UDC 66.081.6:663.81

APPLICATION OF MEMBRANE TECHNOLOGIES IN MODERN CONDITIONS OF JUICE PRODUCTION

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The article analyzes the existing technologies and equipment that are used to clarify juice from fruit raw materials. The disadvantages of existing technological processes are revealed. The necessity of improving the apple juice clarification process and equipment for its implementation has been proved. The application of membrane technologies for apple juice processing is proposed. The main advantages of introducing membrane technologies into the process are indicated. The disadvantages that complicate the use of membrane technologies in the process of processing liquid food media have been identified. The use of ultrafiltration membranes for the apple juice clarification process has been substantiated.

Keywords: *apple juice, fruit raw materials, membrane processing, ultrafiltration, clarification.*

ВИКОРИСТАННЯ МЕМБРАННИХ ТЕХНОЛОГІЙ У СУЧАСНИХ УМОВАХ ВИРОБНИЦТВА СОКІВ

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Однією з основних стадій виробництва яблучного соку є освітлення. Цей процес проводиться з метою колоїдної стабілізації продукту під час зберігання, а також для поліпшення споживчого вигляду продукту і його органолептичних властивостей. Для того щоб продукт відповідав міжнародним стандартам, необхідно застосовувати сучасне обладнання, яке базується на передових технологіях. До такого обладнання відносяться мембранні технології, які забезпечують більший вихід, поліпшення смаку, товарного вигляду і харчової цінності плодово-ягідних соків. При цьому у продукції зберігаються вітаміни, амінокислоти та інші біологічно активні компоненти. Це можливо завдяки відмові від консервантів і стадії теплової

стерилізації. Комбінування різних видів мембранних процесів дозволяє створювати енергоефективні технології концентрування соків і отримувати нові види продуктів. Одним з основних напрямів застосування мембран у виробництві соків є їх освітлення. Освітлення соків здійснюється з метою руйнування колоїдної системи продукту, видалення високомолекулярних білкових, пектинових і поліфенольних речовин і мікроорганізмів. При цьому необхідною умовою є збереження біологічно активних і цінних компонентів, таких як вітаміни, цукри, мінеральні й ароматичні речовини, кислоти.

Останнім часом поширення набули мембранні методи розділення сумішей. Ці технології характеризуються простотою, економічністю й ефективністю.

Проаналізовано традиційні технології та обладнання, що застосовується для обробки харчових рідин. Визначено недоліки існуючих технологічних процесів. Доведено доцільність удосконалення процесу освітлення соків із плодової сировини і створення устаткування для його реалізації. 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 процесі переробки рідких харчових середовищ. Обґрунтовано доцільність застосування ультрафільтраційних мембран для освітлення яблучного соку.

Ключові слова: *яблучний сік, плодова сировина, мембранна обробка, ультрафільтрація, освітлення.*

Statement of the problem. Processing of fruits and vegetables is one of the main directions of the food industry. The fruit and vegetable industry performs one of the main tasks of supplying the population with food products that have a high biological and nutritional value, and also contain a number of vitamins and biologically active substances that are indispensable for humans. Juices are one of the 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 physiologically active substances – vitamins, macro- and microelements, polyphenols and many others, necessary for normal human life [1–3].

One of the main stages in the apple juice production process is the clarification stage. This process is carried out with the aim of colloidal stabilization of the product during storage, as well as to improve the consumer appearance of the product and its organoleptic properties. In order for the product to comply with international standards, it is necessary to use modern technologies and equipment, which is based on advanced developments. This type of equipment includes membrane technologies that provide a higher yield, improve the taste, presentation and nutritional value of fruit and berry juices. At the same time, vitamins, amino acids and other biologically active components are preserved. This is possible due to the elimination of preservatives and the stage of heat sterilization. The combination of various types of membrane processes makes it possible to create energy efficient technologies for concentrating juices and obtain new types of products. By using microfiltration and reverse osmosis processes it is possible to obtain products with a controlled mineral and carbohydrate composition [4–6].

One of the main areas of application of membranes in juice production is their clarification. Clarification of juices is carried out with the aim of destroying the colloidal system of the product, removing high molecular weight protein, pectin and polyphenolic substances and microorganisms. In this case, a necessary condition is the preservation of biologically active and valuable components – vitamins, sugars, mineral and aromatic substances, acids.

