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A METHOD FOR COLLECTING AND DISPOSING OF PETROLEUM PRODUCTS USING POLYURETHANE SORBENTS

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Abstract — Environmental pollution by petroleum products represents a critical global challenge, necessitating the development of efficient, sustainable, and reusable remediation technologies. Sorption is widely recognized as one of the most environmentally friendly methods for oil spill cleanup. This review article provides a comprehensive analysis of polyurethane (PU) sorbents, focusing on their structural morphology, sorption capacity, and performance under varying environmental conditions. We examine recent advancements in patent developments, ranging from basic porous architectures to nanomodified matrices and stimuli-responsive "smart" sorbents. Furthermore, the article evaluates the trade-offs between mechanical strength, sorption efficiency, and reusability, while addressing the challenges of scaling laboratory prototypes to real-world industrial applications. The study highlights the role of polyurethane sorbents in promoting a circular economy and outlines future research trajectories, including the shift toward bio-based synthesis and integrated autonomous collection systems.

Keywords — polyurethane sorbents; oil spill remediation; circular economy; environmental protection; nanomodified materials; sorption capacity; sustainable development.

ПОЛИУРЕТАНДЫ СОРБЕНТТЕРДІ ПАЙДАЛАНА ОТЫРЫП, МҰНАЙ ӨНІМДЕРІН ЖИНАУ ЖӘНЕ КӘДЕГЕ ЖАРАТУ ӘДІСІ

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Абстракт — Мұнай өнімдерімен қоршаған ортаның ластануы - тиімді, тұрақты және қайта пайдалануға болатын тазарту технологияларын дамытуды талап ететін ең өткір жаһандық экологиялық мәселелердің бірі. Сорбция әдісі мұнай төгінділерін жоюдың экологиялық қауіпсіз тәсілдерінің бірі ретінде танылған. Бұл шолу мақаласында полиуретанды (ПУ) сорбенттерге, олардың құрылымдық морфологиясына, сорбциялық сыйымдылығына және қоршаған ортаның әртүрлі жағдайларындағы өнімділігіне кешенді талдау жасалған. Біз патенттік әзірлемелердегі соңғы жетістіктерді: қарапайым кеуекті құрылымдардан бастап наномодификацияланған матрицаларға және сыртқы әсерлерге жауап беретін «ақылды» сорбенттерге дейін қарастырамыз. Сонымен қатар, мақалада механикалық беріктік, сорбция тиімділігі мен қайта пайдалану мүмкіндігі арасындағы тепе-теңдік бағаланады, сондай-ақ зертханалық прототиптерді өнеркәсіптік ауқымға дейін ұлғайту мәселелері талқыланады. Жұмыс полиуретанды сорбенттердің айналым экономикасын (circular economy) дамытудағы рөлін көрсетеді және биологиялық негіздегі синтезге көшу мен автономды жинау жүйелеріне интеграциялауды қоса алғанда, зерттеудің перспективалық бағыттарын айқындайды.

Кілт сөздер — полиуретанды сорбенттер; мұнай төгінділерін жою; айналым экономикасы; қоршаған ортаны қорғау; наномодификацияланған материалдар; сорбциялық сыйымдылық; орнықты даму.

МЕТОД СБОРА И УТИЛИЗАЦИИ НЕФТЕПРОДУКТОВ С ИСПОЛЬЗОВАНИЕМ ПОЛИУРЕТАНОВЫХ СОРБЕНТОВ

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Аннотация — Загрязнение окружающей среды нефтепродуктами остается одной из наиболее острых глобальных экологических проблем, требующей разработки эффективных, устойчивых и многообразных технологий очистки. Метод сорбции признан одним из наиболее экологически безопасных способов ликвидации разливов нефти. В данной обзорной статье представлен комплексный анализ полиуретановых (ПУ) сорбентов, с особым вниманием к их структурной морфологии, сорбционной емкости и характеристикам в различных условиях окружающей среды. Мы рассматриваем последние достижения в области патентных разработок - от базовых пористых структур до наномодифицированных матриц и «умных» сорбентов, реагирующих на внешние раздражители. Кроме того, в статье оценивается баланс между механической прочностью, эффективностью сорбции и возможностью повторного использования, а также рассматриваются проблемы масштабирования лабораторных прототипов для промышленного применения. Работа подчеркивает роль полиуретановых сорбентов в развитии экономики замкнутого цикла и определяет перспективные направления исследований, включая переход к синтезу на биологической основе и интеграцию в автономные системы сбора.

