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A NEW METHOD OF ELIMINATION THE POLARIZING LAYER DURING THE MEMBRANE PROCESSING OF BUTTERMILK

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A new method of eliminating the polarizing layer on the membrane surface during ultrafiltration of buttermilk is considered. An experimental equipment and processing methodology the results of studying buttermilk ultrafiltration are presented. This methodology involves the use of bubbling to eliminate the polarization layer. Also presented experimental results of the bubbling influence on the productivity of ultrafiltration membranes. Mathematical models, which were obtained, based on the regression equations of the factorial experiment. Factorial experiment provides the selection of technological parameters of buttermilk ultrafiltration using bubbling of the feedstock over the membrane surface. The rational parameters of the buttermilk ultrafiltration process using bubbling mixing in close proximity to the membrane surface have been determined. These operating parameters are: pressure – 0.4...0.5 MPa, buttermilk temperature – 45...55 °C, process duration 1.5...2.0 hours, bubbling frequency should be within 0.10...0.15 min-1.

Keywords: buttermilk, membrane processing, polarizing layer, ultrafiltration, bubbling mixing.

INTRODUCTION

Among the large number of animal and plant products one of the most valuable are milk and dairy products. These products have a high nutritional value because they contain all the nutrients necessary for a person (proteins, fats, carbohydrates, minerals, vitamins, water) (1). Studies have established that the nutritional value of buttermilk is quite high (2).

Traditional technologies of the whole milk processing provide the transition to the finished product of only a certain part of the substances contained in the feedstock. During the production of butter, buttermilk is formed at the stages of whipping or separating the cream, which is the liquid part of the cream that is not whipped (3). In the process of obtaining butter, only the fatty part of milk and a small amount of other components (proteins, mineral salts, milk sugar, water-soluble vitamins, enzymes) pass into the finished product. Approximately 80-90% of proteins, a significant part of minerals and water-soluble vitamins pass into skim milk and buttermilk, and some of them are lost during the buttermilk processing. This is especially true for buttermilk, which is obtained in the production of butter by churning high-fat cream. It contains biologically important phospholipids (lecithin, etc.) with high emulsifying properties (4). All the main components of milk (except fat) are contained in buttermilk in the same quantities, so they can be used without restrictions by people of any age (5).

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The high efficiency of using membrane processes in various industrial technologies, as well as their ecological safety, promoted rapid growth of membrane technology in all developed countries (6). Membrane methods for the separation of liquid mixtures are widely used in various countries. The use of semi-permeable membranes opens up great opportunities in food industry. Concentration of fruit and vegetable juices, syrups, protein extracts, various essences, beer and other food products can be carried out by ultrafiltration much cheaper than by evaporation or freezing. The ultrafiltration takes place without loss of volatile components and taste deterioration (7-11).

Membrane concentration of buttermilk, particularly by ultrafiltration, provides great opportunities for obtaining dairy products with increased biological and nutritional value. Ultrafiltration eliminates the loss of the native properties of thermolabile components with the production of two products from them, which differ significantly from buttermilk: protein concentrate and lactase solution (permeate) (12). Advantages of the ultrafiltration include relatively low energy consumption of the process and its high efficiency. This process does not require the use of chemicals, contributes to the production of valuable products for consumers. Simultaneously with the concentration of the food product, it is purified from low molecular weight fractions and bacteria (13), the pH of the solution remains constant.

Buttermilk processing using membrane technologies allows to obtain milk-protein concentrate with high quality physicochemical and structural parameters with low energy consumption. The process of concentration of buttermilk includes parameters, determination of which allows to select the optimal modes of the process, as well as to determine the structural characteristics of the membrane that is used in the process (14).

Concentration of buttermilk is carried out in modes of ultrafiltration on membrane equipment, the working elements of which are membranes made of various materials (15).

However, the disadvantage of the buttermilk concentrating process is formation of a polarizing layer on the selective surface of the semi-permeable membrane. This disadvantage makes the processing of buttermilk time-consuming and economically ineffective (16-17). Therefore, the problem arises to prevent the formation of a layer of polarizing gel on the selective surface of the ultrafiltration membrane (18-19).

