.15 min^{-1}, which stabilizes the performance in the UF-concentration of skimmed milk.

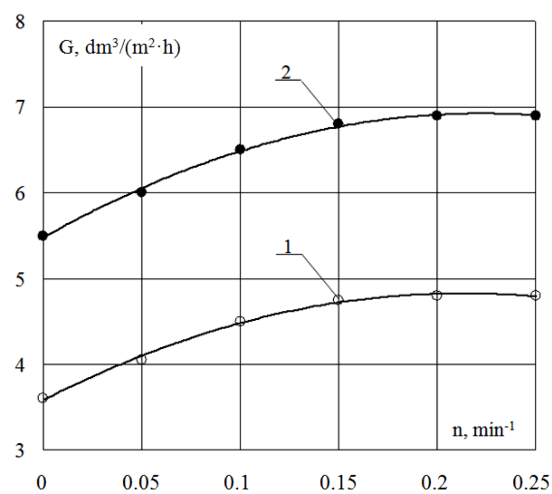

Fig. 1. Dependence of the performance (G) of UF-membranes on the frequency of bubbling (n) the feedstock processed in the UF-concentration of skimmed milk (the temperature is 20 °C, filtration pressure – 0.4 MPa, and bubbling pressure – 0.46 MPa): 1 – membrane PAN-50; 2 – membrane PAN-100

In addition to the frequency of bubbling of the separable milk feedstock, hydrodynamic conditions at the surface of the semipermeable UF-membranes are affected by the bubbling pressure (P_1). Therefore, at the next stage we studied how the bubbling pressure affects the performance of PAN-type membranes. The research findings are shown in Fig. 2.

Fig. 2 shows that the bubbling pressure affects the ultrafiltration process much less than the bubbling frequency. When the value of the bubbling pressure increases, the performance of PAN-type UF-membranes monotonically grows; this dependence is linear.

The most rational bubbling pressure values are within the interval of 0.56–0.58 MPa, since they most of all contribute to improving the performance of PAN-type ultrafiltration membranes; however, the critical pressure values in the UF-module are unattainable.

The mathematical modeling allowed determining the optimal conditions of UF concentration with the use of PAN-type ultrafiltration membranes (PAN-50 and PAN-100), the rational performance indices, as well as the possible maximum values of the characteristics under optimal parameters of the process.

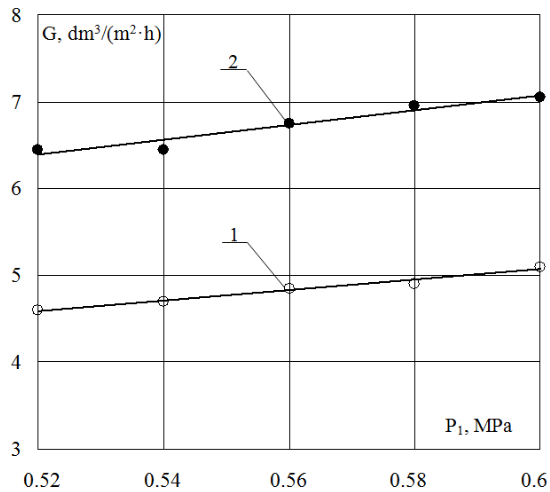

Fig. 2. Dependence of the performance (G) of UF-membranes on the pressure of bubbling (P_1) in the membrane separation of skimmed milk (the temperature is 20 °C, filtration pressure – 0.4 MPa, and bubbling frequency – 0.15 min^{-1}): 1 – membrane PAN-50; 2 – membrane PAN-100

Optimization of the technological modes of ultrafiltration of raw milk that was studied in a dead-end mode with the use of an anti-polarization method allowed building three-dimensional graphic dependences typical of the above processes (Fig. 3). The most rational modes of UF-concentration are marked in the graphics with special shadings.

Experimental studies of the technological modes combined with the mathematical model allowed selecting rational technological parameters of the UF-concentration of skimmed milk in the normal mode with the use of bubbling at the surface of PAN-type UF-membranes. Maximum efficiency of the UF-concentration of skimmed milk in the normal mode, as well as with the use of the feedstock bubbling, is achieved at a filtration pressure of 0.4–0.5 MPa and the UF-feedstock processing temperature of 40–50 °C.

A comparative analysis of the calculated and experimental characteristics of the UF-obtained concentrates showed a good match of the calculated and experimental data on the performances of the two types of membranes.

Analysis of the mathematical modeling data proves that as the temperature increases to 40–50 °C, the permeate rate rises in the UF-concentration of skimmed milk due to its reduced viscosity. With further increase in temperature the rate of UF-concentration remains almost constant, which can be explained by the latent protein coagulation that results in its settling on the surface of the semipermeable membranes and condensing the polarization layer [26, 27].

