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A Review on Remote Controlled Oil Skimming Device with IoT based Mobility and Mechanical Filtration

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***Abstract*— The need for effective, automated, and responsive recovery solutions has grown as oil spills continue to pose serious risks to coastal environments and aquatic ecosystems. The flexibility, effectiveness, and real-time monitoring of traditional oil skimmers are frequently limited. Additionally, traditional cleanup techniques are frequently labor-intensive, slow, and inadequate to handle the scope and urgency of environmental hazards. This review classifies current skimmer technologies with an oleophilic (oil-attracting) and hydrophobic (water-repellent) rotating belt as the system's central component. Through the belt the floating oil over the water is continuously skimmed, which is then collected in the oil storage tank. The oil skimmer system can move to the surfaces that have oil content because of its floating base and water-resistant wheel. The mechanical design of the system makes it stable and buoyant, so it can work in water. In conclusion, current oil skimmer technologies are of different mechanical and material base which are not suitable for large scale spills as well as for dynamic changes. Using remote-controlled systems, IoT-based mobility, and advanced mechanical filtration design, together can lead to improved recovery rate and efficiency, responsiveness, and automation of oil spill recovery efforts.**

***Index Terms*— IoT-Based, Belt-type Skimmer, Efficiency, Mechanical, Recovery Rate.**

I. INTRODUCTION

As we are moving into advanced innovation and infrastructure era, the development of these concepts have led to increase in the pollution. One such is the contamination of water source caused by various factors. One such factor includes oil spill which have become major cause of water pollution around the world, hence to solve this problem it is very important to make technologies that can separate oil from water. To avoid this problem and ensure the safety of the aquatic ecosystem it has become necessary to collect and store oil properly. The best approach for this is the use of the oil skimmer device to clean the oil spill, separate oil and water and protect the environment. Past the years, various types of skimmers have been developed and implemented for broader range of oil type and spill scenarios. For example, belt-type, weir-type and suction skimmers are widely available in today's world. These types use physical mechanism for oil extraction but still has certain drawbacks such as low efficiency, lack adaptability and not suitable for certain oil types. Fixed and floating design skimmer often lack mobility, not suitable for real-time monitoring and dynamic changes. Traditional skimmers have low efficiency when used for large-scale operation. However, oil skimmer still plays an important role in the removal of the oil, reducing environmental pollution and even protect equipment from destruction caused by oil.

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Oil skimmers are useful in both preventive measures and emergency response to control water pollution caused from oil because of their simplicity, flexibility, and efficiency. Hence, several steps and advancement have been implemented in the existing skimmer for even more better functioning of the oil skimmer. For example, integration of IoT design, use of various sensors and increase the quality of the material.

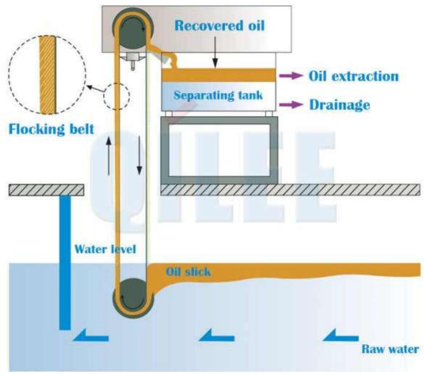

Figure 1. Oil-water separation using flocking belt

Fig. 1 illustrates an oil skimmer system used to separate oil from water. A rotating flocking belt is submerged in raw water, attracting and collecting the oil slick on its surface. As the belt moves upward, it carries the oil to the separating tank above water level. Inside the tank, the oil is separated from the belt and collected as recovered oil. The belt then rotates back down for continuous operation. The system includes outlets for oil extraction and drainage of water. This method is effective for removing floating oil from contaminated water surfaces.

II. Literature Review

The literature survey explores existing research and developments related to remote-controlled oil skimming devices, which are essential tools in mitigating the environmental impact of oil spills. Understanding the latest designs, technologies, and control systems utilized in oil skimming especially those that incorporate remote operation is the goal of the review. In the current study, this foundation is essential for directing the design and deployment of an efficient, remotely operated oil skimming system.