The aim of the work is to study the process of ultrafiltration of buttermilk using the bubbling stirring mode to prevent the formation of a polarizing layer on the surface of the ultrafiltration membrane.

EXPERIMENTAL

MATERIALS AND RESEARCH METHODS

For experiments, buttermilk was used with the following chemical composition: dry matter – 8.0%; protein 3.2%; fat – 0.43%. The work investigated ultrafiltration membranes of the PAN type: PAN-50 and PAN-100. PAN type membranes are ultrafiltration membranes of the second generation that based on acronitrile copolymers.

To study the process of ultrafiltration of buttermilk both in a dead-end mode and in a hydroacoustic mode (using an intensifying method – a bubbling device) (18), an experimental equipment was used, which is shown in Figure. 1.

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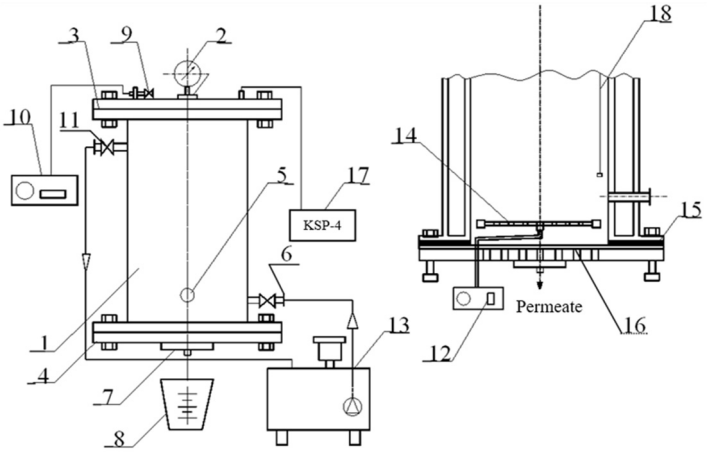


Figure 1. Scheme of a membrane experimental equipment based on a membrane module with a bubbling device: 1 – housing; 2 – manometer; 3 – top cover; 4 – bottom cover; 5 – tap for removing the formed concentrate; 6 – coolant inlet pipe; 7 – tap for removing the filtrate; 8 – vessel for collecting permeate; 9 – tap for supplying and releasing pressure; 10 – compressor for pressure build-up; 11 – coolant outlet branch pipe; 12 – compressor for bubbling; 13 – ultrathermostat (UT-15); 14 – device for bubbling; 15 – sealing gasket; 16 – ultrafiltration membrane; 17 – potentiometer KSP-4; 18 – thermocouple

At the base of the equipment there is a filter module 1 made of stainless steel with an internal volume of 5 litres. Flanges are welded to the lower and upper bases of the module, to which the upper 3 and lower 4 covers are attached. The tightness of the fastening of the covers is ensured by the gaskets 15. Ultrafiltration membrane 16 attached to the bottom cover, which has an opening for the permeate outlet. A pressure manometer 2 is mounted on the top cover to control the process pressure and a thermocouple 18 connected to a potentiometer 17 KSP-4. On the cover there is also a tap 9 for supplying and releasing pressure from the compressor 10.

Inside the working chamber of the module, there is a bubbling device (bubbler) 14 which parallel to the surface of the semi-permeable membrane. This device made in form of a torus with holes, which to the compressor for bubbling 12. The filter module is equipped with a water jacket, temperature of water in which regulated by means of an UT-15 13 ultrathermostat through the inlet 6 and outlet 11 of the coolant. In the lower part of the filtering module, a tap 5 made to drain the concentrate of the buttermilk to be separated. The permeate is discharged from the module by means of a fitting 7 and collected in a container 8. The total surface area of the membranes in the equipment is 0.024 m^2.

Compressor used to study the effect of bubbling on the process of ultrafiltration food liquid. The compressor through the bubbling device creates turbulence of the system at the surface of the semi-permeable membrane. During the process of ultrafiltration, permeate passes through the pores of the membrane, and then it is removed from the filter module using a fitting and is collected in a container. When the required concentration value reached, the concentrate of the separated liquid taken from the filter module using a tap.

