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Research Progress on the Application of Aerogel for Oil-water Separation

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Abstract. **:** With the acceleration of industrialization, oil-water separation technology is becoming more and more important in environmental protection and resource recovery. Traditional separation technologies, such as gravity separation, centrifugal separation, and chemical emulsification, have low efficiency, high energy consumption, and are prone to secondary contamination, and there is an urgent need for new high-efficiency materials. As an emerging nanoporous material, aerogel shows great potential in oil-water separation due to its ultra-high porosity, low density and large specific surface area. This paper reviews the principles and advantages and disadvantages of traditional oil-water separation methods, and analyzes the preparation methods of different kinds of aerogel materials and their effect advantages in oil-water separation applications. It focuses on the preparation process, performance characteristics and application areas of natural polymer-based aerogels, synthetic polymer-based aerogels and composite aerogels. In addition, the article outlines the structural optimization and separation principles of aerogels, points out the key influence of structural factors such as porosity and specific surface area on adsorption performance, and analyzes a variety of separation mechanisms, such as adsorption, filtration, and gravity-driven. Finally, the current development status and challenges of aerogel materials are summarized, and future development directions are proposed.

Keywords: Aerogel, Oil-Water Separation, Adsorption

1. Introduction

With the continuous advancement of global industrialization and the rapid growth of energy demand, the importance of high-efficiency oil-water separation technology in the field of environmental protection and resource recovery is becoming more and more prominent [1-3]. However, traditional separation technologies such as gravity separation, centrifugal separation and chemical demulsification are generally characterized by low separation efficiency, complex operation process, high energy consumption and easy to produce secondary pollution and other technical bottlenecks. These inherent defects seriously restrict the practical application of oil-water separation technology, and there is an urgent need to develop new high-efficiency separation materials to break through the existing technical barriers.

Traditional separation materials can be divided into three categories: polymer materials, inorganic materials and biomass materials. There are many polymer oil-absorbing materials, such as

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polystyrene [4] (PS), polyacrylamide [5] (PAM), polypropylene [6] (PP), polyvinylidene fluoride [7] (PVDF), etc.; as inorganic oil-absorbing materials, there are graphene [8], silica [9], activated carbon [10], etc.; and biomass oil-absorbing materials, including Corn stover, grain husk, rice straw, nut shells, etc. Polymer materials are commonly used in the preparation of oil-water separation membranes [11], although they have the advantages of fast oil absorption rate, good reusability, convenient recycling, etc., but there are still problems such as slow oil absorption rate, high price, difficult to degrade; inorganic oil-water separation materials have small particle size, recycling difficulties, and their own structural limitations resulting in adsorption capacity is not high; biomass materials are widely used as raw materials but lack of selectivity of oil and water in the actual application process and relatively high recycling costs. Biomass materials come from a wide range of raw materials, but lack selectivity for oil and water in the actual application, and the recovery cost is relatively high.

Compared with the traditional oil-water separation materials, aerogels have become the current research hotspot in the field of oil-water separation due to their excellent oil-water selective separation performance by virtue of their three-dimensional network junctions with ultra-high porosity, extremely low density and large specific surface area. Especially, the superhydrophobic-super lipophilic functional materials after modification[12-14] can realize up to 99% oil-water separation efficiency by regulating the surface microstructure and chemical composition, and show a broad application prospect in the fields of marine oil spill treatment and industrial oily wastewater purification. Aerogel is an ultralight three-dimensional porous material composed of gel scaffold and filling medium (air). The world's first aerogel was prepared by Kistler [15] through supercritical drying technology in 1931, and many performance breakthroughs have been carried out subsequently, for example, Xiao [16] et al. prepared high-performance quaternary ammonium-functionalized chitosan/graphene oxide composite aerogel showed excellent performance in oil-water separation, which can efficiently separate oil-water mixtures with good recyclability. Piotr [17] and other teams carried out a systematic study based on the composite aerogel system, on the basis of which performance optimization and structural modulation were carried out, which significantly improved the mechanical properties and cyclic stability of the material, and provided a new paradigm for the design of oil-water separation materials. The article adopts a comprehensive and detailed categorization and review approach to discuss various types of aerogel materials in depth. Finally, the article provides a comprehensive and in-depth summary and outlook of the various types of aerogel materials mentioned above.

