2023 SICASH
SLIIT INTERNATIONAL CONFERENCE ON ADVANCEMENTS IN SCIENCES & HUMANITIES

# An Overview of Bioinspired Materials and Their Role in Modern Day Oil-water Separation Processes

* [1]Warahena, T.A, [2]Edirisinghe, U. A. S. K

[1]Institute of Chemistry Ceylon, Adamantane House, 341/22 Kotte road, Welikada, Rajagiriya, Sri Lanka

[2]Dept. of Agriculture and Food Technology, Faculty of Industrial Technology, University of Vocational Technology, 100 Kandawala, Rathmalana, Sri Lanka

Email address of the corresponding author - * stu185069@student.ichemc.edu.lk

**ARTICLE INFO**

**Article History:**
**Received: 10 September 2023**
**Accepted: 01 November 2023**

**Keywords:**
**Bioinspired materials; Biomimetic membranes; Mesoporous support materials; Nanomaterials; Water purification**

**Citation:**

**Warahena, T.A, Edirisinghe, U. A. S. K. (2023). An Overview of Bioinspired Materials and Their Role in Modern Day Oil-water Separation Processes. Proceedings of SLIIT International Conference on Advancements in Sciences and Humanities, 1-2 December, Colombo, pages 364-369.**

**ABSTRACT**

Unexpected oil spills and industrial oily wastewater discharges are becoming more common as global energy demand rises. Due to the significant water contamination caused by oil spills and industrial organic pollutants, the ecological system is in peril. Over the last ten years, specialized wettability-stimulated materials have been created to separate oil-and-water combinations in order to cope with spilt oil. Frequent oil spills and an increase in oily sewage not only cause considerable water contamination and other environmental issues, but they also have significant economic consequences. Designing cutting-edge technologies and materials for successful oil-water separation is a key strategy for tackling such issues, and it is now a significant research field. Bioinspired materials are generated by adapting design concepts from biological systems and biological materials to creatively improve material performance for a wide range of applications including marine, aerospace, medical, and engineering. Scientists evaluated recent advances in oil-water separation utilizing superwetting porous materials, encouraging researchers to create bioinspired materials with the necessary features and capabilities by uniting science and nature. These new biomimetic materials are expected to make their way into existing water


https://doi.org/10.54389/LTCF4861

purification systems, where they will improve purification/removal efficacy while remaining cost-effective and environmentally benign. This article addresses recent advancements in bioinspired structures, as well as the challenges and opportunities encountered in manufacturing bioinspired materials for sustainable water purification procedures, mainly oil-water separation to create bioinspired materials with the necessary features and capabilities by uniting science and nature.

## 1. INTRODUCTION

Biological materials are superbly conceived and refined instruments that nature provides to help organisms grow and survive in harsh environments. They are concise systems that address a myriad of mechanical and functional purposes with optimal in performance. This contrasts with most bio - based materials, which typically rely on complex chemistry or costly processing and thereby frequently face a dilemma between qualities (e.g., increasing weight to increase strength)(Y. Wang et al., 2020). A primary phase of observation of design or function that generates ideas for producing similar products is referred to as inspiration. Mimicry, or biomimicry is a refined form of inspiration that uses advanced technical instruments to build materials that are similar to natural biological materials, with the main goal of achieving sustainability. As depicted in Table 1.a, bioinspired materials used for oil and water separation processes tend to mimic the surface properties of certain natural organisms or structures, such as lotus leaves(Geraldi et al., 2018), fish scales, cactus, or bird feathers(Zhang et al., 2020), that have evolved to repel water and attract oil. These structures have micro and nanostructures on their surfaces that can be synthetically morphed into fabrics, meshes and sponges, which create rough, textured topographies designed to reduce the contact area between water and the material, making it difficult for water to adhere to the surface and resulting in the separation of oil and water from the system.