Khane et.al.[1] using oil adhesion for collection, created a PVC belt-based oil skimmer powered by a Johnson DC motor. The system has problems like high power consumption, a lack of components that are explosion-proof, and frequent maintenance, even though it works well for minor spills. Its use is restricted in larger or riskier situations due to its lack of automation and remote control. The study identifies areas that could be improved in the future by integrating IoT and energy-efficient components.

S. Patil et.al.[2] In order to ensure effective separation from water, presented a system that uses a mechanical skimming mechanism that attracts and collects oil using oleophilic materials. In order to reduce the ecological impact of oil spill cleanup, the design places a strong emphasis on environmental sustainability. Real-time monitoring features also enable ongoing evaluation of the skimming process, improving operational effectiveness and guaranteeing adherence to environmental regulations.

Junnan Song et.al.[3] An adaptive approach for cleaning up oil spills using self-driving cars that function with incomplete or sparse environmental data, modifying its course according to the shape and distribution of the spill, the system is intended to cover the entire area with the least amount of overlap. However, there are few drawbacks highlighted in this paper which includes obstacle avoidance, remote oil detection and lack of adaptability to dynamic changes in the environment. Hence, it becomes necessary to concentrate on the improvement in navigation and sensing factors.

Alireza Zahedi et.al.[4] it examines the procedure to develop advanced oil skimmer coating to improve oil recovery in marine spill. In order to improve extraction of oil and reject the intake of water, it concentrates on the material which has non-polar coating, that enables to attract oil and reject water. This quality coating material are mostly found in polymer base and nanostructures surface. These does not only improve the oil recover rate but also ensures that the operation of the skimmer to be stable.

Sonali Dhaneshwar et al. [5] compare the performance of PVC and polyurethane belts for oil skimming, emphasizing the impact of skimming angle. Due to their superior oil absorption and adhesion, polyurethane belts typically perform better than PVC. Despite the benefits of the material, design flaws such as excessive thickness and poor surface texture limit the efficiency of polyurethane belts by reducing flexibility, increasing drag, and limiting oil capture and retention. Performance is also impacted by skimming angle, which has an impact on belt adhesion and oil absorption. The secret to efficiency is to optimize surface texture, thickness, and material according to operating conditions.

A. S. Patil et.al.[6] introduces an oil detection method based on the differing conductivity of oil and water, combined with polyurethane belts that absorb oil for automated skimming. The system shows potential for efficient oil-water separation, but challenges remain with extraction rates and adapting to varying environmental conditions. Additionally, changes in oil viscosity before and after separation impact skimming efficiency, as thicker oils are harder to absorb while thinner oils may disperse more easily. Enhancing adaptability and handling viscosity variations is key for effective oil spill cleanup.

S. M. M. Rahman et.al.[7] provides information on the design and testing of an Internet of Things (IoT)-based autonomous system for oil spill detection and recovery. In this paper it has emphases that, as we increase the number of discs in the rotatory mechanism the performance of the skimmer system improves, due to which the efficiency of the oil recovery improves. It happens due to the constant speed of the rotatory mechanism. Hence it shows the importance of the number of discs used.

V. Kavin et.al.[8] this proposal concentrates on the belt-type oil skimmer integrated with IoT technique for the efficient removal of oil from the waste water caused by the industries and factories. It shows how the IoT system monitors the performance and oil level and the belt-type uses oleophilic material to remove oil from the water surface. This type of device often is inexpensive, efficient and environmentally friendly.

F. Budiman et.al.[9] this paper explains how to support oil pollution monitoring systems in water. Hence Internet of Things-based automatic oil and water separation device have been developed. The system effectively detects oil and separates it from water bodies by combining real-time data collection with remote monitoring capabilities. By using IoT technology the system protects aquatic environment and improve oil spill cleanup.

H. Erfani et.al.[10] this paper reviews the different methods used for treating oily water produced during refining work. It covers various techniques such as physical, chemical, biological which includes flotation, gravity separation, oxidation and filtration. Each of the technique in this paper is based on the efficiency, cost and environmental impact. It highlights how the oil industry is demanding sustainable and high performance solutions. This paper also highlights the gaps and potential scope for advanced and hybrid technologies for oil-water separation.

