

Mass Transfer and Bioremediation of PAHs in a Bead Mill Bioreactor

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Outline

- Background
- Experimental Procedures
- Mass Transfer experiments
- Biodegradation experiments
- Scale up experiments
- Summary/Conclusions
- Questions



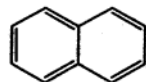
Background

- Polycyclic aromatic hydrocarbons (PAH's) are very stable, toxic compounds
- Most are very hydrophobic, requiring enclosed reactors to ensure minimal stripping losses
- Associated with oil and gas processing

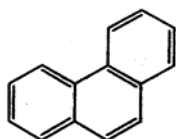
Background

- PAH contamination in soil is usually free solid particles or as large particles sorbed directly to the organic portion of the soil.
- PAHs generally have extremely low rates of biodegradation because of low water solubility, high hydrophobicity and low bioavailability
- Dissolution limited biodegradation

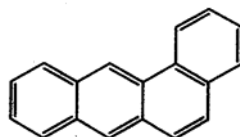
Background



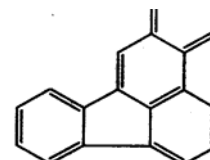
naphthalene



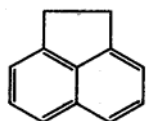
phenanthrene



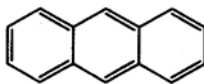
benz[a]anthracene



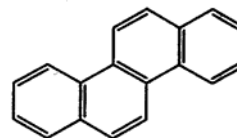
benzo[b]fluoranthene



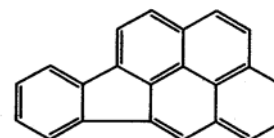
acenaphthene



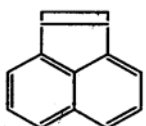
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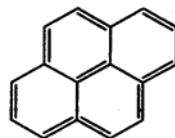
chrysene



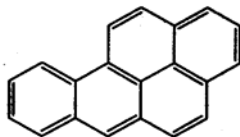
indeno[123cd]pyrene



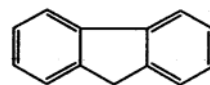
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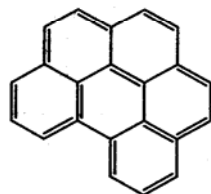
pyrene