2. Adsorption principle of aerogel for oil-water separation

2.1. Lipophilic hydrophobic adsorption

Numerous aerogel materials have been treated with special processes to exhibit superhydrophobic and superoleophilic surfaces. When such aerogels come into contact with oil-water mixtures, they can rapidly and efficiently adsorb oil while strongly repelling water based on their unique surface wettability.

It is a low cross-linked polymer polymerized with lipophilic monomers, with cross-linked three-dimensional network structure between macromolecules and certain micropores inside the material. The cellulose-based oil-absorbing material is put into the oil, initially for the molecular diffusion control, the use of polymer lipophilic groups and oil molecules in the mutual affinity force for the oil-absorbing impetus, the oil inhalation is stored in the three-dimensional network structure. When enough oil molecules enter, the oil-absorbing material undergoes swelling, the polymer chain

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segments are fully extended, and covalent bond cross-linking points exist in the network, and only then does it begin to be controlled by the Flory - Huggins equation, i.e., it is driven by thermodynamic propulsion. However, the polymer chain segments will slowly retract when they are stretched to a certain extent, i.e., there is an elastic retracting force, and ultimately thermodynamic equilibrium is reached [18]. Therefore, the cellulose-based polymer is controlled by molecular diffusion. equilibrium [19]. Thus, the oil absorption process of cellulose-based oil-absorbent materials is the process of their full swelling in oil to form a gel.

2.2. Reversible adsorption

Some smart aerogels can realize reversible adsorption of oil and water by stimulating response under the action of external field. Some smart aerogels can realize reversible adsorption of oil and water by stimulating response under the action of external field. For example, moisture-sensitive aerogel, its oil and water absorption capacity changes with temperature, by controlling the humidity, the aerogel is switched between the oil absorption state and the oil release state, to achieve the purpose of oil-water separation and aerogel regeneration.

3. Different kinds of aerogel oil-water separation materials

We have broadly classified aerogel materials into three categories as shown in Figure 1.



Fig. 1 Main classifications of aerogels

Figure 1. Main classifications of aerogels

3.1. Effectiveness of natural polymer-based aerogels for oil-water separation applications

Natural polymer aerogels are aerogels prepared by chemical or physical cross-linking using cellulose, lignin, chitosan, etc. as the matrix. These materials emphasize the renewability of raw materials, and their high specific surface area and porous structure make them promising for a wide range of applications in the field of adsorption, in order to The following classification discusses the application of different types of hydrogel materials in oil-water separation.

3.1.1. Cellulose-based aerogels

Generally prepared cellulose nanocellulose aerogels absorb both water and oil, and in order to meet the hydrophobicity requirements for oil-water separation applications, they need to be prepared by chemically modifying cellulose or compounding it with other materials. Tan [25] et al. reported cellulose aerogels for the first time in 2001, and cellulose-based aerogels are a new, green, biodegradable and porous material compared to traditional inorganic and organic aerogels.

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Cellulose, as a precursor for the preparation of aerogels, is an environmentally friendly biopolymer that is abundantly sourced, inexpensive, and renewable in nature.

Ma's [26] team successfully prepared a novel carbon aerogel (NM/RCA) consisting of natural microfibers composited with regenerated cellulose by innovatively adopting a composite solvent system of deep eutectic solvent (DES) and N-methylmorpholine-N-oxide monohydrate ($NMMO \cdot H_2O$), using economic hardwood pulp as the precursor. After carbonization at 400°C, the material still maintains the morphological characteristics and structural integrity of its original filamentary microfibers. Test data show that the resulting aerogel material exhibits the following excellent properties: a density of only 8-10 mg/cm³, a specific surface area of 768.89 m^2/g and excellent adsorption properties for a wide range of oils and organic solvents, with an adsorption capacity of up to 65-133 times of the material's self-weight and a separation flux of 11,718.8 L (m^2h^{-1}).

