Comparison of Pilot Scale Bioremediation of PAH Contaminated Construction Rubble with Laboratory Tests

B. Gemende, A. Gerbeth (University of Applied Sciences Zwickau)
G. Müller, C. Höse, J. Seidel (P-D Industriegesellschaft)
R. Lange (Dresden University of Technology)
R. H. Müller (UFZ Centre for Environmental Research)

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Introduction

- Experiences in bioremediation of herbicide and PHC contaminated building rubble
- At various sites (gas works, coking plants ...) major or cross-contaminants are PAH

Characteristics of Contaminated Material

- Usually high pH values in eluate → varying from 9 up to 12
- Low water holding capacity → usually between 10 and 30 % of dry mass content
- Low content of nutrients

And:

- High diversity of materials (bricks, concrete, wood, metals etc.)
- High inhomogeneity of contamination ("hot spots")
Characteristics of Contaminated Material

Properties of the used building rubble:
- Originated from a former gaswork plant
- Total content of 16 EPA-PAH:
  - 355…430 mg/kg in the original charge
  - 495…790 mg/kg in the charges for laboratory scale tests
- Content of petroleum hydrocarbons: 1,655…3,535 mg/kg
- pH value of eluate: 8.1…9.4
- No definable nutrient concentration
- No (known) cross-contamination

Introduction

Properties of the Relevant Pollutants

PAH = Polycyclic Aromatic Hydrocarbons
- Compounds consisting of 2 or more condensed benzene ring structures (more than 100 different substances – 16 of them are listed by US-EPA as “priority pollutants”)
- Occurring in all parts of environment
- Partly known or supposed to be cancerogenic and/or mutagenic

Physical and chemical properties of selected PAH:

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular weight</th>
<th>Chemical structure</th>
<th>Vapour pressure at 25 °C (mPa)</th>
<th>Water solubility at 20 °C (mg/l)</th>
<th>lg K_{OW}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphthalene</td>
<td>128</td>
<td><img src="image" alt="Chemical structure" /></td>
<td>10.8 x 10^3</td>
<td>30.00</td>
<td>3.37</td>
</tr>
<tr>
<td>Fluorene</td>
<td>166</td>
<td><img src="image" alt="Chemical structure" /></td>
<td>4.5 x 10^2</td>
<td>1.8</td>
<td>4.18</td>
</tr>
<tr>
<td>Benzo(a)pyrene</td>
<td>252</td>
<td><img src="image" alt="Chemical structure" /></td>
<td>3.8 x 10^-3</td>
<td>0.0038</td>
<td>6.04</td>
</tr>
</tbody>
</table>
Isolation of Microorganisms

- Bacteria enrichment from PAH contaminated building rubble (former gaswork) using a percolation column
- Clean up and isolation of strains on PYE agar plates
- Isolation and selection of PAH degrading strains on PAH coated agar plates

Selection criteria:
- Broad degradation spectra (different PAH)
- Special degradation abilities (e.g. high pH tolerance)

Selected Bacterial Strains

<table>
<thead>
<tr>
<th>Strain</th>
<th>Taxonomy</th>
<th>Degradation abilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>SK3</td>
<td><em>Dietzia</em> sp.</td>
<td>Fluorene und Anthracene, also Phenanthrene und Pyrene</td>
</tr>
<tr>
<td>KB-K2</td>
<td><em>Micrococcus</em> sp.</td>
<td>Especially Phenanthrene, conditionally also Fluorene</td>
</tr>
<tr>
<td>KB-K5</td>
<td><em>Micrococcus</em> sp.</td>
<td>Especially Phenanthrene and Anthracene, conditionally also Fluorene</td>
</tr>
<tr>
<td>KB-F8</td>
<td><em>Rhodococcus</em> sp.</td>
<td>Especially Fluorene, also Phenanthrene</td>
</tr>
</tbody>
</table>

Introduction
Configuration of Laboratory Test Columns

- 1.5 kg rubble (dry substance)
- 10...270 ml biomass suspension
- 1...2 g fertilizer
- 16...20 % moisture
- 5 l/h air flow

Configuration of Pilot Scale Test Boxes

- 500...900 kg rubble (original substance)
- 1.2...5 l biomass suspension
- 0.36...1.44 kg N-P-K fertilizer
- 25...70 l water (8...15 % moisture)
- 400 l/h air flow
Scale-up to Windrows

Experimental Work

- Laboratory Scale Tests
  - 1.5 kg rubble
  - Scale-up factor: 300…400

- Pilot Scale Tests
  - ca. 500…600 kg rubble

- Technical Scale Windrow
  - ca. 500…1,000 t rubble
  - Scale-up factor: 1,000…2,000

Sampling and Analysis

Sample

- Homogenising / Splitting
- Crushing
- Drying

PHC-Analysis
- Extraction
- Drying and clean up of the extract
- Analysis with IR-Analyser

PAH-Analysis
- Extraction
- Clean up of the extract using SPE
- Analysis with HPLC-PDA

Further Analysis
- Elution and measurement of pH value and conductivity
- Determination of dry mass content (DMC)
Laboratory Scale Test Results (Total PAH)

Results and Discussion

Laboratory Scale Test Results (3 PAH)

- Comparative column
- Comparative column (sterilised material)
- Strain SK3 (on sterilised material)
- Strain KB-K2
- Strain KB-F8
- Strain KB-K5

![Graphs showing residual content of naphthalene, fluoranthene, and phenanthrene over test duration.](image)
Results and Discussion

Comparison of Results

Pilot Scale Test Results (Total PAH)

![Graph showing mass content over test duration for different strains.]

Laboratory Scale Tests

Pilot Scale Tests

<table>
<thead>
<tr>
<th>Strain</th>
<th>Residual Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain SK3 (150 ml)</td>
<td>49.8</td>
</tr>
<tr>
<td>Strain SK3 (sterilised m.)</td>
<td>52.1</td>
</tr>
<tr>
<td>Strain SK3 (100 ml)</td>
<td>75.2</td>
</tr>
<tr>
<td>Strain KB-K2</td>
<td>79.4</td>
</tr>
<tr>
<td>Strain KB-F8</td>
<td>90.5</td>
</tr>
<tr>
<td>Strain KB-K5</td>
<td>80.7</td>
</tr>
<tr>
<td>Strain SK3</td>
<td>79.7</td>
</tr>
<tr>
<td>Strain KB-K2</td>
<td>74.4</td>
</tr>
<tr>
<td>Strain KB-F8</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Residual Content (%)
Summary

- Alkaliphilic strains (*Dietzia* sp., *Rhodococcus* sp.) used for PAH degradation on building rubble
- Degradation rates:
  - \( \approx 10\% \) for benzo(ghi)perylene (6 rings)
  - \( \approx 30\% \) for benzo(a)pyrene (5 rings)
  - \( \approx 90\% \) for naphthalene (2 rings)

**Problems:**
- Degradation not clearly attributed to allochthone strains
- Lower degradation rates in pilot scale
- Further studies for scale-up