Lecture 4: Atmospheric Dispersion and Health Risk Assessment

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1 Scientific Fundamentals

In environmental pollution studies, we analyze the transition of pollutants from a source to a receptor:

- **Emission Rate (Q):** The total mass of pollutant discharged from the stack exit per unit time (g/s).
- **Ambient Concentration (C):** The level of pollutant in the surrounding air after dispersion, representing the exposure dose ($\mu g/m^3$).

2 Environmental Indicators and Standards

2.1 WHO 2021 Air Quality Guidelines

All calculated concentrations must be evaluated against these international safety limits:

Pollutant	WHO Limit	Averaging Period	Unit Conversion
$PM_{2.5}$	$15\,\mu g/m^3$	24 Hours	$C(g/m^3) \times 10^6$
NO_2	$25\,\mu g/m^3$	24 Hours	$C(g/m^3) \times 10^6$
SO_2	$40\,\mu g/m^3$	24 Hours	$C(g/m^3) \times 10^6$
CO	$4\,mg/m^3$	24 Hours	$C(g/m^3) \times 10^3$

2.2 Air Quality Index (AQI) Breakpoints

The following indicators are used to classify the health risk based on concentration levels:

Category	**AQI Range (I)**	C_{low}	C_{high}	**Health Color**
Good	0 – 50	0	53	Green
Moderate	51 – 100	54	100	Yellow
Unhealthy (SG)	101 – 150	101	150	Orange
Unhealthy	**151 – 200**	**150.5**	**200**	**Red**
Very Unhealthy	201 – 300	201	360	Purple

Table 1: AQI Breakpoints for Nitrogen Dioxide (NO_2)

3 The Gaussian Plume Dispersion Model

The ground-level concentration is predicted using the following mathematical framework:

$$C = \frac{Q}{\pi \cdot u \cdot \sigma_y \cdot \sigma_z} \exp\left(-\frac{H^2}{2\sigma_z^2}\right) \tag{1}$$

4 Empirical Analysis and Case Studies

4.1 Case Study I: Industrial Nitrogen Dioxide (NO_2)

Problem Statement: A thermal power plant located near a residential area discharges Nitrogen Dioxide (NO_2) from a stack with an effective height $H = 80\,m$. The emission rate $Q = 40\,g/s$ under a steady wind speed $u = 5\,m/s$. Given the atmospheric stability conditions, the dispersion coefficients are determined to be $\sigma_y = 110, \sigma_z = 70$.

Mathematical Solution Steps:

1. **Substitution in the Formula:**
$$C = \frac{40}{\pi \cdot 5 \cdot 110 \cdot 70} \exp\left[-\frac{80^2}{2 \cdot 70^2}\right]$$
2. **Denominator Calculation:** $\pi \cdot 5 \cdot 110 \cdot 70 = \mathbf{120,951.3}$
3. **Exponent (Vertical Factor) Calculation:** $\frac{-(80^2)}{2 \cdot 70^2} = \frac{-6400}{9800} = \mathbf{-0.653}$
4. **Exponential Result:** $e^{-0.653} = \mathbf{0.520}$
5. **Final Concentration:** $C = \left(\frac{40}{120,951.3}\right) \times 0.520 \times 10^6 = \mathbf{172\,\mu g/m^3}$

4.2 Case Study II: Carbon Monoxide (CO) from a Power Generator

Problem Statement: A large electric generator in an urban area is emitting Carbon Monoxide (CO) at a rate of $Q = 100\,g/s$. The exhaust stack height is $H = 100\,m$ and the wind velocity is $u = 5\,m/s$. If the dispersion parameters are estimated as $\sigma_y = 150, \sigma_z = 90$, determine if the local air quality meets the safety requirements.

Mathematical Solution Steps:

1. **Substitution in the Formula:**

$$C = \frac{100}{\pi \cdot 5 \cdot 150 \cdot 90} \exp\left[-\frac{100^2}{2 \cdot 90^2}\right]$$

2. **Denominator Calculation:** $\pi \cdot 5 \cdot 150 \cdot 90 = \mathbf{212,057.5}$

3. **Exponent Calculation:** $\frac{-10000}{16200} = \mathbf{-0.617}$

4. **Final Result (mg/m^3):** $C = \left(\frac{100}{212{,}057.5}\right) \times e^{-0.617} \times 10^3 = \mathbf{0.254\,mg/m^3}$

5 The Air Quality Index (AQI) Calculation

The AQI is calculated using the linear interpolation formula:

$$I = \left[\frac{I_{high} - I_{low}}{C_{high} - C_{low}}\right] \cdot (C - C_{low}) + I_{low} \tag{2}$$

Example for $NO_2 = 172\,\mu g/m^3$:

- **Substitution:** $I = \left[\frac{200-151}{200-150.5}\right] \cdot (172 - 150.5) + 151$
- **Final Index Value:** $I = \mathbf{172}$ (Category: **Red - Unhealthy**).

6 Academic Homework Assignment

Problem Statement: An oil refinery station discharges Sulfur Dioxide (SO_2) at an emission rate of $Q = 30\,g/s$, through a stack with an effective height $H = 70\,m$. Given a wind velocity $u = 4\,m/s$ and dispersion coefficients $\sigma_y = 100, \sigma_z = 60$: 1. Calculate the ambient concentration in $\mu g/m^3$. 2. Evaluate results against WHO limits. 3. Determine the final AQI numerical value and color category.