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MATHEMATICAL MODELLING

To study the process of buttermilk ultrafiltration the main parameters of the process were selected: t – ultrafiltration temperature, °C; τ – duration of the process, h; P – filtration pressure, MPa.

Mathematical model was used according to the experimental planning method in order to determine the characteristics of the process of buttermilk ultrafiltration, (21, 22).

Equations were obtained for the PAN-50 semipermeable membrane:

– for dead-end productivity:

$$G1_b = 4.826 + 0.062\,t + 4.299\,P - 1.849\,\tau + 8.828\cdot10^{-4}\,t^2 + 0.023\,P^2 + 0.332\,\tau^2 + 0.032\,t\cdot P - 1.786\cdot10^{-3}\,t\cdot\tau - 0.08\,P\cdot\tau; \quad [1]$$

– for productivity in vibratory stirring mode:

$$G1^b_b = -138.588 + 0.11t + 32.768\,P + 99.803\,P_1 + 17.583\,n + 8\cdot10^{-5}\,t^2 - 55.556\,P^2 - 406.25\,P_1^2 - 7.668\,n^2 + 0.013\,t\cdot P - 0.152t\cdot P_1 + 0.032t\cdot n + 25.365P\cdot P_1 - 5.353P\cdot n - 20.073P_1\cdot n; \quad [2]$$

Equations were obtained for the PAN-100 semipermeable membrane:

– for dead-end productivity:

$$G2_b = -2.851 + 0.142\cdot10^{-3}\,t + 28.825\,P - 0.554\,\tau + 6.672\cdot10^{-4}\,t^2 + 30.826\,P^2 + 0.061\,\tau^2 - 0.01\,t\cdot P - 8.48\cdot10^{-3}\,t\cdot\tau - 2.2\cdot10^{14}\,P\cdot\tau; \quad [3]$$

– for productivity in vibratory stirring mode:

$$G2^b_b = -127.391 + 0.076\,t + 28.309\,P + 437.924\,P_1 + 17.647\,n - 4.667\cdot10^{-4}\,t^2 - 33.185\,P^2 - 385.417\,P_1^2 - 19.871\,n^2 - 2.401\cdot10^{-3}\,t\cdot P - 9.002\cdot10^{-3}\,t\cdot P_1 + 0.021\,t\cdot n + 9.834\,P\cdot P_1 - 3.487\,P\cdot n - 13.078\,P_1\cdot n;. \quad [4]$$

RESULTS AND DISCUSSION

CALCULATION OF MEMBRANE PRODUCTIVITY

One of the main characteristics of ultrafiltration membranes is productivity. There is an initial productivity of membranes, that is, the productivity of new membranes in the initial period of their operation (16) and actual productivity, which characterizes operation of membranes under conditions of continuous operation (17).

In order to intensify buttermilk ultrafiltration, a process improvement method has been proposed. The improvement consists of bubbling the processed buttermilk with air or inert gas bubbles in the immediate vicinity of the surface of semi-permeable ultrafiltration membranes. Intensification of the ultrafiltration occurs due to the cumulative effect on the gel formed on the membrane surface, bubbling pressure, turbulization of buttermilk flows and water hammer of buttermilk on the surface of the ultrafiltration membrane.

Influence of the bubbling frequency and bubbling pressure (P_1) on the productivity of PAN ultrafiltration membranes (PAN-50 and PAN-100) during the buttermilk separation was investigated at a temperature of 20 °C and a pressure of 0.4 MPa (Figure 2, 3).

Analysis of the dependence presented in Figure 2 shows that an intensive increase in the productivity of both membranes occurs with an increase in the bubbling frequency to values of 0.10...0.15 min^{-1}. Thereafter, the productivity indicators for ultrafiltration of buttermilk stabilize.