3.1.2. Chitosan-based aerogel

Chitosan (CS), as the second most abundant natural polymer-derived material in nature, has many advantages such as non-toxicity, bacteriostasis, biodegradability, etc. It can be used to enhance the cellulose nanocellulose (CNC) gel network, etc. However, the large number of hydroxyl groups makes it also highly hydrophilic, and it is necessary to introduce a variety of functional groups into the hydrophobicity modification of CNC/CS composite aerogels by physical or chemical methods in order to improve the oil-water selectivity and oil-absorption efficiency. It is necessary to introduce various functional groups to hydrophobic modification of CNC/CS composite aerogels by physical or chemical methods in order to improve its oil-water selectivity and oil absorption efficiency. For example, Li [28] et al. used microcrystalline cellulose and chitosan as the dual network unit, sodium hydroxide/urea/water as the solvent system, and methyltrimethoxysilane (MTMS) as the modifier, and adopted the two-step method of “freezing and thawing-impregnation” to obtain superhydrophobic cellulose/chitosan composite aerogels. The results showed that the aerogel has good oil/water selective absorption ability, the maximum oil absorption reached 9.3 g/g, and the adsorption amount of isopropanol could still maintain 92.8% of the initial value after 5 regeneration cycles, which is a benign and renewable biomass-based oil-absorbing material.

3.1.3. Alginate-based aerogel

Alginate is a naturally occurring anionic polymer derived from marine organisms (e.g. seaweeds), usually from Sargassum or brown algae such as kelp. It consists of β-D-mannuronic acid (M-unit) linked to its stereoisomer α-L-guluronic acid (G-unit) relying on β-1,4-glycosidic bonds, and has non-toxicity, bioadhesion, biodegradability, and good gelation properties. Alginate-based aerogels with abundant surface groups and porous structures have potential applications in catalyst carriers, wastewater treatment, and so on.

Tian [30] prepared calcium alginate aerogel (CA) using sodium alginate as raw material, and calcium alginate carbon aerogel (CCA) was obtained after high temperature carbonization under the protection of nitrogen, and was held at 1000 °C for 1 h to obtain calcium alginate carbon aerogel-1000 (CCA-1000).The separation of CCA-1000 from a mixture of 3 mL of carbon tetrachloride and 3 mL of water took 6 min, and 24 h after the separation was completed, it could be seen that the volume of water in the glass tube did not change.CCA-1000 took 18 min to separate the mixture of 3 mL hexane and 3 mL water, and 24 h after the separation was completed, it could be seen that the glass tube still contained hexane (the content of hexane was reduced due to volatilization).

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3.2. Effectiveness of synthetic polymer-based aerogels for oil-water separation applications

3.2.1. Polyacrylamide aerogels

Hydrogels with different properties can be prepared by adjusting parameters such as monomer ratio and crosslinking degree. These hydrogels have high water absorption and stability, and can adsorb impurities in the oil phase to a certain extent, thus realizing oil-water separation. For example, Lang [32] processed polypropylene aerogels using supercritical CO_2 drying technology to remove residual solvents from the molecular network to form materials with petal-like micro-nano-structures. Subsequently, the aerogels were loaded onto polyurethane sponges and polypropylene (PP) nonwoven fabric substrates by a coating process to ultimately obtain composite hybrid materials with both aerogel surface properties.The results show that the material has very high oil absorption capacity and cycling performance.

3.2.2. Polyurethane-based aerogels

Wu [33] et al. successfully prepared a series of SiO_2 /polyurethane aerogels with different SiO_2 contents by gel injection molding and freeze-drying using polyurethane and silica nanoparticles as the main raw materials, and modified the prepared samples using silane coupling agent γ-aminopropyltriethoxysilane (KH550) by chemical vapor deposition. The results are the SiO_2 samples with a mass fraction of 12% achieved oil absorption rates of 3.2675, 4.2382, 10.7112, and 4.1019 g/g for pump oil, petroleum ether, dichloromethane, and vegetable oil, respectively.

3.2.3. Polyvinyl alcohol-based aerogels

Poly (vinyl alcohol) -based aerogels have good film-forming and hydrophilic properties, and their oil-water separation performance can be further improved by compounding with other materials. For example, Gong [34] et al. prepared highly porous (porosity >97.7%), hydrophobic and compressible cellulose nanocrystals/polyvinyl alcohol aerogels on the surface of cellulose nanocrystals (CNCs) as the raw material, with the assistance of polyvinyl alcohol (PVA) by thermal chemical vapor deposition (CVD), which have good adsorption selectivity and adsorption capacity of the oil phase, and the maximum adsorption capacity can reach 32.7 times its own weight, which is a potential recyclable aerogel. The maximum adsorption capacity was up to 32.7 times of its own weight, which is a promising recyclable adsorption material.

