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Bioremediation of Oil Spill using Dried Coconut Husk as an Absorbent Material

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Abstract

Oil spills represent a serious environmental hazard, particularly to marine ecosystems. This study explores the use of dry coconut husk, an abundant agricultural waste, as a natural sorbent for oil spill remediation. The oil absorption performance of coarse and powdered coconut husk was evaluated under various conditions, including different contact times, absorbent masses, and oil–water mixtures. A commercial oil absorbent pad (SABER) was used as a benchmark. Results show that powdered coconut husk has higher absorption capacity and efficiency compared to coarse husk, attributed to its finer particle size and increased surface area. In oil–water systems, powdered husk exhibited selective oil uptake with minimal water absorption, approaching the performance of the commercial pad. These findings highlight the potential of coconut husk as a biodegradable, low-cost, and sustainable sorbent material, especially in resource-limited settings. Its direct use without chemical modification supports practical applications and aligns with circular economy principles. Further optimization and field-scale validation are recommended to enhance its applicability in real spill scenarios.

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Abstrak

Tumpahan minyak merupakan bahaya lingkungan yang serius, khususnya bagi ekosistem laut. Penelitian ini mengeksplorasi pemanfaatan sabut kelapa kering, yang merupakan limbah pertanian yang melimpah, sebagai sorben alami untuk remediasi tumpahan minyak. Kinerja penyerapan minyak dari sabut kelapa kasar dan berbentuk serbuk dievaluasi pada berbagai kondisi, meliputi variasi waktu kontak, massa sorben, serta sistem campuran minyak–air. Bantalan penyerap minyak komersial (SABER) digunakan sebagai pembanding. Hasil penelitian menunjukkan bahwa sabut kelapa berbentuk serbuk memiliki kapasitas dan efisiensi penyerapan yang lebih tinggi dibandingkan dengan sabut kelapa kasar, yang dikaitkan dengan ukuran partikel yang lebih halus dan luas permukaan yang lebih besar. Pada sistem minyak–air, sabut kelapa serbuk menunjukkan kemampuan penyerapan minyak yang selektif dengan penyerapan air yang minimal, mendekati kinerja sorben komersial. Temuan ini menegaskan potensi sabut kelapa sebagai material sorben yang biodegradable, berbiaya rendah, dan berkelanjutan, khususnya untuk penerapan di wilayah dengan keterbatasan sumber daya. Penggunaan langsung tanpa modifikasi kimia mendukung aplikasi praktis serta sejalan dengan prinsip ekonomi sirkular. Optimalisasi lebih lanjut dan validasi skala lapangan direkomendasikan untuk meningkatkan penerapannya pada kondisi tumpahan minyak yang nyata.

1. Introduction

Oil spills are common occurrences during the handling and transfer of petroleum. A representative case of an oil spill incident occurred at a fuel tanker dock, primarily during standard operational procedures involving the fuel oil transfer from the vessel to onshore storage facilities. Contributory sources of contamination included the discharge of tank washing effluents and the release of oil-contaminated ballast water, both of which are common by products

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of marine fuel handling operations (Galieriková & Materna, 2020). Oil spills in the marine environment result in a serious threat to aquatic ecosystems. Various components of the marine ecosystem, such as plankton, benthos, fish, seabirds, and coastal vegetation, are highly susceptible to contamination and its cascading effects. (Kurniawan et al., 2024) In seabirds, oil coating the feathers can impair flight and navigation, often resulting in mortality (Fraser et al., 2022) Additionally, exposure to oil-contaminated water may disrupt reproductive processes in marine organisms, leading to population declines. These ecological disturbances can have direct socioeconomic consequences, particularly for coastal communities that depend on marine resources for their livelihoods (Annisa et al., 2024). The infiltration of oil into plant cells causes an effect on transpiration, inhibiting photosynthesis, and potentially genotoxicity on both plant physiology and genetics (Sharma et al., 2024). To solve this problem, bioremediation its need to mitigate a hazardous from oil spill.

