Effective Control of Gaseous VOC Mixture in a TBAB Coupled with Cyclic Adsorption/Desorption Beds

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Use of Integrated Systems

**Load fluctuation**

Solution? Buffer unit

- Adsorption unit can be a buffer unit for a biofilter
- Current application: Single bed of carbon filter
- Consideration of current adsorption unit:
  - High loading & Large fluctuation → Losing buffer capacity
  - Initial period of operation → No contaminant in effluent
Theory of 2-Bed Adsorption

2-Bed Adsorption Unit

- Conceptually simple process to PSA
- PSA (Pressure Swing Adsorption):
  → A technology for separation and purification for gas mixtures
  → 4 Steps for operational function

Flow Chart:
- Feeding (Adsorption)
- Depressurization
- Purging (desorption)
- Repressurization
- Regeneration
Conceptually simple process to PSA

Hypothetically, adsorption rate is equal to its desorption rate

→ Operational function is simplified to a 2-step

- Feeding (Adsorption)
- Purging (desorption)
- Regeneration
Theory of 2-Bed Adsorption

2-Bed Adsorption Unit

- Cyclic operation: Shift of air flow direction
  → Each bed will not be fully saturated with adsorbate

Clockwise

Gas to biofilter  Waste Gas

Counterclockwise

Waste Gas  Gas to biofilter
Theory of 2-Bed Adsorption

2-Bed Adsorption

- Concept

Will serve as
- Polishing unit during the initial acclimation period of the biofilter
- Buffer unit in load fluctuation
- Feeding source without any feeding phase during non-use periods
Main Objective

Propose and apply a new technology by integrating a trickle-bed air biofilter with cyclic adsorption/desorption beds to maintain long-term high level VOC removal

Specific Objectives

- **To evaluate the overall performance of a combined process scheme** (2-bed adsorption unit + Biofilter)
- **To compare with that of a control unit without adsorption unit** (Biofilter only)
Feed VOCs Mixture

**Toluene: Styrene: MEK: MIBK = 0.448: 0.260: 0.234: 0.058**

(*EPA 2003 toxic release report for chemical industries*)

<table>
<thead>
<tr>
<th></th>
<th>Aromatic compounds</th>
<th>Oxygenated compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Toluene</td>
<td>Styrene</td>
</tr>
<tr>
<td><img src="image" alt="Toluene" /></td>
<td>0.280</td>
<td><img src="image" alt="Styrene" /></td>
</tr>
<tr>
<td><strong>$K'_H$</strong></td>
<td>0.280</td>
<td>0.109</td>
</tr>
<tr>
<td><strong>Log $K_{ow}$</strong></td>
<td>2.58</td>
<td>3.16</td>
</tr>
</tbody>
</table>

*$K'_H$ = dimensionless Henry’s law constant, $K_{ow}$ = Octanol-water partition coefficient*
1. Air cleaner
2. Mass flow controller
3. Syringe pump
4. Equalizing tank
5. Flow meter
6. 2-bed adsorber
7. 4-way solenoid valve
8. Supplemental air valve
9. Biofilter

Control Unit

Combined Unit
Materials and Methods

Adsorption Unit

- 2 Beds
- Dimension: 2.5 cm (D) × 20 cm (L)
- Duration of one cycle: 8 hours
- EBRT: 9.1 sec (1.35 L/min)

- Absorbent: GAC (BPL 6 × 16)
Materials and Methods

**Biofilter**

**Trickle Bed Air Biofilter (TBAB)**
- Dimension: 76 mm (D) × 130 cm (L)
- Buffered nutrient solution supply
- Operating Temp.: 20 °C
- EBRT: 2.0 min (1.35L/min)

**Media**
- Celite® 6 mm R-635 Bio-Catalyst Carrier
- Packing depth: 60 cm
- Seeded with aerobic microbial culture
  - pre-acclimating to toluene
### Operating conditions

<table>
<thead>
<tr>
<th>Square Wave Change</th>
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<th>Square Wave Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Base = 250 ppmv</td>
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<td>• Base = 300 ppmv</td>
<td>• Base = 300 ppmv</td>
</tr>
<tr>
<td>• Peak = 500 ppmv (12 mins / hour)</td>
<td>• Peak = 700 ppmv (7 mins / hour)</td>
<td>• Middle = 500 ppmv (15 mins/hour)</td>
<td>• Peak = 700 ppmv (15 mins / hour)</td>
</tr>
<tr>
<td>• Average concentration : 300 ppmv</td>
<td>• Average concentration : 300 ppmv</td>
<td>• Average concentration : 350 ppmv</td>
<td>• Average concentration : 450 ppmv</td>
</tr>
</tbody>
</table>
Materials and Methods

- **Biomass control**
  - Backwashing: 1 hour of duration / week
  - Starvation: two days / week
Effective Control of Gaseous VOC Mixture in a TBAB Coupled with Cyclic Adsorption/Desorption Beds

Experimental Results

- Performance review
- Starvation effect
- Kinetics analysis
Effective Control of Gaseous VOC Mixture in a TBAB Coupled with Cyclic Adsorption/Desorption Beds

Experimental Results

- Performance review
Summary of Previous Mixture Study

- Critical loading
  2.4 kg COD/m$^3$·day
  (34.0 g/m$^3$·hr)

- Maximum removal capacity
  3.6 kg COD/m$^3$·day
  (50.7 g/m$^3$·hr)

