Module 2: Pollutant Types, Effects, and Emission Sources

Air Pollution Effect on Humans
Environmental Effects: Haze

- Caused by scattering and absorption of light by particles and gases
  - Primary PM
  - Soot (elemental carbon)
  - PM precursors: SO\(_x\), NO\(_x\), VOC, NH\(_3\)
- Effects:
  - Acid Rain formation
  - Reduced visual range

Environmental Effects: Acid Rain

- Acid Rain is primarily a result of
  - SO\(_2\) and NO\(_x\) emissions interacting with sunlight and water vapor to form sulfuric and nitric acids
- Effects:
  - Damage to vegetation
  - Damage to crops
  - Damage to animals
  - Damage to monuments
  - Damage to drinking water
**Environmental Effects: Photochemical Smog**

- Ozone is primary component of smog
  - Formed when NOx and VOC and other pollutants are in presence of sunlight
- Effects:
  - Damage to vegetation
  - Haze

**Environmental Effects: Global Warming**

- Primary pollutants:
  - Carbon dioxide
  - Methane
  - Nitrous oxide
- Affects:
  - Forests
  - Crop yields
  - Water supplies
  - Animals
  - Ecosystems
Example Classification of Air Pollutants

Example classification of pollutants
- CO, Lead, NO\textsubscript{x}, Particulate Matter, SO\textsubscript{2}, Ozone (these 6 pollutants are known in U.S. as criteria air pollutants)
- Air Toxics
- Ozone Depleting Substances
- Greenhouse Gases
- Photochemical Smog
- Visibility Degrading Pollutants

Criteria Pollutants

- Key air pollutants for which ambient air quality standards are being established:
  > Carbon monoxide (CO)
  > Nitrogen oxides (NO\textsubscript{x})
  > Sulfur dioxide (SO\textsubscript{2})
  > Lead (Pb)
  > Particulate matter (PM)
  > Dust fall
  > Benzene
  > Ozone (O\textsubscript{3})
Primary and Secondary Pollutants

- Primary pollutants
  - Emitted directly from a source
  - Examples: Carbon monoxide (CO), nitrous oxide (N₂O), lead (Pb), sulfur dioxide (SO₂), particulate matter (PM), volatile organic compounds (VOC), ammonia (NH₃)

- Secondary pollutants
  - Formed in the atmosphere
  - Examples: Ozone (O₃), nitrogen dioxide (NO₂), PM, Formaldehyde

- Pollutants can be both primary and secondary

Concentration Units

Concentration of Air Pollutants may be reported in the following units:

- Parts per million (ppm) or parts per billion (ppb)
  - For gaseous pollutants
  - Assumes a dimensionless volume fraction \( V_{\text{pollutant}} : V_{\text{air}} \)

- Microgram per cubic meter (µg/m³)
  - For gaseous pollutants and particles

- Conversion of µg/m³ to ppm
  - \( \mu g/m^3 = ppm \times 40.9 \times \text{molecular weight of pollutant (MW)} \)

- Example:
  - Convert 0.120 ppm of O₃ to µg/m³ when MW of O₃ = 48
  - \( 0.120 \text{ ppm} \times 40.9 \times 48 = 236 \mu g/m^3 \)
### Proposed South Africa Standards under “SANS 1929, Ambient Air Quality”

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>10 min</th>
<th>1- hr</th>
<th>8 - hr</th>
<th>24 -hr</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (ppm)</td>
<td></td>
<td>26</td>
<td>8.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO₂ (ppb)</td>
<td></td>
<td>106</td>
<td></td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Pb (µg/m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.25</td>
</tr>
<tr>
<td>PM-10 (µg/m³)</td>
<td></td>
<td></td>
<td>75</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>SO₂ (ppb)</td>
<td></td>
<td>191</td>
<td>48</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>Benzene (µg/m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>O₃ (ppb)</td>
<td></td>
<td>102</td>
<td>61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example: U.S. National Ambient Air Quality Standards

