N. Mkheidze, R. Davitadze, N. Kiknadze,
A. Khakhutaishvili, N. Megrelidze, R. Gotsiridze
ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER
WASTE FOR WATER PURIFICATION…

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER WASTE FOR WATER PURIFICATION FROM OIL CONTAMINATION

Nino Mkheidze, Ruslan Davitadze, Nino Kiknadze, Ana Khakhutaishvili, Nargiz Megrelidze, Raul Gotsiridze

•

Agrarian and Membrane Technologies Scientific Research Institute
of Batumi Shota Rustaveli State University, GEORGIA
mkheidze.nino@bsu.edu.ge
ruslan.davitadze@bsu.edu.ge
Nino.kiknadze@bsu.edu.ge
xaxutaishvili_ana@mail.ru
nargiz.megrelidze@bsu.edu.ge
amti@bsu.edu.ge

Abstract

The increased production of polymer-based materials has made polymer waste management more challenging. Plastic bottles, medical tubing, bags and polymer foams are all persistent environmental pollutants. The recycling of these materials often requires high energy consumption and is commonly accompanied by the emission of toxic compounds and gases, posing significant environmental risks. This study investigated waste materials from the furniture manufacturing and packaging industries, which are primarily made of porous polymers. FTIR spectroscopy was employed to analyze their polymer composition. The results indicate that the dominant polymer constituents in municipal waste are polyethylene, polypropylene, polystyrene, and polyurethane. The potential use of waste porous polymeric materials for purifying water contaminated with oil and petroleum products (PPs) was also examined. Porous polymers were used as sorbents in the water treatment process. Their sorption capacity (g/g) and the factors affecting sorption efficiency — including pH, temperature and loading density — were analyzed systematically. Research indicates that polyurethane demonstrates the highest sorption efficiency. Under dynamic conditions in sorption columns, polyurethane effectively reduces the concentration of oil contaminants in water to levels permissible under wastewater discharge regulations.

Keywords: waste polymers, sorption, waste water purification, diesel removal

I. Introduction

With the increasing production of polymer-based products, the issue of polymer waste disposal, such as used bottles, medical tubing, plastic bags, and polymeric sponges, has become a significant challenge [1]. Polymeric waste poses a growing environmental threat [2,3,15].

Since 1950, approximately 8.3 billion metric tons of plastic have been produced, with only 9% being recycled into secondary raw materials and 12% incinerated [4]. In many cases, recycling is not a feasible option due to its high energy requirements and the emission of toxic compounds and gases into the environment during the process [5,15].

In addition to recycling, the development of technologies for the secondary utilization of polymer waste is crucial. Using waste polymeric materials for the treatment of petroleum-contaminated water simultaneously addresses two environmental challenges: plastic waste management and oil pollution remediation [6,7,8,15].

N. Mkheidze, R. Davitadze, N. Kiknadze,
A. Khakhutaishvili, N. Megrelidze, R. Gotsiridze
ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER
WASTE FOR WATER PURIFICATION…

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

The study by Aboul-Gheit et al. [9] demonstrated through laboratory experiments that certain plastic waste materials, including polyethylene (PE) and polypropylene (PP) waste powders and sheets, as well as polyurethane (PU) foam, possess a high oil sorption capacity. These materials have the potential to be effectively utilized for oil spill remediation in marine environments.

The studies by Nguyen et al. [10] and Haridharan et al. [11] emphasize the potential of innovative polymeric sorbents in mitigating ocean pollution. These sorbents demonstrate enhanced porosity and improved biodegradability.

The highly porous structure of sorbents can be achieved through various techniques. One modification approach involves the fabrication of polymeric sorbents with a three-dimensional structured framework [12, 15].

Shredded hydrophobized polyurethane, treated with silanes, is widely used for oil spill remediation. After collecting, approximately 80% of the absorbed oil can be recovered through mechanical squeezing, enabling the material to be reused [13, 15].

Various types of porous materials, both natural and synthetic, are utilized as sorbents [14-18]. From an economic and efficiency perspective, sorption using synthetic sorbents is particularly advantageous. In this approach, the sorbent matrix consists of waste (secondary) polymeric materials, which themselves contribute to environmental pollution.