Bioremediation offers a sustainable and environmentally friendly alternative for mitigating the impact of oil spills. The ability of microorganisms, particularly fungi, to degrade crude oil has been reported. These fungi utilize crude oil as a source of energy and cellular growth. (Bovio et al., 2017) Other microorganisms, bacteria, were also suggested to use as a bio-surfactant (Durval et al., 2020). The utilization of natural absorbent, stearic acid grafted coconut husk, was reported to successfully adsorb crude oil contaminated water.(Asadu et al., 2021) However, the selection of the materials for bioremediation is indeed affected by economic and efficacy considerations. Utilizing agricultural waste has emerged as a sustainable strategy for developing bioremediation agents. One such promising candidate is coconut-based waste, a choice further justified by Indonesia's high coconut production trends between 2018 and 2023 (**Figure 1**) (Badan Pusat Statistik, 2023).

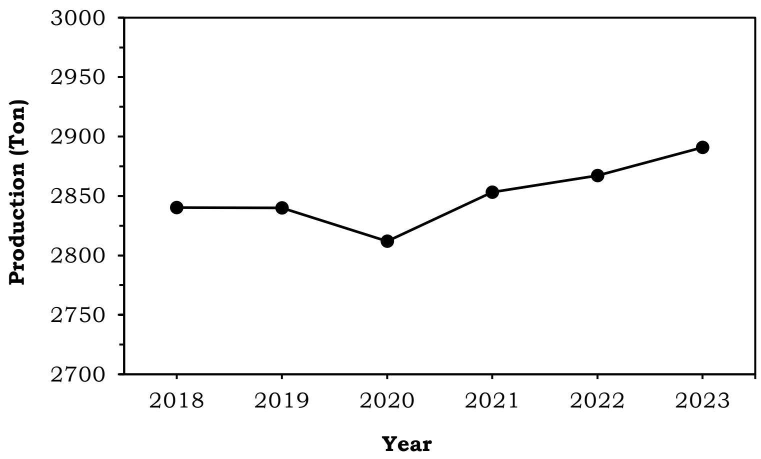

Figure 1. Annual coconut production in Indonesia from 2018 to 2023

According to the Badan Pusat Statistik (Badan Pusat Statistik, 2023) as shown in **Figure 1**, coconut production in Indonesia has shown an overall upward trend over the past six years, reaching an estimated 2,890.9 tons (Badan Pusat Statistik, 2023). Typically considered an agricultural waste, coconut husk can be upcycled into value-added materials such as activated carbon, bio-composites for growing media, water filtration materials, biochar, and various artisanal products. However, the upcycling process is often constrained by both technical limitations and economic feasibility challenges (Atapattu et al., 2024). Furthermore, coconut husk has demonstrated potential as a natural absorbent for mitigating oil spill contamination. A study by Omoniyi & Henry (2014) demonstrated that coconut fiber is a more effective absorbent than ground and whole corn cobs for separating oil from water. The experimental results showed that coconut fiber was able to completely absorb the oil, reducing the oil volume from 50 mL to 0 mL. In contrast, ground and whole corn cobs only reduced the oil volume to 26 mL and 44 mL, respectively. Meanwhile, Majadas et al. (2025) reported that heated coconut fiber exhibited an adsorption capacity of 34.62% and was able to absorb 64.29% of oil within 30 minutes. Liang et al. (2024) shown that coconut husk-derived and coir fiber-reinforced bio-composites can selectively absorb oil from oil-water mixtures through a tailored synthetic strategy. The effectiveness of coconut husk as an oil sorbent is attributed to its porous fibrous morphology and high lignocellulosic content, particularly lignin, which enhances its affinity for hydrocarbons (van Dam et al., 2006). These characteristics position coconut husk as a promising sustainable material for oil spill remediation applications.

