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IMPROVEMENT OF ENVIRONMENTAL SUSTAINABILITY OF MILK PROCESSING ENTERPRISES

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Summary. *Sewage from milk processing enterprises remains a factor of environmental pollution. This is caused by a high concentration of organic pollutants contained in a dispersed and dissolved state, among which protein predominates. An effective way to increase the environmental friendliness of dairy enterprises is to minimize emissions of pollutants. In particular, this applies to dairies, the main products of which are protein products – cheese and casein, and the main pollutant – whey. This could be achieved through complete processing of whey. The article considers the possibility of reducing the polluting effect of wastewater from milk processing enterprises by separating dispersed protein from milk whey. The results of the study of the content and granulometric composition of dispersed whey protein are presented. The design of the filter with a self-cleaning filter element developed by the authors is presented, which allows for a continuous process of serum purification with a consistently high degree of separation.*

Key words: *purification, whey, protein, filter.*

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Statement of the problem. Wastewater from a dairy processing plant is a pollutant with a high content of organic matter. These contaminants can be in both dispersed and dissolved form. The dispersed phase consists of fats and particles of scavenged protein. For example, in cheese factories, the majority of the dispersed particles are the so-called «cheese dust» generated during production. The size of these milk protein particles is 0.2–2.0 mm [1]. In the dissolved state, it contains partially protein, organic acids and milk sugar. Another significant component is albumin, another milk protein that accounts for a significant portion of biological oxygen demand (BOD). High concentrations of organic compounds that are easily oxidised in dairy wastewater lead to a significant decrease in oxygen in water bodies. It is also known that these wastewaters are characterised by a low pH level, which is explained by the formation of acid in the process of biochemical decomposition. Large volumes of suspended solids of protein origin entering water sources cause a significant accumulation of bottom sediments, which are often subject to decay. Wastewater from casein and hard cheese production facilities poses a particularly high risk to water bodies, as it is characterised by high values of both chemical and biological oxygen consumption [2].

Evaluation of known research findings. Dairy wastewater is a suspension, where the dispersed phase is the so-called «cheese dust», which is particles of cheese grains that occur when the product grains are destroyed during mechanical processing. This suspension also includes fat globules and product particles that fall into the waste during the washing of technological equipment.

The strong polluting effect of dairy production waste is mainly due to the content of organic substances that are rapidly oxidised, in particular protein. The bulk of these substances enter the wastewater system with whey. Studies have shown that the oxidation of organic compounds contained in 25 tonnes of whey would require as much oxygen as is needed to oxidise the household waste of a city with a population of 40,000 people [3]. It

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should be borne in mind that the volumes of whey produced are quite large, especially in the production of hard cheeses, where its yield is about 90% of the volume of milk used for cheese production.

Environmental pollution from dairy processing plants becomes even more serious when whey is not sufficiently processed. As the bulk of this secondary product ends up in wastewater, it overloads treatment systems and aggravates the environmental situation in the natural environment.

One of the most effective methods of improving the environmental friendliness of dairy enterprises is to reduce pollutant emissions [4, 5]. This is especially important for dairies that produce mainly protein products such as cheese and casein, and the main source of pollution is whey.

In turn, the organisation of full whey processing, in addition to the environmental effect, can also provide a significant economic benefit. And given that whey losses in our country are at the level of 300–400 thousand tonnes per year [1], we can conclude that the dairy industry will receive additional millions of euros.

Therefore, organising whey processing is one of the main challenges facing the dairy industry.

Currently, there are many ways to process and use whey, which can be summarised into four main areas:

- use without processing;
- separation and use of its most valuable components;
- processing in the form of concentrates;
- biological processing.

The use of whey without special processing may include its use in baking bread and other bakery products.

Processing in the form of concentrates involves the production of concentrated products by drying or thickening. Today, the most common method of whey processing is drying.

A common method is to remove fat from whey using a centrifugal method such as separation. However, problems arise during the separation process due to the rapid contamination of the inter-cell space. This is due to protein particles sticking to the surface of the plates. Only with a well-organised process can a residual whey fat content of 0.05% be achieved, although this figure is usually only 0.1%. In order to successfully separate the fat from whey in a separator, it is important to first clean the whey from dispersed protein.