Review of the latest research and publications. Traditional juice production technologies provide for the 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 required shelf life. The use of these technologies does not guarantee the complete removal of fruit pulp particles and the production of a final product with a high level of organoleptic characteristics and nutritional value [7–10].

Some methods of clarifying and stabilizing fruit juices are based on the introduction of foreign additives into the product, namely, clarifying materials. Excess minerals and other substances are often transferred from the clarifying materials to the juice. The processing time of juices according to traditional technology is from 24 to 30 hours. Due to such a long contact of the product with atmospheric oxygen, a part of the biological value of the juice components is lost. This phenomenon negatively affects the quality of the finished product.

Recently, membrane methods for the separation of mixtures have become widespread. These technologies are simple, economical and efficient.

Membrane filtration separates the various components in the stream based on the size and shape of the microparticles. With improved filtration, the quality improves and the yield of the finished product increases [11].

In addition to improving the quality of products, the use of membrane units as part of technological lines for the production of juices makes it possible to improve the economic performance of enterprises by simplifying the composition of the lines and reducing the energy intensity of the processes [12–14].

As the analysis of literature sources has shown, the main problems hindering the widespread use of membrane technologies in the production of fruits and vegetables and, in particular, apple juices, is the very high cost of membrane plants, due to the large filtration area, which compensates for the decrease in productivity due to sediment deposition on the membrane surface. The choice of effective parameters for the functioning of continuous flow microfiltration plants is complicated by the lack of scientifically grounded calculation methods that would take into account the non-stationarity of the process, the nonlinearity of the rheological behavior of the processed media and allow the optimal arrangement of membrane modules in concentration stages.

The objective of the research. The purpose of the article is to substantiate the use of ultrafiltration membrane units in the production of juices from fruit raw materials for clarification and improvement of consumer qualities of the product.

Presentation of the research material. For clarification, stabilization and concentration of juices, various soft drinks and wines, the processes of reverse osmosis, ultrafiltration, microfiltration and electrodialysis are used.

It is advisable to use membrane processes in situations where the mixture to be separated contains labile substances that are easily destroyed. These mixtures most often include liquid food media, such as juices, extracts, protein solutions, and others. The development of membrane processes for the separation of such liquid media makes it possible to create fundamentally new technological schemes and equipment for the complex processing of plant raw materials. In addition, the use of membrane separation processes makes it possible to reduce environmental pollution through the use of waste-free technologies, as well as to obtain food products with new functional properties and high nutritional value.

At present, membrane processes and technologies in the production of fruit and vegetable juices are used for their clarification and concentration. Freshly squeezed fruit juice is a complex colloidal system formed by plant tissue particles that do not dissolve in water. In addition to pulp and fruit tissue particles, juices contain yeast cells, various ballast impurities, which cause the formation of turbidity and sediments. Such particles during storage of juices aggregate and precipitate.

With the advent of modern high-performance membranes, it has become possible to effectively clarify juice, while maximizing the preservation of all valuable juice components [15].

To clarify juices, both microfiltration and ultrafiltration membranes are used. The prepared juice on the filtration unit is separated into clarified permeate and retentate with colloidal substances and microorganisms. The retentate is a concentrate that forms 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%.

Depending on the capacity of the equipment, the retentate flow rate during circulation in the filter circuit of the equipment is 5 to 25 times higher than the value of the main flow. During filtration, the retentate is saturated with suspended solids. At a certain concentration, the retentate requires further processing in a batch mode to obtain the target juice. The unit washing cycles are determined by the formation of a surface layer on the membrane surface and the concentration of suspended solids in the retentate. In cases where a separator is used to treat the secondary stream in the retentate loop, the time between wash cycles and the permeate output can be significantly increased. At the exit of the secondary stream, which is 10–20% of the flow rate in the retentate circulation loop, suspended solids will be continuously separated. This, in turn, will eliminate too high a concentration in the primary circuit of the retentate [16].