3.3. Effectiveness of composite aerogel for oil-water separation applications

3.3.1. Inorganic nanomaterials composite aerogel

Compositing inorganic nanomaterials such as silica nanoparticles, zinc oxide nanoparticles, and clay nanoparticles with natural or synthetic polymer aerogels can significantly improve the mechanical properties, thermal stability, and oil-water separation efficiency of the aerogels. For example, atmospheric pressure-drying silica aerogel-melamine foam composites with superhydrophobicity, self-cleaning and water-repairing properties. researchers such as Fashandi [35] innovatively introduced flexible melamine foam (MF) into the silica aerogel system, and successfully realized drying treatment of the composite under atmospheric pressure, a breakthrough which provides a new way of thinking for large-scale preparation and application of aerogels. This breakthrough provides a new idea for the large-scale preparation and application of aerogel. In addition, by constructing a

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dual crosslinked network, polyvinyltrimethoxysilane (PVTMS) combines with methyltrimethoxysilane (MF) to endow the material with mesoporous structure and high specific surface area. Meanwhile, the introduction of MTMS transformed MF from hydrophilic to superhydrophobic without additional surface modification. Due to its superhydrophobicity and porous structure, the material was able to quickly adsorb toluene and completely separate toluene from water within 33 seconds, and maintained a stable ultra-high oil flux (~120,000 L-m-^{2}-h-^{1}) after 10 consecutive cycles of use.

3.3.2. Graphene-based composite aerogel

Graphene-based composite aerogel is a three-dimensional porous and lightweight material constructed based on graphene and its derivatives (e.g., graphene oxide, reduced graphene oxide), which has unique physicochemical properties and exhibits promising applications in the fields of energy, environment, catalysis, sensing, and biomedicine.

Luo [36] et al. prepared porous nanocellulose/graphene composite aerogel materials with hydrophobic properties, i.e., CNC/GA materials, by a two-step reduction method based on a liquid-phase self-assembly process, using cross-linked porous graphene aerogel (GA) as a backbone, and cellulose nanocrystals (CNC) as an additive, for the purpose of preparing a new type of green and environmentally friendly graphene-based oil-absorbent materials. The results showed that the mass adsorption ratio of this CNC/GA material for common organic solvents, such as silicone oil, could exceed 80 g/g, and the saturated adsorption of n-hexane remained at 78 g/g after 20 cycles.

4. Structural optimization

4.1. Effect of porous structure on performance

The porous structure of nanocellulose aerogel is an important factor affecting its oil absorption ability. The oil-absorbing material mainly relies on the material's own pores to first adsorb the oil through the van der Waals force on the oil molecules generated by the fiber surface, and then use the pores of the fibers to absorb the oil through the capillary principle. The porous structure not only increases the specific surface area of nanocellulose aerogel, but also provides a large number of pore structures, which is conducive to the diffusion of oil substances inside the aerogel [37]. The porosity of nanocellulose aerogel is directly proportional to its adsorption capacity, and the high porosity provides a channel for the adsorption of oil substances by the aerogel [38]. Generally speaking, the smaller the diameter of the fibers is, the smaller the pore diameter is, and the larger the porosity is, the stronger the capillary effect is, the more favorable for oil adsorption; however, when the pore size is too small and prevents oil molecules from passing through, it is not favorable for oil adsorption [39]. In addition, hydrophobic modification of nanocellulose aerogels also reduces the pore size of nanocellulose aerogels to a certain extent. The pore size of nanocellulose aerogels is also reduced by the hydrophobic modification [40].

4.2. Effect of specific surface area on performance

The total surface area of a substance per unit mass is the specific surface area. Based on the porous and fibrous nature of nanocellulose aerogels, nanocellulose aerogels usually have a high specific surface area, and a high specific surface area can provide more adsorption sites, which is conducive to the diffusion and adsorption of oil molecules in nanocellulose aerogels. The specific surface area of the nanocellulose aerogels can be adjusted to some extent by changing the preparation parameters

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of the nanocellulose aerogels, such as the concentration of nanofibrillar cellulose and the crosslinking method [41].

