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ULTRAFILTRATION AS A BARRIER METHOD FOR MICROPLASTIC REMOVAL FROM SURFACE WATERS

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The article addresses the problem of surface water contamination by microplastics caused by the intensive use of polymeric materials and their accumulation in the natural environment. It is shown that microplastic particles can persist in water bodies for long periods, adsorb and transport toxic impurities, and negatively affect aquatic ecosystems and drinking water quality, creating additional risks for centralized and local water supply systems and necessitating the improvement of modern water treatment technologies.

Modern approaches to the purification of surface waters from fine-dispersed polymer particles are analyzed, and the limitations of conventional water treatment methods are identified, as they do not ensure stable microplastic removal across a wide particle-size range and under variable source water quality conditions. The feasibility of applying membrane technologies, particularly ultrafiltration, as an effective barrier purification method capable of providing selective separation of the flow and stable treated water quality is substantiated.

A conceptual technological scheme for multistage surface water treatment has been developed, including mechanical pretreatment, reagent conditioning, an ultrafiltration membrane unit, sorption polishing, and ultraviolet disinfection. The main technological parameters of the treatment process determining productivity, hydraulic stability, and operational reliability of the membrane system were evaluated. It is shown that the application of ultrafiltration ensures removal of more than 95% of microplastics, reduction of treated water turbidity to values below 0.1 NTU, and specific energy consumption within 0.10–0.22 kWh/m³ of permeate. It was established that combining membrane separation with preliminary reagent treatment reduces membrane loading, decreases fouling intensity, and improves operational stability.

It is concluded that membrane technologies are advisable for use in surface water treatment schemes and can be applied in the modernization of existing water treatment plants as well as in the development of modular local water purification units providing predictably stable permeate quality.

Key words: *microplastics, surface waters, membrane technologies, ultrafiltration, water treatment, drinking water quality, membrane processes, barrier treatment, water supply.*

Коваленко Р. Ю. Ультрафільтрація як бар'єрний метод видалення мікропластику з поверхневих вод

У статті розглянуто проблему забруднення поверхневих вод мікропластиком, що зумовлена інтенсивним використанням полімерних матеріалів та їх накопиченням у природному середовищі. Показано, що мікропластикові частинки здатні тривалий час зберігатися у водних об'єктах, адсорбувати та переносити токсичні домішки, а також негативно впливати на водні екосистеми і якість питної води, що створює додаткові ризики для систем централізованого та локального водопостачання і обумовлює необхідність удосконалення сучасних технологій водопідготовки.

Проаналізовано сучасні підходи до очищення поверхневих вод від дрібнодисперсних полімерних частинок та встановлено обмеження традиційних методів водоочищення, які не забезпечують стабільного вилучення мікропластику у широкому діапазоні розмірів частинок та за змінної якості вихідної води. Обґрунтовано доцільність застосування

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мембранних технологій, зокрема ультрафільтрації, як ефективного бар'єрного методу очищення, здатного забезпечувати селективне розділення водного потоку та стабільну якість очищеної води.

У роботі розроблено принципову технологічну схему багатоступеневого очищення поверхневої води, що включає механічне попереднє очищення, реагентну обробку, ультрафільтраційний мембранний блок, сорбційне доочищення та ультрафіолетове знезараження. Виконано оцінювання основних технологічних параметрів процесу очищення, що визначають продуктивність, гідравлічну стабільність та експлуатаційну надійність мембранної системи, і показано, що застосування ультрафільтрації забезпечує видалення понад 95 % мікропластику, зниження мутності очищеної води до значень менше 0,1 NTU та питомі енерговитрати в межах 0,10–0,22 кВт·год/м³ пермеату. Встановлено, що поєднання мембранного розділення з попередньою реагентною обробкою зменшує навантаження на мембрани, знижує інтенсивність фаулінгу та підвищує стабільність роботи установки.

Зроблено висновок про доцільність використання мембранних технологій у схемах очищення поверхневих вод, а також про можливість їх застосування під час модернізації існуючих станцій водопідготовки та створення модульних установок локального водоочищення з прогнозовано стабільною якістю пермеату.

Ключові слова: *мікропластик, поверхневі води, мембранні технології, ультрафільтрація, водопідготовка, очищення води, якість води, мембранні процеси, бар'єрне очищення, водопостачання.*

Introduction. Surface water contamination by microplastics is one of the most pressing environmental problems of modern times, caused by the intensive use of polymeric materials and their long-term persistence in the natural environment [1,2]. Microplastic particles can accumulate in water bodies, adsorb and transport toxic substances, and negatively affect aquatic ecosystems and drinking water quality [1]. In this regard, their removal from natural water sources has become an important task for ensuring environmental safety and the reliability of water supply systems.