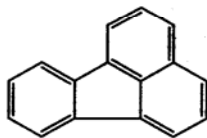
benz[a]pyrene



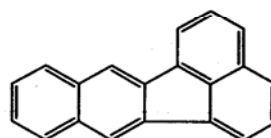
fluorene



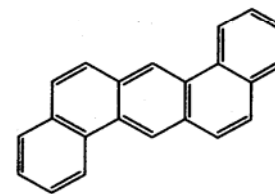
benzo[ghi]perylene



fluoranthene



benzo[k]fluoranthene

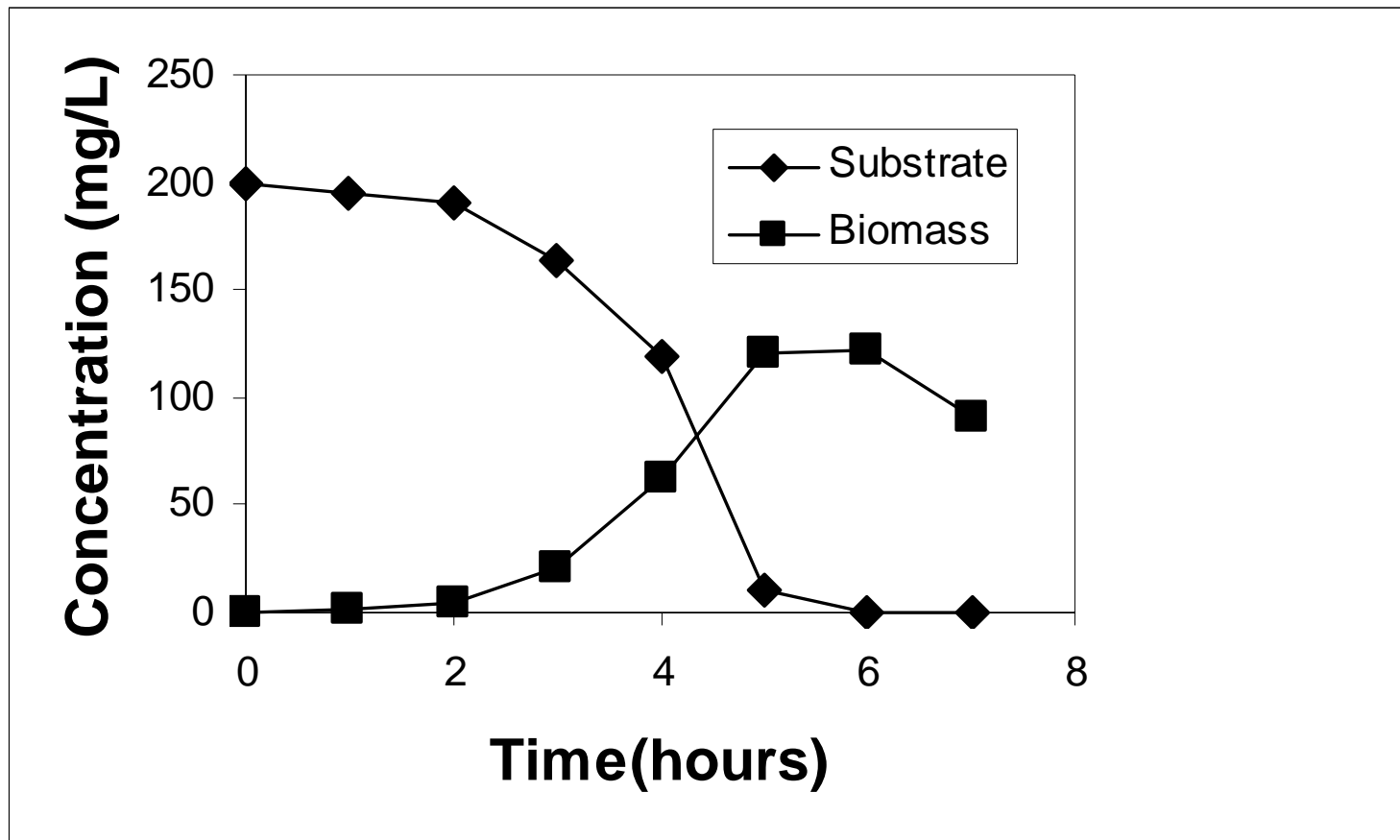


dibenz[ah]anthracene

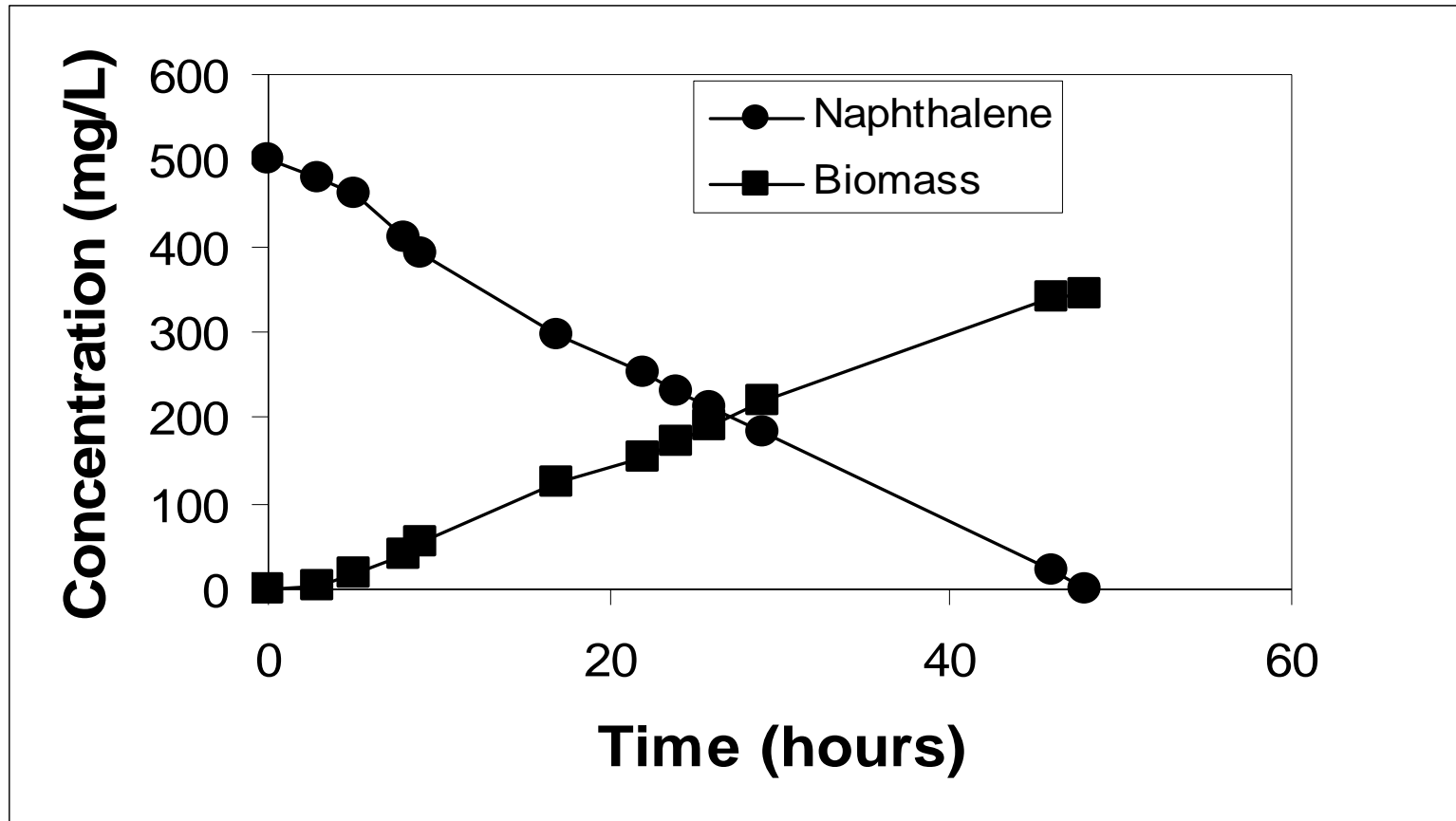
Background

- Naphthalene, a simple PAH can be biodegraded in a roller bioreactor using *Pseudomonas putida*
- Rate limiting step mass transfer rate
- This project - economically increase the mass transfer, biodegradation rates in a rotating bioreactor

Typical Biodegradation curve (Black, 1996)



Mass Transfer Controlled



Approach

- Needed to increase mass transfer rates within bioreactor
- Explored some different options including faster rotation, different reactor types and baffles within reactor
- Settled upon addition of inert particles to roller bioreactor



