Aerosols in Industrial Hygiene

Industrial Hygiene 1
Why study aerosols?
Man-made Aerosols

T.Peters Fall 2004
Long-term Health Effects

- Asbestos → Asbestosis
- Cotton Dust → Byssinosis
- Coal Dust → Pneumoconiosis
Lung Disease

Healthy

Cancer – white area on top and anthracosis – black spots

Mesothelioma due to asbestos exposure

emphysema, the swollen "blebs" at base

T.Peters Fall 2004
Kinston, NC Dust Explosion
January 29, 2003
Explosion of DeBruce Grain Elevator
Wichita, Kansas 8 June 1998

Problem Recognized for Thousands of Years
To recognize, evaluate, and control particle hazards...

We must understand particle behavior

- Generation
- Transport
- Fate
Overview

• Week 1
  – Wed: Aerosol physics
  – Thurs: Sampling aerosols – manual methods

• Week 2
  – Wed: Analyzing aerosol samples
  – Thurs: Sampling aerosols – direct-reading instruments

• Week 3
  – Wed: Aerosol exposure calculations
  – Thurs: Exam
Supplemental Material

• In-class problems
• Supplemental problems
• Formula sheet
Be the Ball

“There is a force in the universe that makes things happen...and all you have to do is get in touch with it.
Stop thinking...let things happen... and Be the Ball.”

Ty Webb (Chevy Chase), Caddyshack
What is an aerosol?

An assembly of liquid or solid particles suspended in a gaseous medium
Particle Size

1 µm = 10^{-4} cm = 10^{-6} m

- Pea: 1 µm
- Golf ball: 10 µm
- Soccer ball: 100 µm
- Me: 1000 nm (0.1 µm)
- Room: 10 µm
- Building: 1000 µm

- Gas Molecules: 0.001 µm
- Light: 0.01 µm
- Bacteria: 0.1 µm
- Virus: 1.0 µm
- Human Hair: 10 µm
- Raindrops: 100 µm

T. Peters Fall 2004
Particle Shape

- Fiber
- Crystal
- Chain agglomerate
- Droplet

T. Peters Fall 2004
Particle Density, $\rho_p$

- ~ 1000 times greater than air (1.2 x 10^{-3} \text{ g/cm}^3)

<table>
<thead>
<tr>
<th></th>
<th>Density g/cm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pollen</td>
<td>0.4 - 1</td>
</tr>
<tr>
<td>Oil</td>
<td>0.9</td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
</tr>
<tr>
<td>Sand</td>
<td>2.5</td>
</tr>
<tr>
<td>Lead</td>
<td>11.3</td>
</tr>
<tr>
<td>Quantity</td>
<td>Units</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Number</td>
<td>#/cm³</td>
</tr>
<tr>
<td>Surface Area</td>
<td>µm²/cm³</td>
</tr>
<tr>
<td>Volume</td>
<td>µm³/cm³</td>
</tr>
<tr>
<td>Mass</td>
<td>mg/m³</td>
</tr>
</tbody>
</table>
Size Distribution

Polydisperse

Monodisperse

N

0

d

N

d on logscale

T.Peters Fall 2004
Quantity vs Size

Particle Diameter

- Ultrafine
- Fine
- Coarse

Quantity vs Size Chart:

- Mass
- Surface
- Number

Vapor
Nucleate
Condense
Mechanical Generation
Coag
Forces Acting on Particles

- Gravity
- Diffusion
- Electrical
- Centrifugal

10-µm Particle

Gas Molecule

0.005-µm Particle

T. Peters Fall 2004
Force Balance for Gravitational Settling

How fast does a particle settle in air?

Gravity

Buoyancy

Drag
Particle Reynolds Number

\[ Re = \frac{\rho_g V d_p}{\mu} \]

- Inertial Forces
- Viscous Forces

- \( Re < 1 \) Viscous Forces Dominate
- \( Re >> 1 \) Inertial Forces Dominate

\[ Re = 6.6 \ V[\text{cm/s}]d[\text{cm}] \] for air at STP

T. Peters Fall 2004
Stokes’ Regime
Laminar Flow
\( C_D = \frac{24}{Re} \)

Transition

Newton’s Law
\( C_D = 0.44 \)

\( F_{\text{drag}} = \frac{3 \pi \mu d V_{TS}}{C_c} \)
Terminal Settling Velocity – Stokes’ Law

At Equilibrium
Force of Gravity = Force of Drag

\[ F_{\text{gravity}} = mg = \frac{\pi}{6} d^3 \rho_p g \]

\[ F_{\text{drag}} = \frac{3 \pi \mu d V_{TS}}{C_c} \]

\[ V_{TS} = \frac{C_c \rho_p d^2 g}{18 \mu} \]
Cunningham Correction Factor

- Corrects for a small particle that slips past gas molecules
- Factor increases as particle size decreases
  - Negligible above 10 µm
  - Do not forget below 1 µm

\[
C_c = 1 + \frac{\lambda}{d} \left[ 2.514 + 0.800 \exp \left( -0.55 \frac{d}{\lambda} \right) \right]
\]

\[
C_c = 1 + \left( \frac{0.167}{d[\mu m]} \right) \text{ for air at STP}
\]
Example Calculation

• Particle diameter = 10 µm
• Silica Sand (Particle density = 2.5 g/cm³)
• What is $V_{TS}$?
• Check Re to make sure that we are in Stokes
• What if $d = 100$ µm?
Outside Stokes Regime

Tabular Procedure

Calculate $V_{TS}$ when $d$ known

$C_D \text{Re}^2 = \left( 4 \ d^3 \ \rho_p \ \rho_g \ g \right) / \left(3 \ \mu^2 \right)$

Look up Re on chart

Calculate $V_{TS} = \text{Re} \ \mu / (\rho_g \ d)$

Calculate $d$ when $V_{TS}$ given

$C_D / \text{Re} = \left( 4 \ \rho_p \ \mu \ g \right) / \left(3 \ \rho_g^2 \ v^3 \right)$

Look up Re on chart

Calculate $d = \text{Re} \ \mu / (\rho_g \ V_{TS})$
Homework

• Go over short homework questions for next time