Particular concern is associated with the entry of microplastics into centralized water supply sources, since conventional water treatment methods do not ensure sufficient removal of fine-dispersed polymer particles, especially across a wide particle-size range [3]. This necessitates the improvement of existing technological approaches and the search for effective solutions for removing microplastics from surface waters.

One of the promising approaches to improving water purification efficiency is the application of membrane technologies, particularly ultrafiltration, which makes it possible to create a reliable barrier for suspended particles, colloidal impurities, and microorganisms [4]. Membrane processes provide selective flow separation and can be used as a key stage in modern multistage water treatment schemes.

Therefore, investigating the potential application of membrane systems and developing technological schemes for surface water treatment using ultrafiltration, as well as evaluating their technological efficiency and operational parameters in microplastic removal, is of considerable relevance.

Analysis of Recent Research and Publications. In recent years, the problem of microplastic contamination of aquatic ecosystems has attracted considerable attention from researchers due to its persistence in the natural environment and its potential impact on environmental safety and public health [2,5]. Studies indicate that microplastics are widely distributed in surface waters, and their concentration in water supply sources may reach thousands of particles per liter [6,7], which confirms the need to improve water treatment technologies.

Scientific publications report that conventional water treatment methods (coagulation, sedimentation, sand filtration) do not ensure complete removal of fine-dispersed polymer particles, especially in the micro- and nanoscale ranges [8,9]. Therefore, modern barrier treatment methods are being actively investigated, among which membrane technologies occupy a leading position [4].

Studies devoted to the application of membrane processes have shown that microfiltration, ultrafiltration, and membrane bioreactors can provide very high microplastic removal efficiency, which in some cases reaches 99–100% [4,10]. Research also confirms that the size of most microplastic particles exceeds the pore size of ultrafiltration membranes, making this method effective for their retention [3,4].

Individual experimental studies demonstrate that membrane installations are capable of ensuring effective purification of natural and river waters from microplastics while simultaneously reducing turbidity and suspended solids [11,12]. At the same time, researchers note a number of technological challenges, in particular the possibility of membrane fouling and an increase in transmembrane pressure due to the accumulation of microplastic particles in the feed water [4,10].

Recent studies also consider new composite and modified membranes capable of increasing selectivity and reducing fouling effects, which opens prospects for the wide application of membrane technologies in water supply systems and local water purification [4].

Thus, the analysis of scientific sources indicates the high efficiency of membrane technologies in removing microplastics from water and confirms the feasibility of further research into their application in surface water treatment schemes.

The aim of this study is to provide a scientific justification for the application of membrane technologies for the removal of microplastics from surface waters and to evaluate their technological efficiency within modern water treatment systems.

Materials and Methods. The study materials included data on the current state of surface water contamination by microplastics, hydrochemical parameters of natural water supply sources, as well as analytical and calculation materials obtained during the qualification study devoted to substantiating membrane water treatment technology.

The study considered a water treatment process scheme involving multistage purification of surface water using mechanical pretreatment, coagulation treatment, and an ultrafiltration membrane unit. Hollow-fiber ultrafiltration membranes were investigated as the primary barrier for microplastic removal, capable of retaining suspended and colloidal particles through selective flow separation.

The methodological framework of the study included analytical, comparative, and engineering calculation methods. The analytical method was applied to summarize scientific sources concerning the distribution of microplastics in the aquatic environment and modern methods for their removal. Comparative analysis was used to evaluate the efficiency of membrane technologies in comparison with conventional water treatment methods.

Engineering calculation methods were used to determine the key parameters of the ultrafiltration process, including hydraulic loading, membrane module productivity, membrane surface area, and specific energy consumption of the installation. Treatment efficiency was evaluated based on indicators such as turbidity reduction, suspended solids concentration, and the estimated content of microplastic particles in the permeate.

The obtained results were generalized taking into account regulatory requirements for drinking water quality and current technological recommendations for the operation of membrane water treatment systems [4].

Results. As a result of the conducted study, a technological scheme for surface water purification from microplastics using membrane ultrafiltration was developed, providing multistage removal of suspended and colloidal impurities and forming a stable barrier effect for fine-dispersed polymer particles. The conceptual scheme of the treatment unit is shown in Fig. 1.

