Performance Optimization of Orange Peel as a Natural Adsorbent for Oil Removal from Water

Alamee Binsammaae, Saweeyah Chengoh, Charuwan Daengroj, Kanokwan Phumivanichakit, and Rawiwan Wattanayon*

Faculty of Science and Technology, Princess of Naradhiwas University, Narathiwat, Thailand
Email: 6461001012@pnu.ac.th (A.B.); sw.saweeyah@gmail.com (S.C.); charawan.d@pnu.ac.th (C.D.); kanokwan.p@pnu.ac.th (K.P.); rawiwan.w@pnu.ac.th (R.W.)
*Corresponding author
Manuscript received April 25, 2026; accepted May 21, 2026; published June 26, 2026

***Abstract*—The issue of oil leakage into natural water sources has a significant impact on the environment and aquatic ecosystems. Contaminated oil in water can harm aquatic organisms and disrupt the food chain. Therefore, effective oil absorption technology is essential to manage oil spills. Currently, research focuses on using bio-based adsorbent materials such as plant fibers, fruit peels, and agricultural waste to reduce costs and organic waste. This study aims to enhance the efficiency of orange peel for oil absorption by conditioning it with nitric acid and sodium hydroxide, followed by heating at 120 °C for 3 h. The results showed that orange peel treated with nitric acid had the highest efficiency in absorbing vegetable oil 99.48% and diesel oil 99.29% which is classified as "very good". The factors affecting absorption efficiency included adsorbent size, adsorbent quantity, and absorption time. It was found that orange peel of 1 mm in size exhibited the best absorption efficiency. Compared with recent studies, these findings demonstrate that nitric-acid-modified orange peels exhibit superior oil adsorption performance. The developed adsorbent represents an effective, economical, and environmentally friendly alternative for oil spill remediation, while also contributing to organic waste reduction and sustainable environmental management.**

***Keywords*—adsorbent, oil removal, environmental water, orange peel, absorption, agricultural waste, sustainability**

I. Introduction

Oil spills arise from both natural sources, such as seepage from subsurface petroleum reservoirs, and anthropogenic activities including offshore drilling, oil and gas extraction, pipeline leakage, maritime transportation, and illegal discharge. The majority of spill incidents are associated with human activities and pose severe environmental and socio-economic risks. Once released into aquatic environments, spilled oil undergoes complex physicochemical and biological processes, including evaporation, oxidation, dispersion, and biodegradation, which are governed by oil composition and environmental factors such as solar radiation, hydrodynamics, and temperature [1–3]. Surface oil films significantly reduce dissolved oxygen levels and inhibit photosynthesis in phytoplankton, algae, and aquatic plants, thereby disrupting microbial degradation processes and aquatic ecosystems. These impacts lead to bioaccumulation of toxic compounds along the food web, ultimately affecting higher trophic levels, including humans, and causing long-term ecological degradation, particularly in sensitive ecosystems such as coral reefs. In Thailand, 176 oil spill incidents were recorded between 1997 and 2022, with an average frequency of 6–7 events per year, especially in industrialized coastal regions such as Rayong and Chonburi, highlighting the persistent vulnerability of marine environments [1]. Although various remediation techniques—such as physical containment, chemical dispersants, in situ burning, and shoreline cleaning—have been employed, chemical methods often exhibit high toxicity, environmental persistence, and elevated costs. Consequently, increasing attention has been directed toward biodegradable, low-cost, and environmentally benign sorbents derived from agricultural waste. Among these, orange peel represents a promising bio-based adsorbent due to its abundant availability, low cost, biodegradability, and high adsorption potential. Orange peel possesses favorable chemical composition and structural properties for efficient oil adsorption. Its cellulose and hemicellulose fiber network provides a porous structure with high surface area, enhancing oil uptake. Lignin contributes to structural stability, while pectin improves oil adhesion, making orange peel an effective natural adsorbent [4–9]. Recent studies have demonstrated the potential of Orange Peel (OP) as a low-cost biosorbent for oil spill remediation. Gheriany *et al.* [8] reported that dried orange peel exhibited an oil sorption capacity of 3–5 g/g at 25 °C, with water uptake below 1 g/g, indicating high selectivity toward oil. More recently, Abubakar *et al.* [10] optimized OP adsorption using Response Surface Methodology (RSM) and Central Composite Design (CCD), achieving a maximum adsorption capacity of 34.17 g/g under optimal conditions (0.2 g adsorbent and 50 min).

