STM JOURNALS

Journal of
Water Pollution &
Purification Research

ISSN: 2394-7306
Volume 13, Issue 1, 2026
January–April
DOI (Journal): 10.37591/JoWPPR

https://journals.stmjournals.com/jowppr

Research JoWPPR

Development and Application of Advanced Materials for Oil- Spill Cleanup and Contaminant Removal

S. V. Joshi[1,*], S. P. Borhade[1], K. G. Mhalunde[1], S. D. Sambare[1], V. P. Bhaurkar[1]

Abstract

Oil spills and environmental contaminants representing critical challenges to ecosystems and human health, demanding innovative and effective solutions. Advanced materials have emerged as transformative tools in addressing these issues, offering superior efficiency and sustainability compared to conventional methods. They are environmental and ecological threats, necessitating effective cleanup and removal strategies. The development and application of advanced materials are developing promising solutions for addressing the challenges. This study focuses on the design, synthesis, and deployment of innovative materials for oil spill remediation and contaminant removal, emphasizing their efficiency, sustainability, and cost-effectiveness. Key materials, such as functionalized graphene, aerogels, metal-organic frameworks (MOFs), and bio-based sorbents, are reviewed for their exceptional adsorption capacity, selectivity, and reusability. Recent advancements highlight the potential of hydrophobic and oleophilic materials to efficiently separate oil and water, while nanomaterials exhibit unparalleled properties for tackling contaminants at a molecular level. The findings underscore the transformative potential of advanced materials in safeguarding ecosystems, promoting sustainable practices, and supporting global environmental conservation efforts. This research shows the way for interdisciplinary innovations that combine material science, environmental engineering, and biotechnology to develop eco-friendly solutions for a cleaner and more sustainable future.

Keywords: Chemical dispersant, in-situ burning, oil-spillage, contaminants and sustainable environment

INTRODUCTION

Now a days oil spillage has become a major problem. Oil spillage means when liquid petroleum is released in the water bodies mostly seas i.e. Marine bodies because of human activities such as transportation by ships, industrial waste supplied to the sea, etc. This has adverse and devasting effects on ecosystems, marine and wildlife, and coastal economies. Oil spill is one of the challenges which faces global ecosystems and human health. Due to oil spillage the major damage is that these pollutants disrupt marine life, soil quality, and water resources, also it creates long-term ecological and economic impacts. For deducting this effect, we have seen conventional cleanup methods, like booms and dispersants, which often fall short in efficiency, environmental safety, and scalability. Advanced materials, with their unique properties and tailored functionalities, offer innovative solutions to these issues, paving the way for more effective and sustainable remediation strategies. This research involves the development and application of advanced materials for tackling oil

***Author for Correspondence**
S. V. Joshi
E-mail: joshisarthak027@gmail.com

[1]Assistant Professor, Department of Mechanical Engineering, Sanjivani College of Engineering, Kopargaon, Maharashtra, India

Received Date: February 24, 2026
Accepted Date: March 06, 2026
Published Date: March 15, 2026

Citation: S. V. Joshi, S. P. Borhade, K. G. Mhalunde, S. D. Sambare, V. P. Bhaurkar. Development and Application of Advanced Materials for Oil- Spill Cleanup and Contaminant Removal. Journal of Water Pollution & Purification Research. 2026; 13(1): 17–25p.

spills and contaminants, focusing on their potential to revolutio niz.e environmental cleanup [1].

In Figure 1 There are different photos indicating oil spillage.

(a) Due to oil spilled in sea the bird is struggling (AP Photo/Gerald Herbert).
(b) lt is In-situ Burning of oil Spill at Sea.
(c) In this image the aircraft is monitoring the pattern of oil spill on the ocean surface (John Moore/Getty Images).
(d) large oil accumulation leading to bad sea water level.

Impact of Oil spill

(a) *Environmental:* The Oil can suffocate marine life, damage habitats like coral reefs and mangroves, and disrupt the food chain.
(b) *Economic:* Fishing and tourism industries can be severely impacted, leading to significant economic losses for coastal communities.
(c) *Health Risks:* If there is any contact with oil and its fumes then it may lead to severe health issues for humans, like respiratory problems and skin irritation.
(d) *Water Quality:* Oil spills degrade water quality this affects marine life and makes the water non consumable for humans.