A similar effect can be obtained by installing a separator on the supply line to the working tank of an ultrafiltration plant. In this case, the entire batch of juice undergoes preliminary clarification. In this case, the throughput of the separator must be adjusted in accordance with the flow rate of the permeate. When separating the secondary stream in the retentate loop, the centrifuge can be smaller. In order not to create a separate waste stream, the removal of the sludge from the centrifuge is possible together with the squeezing.

From the point of view of organizing the process of membrane clarification of juice, several options for its implementation can be realized. The most common are the following scheme (Fig. 1).

The performance of the membrane will significantly depend on the method of processing fruit and berry raw materials, as well as on the processing of primary juice with enzymes [17].

In order to obtain the necessary data for the development of an industrial system, the basic technology is assessed and tested to select rational filtration conditions.

Today, the ultrafiltration process is widely used during the production of clarified concentrated apple juices. In this case, ultrafiltration can replace the separator, kieselguhr and plate filter press. In addition, ultrafiltration replaces the processing of raw materials with clarifying agents [18].

The use of ultrafiltration treatment removes suspended solids, as well as high molecular weight components, which are starch and proteins. Ultrafiltration has become a replacement for the traditional clarification process, while providing higher process profitability and product quality. To reduce the pectin content before ultrafiltration, the juice must be purified with enzymes. These technological processes guarantee high product yields, optimum productivity and superior quality [19].

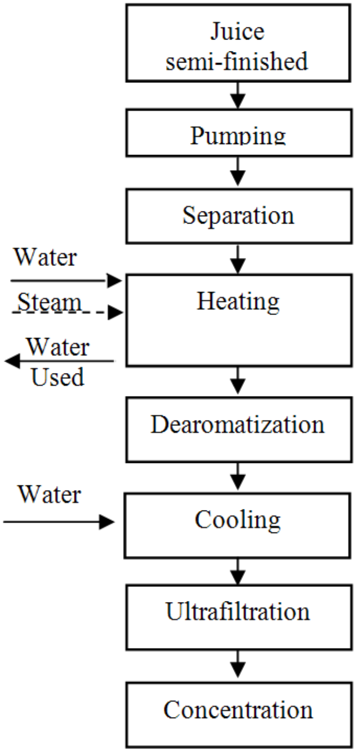

Fig. 1. Technological scheme for the production of juice from fruit raw materials using ultrafiltration

In contrast to microfiltration treatment, ultrafiltration of juices and wines eliminates not only insoluble, but also soluble substances such as pectin, starch, proteins, various condensed forms of polyphenols. Clarification of juices using ultrafiltration is widely used in industry to clarify and stabilize the quality of apple, grape, cherry, lemon, orange and other juices. For example, during ultrafiltration, 19–32% of pectin, 9.5–18.4% of protein compounds, 38.5–45.0% of colloids are removed from apple juice. Removal of high molecular weight substances from apple juice in the specified volume makes it possible to obtain clarified juice with high nutritional quality and organoleptic characteristics.

Among the advantages of using ultrafiltration for clarifying fruit and berry juices, one can single out the high quality of the purified juice, in terms of color, transparency and taste. Another advantage is the high juice extraction, which is approximately 98–99%. The processing of enzymes in ultrafiltration can be automated and costs are reduced by up to 25% of the usual. In addition, additional treatments with gelatin, bentonite and diatomaceous earth can be excluded. In addition to the listed advantages, ultrafiltration has low production costs and a hygienic design.

After ultrafiltration of juices, a certain amount of precipitation remains, containing pomace and part of the juice, but their percentage is very insignificant compared to the amounts obtained in the classical processing process. For example, for 1 ton of juice, with the classical method, 0.468 m^3 of sediment is formed, and with ultrafiltration clarification, this amount is only 0.025 m^3. Comparing the quality indicators of finished products obtained by ultrafiltration and traditional processing, it can be argued that during ultrafiltration, the content of useful substances in the clarified juice increases by an average of 10%. The clarity of the clarified juice is increased by more than 10 times. The mineral composition of the clarified juice becomes richer in comparison with that made using traditional technology.

An important positive factor of ultrafiltration clarification is the fact that membranes, retaining colloids, allow all valuable components of juices to pass through. These components include sugars, organic acids, minerals, soluble vitamins and amino acids. As a result, the nutritional and biological value of the juice does not decrease.