Mahesh N et.al.[11] proposed a Bluetooth-controlled boat system designed to clean oil spills along coastlines, featuring virtual cameras for real-time monitoring and remote operation. This allows for targeted skimming and reduces the need for manual intervention. However, its Bluetooth connectivity allows for easy control within short distance, restricting its use to small or nearshore areas. The system also faces challenges in adapting to environmental conditions such as waves, debris, and strong currents, which reduce its overall effectiveness. Despite its innovative design, these limitations hinder performance. Future improvements in control technology and mobility could enhance its reliability and scalability.

L. N. Patil et.al.[12] this paper highlights an innovative approach used for extracting oil from sea water for the reduction for marine pollution. This paper aims to present oil separation device that focuses on less cost, low environmental pollution and high efficiency in extraction of oil through mechanical design. It concentrates on improving the oceanic environment and eventually reducing negative impact on aquatic ecosystem.

S. Rajesh Kannan et.al.[13] provides information on IoT-based skimmer, sensing systems and different materials used for the recovery rate. In this is shows that remote monitoring and control can be achieved through IoT technique but it does not highlight the efficiency through mechanical extraction. On the other hand, it also highlights how autonomous based on GPS and image processing provides smart navigation but lacks scalability and power consumption. Based on material research Joule-heated PDMS sponges have promising oil recovery but cannot be implemented for real-time.

Pulu Gujju Rajesh et.al.[14] this paper is based on IoT-based oil skimmer device which uses polyurethane belt for high oil skimming capability. Its uses mechanism that filters the water before it is returned back thus concentrating on environmental safety. However, the speed of the belt decides the recovery efficiency and the operational function when disturbed can result in reduce reliability.

S. Saranya et.al.[15] provides information on IoT technique used for oil recovery in marine spill. This system uses Raspberry Pi and sensors such as pH sensor, MQ-3 sensor and ultrasonic sensor. It aims to achieve two goals, to automate the skimming process and ensure environmental safety. The usage of sensor improves the ability to detect and control but has excessive battery usage. It also highlights the drawbacks such as limiting to adapt in changing environment and efficiency.

Bo Liu et.al.[16] highlights the main goal for the oil recovery from the coastal area to enhance the oil-water separation. It concentrates on how demulsification and on-site treatment methods can improve the effectiveness of oil-water separation. This paper also highlights the importance of removal of toxicity in water before sending it back, to prevent ecological safety and to ensure that efficiency and security of the recover process is not affects due to oil viscosity during decanting operation.

R. Ramanathan et.al.[17] provides significance of user-cantered design (UCD) techniques in the creation of portable oil spill skimmers. This traditional design usually neglects the user needs and ease of use in favour of mechanical performance. Prototyping, iterative testing, and user feedback are examples of UCD techniques that guarantee the design is in line with actual circumstances. These techniques can result in more useful, effective, and in-built skimmers that are applicable for quick deployment and field operations.

Marko Dordvic et.al.[18] A methodical approach to choosing the best skimmer device based on a variety of operational and environmental factors. It examines various skimmer types, including disc, drum, and weir skimmers, and assesses them according to factors like cost, recovery efficiency, sea conditions, and type of oil. In order to ensure effective and efficient oil spill response under a variety of marine conditions, the study presents an optimization framework or decision-making model to guide selection. The approach facilitates the deployment of skimmers in oil spill management plans in a more contextualized and knowledgeable manner.

N. N. S. Sambary et.al.[19] The design and development of an unmanned aquatic multifunctional robot aim to feed fish, cut aquatic weeds, collect waste and oil spills from water bodies, and monitor water quality. The system reduces operating time and manual labour. Even when the bin was filled with waste, tests revealed that it was 85% buoyant, demonstrating its effective floating capabilities. However, the robot's reliance on stagnant water conditions and need for robust network connectivity limit its functionality. It is also less appropriate for larger or farther-flung bodies of water due to its limited operating range.

M. F. Khalil et.al.[20] In their review of developments in belt skimmer technology they highlight how prismatic roughness can improve oil recovery. According to studies, oil viscosity has a major impact on skimmer effectiveness, and rough belts enhance performance. However, high-speed operation decreases the overall recovery efficiency, and also the use of rough belts demonstrated decreased efficiency when working with lower viscosity oils and different skimmer angles.

M. A. Khan et.al.[21] A smart oil skimmer with two revolving circular discs and an Internet of Things (IoT) system for remote control through a smartphone application and real-time weather monitoring. In order to evaluate weather conditions, the system measures environmental parameters like temperature, humidity, and moisture. By combining these data, the skimmer's operation can be remotely modified to maximize its effectiveness in a range of environmental circumstances. According to experimental results, the average oil recovery efficiency is an impressive 89.87%.