The aim of this study is to evaluate the effectiveness of dry coconut husk as a natural absorbent for oil spill mitigation. The use of dry coconut husk without any chemical or physical modification offers a low-cost, abundant, and environmentally sustainable alternative for oil sorption. Its direct application highlights its potential as a practical sorbent material, particularly in resource-limited settings.

2. Research Methods

2.1 Preparation of Materials.

Absorbents used in this study included dry coconut husk and SABER oil absorbent pad. Coconut husk sorted into two particle size categories, coarse husk and fine powder, the latter obtained by sieving through a 100-mesh screen. The SABER pad was included to compare the oil absorption efficiency between a commonly used commercial material and the natural absorbent. Pertalite fuel (RON 90) with a density range of 715-770 kg/m3 at 15°C, was used as the test oil. Freshwater was used instead of seawater, as the density difference was deemed negligible for this study.

2.2 Absorption Test Setup.

The oil absorption tests were conducted in three separate stages. The first and second involved pure oil with a volume of 100 mL, while the third utilized an oil-water mixture with a ratio of 70 mL oil and 250 mL water. In the first test, the effect of contact time on absorption capacity was evaluated using a fixed absorbent mass of ±3 grams. To match this, the SABER oil pad was cut into 10×14 cm pieces. The second test, the effect of varying absorbent mass on absorption capacity was evaluated. In the third test, an oil–water mixture was used to assess the absorbency of the materials under more realistic spill conditions. A uniform absorbent mass was applied across all samples. The oil absorption tests were carried out in a plastic container measuring 16.5 × 11 × 4.3 cm. The coconut husk samples were separated from the liquid phase using a filter cloth placed over a glass funnel to drain excess fluid, minimizing measurement error due to residual surface oil.

2.3 Determination of Oil Absorption Efficiency

The oil absorption efficiency of each absorbent was determined by measuring the volume of oil retained after the absorption test. It was assumed that the difference between the initial and final oil volumes represents the volume oil absorbed. The absorption efficiency (AE) was calculated using the following equation (1). This equation modified from Majadas et al. (2025), in this research AE equation using oil volume absorbed by dried coconut husk.

$$AE = \frac{V_1 - V_2}{V_1} \times 100\% \quad (1)$$

where V_1 is the initial oil volume before absorption, and V_2 is the remaining oil volume after the absorption test, both are measured in mL. This approach provides a simple yet effective means of quantifying an absorbent's performance based on the volume oil removed from the system.

3. Results and Discussions

3.1 Effect of Absorption Time on Absorption Capacity and AE

The first experiment aimed to evaluate the absorption capacity of each absorbent over varying contact times (10, 20, and 30 minutes) using a fixed absorbent mass of ±3 grams. As shown in **Figure 2**, the absorption capacity of the powdered coconut husk increased progressively with longer contact times. In contrast, the coarse coconut husk exhibited a decline in absorption capacity over time, possibly due to early saturation or reduced surface interaction efficiency. This may be attributed to the large number of vacant absorption sites still available on the absorbent surface (Salaenoi et al., 2024), resulting in maximum absorption occurring within 10 minutes. To further enhance the absorption capacity, coarse coconut fiber can be processed into powdered coconut fiber. This modification aims to increase the surface area, thereby maximizing oil uptake through the availability of vacant absorption sites. This indicates that the fiber surface no longer contains available pore spaces capable of adsorbing additional oil (Askari et al., 2025).

These findings are further supported by the results in **Figure 3**, which illustrates the absorption efficiency of each absorbent. After 30 minutes of contact, the absorption efficiency of powdered coconut husk approached that of the SABER pad, suggesting its comparable performance. This highlights the promising potential of powdered coconut husk as a sustainable and effective natural absorbent for oil spill mitigation. Thus, powdered coconut husk has a smaller particle size, resulting in a larger surface area that enhances the maximum absorption of oil.

