Bioremediation of maleic anhydride contaminated soil

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Abstract

This paper presents a bench-scale study of bioremediation of soil contaminated with maleic anhydride. A quantity of 300 kg of contaminated soil was collected from a petrochemical plant in Malaysia and divided into three portions in order to investigate the effects of nutrient addition as well as mechanical aeration on the biodegradation rate of the contaminants. Online parameters measured included moisture content, redox potential, temperature and pH. The highest first-order biodegradation rate constant was determined to be 6.658 day^{-1} for soil pile with addition of nutrients and mechanical aeration.
Keywords: bioremediation, maleic anhydride, petrochemical industry.

1 Introduction

Bioremediation is an established means of treating contaminated soils especially when the contaminants are organic-based. Research in bioremediation is often focused on *ex-situ* bench-scale studies as such setups facilitate control of important experimental parameters such as temperature and pH. Previous studies on *ex-situ* bench-scale bioremediation include biodegradation of hydrocarbon petroleum contaminated soil [1], gasoline-contaminated sediments [2] and diesel-contaminated soil [3].

Maleic anhydride is used as a chemical intermediate in the synthesis of fumaric and tartaric acid, certain agricultural chemicals, resins in numerous products, dye intermediates and pharmaceuticals [4]. Its detrimental effects on

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human health include dyspnea [5] as well as acute asthmatic reactions [6]. Its presence at elevated concentrations in the soil environment as a result of industrial activities such as hydrocarbon processing presents an undesirable circumstance as humans may come into direct contact with them. In this study, soil contaminated with maleic anhydride was subjected bioremediation processes. The objective of this study was to assess the biotreatability of maleic anhydride contaminated soil via determination of biodegradation rate and half-life of the contaminant under the effect of nutrient addition and aeration.

2 Materials and methods

2.1 Soil sampling

Soil samples were taken from a petrochemical plant in Malaysia, which were contaminated with maleic anhydride due to improper storage and leakage. A total of 300 kg of contaminated soil was collected at depths between 3 to 4 m at the affected area within the petrochemical plant. The soil appeared to be coarse and dark brown in color. The pH of the soil sample was adjusted to 7 by using lime prior to treatment.

2.2 Bench-scale treatment

Due to the readily biodegradable properties of maleic anhydride as determined via a preliminary study, bioremediation was selected as the most appropriate treatment option. For the bench-scale treatment, three soil piles at 100 kg each were constructed:

i) Control soil pile (CP).
ii) Treatment pile mixed with raw nutrients and sawdust (TP1).
iii) Treatment pile mixed with raw nutrients, sawdust and equipped with mechanical aerators (TP2).

The source of the raw nutrients was chicken faeces in which the carbon and nitrogen ratio was 1:30. Sawdust layers, which acted as partition for the soil piles, were laid in three layers sandwiching two layers of soil. The sawdust and soil composition was fixed at 30% on v/v basis. The mechanical aerators for TP2 consisted of two-inch diameter slotted perforated pipes with attached mechanical blower. The three piles were subjected to a monitoring program for a period of two months in which online parameters measured included moisture content, redox potential, temperature and pH. The concentrations of maleic anhydride before and after treatment were determined via high performance liquid chromatography (HPLC).

3 Results and discussion

The initial concentration of maleic anhydride was determined to be 223,000 mg/kg soil respectively. The concentration of maleic anhydride that exceeds the U.S. Environmental Protection Agency (USEPA) preliminary remediation goal of 88,000 mg/kg indicates the need to remediate the soil. Table 1 shows the online parameters recorded during the study period. The range of temperatures in the three soil piles indicates that mesophilic microorganisms are mainly responsible for biodegradation of the contaminants. This is consistent with most of the reported studies on bioremediation in which recorded temperatures were in the mesophilic range [7,8]. In addition, redox potential ranges clearly show that degradation predominantly occurs under aerobic conditions.

Table 1: Online parameters recorded during the study period.

Soil piles	Moisture content (%)	Redox potential (mV)	Temperature (°C)	pH
CP	9.2 – 25.8	207 – 287	28 – 35	3.8 – 8.2
TP1	6.6 – 44.0	82 – 203	27 – 41	4.9 – 8.5
TP2	3.6 – 36.0	92 – 201	26 – 38	6.7 – 8.9

3.1 Biodegradation kinetics

The biodegradation kinetics are evaluated via determination of first-order degradation rate constant, k' (day^{-1}) and half-life of the chemical, $t_{1/2}$ (day). To determine the value of k', the following equation [9] is used:

$$S_t = S_0 e^{-k't} \tag{1}$$

where S_0 is the initial contaminant concentration (mg/L) and S_t the contaminant concentration at time t (day). Half-life is determined from the following equation [9]:

$$k' = \frac{0.693}{t_{1/2}} \tag{2}$$

Table 2 shows the first-order degradation rate constant and half-life of maleic anhydride in the soil piles. The addition of nutrients into the soil clearly increase the degradation rate as evident by the increase in k' value by a factor of nine. Aeration of the soil in TP2 also appears to increase the biodegradation rate constant by 12.2% as compared to TP1. This is due to increased concentration of oxygen in the TP2 as a direct result of aeration. Table 3 compares first-order degradation rate constants for maleic anhydride found in this study with other contaminants. It is obvious that biodegradation of maleic anhydride in this study is very effective as compared to degradation of other hydrocarbon contaminant such as diesel.

Table 2: First-order degradation rate constant and half-life of maleic anhydride.

Soil piles	k' (day^{-1})	$t_{1/2}$ (day)
CP	0.592	1.1
TP1	5.935	0.1
TP2	6.658	0.1

Table 3: Comparison of first-order degradation rate constants with other contaminants.

Contaminant	Addition of nutrient	*k'* (day^{-1})	References
Diesel-contaminated soil	Yes	0.027	[10]
Diesel-contaminated soil	No	0.010	[10]
Diesel-contaminated soil	Yes (sewage sludge)	0.272	[11]
Diesel-contaminated soil	Yes (compost)	0.182	[11]
Diesel-contaminated soil	No	0.052	[11]
Maleic anhydride-contaminated soil	No	0.592	This study
Maleic anhydride-contaminated soil	Yes (Chicken faeces)	5.935	This study

4 Conclusions

Biodegradation of maleic anhydride in the soil was carried out by mesophilic microorganisms under aerobic conditions. Results of the study indicated that bioremediation of maleic anhydride in soils was effective and feasible judging by the high biodegradation rate. The addition of nutrients into the contaminated soil significantly increased the maleic anhydride biodegradation rate as evident by the increase in *k'* value by a factor of nine. Aeration of the soil in TP2 increased the biodegradation rate constant by 12.2% as compared to TP1.

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