Sophiya Susan S et.al.[22] A lightweight, microcontroller-based marine system that can simultaneously collect oil spills and surface waste was proposed, additionally, the intelligent system keeps an eye on dangerous gases and water levels, triggering notifications and taking appropriate action when necessary. It is perfect for controlling aquatic pollution in real time because of its small size and effective design. Onboard sensor efficiency is still an issue, though, and in some circumstances, it can compromise system dependability.

T. S. Birdi et.al.[23] The goal was to design and produce an inexpensive belt-type oil skimmer with components that were appropriately dimensioned. The skimmer provided a straightforward, affordable substitute for expensive treatments like membranes and chemicals and was designed to effectively remove oil and impurities from water. The study attested to the device's affordability and ease of construction. The primary disadvantage, though, was the inefficiency of the chosen belt material, which reduced the skimmer's capacity to recover oil.

R. K. Nanwatkar et.al.[24] The performance of an oil skimmer and the ways in which different physical factors impact its oil recovery efficiency are examined, it concludes that higher belt rotational speeds result in lower recovery rates and that oil recovery declines with increasing oil temperature. It has been demonstrated that the oil's viscosity has a major impact on the separation process, and the presence of water further reduces the system's efficiency. The study comes to the conclusion that in order to manage impurities and optimize recovery, design enhancements and component optimization are crucial.

S. S. Godawarikar et.al.[25] provides an analysis of different oil skimmer technologies with main focus on belt-type skimmers and the impact of belt materials on oil absorption. It highlights the effectiveness of different materials in recovering oil and also the importance of material compatibility with oil types. However, few oil types cannot be absorbed due to its non-polar nature. Even slight changes in the design of the skimmer can have adversely effect on it.

L. Chen et.al.[26] presents an analysis of various cooperative control strategies for waterborne transport systems. It focuses on how different methods and management systems are used by autonomous vehicles and vessels to coordinate actions. It emphasizes on the need for synchronized control but also includes the drawback such as bandwidth limitations, loss, communication issues. Parameters like distance and time leads to even more complex coordination.

M. A. Dawood et.al.[27] provides the information on the impact of operational parameters such as material viscosity and belt speed on oil skimming performance. Higher rotational speed help to collect more oil, but reduces the overall efficiency since the oil-water separation becomes less. High-viscosity oils are simpler to recover, but as the belt speed increases, the thin layer of oil becomes difficult to remove leading to reduce efficiency. Performance is greatly impacted by the belt material's surface structure.

S. Choi et.al.[28] presents an innovative oil skimmer with Internet of Things integration for remote monitoring and real-time control. The system's user-friendly interface enables users to control and monitor the skimmer through Bluetooth Low Energy (BLE) communication. This solution, which was created using open-source hardware, provides an easily and inexpensive way to handle oil spills and improve environmental pollution.

M. Abdul Rahman et.al.[29] An additional belt shaft and steel belts in place of rope belts were two design enhancements made to a conventional oil skimmer, better oil recovery and a stronger, more straightforward structure were the outcomes of these modifications. Steel was used to make the skimmer stronger and more effective. Despite its better performance, the disadvantage was the increased manufacturing cost, which made it less appropriate for low-budget applications.

Sathiyamoorthy V et.al.[30] Improvements in the functionality and design of mobile oil skimmers are reviewed. It demonstrates how oil recovery performance can be significantly increased by altering the type of skimmer belt and enhancing the overall design. The study highlights how even minor structural adjustments can increase efficiency and streamline operations. It also points out that too fast belt speed can hinder recovery and that controlling the volume of water collected with the oil is crucial for improved operational results.

The survey highlights the advancements made in the field while identifying gaps and challenges that still exist. This was accomplished by analysing previous studies and focusing on the various oil-water separation mechanisms, such as belt-type, disk-type, and innovations in skimmers, autonomous navigation, IoT-based, material selection, fluid dynamics, and various other approaches.