This study aims to develop a cost-effective approach for treating water contaminated with oil and petroleum products by utilizing locally sourced polymer waste materials as sorbents.

To optimize purification conditions, the study investigates the impact of key factors on treatment efficiency, including sorbent loading density, pH and temperature effects on the sorption process.
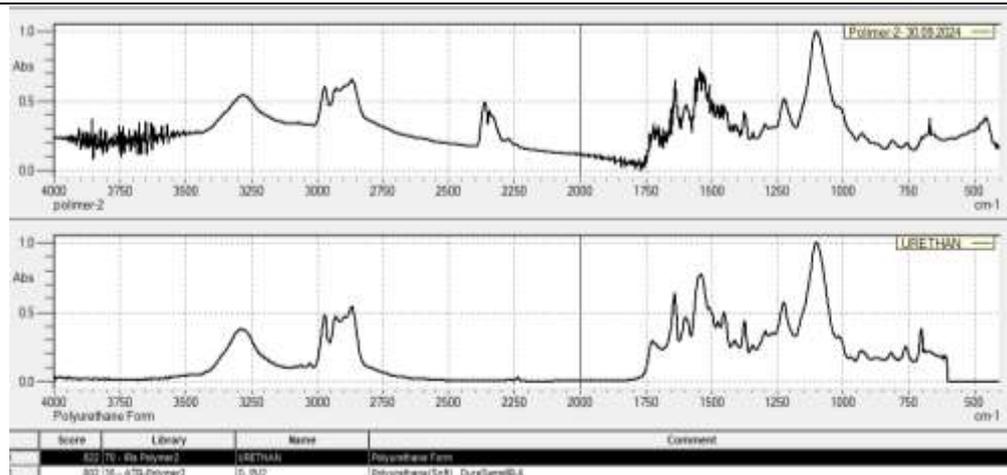
II. Experimental part

Materials. The objective of the research was to assess the feasibility of employing synthetic polymers for the treatment of water contaminated by petroleum products. To this end, samples of diverse polymeric materials were obtained (see **Images:** Samples of diverse polymeric materials), predominantly consisting of locally sourced waste porous polymers from furniture manufacturing, packaging materials, and other sources.

The analysis was performed using an FTIR IRSpirit spectrophotometer (Shimadzu) to identify the polymers studied. Spectral scans were conducted on the FTIR spectrophotometer, and the Shimadzu database was utilized for spectral comparison. Based on the obtained spectra (see Curve 1: Identification of the Unknown Polymer), the polymers were identified as polyurethane (PU), polystyrene (PS) (in four different modifications), low-density polyethylene (PE), starch-based foam, and polyester

Images: Samples of diverse polymeric materials

N. Mkheidze, R. Davitadze, N. Kiknadze,
A. Khakhutaishvili, N. Megrelidze, R. Gotsiridze
ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER
WASTE FOR WATER PURIFICATION…

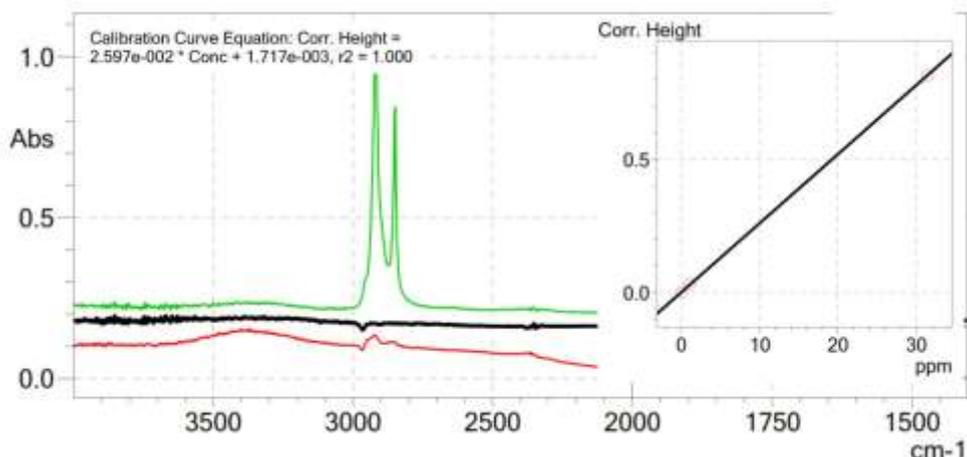RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

