Effect of Ethanol and Ethanol Biodegradation Products on Prospects for Natural Anaerobic Biodegradation of Benzene at Gasoline Spill Sites

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Background

There has been an increasing use of biofuels (ethanol in particular) in the fuel supply nationwide, the anaerobic biodegradation of ethanol in aquifer sediment from a fuel spill site to the underground storage tank systems. The U.S. EPA needs to understand the fate of these materials if they are released from construction or sampling.

Field Studies

Laboratory microcosm experiments were conducted using sediment from an old spill of JP-4 fuel at the U.S. Coast Guard Support Facility on Elizabeth City, North Carolina. This sediment was well suited for anaerobic biodegradation of fuel components.

Microcosms were constructed in late July 2009. The microcosms were constructed in 160 mL serum bottles. They contained 40 mL of sediment (approximately 166 mL serum bottle), 5 mL of water, with 510 mL of gas phase (Figure 1). The microcosms that were amended with ethanol were exposed to molecular hydrogen during construction or sampling. Ethanol was degraded to acetate and molecular hydrogen. These substances can accumulate to concentrations that make the anaerobic biodegradation of BTEX compounds impossible.

Results

Laboratory Studies

Figure 3B. Concentrations of molecular hydrogen are high as long as ethanol is available to degrade molecular hydrogen.

Field Studies

Ground water samples were collected from conventional monitoring wells. The concentration of ethanol, acetate, ethanoate, and benzene were determined in the ground water samples.

Method

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Effect of Ethanol on the Energy Available from Anaerobic Biodegradation of Benzene

The energy available from a chemical reaction can be calculated by comparing the energy required to make the reactants and the energy required to make the products. The change in energy between the reactants and the products is the energy released during the reaction. The Gibbs free energy (G) is a quantitative estimate of the energy that is available to microorganisms that use the reaction as an energy source.

$\Delta G' = G' - G$ (kJ mole$^{-1}$)

The values of ΔG' depend on the energy content of reactants and products. If the concentration of reactants and products is high, the value of ΔG' is high. If ΔG' is between 0 and $-20 \text{kJ/mole}$, the biodegradation of BTEX compounds is possible. If ΔG' is greater than $-20 \text{kJ/mole}$, the biodegradation of BTEX compounds is impossible.

$\Delta G' = 0$ is the reaction at equilibrium.

$\Delta G' < 0$ is the reaction that is spontaneous.

$\Delta G' > 0$ is the reaction that is not spontaneous.

Effect of Degradation of Ethanol on the Energy Available from Anaerobic Biodegradation of Benzene

Ethanol is fermented by bacteria to acetate and molecular hydrogen as described in the reaction below.

$\text{CH}_3\text{CH}_2\text{OH} + 2 \text{H}_2 \rightarrow 2 \text{CH}_3\text{COOH} + 2 \text{H}_2$

Under anaerobic conditions, acetate is further degraded to carbon dioxide and hydrogen.

$2 \text{CH}_3\text{COOH} + \text{H}_2 \rightarrow 2 \text{CO}_2 + 3 \text{H}_2$

Acetate and hydrogen can be fermented to butyrate and water.

$2 \text{CH}_3\text{COOH} + 3 \text{H}_2 \rightarrow 4 \text{CH}_3\text{COO}^{-} + 4 \text{H}_2$

These last two reactions are reversible depending on concentrations of reactants and products.

Pathways of Anaerobic Biodegradation

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