Whey protein can be separated in its natural form while retaining its functional properties. The main direction of development in the dairy industry in recent years has been the widespread use of membrane methods. One of the most promising membrane processes, electrodialysis, is considered to be an effective way to demineralise whey. However, the content of dispersed particles in whey leads to severe contamination of membrane surfaces, and therefore is unacceptable when using this type of treatment. Therefore, before membrane treatment of whey, it is necessary to separate the dispersed protein.

So, the first step in whey processing and whey-containing wastewater treatment is to remove dispersed protein particles.

At the request of production, scientists and engineers are working to develop modern equipment for whey purification. However, despite certain achievements, the solution to this problem has not yet been unambiguous, and the available equipment does not take into account all the differences and features of the process, which is why it can be inefficient or work effectively only under certain production conditions.

Among the latest developments in this area, it is worth noting the installation created by the specialists of the «Dubnozagatprom enterprise» [7] (Fig. 1).

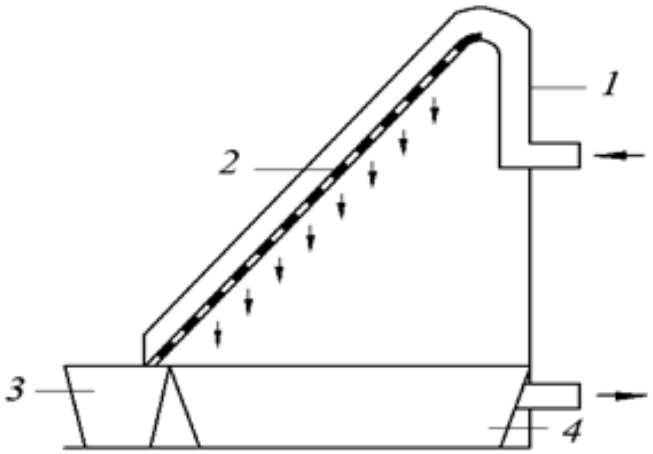

Figure 1. Scheme of the apparatus for separating protein from milk whey
1 – nozzle; 2 – filter element; 3, 4 – containers

The unit is designed to separate protein from whey used in the production of hard cheeses at enterprises of various capacities and methods of cheese mass formation. The whey is fed into the nozzle 1, from where it enters the flat stainless steel filter element 2, placed at an angle to the horizontal plane. The whey seeps through the filter holes and enters the container 4, from where it is removed from the device. The particles of the protein dispersed phase are collected in the container 3. The capacity of the device can be adjusted from 5.0 to 50 m³/h. Among the disadvantages are the lack of a filter surface regeneration system and the limited scope of application – this device is only suitable for whey obtained from the production of hard cheeses.

Objective. The objective of the study was to reduce the polluting effects of dairy processing plant wastewater by separating dispersed protein from whey.

Statement of the task. Despite the interest of many dairies, the organisation of whey purification is severely hampered by the lack of appropriate equipment that is both efficient and affordable for enterprises of different capacities.

Therefore, enterprises often use less efficient methods of whey purification, ranging from conventional straining through filter materials to the use of outdated equipment, such as vibrating sieves.

This work is aimed at reducing the pollution of wastewater from dairy processing plants. As part of this research, equipment was developed to separate dispersed protein from whey.

However, before developing such equipment, it is necessary to investigate the properties of dispersed milk protein particles. Analysing the concentration in the initial whey and their size distribution will allow for an efficient design of the protein separator. To achieve this goal, several tasks need to be performed: to determine the concentration of dispersed protein in whey, to find out the size structure of dispersed protein particles, and to develop the design of the whey purification plant.

Analysis and discussion of findings. The studies revealed that whey obtained during the production of cottage cheese has a concentration of suspended solids of 2.7 kg/m³. The results of the granulometric analysis of dispersed protein in different types of whey showed a range of protein particle sizes (diameters) from 0.23 to 1.9 mm (Fig. 2).