EBRT: 2.02 min

Inlet Conc. = 300 ppmv
Results

First square wave

Square Wave Change
- Base = 250 ppmv
- Peak = 700 ppmv (7 mins / hour)
- Average concentration : 300 ppmv
- Average Total Loading = 34.0 g/m³.hr
- Toluene Loading = 15.4 g/m³.hr
- Styrene Loading = 10.1 g/m³.hr
- MEK Loading = 6.3 g/m³.hr
- MIBK Loading = 2.2 g/m³.hr
Biofilter Performance in Combined System

Results

First square wave
Results

First square wave

Toluene

Removal Efficiency, %

Styrene

MEK

Removal Efficiency, %

MIBK

Sequential Time, hr
Results

First square wave

Biofilter Performance in Control System
Results

First square wave

Sequential Time, hr

Toluene Con., ppmv

Removal Efficiency, %

Styrene Con., ppmv

Removal Efficiency, %

MEK Con., ppmv

Removal Efficiency, %

MIBK Con., ppmv

Removal Efficiency, %
**Results**

First square wave

<table>
<thead>
<tr>
<th>Control Unit</th>
<th>Ave</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppmv</td>
<td>204.4</td>
<td>30.8</td>
</tr>
</tbody>
</table>

![Graph showing inlet concentration and effluent load over time for combined and control units.](image-url)
Carbon Mass Balance

Inlet  Outlet  Biofilter

Cumulative CO₂, moles

Sequential Date, days

Carbon accumulation in the two beds

Inlet  Outlet  Biofilter

96.6%  31.1%  96.4%
Square Wave Change
• Base = 250 ppmv
• Peak = 500 ppmv (12 mins / hour)
• Average concentration : 300 ppmv
• Average Total Loading = 34.0 g/m³.hr
• Toluene Loading = 15.4 g/m³.hr
• Styrene Loading = 10.1 g/m³.hr
• MEK Loading = 6.3 g/m³.hr
• MIBK Loading = 2.2 g/m³.hr
Results

Second square wave

<table>
<thead>
<tr>
<th>Combined ppmv</th>
<th>Ave</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>188.6</td>
<td>19.2</td>
</tr>
</tbody>
</table>

Inlet Conc., ppmv

Effluent Load, g/m³·hr
Square Wave Change
- Base = 250 ppmv
- Peak = 500 ppmv (2 × 12 mins / hr)
- Average concentration : 350 ppmv
- Average Total Loading = 39.6 g/m³/hr
- Toluene Loading = 17.9 g/m³/hr
- Styrene Loading = 11.8 g/m³/hr
- MEK Loading = 7.4 g/m³/hr
- MIBK Loading = 2.5 g/m³/hr
Results

Third square wave

Graph showing:
- Time in minutes from 0 to 180
- Inlet concentration ppmv
- Effluent load g/m³/hr

Table:

<table>
<thead>
<tr>
<th></th>
<th>Ave</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td>ppmv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>230.1</td>
<td>25.2</td>
</tr>
</tbody>
</table>

Graph showing comparison between Combined Unit and Control Unit.
Square Wave Change

- Base = 300 ppmv
- Middle = 500 ppmv (15 mins/hour)
- Peak = 700 ppmv (15 mins / hour)
- Average concentration : 450 ppmv
- Average Loading = 50.9 g/m$^3$.hr
- Toluene Loading = 23.0 g/m$^3$.hr
- Styrene Loading = 15.1 g/m$^3$.hr
- MEK Loading = 9.5 g/m$^3$.hr
- MIBK Loading = 3.3 g/m$^3$.hr
**Results**

**Fourth square wave**

- **Inlet Conc., ppmv**
  - 0 60 120 180
  - 200 300 400 500 600 700 800
- **Effluent Load, g/m^3^.hr**
  - 0 4 8 12

<table>
<thead>
<tr>
<th>Combined</th>
<th>Ave</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppmv</td>
<td>338.1</td>
<td>21.2</td>
</tr>
</tbody>
</table>
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Experimental Results

- Starvation effect (Fourth Square Wave)
Biofilter Performance in Combined System-Backwashing
Biofilter Performance in Control System - Backwashing
Biofilter Performance in Combined System-STARVATION

![Graph showing biofilter performance over sequential time with inlet and outlet concentrations and removal efficiency.](Image)
Biofilter Performance in Control System-Starvation
Effective Control of Gaseous VOC Mixture in a TBAB Coupled with Cyclic Adsorption/Desorption Beds

Experimental Results

- Kinetics analysis
Toluene removal kinetics in mixture
Styrene removal kinetics in mixture

![Graph showing removal rate constants for different load conditions.]

- High Load-control
- Low Load-control
- High Load-combined
- Low Load-combined
- Middle Load-control
- Middle Load-combined
Conclusions

- The cyclic 2-bed adsorption/desorption unit successfully dampened loading fluctuation of VOCs mixture to the followed biofilter.

- The integrated trickling biofilter with cyclic 2-bed adsorption/desorption unit could maintain long-term high level removal efficiency.

- The integrated system showed significant improvement as compared to a stand alone biofilter for more frequent or/and higher magnitude fluctuation in feeding conditions.

- The cyclic 2-bed unit successfully functioned as feeding source to the followed biofilter during starvation period.
Acknowledgement

- Dr. Daekeun Kim
- Environmental Chemistry Lab graduate students
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Questions?

Department of Civil and Environmental Engineering