*Table 1.a Biologically inspired structures used for oil-water separation and their advantages and limitations.*

| Material Type | Source/Inspiration | Advantages | Limitations |
|---|---|---|---|
| Lotus Leaf Nanocoating | Lotus Leaves(Geraldi et al., 2018) | Self-cleaning(Zhang et al., 2020), high water repellency | Limited oil absorption capacity(Geraldi et al., 2018) |
| Cactus Spines | Cactus Plant(Zhang et al., 2020) | Effective oil capture, Reusable(Yao et al., 2011) | Limited scalability, Material fragility |
| Shark Skin Textures | Shark Skin(Su et al., 2016) | Reduced turbulence, Low friction(Yao et al., 2011) | Limited oil absorption capacity |

Oil spills introduce toxic substances into the sea, endangering marine life. Isolating and removing spilled oil from water is a favored approach to prevent environmental damage and enable potential reuse. Common methods like centrifugation, filtration, and gravity separation of the collected water, however, have drawbacks like low efficiency, energy dependence and the production of secondary pollutants, leading to the search for better separation materials and technologies. Due to the fact that water and oil have different interfacial effects, bioinspired superwetting(Yong et al., 2018) micro-porous materials with surfaces that exhibit superhydrophobic/superoleophilic (SHBOI) properties have recently been effectively brought into the research field of oil-water separation. These display good separating performances in contrast to conventional materials. Physical structures or chemical elements on the surface can produce superwettability as well as other uses, including self-cleaning, anti-fouling and oil/water separation materials.

Separating oil from water during an oil spill using bioinspired materials involves a multi-step process that mimics natural phenomena to efficiently remove and recover the spilled oil. Firstly, these materials, with nanostructures mimicking biological surfaces, are deployed in affected areas, either directly into the water or integrated into floating devices. As they come into contact with the oil spill, their oleophilic nature attracts and adheres to the oil, while their superhydrophobic surface minimizes water interaction. This results in an isolated oil layer on the material's surface, with water droplets forming beads. The adhered oil is then mechanically collected using methods like scooping or conveyor systems. The material can be cleaned for potential reuse, and responsible oil recovery and management are prioritized in oil spill cleanup efforts through continuous monitoring and optimization. Ongoing research aims to enhance the efficiency and adaptability of these materials for various spill scenarios, often in combination with other cleanup techniques like booms and skimmers to improve overall oil spill response efforts. Generally, bioinspired materials can be used to separate various types of oils, including crude oil, petroleum-based oils, synthetic oils, biodiesel, diesel fuel and gasoline, oil-based contaminants like PCBs (polychlorinated biphenyls) and various other organic pollutants.

It is worth noting that the success of this approach depends on several factors, including the design and properties of the bioinspired SHBOI material, the type and viscosity of the spilled oil, and the environmental conditions at the spill site. To develop SHBOI materials, two approaches can be used: the first is to establish a rough structure on a hydrophobic surface, and the second is to change chemicals with a low surface energy on a rough surface (Geraldi et al., 2018). The capacity of particle deposition to create superhydrophobic surfaces allows for increased coverage and works well with simple spray coating processes. One of the current ways is to spray synthetic coatings onto modified metal and silica nanoparticles (Geraldi et al., 2018).

The most popular oil-removing materials are textiles, sponge-based materials, metallic mesh-based materials, Carbon and compounds derived from it. The next sections go over these topics in further depth.

## 2. METALLIC MESH-BASED MATERIALS.

Recent studies have revealed that the use of stainless-steel mesh(Bhushan, 2019) was the first medium for generating SHBOI surfaces utilizing a spray-and-dry approach to enhance separation. It was proved that the mesh, in its initial state, was capable of separating the diesel oil and water mixture. Copper mesh was another popular substrate material for oil-water separation. Furthermore, these meshes' superhydrophobicity remained persistent even in corrosive conditions, expanding its range of potential applications to several severe aqueous environments. Moreover, the oil-water separation procedure can be paired with other qualities like catalysis.

The flexible cubic 3D-SMF (Simple Model Format) represents a promising technology for selectively extracting and storing oils from oil-water mixtures while significantly improving wettability performance. However, it faces several challenges. The rough structure of these metallic meshes can easily damage their superhydrophobic properties, reducing their effectiveness in separating oil from water. Additionally, these meshes require pre-collection of oil-contaminated water before filtration, limiting their suitability for in-situ oil treatment and large-scale oil spills. Furthermore, the lower density of most oils compared to water hinders effective oil-water separation on these meshes. Lastly, the predominant use of stainless steel and copper meshes underscores the need for exploring alternative metallic mesh options to address diverse and complex environmental scenarios effectively.

