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Biodegradation of a Light NAPL under Varying Soil Environmental Conditions

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Introduction

Bioremdiation is an eco-friendly technology for removing petroleum derived contaminants, commonly referred to as dense and light non-aqueous phase liquids (DNAPL and LNAPL respectively) from polluted sites. However, effective implementation of the bioremediation for these contaminants requires a thorough understanding of their fate and transport processes under site-specific conditions.

In semi-arid and arid coastal regions, soil moisture and temperature variations are very important environmental factors along with water table dynamics. The water table dynamics affect the spatial distribution of LNAPL, particularly in the vertical direction, in addition to the soil moisture and temperature distribution. Similarly, seasonal and diurnal fluctuations of soil temperature and moisture in these regions significantly influence the activity and survival of microorganisms responsible for the biodegradation.

Objective

The aim of this research is to investigate the complex soil-water-LNAPL-atmospheric continuum processes during bioremediation under varying environmental conditions relevant to coastal areas in (semi)-arid regions using different scales of laboratory experiments. The specific research questions are:

1.How does soil moisture content influence the biodegradation rate of toluene (an LNAPL)?

2.What is the effect of temperature variation on the LNAPL biodegradation rate?

3.What is the impact of water table fluctuations on the spilled LNAPL fate and transport?

4.How much contaminant is transferred from LNAPL pool to saturated and vadose zones receptors?

Materials and Methods

To see the impact of different soil environmental conditions on the considered LNAPL biodegradation, a series of batch, microcosm, column and 2-D tank experiments under controlled conditions have been planned.

Batches

Several batches have been assembled for a water abundant soil (Fig. 1) . The experiments involve adding soil, groundwater and toluene stock solution to bottles of 120mL. The batches contain aqueous or soil-water solution of 18.75mL leaving rest for the headspace. The pore water as well as the headspace air are sampled at different times and analyzed using gas chromatography.

Materials and Methods

Fig. 1: Completely mixed batches at a) room and b) 30 ^{0}C temperatures with c) measuring vials positioned in an auto-sampler.

Microcosms Study

Fifteen microcosms have been designed for four different soil moisture contents ranging from residual to saturated, and under varying temperature conditions (Fig. 2). The microcosms consist of a transparent outer column and an air-permeable, but water-tight, inner tube comprised of toluene-phobic material. The space between the outer column and the inner tube is filled with a soil having a particular moisture content with a known amount of toluene. The inner tube is filled with air at atmospheric pressure, providing sufficient oxygen for the degradation of the LNAPL. The whole setup is air-tight. Also, a special sampling mechanism, mounted on a sliding base, has been fabricated to enable air-tight soil sampling.

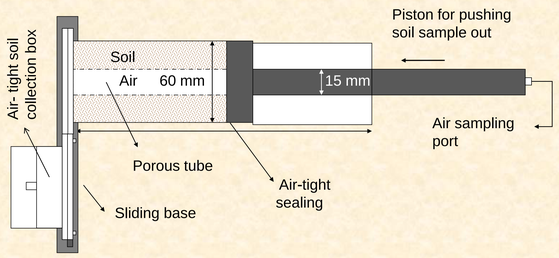


Fig. 2: Schematic diagram of the microcosm with air-tight sampling mechanism, for investigating the impact of soil moisture content and temperature on biodegradation rate of toluene.

Column Experiment

Four columns have been designed for studying the impact of water table fluctuations on the LNAPL fate and transport in variably-saturated soil. Water table in two columns (Fig. 3a) will be static and remaining two will be subjected to a fluctuation (Fig. 3b). Sufficient head space will be provided to prevent oxygen limitation.

