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PROSPECTS OF USING EQUIPMENT FOR MEMBRANE SEPARATION OF FOOD LIQUIDS

Summary. The article analyzes modern equipment used for juice clarification and concentration. The sequence of obtaining clarified juice using existing technologies and equipment is considered. The shortcomings of traditional technological processes are determined. The directions for improving the processes of concentrating and clarifying juice from fruit and vegetable raw materials, as well as the need to develop equipment for their implementation, are substantiated. The use of microfiltration and ultrafiltration membrane devices for juice processing is proposed. The reasons that impede the widespread use of membrane technologies in juice processing processes have been identified. The introduction of membrane technologies into the processing process will increase the yield of the product, preserve the nutritional and biological value of clarified juice, and improve the quality of the final product.

Key words: ultrafiltration, membrane processing, baromembrane processes, clarification of fruit juices, concentration of food liquids, membrane devices.

Formulation of the problem. Processing of fruits and fruit and berry raw materials is a fairly promising area of the food industry. The fruit and vegetable industry performs one of the main tasks of providing the population with food products that have high biological and nutritional value, and also contain vitamins and biologically active substances that are indispensable for humans. Juices are one of the main products of the fruit and vegetable industry. Juices are an important food product because, together with fresh fruits and vegetables, they provide the human body with a set of all the necessary physiologically active substances - vitamins, macro- and microelements, and many other useful substances necessary for normal human activity. One of the main stages of apple juice production is illumination. This process is carried out for the purpose of colloidal stabilization of the product during storage, as well as to improve the consumer appearance of the product and its organoleptic properties. Traditional juice production technologies involve filtration of freshly squeezed juice through porous partitions with the loss of some valuable substances, as well as the introduction of preservatives and the use of heat sterilization to ensure the necessary shelf life. The use of these technologies does not guarantee complete removal of fruit pulp particles and obtaining a final product with a high level of organoleptic indicators and nutritional value. Some methods of brightening and stabilizing fruit juices are based on the addition of third-party additives to the product, namely brightening materials. Together with these materials, an excessive amount of mineral and other substances often enters the composition of the juice [1]. The duration of juice processing according to traditional technology is from 24 to 30 hours. As a result of such long-term contact of the product with air oxygen, part of the biological value of the juice components is lost. It is obvious that such a phenomenon negatively affects the quality of finished products. In order for the product to meet international standards, it is necessary to use modern equipment based on advanced technologies. Such equipment includes membrane technologies that provide greater yield, improvement in taste, appearance and nutritional value of fruit and berry juices. At the same time, the products retain vitamins, amino acids and other biologically active components. This is possible thanks to the rejection of preservatives and the thermal sterilization stage [2]. Combining different types of membrane processes allows you to create energy-efficient juice concentration technologies and obtain new types of products. One of the main areas of application of membranes in the production of juices is their clarification [3]. Clarification of juices is carried out with the aim of destroying the colloidal system of the product, removing high-molecular protein, pectin and polyphenolic substances and microorganisms. At the same time, a necessary condition is the preservation of biologically active and valuable components, such as vitamins, sugars, mineral and aromatic substances, acids [4]. Membrane operations such as ultrafiltration and microfiltration have been extensively researched and widely used over the past few decades in the industrial processing of fruit juices. The latter include illumination, stabilization, concentration and recovery of aromatic compounds [5]. Concentrated juice is obtained during the processing of direct-pressed juice. For this purpose, the direct-pressed juice can be concentrated in various ways. Among these methods, the membrane method of concentration has become widespread. As a rule, neither sugar nor other substances for sweetening are added to the composition of concentrated juices [6].

Membrane processes make it possible to create energy-efficient juice concentration technologies and expand the range of products. Using microfiltration and ultrafiltration processes, you can get products with adjustable mineral and carbohydrate composition. One of the main areas of application of membranes in the production of juices is their clarification and concentration. The use of membrane processes allows obtaining products with improved indicators of safety, quality and nutritional value. These processes are characterized by low energy consumption and little impact on the environment.