### 2.1. FABRICS BASED MATERIALS.

Soft and flexible organic fabric materials(Li et al., 2018) are also regarded as an excellent nominee for oil-water separation after undergoing various post-treatments including dip coating, chemical in situ growth, electrospinning etc., because the ready-made fibers included in the integral fabric have already provided the micro-scale roughness and the needed porosity. Due to the presence of oxygen groups within the fabric's composition, they portray unstable hydrophobic properties as the contact angle will eventually reduce as water penetrates. Creating rough structured surfaces on fabric that are both superhydrophobic and superoleophilic is a potential option for separating a mixture of water and oils or organics. As an example, organic cotton fabrics were submerged in titania sol to create a dual-sized surface roughness prior to getting hydrophobized with stearic acid to yield superhydrophobic cotton fabrics. Likewise, superhydrophobic fabrics can be overloaded with inorganic elements to improve their mechanical stabilities, controllability of coated nanocrystals, and time- and resource-saving possibilities. Transition-metal/metal oxides have received more attention in this field. For example, Ag nanocrystals (Bu et al., 2018) have an antimicrobial effect, while Fe, Co, and Ni nanoparticles are magnetic materials that have been widely employed in recyclable materials. CuO (B. Wang et al., 2013) is a semiconductor that provides a variety of capabilities. However, one significant limitation of materials such as metal mesh film and fabric is that they cannot be used immediately to clean up oil spills in the ocean because doing so would require collecting the contaminated water first and then filtering it, which is impractical in the actual process.

### 2.2. POROUS 3D MATERIALS, SPONGES AND FOAMS

To separate oil-water systems, three-dimensional (3D) porous bulk materials can be used in an absorption-based technique. Porous inorganic minerals such as zeolite beds, activated carbon, silica aerogels, and cleaned graphite, as well as porous organic synthetic polymers such as polyurethane (PU) foams (Yong et al., 2018), and rubbers, are examples of traditional absorbents. To improve oil absorption and reusability, SHBOI 3D porous materials with unique coatings have recently been created. In some cases, 3D oil-absorption materials are preferable over separating mesh membranes and textiles to separate oil from water. If a tiny amount of oil spills onto the ocean's surface, for example, it may merely need to be cleaned up with an oil-absorbent material, such as foam and sponges which are readily available, inexpensive porous materials with good wettabilities. Since they can soak up a wide variety of liquids, including water, they are often unable to draw out oils or organics from the aqueous phase as a result of their limited selectivity. However, significant selective absorption can be attained on sponges by cautiously creating an appropriate surface morphology and changing it with a material with lower surface energies. It is an efficient technique for developing oil-water separation materials.

### 2.3. CARBON AND ITS DERIVED MATERIALS

Due to their exceptional qualities, including low density, high porosity, excellent electrical conductivity, a large specific surface area, good chemical inertness, and flexibility, carbon-based aerogels(Kapoor et al., 2022), which are composed of interconnected three-dimensional networks, have attracted significant condensation. In the realm of oil-water separation, their low density, high porosity, and inherent hydrophobicity make them particularly strong contenders for the oil-removing materials.

Twisted carbon fibers (TCF) aerogels were developed through employing a simple pyrolysis technique in an argon gas atmosphere using affordable raw cotton. TCF aerogels were capable of absorbing a wide spectrum of organic solvents and oils. In general, pyrolyzation-treated carbon-based materials are classified as flexible or inflexible based on their elasticity. This makes a significant difference in terms of oil reusability because flexible carbon-based aerogels can recycle ingredients by direct squeezing, burning, and distillation. The squeezing approach, however, is not applicable for an inflexible carbon material. As another example, spongy graphene(Y. Wang et al., 2020) was generated by compressing a solution of graphene oxide (GO) platelets and then shaping through a hydrothermal treatment and freeze-drying procedure. Without any further modification or treatment, as-obtained spongy graphene displayed successful oil removing ability to petroleum-based oils, alkanes, toluene, and other organic solvents.

