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Comparison of bio-augmentation and composting for remediation of oily sludge: A field-scale study in China

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Abstract

Two bioremediation technologies were performed in order to explore a better treatment process for an oily sludge restoration in China during 2004. The bioremediation by augmentation of biopreparation was compared with a conventional composting. The oily sludge and oil-polluted soil were received from an oil production plant. The 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}. Before application of preparation, straw, sawdust, top sand and pure soil were added in different proportions to the sludge and soil and mixed thoroughly. Such sludge and soil composites were used for negative controls and for activation of indigenous oil degrading microorganisms with addition of fertilizer (positive controls). For composting, crude manure and straw were added to the oily sludge and the THC was 101.4 g kg^{-1}. The biopreparation was applied every 2 weeks and experiment lasted 56 days under the ambient temperature. The sludge was mixed and watered every 3 days. After three times of biopreparation application, the 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%, and there was no oil degradation in negative controls After composting, the THC decreased by 31% in the oily sludge. The planting of Tall Fescue (*Festuca arundinace*) revealed a decrease of sludge toxicity after application of both bioremediation technologies and additionally decreased the THC by 5–7%.

Keywords: Oily sludge; Preparation; Iindigenous oil degrading bacteria; Bio-augmentation; Composting

1. Introduction

A huge amount of oily sludge is produced during the oil production and processing activities. This sludge usually contains a considerable quantity of heavy oil, which should be removed before its land disposal. The physico-chemical treatments can be applied for the oily sludge, but these methods are extremely expensive [1–3]. In this respect, composting and bioremediation with an introduction of oil degrading microorganisms (bio-augmentation) or activation of indigenous ones are now considered as two major economic methods for the decontamination of oil pollutions [4–6]. Composting has some visible advantages including relatively low capital and maintenance costs, simple design and operation and some (but incomplete) removal of oil pollution. For example, Jiang applied composting for oil contaminated soil and achieved 45–57% of the THC decrease [7]. However, in general, the efficiency of composting is unsatisfactory to meet the current environmental regulations.

For more content of the oil, the oily sludge is much more difficult for the bioremediation. Numerous researches have demonstrated high bioremediation efficiency for oil polluted soils, but these methods have limitations for the oily sludge mainly dealt with extremely high pollution level and recalcitrance of contaminants for biodegradation [8–10]. Most of the experiments were carried out in the lab, while the field experiments were very few.

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Table 1
Chemical characteristics of the original oily sludges and oil contaminated soil

Samples	Initial THC (g kg^{-1} DW)	pH	Moisture content (%)	[N-NH_4^+] (mg kg^{-1} DW)	[P-PO_4^{3-}] (mg kg^{-1} DW)
Sludge 1	327.7	7.2	6.16	308.4	64.3
Sludge 2[a]	327.7	7.2	0.64	308.4	64.3
Sludge 3	371.2	7.6	5.23	136.7	77.8
Soil 4	151.0	7.7	0.17	102.1	5.5

[a] Without water sludge.

The bioremediation treatment of the oily sludge was just beginning. These experiments were meaningful for the advance of this technology. This article deals with the bioremediation of oily sludge using the bioaugmentation by preparation ''Rhoder'' and composting with manure in order to explore a better treatment process for this type of residues. The field experiments were performed at Shengli Oil Production Plant, (Dongying, China).

2. Materials and methods

The oily sludge and oil-polluted soil for this research were taken from Shengli Oil Production Plant and analysed before start the experiments (Table 1). Sawdust, straw, top sand and clean soils were used as additives to the sludge and soil. The moisture content of sawdust and straw was 23.7 and 7.4%, respectively. Carbamide and KH_2PO_4 were used as fertilizers.

The oil-degrading microbial preparation (''Rhoder'', Certificate number 77.99.04.515 D. 004855. 08. 01 issued by the Russian Ministry of Health) was developed in nineteen in Russia [11]. The preparation was successfully tested in the Western Siberia on different types of oil contaminated wetlands, marshy soils and water surfaces during 1995–1999 as well as in laboratory, pilot and field tests in Komi Republic during 2001–2003 [12,13]. The preparation consists of two *Rhodococcus* oil-degrading strains and represents dry powder of alive bacterial cells with concentration till 10^{10} CFU g^{-1}. The working suspension of preparation for bioremediation contained 10^6–10^7 oil degrading cells per ml.

The oily sludge samples were taken randomly every 3 days from the upper layer (5.0 cm of depth) and 0.5 month after the last treatment from five equidistant points. The THC was determined gravimetrically as follows. 7–8 g sludge samples were dried at 70 °C and after sieving through a 2 mm sieve were extracted with 50 ml petroleum ether by 7–10 times. The extract was evaporated to dryness in water-boring box, and then dried under 70 °C for 1 h and finally weighted.

Individual hydrocarbons were analysed by gas chromatographic (GC) (Trace 2000, TermoQuest, Milan, Italy) and mass spectrometric (Voyager Applied Biosystems, Foster City, CA, U.S.A.) methods. The initial and final oily sludge samples after applied three times of preparation were extracted by petroleum ether and re-dissolved in 10 ml. The samples were analysed for GC profiles. The hydrocarbon concentrations were calculated by comparing the peak areas of samples with internal standard (hexadec-1-en) [14]. The gas chromatograph was equipped with a flame ionisation detector and a 30 m stainless steel column. The operation conditions were as the following: initial temperature was 50 °C, and was increased at 10 °C min^{-1} to 200 °C and then increased at 5 °C min^{-1} to the final temperature of 290 °C. Helium as a carrier gas was delivered at a rate of 0.8 ml min^{-1}.

Numbers of microorganisms in the treated sludge were estimated by MPN method, using meat-peptone agar in Petry dishes. Ten grams of oil sludge was suspended in 90 ml of sterile water and submitted to vigorous shaking, and then the method of ten-fold dilutions and triplicate Petry dishes for each variant was applied.

To determine pH the samples were dried at 70 °C and sieved through a 1 mm sieve, then 5 g samples were extracted with distilled water by five times with electro-magnetic stirrer during 30 min. The water samples were measured after complete mixing.

The composting pile temperature was recorded every day randomly from the five-equidistant points of the upper layer (0.05 m depth) of the pile.

3. Experimental design

The field scale experiments were performed under roof on the surface of a concrete slab. There were four sections (2.5 m × 2.0 m × 0.2 m) for experiments with the biopreparation in oily sludges at the same time. Two sections (1.6 m × 1.0 m × 0.2 m) were used for positive controls (i.e., activation of indigenous microorganisms), 2 of the same size - for negative controls and 1 (0.75 m × 0.5 m × 0.2 m) – for composting.

Before composting (CM), 60 kg raw manure and 10 kg straw were added to 280 kg of oily sludge (the initial THC 126.8 g kg^{-1}), mixed thoroughly and made a pile. The THC in this modified sludge became 101.4 g kg^{-1}.

The initial concentrations of hydrocarbon (HC) in oily sludges varied from 327.7 to 371.2 g kg^{-1}, whereas in the old oil contaminated soil it was 151.0 g kg^{-1}. Straw, sawdust, top sand and clean soil were added to the sludges and soil, and mixed thoroughly before the first application of the biopreparation. The materials used for composting are presented in Table 2. The mentioned above supplements