Analysis of recent research and publications. The consumption of fruit juices has grown significantly in recent years as consumers are interested in quality products that are convenient and ready to consume. Fruit juices act as nutritional beverages and have an important role in a healthy diet because they have a chemical composition that is naturally found in fruit. In addition to this, fruit juices are rich in nutrients with a wide range of vitamins, minerals, proteins and various sources of protective antioxidants. This, combined with a refreshing taste and a long shelf life, makes fruit juices one of the most popular drinks. During juice processing, the main aspects have always been safety and quality improvement, nutritional value, minimization of product manufacturing costs and process implementation [7].

Traditional methods of juice production involve several serial operations that require a lot of work and time. The technological scheme of traditional production involves mechanical pressing of juice from the pulp of the fruit, squeezing of the juice, clarification of the juice by centrifugation or filtration, and the subsequent stage of concentration by means of multi-stage vacuum evaporation [8].

Membrane processes are one approach to juice concentration and clarification that offer a number of advantages over traditional separation processes. These advantages include high selectivity, lack of thermal stress of the fluids processed due to moderate operating temperatures, lack of use of chemical additives, compact and modular design, low energy consumption. Currently, membrane processes carried out under pressure, such as microfiltration, ultrafiltration, represent the most modern technology for juice clarification, fractionation, and concentration. Recently, other membrane processes such as osmotic distillation, membrane distillation, and pervaporation have been used to concentrate juice and recover aromatic compounds [9]. Both microfiltration and ultrafiltration membranes are used to clarify juices. The prepared juice on the filtration unit is divided into clarified permeate and retentate with colloidal substances and microorganisms. Retentate is a concentrate formed during filtration. The retentate consists mainly of retained sediment particles and a suspension of microorganisms. An increase in the concentration of solids in the retentate leads to a decrease in its total volume. Depending on the technology used for processing, the yield of clarified juice can reach up to 98%. From the point of view of the organization of the process of membrane clarification of juice, several variants of its implementation can be implemented [10]. The membrane used in ultrafiltration and microfiltration is a semipermeable barrier. This barrier allows certain components of liquid mixtures to pass through. Membranes must have high resolution (selectivity); high specific productivity (permeability); chemical resistance to the environment of the isolated system; mechanical strength [11].

The duration of action of the membranes, as well as their service life, is significantly affected by the sediment formation process. The sediment layer is usually impermeable to salt, clogs the surface pores of the membrane, creates additional flow resistance and mass transfer in the boundary layer. As a result, the concentration polarization on the membranes increases and their productivity decreases. The phenomenon of concentration polarization is inherent in almost all baromembrane processes. This phenomenon is an increase in the concentration of a dissolved substance near the surface of the membrane [12]. The productivity of the membrane apparatus depends significantly on the method of processing fruit and berry raw materials, as well as on the processing of primary juice with enzymes. In order to obtain the necessary data for the development of an industrial system, an assessment of the main technology and tests are carried out to select rational filtration conditions [13]. Nowadays the ultrafiltration process has become widespread during the production of clarified concentrated apple juices. In this case, ultrafiltration can replace a separator, kieselguhr and plate filter press. In addition, ultrafiltration replaces the treatment of raw materials with brightening substances. The use of ultrafiltration treatment allows you to remove solid particles, as well as high-molecular components, which are starch and proteins. In modern production conditions, ultrafiltration has become an alternative, and in some cases, a replacement for the traditional lighting process, while ensuring higher profitability of the process and product quality. In order to reduce the pectin content, the juice must be purified by enzymes before ultrafiltration. This technology guarantees a high product yield, optimal productivity and quality of the final product. Unlike microfiltration treatment, ultrafiltration of juices removes not only insoluble but also soluble substances. These substances include pectin, starch, proteins, as well as various condensed forms of polyphenols.

Formulation of the purpose of the article. The purpose of the article is to conduct an analysis of membrane processes used for clarification and concentration of liquid food media, as well as to identify the most effective and energy-saving methods and equipment for clarification of fruit juices.