Ключевые слова — полиуретановые сорбенты; ликвидация разливов нефти; экономика замкнутого цикла; охрана окружающей среды; наномодифицированные материалы; сорбционная емкость; устойчивое развитие.

MAIN PROVISION

The study demonstrated that polyurethane-based sorbent architectures achieve high oil sorption capacities ranging typically from 18 to 22 g/g, with specialized low-density formulations ($<20 \text{ kg/m}^3$) reaching up to 50 g of oil per 1 g of material.

Polyurethane matrices exhibit high operational stability and structural retention, maintaining effective sorption performance across at least 10 mechanical regeneration cycles (pressing/extraction) without significant loss of absorption efficiency.

Optimization of structural morphology -specifically the formation of a bimodal porous network combining macropores ($>100 \text{ }\mu\text{m}$) for rapid absorption and micropores ($<10 \text{ }\mu\text{m}$) for retention-significantly accelerates hydrocarbon uptake kinetics and selective retention over water.

The incorporation of natural fillers, such as rice or buckwheat husks up to 60 wt%, reinforces the mechanical strength of the polyurethane matrix while preserving high oil capacities of up to 40 g/g in granular formats.

The proposed collection and disposal method enables chemical-free remediation and circumvents high-temperature thermal incineration, making it a reusable, circular-economy-compliant solution for both freshwater and sub-zero marine environments.

INTRODUCTION

Environmental pollution by petroleum products remains one of the most urgent environmental problems. According to the International Tanker Owners Pollution Federation (ITOPF, 2023), up to 10,000 oil spills are recorded worldwide each year, 70% of which affect aquatic ecosystems. The economic damage from such accidents is enormous: for example, the elimination of the consequences of the spill on the Deepwater Horizon platform cost \$ 65 billion. Oil spills also pose a threat to biodiversity, the sustainability of marine and freshwater ecosystems, as well as the safety of drinking water and food chains [1]. Modern methods of eliminating oil pollution include mechanical removal, the use of dispersants, combustion and sorption. Of these, the sorption method is recognized as the most environmentally friendly and universal [4].

The scientific community is paying more and more attention to the development of new generations of sorbents: textile, biodegradable, nanomodified, magnetic and superhydrophobic. Studies have shown that the use of natural materials (cellulose, coconut fibers, sphagnum) after chemical modification provides efficiency comparable to synthetic analogues with a smaller ecological footprint [2-3].

Research Gap.

Although numerous studies have reported synthetic sorbents with high initial oil absorption capacities, the systematic integration of structural modification, cyclic mechanical recovery, and circular lifecycle management remains insufficiently investigated. Existing literature predominantly focuses on pristine laboratory prototypes operating in idealized static conditions, leaving critical questions unanswered regarding pore-collapse mechanisms under cyclic compression, selective phase separation in turbulent oil-water emulsions, and low-temperature kinetic performance. Furthermore, a coherent synthesis bridging patented technological advances (such as bimodal open-cell tailoring and bio-filler reinforcement) with practical scalable manufacturing and non-thermal regeneration is currently lacking. This study fills these gaps by analyzing the direct correlation between microstructural architecture and multi-cycle durability, providing a consolidated framework for sustainable PU sorbent deployment.

Scientific Novelty.