<table>
<thead>
<tr>
<th></th>
<th>Carbon monoxide: 8-hour average</th>
<th>9 ppm</th>
<th>35 ppm</th>
<th>(10 mg/m³)</th>
<th>40 mg/m³</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-hour average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen dioxide:</td>
<td>Annual arithmetic mean</td>
<td>0.053 ppm</td>
<td>(100 µg/m³)</td>
<td>Primary &amp; Secondary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone:</td>
<td>1-hour average</td>
<td>0.12 ppm</td>
<td>(225 µg/m³)</td>
<td>Primary &amp; Secondary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8-hour average</td>
<td>0.08 ppm</td>
<td>(157 µg/m³)</td>
<td>Primary &amp; Secondary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead:</td>
<td>Quarterly average</td>
<td>1.5 µg/m³</td>
<td>Primary &amp; Secondary</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

| Particulate matter (PM₂₅) | Annual arithmetic mean         | 50 µg/m³ | Primary & Secondary |         |
|                          | 24-hour average                | 150 µg/m³ | Primary & Secondary |         |
| Particulate matter (PM₁₀) | Annual arithmetic mean         | 15 µg/m³ | Primary & Secondary |         |
|                          | 24-hour average                | 65 µg/m³ | Primary & Secondary |         |

| Sulfur dioxide:          | Annual arithmetic mean         | 0.030 ppm | (80 µg/m³) | Primary |         |
|                          | 24-hour average                | 0.14 ppm | (265 µg/m³) | Primary |         |
|                          | 3-hour average                 | 0.50 ppm | (1300 µg/m³) | Secondary |         |

Carbon Monoxide (CO)

- Created by incomplete combustion of carbonaceous fuel
- Sources
  - Automobiles
  - Residential heating and cooking
  - Industrial processes
  - Open burning
  - Prescribed or agricultural burning
Effects of Carbon Monoxide

- Global warming potential
- Health effects
  - Heart diseases
  - Prohibits the oxygen carrying ability of blood
  - Respiratory problems
  - Affects the central nervous system
  - Death at higher concentrations

CO Emissions in South Africa (1990)

CO Emissions in Durban Metro Area

Source: Durban Local Agenda 21, 1999

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Nitrogen Oxides \((\text{NO}_x)\)

- \(\text{NO}_x\) includes two primary species
  - Nitric oxide (NO)
  - Nitrogen dioxide (NO\(_2\))
- Formed when fuel is burned
  - Nitrogen and oxygen in air \(\Rightarrow\) NO\(_x\)
  - Organically bound nitrogen in fuels form NO\(_x\)
- \(\text{NO}_x\) is highly reactive and a major ozone precursor
**NO\textsubscript{x} Sources in South Africa**

- Vehicle traffic
- High-temperature combustion processes
  - Power plants (thermal and cogeneration)
  - Industrial combustion (fossil fuels)

**Effects of Nitrogen Oxides**

- Photochemical smog
- Ozone formation
- Visibility degradation
- Acid deposition
- Secondary particulate matter precursor
- Eutrophication
  - Nutrient buildup in water
- Human health effects
  - Respiratory problems
  - Lung diseases
**NO\textsubscript{x} Emissions in South Africa (1990)**


**NO\textsubscript{x} Emissions in Durban Metro Area**

Source: Durban Local Agenda 21, 1999
Lead (Pb)

- A metal found naturally in the environment
- Used in manufactured products
- Sources of lead emissions in the air
  - Metal processing
  - Fuel combustion
  - Waste incinerators
  - Lead-acid battery manufacturing
  - Lead-based paint manufacturing

Effects of Lead

- Slowing of vegetative growth
- Elevated levels in water causing reproductive damage to some aquatic and animal life
- Health effects in humans
  - Damage to kidneys, liver, brain, and nerves
  - Leads to osteoporosis and reproductive disorders
  - Causes high blood pressure and increased risk of heart attacks
Particulate Matter (PM)

- Primary PM is directly emitted by dust and soot sources
- Secondary PM is formed by gas conversion reactions of NO\textsubscript{x}, SO\textsubscript{x}, VOCs, and NH\textsubscript{3}
- PM size is an important property
  - Total suspended particulate (TSP) = 30 \textmu m and larger
  - Respirable particulate = 10 \textmu m and smaller (PM\textsubscript{10})
  - Fine particulate = 2.5 \textmu m and smaller (PM\textsubscript{2.5})
- While other pollutants experiencing decreases, PM levels on the rise in some areas (e.g., Cape Town 2002 levels in Khayelitsha are highest on record)

