Treatment of VOCs emitted from Wastewater Treatment Plant by a hybrid process scheme of a 2-bed adsorber and a biofilter

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Introduction

2. The passage of the 1990 Amendments to the Clean Air Act: significantly heightened the interest in the development of innovative technologies for VOCs removal.

3. VOCs are precursors to the formation of ozone, and they have their own toxicity.

1. Source of VOCs to ambient atmosphere affected by the Clean Air Act Amendments.

2. Depend on domestic, commercial, and industrial sources

3. VOCs are transferred into the air mainly in case of aerated bioreactor.
   (activated sludge process)
VOC Removal technology

1. Thermal oxidation, Catalytic oxidation, Condensation, Carbon adsorption, Membrane separation...

2. Biological treatment: economical and ecological technology

3. Biofiltration
1. **Owner and location:**
   Novartis; Basle, Switzerland

2. **Air flow rate:**
   60,000 – 75,000 m³/h
   (Exhaust air from plant)

3. **Pollutants:**
   toluene, xylene,
   methanol, isopropanol,
   chloroform...
   **Total conc.** : 180 – 500 mg/m³
4. Biofilter Design
   Investment costs ($2,000,000)
   Treatment costs
   ($1.44 per 1000 m³ off gas)

5. Biofilter Performance
   Removal: 80 %
   (depends on inlet loading)
Introduction

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
Objective
Main Objective

A 2-bed adsorption unit is proposed to establish long-term stable buffer capacity of adsorption unit in mitigating biofilter performance

Specific Objective

• To design and evaluate a 2-bed adsorption unit
• To evaluate the overall performance of a combined process scheme (2-bed adsorption unit + Biofilter)
• To be compared with that of a control unit without adsorption unit (Biofilter)
Theory of 2-Bed Adsorption
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

1. Feeding (Adsorption)
2. Depressurization
3. Purging (desorption)
4. Repressurization

Regeneration
Theory of 2-Bed Adsorption

2-Bed Adsorption Unit

- 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 Unit

Will Serve as
- Polishing unit during the initial acclimation period of the biofilter
- Buffer unit in load fluctuation
- Feeding source without any feeding phase while non-use periods
Materials and Methods
Targeted VOC

Toluene (C\(_7\)H\(_8\))
- Comment solvent employed in the industry
- A major component in paints and varnishes

Concentration & Loading

1\(^{st}\) Condition: Square Wave Change
- Base = 200 ppmv
- Peak = 400 ppmv (15 mins / hour)
- Average concentration : 250 ppmv
**Feeding Condition**

**Targeted VOC**

Toluene (C₇H₈)
- Comment solvent employed in the industry
- A major component in paints and varnishes

**Concentration & Loading**

1ˢᵗ Condition: Square Wave Change
- Base = 200 ppmv
- Peak = 400 ppmv (15 mins / hour)
- Average concentration : 250 ppmv

Previous Study

![Graph showing removal of Toluene at different inlet concentrations.](image)
Toluene (C₇H₈)
- Comment solvent employed in the industry
- A major component in paints and varnishes

**Targeted VOC**

Concentration & Loading

1st Condition: Square Wave Change
- Base = 200 ppmv
- Peak = 400 ppmv (15 mins / hour)
- Average concentration : 250 ppmv
- Average loading rate : 46.9 g/m³·hr
Materials and Methods

Adsorption Unit

- 2 Beds
- Dimension: 2.5 cm (D) \times 20 \text{ cm (L)}
- Cyclic operation: 8 hours/cycle
- Supplemental fresh air valve
- EBRT: 5.6 sec (2.2 L/min)

- Absorbent: GAC (BPL 6 \times 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: 1.2 min (2.2L/min)

**Media**
- Celite® 6 mm R-635 Bio-Catalyst Carrier
- Packing depth: 60 cm
- Seeded with aerobic microbial culture pre-acclimating to toluene
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
Experimental Results
2-Bed Adsorption Performance

Square wave change of inlet concentration
2-Bed Adsorption Performance

Square wave change of inlet concentration

- Effluent Concentration (ppmv)
  - W/ Cyclic operation
  - 250 ppmv

- Sequential Time, hrs
  - 0 8 16 24 32 40 48 56
2-Bed Adsorption Performance

Square wave change of inlet concentration

Graph showing effluent concentration over sequential time with and without cyclic operation.
Toluene Removal Performance

Effluent Concentration

Exposure guideline: 5 mg/m$^3$ (AIHA)

Control: 39 ± 19 mg/m$^3$
Toluene Removal Performance

**Effluent Concentration**

- **Control Day 44**
  - Time, hrs: 1072, 1076, 1080
  - Effluent Conc, mg/m³: 39 ± 19 mg/m³

- **Day 44**
  - Time, hrs: 1072, 1076, 1080
  - Effluent Conc, mg/m³: 39 ± 19 mg/m³
Toluene Removal Performance

**Effluent Concentration**

- **Control**: $39 \pm 19 \text{ mg/m}^3$
- **Combined**: $3 \pm 2.5 \text{ mg/m}^3$

![Graph showing effluent concentration over time](chart.png)
Toluene Removal Performance

Removal Efficiency

Sequential Time, hrs

Effluent, mg/m³

Control
Combined

Eff. %

Effluent, mg/m³

Sequential Time, hrs

1 10 100 1000
Effect of Non-Use Periods
Effect of Non-Use Periods

Reacclimation

Effluent response after 2 days of starvation

Sequential Time After Non-Use, hrs

Effluent conc., mg/m³

Control

Combined
Effect of Non-Use Periods

Reacclimation

Effluent response after 2 days of starvation

![Graph showing effluent concentration over time after non-use periods. The graph compares control and combined conditions.](image)
Effect of Non-Use Periods

Reacclimation

Effluent response after 2 days of starvation

[Graph showing effluent concentration over time for Control and Combined conditions]
Further Application

Feeding Conditions
Further Application

Feeding Conditions

- \(1^{st} : 46.9 \text{ g/m}^3\cdot\text{hr}\)
Further Application

Feeding Condition

- 2\textsuperscript{nd} : High concentration of peak, 46.9 g/m\textsuperscript{3}\cdot hr
Further Application

**Feeding Condition**

- **2nd**: High concentration of peak, 46.9 g/m³·hr
- **3rd**: Frequent peak, 56.3 g/m³·hr

![Graph showing Inlet Concentration and Effluent Concentration over time for Combined Unit and Control Unit.](image-url)
Further Application

Feeding Condition

- 2nd: High concentration of peak, 46.9 g/m³·hr
- 3rd: Frequent peak, 56.3 g/m³·hr
- 4th: High con. and frequent peak, 65.9 g/m³·hr
Conclusion
1. During unsteady-state loading conditions, the 2-step of adsorption and desorption cycle in the 2-bed adsorption system mitigated the adverse effects of load fluctuation on biofilter performance.

2. The 2-Step cycle, i.e., adsorption and desorption, functioned as:
   - A polishing unit to abate the initial acclimation for the biofilter
   - A buffering unit to dampen the biofilter performance
   - A feeding source to the biofilter during non-use periods
3. By mitigate the adverse effects of load fluctuation, it also has the potential to reduce the total size of the system as compared with the single biofilter.
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