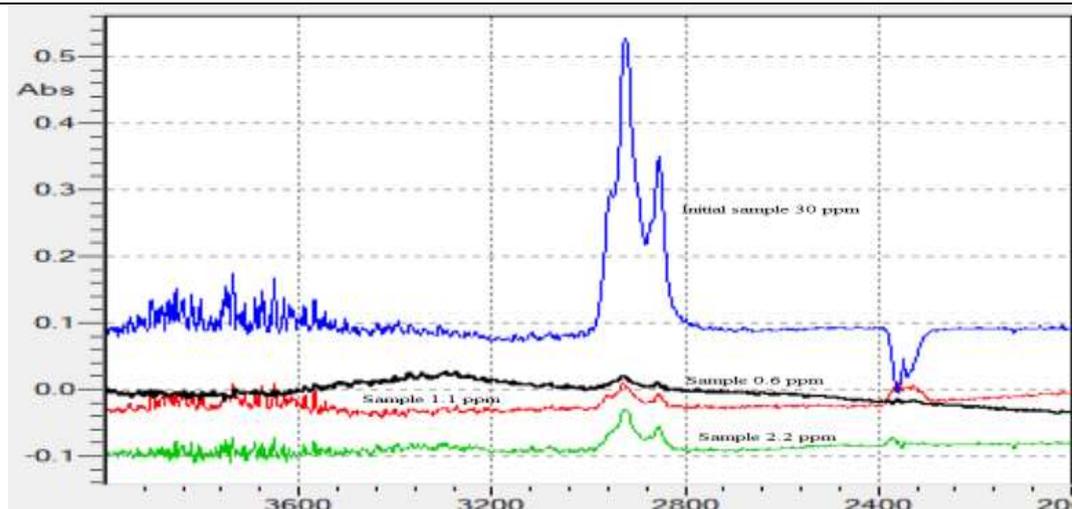**Curve 1:** *Identification of the Unknown Polymer*

The first curve represents the polymer under investigation, while the second curve corresponds to polyurethane. The spectra were obtained using an FTIR IRSpirit spectrophotometer.

These polymers are derived from industrial waste and secondary raw materials. For example, expanded polystyrene (EPS) foam is widely used for thermal insulation, packaging, and construction. Polystyrene materials are commonly utilized in the form of rigid sheets or small granules (packing peanuts), which serve as protective cushioning during transportation. Starch-based foam, a biodegradable packaging material, is typically manufactured from plant-derived starch. Polyurethane is employed for packaging fragile items due to its high shock-absorbing properties. Expanded polyethylene (EPE) foam is extensively used for packaging, insulation, and cushioning. Polyurethane is also widely applied in the production of upholstered furniture, making furniture manufacturers its primary source.

Methods. To determine the concentration of petroleum products in water, the Standard Test Method for Solvent-Free Membrane Recoverable Oil and Grease by Infrared Determination (D7575 – 11) [19] was applied. In this method, the test solution was filtered through an OSS Clear Shot membrane filter (cartridge), and the concentration of sorbed oil and petroleum products was subsequently determined using Fourier-transform infrared (FTIR) spectroscopy. The application of this standard eliminated the need for solvent-based extraction.

Curve 2: *The FTIR of the background was obtained using an FTIR IRSpirit spectrophotometer.*

N. Mkheidze, R. Davitadze, N. Kiknadze,
A. Khakhutaishvili, N. Megrelidze, R. Gotsiridze
ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER
WASTE FOR WATER PURIFICATION…

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

Curve 3: *Petroleum Product Concentration in the Initial Sample and Various Filtrate Samples*.

To determine the concentration of petroleum products in an unknown sample, 10 mL of the analytical solution was passed through a membrane filter (OSS part: 1013 SPE) using a syringe. The filter cartridge was then dried for 10–15 minutes under a dry air stream. Subsequently, the concentration of petroleum products was measured using an IRSpirit spectrophotometer. The obtained infrared spectra were analyzed by measuring the peak heights from the baseline at 2920 cm^{-1}.

