Atmospheric Aerosols

1. Introduction

2. Sources and Measurement

3. Concentrations and Residence times

4. Emission controls and abatement technology
Beijing, Jan., 2013

PM$_{2.5}$ = 122 ug/m$^3$
BC Forest Fires: July – August 2017
Smoke relief in the forecast comes too late for marathon runners

Vancouver, August 11, 2017
B.C. wildfire smoke triggers air quality statement for southwestern Manitoba
Smoke could cause issue for people living with asthma, irritate eyes
Total particulate matter (TPM)
(diameter < 100 micrometres)

$PM_{10}$
(diameter $\leq$ 10 micrometres)

$PM_{2.5}$
(diameter $\leq$ 2.5 micrometres)
Size matters

Deposition potential for particles of varying sizes

- 7 - 11 Microns  Pharynx
- 4.47 - 7 Microns  Trachea & Primary Bronchi
- 3.5 - 4.7 Microns  Secondary Bronchi
- 2.1 - 3.3 Microns  Terminal Bronchi
- 1.1 - 2.3 Microns  Alveoli
- 0.65 - 1.1 Microns  Alveoli
- 0.43 - 0.65 Microns  Alveoli
Classification and properties of atmospheric particulates

<table>
<thead>
<tr>
<th>Particle diameter / μm</th>
<th>Electromagnetic radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X-rays</td>
</tr>
</tbody>
</table>

**Categories and examples**

- Gas molecules: CO₂, Ar, O₂, SO₂, CH₄, C₆H₁₀
- Alken particles
- Large particles: dust, pesticide dusts, fly ash, pollen
- Giant particles: smoke, smog, sea salt, cloud & fog, clay, silt, sand

**Properties**

- Readily coagulate
- Relatively long residence times
- Readily settle
- Readily incorporated into water droplets
- Respirable particulate matter PM₁₀

<table>
<thead>
<tr>
<th>Settling velocity / cm s⁻¹ (25°C, P₀)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10⁻⁶</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diffusion coefficient / cm² s⁻¹ (25°C, P₀)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10⁻⁶</td>
</tr>
</tbody>
</table>

Fig. 6.1 Van Loon
Residence time of atmospheric aerosols

10 days
Canadian Ambient Air Quality Standards: Current and Proposed

<table>
<thead>
<tr>
<th>Management Level</th>
<th>Management Actions</th>
<th>Proposed Air Management Threshold Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ozone (ppb)</td>
</tr>
<tr>
<td>RED</td>
<td></td>
<td>63 ppb</td>
</tr>
<tr>
<td>ORANGE</td>
<td></td>
<td>56 ppb</td>
</tr>
<tr>
<td>YELLOW</td>
<td></td>
<td>50 ppb</td>
</tr>
<tr>
<td>GREEN</td>
<td></td>
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</tr>
</tbody>
</table>
Aerosol Processes

• Diffusion

• Coagulation

• Condensation

• Chemical reactions

• Sedimentation
Physical and chemical processes influencing size distribution of aerosols
chemical cloud processing

gas phase transfer
aqueous phase reactions

growth by diffusion and condensation (uptake) of water vapour

collision coalescence

impaction

evaporation

nucleation of cloud droplets

H₂O(ω)  H₂O(aq)

aerosol particles and gases in a heterogenic mixture

precipitation

cloud processed aerosol particles and gases in a heterogeneous mixture
Figure 6.8. Schematic diagram of some of the primary pathways for trace gases to be converted to aerosols (A) in the troposphere. The major reactions involving gas-phase constituents are indicated by the solid lines. Interactions between chemical families are indicated by the dashed lines. Pathways leading to incorporation into precipitation (P) are also shown. [Adapted from R. P. Turco et al. in Heterogeneous Atmospheric Chemistry, ed. D. R. Schreyer, American Geophysical Union, p. 234 (1982). Copyright © 1982 by the American Geophysical Union.]
Figure 7.11. Schematic diagram illustrating a conceptual model for new particle production near marine convective clouds. [From K. Perry and P. V. Hobbs, J. Geophys. Res., 99, 22813 (1994). Copyright © by the American Geophysical Union.]
2. Sources and measurement

- Sea spray
- Dust
- Combustion
- Condensation – inorganic and organic
- Arctic haze
- Volcanoes
Sea spray

Chemical Concentration Factors (CCF)

$$CCF = \frac{(C_x / C_{Na})_{aerosol}}{(C_x / C_{Na})_{seawater}}$$

CCF > 100 for some heavy metals (e.g., Hg, Cd, Pb) & organics

After water evaporation, fine salt aerosol remains (i.e., 5 – 300 pg of NaCl(s))
Dust

Chemical composition reflects source

- Natural $\rightarrow$ soil and rock types

- Anthropogenic $\rightarrow$ brake lining, tire components, cement, construction materials
Combustion aerosols