5. Conclusions and overlook

With the increasing pollution of industrial oily wastewater, the development of efficient and sustainable oil-water separation technologies has become a key challenge for environmental management. Aerogel materials exhibit significant advantages in the field of oil-water separation due to their unique three-dimensional porous structure, high specific surface area and tunable surface chemistry. The paper outlines the principles and advantages and disadvantages of traditional oil-water separation methods, and analyzes the preparation methods of different kinds of aerogel materials and the effect advantages in oil-water separation applications. It focuses on analyzing and summarizing the development status of three types of aerogel materials: natural polymer-based aerogel, synthetic polymer-based aerogel, and composite aerogel, as well as characterizing the effects of different properties on oil-water separation, and at the same time provides a brief overview of the structural optimization and the principles of separation (e.g., gravitational separation, adsorption, membrane separation, etc.). Future research can advance the application of aerogels in the field of oil-water separation in the following directions: the use of green preparation and large-scale production, sustainable development and circular economy, structural optimization and biomimetic design.

References

[1] H. Escobar, Mystery oil spill threatens marine sanctuary in Brazil, Science 366 (2019) 672–672. https: //doi.org/10.1126/science.366.6466.672.
[2] A. Jernelöv, How to defend against future oil spills, Nature 466 (2010) 182–183. https: //doi.org/10.1038/466182a.
[3] M. Salomone, Ecological riches threatened as oil-spill history repeats itself, Nature 420 (2002) 347–347. https: //doi.org/10.1038/420347a.
[4] N. Zhang, Y. Zhou, Y. Zhang, W. Jiang, T. Wang, J. Fu, Dual-templating synthesis of compressible and superhydrophobic spongy polystyrene for oil capture, Chemical Engineering Journal 354 (2018) 245–253. https: //doi.org/10.1016/j.cej.2018.07.184.
[5] J.-C. Wang, H. Lou, Z.-H. Cui, Y. Hou, Y. Li, Y. Zhang, K. Jiang, W. Shi, L. Qu, Fabrication of porous polyacrylamide/polystyrene fibrous membranes for efficient oil-water separation, Separation and Purification Technology 222 (2019) 278–283. https: //doi.org/10.1016/j.seppur.2019.04.044.
[6] C. Li, J. Hu, H. Yan, Y. Yao, L. Zhang, J. Bao, Preparation of Open-Cell Long-Chain Branched Polypropylene Foams for Oil Absorption, ACS Omega 8 (2023) 49372–49382. https: //doi.org/10.1021/acsomega.3c07915.
[7] G. Prasad, X. Lin, J. Liang, Y. Yao, T. Tao, B. Liang, S.-G. Lu, Fabrication of intra porous PVDF fibers and their applications for heavy metal removal, oil absorption and piezoelectric sensors, Journal of Materiomics 9 (2023) 174–182. https: //doi.org/10.1016/j.jmat.2022.08.003.
[8] Mohiuddin_2024_Mater._Res._Express_11_085605 graphene.pdf, (n.d.).
[9] C. Wang, Y. Bu, H. Liu, S. Guo, Preparation and characterization of core-shell oil absorption materials stabilized by modified fumed silica, Journal of Polymer Engineering 37 (2017) 391–399. https: //doi.org/10.1515/polyeng-2016-0075.
[10] R.I. Kosheleva, G.Z. Kyzas, N.C. Kokkinos, A.C. Mitropoulos, Low-Cost Activated Carbon for Petroleum Products Clean-Up, Processes 10 (2022) 314. https: //doi.org/10.3390/pr10020314.
[11] P.D. Sutrisna, K.A. Kurnia, U.W.R. Siagian, S. Ismadji, I.G. Wenten, Membrane fouling and fouling mitigation in oil–water separation: A review, Journal of Environmental Chemical Engineering 10 (2022) 107532. https: //doi.org/10.1016/j.jece.2022.107532.
[12] S. Chatterjee, W.-T. Ke, Y.-C. Liao, Elastic nanocellulose/graphene aerogel with excellent shape retention and oil absorption selectivity, Journal of the Taiwan Institute of Chemical Engineers 111 (2020) 261–269. https: //doi.org/10.1016/j.jtice.2020.04.020.