During the clarification process, it was found that membrane ultrafiltration practically does not change the quantitative content of alcohol, sugar, volatile acids, minerals, as well as the acidity of the medium. At the same time, the content of phenolic and nitrogenous substances decreases, which leads to the stability of the product to proteinaceous, reversible and irreversible colloidal turbidity.

To date, the dependence of the degree of clarification of apple juice in ultrafiltration membrane installations on the pore diameter of the membranes has been studied. Experimental data indicate that membranes with a pore diameter of 0.025–0.045 microns 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 large pore diameters do not allow obtaining the required degree of clarification. Membranes with smaller pores have low flow rates.

Studies have shown that ultrafiltration is a cost-effective clarification method with significant advantages over traditional clarification methods. It should be noted, however, that juices must be well prepared. Studies to determine the effect of preliminary preparation of juice on the speed and filtering capacity of ultrafiltration plants when processing apple juice have shown that the most effective treatment with enzymes followed by separation. The use of additional clarification of apple juice with gelatin and silica sol before ultrafiltration showed low efficiency.

Depending on the type of ultrafiltration unit used, the apple juice is often treated with enzymes prior to ultrafiltration and separated or filtered.

Conclusion. It has been found that ultrafiltration membranes retain colloids, while allowing all valuable juice components such as sugars, organic acids, minerals, soluble vitamins and amino acids to pass through. As a result of the use of ultrafiltration units, the food and biological value of clarified juices does not decrease.

References

1. Khulbe, K.C., Feng, C., Matsuura, T. (2010), "The art of surface modification of synthetic polymeric membranes", *Journal of Applied Polymer Science*, Vol. 115, pp. 855-895. DOI: 10.1002/app.31108.
2. Pavan, K., Neelesh, S., Rajeev, R., Sunil, K., Bhat, Z.F., Dong, K.J. (2013), "Perspective of Membrane Technology in Dairy Industry: A Review", *Asian-Australasian Journal of Animal Sciences (AJAS)*, Vol. 26(9), pp. 1347-1358. DOI: https://doi.org/10.5713/ajas.2013.13082.
3. Conidi, C., Drioli, E., Cassano, A. (2020), "Perspective of Membrane Technology in Pomegranate Juice Processing: A Review", *Foods*, Vol. 9, pp. 889-914. DOI: https://doi.org/10.3390/foods9070889.
4. Johanningsmeier, S.D., Harris, G.K. (2011), "Pomegranate as a Functional Food and Nutraceutical Source", *Annual Review of Food Science and Technology*, Vol. 2. pp. 181-201. DOI: https://doi.org/10.1146/annurev-food-030810-153709.
5. Sharifanfar, R., Mirsaeedghazi, H., Fadavi, A., Kianmehr, M.H. (2015), "Effect of feed canal height on the efficiency of membrane clarification of pomegranate juice", *Journal of Food Processing and Preservation*, Vol. 39, pp. 881-886. DOI: https://doi.org/10.1111/jfpp.12299.
6. Haci, A.G., Pelin, O.B., Ufuk, B. (2017), "Clarification of Apple Juice Using Polymeric Ultrafiltration Membranes: a Comparative Evaluation of Membrane Fouling and Juice Quality", *Food and bioprocess technology*. Vol. 10, pp. 875-885. DOI: https://doi.org/10.1007/s11947-017-1871-x.
7. Bagci, P.O. (2014), "Effective clarification of pomegranate juice: a comparative study of pretreatment methods and their influence on ultrafiltration flux", *Journal of Food Engineering*, Vol. 141, pp. 58-64. DOI: https://doi.org/10.1016/j.jfoodeng.2014.05.009.
8. 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*, Vol. 121, pp. 73-79. DOI: https://doi.org/10.1016/j.jfoodeng.2013.07.037.

9. Echavarria, A.P., Falguera, V., Torras, C., Berdun, C., Pagan, J., Ibarz, A. (2012), "Ultrafiltration and reverse osmosis for clarification and concentration of fruit juices at pilot plant scale", *LWT-Food Science and Technology*, Vol. 46(1), pp. 189-195. DOI: https://doi.org/10.1016/j.lwt.2011.10.008.