This study provides a unified comparative assessment that directly correlates specific microcellular parameters particularly the synergy between macroporous transport conduits ($>100 \text{ }\mu\text{m}$) and microporous retention cells ($<10 \text{ }\mu\text{m}$) with multi-cycle mechanical pressing resilience and operational longevity across diverse hydrocarbon grades. For the first time, this work integrates an analytical patent-landscape evaluation with technical performance benchmarks to establish quantitative trade-offs between chemical hydrophobization, natural byproduct incorporation (such as agricultural biomass up to 60 wt%), and non-thermal regeneration efficiency. It extends conventional sorbent research by identifying

the precise mechanical and thermodynamic boundaries required to retain up to 90% sorption capacity over 10 consecutive cycles without generating toxic secondary emissions. The scientific value lies in establishing an actionable structural-property guideline for engineering low-cost, bio-augmented polyurethane matrices ready for industrial transition within a circular economy framework.

LITERATURE REVIEW

Foamy (porous) sorbents: They are porous materials that have many micropores and macropores. This allows them to effectively absorb liquids and gases.

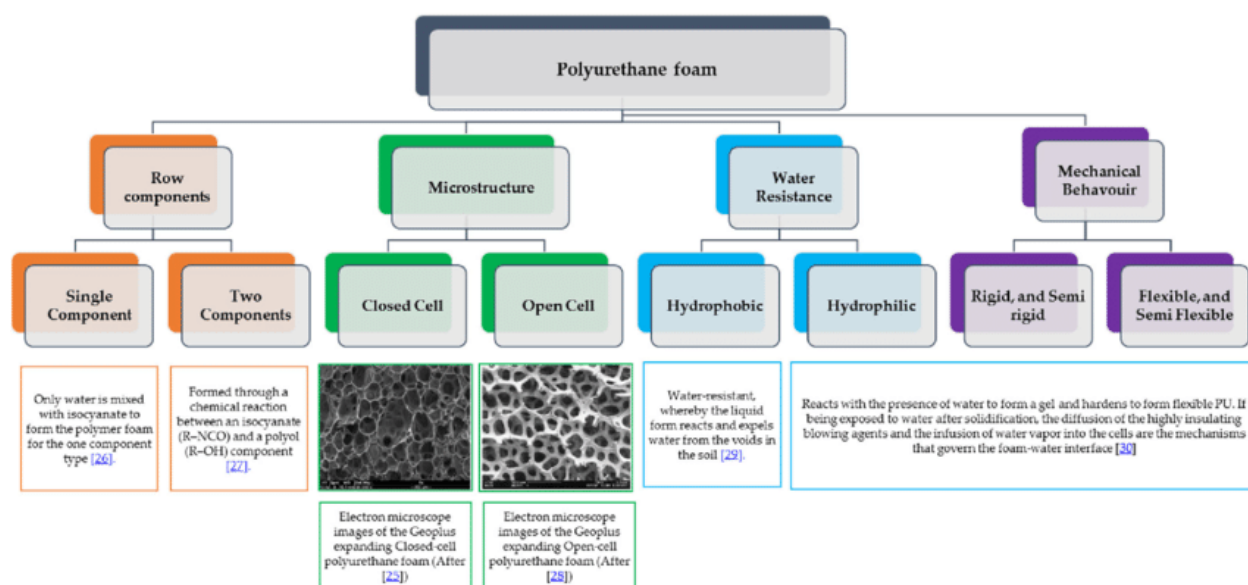


Figure 1 – Types and main characteristics of polyurethane foam materials [5].

Powder sorbents: These are materials consisting of polyurethane powder or granules that are used to adsorb pollutants.

Film sorbents: Used for surface treatment or filtration, have a thin film structure.

Granular sorbents: Polyurethane granules that can be used to remove various pollutants from water or air.

Amorphous sorbents: These are materials without a well-defined crystal structure. They can absorb large amounts of liquid, as they have a disordered porous structure.

Crystalline sorbents: They have an organized structure that limits their absorption capacity, but they can be more stable and durable under certain conditions.

Microporous sorbents: They have small-diameter pores that are capable of adsorbing small molecules.

Mesoporous sorbents: Medium-sized pores suitable for capturing larger molecules.

Macroporous sorbents: With a large pore diameter that absorb molecules with a larger molecular weight.

Currently, various technologies are used to eliminate oil spills:

Mechanical methods: booms, skimmers, vacuum installations.