- Forest fires
- Volcanoes
- Internal combustion engines
- Coal burning power plants
- Industry, roasting and smelting

Fly Ash & Bottom Ash

Inorganic minerals (Ca, Mg, SO4 etc)

Trace metals (Hg, Pb, Cd, Se, As)

Soot – elemental carbon

Trace organics (PAHs, PCBs etc)
Condensation aerosols

Inorganics: Ammonium Sulfate and Ammonium Hydrogen Sulfate

From: Contribution of Arctic seabird-colony ammonia to atmospheric particles and cloud-albedo radiative effect
Condensation aerosols

Organics: secondary organic aerosols
Measurement
Particle Size Fractionation

aerodynamic impactors
Measurement
Optical Particle Sizer & Counter

Figure 2
Flow Through an Optical Particle Counter
3. Concentrations and Residence times

Concentrations reported as either
Number density (\# particles/m$^3$)
Mass density (\(\mu g/m^3\))

Typical range: \(10 - 500 \mu g/m^3\)
Rural forested \(10 - 50 \mu g/m^3\)
Open ocean \(10 - 150 \mu g/m^3\)
Urban \(10 - 300+ \mu g/m^3\)
Settling velocity

\[ V_t = \frac{(\rho_p - \rho_{air}) \cdot C \cdot g \cdot d_p^2}{18\eta} \]

meters per second

\( \rho_p = \) density of particle (g m\(^{-3}\))

\( \rho_{air} = \) density of air (g m\(^{-3}\))

\( C = \) correction factor (see Table 6.4 Textbook)

\( g = 9.81 \text{ m s}^{-2} \)

\( d_p = \) diameter of particle (m)

\( \eta = 1.9 \times 10^{-2} \text{ g m}^{-1} \text{ s}^{-1} \) at \( T=298K, P=1\text{atm} \)
Coagulation kinetics

\[ \frac{-dN}{dt} = 4\pi D C d_p N^2 \]

\[ \frac{-dN}{dt} = k_2 N^2 \]

where \( k_2 = 4 \pi D C d_p \)

N =

D =

C =

d_p =
<table>
<thead>
<tr>
<th>$d_p/\mu m$</th>
<th>C</th>
<th>$v_t/\text{cm s}^{-1}$</th>
<th>$D/\text{m}^2 \text{s}^{-1}$</th>
<th>$t_{1/2}$</th>
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</thead>
<tbody>
<tr>
<td>0.001</td>
<td>216</td>
<td></td>
<td>$5.14 \times 10^{-6}$</td>
<td>1 min</td>
</tr>
<tr>
<td>0.005</td>
<td>43.6</td>
<td></td>
<td>$2.07 \times 10^{-7}$</td>
<td>0.5 h</td>
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<tr>
<td>0.01</td>
<td>22.2</td>
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<td>$5.24 \times 10^{-8}$</td>
<td>2 h</td>
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<tr>
<td>0.05</td>
<td>4.95</td>
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<td>$2.35 \times 10^{-9}$</td>
<td>38 h</td>
</tr>
<tr>
<td>0.1</td>
<td>2.85</td>
<td>$1.7 \times 10^{-4}$</td>
<td>$6.75 \times 10^{-10}$</td>
<td>110 h</td>
</tr>
<tr>
<td>0.5</td>
<td>1.326</td>
<td>$2.0 \times 10^{-3}$</td>
<td>$6.32 \times 10^{-11}$</td>
<td>520 h</td>
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<tr>
<td>1.0</td>
<td>1.164</td>
<td>$6.8 \times 10^{-3}$</td>
<td>$2.77 \times 10^{-11}$</td>
<td>690 h</td>
</tr>
<tr>
<td>5.0</td>
<td>1.032</td>
<td>$1.5 \times 10^{-1}$</td>
<td></td>
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<td>10.0</td>
<td>1.016</td>
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<td>50.0</td>
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<td>15</td>
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</tr>
<tr>
<td>100.0</td>
<td>1.0016</td>
<td>58</td>
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</tr>
</tbody>
</table>

For half-life calculations, particle number density in the atmosphere is taken as $10^9 \text{m}^{-3}$.  

Table 6.4  Aerosol transport properties assuming spherical particles, density 2.0 g cm$^{-3}$, in air at $P^0$ and 25°C
4. Emission controls and abatement technology
Aerosol control for larger particles

Cyclone precipitator

Fabric filtration
Aerosol control for smaller particles

Wet Scrubber

Electrostatic Precipitator
Cyclone Collection (Particle Removal) 
Efficiency Formula

\[ \eta = \frac{1}{1 + (d_{pc}/d_p)^2} \]

\( \eta \) – fractional particle collection efficiency
\( d_{pc} \) – diameter of particle collected
with 50% efficiency in m
\( d_p \) – diameter of particle of interest in m
Size distribution of aerosols in engine exhaust

![Graph showing size distribution of aerosols in engine exhaust](image)