Primary Particulate Matter Sources

- Industrial processes
- Industrial, commercial,
- residential fuel combustion
- Windblown dust (e.g., from mines)
- Reentrained dust from vehicle traffic on public and industrial roads
- Open burning, agricultural burning
- Natural sources (sea salt, volcanoes)
Effects of Particulate Matter

- Regional haze, visibility degradation
- Smog
- Soiling of buildings and property
- Alteration of local weather
- Health effects
  - Respiratory problems
  - Lung diseases
  - Premature death
  - Chronic bronchitis

PM Emissions in Durban Metro Area

Source: Durban Local Agenda 21, 1999
Sulfur Dioxide (SO$_2$)

- Produced from combustion of sulfur-containing materials (e.g., coal)
- SO$_x$ used to categorize SO$_2$ and SO$_3$
- Sources
  > Fossil-fuel combustion
  > Industrial processes
  > Volcanoes

Effects of Sulfur Dioxide

- Visibility degradation
- Acid deposition
- Secondary particulate matter precursor
- Corrosion
- Human health effects
  > Respiratory problems
  > Lung diseases
  > Aggravation of existing cardio-vascular diseases
SO$_2$ Emissions in South Africa (1990)


SO$_2$ Emissions in Durban Metro Area

Source: Durban Local Agenda 21, 1999
Volatile Organic Compounds (VOCs)

- VOC species are part of the broad group of compounds called total organic gases (TOG)
- VOC species do not include organic compounds with limited or no photochemical reactivity
- VOCs are a significant contributor to ground-level ozone formation

Visual Representation of TOG/TOC Definition

Box includes all carbonaceous compounds

Shaded area includes total organic gases (TOG), also known as total organic compounds (TOC)
Visual Representation of ROG/ROC/VOC Definition

VOC Sources in South Africa

- Combustion sources
  - Stationary fuel combustion
  - Vehicular traffic
- Evaporative sources
  - Surface coatings and paints
  - Petroleum product storage and distribution (e.g., at refineries, fuel stations)
  - Solvents (consumer products, industrial uses)
### Effects of Volatile Organic Compounds

- Secondary aerosol formation (haze and particulate matter precursor)
- Photochemical smog, ground-level ozone formation
- Health effects
  - Respiratory problems
  - Nose and throat infections
  - Skin allergies
  - Cancer
  - Kidney, liver, and brain damage
  - Damage to nervous, reproductive and immune systems

### VOC Emissions in South Africa (1990)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Energy: 22.8%</td>
<td>Transport: 10.3%</td>
</tr>
<tr>
<td>Industrial: 66.9%</td>
<td></td>
</tr>
</tbody>
</table>
TOC Emissions in Durban Metro Area

Source: Durban Local Agenda 21, 1999

Air Toxics Example: Mercury (Hg)

- Mercury is toxic, persistent, and bioaccumulates in food chains
- Mercury is released from various sources throughout the world
- These releases can be transported great distances through air and oceans, easily crossing national borders, cycling globally
- Even nations with minimal releases, and remote areas (such as the Arctic) are adversely affected
- Current releases add to the “global pool”...
Globally, Many Humans/Wildlife May Be At Risk

- Generally due to consumption of significant amounts of contaminated fish;
- Also due to other sources of exposure (such as artisanal mining and other occupations, cosmetics, spills, ritualistic uses, etc...)

- Note: Moderate consumption of a variety of fish is not likely to pose risks. Fish are a nutritious, beneficial food....

Summary: Pollutants and Sources

- Air pollutants can be directly emitted by anthropogenic and natural sources to the atmosphere or formed in the atmosphere by chemical reactions.
- Air pollutants have human health and environmental effects.
- Focus of training is on pollutants for which air quality standards have been established by various agencies.
  > PM, CO, NO₂, SO₂, Pb, NH₃, O₃
- Other important pollutants with health and environmental impacts:
  > Air toxics, ODS’s, GHG’s, haze pollutants
Questions or Comments?

END

Module 4: Pollutant Types and Emission Sources