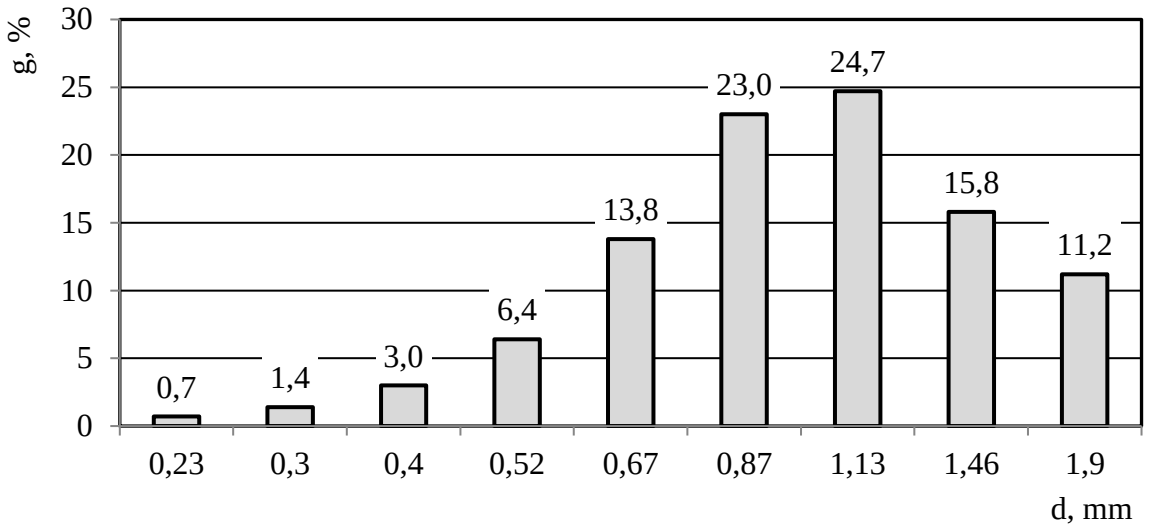

Figure 2. Granulometric composition of dispersed protein in milk whey

Based on the data obtained, it can be assumed that a significant portion of the «cheese dust» can be successfully separated from the whey by the filtration process. The obtained particle sizes of the protein indicate that a significant part of it can be separated by filtration.

The fact that the particle sizes vary widely, with about 11% of the total mass concentrated in particles with an average size of 1.9 mm, may indicate the need for a stepwise filtration of the whey. Effective purification can be achieved if the process is carried out in two stages: first, using filters for coarse purification, and then for fine purification. This approach allows for more efficient separation of particles of different particle sizes.

A histogram was used to determine the optimal size of the holes in the coarse and fine filter membranes (Fig. 3). In cases where sieves with exponentially increasing size intervals are used in studies, it is recommended to use the relative mass fraction of a certain fractional class q_i instead of the mass fraction in the histogram. This value was calculated as the ratio of the mass fraction of a particular fraction g_i to the corresponding particle size interval Δd:

$$q_i = \frac{g_i}{\Delta d_i} = \frac{g_i}{d_{i+1} - d_i}$$

Analysing the histogram (Figure 3), it is worth noting that although the mass fraction is highest for the 1.1 mm fraction (Figure 2), the relative mass fraction will be maximum for the fraction with an average size of 0.87 mm. This is important to consider when choosing a filter: the optimal range of mesh sizes for a coarse filter should be between 0.87 and 1.1 mm. Based on this, it can be assumed that up to 52% of the cheese dust will be separated on the coarse filter.

Consequently, for a fine filter, the optimal mesh size is 0.5–0.6 mm, which will allow for the separation of about 36% of the protein. It is not advisable to use filter elements with holes smaller than 0.5 mm.