Chemical methods: dispersants, coagulants.

Biological methods: the use of microorganisms for biodegradation.

Sorption methods: the use of sorbents of various origins (organic, inorganic, synthetic).

Each of these methods has its advantages and disadvantages. For example, mechanical means are effective only under certain conditions, chemical reagents can be toxic, and biological purification requires a long time. Among sorption materials, polyurethane sorbents with high absorption capacity attract special attention.

Table 1 – Table of comparative parameters of oil collection and utilization methods.

Method	Effectiveness	Cost	Environmental friendliness
Mechanical	Medium	High	Neutral
Chemical	High	Low	Toxic
Biological	Low	Medium	Safe
Polyurethane	High	Medium	Safe

Despite the widespread use of traditional methods of oil spill response, their use is associated with a number of significant limitations. In particular, the effectiveness of most technologies is significantly reduced in conditions of high seas and low

temperatures, which limits their use in marine and Arctic regions [6]. In addition, the high cost of chemicals and specialized equipment makes it difficult to implement them into

operational environmental programs, especially in hard-to-reach

areas [7]. An equally important factor is the likelihood of secondary environmental pollution by processed products resulting from the use of chemical and thermal methods. It should also be noted the duration and energy intensity of the recycling process of collected petroleum products, which reduces the overall effectiveness of emergency rescue measures and requires additional logistical and financial resources [8]. These disadvantages emphasize the need to develop new solutions, in particular, the use of polyurethane sorbents, which demonstrate high efficiency and environmental friendliness.

MATERIALS AND METHODS

The patented method of collecting and disposing of petroleum products is based on the use of polyurethane sorbents with high sorption capacity, resistance to repeated use, as well as ease of handling and environmental safety. The sorbents used are characterized by a developed porous structure, which ensures effective absorption of oil and petroleum products from the water surface even in difficult climatic conditions. The process includes immersion of the sorbent in the contamination zone, mechanical extraction and subsequent extraction in order to extract oil, after which the material can be reused. Modern research confirms that modified polyurethane compositions retain their performance properties at low temperatures and at high salinity, and also allow up to 10 regeneration cycles without significantly reducing efficiency. Such characteristics make this approach particularly promising for use in emergency situations, including remote and hard-to-reach regions, as well as within the framework of a sustainable development strategy and a circular economy.

For a more detailed analysis of the effectiveness of the patented method, it is advisable to consider its comparative advantages over existing technologies. First of all, polyurethane sorbents can significantly reduce the total oil spill response time compared to biological and chemical methods, which is especially important in rapid response conditions. An important advantage is economic efficiency: the possibility of repeated use of sorbents significantly reduces the cost of both consumables and waste disposal. In addition, the proposed method does not require the use of toxic chemicals, so its impact on the environment is minimal, which makes it preferable from the point of view of environmental safety.

RESULTS AND DISCUSSION

In recent years, sorption purification methods using polyurethane materials have received

significant development, which is reflected in numerous patent developments.

However, the practical application of polyurethane (PU) sorbents faces significant limitations, among which it should be noted low selectivity when working with oil-water emulsions, gradual degradation of the structure during multiple regeneration cycles, as well as a pronounced dependence of efficiency on external conditions - temperature, salinity of water and degree of turbulence. Within the framework of this review article, special attention is paid to the analysis of experimental data presented in modern patent solutions, which makes it possible to identify the main areas of improvement of PU sorbents. Modern research demonstrates three key areas of modification: optimization of the porous architecture by creating a bimodal structure with a combination of macropores (>100 microns) for rapid absorption and micropores (<10 microns) for effective retention of petroleum fractions; introduction of functional additives, including magnetic nanoparticles and fluorinated polymers; development of advanced regeneration methods such as mechanical heat treatment and solvent extraction. A special emphasis in the review is placed on the correlation between the structural features of sorbents and their operational characteristics in real conditions.

