EVE 402
Air Pollution Generation and Control

Chapter #6 Lectures
Adsorption

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Introduction

- ***Adsorption***: the taking up of a gas (or liquid or dissolved substance) on the surface of a solid or a liquid
  - Liquid surface adsorption is insignificant, though
  - Certain finely divided solids (GAC, silica gel) have extremely large surface areas available and adsorb large quantities of material
  - ***Adsorbent***: the adsorbing solid
  - ***Adsorbate***: the adsorbed gas

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Common Adsorbents

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Types of Adsorption

- Physical
  - Consists of attracting gas molecules by van der Waals or electrostatic forces
  - Result is a weak bonding of gas molecules to the solid
  - Process is exothermic
  - Adsorbent is cleaned (rather easily) by either applying heat to or reducing pressure in the adsorption vessel(s)

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Types of Adsorption (2)

- Chemical (chemisorption)
  - Involves a chemical reaction and bonding of the adsorbate and the adsorbent
    - Bonds are much stronger than for physical adsorption
  - Not easily reversible (i.e., difficult to clean adsorbent)
    - As a result, if recovery of the adsorbate is desirable, chemisorption is not feasible

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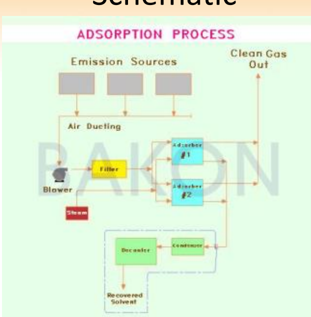
Schematic



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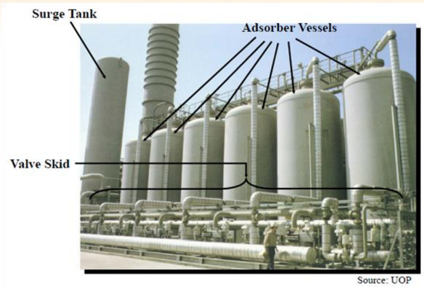
Industrial Adsorption Tower



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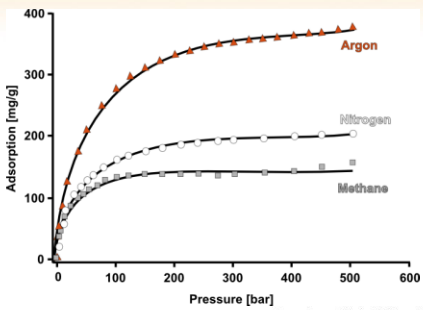
The capacity of an adsorbent for a specific gas or vapor is often presented as an *isotherm*



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Adsorption Isotherms

- A point on an isotherm represents the mass of adsorbate per unit mass of adsorbent at a specific temperature
- One of the best known adsorption models is the *Langmuir isotherm*:

$$\frac{\bar{P}}{a} = \frac{1}{k_1} + \frac{k_2}{k_1}\bar{P},$$ where

$\bar{P}$ = partial pressure of the adsorbate
a = mass of adsorbate adsorbed per unit mass of adsorbent
k_1, k_2 = constants

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Adsorption Isotherms (2)

Re-arranging the equation: $a = \frac{k_1\overline{P}}{k_2\overline{P} + 1}$

At very low adsorbate partial pressure: $a = k_1\overline{P}$

At high partial pressure: $a = \frac{k_1\overline{P}}{k_2\overline{P}} = \frac{k_1}{k_2}$

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Adsorption Isotherms (3)

Over a narrow, intermediate range of partial pressure: $a = k(\overline{P})^n$

where

k = constant

n = constant (with a value between 0 and 1)

This equation is called the Freundlich isotherm

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Adsorbents: Activated Carbon

- By far, the most frequently used adsorbent
- "*activated*" →dehydration and oxidation steps impart increased surface area
- Any carbonaceous material can be activated
  - Coconut shells, wood, bone, coal, etc.
  - Ideal material is porous, with a uniform pore distribution
- Surface area: 600-1400 m^2/g

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Other Adsorbents

- Activated alumina
  - Surface area: ≈ 300 m^2/g
  - Major applications
    - Drying gas streams
    - Solvent recovery
- Silica gel
  - Used for over 50 years
  - Surface area: ≈ 320 m^2/g
  - Major application is gas drying

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Fixed Bed Adsorption: Description

- During gas flow through the bed, an active *adsorption zone* (AZ) moves through the bed
- Behind (above) the AZ, adsorbent is saturated
- In front of (below) the AZ, absorbent is clean
- The length of the AZ determines the minimum depth of the adsorbent bed
- At some point, there is very little clean carbon and the gas "breaks through" the bed

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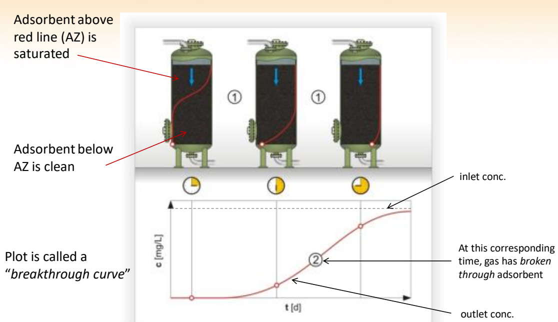
Fixed Bed Adsorption: Schematic



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Pressure Drop

In the absence of measured pressure loss data, the pressure drop across the bed can be estimated with the following empirical relationship:

$$\frac{\Delta P g_c \varepsilon^3 d_p \rho_g}{D(1-\varepsilon)G^2} = \frac{150(1-\varepsilon)\mu}{d_p G} + 1.75$$

where

ΔP = pressure drop [lb_f/ft^2]
g_c = gravitational constant = 4.17 x 10^8 lb_m-ft/lb_f-hr^2
ε = void fraction [ft^3 voids/ft^3 packed bed]
d_p = particle diameter [ft]
ρ_g = gas density [lb_m/ft^3]
D = bed depth [ft]
G = gas superficial mass flux [lb_m/hr-ft^2]
μ = gas viscosity [lb_m/hr-ft]

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Pressure Drop

A simpler empirical relationship, published by Union Carbide, is as follows:

$$\Delta P = 0.37D\left(\frac{V}{100}\right)^{1.56}$$

where

ΔP = bed pressure drop [in H_2O]
D = bed depth [in]
V = superficial gas velocity [ft/min]

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Example Problem

- The data given below are for the adsorption of CO on charcoal at 273 K. Determine the isotherm that fits the data and give the constants of the equation using the given units.

P (kPa)	13.3	26.7	40.0	53.3	66.7	80.0	93.3
a (kg/kg)	0.150	0.122	0.094	0.059	0.045	0.038	0.033

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