III. Comparative Analysis based on Key Performance Parameters

Key performance parameters such as oil recovery rate/efficiency, installation, mobility, cost-effectiveness and environmental impact were extracted and analysed. Based on the collected data, a comparison table as given in Table I, is generated to evaluate the advantages and limitations of each skimmer type, providing a foundation for selecting the most suitable system for specific industrial applications.

Oil Recovery Rate/ Efficiency: It refers to the amount of oil collected by the skimmer compared to the total oil available on the water surface, it indicates how effectively the system separates and collect oil without picking up much water. It is usually expressed as a percentage. For example: a skimmer with 85% recovery efficiency collects 85% oil and 15% water.

$$\eta = \left(\frac{\text{Amount of oil recovered}}{\text{Total amount of oil available}}\right) \times 100 \qquad (1)$$

where,

η = Oil recovery efficiency (%)

Amount of oil recovered = Quantity of oil collected by the skimmer (in litres or kilo-grams)

Total amount of oil available =Total oil present on the water surface before skimming

Installation: Installation refers to the fixing and process of setting up the oil skimming system for smooth operation. Example: a portable belt skimmer requires minimal installation effort and can be quickly positioned on small tanks.

Mobility: It is the ability of the oil skimming unit to move or be relocated easily between different site or water bodies.

Cost effectiveness: It is the measure how economically efficient the system is in terms of its construction, operation and maintenance cost compared to the amount of oil it can recover. Example using locally available materials can make the skimmer more cost effective

Environmental impact: It refers to the effect of the oil skimming system on the surrounding ecosystem including water quality aquatic life and emissions. An environmentally friendly system removes oil without disturbing aquatic organisms or releasing harmful substances.

Hence from Table I the comparison summary can be given as, traditional belt, drum, and disk skimmers offer moderate to high recovery rates, improved by optimizing materials like PU and PVC. On other hand, skimmer that are autonomous and advanced have high efficiency, particularly when used on large-scale such has marine spill. Devices which are integrated with IoT techniques and used sensors are used for wide range of oil recovery. Petrol or crude oil which are viscous in nature can be skimmed through autonomous skimmer system. In industrial usually fixed and semi-fixed skimmers are found whereas, on large-scale mobile or floating design is appropriate. IoT-based skimmer often is high cost and requires high maintenance but promising long-term scalability. Skimmer having IoT monitoring and material optimization and robotic system have less negative impact on the environment.

TABLE I. COMPARATIVE ANALYSIS OF OIL SKIMMING METHODS

Skimmer Type / Approach	Recovery Rate / Efficiency (in %)	Installation & Mobility	Cost	Environmental Impact
Belt-type skimmer [1]	65%	Fixed tanks	Low–Medium	Minimal
Innovative mechanical [2]	75%	Portable, flexible	Low	Eco-friendly
Autonomous vehicle [3]	70%	Mobile, offshore	High	Reduced manual waste
Advanced coating (oleophilic & hydrophobic) [4]	85%	Adjustable	Moderate- high	Low
Belt (PU vs PVC) [5]	65%	Fixed/adjustable	Low	Eco-friendly (belt-reuse)
Conductivity-based [6]	82%	Semi-fixed	Medium	Prevents waste
IoT-based system [7]	85%	Mobile, autonomous	Medium	High eco benefit
AQUA PURE IoT [8]	75%	Fixed, monitored	Medium	Clean monitoring
IoT separator device [9]	80%	Semi-fixed	Medium	Strengthens monitoring
Not Specific [10]	85%	Fixed	Low - High	Moderate
Bluetooth- Controlled boat [11]	60%	Fully mobile	Low–Medium	Low emissions
Oil separator [12]	75%	Floating	Medium–High	Reduce marine pollution
Disc Skimmer [13]	70%	Portable	Moderate	Low
IoT skimmer robot [14]	80%	Mobile robot	Medium	High eco
Marine monitoring [15]	75%	Semi-floating	Medium	Pollution prevention
Advanced separator tech [16]	90%	Offshore vessels	High	Eco-optimized
Portable Skimmer [17]	70%	Portable	Low –Moderate	Eco-friendly
Optimisation-Based [18]	90%	Adjustable	Scalable	Moderate
Multi-functional robot [19]	60%	Mobile	High	Eco-friendly
Belt skimmer [20]	92%	Fixed	Low	Optimized
Double disc IoT skimmer [21]	89.87%	Semi-floating	Medium	Reduced losses
Smart Marine Saver [22]	75%	Semi-floating	Medium	Safety focused
Fabricated mech. Skimmer [23]	65%	Simple fixed	Low	Low
Oil skimmer for filtration [24]	77%	Semi-fixed	Medium	Improved separation
Mechanical Skimmers [25]	81%	Semi-fixed	Low	Moderate
Cooperative control survey [26]	63%	Marine transport	Medium-High	Control optimization
Mechanical skimmer [27]	85%	Semi-fixed	Medium	Reduces spill waste
IoT monitoring skimmer [28]	83%	Semi-fixed	Medium	Pollution prevention
Fabricated skimmer [29]	90%	Fixed	Low	Basic eco
Mobile skimmer review [30]	85%	Mobile	Low	Moderate

