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Abstract

Sludge is a complex emulsion of various petroleum hydrocarbons (PHCs), water, heavy metals, and solid particles. Polycyclic aromatic hydrocarbons (PAHs), which are components of crude oil sludge, constitute serious

Compounds present in oil sludge

Oil sludge is mainly composed of alkanes, aeromatics, asphaltenes and resin [1]. Oil sludge contains volatile organic carbons (VOCs) and semivolatile organic carbons (SVOCs) (for example, PAHs) which over the years have been reported as being genotoxic [14,15]. e oil from the pyrolysis was composed basically of PAHs such as naphthalene, acenapthylene, phenanthrene, uoranthene, benzo[a] anthracene, benzo uoranthenes, benzopyrenes, indenepyrene, benzo[ghi]perylene, and anthanthrene [16]. Quanti cation of the main compounds showed that sewage sludge pyrolysis oils contain signi cant quantities of potentially high-value hydrocarbons such as mono-aromatic hydrocarbons and phenolic compounds [17]. Based on the EU guidelines and the mean concentration values for metals found in the oily sludge, e.g., Pb (135.4 ± 125.8), Cu (105.2 ± 79.1), Hg (42.8 ± 31.3), Ni (320 ± 267.4), and Zn (1321.7 ± 529.9 mg kg^{-1}), disposal of oily sludge even in land lls for hazardous waste is not allowed [18]. One time composting in static aerated biopiles with organic amendments as the sole strategy to treat oily sludge is very e ective in reducing the content of 2–4 rings PAH, but it is not e ective in reducing the content of 5–6 ring PAHs, even a er a relatively long time span (370 d) [19] (Figure 1).

Naphthalene: It is an aromatic hydrocarbon, with molecular formula $C_{10}H_8$ and the structure of two fused benzene rings. e thermophilic aerobic bacterium Bacillus thermoleovorans Hamburg 2 grows at 60°C on naphthalene as the sole source of carbon and energy. Naphthalene degradation by the thermophilic B. thermoleovorans di ers from the known pathways found for mesophilic bacteria [20]. Naphthalene-degrading strain with high activity was isolated from soil polluted by cooking oil,which was identi ed and named Hydrogenophaga Palleronii LHJ38. naphthalene-degrading activity of this strain was developed and the optimum growth conditions of this strain were studied. Under the optimum conditions of 28 (,initial pH(6.6) and mol ratio of carbon to nitrogen 4 and naphthalene mass concentration 2 000mg/L,the degradation rate of naphthalene is more than 98% in 96 h [21].

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Anthracene: is is a polycyclic aromatic hydrocarbon consisting of three fused benzene rings. It is also component of coal tar [22]. e initial reactions in the bacterial degradation of anthracene involve the formation of trans-1, 2-dihydroxyanthracene prior to ring ssion [23].

PhenanthrenePhenanthrene is a polycyclic aromatic hydrocarbon composed of three fused benzene rings. Many species of bacteria found in soil are capable of utilising phenanthrene as a growth substrate [24].

Fluoranthene: Fluoranthene, a nonalternant PAH containing a ve-membered ring, has been shown to be metabolized by a variety of bacteria, and pathways describing its biodegradation have been proposed. Fluoranthene has been used as a model compound in studies which have investigated the e ects of surface-active compounds on PAH biodegradation [25].

Fluorene: Fluorene is a polycyclic aromatic hydrocarbon and has been found to be susceptible to microbial degradation to varying extent [23,26].

Pyrene: Pyrene is a PAH consisting of four fused benzene rings. It is the smallest peri-fused PAH (the rings are fused through more than one face). Many microorganisms have shown the capability of utilising four ringed aromatic hydrocarbons such as pyrene [27,28]. Bacteria such as Rhodococcus sp. strain UW1 are capable of growing on pyrene as sole carbon source. is organism was found to mineralise up to 72% of pyrene to CO_2 within two weeks [29].

