

1. Monitoring Bioremediation using stoichiometry of electron acceptor utilization when the contaminant is the Electron Donor and bioremediation is limited by supply of electron donor

Oxygen depletion
Sulfate reduction
Nitrate reduction

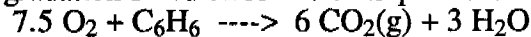
Methanogenesis
Iron reduction

2. Contaminant - Electron Acceptor: Bioremediation limited by supply of electron donor
Reductive dechlorination

3. National Research Council (1993):

- (1) Documented loss of contaminants at field scale
- (2) Microbial potential to biodegrade contaminants in laboratory microcosm studies
- (3) Other lines of evidence (geochemical indicators, toxicity, metabolites)

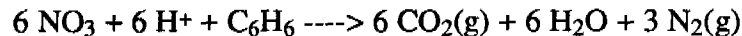
4. Aerobic Biodegradation based on Aerobic Respiration: Benzene Oxidation



Mass Ratio of O_2 to C_6H_6 = 3.1 : 1

0.32 mg/L C_6H_6 degraded per mg/L O_2 consumed, i.e., $\frac{0.32 \text{ mg/L BTEX}}{1 \text{ mg/L O}_2}$

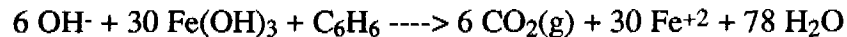
5. Denitrification: Benzene Oxidation



Mass Ratio of NO_3 to C_6H_6 = 4.8 : 1

0.2 mg/L C_6H_6 degraded per mg/L NO_3 consumed, i.e., $\frac{0.21 \text{ mg/L BTEX}}{1 \text{ mg/L NO}_3}$

6. Iron Reduction: Benzene Oxidation

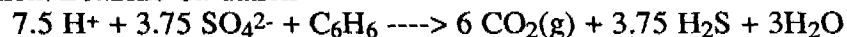


Mass Ratio of $\text{Fe}(\text{OH})_3$ to C_6H_6 = 41 : 1

Mass Ratio of Fe^{+2} produced to C_6H_6 degraded = 15.7 : 1

0.05 mg/L C_6H_6 degraded per mg/L Fe^{+2} produced, i.e., $\frac{0.05 \text{ mg/L BTEX}}{1 \text{ mg/L Fe}^{+2}}$

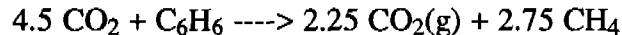
7. Sulfate Reduction: Benzene Oxidation



Mass Ratio of SO_4 utilized to C_6H_6 degraded = 4.6 : 1

0.22 mg/L C_6H_6 degraded per mg/L sulfate consumed, i.e., $\frac{0.22 \text{ mg/L BTEX}}{1 \text{ mg/L SO}_4}$

8. Methanogenesis: Benzene Oxidation



Mass Ratio of CH_4 produced to C_6H_6 degraded = 0.8 : 1

1.25 mg/L C_6H_6 degraded per mg/L CH_4 produced, i.e., $\frac{1.25 \text{ mg/L BTEX}}{1 \text{ mg/L CH}_4}$

[Reference: Bioremediation of Hazardous Waste Sites: Practical Approaches to Implementation. EPA/625/K-96/001. Office of Research and Development, U.S. EPA. May 1996.]

[Additional Reference: Microbial Processes in Porous Media, pp. 639-692, in: Transport Processes in Porous Media. [J.Bear and Y.Corapcioglu, eds.] Kluwer Publishers. London. 1991.]

EXAMPLE - COAL TAR CONTAMINATED SITE

- * Problem Statement
1. Coal tar residues deposited in a trench along a rural road in New York about 35 years ago
 2. Ground water contamination observed in a nearby stream
- * Characterization of PAH in soil at Source (mg/Kg soil)
- | | | | |
|---------------------|-----|----------------|-----|
| Naphthalene | 750 | Phenanthrene | 315 |
| 2-methylnaphthalene | 680 | Pyrene | 130 |
| Acenaphthylene | 270 | Benzo(a)pyrene | 35 |
| Fluorene | 150 | | |
- * National Research Council. 1993. In Situ Bioremediation: When Does It Work?, National Academy Press, Washington, D.C.
- I. Parent Compound Reduction at Field Scale
 - II. Microbial Potential for Bioremediation in Site Material
 - III. Other Evidence Supporting Bioremediation
- * I. Compounds Monitored at Field Scale
1. Naphthalene (most soluble, most mobile)
 2. Phenanthrene
- * II. Microbial Degradation Potential Laboratory Tests
1. ¹⁴C-Naphthalene
 2. ¹⁴C-Phenanthrene
- * III. Other Evidence using Field Samples
1. Metabolites
 2. Toxicity Reduction
- * Fugacity used to characterize distribution of target PAH and metabolites

<u>PAH and Metabolites</u>	<u>Air</u>	<u>Water</u>	<u>Soil</u>	<u>NAPL</u>
	-----%-----			
<u>Parent Compounds</u>				
Naphthalene	0.00	0.52	30.1	69.4
Anthracene	0.00	0.04	22.7	77.2
Phenanthrene	0.00	0.04	22.7	77.2
<u>PAH Metabolites</u>				
1-hydroxy-2-naphthoic acid	0.00	87.9	2.7	9.3
3,4-dihydroxybenzoic acid	0.00	50.2	11.3	38.4
2-carboxybenzaldehyde	0.00	23.3	17.5	59.2
2,3-dihydroxynaphthalene	0.00	18.7	18.5	62.7

Fugacity Capacity

Water $Z_w = 1/H$

$f = M / \sum (V_i Z_i)$

Air $Z_a = 1/RT = 4(10^{-4}) \text{ mole/m}^3\text{-atm}$ $C_i = f Z_i$

NAPL $Z_o = K_{ow} Z_w$

Soil $Z_s = K_{dp_b} Z_w$

Volume: V_a, V_w, V_s, V_o