Presentation of the main research material. At present, clarification of juices by ultrafiltration is widely used in industry for clarification and stabilization of the quality of cherry, apple, grape, lemon, orange and other juices. It is known that during ultrafiltration, approximately 19...32% of pectin compounds, 9.5...18.4% of protein compounds, and 38.5...45% of colloids are removed from apple juice. Removal of high molecular weight substances from apple juice in the specified amount allows to obtain clarified juice with high nutritional qualities and organoleptic indicators. The advantages of using ultrafiltration during clarification of fruit and berry juices include the high quality of purified juice, especially in terms of color, transparency and taste. In addition, the advantage is a high extraction of juice, which is approximately 98...99%. Enzyme processing during ultrafiltration can be automated, and costs are reduced by up to 25% compared to traditional methods. It should also be noted that additional treatments with gelatin, bentonite and kieselguhr can be excluded. In addition to the above-mentioned advantages, ultrafiltration has low production costs and is also characterized by a hygienic design. After ultrafiltration of the juice, a certain amount of sediment remains, containing the pomace and part of the juice, but their content is very small compared to the amount obtained during the classical processing process [14].

An important indicator of ultrafiltration lighting is that the membranes, retaining colloids, pass many valuable components of the juice. These components include sugars, soluble vitamins, amino acids, organic acids, and minerals. As a result, the nutritional and biological value of the juice does not decrease [15]. Today the studies of the dependence of the degree of clarification of apple juice on ultrafiltration membrane installations on the diameter of the membrane pores have been carried out. According to experimental data, membranes with a pore diameter of 0.025-0.045 μm provide a high degree of removal of colloidal substances while preserving the original amounts of sugars, vitamins and other valuable soluble substances in the juice. Membranes with a large pore diameter do not allow obtaining the required degree of illumination. Membranes with smaller pores have a low permeability. Conducted research proves that ultrafiltration is a cost-effective way of lighting, which has significant advantages over traditional lighting processes. However, it should be noted that the juices must be pre-treated. Studies on determining the effect of preliminary preparation of juice on the speed and filtering capacity of ultrafiltration units during apple juice processing have shown that the most effective treatment with enzymes followed by separation. The use of additional clarification of apple juice with gelatin and kieselsol before ultrafiltration showed low efficiency. Depending on the type of ultrafiltration unit, apple juice is often treated with enzymes before ultrafiltration and separated or filtered.

If we consider the materials from which membranes are made, polymer membranes dominate the industrial market of membrane technologies. They are relatively cheap, easy to manufacture, and available in a wide range of pore sizes. The most common polymer membranes are made from cellulose acetate, polysulfone, polyethersulfone, polytetrafluoroethylene, polypropylene, polyethylene, polyvinylidene fluoride, polyacrylonitrile, and polyamide. Ceramic membranes are made from inorganic materials (for example, aluminum oxide, zirconium, titanium, and silica). They exhibit high resistance to aggressive environments (acids, alkalis, strong solvents), as well as high mechanical and thermal resistance. Despite the fact that the cost of their production is higher than that of polymer membranes, they are environmentally friendly, durable and have a longer service life. The most effective and cost-effective membrane separation method is tangential filtration. This is due to the fact that along with traditional separation methods, which include centrifugation, filtration, settling, tangential filtration in flow membrane elements has significant advantages, namely: the absence of stagnation zones, high selectivity in relation to the component passing through membrane, the possibility of washing the filter without disassembling the device, as well as low energy consumption, compactness and simplicity of the hardware design. However, their performance is not always satisfactory. One of the ways to increase it is the artificial turbulence of the flow with the help of built-in devices. The implementation of this approach requires the development of methods of calculation and design of tubular membrane devices with turbulating devices, as well as the search for optimal design solutions and the determination of conducting conditions.

Dead-end and tangential filtration is used in modern enterprises of the food industry. Dead-end filtration is a highly effective and economical way of cleaning food products, and the equipment for its implementation is compact and easy to use (Fig. 1).

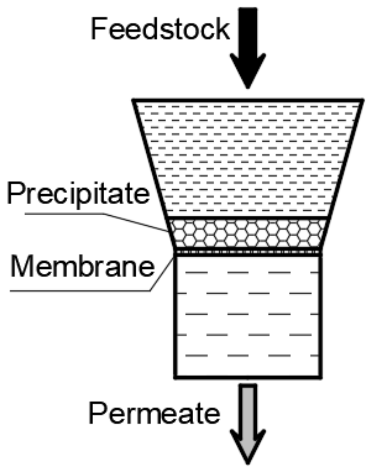

Figure 1. Scheme of dead-end membrane filtration

Tangential filtration is characterized by the product flow passing over the membrane surface (Fig. 2).