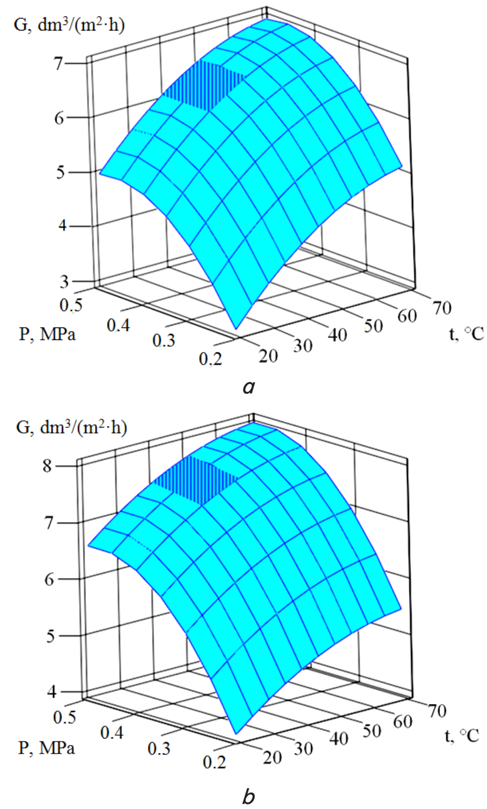

Fig. 3. A mathematical model of selecting technological parameters of PAN-type semipermeable membranes for the UF-concentration of skimmed milk: *a* – the normal mode; *b* – with the use of bubbling (the bubbling frequency n=0.15 min^{-1} and the bubbling pressure P_1=0.58 MPa)

When the UF pressure increases, the performance of PAN-type UF-membranes rapidly increases to pressure values of 0.3–0.4 MPa for the normal mode and 0.4–0.5 MPa – with the use of the feedstock bubbling, after which the increase rate slows down. Probably, this is due to the increase in the hydraulic resistance of the precipitate that is formed on the UF-membrane surface [28].

The pressure increase above the values of 0.4–0.5 MPa is inappropriate, since it does not significantly improve the performance of the UF-membranes under study.

Analysis of the obtained regression equations of the mathematical model shows that the performance of PAN-type UF membranes depends on the pressure, duration, temperature, as well as frequency and pressure of the bubbling process. The highest increase in the performance of UF-membranes is observed when the temperature of the UF-concentration of skimmed milk increases, whereas the working pressure and the bubbling pressure are high.

The research shows that bubbling of the skimmed milk material in the vicinity of the semipermeable membrane surface greatly accelerates the process of ultrafiltration of skimmed milk and allows prolonging its duration to 3.0–4.0 hours. The rational modes and the technological parameters of the bubbling method require a bubbling frequency of 0.10–0.15 min^{-1} and a bubbling pressure of 0.56–0.58 MPa.

Furthermore, the performance of UF-membranes during ultrafiltration of skimmed milk is largely affected by double impacts of the process temperature and duration, the feed temperature and the working pressure, the feed temperature and the bubbling pressure, as well as the working pressure and the bubbling frequency.

6. Discussion of the research findings on the new anti-polarization method

It is experimentally proved that the bubbling method that has the advantage of preventing the formation of a polarization layer improves the efficiency of the UF-separation of skimmed milk. It is found that in the bubbling mode, the UF-concentration of skimmed milk is 1.3–1.4 times more intensive in comparison with UF in the dead-end mode.

The increased productivity of UF membranes in case of increase in the bubbling pressure is due to the periodic discharge of pressure in the working chamber and the hydraulic fluid hitting on the surface of the membrane. However, this results in a partial elimination of the polarization layer from the membrane surface. The consequence is a condensed remaining layer on the membrane surface in a longer UF process, which still results in a significant performance degradation of the membrane.

Despite this, research on the PAN-types of UF-membranes in the UF-concentration of skimmed milk shows that the proposed method of controlling the polarization layer on the membrane can improve the latter's performance due to a thinner layer of the accumulated macromolecular substances thereon and an enhanced working surface of the membrane.

The research findings can be used to investigate other technological parameters in the process of the UF-concentration of low-fat dairy products, as well as to improve the hardware equipment of the production lines for raw milk processing.

The study continues research on improving the membrane processing of food macromolecular liquids with the use of new types of membrane elements and the development of new techniques to control polarization layers on their surfaces.

7. Conclusions

1. The research findings prove that the most promising methods of controlling the polarization layer in terms of improving the process of skimmed milk ultrafiltration are hydraulic ones, whereas it is still relevant to develop new methods that would prevent the polarization layer on the surface of a semipermeable membrane, which would increase the efficiency of the membrane equipment.

2. The experiments have proved a significant bubbling method effect on the formation of a polarization layer on the surface of the ultrafiltration membrane.

3. The research findings allow determining the rational parameters of the UF-concentration of skimmed milk with the use of the PAN-type UF-membranes and the bubbling method, when the pressure is 0.4–0.5 MPa, the temperature of skimmed milk – 40–50 °C, the bubbling frequency – 0.10–0.15 min^{-1}, and the bubbling pressure – 0.56–0.58 MPa.

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