Processing. To assess the sorption properties of porous polymers, an aqueous solution artificially contaminated with petroleum products was prepared. For the preparation of a solution with a known concentration, 500 mg of diesel (gas oil) was dissolved in 1 L of water. To ensure homogenization, the resulting emulsion was subjected to ultrasonication for 30 minutes at 40°C.

Construction of Adsorption Curves. To evaluate the sorption properties of the studied polymers, eight different sorbents were introduced into glass sorption columns. The amount of petroleum products adsorbed onto the polymeric sorbents under dynamic conditions was assessed using an initial aqueous solution. After each 100 mL addition of the initial solution, the concentration of petroleum products remaining in the filtrate was measured according to the D7575 – 11 standards.

During the experiment, the adsorption capacity (q_a, mg/g) was calculated to evaluate the adsorption process. The following equation was used:

$$q = \frac{(C0 - C) \times V}{m}$$

where: C_0 – Initial oil concentration; C – Oil concentration in the filtrate (ppm); V – Volume of the filtrate (mL); m – Mass of the sorbent (g).

III. Results and Discussion

To investigate the sorptive properties of the studied polymers, sorbents were introduced into glass sorption columns. Diesel sorption from the initial aqueous solution by various polymeric sorbents was analyzed under dynamic conditions. After each addition of 100 mL of the initial solution, the concentration of residual petroleum hydrocarbons in the filtrate (ppm) was measured.

Based on the experimental results polyurethane was identified as the sorbent with the most favorable sorption properties. The sorption process was analyzed under varying pH conditions and different temperatures of the test solution.

N. Mkheidze, R. Davitadze, N. Kiknadze,
A. Khakhutaishvili, N. Megrelidze, R. Gotsiridze
ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER
WASTE FOR WATER PURIFICATION…

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

The collected data were utilized to generate curves (see curves below) depicting the concentration of residual petroleum hydrocarbons (ppm) in the filtrate following the passage of the solution through the sorbent.
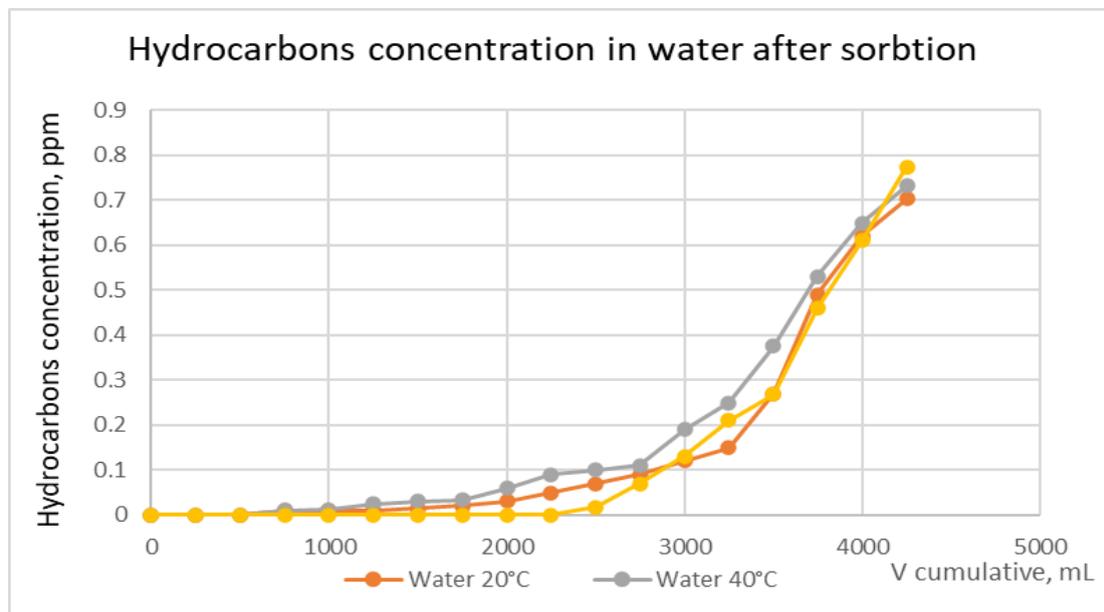

Figure 1: *Hydrocarbons concentration in water after sorbtion*

Based on the data, it can be concluded that neither an increase in temperature nor acidification of the solution significantly affects the sorption process.