Need of removal of Oil spills

(a) Removing oil quickly helps protect wildlife especially aquatic life and their habitats.
(b) Cleaning up spills restores the balance and promotes the recovery of affected areas.
(c) Removing oil helps to restore these vital economic resources.
(d) Removing oil reduces these health risks.
(e) Effective oil spill removal supports the natural recovery processes of affected ecosystems, promoting resilience and sustainability.

LITERATURE SURVEY

Introduction

Biggest fight for the humans is to face the pollution whether that is air or water. Both have been significant types degrading the ecosystem. Advanced eco-friendly technologies play a crucial role in cleaning up these spills effectively. Organic materials have shown great potential in addressing this issue, serving as sorbents, surfactants, and separators for oil removal. However, it is essential to ensure these materials are non-toxic, cost-effective, and environmentally safe, as some organic substances might inadvertently worsen the contamination [2]. If the oil is recovered from the environmental surface, then after the success fig.1 removal of that oil, it can be conducive to sustainable development This review summarizes the overall perspective on the potential of different biomaterials for the removal of accidentally spilled oils.

Figure 1. (a–d) Example of oil spillage.

Figure 2 is showing the accident occurred in Gulf of Mexico. This also shows that aquatic life is totally affected due to this.

One of the biggest oil spillage accidents happened over the growing concern over pollution, especially water contamination from oil spills, poses a significant threat to marine ecosystems and demands immediate attention. Oil spills are often caused by shipping accidents, pipeline leaks, or tanker mishaps, though less frequent nowadays, still result in catastrophic environmental damage [5]. Advanced eco-friendly technologies play a crucial role in cleaning up these spills effectively. Organic materials have shown great potential in addressing this issue, serving as sorbents, surfactants, and separators for oil removal. However, it is essential to ensure these materials are non-toxic, cost-effective, and environmentally safe, as some organic substances might inadvertently worsen the contamination. Among the solutions, biomaterials stand out as a promising and affordable option to tackle accidental oil spills while restoring the balance of aquatic ecosystems. At this time a lot of oil was spilled over the oceans, and it was for more than 85 days. At that time the oil affected fishes, aquatic plants and the fishing economy. The accident occurred because of poor storage condition, transportation, mechanical dysfunction and utilities. As we know evaporation process, most of oil disappeared from the ocean and some part got mixed with surface and some remaine in environment as small droplet which polluted the environment.

Methods for Oil Spillage Removal

Methods of oil spillage removal are shown in Figure 3 and they are briefly explained below.

Chemical Dispersant/Emulsifier

In this method chemical break oil into small droplets and promotes natural biodegradation. Dispersants are sprayed on the oil, but their environmental impact is an important point to be noted. We know that Chemicals prevent the mixing of oil and water, also they reduce the formation of emulsions. They can be quickly applied over large areas, helping to reduce the size of the oil layers and avoid it to reach shorelines.

Figure 2. (a-d) Oil incident at Gulf of Mexico (2012).

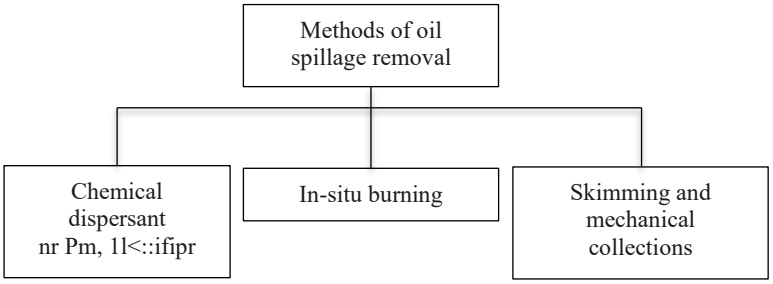

Figure 3. Methods of oil spillage removal.

The In-Situ Burning

The Controlled Burning method for oil spill which removes large amounts of oil quickly but produces air pollution and is unsuitable near populated areas. It is fast and efficient it removes up to 90% of the oil in ideal conditions. It also prevents oil from reaching sensitive ecosystems like shorelines or mangroves. It requires minimum equipment compared to other cleanup methods. It also generates less residual waste for disposal compared to physical methods.