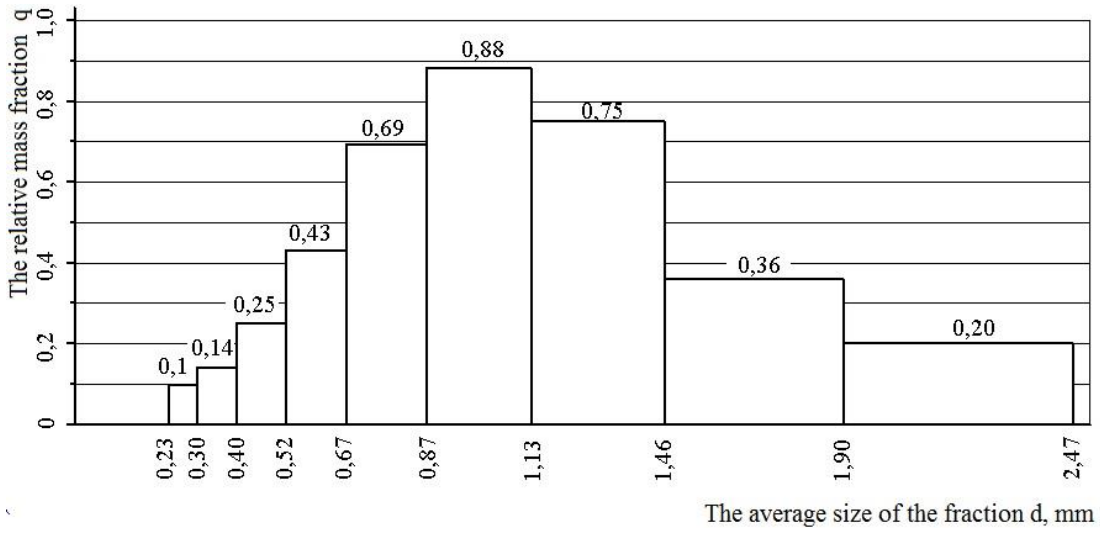

Figure 3. Histogram of dispersed protein fractions by size

Taking into account the data on the particle size distribution of dispersed protein in whey, it can be calculated that the use of the proposed installation will create opportunities for a significant reduction in the concentration of protein particles in whey (Fig. 4).

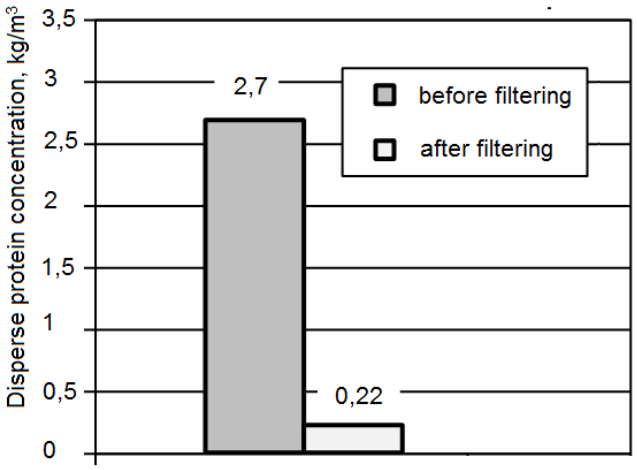

Figure 4. Concentration of dispersed protein in milk serum before and after its purification on a filter

The separation of protein from whey will lead to an impressive economic effect. It is estimated that if 100 tonnes of milk is processed into cottage cheese, the use of the proposed filter will allow approximately 240 kg of protein to be returned to the main product.

The design of the filter with a self-cleaning filter element, which guarantees continuous whey purification at a high level of separation, is an important step to ensure efficient operation in the production process [8–11].

The proposed design consists of a cylindrical body 1 (Fig. 5), nozzles 2 and 3 for whey supply and discharge, respectively, a guide cup 4, a screw 5, a cylindrical filter element 6, a movable cylindrical frame 8 and a cone 7. The serum is introduced into the housing through the nozzle 2 and passes through the cylindrical filter element 6, where the protein particles settle and are transported by the screw 5 to the bottom of the housing. The sediment is then discharged from the filter through the gap between the housing and the cone 7.