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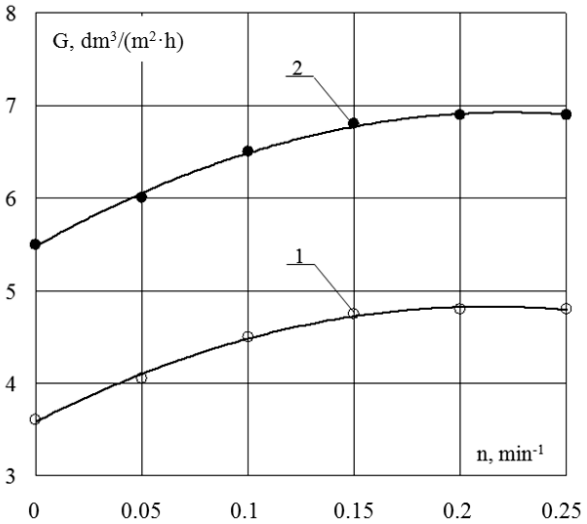


Figure 2. Dependence of productivity (G) of ultrafiltration membranes on the bubbling frequency (n_b) at membrane concentration of buttermilk (temperature 20 °C, filtration pressure 0.4 MPa and bubbling pressure 0.46 MPa): 1 – PAN-50 membrane; 2 – membrane PAN-100

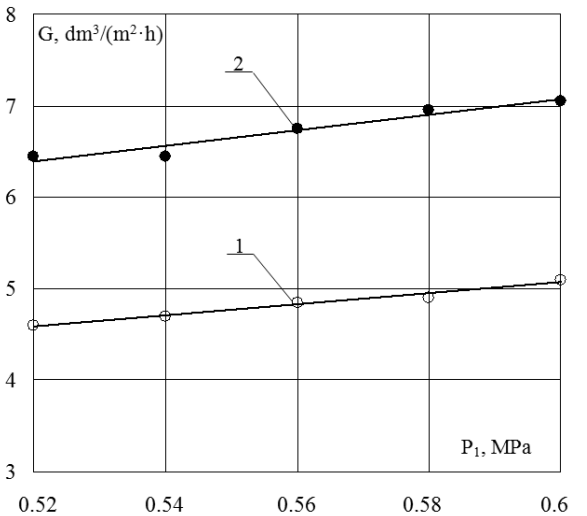


Figure 3. Dependence of productivity (G) of ultrafiltration membranes on the bubbling pressure (P) at membrane concentration of buttermilk (temperature 20 °C, filtration pressure 0.4 MPa and bubbling frequency 0.15 min^{-1}): 1 – PAN-50 membrane; 2 – membrane PAN-100

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Dependencies in Figure 3 show that the bubbling pressure affects the ultrafiltration to a lesser extent than the bubbling frequency. With an increase in the bubbling pressure, the productivity of the ultrafiltration membranes monotonically increases, and this dependence is linear.

Using the obtained mathematical model, conditions for the ultrafiltration were determined using two types of semi-permeable membranes of the PAN type to ensure rational productivity indicators. Mathematical model also makes it possible to determine maximum value of productivity with optimal parameters.

The optimal results, which were calculated using a mathematical model presented in table 1.

Table 1. Calculated values of the optimal parameters of ultrafiltration of buttermilk on PAN-type membranes in the bubbling mode

Y_{max} characteristic, which was determined	Optimization options				
	t, °C	P,·MPa	P_1, MPa	n, min^{-1}	Y_{max}
Membrane PAN -50					
Buttermilk productivity, $G1_b$ ($dm^3/m^2 \cdot h$	70	0.4	0.57	0.25	8.18
Membrane PAN-100					
Buttermilk productivity, $G2_b^b$ ($dm^3/m^2 \cdot h$)	70	0.5	0.57	0.25	9.5