Skimming and Mechanical Collections

They are among the most employed techniques for oil spill cleanup due to their effectiveness in recovering large volumes of oil with minimal environmental damage. Skimming and mechanical collection are effective for oil spills with thicknesses between I and 10 mm and in calm sea conditions.

Key Findings About Contaminants Removal

(a) Oil spills present serious environmental and economic challenges, threatening marine ecosystems, wildlife, and coastal communities.
(b) Use of Graphene for the control of oil spill.
(c) Materials like straw, peat moss, and sawdust have been used as absorbents in oil spill clean-ups.
(d) Booms and skimmers are common but often inefficient in rough weather or large spills.
(e) Dispersants can spread oil droplets, but they may introduce toxic chemicals into marine environments, making them less sustainable.
(f) Hydrophobic and oleophilic surfaces: These materials repel water and attract oil, improving clean-up efficiency.

Oil Spillage Treatment Methods

Figure 4 shows the different techniques applied to separate oil and water.

Gravity Separation

This method uses the natural difference in density between oil and water. The oil-water mix is first contained, then stored so the oil can rise to the top. Once separated, the oil is skimmed off.

Advantages: It's simple, low-cost, and doesn't use harmful chemicals.

Membrane Separation

In this method the special membranes consisting tiny pores permit the water to flow while blocking oil. Here few members were coated for enhancing performance.

Advantages: Method is eco-friendly as no chemicals are added.

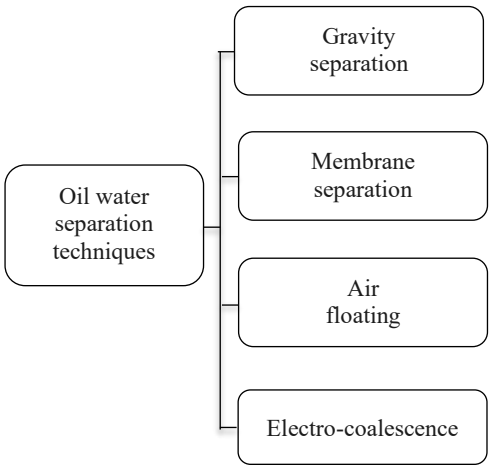

Figure 4. Oil water separation techniques.

Air Flotation

Mixture consists of air bubbles that are attached to oil drops and helping them float on surface. Oil is removed off due to this.

Advantages: It is non-chemical and good for cold conditions.

Electro Coalescence

The electric field is introduced to the mixture, and it leads for clumping and rising of water droplets also separates oil.

Advantages: No use ofchemicals for effective cleaning ofoil.

Membranes of Oil and Water Separation

In this process the focus is to remove the oil from water when there is oil spill. Here the contaminated water is passed by special membrane which is made by polymers/metals. Membranes contain small pores which allow only water to flow through and blocks oil. The method is environment friendly and impactful for separating oil from water [6].

Figure 5 is showing the understandable diagram for oil and water membrane separation.

Possible Research gaps

(a) *Natural and Sustainable Technologies:* The need for new solutions in oil spillage cleanup by eco-friendly is very crucial.
(b) *Directions for Cleanup Technologies:* There should be proper guidelines by the international organizations for maintaining the eco-friendly cleanup technology.
(c) *Research on new materials:* Research should be done for creating best materials like natural sorbents that are good for oil spill cleanup.
(d) *Study on effects on environment:* Finding out alternatives for old methods that harm environment.

METHODOLOGY

Procedure

Water Pollution control is the first thing required for the research. Oil spillage affects aquatic life and human life too. It is needed to understand the advancements in oil spill cleanup technologies. Use of biomaterials and natural sorbents lead to good approach for removing spilled oil from sea. For example, chemical sprays can break the oil into smaller droplets, and sorbent materials are often used for small spills. However, not all methods are equally effective [7].