The sorption capacity of polyurethane was assessed by measuring the mass of petroleum hydrocarbons retained on the sorbent (see Fig.2).
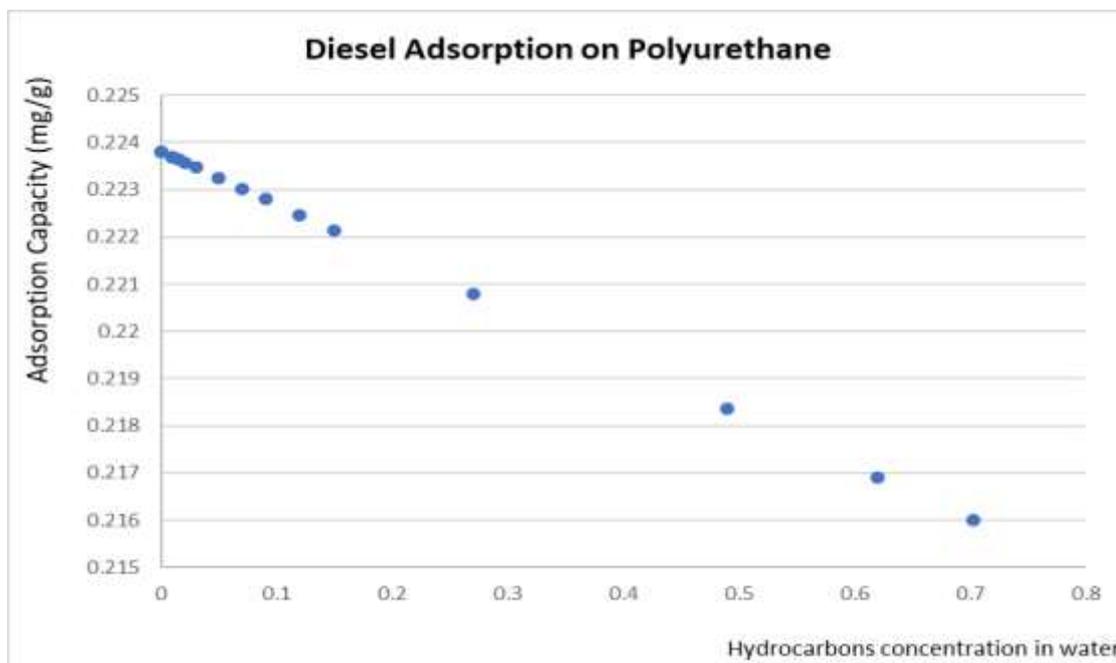

Figure 2: *Isotherm Curve for Diesel Adsorption on Polyurethane (T=20 ⁰C)*

The relationship between sorbent loading density and sorption capacity was examined. As illustrated in Fig. 3, sorption capacity increases as the loading density of the sorbent increases.
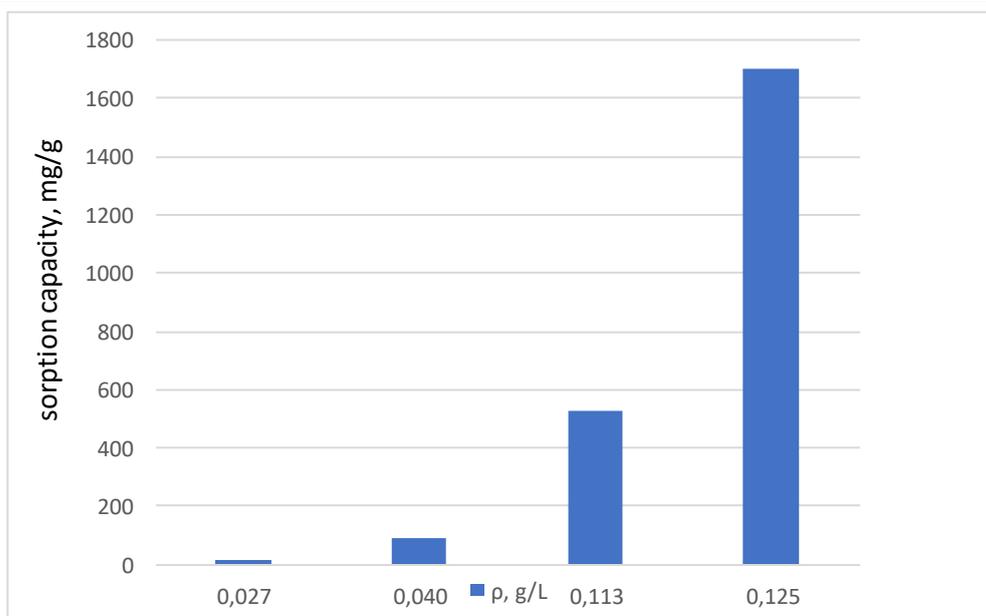
N. Mkheidze, R. Davitadze, N. Kiknadze,
A. Khakhutaishvili, N. Megrelidze, R. Gotsiridze
ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER
WASTE FOR WATER PURIFICATION…

