

# Aggregation of Diesel Contaminated Soil for Bioremediation

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**Abstract:** Diesel contaminated soil (DCS) contained a large amount of the hydrocarbons and salt which was dominated by soluble sodium chloride. Aggregation process which made the desired aggregate size distribution could speed up the degradation rate of the hydrocarbons since the aggregated DCS had better physical characteristics than the non-aggregated material. Artificial aggregation increased pores  $>30\ \mu\text{m}$  by approximately 5% and reduced pores  $<1\ \mu\text{m}$  by 5%, but did not change the percentage of the pores between 1 and  $30\ \mu\text{m}$ . The saturated hydraulic conductivity of non-aggregated DCS was  $5 \times 10^{-6}\ \text{m} \cdot \text{s}^{-1}$ , but it increased to  $1 \times 10^{-5}\ \text{m} \cdot \text{s}^{-1}$  after aggregation. The compression index of the non-aggregated DCS was 0.0186; however, the artificial aggregates with and without lime were 0.031 and 0.028, respectively. DCS could be piled 0.2 m deep without artificial aggregation; however, it could be applied 0.28 m deep when artificial aggregates were formed without limiting  $\text{O}_2$  transport.

**Key words:** diesel contaminated soil, aggregation, non-aggregation, salt leaching, aeration

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## Introduction

A considerable amount of the oily contaminated soil can be generated from the petroleum industry during its crude oil exploration, production, transportation, storage, and refining processes (Xu *et al.*, 2009; Mrayyan and Battikhi, 2005). In particular, the soil sludge generated during the petroleum refining process has received increasing attention in recent years. It contained a high concentration of the petroleum hydrocarbons (PHCs) and other recalcitrant components. As being recognized as a hazardous waste in many countries, the improper disposal or the insufficient treatment of the oil contaminated soil can pose serious threats to the environment and human health (Xu *et al.*, 2009; Mrayyan and Battikhi, 2005; Liu *et al.*, 2009; Mater *et al.*, 2006; Rocha *et al.*, 2010).

Bioremediation of petroleum and salt-contaminated soil, as found often in oil-fields due to pipeline leakage and inappropriate operations, is challenged by the coexistence of the salt and petroleum in the contaminated soil (Nicholson and Fathepure, 2004). On one hand, salt at high concentration inhibits microbial growth and subsequent petroleum degradation (Rhykerd *et al.*, 1995). On the other hand, the petroleum makes the soil granules hydrophobic and thus hinders the salt leaching via water infiltration (Andrade *et al.*, 2004). Bioremediation of the contaminated soil is performed via the addition of microorganisms so as to enhance a specific biological activity; however, the properties of the treated materials and environmental factors are also validated important in removing organic pollutants from soil (Vogel, 1996; Ellis *et al.*, 2000; Salanitro *et al.*, 2000; Lendvay *et al.*, 2003; Fantroussi and Agathos, 2005).

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To decrease the bulk density and improve the aeration and leaching characteristics, an aggregation experiment was conducted to broke up large clods of diesel contaminated soil (DCS) and recombine the individual mineral particles into aggregates, which was considered to provide better environment for the hydrocarbon biodegradation. The aggregate characteristics and some parameters influencing microbial activity in soil were also tested in the experiment.

## Materials and Methods

A food mixer (Kitchen Aid, model K5SS) was used to produce artificial aggregates. Both DCS and amendments were added to the mixing bowl at the same time. Approximately 1 to 1.5 kg of the material was used for each mixing. The speed of the mixer was 2-4 cycles per second. Each mixing lasted for 5 min. The soil amendments including water were added while mixer was operating.

Wet aggregate stability was measured using the fraction of the aggregates between 1.4 and 2.4 mm. Five to seven grams of the aggregates were placed into a 1.2 mm sieve and shaken to sieve out any loose particles. The aggregates were wetted slowly using 30 kPa of vacuum for 2 to 3 h depending on the wettability of the aggregates. The sieve with pre-wetted aggregates was then placed into the wet sieving apparatus which provided a sieving frequency of 35 cycles per min. The sieving time was 3, 10, 20, 30, and 40 min. The aggregates remained in the sieve were soaked into a container containing 110 mL of 0.2% sodium hexametaphosphate (NaHMP, dispersing solution).

The stable aggregate fraction ( $ST_i$ ) was calculated by

$$ST_i(\%) = \frac{W_{sNa}}{\sum_1^i W_{sH_2O} + W_{sNa}} \times 100 \quad i=1, 2, 3, 4, 5 \quad (1)$$

Where,  $W_{sNa}$ =soil in NaHMP solution,  $W_{sH_2O}$ =soil in the water. When  $i=1$ ,  $t=3$  min, and  $i=5$ ,  $t=40$  min. The detailed procedure is given by Kemper and Chepil (1965).

The water release curve was measured up to 300 kPa, using pressure plates with a continually weighing method. The pore sizes of DCS were calculated by

$$r = \frac{2\sigma}{\rho gh} \quad (2)$$

Where,  $r$ =pore radius (m);  $\sigma$ =surface tension of water ( $72 \text{ N} \cdot \text{m}^{-1}$ );  $\rho$ =density of water ( $\text{Mg} \cdot \text{m}^{-3}$ ),  $g$ =gravitational acceleration ( $9.8 \text{ m} \cdot \text{s}^{-2}$ ); and  $h$ =hydraulic head (m).

Compressibility of DCS was tested in a one-dimensional consolidation test (McNabb *et al.*, 1994). The DCS was gently packed into plastic columns with a diameter of 74 mm and a height of 35 mm by tapping the column on a flat surface. The column of DCS was saturated for 24 h. The consolidation curve was measured using a consolidation machine.

A 14 cm PVC column (7.4 cm diameter) was used for the leaching test. Two centimetres of the sand were packed at the bottom of the column. The sand layer prevented water flow from disturbing the aggregates. The ends of the column were sealed with rubber plungers. The rubber plungers were connected to a Mariott bottle, which controls hydraulic head, with a Tygon tubing of 0.75 cm in diameter.

DCS was packed into a column at a bulk density of  $1 (\pm 0.2) \text{ Mg} \cdot \text{m}^{-3}$ , simulating natural consolidation. DCS was then divided into three portions. Each portion was successively poured into the column and gently pressed with a rubber plunger to occupy one third of the column length. This procedure produced uniform packing and avoided channels which could cause preferential water movement in the column. After packing each layer, the top 0.5 cm of the material was loosened before another layer was added. This ensured continuity within the column.

The column was then saturated by applying water with 10 cm of the hydraulic head from the bottom. This allowed air to escape from the top. It took approximately 2 to 3 h to saturate a 10 cm column. After reaching saturation, the effluent was collected and measured every 10 min. The electrical conductivity was measured on each leachate fraction. Leaching

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