Therefore, this study investigates the adsorption performance of orange peel for the removal of different oil types in natural water systems, aiming to mitigate environmental impacts while simultaneously valorising agricultural waste.

II. Method

A. Materials

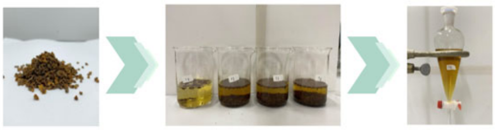
Orange was obtained from a fruit market in Narathiwat, Thailand. All chemicals/reagents were of analytical grade. Diesel and vegetable oil were obtained from gas station and shop in Narathiwat, Thailand. All experiments were conducted at laboratory, faculty of science and technology, Princess of Naradhiwas University, Naratghiwat, Thailand.

B. Experimental Procedure

The method for oil spill adsorption using modified orange peel was developed based on previous studies [3].

Orange peels were washed, cut into small pieces, and oven-dried. The dried samples were chemically modified by soaking in sodium hydroxide and nitric acid solutions for 24 h, followed by rinsing with deionized water to remove residual chemicals. The treated peels were then dried, ground, and sieved to obtain adsorbent sizes.

The effects of chemical modification and adsorbent size on oil adsorption efficiency were investigated using vegetable oil and diesel oil. In each experiment, water was placed in a 250 mL beaker, followed by the addition of of oil. Chemically modified orange peel adsorbents treated with nitric acid and sodium hydroxide, with adsorbent were added and allowed to adsorb the oil for 20 min. After the contact time, the mixture was filtered to separate the adsorbent, and the remaining oil was extracted using hexane in a separatory funnel. The oil phase was then collected, heated to remove residual solvent, and weighed. The oil adsorption efficiency was calculated based on the amount of oil removed (Fig. 1).



Adsorbent Absorption testst Oil-water separation

Fig. 1. Method for oil spill adsorption using modified orange peel.

III. Results and Discussion

Modification and adsorbent size effects on adsorption efficiency.

The orange peel was modified using different chemical treatments, namely nitric acid (HNO_3) and sodium hydroxide (NaOH), to enhance its adsorption efficiency. The treated orange peel was then ground to the desired adsorbent sizes and subsequently tested for the adsorption of vegetable oil and diesel oil. These experiments were conducted to evaluate which modification method and adsorbent size provided the highest adsorption performance. The results of the adsorption tests are presented as follows.

Figs. 2 and 3 depict the influence of chemical modification and adsorbent size on the adsorption efficiency of vegetable oil and diesel oil. Orange peel adsorbents treated with HNO_3 and NaOH were prepared with adsorbent sizes of 1, 2, and 3 mm (Fig. 4).

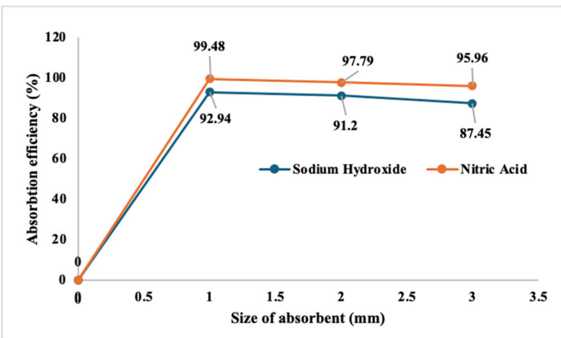


Fig. 2. Effect of surface modification and adsorbent size on vegetable oil adsorption efficiency.