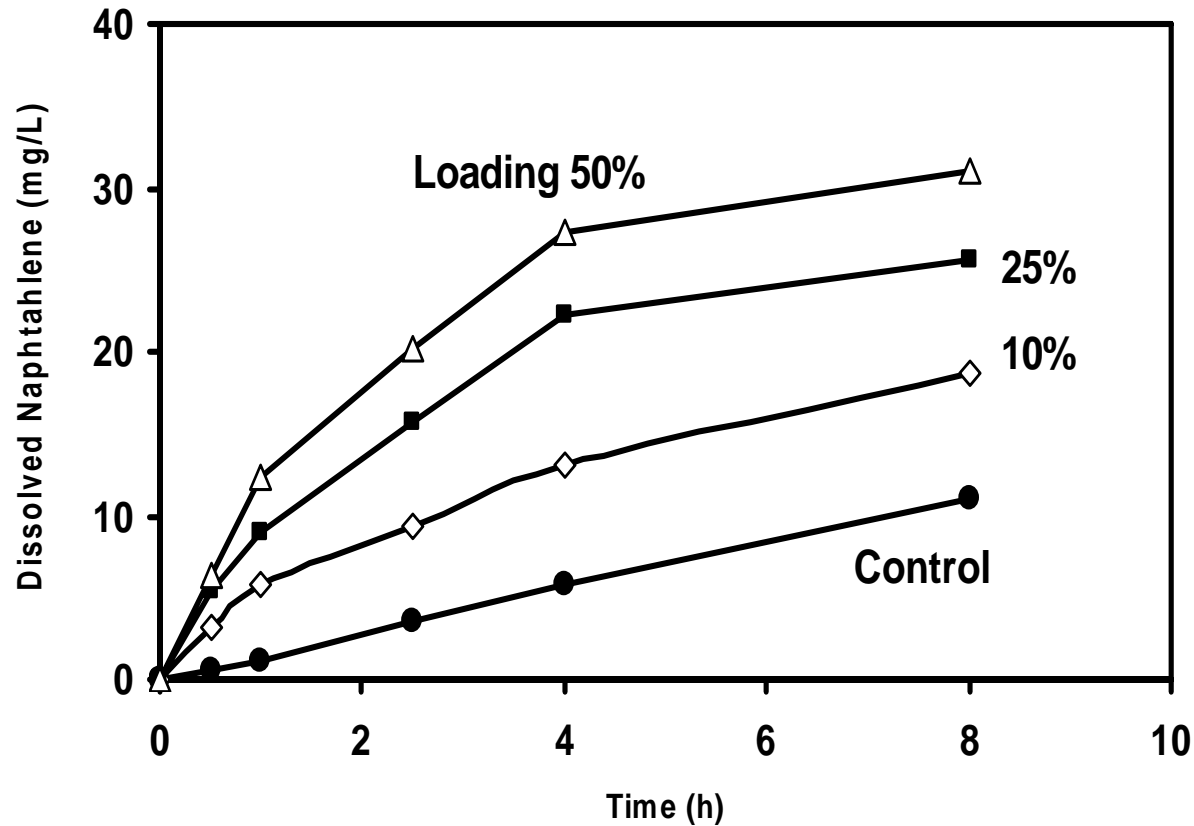
Experimental Procedures

- Experiments were carried out in 1L working volume
- Temperature: 22-23 °C
- *Pseudomonas putida* was used as the candidate bacterium
- Bioreactor rotated at 50 rpms
- Analysis carried out on HPLC