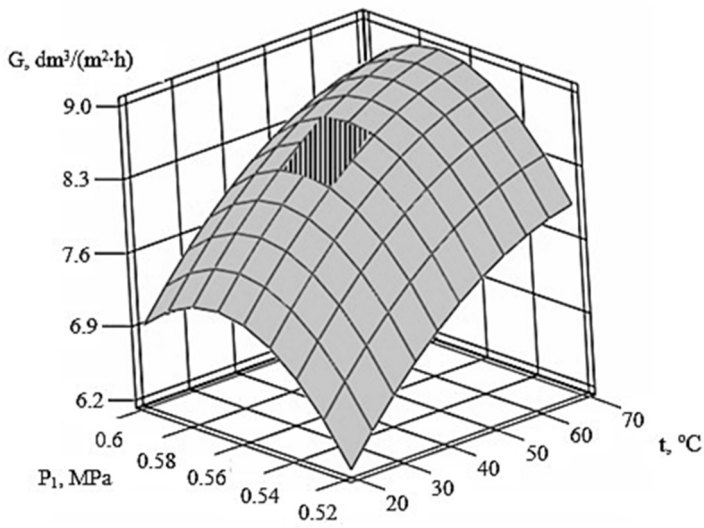
Optimization of the technological modes of the buttermilk ultrafiltration in the bubbling mode made it possible to obtain volumetric graphical dependencies. Dependences allow to determinate the nature of the buttermilk ultrafiltration process (Figure 4). The most rational modes of ultrafiltration indicated on the graphical dependencies by corresponding hatching.

Analysis of the obtained data of mathematical modelling indicates that with an increase in temperature from 20 °C to 40…50 °C, the speed of permeate movement increases by 1.29…1.32 times during ultrafiltration of skim milk due to a decrease in its viscosity. With a further increase in temperature, the rate of ultrafiltration remains almost unchanged. This can be explained by the latent coagulation of the protein, because of which it settles on the surface of semipermeable membranes, thickening the polarizing layer (23).

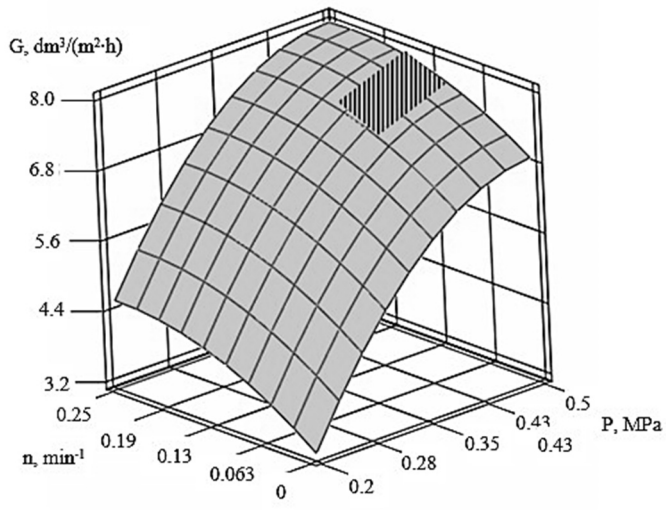
In case of ultrafiltration pressure increase, it can be observed that productivity of PAN ultrafiltration membranes increases intensively up to pressure values of 0.3…0.4 MPa for the normal mode and 0.4…0.5 MPa using the method of bubbling the feedstock. After this, increasing in membrane productivity slows down. Obviously, this is due to an increase in the hydraulic resistance of the sediment on the surface of the ultrafiltration membrane (24).

Mathematical model showed that productivity values of PAN type membranes ultrafiltration depend on pressure, duration, temperature, frequency and pressure of bubbling. However, the greatest influence on the increase in the productivity of ultrafiltration membranes has temperature.

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a)



b)

Figure 4. Optimization of technological parameters of buttermilk ultrafiltration in the bubbling mode: a) P = 0.4 MPa; n = 0.15 min^{-1}; t = 20 °C; b) P = 0.4 MPa; P_1 = 0.58 MPa; t = 20 °C

In addition, significant effect on productivity has simultaneous influence of buttermilk temperature and operating pressure. Besides this productivity is influenced by the paired effect of the bubbling pressure and temperature, as well as the simultaneous effect of the

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operating pressure and the bubbling frequency. Based on results of the studies and calculation of the process of buttermilk ultrafiltration, it was found that the optimal parameters of the process are:

– process temperature t = 45…55 °C;
– process duration $\tau = (1.5…2.0) \cdot 60^2$ s;
– pressure P = 0.4…0.5 MPa;
– frequency of bubbling skim milk 0.10...0.15 min^{-1};
– the bubbling pressure should be 0.56...0.58 MPa.

