



Bioremediation of Petroleum-Contaminated Soil Using Compost Produced from Food Waste

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ABSTRACT

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This study evaluated the potential of food waste-derived compost for the bioremediation of crude oil-contaminated soil from the Bahregan oil field, Bushehr Province, southern Iran. The experiment was conducted for 180 days using four treatments: a control without aeration and moisture addition, a control with aeration and moisture addition, and treatments containing 30% and 50% compost. Total petroleum hydrocarbons (TPH) were measured using gas chromatography equipped with a flame ionization detector (GC-FID), and changes in TPH concentrations were monitored throughout the experimental period. In addition, some physicochemical characteristics affecting the bioremediation process, including pH, organic carbon, total Kjeldahl nitrogen, and total phosphorus, were monitored. The results showed that after 180 days, TPH removal efficiencies in the control without aeration and moisture addition, the control with aeration and moisture addition, and the 30% and 50% compost treatments were 8.6%, 78%, 94.45%, and 94.91%, respectively. Comparison of the control treatments showed that oxygen supply and maintenance of appropriate moisture substantially increased TPH removal, indicating the important role of suitable environmental conditions in the activity of indigenous microorganisms. Compost addition under the same aeration and moisture conditions also increased the removal efficiency compared with the aerated and moistened control. The 30% and 50% compost treatments showed 16.45 and 16.91 percentage points greater TPH removal, respectively, than the aerated and moistened control. However, the difference in final removal efficiency between the two compost levels was only 0.46 percentage points. Therefore, under the conditions of this study, the use of 30% compost may be a more suitable option in terms of the amount of amendment required and operational costs. Overall, the results showed that food waste-derived compost, together with appropriate moisture and aeration management, has high potential for the bioremediation of petroleum-contaminated soil and can simultaneously contribute to reducing hydrocarbon contamination and the beneficial reuse of organic waste.

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Introduction

Crude oil is one of the world's most important energy resources and plays a major role in the economies of oil-producing countries, particularly those surrounding the Persian Gulf. However, oil exploration, drilling, extraction, transportation, storage, and processing can lead to significant environmental contamination. Oil spills, leakage from petroleum facilities, contaminated wastewater, and other petroleum-related activities are major sources of petroleum hydrocarbons in the environment. These contaminants can adversely affect soil properties, microbial communities, and surrounding ecosystems. Petroleum contamination is an important environmental concern because crude oil contains a complex mixture of hydrocarbons with different physical, chemical, and biological properties. Once introduced into soil, petroleum hydrocarbons may undergo volatilization, dissolution, adsorption, desorption, transport, and biodegradation. Their presence can also alter soil properties, nutrient availability, and microbial activity. Therefore, effective, environmentally compatible, and economically feasible remediation methods are particularly important in oil-producing regions. Bioremediation is a promising approach for treating petroleum-contaminated soils because microorganisms can transform and degrade petroleum hydrocarbons. Its efficiency depends on factors such as oxygen availability, moisture, nutrients, pH, temperature, and contaminant bioavailability. Compost can improve several of these conditions by supplying organic matter and nutrients, enhancing moisture retention, and improving soil properties. In addition, the use of food-waste compost can provide the combined benefits of organic waste management and contaminated-soil remediation. The Bahregan oil region in Bushehr Province, southern Iran, is located along the northern Persian Gulf and has a long history of petroleum exploration and production. Therefore, investigating suitable bioremediation approaches in this region is environmentally important. The present study evaluated the effectiveness of food-waste compost for the bioremediation of real crude-oil-contaminated soil collected from the Bahregan oil region. Specifically, the study investigated TPH reduction over 180 days, the effects of aeration and moisture management on TPH removal, and the effects of applying 30% and 50% compost on bioremediation efficiency.