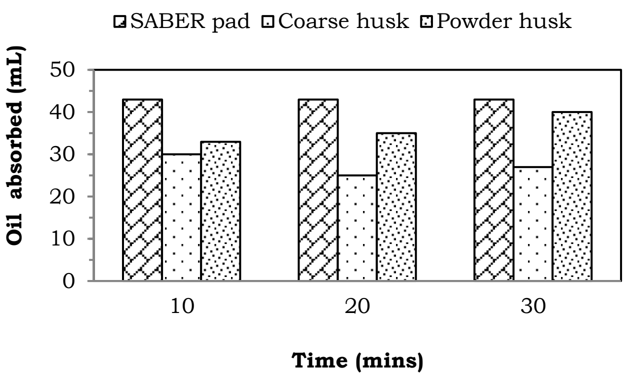

Figure 2. Absorption capacity of each absorbent over varying contact times

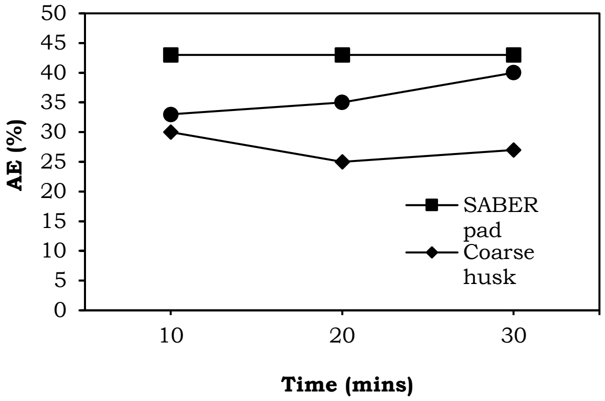

Figure 3. Absorption efficiency of each absorbent over varying contact times

3.2 Effect of Absorbent Mass on Absorption Capacity and AE

The second experiment investigated the effect of varying absorbent mass (4, 5, and 6 grams) on the oil absorption capacity of coarse and powdered coconut husk, with a fixed contact time of 10 minutes. As expected, both forms of coconut husk exhibited an increase in absorbed oil volume with increasing absorbent mass. As illustrated in **Figure 4** and **5**, both the coarse and powdered husk reached a maximum absorption volume of approximately 41 mL at 6 g of material. This is attributed to the increased mass of coarse coconut fiber, which enhances oil absorption capacity. The addition of more absorbent material increases the available surface area, allowing more vacant absorption sites to maximize oil uptake. This indicates that, although powdered husk generally shows higher efficiency per unit mass, similar total absorption can be achieved with coarse husk if a larger quantity is used. These findings suggest that when coconut husk is used directly in coarse form, a significantly greater mass is required to achieve comparable oil uptake to that of its powdered counterpart. This underscores the importance of particle size reduction in enhancing the efficiency and practicality of coconut husk as a natural oil absorbent (Puspa et al., 2024).

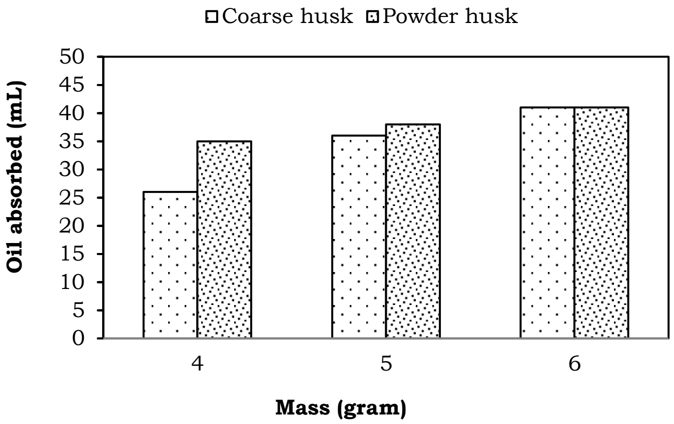

Figure 4. Absorption capacity of each absorbent over varying absorbent mass in oil phase

