Cyclic Operation of a Fixed 2-Bed Adsorption System as Load Equalization for Air Biofiltration System

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

- Feeding (Adsorption)
- Depressurization
- Purging (desorption)
- Repressurization
- Regeneration
Hypothetically, if adsorption rate is equal to its desorption rate, operational function is simplified to a 2-step process:

1. Feeding (Adsorption)
2. Purging (desorption)
3. Regeneration
Concept of 2-Bed Adsorption

- Cyclic operation: Shift of air flow direction
  - Each bed will not be fully saturated with adsorbate
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 during non-use periods
Objective
Main Objective

Evaluate Cyclic operation of 2-bed adsorption unit as load equalization for air biofiltration system.

Specific Objective

- Mathematically simulate 2-bed adsorption unit performance to compare Cyclic operation vs. Non-cyclic operation.
- Experimentally evaluate the performance of the integrated scheme of 2-bed adsorption unit with air biofilter under transient loading of toluene (Integrated unit vs. control unit).
Materials and Methods
Targeted VOC

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

- 2 Beds
- Dimension: 2.5 cm (D) × 20 cm (L)
- Duration of one cycle: 8 hours
- EBRT: 5.6 sec (2.2 L/min)

- Absorbent: GAC (BPL 6 × 16)
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® Bio-Catalyst Carrier)
- Packing depth: 60 cm
- Seeded with aerobic microbial culture pre-acclimating to toluene
- Biomass control: Periodic Backwashing (1 hour / 7 days)
Schematic Diagram of Experimental Setup

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
Results: Model Simulation
Model Simulation

- Model simulation of cyclic operation of 2-bed adsorption
- Model simulation of non-cyclic operation of 2-bed adsorption
Mathematical model is formulated for a packed bed for simulation of the proposed cycle, which consists of overall and component material balances. Linear driving force model is incorporated into the model in order to include a mass transfer resistance with an adsorbent from a bulk gas phase. Freundlich isotherm equation is used for expression of isotherm capacity.

Assumption: (1) no pressure drop along a bed, (2) an isothermal operation, and (3) a plug flow through a bed with no dispersion.

Model simulation of cyclic operation of 2-bed adsorption

Model simulation of non-cyclic operation of 2-bed adsorption
Model Simulation

• Model simulation of cyclic operation of 2-bed adsorption

• Model simulation of non-cyclic operation of 2-bed adsorption

Plug flow homogeneous surface diffusion model (PFHSDM) which is embedded in an Adsorption Design Software (AdDesignSTM) developed by Michigan Technological University is used.

The mechanisms incorporated in this model are:
• Homogeneous surface diffusion
• Film transfer resistance at the adsorbent surface
• Advection dominates axial transport in bed.
• Local equilibrium Freundlich isotherm exists at the adsorbent surface.
• Freundlich isotherm equation is used for expression of isotherm capacity.
**Model Simulation**

- **Effluent Responds in 2-bed Adsorption**

**Transient Feeding Condition 1**: Square wave change of inlet concentration
- Base = 200 ppmv
- Peak = 400 ppmv (15 mins / hour)
Model Simulation

- Effluent Responds in 2-bed Adsorption

![Graph showing effluent response to cyclic operation with critical inlet concentration (250 ppmv) to biofilter](image)
Model Simulation

- Effluent Responds in 2-bed Adsorption

a) Cyclic operation

b) Non-cyclic operation
Model Simulation

- Effluent Responds in 2-bed Adsorption
Results: Experimental Test
Results I: Feeding Condition 1

- **Integrated unit vs. Control unit**

![Graphs showing effluent concentration, removal efficiency, and sequential time for integrated and control units.](image-url)
Results II: Feeding Condition 2

Transient feeding condition 2:
10 hrs square wave change + 14 hrs starvation without toluene loadings

600ppmv (15min) → 200ppmv (15min) → 400ppmv(15min) → 200ppmv(15min) / 1 Hr
Desorption profiles of 2-bed adsorption unit

Square wave change loading  Starvation without toluene loading (only air flow)
Overall Removal Performance (with backwashing as biomass control)

a) Integrated unit (2-bed adsorption+biofilter)

Effluent Conc, ppmv

Sequential Time, hr

Removal Efficiency, %

Day 1

Day 3

Day 5

Day 7

- Removal, %
- Effluent, ppmv

Effluent Concentration and Removal Efficiency over Days 1, 3, 5, and 7.
Overall Removal Performance (with backwashing as biomass control)

a) Integrated unit (2-bed adsorption + biofilter)

b) Control unit (biofilter)
Overall Removal Performance (without backwashing as biomass control)

- Periodic biomass control is necessary for attaining stable, long term high removal efficiencies for the biofilter, even integrated unit.
1. 2-step cycle of adsorption and desorption involved in the fixed 2-bed adsorption unit successfully performed its function as Buffering unit for transient toluene loading.

2. Integrated unit of a 2-bed adsorption followed by a biofilter achieved stable toluene removal performance with +99% removal efficiency.
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