DOI: 10.54254/2755-2721/2025.MH25616

[13] W. Ke, F. Ge, X. Shi, Y. Zhang, T. Wu, X. Zhu, Y. Cheng, Y. Shi, Z. Wang, L. Yuan, Y. Yan, Superelastic and superflexible cellulose aerogels for thermal insulation and oil/water separation, International Journal of Biological Macromolecules 260 (2024) 129245. https: //doi.org/10.1016/j.ijbiomac.2024.129245.
[14] T. Liu, C. Cai, R. Ma, Y. Deng, L. Tu, Y. Fan, D. Lu, Super-hydrophobic Cellulose Nanofiber Air Filter with Highly Efficient Filtration and Humidity Resistance, ACS Appl. Mater. Interfaces 13 (2021) 24032–24041. https: //doi.org/10.1021/acsami.1c04258.
[15] S.S. Kistler, Coherent Expanded-Aerogels, (n.d.).
[16] Y. Xiao, H.-Q. Lu, C.-R. Shi, F.-H. Lei, D. Rackemann, K. Li, W. Li, W.O.S. Doherty, High-performance quaternary ammonium-functionalized chitosan/graphene oxide composite aerogel for remelt syrup decolorization in sugar refining, Chemical Engineering Journal 428 (2022) 132575. https: //doi.org/10.1016/j.cej.2021.132575.
[17] P. Grodzinski, M. Kircher, M. Goldberg, A. Gabizon, Integrating Nanotechnology into Cancer Care, ACS Nano 13 (2019) 7370–7376. https: //doi.org/10.1021/acsnano.9b04266.
[18] Zhang, G., Zhou, M., & Liang, B. (2002). Research and development trends of high oil-absorbent resin. New Chemical Materials, 30(1), [Page range].
[19] Lu, J., & Zhou, M. (2002). The development of oil-absorptive materials. Journal of Dong Hua University (Natural Science Edition), 28(1), [Page range].
[20] W. Kong, F. Li, Y. Pan, X. Zhao, Hygro-responsive, Photo-decomposed Superoleophobic/Superhydrophilic Coating for On-Demand Oil–Water Separation, ACS Appl. Mater. Interfaces 13 (2021) 35142–35152. https: //doi.org/10.1021/acsami.1c08500.
[21] Fan, B. (2024). Construction of cellulose nanofiber-based aerogel and its oil-water separation performance (Doctoral dissertation). Jiangnan University. https: //www.cnki.net
[22] F. Wu, R. Li, A. Yao, Z. Li, H. An, H. Ye, Q. Xin, Y. Zhang, H. Li, L. Zhao, Porous membrane with highly stable liquid-filled surface based on aerogel structure for oil-water separation, Colloids and Surfaces A: Physicochemical and Engineering Aspects 674 (2023) 131913. https: //doi.org/10.1016/j.colsurfa.2023.131913.
[23] F. Wang, X. Zhao, F. Wahid, X. Zhao, X. Qin, H. Bai, Y. Xie, C. Zhong, S. Jia, Sustainable, superhydrophobic membranes based on bacterial cellulose for gravity-driven oil/water separation, Carbohydrate Polymers 253 (2021) 117220. https: //doi.org/10.1016/j.carbpol.2020.117220.
[24] Z. Yan, K. Zhu, X. Li, X. Wu, Recyclable Bacterial Cellulose Aerogel for Oil and Water Separation, J Polym Environ 30 (2022) 2774–2784. https: //doi.org/10.1007/s10924-021-02369-y.
[25] C. Tan, B.M. Fung, J.K. Newman, C. Vu, Organic Aerogels with Very High Impact Strength, Advanced Materials 13 (2001) 644–646. https: //doi.org/10.1002/1521-4095(200105)13: 9< 644: : AID-ADMA644> 3.0.CO; 2-#.
[26] X. Ma, S. Zhou, J. Li, F. Xie, H. Yang, C. Wang, B.D. Fahlman, W. Li, Natural microfibrils/regenerated cellulose-based carbon aerogel for highly efficient oil/water separation, Journal of Hazardous Materials 454 (2023) 131397. https: //doi.org/10.1016/j.jhazmat.2023.131397.
[27] Lou, Z., Tu, Y., Li, N., & Kong, J. (2025). Preparation and Oil-water Separation Performance Study of Superhydrophobic Nanocellulose Aerogels Based on Corn Stover. Journal of Cellulose Science and Technology, 33(1), 1–7. https: //publish.cnki.net/xwsk
[28] Li, R., Feng, X., Li, T., Ma, Z., Yang, A., Jiao, C., & Wang, J. (2022). Construction of Cellulose/Chitosan Super-Hydrophobic Aerogel by Freeze-Thaw Method and Its Oil Absorption Performance. Polymer Materials Science and Engineering, 38(4), 119–125. https: //doi.org/10.16865/j.cnki.1000-7555.2022.0081
[29] Liu, X., Chen, Q., Zhu, R., & Zhu, J. (2024). Preparation of Organic Montmorillonite/Chitosan Aerogels and Its Applications in Organic Pollution Control. Geochimica, 53(1), 142–152. https: //doi.org/10.19700/j.0379-1726.2024.01.012
[30] Tian, X. (2019). Preparation and Performance Study of Multifunctional Calcium Alginate Carbon Aerogels (Master's thesis). Qingdao University.
[31] Zhu, H. (2021). Study on dye adsorption and oil-water separation of sodium alginate carbon aerogel. Industrial Water Treatment, 41(5), 125–129. https: //doi.org/10.11894/jwt.2020-1135
[32] X.H. Lang, T.Y. Zhu, L. Zou, K. Prakashan, Z.X. Zhang, Fabrication and characterization of polypropylene aerogel material and aerogel coated hybrid materials for oil-water separation applications, Progress in Organic Coatings 137 (2019) 105370. https: //doi.org/10.1016/j.porgcoat.2019.105370.
[33] Wu, Y., Zhou, H., & Liu, Z. (2024). Preparation and Oil-water Separation Performance of Polyurethane/SiO_2 Aerogel. Shandong Chemical Industry, 53(9), 68–72. https: //doi.org/10.19319/j.cnki.issn.1008-021x.2024.09.006
[34] gong-et-al-2019-highly-porous-hydrophobic-and-compressible-cellulose-nanocrystals-poly(vinyl-alcohol)-aerogels-as, (n.d.).
[35] M. Fashandi, Z. Ben Rejeb, H.E. Naguib, C.B. Park, Ambient pressure dried silica aerogel – Melamine foam composite with superhydrophobic, self-cleaning and water remediation properties, Separation and Purification