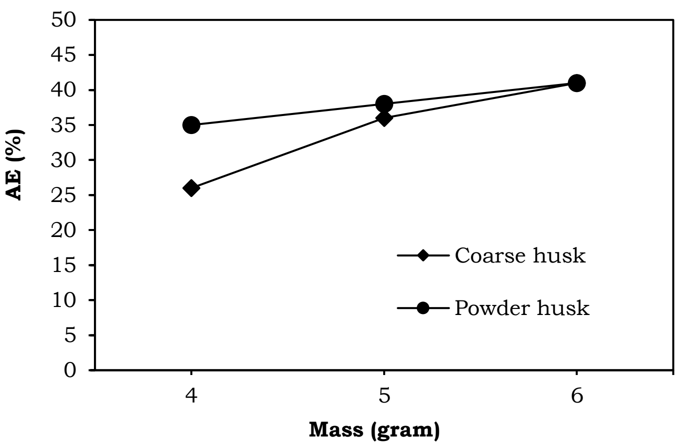

Figure 5. Absorption efficiency of each absorbent over varying absorbent mass in oil phase

3.3 Absorption Capacity of Natural Absorbent in Oil-Water Mixture

The third experiment evaluated the oil absorption capacity of both coarse and powdered coconut husk in an oil–water mixture to assess their potential as natural sorbents under more realistic spill conditions. As shown in **Figures 6** and **7**, absorption tests were conducted at a fixed contact time of 10 minutes with varied absorbent masses (3, 4, 5, and 6 grams).

Powdered coconut husk consistently demonstrated higher oil uptake than the coarse variant across all mass variations. At 6 grams, powdered husk absorbed approximately 43 mL of oil, while coarse husk reached 43 mL as well, but only after a greater mass increase. The improved performance of powdered husk is attributed to its smaller particle size, which increases surface area and enhances capillary absorption. These physical characteristics promote faster oil penetration and more effective retention within the absorbent structure (Puspa et al., 2024).

The oleophilic and hydrophobic nature of coconut husk, especially due to its high lignocellulosic and lignin content, allowed for selective oil absorption while minimizing water uptake. This behavior is critical in oil–water systems where the sorbent must be able to isolate oil without becoming saturated by surrounding water.

Overall, the findings highlight that powdered coconut husk offers superior efficiency and practicality compared to coarse husk, even in aqueous environments. Its enhanced performance under multiphase conditions, without chemical treatment, demonstrates its viability as an environmentally friendly and economical alternative for marine oil spill cleanup (Puspa et al., 2024).

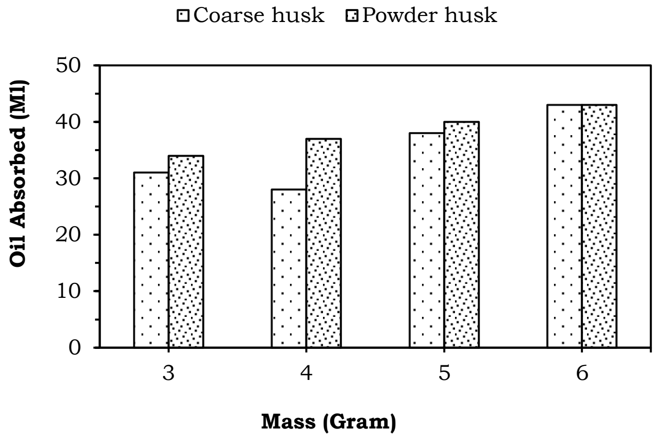

Figure 6. Absorption capacity of each absorbent over varying absorbent mass in oil-water mixture