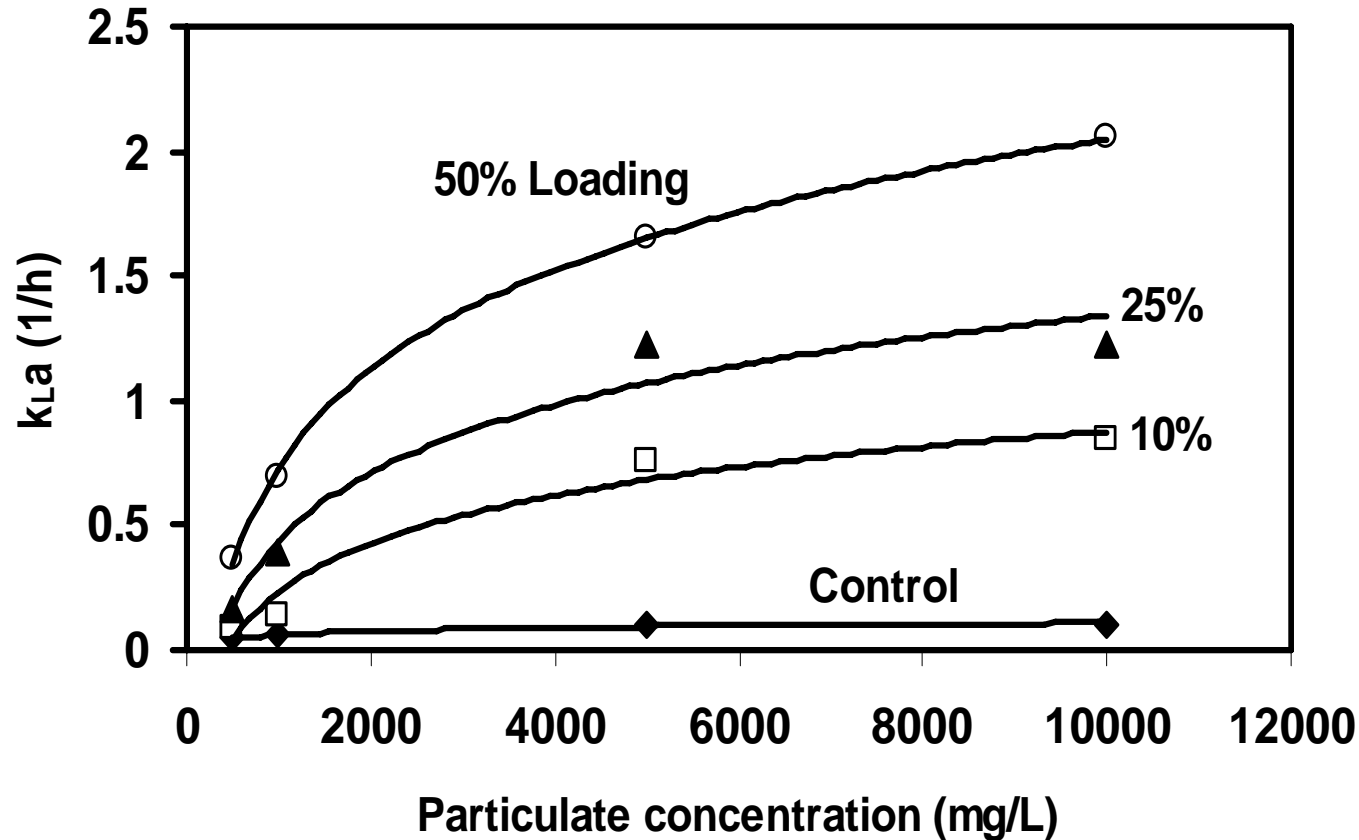
Mass Transfer Variations

- Used 3 mm glass beads for loading experiments
- Did experiments varying initial naphthalene concentrations from 500 mg/L to 10,000 mg/L
- Used some 1 mm beads, 5 mm beads, and 3 mm Raschig rings for comparison

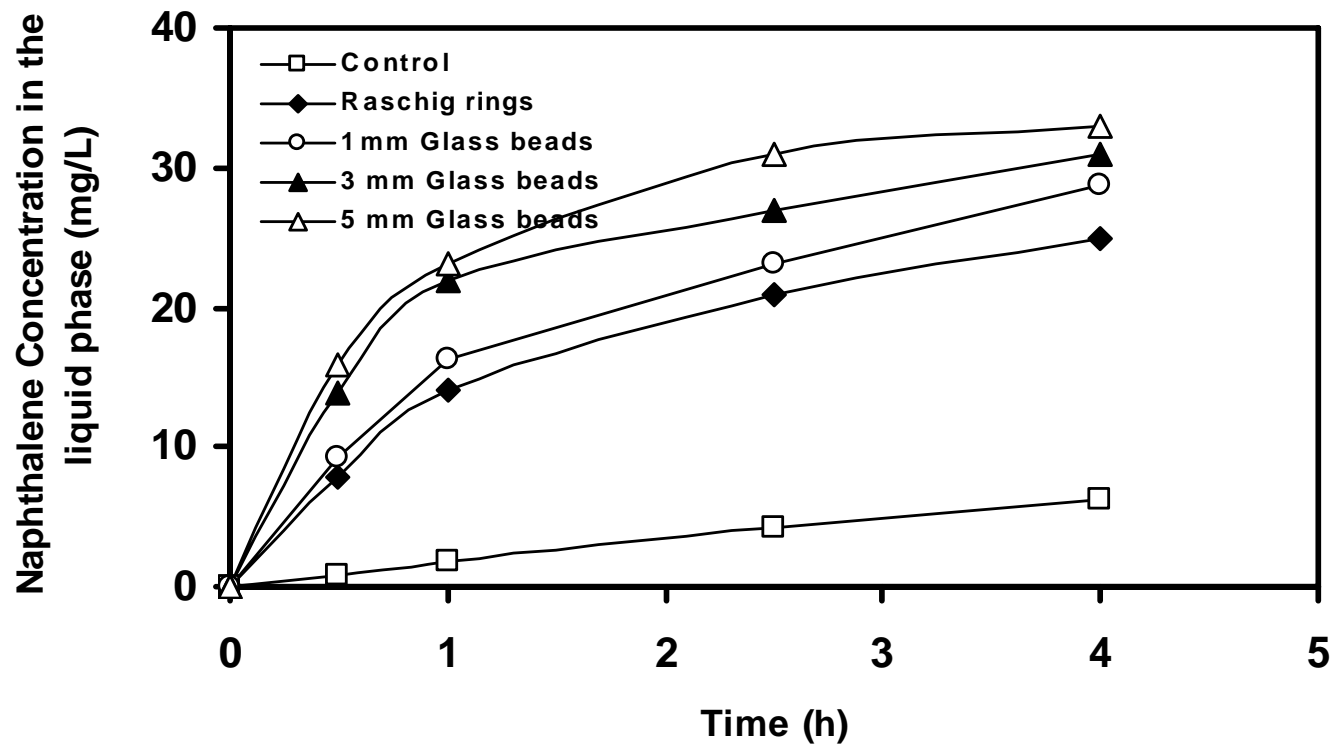
NAPHTHALENE MASS TRANSFER: BEAD LOADING



Increasing naphthalene concentration



Inert particle size and type





Mass Transfer Quantification

- $\ln((C_L^* - C_L)/C_L^*) = -K_L a t$
- Where:
- C_L^* = saturation concentration of naphthalene (mg/L)
- C_L = concentration of naphthalene (mg/L)
- $K_L a$ = volumetric mass transfer coefficient (1/h)
- t = time (h)