Complex characteristic of the products quality of buttermilk ultrafiltration provided by the study of the general chemical composition of the final products – concentrates and permeates. Table 2 shows the chemical composition of the products after ultrafiltration. From the data in table, it follows that ultrafiltration concentrates of buttermilk contain all food nutrients that are inherent in the studied types of buttermilk. It should be noted that the content of protein and fat in the concentrate increases in proportion to the increase in the concentration factor. It is important to state that at different values of the concentration factor, the protein/fat ratio in buttermilk concentrate remains at the level of the feedstock.

Table 2. Chemical composition of buttermilk ultrafiltration products

Index	Buttermilk	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	–	1.20	–	1.80	–
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

As the concentration factor increases, the lactose content in ultrafiltration buttermilk concentrates slightly decreases due to its transfer to the filtrate. The ash content in buttermilk concentrates remains practically unchanged with an increase in concentration factor. At the same time, there is a tendency for ash reduction.

Dry mater content in buttermilk permeates increases with an increase in concentration factor, primarily lactose and ash elements. This is a consequence of the transition during ultrafiltration into permeate. Content of milk protein in permeates is insignificant and is at the level of 0.16...0.26%. Milk fat in these products of ultrafiltration present in insignificant quantities.

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CONCLUSIONS

Investigation has been carried out to develop the process of buttermilk ultrafiltration using method of eliminating the polarization layer on the surface of semi-permeable membranes. Hydroacoustic method is promising for reducing the polarization layer on the membrane surface. The issue of obtaining new methods for eliminating the polarization layer on the surface of a semi-permeable membrane remains urgent. It is advisable to use a mathematical model based on the planning of experiment to identify the nature of change in various characteristics depending on parameters of buttermilk ultrafiltration.

Experimental and calculated results, which were obtained, show the influence of ultrafiltration pressure temperature and its duration on the membranes productivity. Results showed that an increase in pressure with ultrafiltration of buttermilk more than 0.4...0.5 MPa is unreasonable, since this does not lead to a significant increase in the productivity of both types of membranes. Temperature rise by 45...55 °C is also impractical, since there is a slight increase in membrane productivity, as well as deterioration in t functional properties of buttermilk.

Research findings make it possible to determine rational parameters of buttermilk ultrafiltration using PAN type membranes, as well as bubbling mixing of buttermilk: pressure – 0.4...0.5 MPa, skim milk temperature – 40...50 °C, bubbling frequency skim milk – 0.10...0.15 min^{-1}, the bubbling pressure should be 0.56...0.58 MPa.

Results can be used for studying other technological parameters of buttermilk, as well as to improve other technological processes of production lines for the processing of buttermilk. Submitted studies are continuation of research on the development of new methods of membrane processing of high-molecular-weight food liquids using new types of technological equipment and the creation of ways to eliminate the polarization layer on the membrane surface.

REFERENCES

1. Berk, Z. Food process Engineering and Technology, Elsevier, USA, **2009**.
2. Kumar, P.; Sharma, N.; Ranjan, R.; Kumar, S. Technology in Dairy Industry: A Review. *Asian-Australasian Journal of Animal Sciences*. **2013**, *9* (26), 1347–1358.
3. Galanakis, C.M.; Schieber, A. Recovery and utilization of valuable compounds from food processing by-products. *Food Research International*. **2014**, *65*, 299-300.
4. Barukčić, I.; Jakopović, K.; Božanić, R. Valorisation of Whey and Buttermilk for Production of Functional Beverages – An Overview of Current Possibilities. *Food Technol. Biotechnology*. **2019**, *57*(4), 448–460.
5. Kelly, P. Milk Protein Concentrate. *Encyclopedia of Dairy Sciences*, **2011**. 848–854.
6. Waeger, F. System for microfiltration and ultrafiltration processing. Filtration & Separation **2010**, *47*, 6-14.
7. Lau, W. J.; Ismail, A. F.; Matsuura, T.; Nazri, N. A.; Yuliwati, K. Handbook of Membrane Separations: Chemical, Pharmaceutical, Food, and Biotechnological. Taylor & Francis Group, LLC, Abingdon. **2015**.
8. Rombaut, R.; Dejonckheere, V.; Dewettinck, K. Filtration of milk fat globule membrane fragments from acid buttermilk cheese whey. *Journal Dairy Science*. **2007**, *90* (4), 1662-1673.
9. Lutz, H. Ultrafiltration for Bioprocessing. Woodhead Publishing, United Kingdom. **2015**.