Method

Petroleum-contaminated soil was collected from the Bahregan oil region in Bushehr Province, southern Iran. Food-waste compost containing 20% sheep manure was produced from food waste generated at a residential oil company camp and composted for five weeks in wooden boxes with regular turning and moisture control. The initial TPH concentration of the contaminated soil was 535,000 mg kg⁻¹, while TPH was not detected in the compost within the analytical detection limit. A 180-day bioremediation experiment was conducted using four treatments: (1) unaerated and unmoistened control, (2) aerated and moistened control without compost, (3) soil amended with 30% compost, and (4) soil amended with 50% compost. Compost-amended treatments were manually turned every four days, and moisture was maintained at 40–50% by adding water as needed. These treatments allowed the effects of aeration and moisture to be distinguished from the additional effect of compost amendment. TPH concentrations were measured at regular intervals. Before sampling, the mixtures were thoroughly homogenized, and samples were collected from different depths. TPH was extracted from dried samples using n-hexane and quantified by gas chromatography with a flame ionization detector (GC-FID) according to TNRCC Method 1005. Hydrocarbons in the C6–C35 range were considered TPH, and concentrations were reported on a dry-weight basis. pH, temperature, organic carbon, total Kjeldahl nitrogen (TKN), total phosphorus, and moisture were also monitored. TPH, organic carbon, TKN, and total phosphorus were measured weekly, while pH and temperature were monitored daily. Treatment performance was evaluated based

on changes in TPH concentration and percentage TPH removal over the 180-day experimental period.

Results

Initial characterization showed that the compost had substantially higher organic carbon, nutrients, and moisture than the contaminated soil, with organic carbon and moisture of 285.60 g kg⁻¹ and 48.20% compared with 18.50 g kg⁻¹ and 11.60%, respectively. TKN and total phosphorus were also higher in the compost, while pH values were 7.45 and 6.82 for compost and soil, respectively, indicating more favorable conditions for microbial activity and petroleum hydrocarbon degradation. After 180 days, the unaerated and unmoistened control showed only 8.6% TPH reduction, whereas the aerated and moistened control achieved 78.00%, highlighting the importance of adequate oxygen and moisture and the limited contribution of natural attenuation alone. Compost addition further increased TPH reduction, with 94.45% and 94.91% removal in the 30% and 50% compost treatments, respectively, corresponding to additional reductions of 16.45 and 16.91 percentage points compared with the aerated and moistened control. The improved performance may be related to the higher organic matter and nutrient content of compost and its ability to improve soil moisture and the physical environment for indigenous microorganisms. TPH reduction was not constant throughout the experiment. In the aerated and moistened control, reduction increased from 72.03% on day 80 to 78.00% on day 180, while the 30% and 50% compost treatments increased from 55.46% to 94.45% and from 77.87% to 94.91%, respectively. Although degradation continued throughout the experiment, a considerable proportion occurred during the earlier stages, followed by slower reduction later, likely due to the depletion of readily biodegradable hydrocarbon fractions and persistence of less accessible compounds. Increasing compost from 30% to 50% resulted in only a 0.46 percentage-point increase in final TPH removal; therefore, the 30% treatment achieved similarly high removal with a lower compost requirement and may be more practical for further pilot-scale and field investigations.

Conclusion

The findings demonstrated that food-waste compost has considerable potential for the biological remediation of crude-oil-contaminated soil. After 180 days, TPH reductions in the unaerated and unmoistened control, aerated and moistened control, 30% compost, and 50% compost treatments were 8.6%, 78.00%, 94.45%, and 94.91%, respectively. The comparison between the control treatments demonstrated the important role of adequate aeration and moisture in enhancing the activity of indigenous microorganisms. Compost addition further improved TPH removal, presumably by improving the physicochemical conditions and providing organic matter and nutrients required for microbial activity. Because the difference between the 30% and 50% compost treatments was only 0.46 percentage points, the 30% compost treatment can be considered a more practical option under the conditions investigated. The use of food-waste compost may therefore provide a dual environmental benefit by contributing to petroleum-contaminated soil remediation and the beneficial reuse of organic waste. However, the results were obtained under controlled experimental conditions, and further pilot-scale and field studies are required to evaluate the effectiveness, stability, operational requirements, and environmental implications of this approach under actual conditions in oil-producing regions.