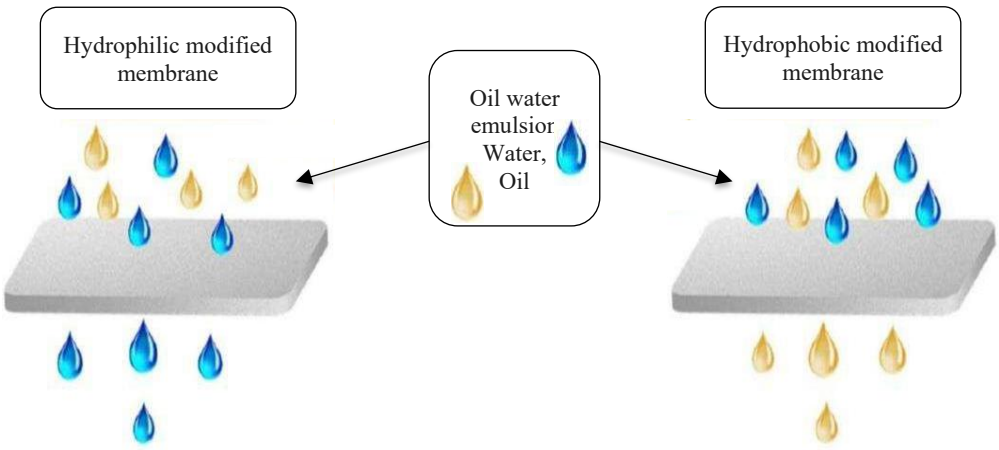

Figure 5. Separation of oil/ water membrane separation.

Method	Oils	Sorbent
White ash (Pyrolysis)	Diesel	Rice husks
	Crude oil	
Black ash (pyrolysis under N_2)	Diesel	Rice husks
	Crude oil	
Pyrolysis at 480°C	Gasoline	Rice husks
	Diesel	
	Light crude oil	
	Motor oil	
	Heavy crude oil	
Alkaline treatment	Marine diesel	Rice husks
Drying (110 °C), cutting, and milling	Motor oil	Silkworm cocoon waste
	Vegetable oil	
Drying (sunlight and 70 °C), crushing, and sieving	Crude oil	Banana skins
Drying (70 °C) and crushing	Waste lubricating oil	Banana skins
Cutting, sieving, washing, and drying (105°)	Diesel oil	Luffa (an agricultural waste)
	Heavy crude oil	
Shaking flask method, autoclave, and drying	Mineral oil	M. rouxii (32.7% chitosan)
	Vegetable oil	
	Cutting oil	
	Mineral oil	A. coerulea (10.4% chitosan)
	Vegetable oil	
	Cutting oil	
Hybridization of peels with NaOH and drying at 70 °C	Lubricant oil	
	Petrol oil	
Media	Mineral oil	Hybrid peel waste (banana skins + orange peel)
	Vegetable oil	Hybrid peel waste (banana skins + orange peel)
	DoALL Bright-Edge Oil	

Figure 6. Shows the sorbent based on biomass for oil spill removal.

Chemical treatments like coagulants and dispersants can remove oil from the ocean, but they're not widely used anymore because they may harm marine life and damage the ecosystem. Even though these chemicals work well, their negative impact on the environment makes them a less preferred option.

The above Figure 6 shows the Biomass-based sorbents, such as those derived from algae, fungi, and plant fibers, are effective and eco-friendly materials for removing oil from water. They offer a sustainable solution due to their abundance, low cost, and renewable nature [8].

Solutions for Removal of Oil Spills

Dispersants

Whenever the spilled oil doesn't contain booms, then we must fasten the breaking ogf oil. The agents like Corexit 9500 are used for spraying on spill by the help of aeroplane or boats, they also aid in the natural breakdown of oil components. The dispersants also permit oil to bond with water to increase surface area. This helps in degrading of oil by microbes.

Advanced Materials

Sorbents Based on Biomass

The natural materials which are biodegradable make huge impact on effective oil spill cleanup (e.g. algae, fungus and plant fibres).

Biomaterials

The small molecular structures of carbon-based molecules offer big surface area and high adsorption range, which makes high effective materials for absorbing oil from sea (e.g. Carbon nanotube, graphene and nanofibers).

Sorbents Made from Polymers

The synthetic polymers are applied for creating sorbents with high mechanical strength and better oil recoverability (e.g. Polyethylene and polypropylene).

Method Used in the Research: Advanced Materials: Graphene

Graphene is a remarkable material with a single layer of carbon atoms arranged in a Honeycomb lattice. It exhibits extraordinary tensile strength, being 300 times stronger than A36 structural steel and 40 times stronger than diamond. Additionally, graphene has excellent thermal, electrical, and physical properties, including a large surface area and high chemical and thermal stability. These attributes make graphene an outstanding adsorption material with numerous applications in water purification process and oil spill cleanup (Figure 7).