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

Figure 3: *The Impact of Sorbent Loading Density on Sorption Capacity*

IV. Conclusion

Locally produced waste-derived porous polymeric materials were examined, with polyurethane (PU), polystyrene (PS), low-density polyethylene (PE), starch-based foam, and polyester identified as primary components. Among these materials, polyurethane was selected as the most effective sorbent due to its superior sorption properties. The diesel sorption process on polyurethane was studied under dynamic conditions, considering different sorbent loading densities, pH levels, and test solution temperatures. It was found that variations in temperature and pH have no significant impact on the sorption capacity of polyurethane. The low cost of polyurethane (as it is derived from waste), along with its high sorption capacity and stability during regeneration, suggests that polyurethane is a promising material for the treatment of water contaminated with petroleum products, particularly at low concentrations.

CONFLICT OF INTEREST.
The authors declare that they have no conflict of interest.

References

[1] Al-Salem, S. M., Lettieri, P., and Baeyens, J. "Recycling and Recovery Routes of Plastic Solid Waste (PSW): A Review." // *Waste Management*, vol. 29, no. 10, 2009, pp. 2625–2643.

[2] Andrady, A. L. "Microplastics in the Marine Environment." // *Marine Pollution Bulletin*, vol. 62, no. 8, 2011, pp. 1596–1605. https://doi.org/10.1016/j.marpolbul.2011.05.03.

[3] Kharisov, B. I., Dias, H. V. R., and Kharissova, O. V. "Nanotechnology-Based Remediation of Petroleum Impurities from Water." // *Journal of Petroleum Science and Engineering*, vol. 122, Elsevier, 2014, pp. 705–718. https://doi.org/10.1016/j.petrol.2014.09.013.

N. Mkheidze, R. Davitadze, N. Kiknadze,
A. Khakhutaishvili, N. Megrelidze, R. Gotsiridze
ENVIRONMENTAL RISKS AND RECYCLING OF POLYMER
WASTE FOR WATER PURIFICATION…

RT&A, Special Issue No. 9 (87),
Volume 20, November 2025

[4] Geyer, R., Jambeck, J. R., and Law, K. L. "Production, Use, and Fate of All Plastics Ever Made." // *Science Advances*, vol. 3, no. 7, AAAS, 2017, e1700782. https://doi.org/10.1126/sciadv.1700782.

[5] Hopewell, J., Dvorak, R., and Kosior, E. "Plastics Recycling: Challenges and Opportunities." // *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 364, no. 1526, 2009, pp. 2115–2126. https://doi.org/10.1098/rstb.2008.0311.

[6] Iftekhar, S., Deb, A., Heidari, G., and Sillanpää, M. "A Review on the Effectiveness of Nanocomposites for the Treatment and Recovery of Oil Spill." // *Environmental Science and Pollution Research*, 2023. https://link.springer.com/article/10.1007/s11356-022-25102-1.