Among all conditions, HNO_3-modified orange peel with a adsorbent size of 1 mm exhibited the highest adsorption efficiencies, reaching 99.48% for vegetable oil and 99.29% for diesel oil, indicating excellent adsorption performance [3]. In contrast, NaOH-modified samples showed comparatively lower efficiencies, reaching 92.94% for vegetable oil and 95.59% for diesel oil particularly at a adsorbent size of 3 mm, where adsorption efficiency decreased to 87.45% for vegetable oil. The superior performance of HNO_3-treated orange peel is attributed to enhanced surface porosity and increased specific surface area induced by acid modification, which facilitates greater oil uptake. Additionally, the smaller adsorbent size provides increased surface contact and improved accessibility to active adsorption sites. Gheriany *et al.* [8] reported that orange peel with a particle size of 1.7 mm achieved oil sorption capacities of 2.38–5.23 g/g after 60 min. Similarly, Abubakar *et al.* [10] found that fine particles (BSS 100 sieve size) enhanced adsorption performance, reaching a maximum capacity of 34.17 g/g. These results highlight the importance of particle size in improving oil adsorption efficiency.

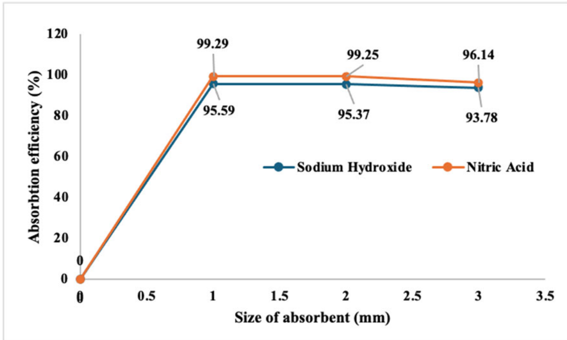


Fig. 3. Effect of surface modification and adsorbent size on diesel oil adsorption efficiency.

Fig. 4. Size of adsorbent.

Based on these findings, nitric acid-modified orange peel with a adsorbent size of 1 mm was identified as the optimal adsorbent. This material demonstrates high efficiency for the adsorption of both vegetable oil and diesel oil and exhibits strong potential for practical application in oil spill remediation in natural aquatic environments.

The drying time of orange peel was investigated to determine the optimal duration required to achieve complete dryness prior to the subsequent modification process. The orange peel was dried at 120 °C for different time intervals of 3, 6, and 9 h.

Fig. 5 presents the effect of drying time on orange peel at 120 °C. The percentage of weight loss was evaluated for orange peel samples modified with nitric acid and sodium hydroxide after drying for 3, 6, and 9 h. At 3 h, the weight loss was 16.58% and 19.06%, respectively. After 6 h, the weight loss decreased to 15.28% and 18.10%, while values of 15.27% and 18.04% were observed after 9 h of drying. The results indicate that a drying time of 3 h provides oil adsorption performance comparable to that obtained at longer drying times. Moreover, shorter drying durations help preserve the cellulose and lignin structures, thereby reducing the risk of structural degradation caused by prolonged thermal exposure.

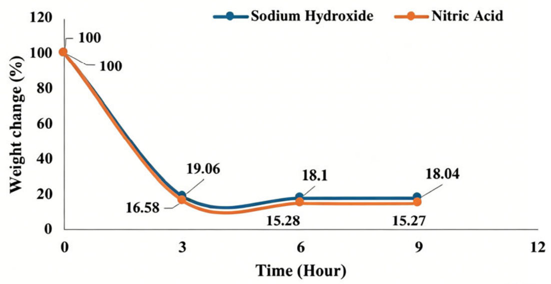


Fig. 5. illustrates the effect of drying time on orange peel at 120 °C.

The developed adsorbent demonstrates an effective, cost-efficient, and environmentally friendly alternative for oil spill remediation, while simultaneously contributing to organic waste reduction and sustainable environmental management. For future studies, key parameters such as the adsorbent-to-oil ratio, contact time, and application in real environmental water systems should be further investigated to evaluate practical performance and scalability.