Oil/Water Separation by Graphene-Based Sponges

These sponges are typically made by coating a porous sponge material with graphene or reduced graphene oxide, which imparts superhydrophobic (water repelling) and super oleophilic (oil-attracting) characteristics. This means that when the sponge is placed in an oil-water mixture, it selectively absorbs the oil while repelling water!. The large surface area and excellent mechanical strength of graphene enhance the sponge's oil absorption capacity and durability [9].

Figure 8 shows the detailed view of oil absorption process. Here Graphene and its derivatives show great promise for oil/water separations, but several challenges remain. Key issues include the weak attachment of graphene and graphene oxide (GO) to support materials due to van der Waals forces, which can lead to detachment during operation. Improving preparation methods and incorporating adhesives is crucial [10]. The graphene-based forms like hydrogel, graphene coated cotton, membranes and sponges are the new technologies (Figure 9).

Physical Property	Value
Charge carrier mobility	200,000 $cm^2/V \cdot s$
Thermal conductivity	5000 W/m·K
C–C bond length	1.42 Å
Specific surface area	2630 m^2/g
Optical transparency	97.7%
Tensile strength	1100 GPa
Young's modulus	2.4 ± 0.4 TPa
Resistivity	10^{-6} Ω·cm^2
Band gap	Zero

Figure 7. Physical properties of advanced material: Graphene.

Figure 8. Oil absorption process.

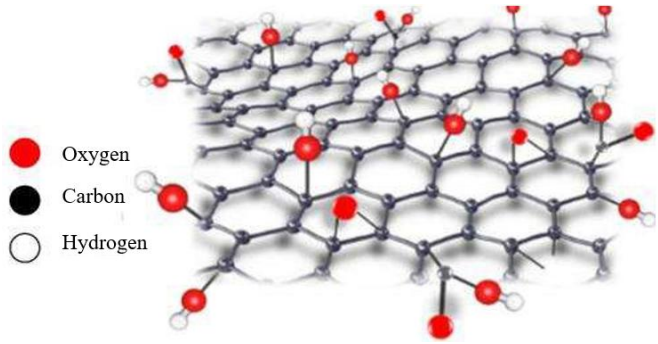

Figure 9. Graphene structure.

Advanced Applications of Graphene in Oil Spill Cleanup

1. *Graphene Aerogels:* These lightweight, porous structures are highly effective for absorbing oil because of their superhydrophobic and super oleophilic nature. They also absorb oil to the range of 900 times of their weight and are reusable, making them both efficient and sustainable. Also, graphene has superhydrophobic and oleophilic properties.
2. *Graphene Membranes:* These are designed for precise separation of oil and water. Their nanoscale pores allow water molecules to pass through while blocking oil, ensuring high separation efficiency. The graphene membrane is quite applicable for wastewater treatment plants. It also has 3D Porus structure for increasing oil adsorption.
3. *Detection of oil spills:* Graphene is good conductor of electricity, and it is surface sensitive therefore it is used for developing sensors real time monitoring of oil spills. As it's capable to detect amount of oil spilled over a distance.

CONCLUSION

The research ends with the conclusion that Graphene-based materials have made the high effective solutions for oil spill cleanup because of their exceptional characteristics like super hydrophobicity, oleophilic nature, high surface area and good mechanical strength. Due to smart sensors, aerogels, functional membranes and foams these material shows best oil absorption rate and eco friendliness. The use of biomaterials and polymers has also contributed more for oil spill removal. The potential they have for high scale deployment by magnetic control, oil/water membrane separation method is commendable. The research gives the alternatives for better spillage removal. This tells that Graphene stands out among all methods and can play a transformative role in creating an oil spill cleaner.

Acknowledgments

I am very thankful to the faculty mentors and research guides for their invaluable support and guidance throughout my research work. I am also grateful to Sanjivani Group of Institutes for providing the necessary resources for research. Special appreciation goes to the authors of the paper "Recent Developments and Advancements in Graphene-Based Technologies for Oil Spill Cleanup and Oil-Water Separation Processes," whose researched really helped me for understanding the need and they had greatly contributed to my understanding and analysis.

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