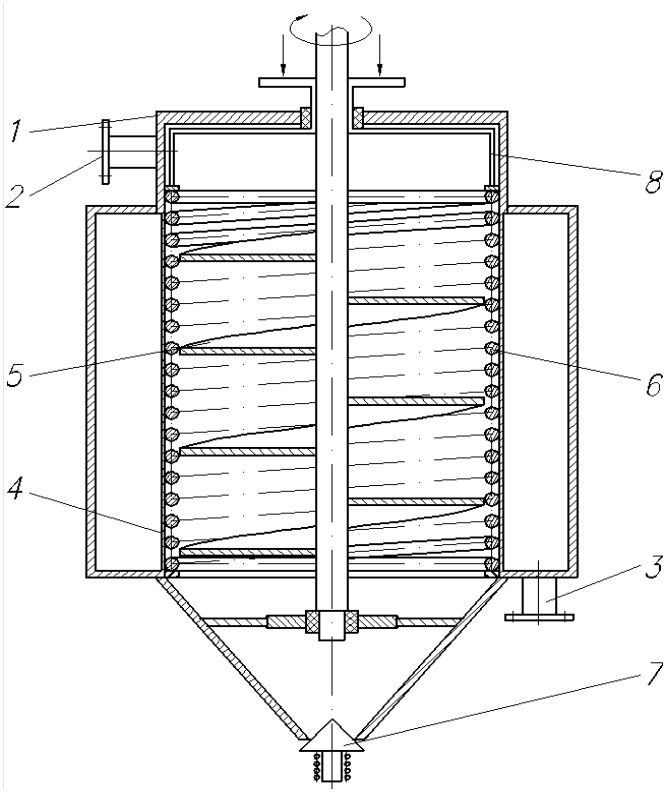

Figure 5. Filter for purification of milk whey
1 – body; 2, 3 – nozzles; 4 – guide cup; 5 – screw; 6 – filter element

The purified serum is discharged from the filter through the nozzle 3. The filter element 7 is essentially a cylindrical compression spring. Regeneration of the filter element is achieved by applying a compressive force to the spring, which reduces the size of the gaps between its individual coils and removes the protein particles in these gaps, as shown in Fig. 6.

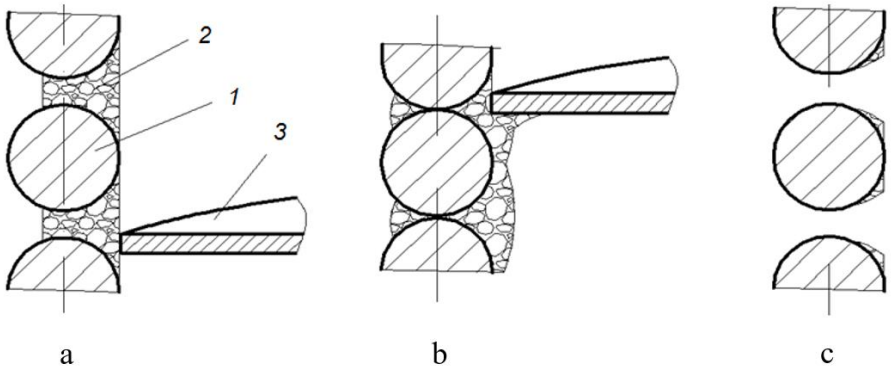

Figure 6. Scheme of operation of the self-cleaning filter element:
a) before regeneration; b) during regeneration; c) after regeneration.
1 – filter element; 2 – sediment; 3 – screw

Cleaning of the filter element takes less than 1 second and is performed simultaneously with the filter operation. Another advantage of this design is the ability to adjust the size of the of the filter element holes in the range from 0.5 to 2.0 mm. This is achieved by partially deforming the filter element.

Conclussions. Removing protein particles from whey before it is discharged into wastewater can significantly reduce the contamination level of dairy processing plant waste and reduce production costs.

Almost 80% of the protein particles in whey are concentrated in fractions with an average size greater than 0.5 mm, making it possible to use filtration to clean whey.

Effective purification can be carried out in two stages: the first for protein particles with a mean size of more than 0.9–1.0 mm, and the second for fractions with a size of about 0.5 mm.

Purification of whey with the proposed filter will improve the conditions for its further processing.

The developed filter can be used in large plants as well as in smaller plants where further processing of whey is inefficient due to small volumes.