Bembel V.M., Basova S.P., Safonov G.A. [9] developed a sorbent based on cellulose fibers (cotton wool, industrial wool) modified with styrene-butadiene block copolymer. The invention is intended for the removal of oil and petroleum products from the surface of water and soil, including emergency spills and wastewater. The sorbent is not wetted with water, is easy to assemble and can be regenerated repeatedly. The production method involves applying a polymer from an organic solution followed by drying. The authors achieved high oil capacity at low cost and simplicity of technology. The composition is resistant to aggressive environments and retains its structure after several cycles of use. This makes the solution particularly suitable for emergency situations and cleaning of polluted reservoirs.

Grebenkin A.A. and Grebenkin A.N. [10] proposed a method for obtaining sorbent from pulp and paper production waste modified with sodium methyl silicate. The main purpose of the invention is to create a material capable of staying on the surface of water for a long time without the risk of immersion, which is critical in the elimination of emergency spills. The sorbent is obtained by the method of aerial spontaneous drying followed by heat treatment, which increases its hydrophobicity. The developed

composition does not sink even after saturation with oil and effectively absorbs

hydrocarbons. The authors achieved an increase in the "buoyancy" time of the sorbent to full saturation. It is easily collected from the surface of the water and must be disposed of. The solution is relevant for cleaning reservoirs and oil sludge barns.

Abdullin I.Sh., Gafarov I.G., Mishulin G.M. and others [11] developed a sorbent based on rice husk enriched with silica. The material is obtained by heat treatment in plasma at reduced pressure with the introduction of silicon oxide powder. The resulting porous matrix has a pore size of 5-30 microns, and SiO_2 particles have a pore size of 50-250 nm. The sorption capacity is 24-45 g of oil per 1 g of sorbent. This approach makes it possible to use cheap vegetable raw materials and ensure high efficiency of wastewater and natural water treatment from hydrocarbons and heavy metals. The sorbent is environmentally friendly and applicable to a wide range of contaminants.

Sirotkina E.E., Safonov G.A., Bembel V.M., Boltrukevich E.P. (patent RU2061541C1) have developed a sorbent for collecting oil and petroleum products from the surface of water. The invention relates to the field of obtaining new adsorption materials and can be used to clean the water surface from contamination. The sorbent contains fibrous materials: textile waste, industrial cotton wool and other cellulose-containing materials treated with oxidized atactic polypropylene at the following component ratio, % by weight: oxidized atactic polypropylene 3-7, fibrous cellulose material 93-97. This composition provides high sorption capacity and resistance to water. The sorbent is easily collected from the surface of the water and must be disposed of. The solution is relevant for cleaning reservoirs and oil sludge barns.

Sergey Baskakov and the staff of the Laboratory of Nanomaterials Spectroscopy at the PHC PHB iMH RAS [12] have developed a superhydrophobic aerogel based on graphene and polytetrafluoroethylene (Teflon) for collecting oil and petroleum product spills. The sorbent has a density of only 8 g/l and a wetting angle of 169° , which ensures its high hydrophobicity and efficiency in collecting hydrocarbons from the surface of water and land. The material is capable of absorbing up to 61 g of oil per 1 g of sorbent and retains its buoyancy even in stormy conditions. The sorbent can be used repeatedly due to the possibility of restoring sorption properties after heat treatment. The invention is relevant for use in Arctic zones and other difficult conditions. The development has aroused the interest of Russian oil companies and sorbent manufacturers.

Dedov A.G., Ivanova E.A., Belousova E.E., and others [13] proposed a biodegradable composite sorbent based on a copolymer of acrylonitrile with methyl acrylate and a crushed plant of the genus *Sphagnum*. The sorbent is

intended for collecting oil and petroleum products at the bottom of water areas. The material has a low buoyancy, which allows it to sink to the bottom and adsorb hydrocarbons from the water surface. The sorption capacity is 35 g of oil per 1 g of sorbent, and for fuel oil — up to 70 g/g. The sorbent is able to retain sorbate for at least 10 minutes when removed from the surface of the water area. The inclusion of sphagnum promotes the biodegradation of polymer fiber, eliminating the need to recycle waste materials. The sorbent is effective for cleaning ballast water from ships and wastewater.