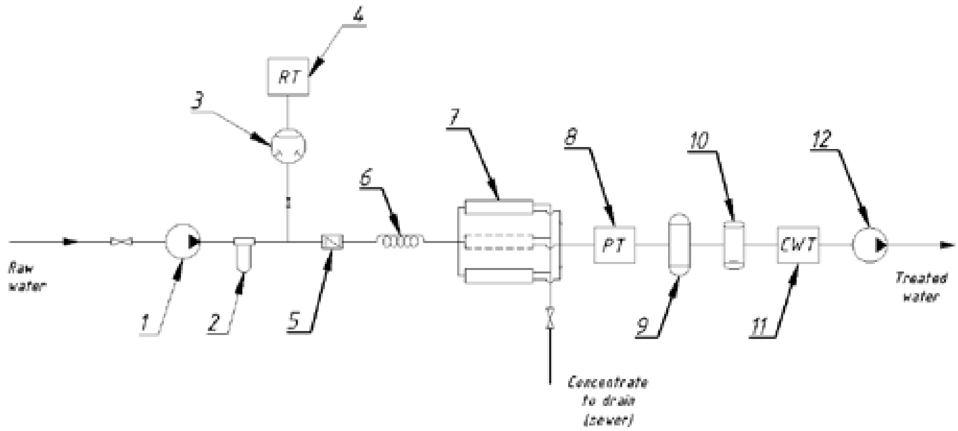

Fig. 1. Conceptual technological scheme of the surface water treatment unit using ultrafiltration: 1 – feed pump; 2 – mechanical filter; 3 – dosing pump; 4 – reagent tank; 5 – static mixer; 6 – contact tubular reactor; 7 – ultrafiltration unit; 8 – permeate buffer tank; 9 – sorption column; 10 – ultraviolet reactor; 11 – clean water tank / supply; 12 – clean water supply pump

The technological process involves pumping raw water into the mechanical pretreatment system, where coarse particles are removed in a mechanical filter. The application of the pretreatment stage makes it possible to reduce the load on subsequent elements of the technological scheme and to ensure more stable hydraulic operating conditions of the membrane equipment. To increase the efficiency of subsequent membrane separation, reagent dosing from the reagent tank is provided using a dosing pump, followed by mixing in a static mixer and a contact tubular reactor, which ensures enlargement of suspended particles, partial aggregation of colloids, and improves the conditions for their retention on the membrane surface.

The main element of the technological scheme is the ultrafiltration unit, in which barrier flow separation occurs with the formation of permeate and concentrate. The membrane process ensures retention of microplastic particles, colloids, microorganisms, and suspended solids due to membrane pore selectivity, formation of a dynamic filtration layer, and the pressure difference across the membrane surface [4]. The efficiency of the ultrafiltration unit is determined by the quality of preliminary water preparation, hydraulic loading, filtration regime, and the degree of membrane fouling [4]. The concentrate is discharged into the drainage system, while the purified water is accumulated in the permeate buffer tank, which allows stabilization of the hydraulic supply regime to subsequent treatment stages.

To ensure stable treated water quality, the scheme includes additional polishing in a sorption column, where residual organic impurities and coagulation products are removed, as well as disinfection in an ultraviolet reactor. After that, the water enters the clean water tank and is supplied to the water distribution system by a supply pump, ensuring the required operational parameters of the system.

The calculated operating parameters of the ultrafiltration unit indicate that the application of membrane technology makes it possible to ensure effective removal of fine-dispersed impurities and microplastic particles from surface waters. The calculated parameters of the technological scheme show that ultrafiltration can provide removal of more than 95% of microplastics, reduction of treated water turbidity to values below 0.1 NTU, and specific energy consumption within 0.10–0.22 kWh/m³ of permeate. These indicators meet modern requirements for the efficiency of membrane water treatment systems and confirm the technical feasibility of using ultrafiltration as the main barrier treatment stage. The obtained results are consistent with previous studies reporting high efficiency of ultrafiltration for microplastic removal [4].

The use of preliminary coagulation treatment and a multistage purification scheme reduces membrane loading, improves the operational stability of the installation, decreases the rate of transmembrane pressure growth, and increases the duration between cleaning cycles. The proposed technological scheme can be applied during the reconstruction of existing water treatment plants as well as for the development of modular surface water treatment units in centralized and local water supply systems.

Conclusions. The analysis of modern scientific studies has shown that microplastics are a widespread contaminant of surface waters, while conventional water treatment technologies do not ensure sufficient removal efficiency, which substantiates the need for barrier purification methods.

In this study, a conceptual technological scheme for surface water treatment was scientifically substantiated and developed, combining mechanical pretreatment, reagent conditioning, an ultrafiltration membrane unit, sorption polishing, and ultraviolet disinfection, ensuring comprehensive removal of suspended and colloidal impurities and forming an effective barrier for microplastic retention.

The obtained calculated parameters confirm that the application of ultrafiltration ensures removal of more than 95% of microplastics, reduction of treated water turbidity to values below 0.1 NTU, and specific energy consumption within 0.10–0.22 kWh/m³ of permeate.

It was established that the use of preliminary coagulation treatment and a multistage purification scheme reduces the load on membrane elements, improves the operational reliability of the installation, and increases the duration of its continuous operation.

The proposed technological solution can be applied during the modernization of existing water treatment plants as well as in the development of modular surface water treatment units for centralized and local water supply systems.

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