DOI: 10.54254/2755-2721/2025.MH25616

Technology 325 (2023) 124201. https: //doi.org/10.1016/j.seppur.2023.124201.
[36] Luo, Y., Ye, Z., Wang, H., Chen, C., & Shao, J. (2022). Preparation of Nanocrystalline Cellulose/Graphene Aerogel and Its Application in Oil-Water Separation. Safety and Environmental Engineering, 29(2), 205-211. https: //doi.org/10.13578/j.cnki.issn.1671-1556.20210481
[37] Cao, H., Li, Y., Zhao, S., Zhang, Y., & Li, W. (2025). Review on recent advances in nanocellulose aerogels for oil-water separation. Acta Materiae Compositae Sinica, 42(2), 598-616. https: //doi.org/10.13801/j.cnki.fhclxb.20240805.004
[38] J. Wang, Y. Zheng, A. Wang, Coated kapok fiber for removal of spilled oil, Marine Pollution Bulletin 69 (2013) 91–96. https: //doi.org/10.1016/j.marpolbul.2013.01.007.
[39] j.chemosphere.2006.05.062, (n.d.).
[40] X. Zhang, X. Zhao, T. Xue, F. Yang, W. Fan, T. Liu, Bidirectional anisotropic polyimide/bacterial cellulose aerogels by freeze-drying for super-thermal insulation, Chemical Engineering Journal 385 (2020) 123963. https: //doi.org/10.1016/j.cej.2019.123963.
[41] Z. Zhai, H. Li, Y. Zheng, Y. Ji, H. Peng, Y. Gao, M. Yan, H. Yu, High specific surface area carbon aerogel derived from starch for methylene blue adsorption and supercapacitors, International Journal of Biological Macromolecules 274 (2024) 133282. https: //doi.org/10.1016/j.ijbiomac.2024.133282.