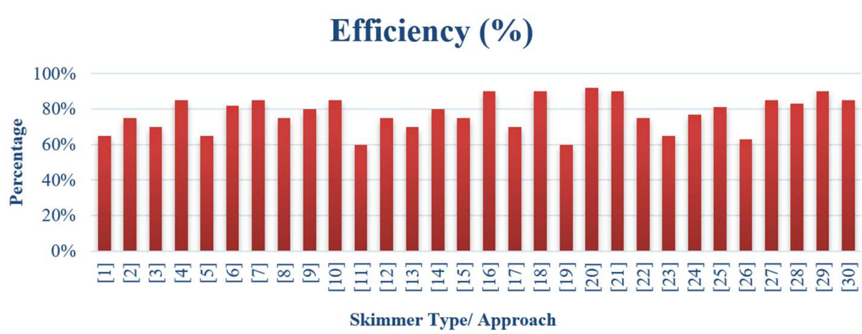

Figure 2. Efficiency (%) of the different skimmers

IoT-based skimmer often faces various challenges in real-world application; this includes network reliability issues. In marine life or large-scale usage due to long distance communication the device may suffers weak network coverage because of which the transmission of data may be delayed and real-time decision making will reduce, hence during emergency situation the device operation will fail. Weather condition and tidal effects may also contribute in connectivity issues. Another challenge faced is, power consumption, when used on large-scale there is more usage of power. Since the device must operate for long duration, sufficient and continuous power supply is required which may hinder due to cloudy weather, high humid, corrosion and harsh marine condition. Even usage of solar panel may not be compatible. Hence, these all factors showed the drawback of IoT integrated oil skimmer.

Material-based skimmers made from PU, PVC, or coated surfaces often do not last long in real marine conditions. The wear resistance is low because waves, sand, and floating debris slowly damage the material. PU becomes soft and weak, while PVC can crack under strong sunlight. Coatings may come off after repeated use. This leads to higher maintenance costs, as the skimmer needs frequent cleaning and replacement of damaged parts. The lifespan is short because saltwater, UV light, and constant movement quickly age the materials.

IV. FUTURE SCOPE

The Future scope for oil skimmer is enhancement in traditional mechanical systems by using stronger, corrosion-resistant materials and improved collection mechanisms. It can focus on stronger, longer-lasting materials, improved IoT-based monitoring, and energy-efficient autonomous systems. Advancements in smart sensors, AI-based spill detection, and eco-friendly coatings can enhance durability and efficiency. Integrating robotics and renewable power may also enable scalable, continuous, and low-maintenance marine oil-recovery operations.

V. CONCLUSIONS

This review paper provides the analysis of various types of skimmer technologies used, which helps to highlight the difference between the traditional skimmer and advanced skimmer. Each type of skimmer can be compared by the parameters such as efficiency, installation, mobility, cost and environmental impact. The gaps identified from the conduction of the survey was, the efficiency of the oil removal depended on the type of materials used. It is also found that certain approaches lack removal of patches of oil in small area oil spill. In small to medium application such as lakes, ponds and other small water bodies the same skimmer which is used for large-scale cannot be used and its drawbacks was, it is expensive and not portable. Completely relying on the autonomous type also had some drawbacks such as, it could not adapt in rigours environment and viscous water. Devices using IoT integration for remote controlling used more power consumption and lacked compatibility. Overall, integrating traditional mechanical designs with emerging technologies presents the most effective approach to balance recovery efficiency, operational flexibility, cost, and environmental sustainability in oil spill response.

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