Materials and Methods

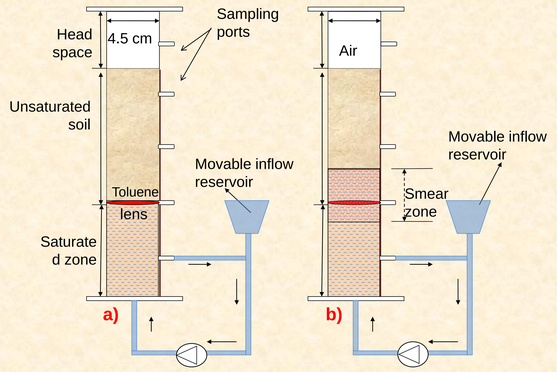


Fig. 3: Schematic diagram of the column setup to study the effect of water table dynamics on concurrent fate and transport of toluene.

2-D Tank Setup

A 2-D tank setup, made of a steel box and a glass cover, has been refurbished for studying bioremediation of toluene from start to finish. The main body is constructed of one piece of 1.5mm thick stainless steel formed into a box with inner dimensions of 2m x 9.4m x .04m. The front cover is made of a 19mm thick glass wall. The soil is packed between the two walls and the groundwater is flowing horizontally from left to right. The spatial and the temporal distributions of toluene along with soil moisture content will be observed using sampling ports and an automated TDR system.

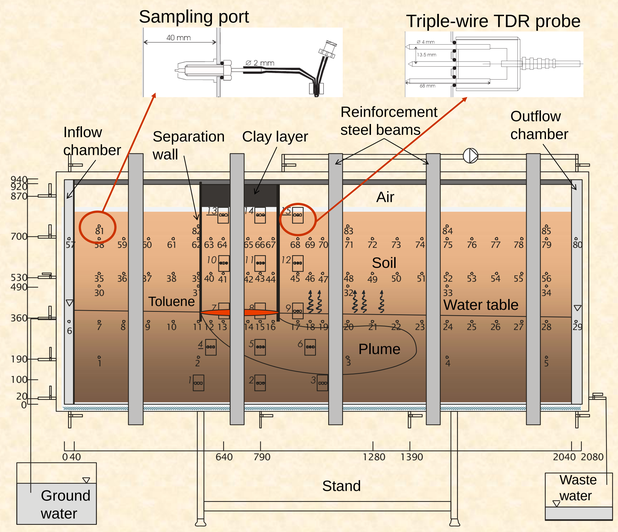
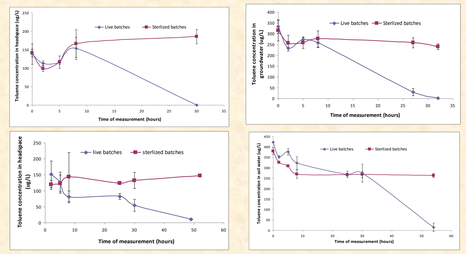


Fig. 4: Schematic diagram of the 2-D tank setup for quantifying toluene transport from source zone to groundwater and its subsequent migration to vadose zone receptors.

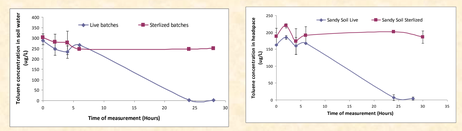
Preliminary Results

The observed toluene concentrations in batches containing groundwater with and without soil at two soil temperatures (21 and 30 ^{0}C) is shown below.

Batch Experiments at Room Temperature



Batch Experiments at 30 ^{0}C Temperature



A significant degradation of toluene, observed during initial two days of the experiments, emphasizes the quick acclimatization and metabolic capabilities of groundwater microbes to decontaminate the toluene. Also, the toluene degradation at 30 ^{0}C is faster than room temperature.

Ongoing and Future Work

- Batch experiments are being conducted under variable temperature (diurnal changes) conditions.
- The effect of soil moisture availability on toluene degradation rate will be examined considering three different soil temperatures using the designed microcosms.
- The column setup will be used for studying the impact of water level fluctuation on the LNAPL fate and transport in variably saturated soil
- The spatial and temporal distributions of the LNAPL and its concentration in water and air phase along with soil moisture content will be observed in the tank setup.

Acknowledgement

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