## 3. CONCLUSION

The separation of oil and water is a vital step in addressing the environmental and industrial issues created by oil contamination. Conventional oil-water separation technologies are usually costly, ineffective, and dangerous to the environment. As a result, innovative materials that can produce successful and long-term oil-water separation are required. Biological and bioinspired materials, which draw inspiration from nature's spectacular marvels, have emerged as attractive choices for this purpose. These materials, which frequently have hierarchical structures and remarkable wettability, can selectively separate oil and water phases under a range of situations, creating a greener environment.

## REFERENCES


Bhushan, B. (2019). Bioinspired oil-water separation approaches for oil spill clean-up and water purification. In *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences , 377* (2150). https://doi.org/10.1098/rsta.2019.0120

Bu, Y., Huang, J., Zhang, S., Wang, Y., Gu, S., Cao, G., Yang, H., Ye, D., Zhou, Y., & Xu, W. (2018). *Robust superhydrophobic surface by nature-inspired polyphenol chemistry for effective oil-water separation*. https://doi.org/10.1016/j.apsusc.2018.01.177

Geraldi, N. R., Dodd, L. E., Xu, B. B., Wood, D., Wells, G. G., McHale, G., & Newton, M. I. (2018). Bioinspired nanoparticle spray-coating for superhydrophobic flexible materials with oil/water separation capabilities. *Bioinspiration and Biomimetics*, *13*(2). https://doi.org/10.1088/1748-3190/aaa1c1

Kapoor, R. T., Rafatullah, M., Qamar, M., Qutob, M., Alosaimi, A. M., Alorfi, H. S., & Hussein, M. A. (2022). Review on Recent Developments in Bioinspired-Materials for Sustainable Energy and Environmental Applications. In *Sustainability (Switzerland),14* (24). MDPI. https://doi.org/10.3390/su142416931

Li, F., Wang, Z., Huang, S., Pan, Y., & Zhao, X. (2018). Flexible, Durable, and Unconditioned Superoleophobic/Superhydrophilic Surfaces for Controllable Transport and Oil–Water Separation. *Advanced Functional Materials*, *28*(20). https://doi.org/10.1002/adfm.201706867

Su, B., Tian, Y., & Jiang, L. (2016). Bioinspired Interfaces with Superwettability: From Materials to Chemistry. In *Journal of the American Chemical Society, 138* (6) 1727–

1748. American Chemical Society. https://doi.org/10.1021/jacs.5b12728

Wang, B., Li, J., Wang, G., Liang, W., Zhang, Y., Shi, L., Guo, Z., & Liu, W. (2013). Methodology for robust superhydrophobic fabrics and sponges from in situ growth of transition metal/metal oxide nanocrystals with thiol modification and their applications in oil/water separation. *ACS Applied Materials and Interfaces*, *5(*5), 1827–1839. https://doi.org/10.1021/am303176a

Wang, Y., Naleway, S. E., & Wang, B. (2020). Biological and bioinspired materials: Structure leading to functional and mechanical performance. *Bioactive Materials*, *5*(4) 745–757. https://doi.org/10.1016/j.bioactmat.2020.06.003

Yao, X., Song, Y., & Jiang, L. (2011). Applications of bio-inspired special wettable surfaces. *Advanced Materials 23*(6), 719–734. https://doi.org/10.1002/adma.201002689

Yong, J., Huo, J., Chen, F., Yang, Q., & Hou, X. (2018). Oil/water separation based on natural materials with super-wettability: Recent advances. In *Physical Chemistry Chemical Physics 20*(39), 25140–25163. Royal Society of Chemistry. https://doi.org/10.1039/c8cp04009e

Zhang, Y., Mei, J., Yan, C., Liao, T., Bell, J., & Sun, Z. (2020Bioinspired 2D Nanomaterials for Sustainable Applications. *Advanced Materials 32*(18). Wiley-VCH Verlag. https://doi.org/10.1002/adma.201902806