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10. Deynichenko, G.; Huzenko, V.; Dmytrevskyi, D.; Tsvirkun, L.; Kravchenko, T. Prospects for the use of membrane technologies for the processing of dairy raw materials. *Progressive technology and technologies of food production of restaurant industry and trade.* **2019**, *2(30)*, 122-133.
11. Bhattacharjee, C.; Saxena, V.; Dutta, S. Fruit juice processing using membrane technology: A review. Innovative Food Science and Emerging Technologies. **2017**, *43*, 136-153.
12. Ferrer, M., Alexander, M., Corredig, M. Changes in the physico-chemical properties of casein micelles during ultrafiltration combined with diafiltration. *Food Science and Technology*. **2014**, *59*(1), 173-180.
13. Audenhaege, M.; Belmejdoub, J.; Dupont, D.; Chalvin, A.; Pezennec, S. Methodology for monitoring globular milk protein changes induced by ultrafiltration: a dual structural and functional approach. *Journal of Dairy Science*. **2010**, *93*(9), 3910–3924.
14. Akoum, O.; Jaffrin, M.; Ding, L. Concentration of total milk proteins by high shear ultrafiltration in a vibrating membrane module. *Journal of Membrane Science*. **2005**, *247*(1-2), 211–220.
15. Strathmann, H.; Giorno, L.; Drioli, E. An Introduction to Membrane Science and Technology. Consiglio Nazionale delle Richerche, Rome, Italy, 2006.
16. Brião, V. B.; Tavares, C. R. G. Pore blocking mechanism for the recovery of milk solids from dairy wastewater by ultrafiltration. *Brazilian Journal of Chemical Engineering*. **2012**, *29*(22), 393-407.
17. Gomaa, H.; Rao, S. Analysis of flux enhancement at oscillating flat surface membranes. *Journal of Membrane Science*. **2011**, *374*, 59–66.
18. Lobasenko, B.; Semenov, A. Intensification of ultrafiltration concentrating by the separation of the concentration boundary layer. *Foods and Raw Materials*. **2013**, *1*(1), 74–81.
19. Cheng, T. Li L. Gas-sparging cross-flow ultrafiltration in flat-plate membrane module: Effects of channel height and membrane inclination. *Separation and Purification Technology*. **2007**, *55*, 50–55.
20. Cai, M.; Zhao, S.; Liang, H. Mechanisms for the enhancement of ultrafiltration and membrane cleaning by different ultrasonic frequencies. *Desalination*. **2010**, *263*, 133-138.
21. Banerjee S. Mathematical Modelling: Models, Analysis and Applications. Chapman and Hall / CRC, New-York, USA. 2014.
22. Farid M. M. Mathematical Modelling of Food Processing. USA: CRC Press. 2010.
23. Deinychenko, G.; Mazniak, Z.; Kramarenko, D.; Guzenko, V. Determination of ultrafiltration membranes shrinkage factor. *Ukrainian Food Journal*. **2015**, *4*(2), 328-334.
24. Deynichenko, G.; Guzenko, V.; Dmytrevskyi, D.; Chervonyi, V.; Kolisnichenko, T.; Omelchenko, O.; Melnik, O.; Simakova, O.; Nykyforov, R. Study of the new method to intensify the process of extraction of beet pulp. *East Europe Journal*. **2018,** *4*(11), 15-20.