شرایط فیزیکوشیمیایی و افزایش فعالیت میکروبی خاک، امکان بازیافت پسماند آلی و کاهش وابستگی به روش‌های شیمیایی و فیزیکی پرهزینه را فراهم می‌کند (Tran et al., 2021; Namkoong et al., 2002). با این حال، نتایج حاضر در شرایط آزمایشگاهی به‌دست آمده و برای استفاده در مناطق نفتی نیازمند مطالعات پایلوت و میدانی است. همچنین، ارزیابی موفقیت فرایند نباید تنها بر کاهش TPH متکی باشد و بررسی ترکیبات هیدروکربنی، سمیت و انتشار ترکیبات فرار مانند بنزن، تولوئن، اتیل‌بنزن و زایلین‌ها^۱ (BTEX) نیز ضروری است (Tran et al., 2018).

نتیجه‌گیری

در این پژوهش، تصفیه زیستی خاک آلوده به نفت با استفاده از کمپوست تولیدشده از پسماند مواد غذایی و با تکیه بر ظرفیت میکروارگانیسم‌های بومی خاک بررسی شد. نتایج نشان داد که فراهم‌کردن شرایط مناسب برای فعالیت میکروارگانیسم‌ها، به‌ویژه از طریق تأمین رطوبت و هوادهی، نقش مهمی در کاهش هیدروکربن‌های نفتی دارد؛ به‌طوری‌که پس از ۱۸۰ روز، کاهش TPH در تیمار شاهد بدون هوادهی و رطوبت‌دهی تنها ۸/۶ درصد بود، درحالی‌که در شاهد تحت هوادهی و رطوبت‌دهی به ۷۸ درصد رسید. این یافته نشان می‌دهد که میکروارگانیسم‌های بومی موجود در خاک منطقه، در صورت فراهم‌بودن شرایط محیطی مناسب، ظرفیت قابل‌توجهی برای تجزیه زیستی هیدروکربن‌های نفتی دارند. افزودن کمپوست موجب افزایش بیشتر راندمان حذف TPH شد و میزان کاهش TPH در تیمارهای حاوی ۳۰ و ۵۰ درصد کمپوست پس از ۱۸۰ روز به‌ترتیب ۹۴/۴۵ و ۹۴/۹۱ درصد رسید. با این حال، اختلاف راندمان دو تیمار تنها ۰/۴۶ واحد درصد بود؛ بنابراین، در شرایط این مطالعه، افزایش مقدار کمپوست از ۳۰ به ۵۰ درصد مزیت قابل‌توجهی از نظر حذف نهایی TPH ایجاد نکرد. از این رو، تیمار ۳۰ درصد کمپوست می‌تواند گزینه مناسب‌تری برای بررسی‌های پایلوت و میدانی باشد، زیرا امکان دستیابی به راندمان بالا با مصرف کمتر کمپوست و احتمالاً هزینه عملیاتی پایین‌تر را فراهم می‌کند.

استفاده از کمپوست پسماند غذایی، هم‌زمان مدیریت پسماندهای آلی و زیست‌پالایی خاک‌های نفتی را ممکن می‌سازد و با کاهش شیرابه و انتشار گازهای گلخانه‌ای، پسماند را به یک اصلاح‌کننده مفید خاک تبدیل می‌کند. با این حال، تأیید قابلیت کاربرد این روش در مقیاس میدانی مستلزم انجام مطالعات پایلوت و ارزیابی هم‌زمان کارایی حذف آلاینده، پایداری فرایند و پیامدهای محیط‌زیستی آن است. همچنین در مطالعات آینده می‌توان شناسایی و تعیین میکروارگانیسم‌های بومی مؤثر در تجزیه هیدروکربن‌ها را در اولویت قرار داد.

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^۱ Benzene, toluene, ethylbenzene, and xylenes

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