10. Gulec, H.A., Topacli, A., Topacli, C., Albayrak, N., Mutlu, M. (2010), "Modification of cellulose acetate membrane via low-pressure plasma polymerization for sugar separation applications. Part I. Membrane development and characterization", *Journal of Membrane Science*, Vol. 350(1–2), pp. 310-321. DOI: https://doi.org/10.1016/j.memsci.2010.01.006.

11. He, Y., Ji, Z., Li, S. (2007), "Effective clarification of apple juice using membrane filtration without enzyme and pasteurization pretreatment", *Separation and Purification Technology*, Vol. 57, pp. 366-373. DOI: https://doi.org/10.1016/j.seppur.2007.04.025.

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

13. Nittami, T., Hitomi, T., Matsumoto, K., Nakamura, K., Ikeda, T., Setoguchi, Y., Motoori, M. (2012), "Comparison of polytetrafluoroethylene flat-sheet membranes with different pore sizes in application to submerged membrane bioreactor", *Membranes*, Vol. 2, pp. 228–236. DOI: https://doi.org/10.3390/membranes2020228.

14. Onsekizoglu, P., Bahceci, K.S., Acar, M.J. (2010), "Clarification and the concentration of apple juice using membrane processes: a comparative quality assessment", *Journal of Membrane Science*, Vol. 352(1–2), pp. 160-165. DOI: https://doi.org/10.1016/j.memsci.2010.02.004.

15. Van der Marel, P., Zwijnenburg, A., Kemperman, A., Wessling, M., Temmink, H., van derr Meer, W. (2010), "Influence of membrane properties on fouling in submerged membrane bioreactors", *Journal of Membrane Science*, Vol. 348, pp. 66-74. DOI: https://doi.org/10.1016/j.memsci.2009.10.054.

16. Verma, S.P., Sarkar, B. (2015), "Analysis of flux decline during ultrafiltration of apple juice in a batch cell", *Food and Bioproducts Processing*, Vol. 94, pp. 147-157. DOI. https://doi.org/10.1016/j.fbp.2015.03.002.

17. Yazdanshenas, M., Tabatabaee-Nezhad, S.A.R., Soltanieh, M., Roostaazad, R., Khoshfetrat, A.B. (2010), "Contribution of fouling and gel polarization during ultrafiltration of raw apple juice at industrial scale", *Desalination*, Vol. 258(1–3), pp. 194-200. DOI: https://doi.org/10.1016/j.desal.2010.03.014.

18. Zhao, D., Lau, E., Huang, S., Moraru, C.I. (2015), "The effect of apple cider characteristics and membrane pore size on membrane fouling", *LWT-Food Science and Technology*, Vol. 64, pp. 974-979. DOI: https://doi.org/10.1016/j.lwt.2015.07.001.

19. Zuo, G.Z., Wang, R. (2013), "Novel membrane surface modification to enhance anti-oil fouling property for membrane distillation application", *Journal of Membrane Science*, Vol. 447, pp. 26-35. DOI: https://doi.org/10.1016/j.memsci.2013.06.053.

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DOI: 10.5281/zenodo.4369743

УДК 664.8.047.014

СПОСОБИ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ПРОЦЕСУ СУШІННЯ НАСІННЄВОГО ЗЕРНА

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У сучасному світі широко використовуються відновлювані джерела енергії як енергоефективний спосіб отримання електричної та теплової енергії. Поєднання сушильних технологій і відновлюваних джерел енергії реалізується через упровадження теплових насосів, що найбільш доцільно за низькотемпературного сушіння насіння зернових культур.

Розглянуто різні варіанти роботи теплового насоса для сушіння насіннєвих матеріалів. За однією з наведених схем розроблено експериментальний зразок сушильної установки з тепловим насосом із повною рециркуляцією теплоносія. Теплові насоси дають можливість ефективно використовувати теплоту довкілля для підігрівання сушильного агента і направлення в шахту сушильної установки.

Експериментальні дослідження на сушильній установці з тепловим насосом показали високі результати схожості насіння зернових культур та зменшення енергоспоживання на 36% порівняно з витратами в інших зерносушарках.

Ключові слова: *енергоефективність, тепловий насос, сушіння насіння, якість, зерносушарка.*