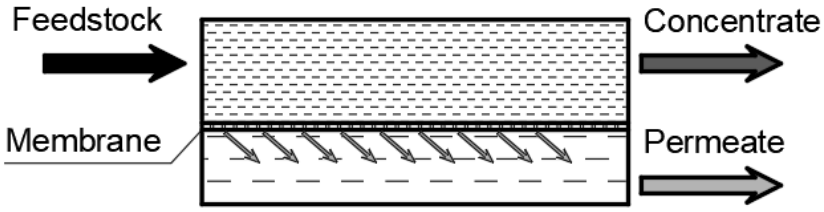

Figure 2. Scheme of tangential membrane filtration

Dead-end and tangential filtering differ significantly. During dead-end filtration, the liquid flow is directed perpendicular to the filter surface, and during tangential filtration, the flow moves in a direction parallel to the membrane surface. As a rule, in tangential filtration machines, the circulation pump creates a flow that moves along the surface of the membrane (Fig. 3). Thus, this flow prevents the formation of sediment on the surface of the membrane.

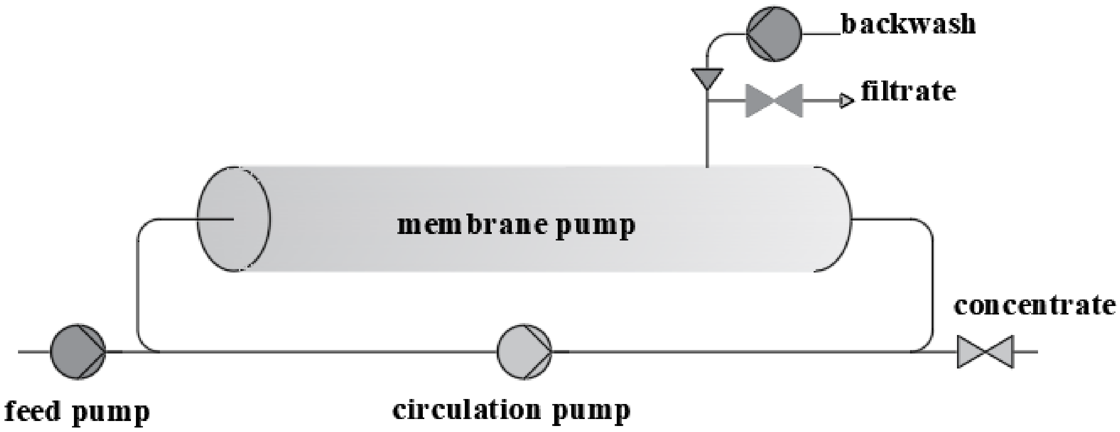

Figure 3. Technical equipment of the tangential filtration process

Tangential filtration is a technology that uses porous membranes capable of trapping particles from 0,2 to 0,4 microns (microns). The membrane used is narrow, so this type of filtration removes spoilage microorganisms such as yeast. The peculiarity of tangential filtration is that the product is supplied tangentially, and not frontally to the membrane. In addition, the advantage of tangential filtration is that the filter medium is clogged only on the surface, which facilitates cleaning, which is carried out after each cycle of use. There are two types of membranes used for tangential filtration. These include organic membranes and ceramic membranes.

The use of membrane methods in the food industry allows cleaning and concentration of solutions without heating and evaporation. They are also used for technological preparation of water, stabilization of soft drinks and grape wines, concentration of natural juices, pasteurization, extraction of valuable components from technological effluents of various industries, clarification of fruit and vegetable juices, syrups. Compared to the processes of evaporation or freezing, membrane methods allow to improve the quality and increase the yield of the obtained products.

Conclusions. Modern technological processes used for membrane separation of food liquids and the corresponding equipment for their implementation are analyzed. It has been determined which technologies are used for clarification and concentration of juices. The main methods of juice processing are considered, in particular, the sequence of obtaining clarified juice with the use of existing technologies and equipment. On the basis of the conducted analysis, the necessity of using membrane technologies for the clarification and concentration of fruit juices is substantiated. The main areas of improvement of the processes of concentration and clarification of juice from fruit raw materials, as well as the need for the development of equipment for their implementation, are given. The process of membrane processing in dead-end and tangential modes is analyzed. The main advantages and disadvantages of their use in fruit juice processing processes have been revealed. The conducted analytical studies prove that the introduction of membrane technologies into the production process will increase product yield, preserve the nutritional and biological value of clarified juice, and improve the quality of the final product. Ultrafiltration membrane units have been found to retain colloids while allowing all valuable juice components such as sugars, minerals, organic acids, soluble vitamins and amino acids to pass through. As a result of the use of ultrafiltration devices, the yield of the product increases, the nutritional and biological value of clarified juices does not decrease, the quality of the final product improves, which makes it possible to obtain food products with new functional properties and high nutritional value.