Dmitrieva Z.T., Bystritskaya M.A. and Bylina I.V. [14] developed a sorbent for collecting oil, oils, fuel oil and other hydrocarbons from the surface of water and land. The invention relates to the field of sorbents and can be used to clean contaminated surfaces. The sorbent is highly effective in removing petroleum products, preventing contamination of water bodies and soil. The material provides fast and efficient absorption of hydrocarbons, reducing environmental damage from oil spills. The sorbent can be used in various conditions, including emergency situations on seas and rivers. The development helps to preserve the ecological balance and prevent the death of flora and fauna.

Melnikov I.N., Olshanskaya L.N., Zakharchenko M.Yu., and others [17] proposed a powdered magnetic sorbent for oil collection containing iron oxide in the form of Fe_3O_4 and coconut activated carbon. The sorbent has a high sorption capacity and activity in a magnetic field, which ensures effective removal of oil from various surfaces. The use of this sorbent makes it possible to quickly and effectively clean contaminated areas, reducing environmental damage. The sorbent is easily collected from the surface of the water and must be disposed of. The solution is relevant for use in emergency situations and for regular cleaning of reservoirs. The development has the potential for wide application in various climatic conditions. The sorbent can be used in various industries, including oil and gas and chemical.

Lektorskaya V.E., Prutenko D.A., Pomogaibo S.B., and others [15] developed a sorbent for collecting oil and a method for its production. The sorbent consists of powdered carbon, polyamide fiber, rubber chips and a hydrophobizer. The manufacturing process involves grinding the rubber material to a crumb about 4-6 mm in size, treating the polyamide fiber with a hydrophobizer, and mixing the components in a specific sequence. This composition provides high sorption capacity and resistance to water. The sorbent is easily collected from the surface

of the water and must be disposed of. The solution is relevant for cleaning reservoirs and oil sludge barns. The development contributes to the effective removal of petroleum products from contaminated surfaces.

M.V. Abramov, L.A. Zekel, V.D. Ivanov, and others [16] have developed a sorbent for collecting petroleum products from the surface of water and a method of its application. The sorbent is based on hydrophobized ash xenospheres treated with bitumen, which ensures high efficiency in the collection of petroleum products. The use of this sorbent makes it possible to effectively clean water surfaces from oil pollution, ensuring environmental safety. The development is relevant for use in emergency situations and for regular cleaning of reservoirs. The sorbent is easily collected from the surface of the water and must be disposed of. The solution helps to reduce environmental damage from oil spills. The development has the potential for wide application in various climatic conditions.

Research by the team led by Kuznetsov, A.V. (2002) showed that polyurethane sorbents with an apparent density of $<20 \text{ kg/m}^3$ and a micropore fraction $>50\%$ demonstrate a sorption capacity of up to 50 g of oil per 1 g of material. Experiments have confirmed that such sorbents remain effective after 10 cycles of regeneration by pressing.

Yerofeevskaya L.A., Sivtsev S.I., Vit A.A., and others [18] have developed an oil biosorbent for cleaning and restoring oil-contaminated lands. The sorbent has the ability to activate the processes of microbiological activity in oil-contaminated soils in a wide range of ambient temperatures from $+5$ to $+40$ °C. The use of this sorbent makes it possible to effectively clean and restore contaminated areas, ensuring environmental safety. The sorbent is easily available for execution and does not require expensive and time-consuming operations. The solution is relevant for use in various natural and climatic conditions. The development has the potential for wide application in various industries, including oil and gas and chemical. The sorbent helps to reduce environmental damage from oil spills.

Petrov, S. I. and co-authors (2008) found that the addition of buckwheat husks or rice (up to 60% by weight) The polyurethane matrix increases the mechanical strength of the sorbent without reducing the oil capacity (up to 40 g/g). Field tests have shown that the granular form (0.5–4 cm) is suitable for use on polluted soils.