Mass Transfer Quantification

- Volumetric Mass Transfer coefficients (1/h)
- Control: 0.06
- 10% beads: 0.17
- 25% beads: 0.34
- 50% beads: 0.52



Mass Transfer Summary

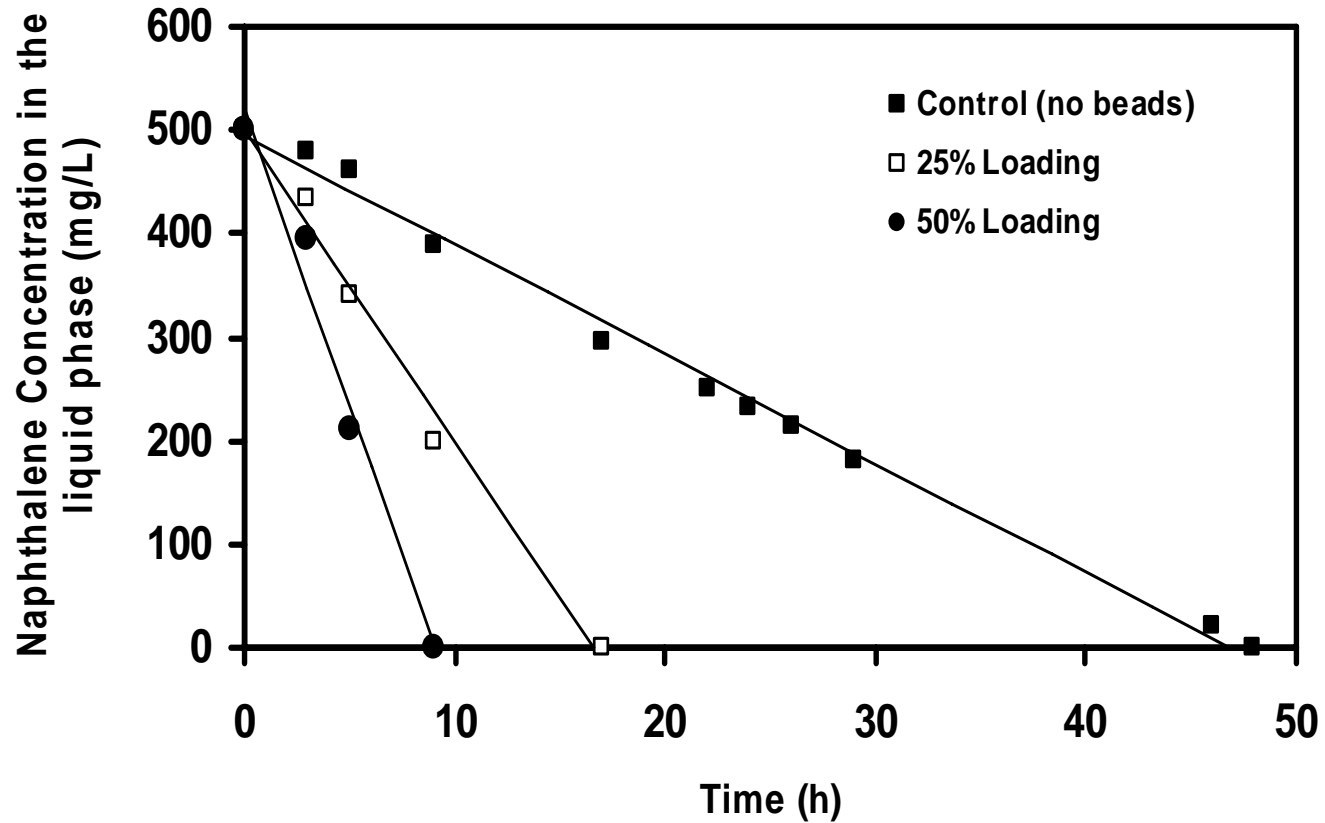
- Optimum: 5 mm beads, 50% loading
- Naphthalene
 - 70 hours, 8 hours
- Methylnaphthalene
 - 212 hours, 28 hours
- Dimethylnaphthalene
 - 148 hours, 12 hours