References

1. Bagci P. O. “Effective clarification of pomegranate juice: a comparative study of pretreatment methods and their influence on ultrafiltration flux”, *Journal of Food Engineering*. 2014. Vol. 141, Pp. 58–64. DOI: https://doi.org/10.1016/j.jfoodeng.2014.05.009.

2. Conidi C., Drioli E., Cassano A., “Perspective of Membrane Technology in Pomegranate Juice Processing: A Review”, *Foods*. 2020. Vol. 9, Pp. 889–914. DOI: https://doi.org/10.3390/foods9070889.

3. Дейниченко Г. В., Дмитревський Д. В., Гузенко В. В., Афукова Н. О. Аналіз застосування мембранних апаратів для виробництва соків із плодової сировини. *Праці Таврійського державного агротехнологічного університету: наукове фахове видання.* 2021. Вип. 21, т. 1. С. 36–43. DOI: 10.31388/2078-0877-2021-21-1-36-43.

4. Cherevko O. I., Deinychenko G. V., Dmytrevskyi D. V., Guzenko V. V., Heiier H. V., Tsvirkun L. O. Application of membrane technologies in modern conditions of juice production. *Прогресивна*

техніка та технології харчових виробництв ресторанного господарства і торгівлі. 2020. Вип. 2 (32). С. 67-77. DOI: 10.5281/zenodo.4369743.

5. Deinychenko G. V., Dmytrevskyi D. V., Zolotukhina I. V., Perekrest V. V., Guzenko V. V. Directions of improvement of processes of membrane separation of juices from fruit and berry raw materials. *Прогресивна техніка та технології харчових виробництв ресторанного господарства і торгівлі*. 2021. Вип. 1 (33). С. 89–98. DOI: 10.5281/zenodo.5036090.

6. Domingues R. C. C., Ramos A. A., Cardoso V., Reis M. H. M. (2014), “Microfiltration of passion fruit juice using hollow fibre membranes and evaluation of fouling mechanisms”, *Journal of Food Engineering*. 2014. Vol. 121, Pp. 73–79. DOI: https://doi.org/10.1016/j.jfoodeng.2013.07.037.

7. Дейниченко Г. В., Золотухіна І. В., Дмитревський Д. В., Гузенко В. В., Перекрест В. В., Гладкова О. С. Сучасні технології баромембранних процесів у харчовій промисловості. *Обладнання та технології харчових виробництв*. 2021. № 2 (43). С 86–93. DOI: 10.33274/2079-4827-2021-43-2-86-93.

8. Yukun Li, Jianquan Luo, Yinhua Wan. Biofouling in sugarcane juice refining by nanofiltration membrane: Fouling mechanism and cleaning. *Journal of Membrane Science*. Vol. 612, 2020. 118432, ISSN 0376-7388. DOI: https://doi.org/10.1016/j.memsci.2020.118432.

9. Emel Yilmaz, Pelin Onsekizoglu Bagci. Ultrafiltration of Broccoli Juice Using Polyethersulfone Membrane: Fouling Analysis and Evaluation of the Juice Quality. *Food and Bioprocess Technology*, 2019. Vol. 12, Pp 1273–1283. DOI: https://doi.org/10.1007/s11947-019-02292-0.

10. Samreen Ch V.V. Satyanarayana, L. Edukondalu, Vimala Beera. Srinivasa Rao. Effect of Pre-treatment on Aggregation, Biochemical Quality and Membrane Clarification of Pomegranate Juice. *Indian Journal of Ecology*, 2022. 49(3): Pp. 910–918 DOI: https://doi.org/10.55362/IJE/2022/3615.

