Aerosol Short Course: Physics, Measurement, and Sampling

Boeing Ed Wells Course

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I. Background and Physics
Why study aerosols?
Naturally Occurring Aerosols
Man-made Aerosols
Aerosols and Aircraft

- **Production**
  - Part manufacturing
  - Assembly of planes

- **Cabin air quality**
  - 1,462 Million airline passengers worldwide (1998)
  - Over 105,000 flight crew in the US

- **Exhaust**
  - Global atmosphere
  - Local exposures to crew, passengers, communities

- **Maintenance**
  - Refurbish older aircraft
Aerosols in Aircraft Production

- **Metals**
  - Aluminum, titanium, beryllium, chromium, cobalt, nickel
  - Pulmonary fibrosis, immune-mediated response, metal fume fever

- **Metalworking fluids**
  - Asthma
  - Hypersensitivity pneumonitis (HP) from microbes

- **Composite materials**
  - Dusts, fibers
Aerosols in Cabins

• On ground
  – Exhaust

• In-air events
  – Air conditioning smoke from incoming bleed air
    • Engine / hydraulic fluid oil leaks
  – Overheated electrical equipment
    • Smoke, fume
  – Person-to-person disease transmission
    • TB, cold, flu, Norwalk virus, SARS
Aircraft Emissions

- Gasses
  - CO
  - NOx
  - Water vapor

- Aerosols
  - Sulphates
  - Soot

http://www.grida.no/climate/ipcc/aviation/004.htm
To recognize, evaluate, and control particle hazards...

We must understand particle behavior

- Generation
- Transport
- Fate
Overview

• Background and Physics
• Measurement
• Sampling
Handouts

- Class slides
- Formula sheet
- Frank chart
What is an aerosol?

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

1 µm = 10^{-4} \text{ cm} = 10^{-6} \text{ m}

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

- 0.001 µm
- 0.01 µm
- 0.1 µm
- 1.0 µm
- 10 µm
- 100 µm
- 1000 µm

- Gas Molecules
- Virus
- Light
- Bacteria
- Human Hair
- Raindrops

Soccer ball
Golf ball
Pea
Virus
Human Hair
Raindrops
Particle Shape

- Fiber
- Crystal
- Chain agglomerate
- Droplet

Asbestos
Sand
MgO
Particle Density, $\rho_p$

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

<table>
<thead>
<tr>
<th>Material</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>#/cm$^3$</td>
</tr>
<tr>
<td>Surface Area</td>
<td>µm$^2$/cm$^3$</td>
</tr>
<tr>
<td>Volume</td>
<td>µm$^3$/cm$^3$</td>
</tr>
<tr>
<td>Mass</td>
<td>mg/m$^3$</td>
</tr>
</tbody>
</table>
Chemical Composition

- **Irritants**
  - Dusts

- **Immune provoking**
  - Pollen
  - Some metals

- **Carcinogenic**
  - PAH

- **Biologically active**
  - Virus
  - Bacteria
Size Distribution

Polydisperse

Monodisperse

N

0

d

N

d on logscale
Quantity vs Size

Particle Diameter

Mass

Surface

Number

Ultrafine  Fine  Coarse

1  10  100  1000  10^4 nm

0.001  0.01  0.1  1  10 µm
Particle Generation

- **Hot processes**
  - Vapor → particle
  - Dp < 1 µm
  - Welding, combusting

- **Dusty processes**
  - Mechanical
  - Dp > 1 µm
  - Grinding, sanding
Forces Acting on Particles

Gravity
Diffusion
Electrical
Centrifugal

10-µm Particle

Gas Molecule
0.005-µm Particle
**Force Balance: Gravitational Settling**

How fast does a particle settle in air?

<table>
<thead>
<tr>
<th>Diameter</th>
<th>1 µm</th>
<th>10 µm</th>
<th>100 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity, cm/s</td>
<td>0.0035</td>
<td>0.36</td>
<td>25</td>
</tr>
<tr>
<td>Distance in 1 min, ft</td>
<td>0.006</td>
<td>0.7</td>
<td>49</td>
</tr>
</tbody>
</table>
Aerodynamic Diameter

All have the same settling velocity; thus equal aerodynamic diameter
Inertial force

Larger particles resist change in direction more $\rightarrow$ larger $\tau$
A Bug on Your Windshield

HUMMER

Airflow

Drag Force

Force of Inertia

Bug
Impactors

Large particles hit plate

Small particles reach filter
Diffusion

- Particles move because gas molecules hit them
  - The smaller the particle, the larger the movement
  - Dominant for particles smaller than 0.1 µm (100 nm)
Electrical Forces

- Charged particle in an electric field
- Very high velocity can result

Electrical Force

Gravity

Millikan Oil Drop Experiment
Optical Behavior

• Light wavelength
  – 0.4 µm → 0.8 µm
  – 400 nm → 800 nm

• Scattering, absorption, extinction
Particles in the Respiratory Tract

**Conducting Passages**

- Upper respiratory tract
  - Nasal cavity
  - Pharynx
  - Larynx
- Lower respiratory tract
  - Trachea
  - Primary bronchi
  - Lungs

**Percent Deposited**

- Total
- Head
- Alv
- TB

**Deposition Mechanism**

- Diffusion Dominated
- Inertial Dominated

Particles Deposited in the Respiratory Tract:

- 0.001 µm
- 0.01 µm
- 0.1 µm
- 1 µm
- 10 µm
- 100 µm
Aerosol Physics Summary

• Important parameters
  – Size, shape, composition, density, quantity

• Size distribution
  – Most aerosols are polydisperse

• Forces
  – Gravity, inertia, diffusion, electrical