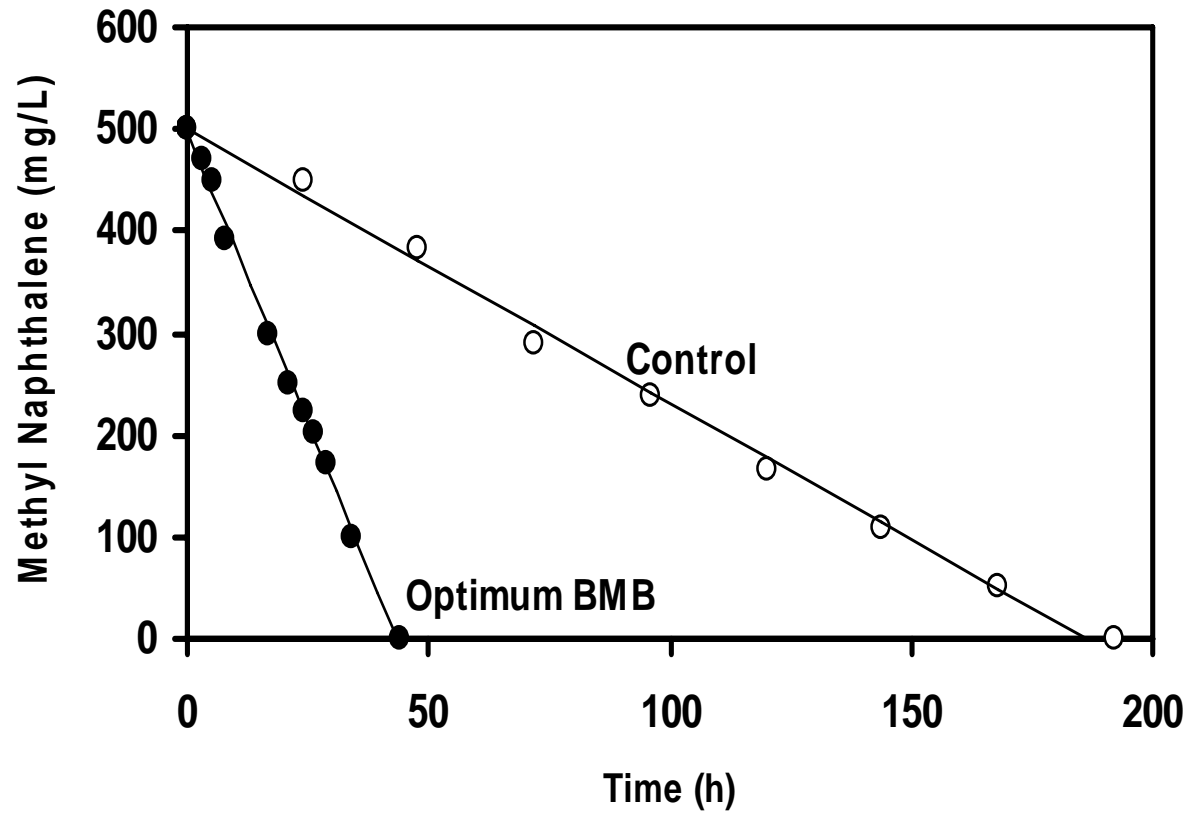
Biodegradation Procedure

- Followed literature procedures as closely as possible
- Increased mass transfer rates demanded more oxygen
- Total naphthalene concentration