[6] Kim, H., Zhang, G., Wu, M., Guo, J., and Nam, C. "Highly Efficient and Recyclable Polyolefin-Based Magnetic Sorbent for Oils and Organic Solvents Spill Cleanup." // *Journal of Hazardous Materials*, vol. 408, 2021, 124984.
https://www.sciencedirect.com/science/article/pii/S0304389421014503.

[8] Sarbatly, R., Krishnaiah, D., and Kamin, Z. "A Review of Polymer Nanofibres by Electrospinning and Their Application in Oil–Water Separation for Cleaning Up Marine Oil Spills." // *Marine Pollution Bulletin*, vol. 107, no. 1, 2016, pp. 174–192. https://www.sciencedirect.com/science/article/pii/S0025326X16301655.

[9] Aboul-Gheit, A. K., Khalil, F. H., and Abdel-Moghny, T. "Adsorption of Spilled Oil from Seawater by Waste Plastic." // *Oil & Gas Science and Technology*, vol. 61, no. 2, 2006, pp. 259–268. doi:10.2516/ogst:2006019x.

[10] Nguyen, X. P., Nguyen, D. T., Pham, V. V., and Vo, D. T. "Highlights of Oil Treatment Technologies and Rise of Oil-Absorbing Materials in Ocean Cleaning Strategy." // *Water Conservation and Management*, 2022.
https://www.watconman.org/archives-pdf/1wcm2022/1wcm2022-06-14.pdf.

[11] Haridharan, N., Sundar, D., Kurrupasamy, L., and Olga, T. "Oil Spills Adsorption and Cleanup by Polymeric Materials: A Review." // *Polymers for Advanced Technologies*, 2022. https://onlinelibrary.wiley.com/doi/abs/10.1002/pat.5636.

[12] Ciesińska, W., Makomaski, G., Zieliński, J., and Brzozowska, T. "Preparation of Sorbents from Selected Polymers." // *Polish Journal of Chemical Technology*, vol. 13, no. 1, 2011, pp. 51–54. https://doi.org/10.2478/v10026-011-0010-0.

[13] Liu, L. "Oleophilic Polyurethane Foams for Oil Spill Cleanup." // *Procedia Environmental Sciences*, vol. 18, 2013, pp. 528–533. https://doi.org/10.1016/j.proenv.2013.04.071.

[14] Nwadiogbu, J., Ajiwe, V., and Okoye, P. "Removal of Crude Oil from Aqueous Medium by Sorption on Hydrophobic Corncobs: Equilibrium and Kinetic Studies." // *Journal of Taibah University for Science*, vol. 10, no. 1, 2016, pp. 56–63. https://doi.org/10.1016/j.jtusci.2015.03.014.

[15] Mkheidze, N., Gotsiridze, R., Davitadze R., Kiknadze, N., Megrelidze N. "Cost-Effective Remediation of Petroleum-Contaminated Waters Using Locally Sourced Wood Sawdust." // *Journal of Environmental Research*, 2024.
https://www.jeeng.net/pdf-185967-107724?filename=Cost_Effective.pdf.

[16] Pires, M. R., Lorenço, M. S., Dias, M. C., da Silva, L. R., Júnior, I. P., and Mori, F. A. "Application of Different Vegetable Fibers as Natural Sorbents and Their Use in Water Decontamination from Crude Oil." // *Chemical Engineering & Technology*, vol. 44, no. 12, 2021, pp. 2269–2278. https://doi.org/10.1002/ceat.202100105.

[17] Yang, Z. W., Li, J. J., Yu, Z., Zheng, J. F., Wang, Y. H., and Ma, W. "Superwetting Functional Polyurethane as a Promising Selective Oil-Absorbing Porous Material for Oily Water Treatment." // *Arabian Journal of Chemistry*, 2024.
https://www.sciencedirect.com/science/article/pii/S1878535224001722.

[18] Sarbatly, R., Krishnaiah, D., and Kamin, Z. "A Review of Polymer Nanofibres by Electrospinning and Their Application in Oil–Water Separation for Cleaning Up Marine Oil Spills." // *Marine Pollution Bulletin*, vol. 107, no. 1, 2016, pp. 174–192. https://www.sciencedirect.com/science/article/pii/S0025326X16301655.

[19] https://www.astm.org/d7575-11r17.html