References

1. Nair P. K, Alexander M, Dalgleish D, Corredi M. Physico-chemical properties of casein micelles in unheated skim milk concentrated by osmotic stressing: Interactions and changes in the composition of the serum phase. Food Hydrocolloids, 2014, vol. 34, pp. 46–53. https://doi.org/10.1016/j.foodhyd.2013.01.001
2. Zhao Z, Corredig M. Serum composition of milk subjected to re-equilibration by dialysis at different temperatures, after pH adjustments. Journal of Dairy Science, 2016, vol. 99, no. 4, pp. 2588–2593. https://doi.org/10.3168/jds.2015-9917
3. Kovalenko V. F., Goncharuk V. F. Ekologicheskoe sostoyanie vodnikh ekosistem Ukraini na primere reki Dnepr. Khimiya i tekhnologiya vodi, 2019, vol. 41, no. 3, pp. 278–292. [In Russian].
4. Shynkaryk M., Kravets O., Venhrynovych S. Features of pressing the juice from viburnum berries. Scientific Journal of TNTU, vol. 101, no. 1, pp. 945–101. https://doi.org/10.33108/visnyk_tntu2021.01.094
5. Shynkaryk M., Voroshchuk V., Yeresko H., Kymachynskyi S. Doslidzhennia zatrat potuzhnosti v pari rotor-stator u rotorno-vykhrovykh emulsorakh pry vyrobnytstvi kompozytsiinykh produktiv na bazi syru domashnoho. Visnyk TDTU, 2008, vol. 13, no. 2, pp. 184–190. [In Ukrainian].
6. Fedotov A. V., Grigorev V. S., Svittsov A. A. Ochistka i kontsentrirovanie stochnikh vod, soderzhashchikh organicheskie veshchestva, sorbtsiei v sochetanii s mikrofiltratsiei. Khimiya i tekhnologiya vodi, 2018, vol. 40, no. 5 (265), pp. 564–572. [In Russian].
7. Pribolotnii A. V. Pervichnaya obrabotka sivorotki, ili kak zarabotat na nei dengi. Molochnaya promishlennost, 2009, no. 6, pp. 23–24. [In Russian].
8. Shynkaryk M., Voroshchuk V., Kravets O., Krupa O., Zvarych N. Heat exchange in a chamber apparatus with a circulation circuit during cheese masses production. Scientific Journal of TNTU, 2022, vol. 108, no. 4, pp. 43–53. https://doi.org/10.33108/visnyk_tntu2022.04.043
9. Kravets O. I., Shynkaryk M. M. Filtr iz samoochysnym filtruvalnym elementom dlia ochystky molochnoi syrovatky. Naukovyi zhurnal “Internauka”, 2021, no. 3 (103), pp. 58–61.
10. Shynkaryk M. M., Kravets O. I. Dekl. pat. na kor. mod. 22756 Ukrainy, MPK B 01 D 35/28. Filtr dlia viddilennia molochnoho bilka vid syrovatky; zaiavnyk i vlasnyk Ternopilskyi nats. tekh. un. im. I.Puliuia. zaiavl. 20.12.06; opubl. 25.04.07, Biul. № 5.
11. Shynkaryk M. M., Kravets O. I., Shynkaryk M. V. Pat. na kor. mod. 77749 Ukrainy, MPK B 01 D 35/28. Filtr dlia ochystky molochnoi syrovatky vid syrnoho pylu; zaiavnyk i vlasnyk Ternopilskyi nats. tekh. un. im. I.Puliuia. zaiavl. 14.08.12; opubl. 25.02.13, Biul. № 5.

Список використаних джерел

1. Nair P. K, Alexander M, Dalgleish D, Corredi M. Physico-chemical properties of casein micelles in unheated skim milk concentrated by osmotic stressing: Interactions and changes in the composition of the serum phase. Food Hydrocolloids. 2014. Vol. 34. P. 46–53. https://doi.org/10.1016/j.foodhyd.2013.01.001
2. Zhao Z, Corredig M. Serum composition of milk subjected to re-equilibration by dialysis at different temperatures, after pH adjustments. Journal of Dairy Science. 2016. Volume 99. Issue 4. P. 2588–2593. https://doi.org/10.3168/jds.2015-9917
3. Коваленко, В. Ф., Гончарук В. В. Экологическое состояние водных экосистем Украины на примере реки Днепр. Химия и технология воды. 2019. Т. 41. № 3. С. 278–292.
4. Shynkaryk M., Kravets O., Venhrynovych S. Features of pressing the juice from viburnum berries. Scientific Journal of TNTU. 2021. Vol. 101. No. 1. P. 945–101. https://doi.org/10.33108/visnyk_tntu2021.01.094
5. Шинкарик М., Ворощук В., Єресько Г., Кимачинський С. Дослідження затрат потужності в парі ротор-статор у роторно-вихрових емульсорах при виробництві композиційних продуктів на базі сиру домашнього. Вісник ТДТУ. 2008. Том 13. № 2. С. 184–190.