Biodegradation results naphthalene



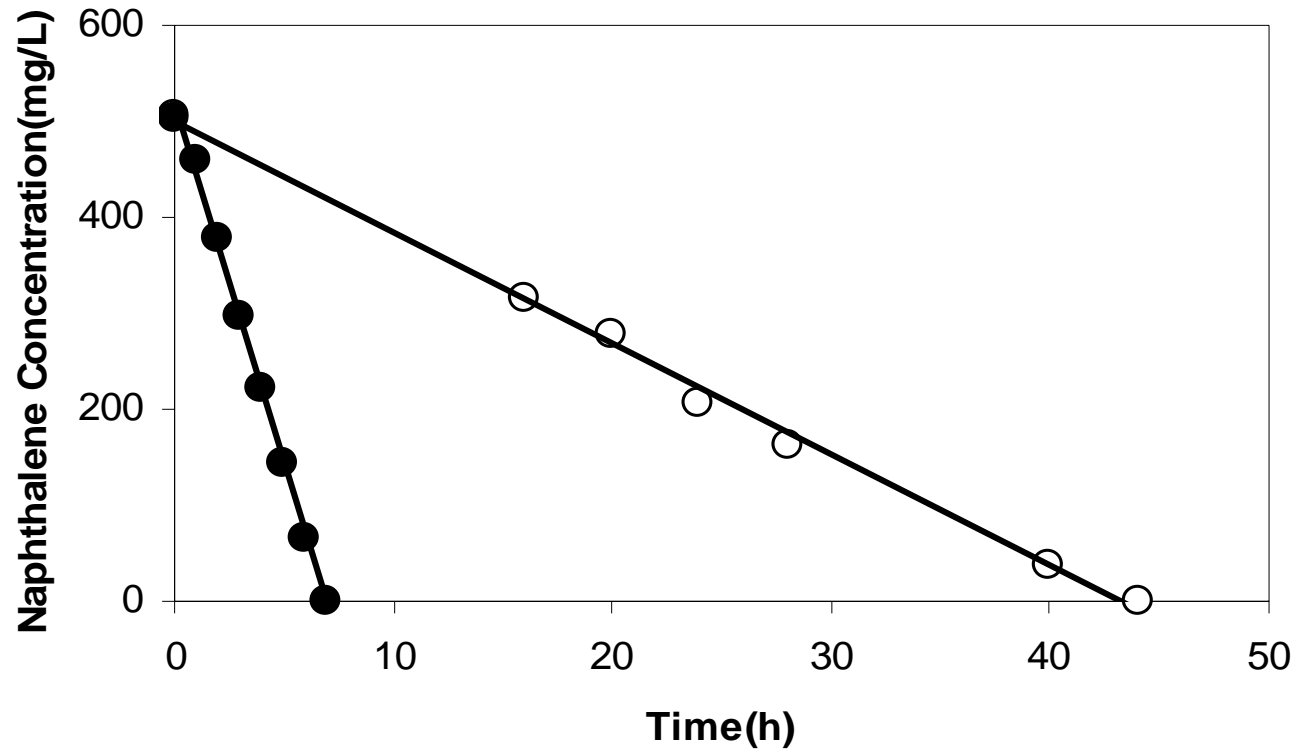
Biodegradation methylnaphthalene



Scale up biodegradation



Scale up biodegradation



Toxicity?

- Experiments performed with brine shrimp
- 96% alive after two hours – control
- 89% alive in bioreactor effluent
- 0% alive in saturated naphthalene solution

Biodegradation Summary

<i>PAH compound</i>	<i>Roller Bioreactor</i>	<i>Bead Mill Bioreactor</i>
<i>Naphthalene</i>	<i>10.5</i>	<i>118.8</i>
<i>2-Methyl Naphthalene</i>	<i>2.7</i>	<i>22.8</i>
<i>Naphthalene (in mixture)</i>	<i>9.9</i>	<i>98.8</i>
<i>2-Methyl Naphthalene (in mixture)</i>	<i>3.4</i>	<i>31.4</i>
<i>Scale up naphthalene</i>	<i>10.9</i>	<i>148</i>

Literature comparison (Naphthalene)

- Freely suspended cells, partitioning reactor:
 - 85 mg/L-h (Janikowski et. al, 2002)
- Large scale partitioning reactor
 - 119 mg/L-h (Daugulis et. al, 2001)
- Present work (Free cells)
 - 148 mg/L-h



Conclusions

- Bead Mill Bioreactor Increases Mass Transfer
- Bioremediation of PAHs Increased Up to Fourteen Fold
- Product of reactor exhibits greatly improved toxicity



Applications/Recommendations

- Treating PAH contaminated water
- Work with Naphthenic acids
- Work with PAH contaminated soil



Acknowledgements

- John Headley-Environment Canada
- Gordon Hill, Mehdi Nemati



Questions?