Composting of oil sludge

Composting o ers an economical and e ective way to treat oil sludge. Composting process which involves the careful control and addition of nutirents, watering, tilling, addition of suitable micro ora and bulking agents (wood-chips or hay) were considered an alternative option to improve the bioremediation of oil sludge [30]. Composting could be divided with respect to modes of operations such as batch operation and continuous or semi-continuous operation. When temperature is the basis, composting can be divided into mesophillic composting (25-40°C) and thermopihillic composting (50-65°). e main advantage of is composting is waste stabilization [31]. Composting matrices and composts are rich sources of xenobiotic-degrading microorganisms including bacteria, actinomycetes and

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ex situ technology where organic matter are added to contaminated soil as a bulking agent. Heavy mineral oil degradation was much faster and more complete in compost-amended soil than in hay-, sawdust-, and mineral nutrient-amended soils. e enhanced degradation of heavy mineral oil in compost-amended soil may be a result of the signi cantly higher microbial activity in this soil [33]. e composting process used to stabilize organic materials can be considered as a bioremediation process. Organic residues constitutes a medium in which the microbial population present can remedy the said sludge as long as the conditions support the microbial activity [34]. In composting factors such as aeration, use of inorganic nutrients or fertilizers and the type of microbial species play a major role in the remediation of oil contaminated sites. Experiments for bioremediation of oil sludge-contaminated soil in the presence of a bacterial consortium, inorganic nutrients , compost and bulking agent (wheat bran) showed 76% hydrocarbon removal compared to 66% in case of inorganic nutrients amended soil [35]. A study reported that oil wastes sludge from petrol stations and petroleum residues from a re nery decomposed to 78-93% during 4.5 months of composting with horse manure. At the end of the experiment, most of the polyaromatic hydrocarbons had been degraded except pyrene, chrysene and dibenz(ah)anthracene [36]. Ecotoxicity tests using luminescent bacteria and tests on plants in Petri dishes demonstrated that the composting process undoubtedly led to the biodegradation of toxic compounds. One of the most e ective treatment is adding the bulking agent, where the initial hydrocarbon content was reduced by 60% in 3 months, compared with the 32% reduction achieved without the bulking agent [34]. Soil contaminated with diesel oil sludge (10,000 mg/kg sample on a dry weight basis) can also be supplemented with sewage sludge or compost for composting of contaminated soil in the ratio of 1:0.1, 1:0.3, 1:0.5, and 1:1 as wet weight basis. e degradation of diesel oil was signi cantly enhanced by the addition of these organic supplements relative to straight soil with degradation rates of total petroleum hydrocarbons (TPH) and n-alkanes the greatest at the ratio of 1:0.5 of contaminated soil to organic amendments on wet weight basis. e rst order degradation constant of n-alkanes was about twice TPH degradation constant regardless of the kind and the amount of organic supplements [37]. In an experiments for the 90-day period bulked soil showed more rapid degradation of oil compared to all other amendments. Wheat bran-amended soil showed 76% hydrocarbon removal compared to 66% in the case of inorganic nutrients-amended soil due to a corresponding increase in the number of bacterial populations. Addition of the bacterial consortium in di erent amendments signi cantly enhanced the removal of oil from the petroleum sludge from di erent treatment units [38]. In a eld-scale study in China bioremediation by augmentation of biopreparation was compared with a conventional composting using oily sludge and oil-polluted soil received from an oil production plant. e total hydrocarbon content (THC) varied from 327.7 to 371.2 g kg 1 of dry sludge and the THC in contaminated soil was 151.0 g kg 1. e. e sludge was mixed and watered every 3 days, biopreparation was applied every 2 weeks and experiment lasted 56 days under the ambient temperature. e THC decreased by 46–53% in the oily sludge and soil, while in the positive controls (activation of indigenous microorganisms) the THC decreased by 13–23%. A er composting, the THC decreased by 31% in the oily sludge. e planting of Tall Fescue (Festuca arundinace) revealed a decrease of sludge toxicity a er application of both bioremediation technologies and additionally decreased the THC by 5–7% [39].

Application of composting to treat oil sludge

Bioremediation has been accepted as an important method for the treatment of oil sludge by employing indigenous or extraneous microbial ora. e bioremediation of a dehydrated oil sludge of 960 m3 in volume was carried out in prepared bed in Binyi oil-containing sewage disposal station, of the oil contaminants, 52.75% was degraded within 160 days when treated in a greenhouse, while the oil contamination decreased by only 15.46% in the untreated sludge [30]

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innocuous compounds and has substantial potential for remediation of polluted materials.

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