6. Федотов А. В., Григорьев В. С., Свитцов А. А. Очистка и концентрирование сточных вод, содержащих органические вещества, сорбцией в сочетании с микрофильтрацией. Химия и технология воды. 2018. Т. 40. № 5 (265). С. 564–572.
7. Приболотный А. В. Первичная обработка сыворотки, или как заработать на ней деньги. Молочная промышленность. 2009. № 6. С. 23–24.
8. Shynkaryk M., Voroshchuk V., Kravets O., Krupa O., Zvarych N. Heat exchange in a chamber apparatus with a circulation circuit during cheese masses production. Scientific Journal of TNTU. 2022. Vol. 108. No. 4. P. 43–53. https://doi.org/10.33108/visnyk_tntu2022.04.043
9. Кравець О. І., Шинкарик М. М. Фільтр із самоочисним фільтрувальним елементом для очистки молочної сироватки. Науковий журнал «Інтернаука». 2021 р. № 3 (103). С. 58–61.
10. Фільтр для відділення молочного білка від сироватки : декл. пат. на кор. мод. 22756 України, МПК B 01 D 35/28 ; заявник і власник Тернопільський нац. тех. ун. ім. І.Пулюя. заявл. 20.12.06 ; опубл. 25.04.07, Бюл. № 5.
11. Фільтр для очистки молочної сироватки від сирного пилу : пат. на кор. мод. 77749 України, МПК B 01 D 35/28 ; заявник і власник Тернопільський нац. тех. ун. ім. І.Пулюя. заявл. 14.08.12 ; опубл. 25.02.13, Бюл. № 5.

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ПІДВИЩЕННЯ ЕКОЛОГІЧНОСТІ МОЛОКОПЕРЕРОБНИХ ПІДПРИЄМСТВ

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Резюме. *Стічні води молочного виробництва залишаються істотним чинником забруднення навколишнього середовища. Це зумовлено високим умістом органічних забруднювачів, що містяться у сироватці в дисперсному та розчиненому станах. Серед цих забруднювачів переважає молочний білок. Потрапляння у водойми значних кількостей речовин білкового походження у дисперсному вигляді призводить до накопичення донних відкладів, для яких є властивими процеси гниття. Найбільшою загрозою для водойм є стоки виробництва твердих сирів і казеїну, що характеризуються значними показниками хімічного та біологічного споживання кисню. Дієвим способом підвищення екологічності молокопереробних підприємств є зменшення викидів забруднюючих речовин. Це поширюється на молокопереробних заводах, серед основних продуктів яких є сир та казеїн, а основним забруднювачем – молочна сироватка. Одним із способів досягнення цього є організація повної переробки сироватки. Передувати існуючим способам перероблення сироватки має її очищення від дисперсного білка. Проте на даний час немає єдиного підходу до подолання цієї проблеми, а в існуючому обладнанні не враховано усіх особливостей об'єкта очищення, а тому часто є неефективним. В таких умовах актуальними є дослідження властивостей об'єкта очищення, зокрема таких, як уміст та гранулометричний склад дисперсних часток білка в сироватці та розроблення на основі отриманих експериментальних даних обладнання для її очищення. Розглянуто можливість зниження негативного впливу стічних вод молокозаводів на навколишнє середовище шляхом відділення дисперсного білка з сироватки. Наведено результати дослідження концентрації та гранулометричного складу дисперсного білки в молочній сироватці. Представлено запропоновану конструкцію фільтра із самоочисним фільтрувальним елементом, використання якого дозволить проводити безперервний процес очищення молочної сироватки при постійному та високому ступені розділення. Запропоновані заходи дозволять не тільки зменшити забруднюючу здатність відходів молоточного виробництва, а й знизити затрати сировини на виробництво готового продукту за рахунок повернення відділеного в процесі очищення сироватки білка у виробничий процес.*

Ключові слова: *очистка, фільтрування, молочна сироватка, білок.*

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