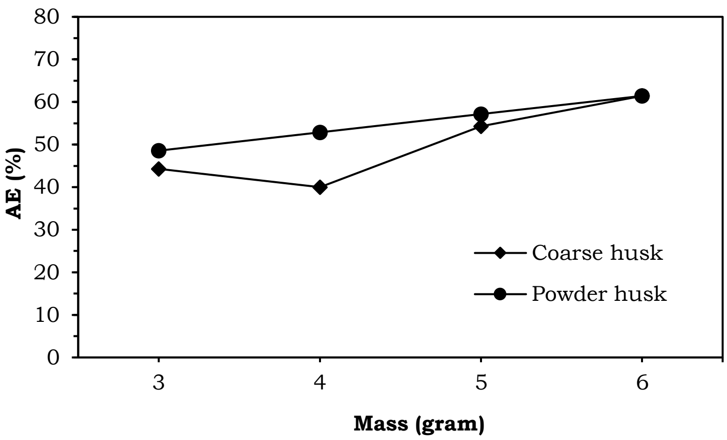

Figure 7. Absorption efficiency of each absorbent over varying absorbent mass in oil-water mixture

3.4 Comparative Absorption Capacity under Varying Conditions

To assess the performance of coconut husk under various operational conditions, oil absorption tests were conducted using both coarse and powdered coconut husk across different contact times and absorbent masses, in both pure oil and oil–water mixtures. As shown in **Table 1**, absorption capacity generally increased with higher absorbent mass and longer contact time for both absorbent types.

Table 1. Comparison Absorption Capacity Under Varying Conditions

Coconut husk	Mass of absorbent (g)	Contact time (mins)	Oil phase (mL)	Oil-water mixture (mL)
Coarse husk	3	10	30	31
		20	25	27
		30	27	28
	4	10	26	28
	5		36	38
	6		41	43
Powder husk	3	10	33	34
		20	35	36
		30	40	41
	4	10	35	37
	5		38	40
	6		41	43

In pure oil, powdered coconut husk consistently outperformed coarse husk due to its finer particle size and higher surface area, facilitating greater interaction with the oil phase. At a contact time of 30 minutes and a mass of 6 grams, both materials achieved a maximum oil absorption of 41 mL, though powdered husk achieved higher absorption at lower masses, indicating greater efficiency per gram of material.

In oil–water mixtures, absorption capacity remained slightly higher than in pure oil for most cases. For example, at 3 grams and 10 minutes, coarse husk absorbed 31 mL in the oil–water system compared to 30 mL in oil alone. This trend was consistent across the data, with powdered coconut husk also showing increased absorption in the presence of water. The enhanced uptake in biphasic systems may be attributed to the hydrophobic–oleophilic nature of coconut husk, which selectively targets oil while repelling water. This behavior is especially pronounced in powdered coconut husk, where capillary action and surface porosity play a more dominant role.

These findings reinforce the suitability of coconut husk, especially in powdered form, as a practical and eco-friendly sorbent for oil spill applications. The data further suggest that moderate increases in absorption can be achieved in oil–water systems without chemical modification, making the material viable for real-world spill scenarios, including aquatic environments This is supported by the findings of Omoniyi & Henry (2014), which demonstrated that coconut fiber without chemical modification can serve as an effective absorbent for separating oil from water.

4. Conclusions

The results highlight the significant potential of coconut husk as a low-cost, biodegradable, and environmentally sustainable alternative to synthetic oil sorbents, particularly in resource-limited settings. This study also supports the valorisation of agricultural waste through bioremediation, aligning with circular economy principles and offering a scalable solution for mitigating the environmental impact of oil spills. The experimental results demonstrated that both coarse and powdered coconut husk can effectively function as natural sorbents for oil spill mitigation under various conditions, including different contact times, sorbent masses, and oil-water mixtures. Among the tested sorbents, powdered coconut husk consistently exhibited higher oil absorption capacity and efficiency than coarse husk due to its smaller particle size and larger surface area, which enhanced oil interaction and retention. In oil-water systems, powdered coconut husk also showed adsorption performance approaching that of commercial absorbents while maintaining selectivity toward oil and resisting water uptake, which is an important characteristic for practical applications in aquatic environments. However, further studies are recommended to optimize sorbent performance through surface modification and field-scale trials to validate its effectiveness under real spill conditions.

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