11. David Inhyuk Kim, Gimun Gwak, Min Zhan, Seungkwan Hong. Sustainable dewatering of grapefruit juice through forward osmosis: Improving membrane performance, fouling control, and product quality. *Journal of Membrane Science*, 2019. Vol. 578, Pp. 53–60. DOI: https://doi.org/10.1016/j.memsci.2019.02.031.

12. Xiaochan An, Yunxia Hu, Ning Wang, Zongyao Zhou, Zhongyun Liu. Continuous juice concentration by integrating forward osmosis with membrane distillation using potassium sorbate preservative as a draw solute. *Journal of Membrane Science*. Vol. 573, 2019, Pp. 192–199. DOI: https://doi.org/10.1016/j.memsci.2018.12.010.

13. Omar J. M., Nor M. Z. M., Basri M. S. M., Che Pa N. F. Clarification of guava juice by an ultrafiltration process: analysis on the

operating pressure, membrane fouling and juice qualities. *Food Research 4,* 2017. (Suppl. 1). Pp. 85–92. DOI: https://doi.org/10.26656/fr.2017.4(s1).s30.

14. Yee W. P., Nor M. Z. M., Basri M. S. M., Roslan J. Membrane-based clarification of banana juice: pre-treatment effect on the flux behaviour, fouling mechanism and juice quality attributes. *Food Research 5*, 2021 (Suppl. 1). Pp. 57–64. DOI: https://doi.org/10.26656/fr.2017.5(s1).046.

15. Miyoshi T., Yuasa K., Ishigami T., Rajabzadeh S., Kamio E., Ohmukai Y., Saeki D., Ni J., Matsuyama H. Effect of membrane polymeric materials on relationship between surface pore size and membrane fouling in membrane bioreactors, *Applied Surface Science*, 2015. Vol. 330, Pp. 351-357. DOI: https://doi.org/10.1016/j.apsusc.2015.01.018.

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ПЕРСПЕКТИВИ ВИКОРИСТАННЯ ОБЛАДНАННЯ ДЛЯ МЕМБРАННОГО РОЗДІЛЕННЯ ХАРЧОВИХ РІДИН

Анотація

Проаналізовано обладнання, що застосовуються для освітлення і концентрування плодово-ягідного та овочевого соку. Розглянуто технології отримання освітленого соку. Визначено характерні недоліки існуючих технологічних процесів. Визначено напрями удосконалення процесів концентрування і освітлення соку та обґрунтовано необхідність розробки обладнання для їх реалізації. Запропоновано використання мікрофільтраційних і ультрафільтраційних мембранних апаратів для обробки соку. Виявлено причини, які ускладнюють використання мембранних технологій в процесах переробки харчових рідин. Проаналізовано існуючі способи мембранної обробки, а також нові перспективні напрями, що розробляються останнім часом. В якості об’єкта дослідження обранні мембранні технології фільтрації, які на сьогоднішній день широко визнані як найбільш перспективні методи очищення рідких харчових середовищ. Дані технології є достатньо ефективними під час проведення процесів концентрування та освітлення фруктових соків. Мембрани сприяють ефективному видаленню твердих речовин та бактерій. Мембранні фільтри забезпечують надійний фізичний бар’єр проходження частинок. Використання мембранних установок із тангенціальними фільтрами сприяє збереженню структурних та органолептичних властивостей продукту. Крім цього, тангенціальні фільтри самоочищаються і не вимагають дорогих витратних матеріалів. Проаналізовано традиційні технології та обладнання, що застосовується для обробки харчових рідин. Визначено недоліки існуючих технологічних процесів. Запропоновано застосування мембранних технологій для обробки соків із плодової сировини. Наведено основні переваги впровадження мембранних технологій у процес обробки. Виявлено недоліки, що ускладнюють застосування мембранних технологій у виробничому процесі переробки рідких харчових середовищ. Обґрунтовано доцільність застосування ультрафільтраційних та мікрофільтраційних мембранних установок для освітлення фруктових соків. В результаті використання ультрафільтраційних мембранних установок суттєво зростає вихід продукту, при цьому харчова та біологічна цінність освітлених соків не зменшується, покращується якість кінцевого продукту, що дає змогу отримувати харчові продукти з новими функціональними властивостями і високою харчовою цінністю.

Ключові слова: ультрафільтрація, мембранна обробка, баромембранні процеси, освітлення фруктових соків, концентрація харчових рідин, мембранні апарати.