IV. Conclusion

Nitric acid (HNO_3) modification significantly enhanced the oil adsorption performance of orange peel by increasing surface porosity and active adsorption sites. HNO_3-modified orange peel with a adsorbent size of 1 mm and a drying time of 3 h at 120 °C achieved the highest adsorption efficiencies for both vegetable and diesel oils. This low-cost, environmentally friendly adsorbent shows strong potential for practical oil spill remediation, with further studies recommended on operational optimization and real-water applications.

Conflict of Interest

The authors declare that there are no personal, professional, or financial relationships that could be construed as a potential conflict of interest regarding the publication of this paper.

Author Contributions

Alamee Binsammaae conducted the experiments and collected the data. Saweeyah Chengoh assisted with the experimental design and data interpretation. Charuwan Daengroj performed the oil extraction process for adsorption measurement and contributed to the methodology. Kanokwan Phumivanichakit was responsible for material preparation and served as a consultant for the research project. Rawiwan Wattanayon supervised the research project, reviewed the manuscript, and served as the corresponding author. All authors have read and approved the final version of the manuscript.Acknowledgment

Funding

Reseacher would like to acknowledge funding from Fundamental Fund (FF), Thailand Science Research and Innovation and supporting from faculty of Science and Technology, Princess of Naradhiwas University.

References

[1] Department of Marine and Coastal Resources, Ministry of Natural Resources and Environment. (Jun. 2023). Oil spill in the sea—Marine tourism warning system. [Online]. Available: https://km.dmcr.go.th/c_262

[2] U. Passow and K. Lee, "Future oil spill response plans require integrated analysis of factors that influence the fate of oil in the ocean," *Current Opinion in Chemical Engineering*, vol. 36, 100769, Jun. 2022.

[3] A. Bayat, S. F. Aghamiri, A. Moheb, and G. R. Vakili-Nezhaad, "Oil spill cleanup from sea water by sorbent materials," *Chemical Engineering & Technology*, vol. 28, no. 12, pp. 1525–1528, Dec. 2005.

[4] R. N. Malhas and K. W. Amadi, "Oil removal from polluted seawater using carbonized avocado peel as a bio-adsorbent," *European Journal of Engineering and Technology Research*, vol. 7, no. 3, pp. 52–65, 2022.

[5] A. Chavan and S. Mukherji, "Treatment of hydrocarbon-rich wastewater using oil-degrading bacteria and phototrophic microorganisms in rotating biological contactor: Effect of N:P ratio," *Journal of Hazardous Materials*, vol. 154, no. 1–3, pp. 63–72, Jun. 2008.

[6] E. O. Kamgba and O. Obi, "Techniques of oil spill response in the sea," *IOSR Journal of Applied Physics*, vol. 6, no. 1, pp. 36–41, 2010.

[7] T. V. Nam, T. T. Nguyen, D. N. Dung, and P. T. H. Phuong, "Esterified durian peel adsorbents with stearic acid for spill removal," *Chemical Engineering Transactions*, vol. 78, pp. 271–276, 2020.

[8] I. A. El Gheriany, F. A. El Saqa, A. A. A. El R. Amer, and M. Hussein, "Oil spill sorption capacity of raw and thermally modified orange peel waste," *Alexandria Engineering Journal*, vol. 59, no. 2, pp. 925–932, Apr. 2020.

[9] D. Ouyang, X. Lei, and H. Zheng, "Recent advances in biomass-based materials for oil spill cleanup," *Nanomaterials*, vol. 13, no. 3, p. 367, Feb. 2023.

[10] A. M. Abubakar, H. D. Diriki, L. B. Umdagas, K. C. Mukwana, W. C. Ulakpa, T. Saka, K. Khan, and A. A. Bhutto, "SigmaXL optimisation of oil spill removal from water using orange peels bio-adsorbent," *Malaysian Journal of Chemical Engineering & Technology*, vol. 7, no. 2, pp. 131–158, 2024.