The results of experimental studies indicate that the sorption capacity of polyurethane sorbents directly depends on the morphology of the porous

structure and the methods of chemical modification used. It has been found that, on average, such sorbents are capable of absorbing from 18 to 22 grams of oil per gram of material,

which makes them highly effective in comparison with a number of alternatives. A significant factor affecting the kinetics of sorption is the preliminary hydrophobization of the surface, which promotes faster and more selective absorption of hydrocarbons. In addition, polyurethane sorbents demonstrate resistance to degradation of their characteristics during reuse: their efficiency is maintained for at least ten sorption and regeneration cycles without significant loss of oil capacity. Such properties confirm the potential of polyurethane materials in the context of sustainable and reusable solutions for oil spill response.

Minimal environmental pollution. Unlike chemical reagents, PU sorbents do not contain toxic components and do not form dangerous by-products during operation. Reducing the amount of waste. Thanks to repeated regeneration, sorbents can be used up to 10 times without significant loss of efficiency, which reduces the amount of waste generated. High selectivity. Polyurethane materials absorb mainly petroleum products, practically without absorbing water. This avoids contamination of the treated environment with secondary impurities. Reduction of greenhouse gas emissions. Traditional recycling systems often use the incineration of contaminated materials. PU sorbents make it possible to dispense with thermal recycling, which reduces emissions of CO_2 and other greenhouse gases. The possibility of environmentally friendly disposal. Modern polyurethane matrixes can be recycled or used as secondary raw materials, which corresponds to the principles of circular economy. Absence of negative impact on biocenoses. Sorbents do not harm flora and fauna, as they do not release harmful substances into the aquatic environment and do not break down into toxic fragments. Together, these factors make polyurethane sorbents an effective and safe solution for environmental protection in both the short and long term.

Application and development prospects

Polyurethane sorbents are widely used in various fields due to their versatility, high sorption capacity and the possibility of repeated use. First of all, they are in demand in the elimination of emergency oil spills in open water bodies, including seas, rivers and coastal zones. Their use is especially important at low temperatures, as modified polyurethanes retain elasticity and

functionality even at subzero temperatures. One of the promising areas is the use of PU sorbents in the oil production and refining industries. In such conditions, it is possible not only to promptly eliminate emergency spills, but also to organize constant monitoring and local wastewater treatment. In addition, polyurethane

materials can be used for wastewater filtration and reuse of purified water at technological stages. In the future, nanomodification of polyurethane matrices will become a key area of development. The addition of nanoparticles (for example, metal oxides or carbon nanostructures) will increase the specific sorption capacity, increase selectivity to certain pollutants, and improve the mechanical characteristics of the material [19]. In addition, it is expected to develop "smart" sorbents capable of changing their structure under the influence of external factors (pH, temperature, magnetic field), which will provide more flexible and precise control of the purification process. Thus, polyurethane sorbents represent not only an urgent, but also a strategically promising solution for combating environmental pollution, having the potential to integrate into innovative technological platforms of the 21st century.

CONCLUSION

The analysis shows that polyurethane sorbents represent one of the most promising areas in the field of collection and disposal of petroleum products. Their high sorption capacity, selectivity, resistance to reuse and environmental safety make them especially valuable in the context of modern environmental protection requirements. Unlike traditional mechanical, chemical and biological methods, the use of polyurethane sorbents makes it possible to achieve higher cleaning efficiency at lower cost and minimal impact on nature. In addition, the ability to regenerate and possible inclusion in the circular economy favorably

distinguish PU sorbents from their analogues. Patented technologies based on

polyurethane compositions demonstrate a variety of development paths: from simple porous structures to nanomodified matrices with controlled properties. It is especially important to create materials adapted to different climatic and operational conditions. In the future, in-depth research is needed to increase the durability of sorbents, reduce the cost of their production and develop environmentally friendly methods of their regeneration and disposal. The development of smart and biocompatible polyurethane systems may be the next step in the evolution of oil pollution control methods. Thus, polyurethane sorbents are not only an effective tool for environmental cleaning, but also an important element of sustainable development, integrated into the global environmental protection agenda.

Conflicts of interest. The authors declare no conflicts of interest, financial or otherwise.

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