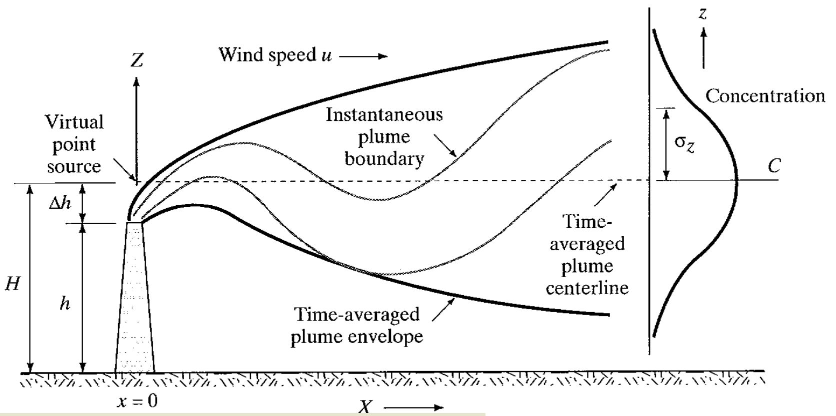

$$C(x,y,0)=\left[\frac{Q}{\pi\sigma_y\sigma_z u_H}\right]\left[\exp\left[-\frac{1}{2}\left(\frac{y}{s_y}\right)^2\right]\right]\left[\exp\left[-\frac{1}{2}\left(\frac{H}{s_z}\right)^2\right]\right]$$

Lecture 6

Air Quality:

Air Pollution Modeling

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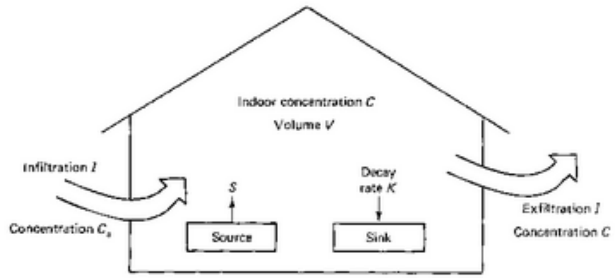
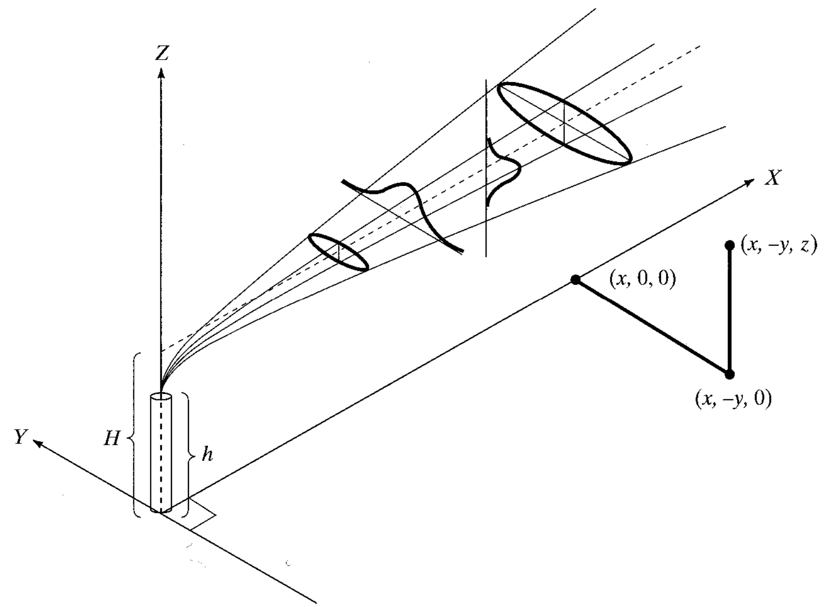


accumulation rate = input rate +sources – output rate – decay

$$\boxed{V\frac{dC}{dt} = S + C_a IV - CIV - KCV}$$

Recap 1



- Air pollution monitoring is crucial for true understanding of the state of the environment but impossible to have wide spatial coverage, hence air quality modeling is needed

- Gaussian Plume (Dispersion) Model (GPM) is used to estimate the ground level concentrations for pollutants coming from a chimney

- Inputs to GPM are: height of chimney; source emission strength; wind rose data; atmospheric stability of the region

$$\chi(x, y, 0, H) = \left[\frac{E}{\pi s_y s_z u}\right]\left[\exp\left[-\frac{1}{2}\left(\frac{y}{s_y}\right)^2\right]\right]\left[\exp\left[-\frac{1}{2}\left(\frac{H}{s_z}\right)^2\right]\right]$$

Recap 2

- Assumption
  - pollutants released from a "virtual point source"
  - advective transport by wind
  - dispersive transport (spreading) follows normal (Gaussian) distribution away from trajectory
  - constant emission rate
  - wind speed constant with time and elevation
  - pollutant is conservative (no reaction)
  - terrain is flat and unobstructed
  - uniform atmospheric stability
- Effective stack height

$$H = h + \Delta H$$

$$\Delta H = \frac{v_s d}{u}\left[1.5 + \left(2.68 \times 10^{-3}(P)\left(\frac{T_s - T_a}{T_s}\right)d\right)\right]$$

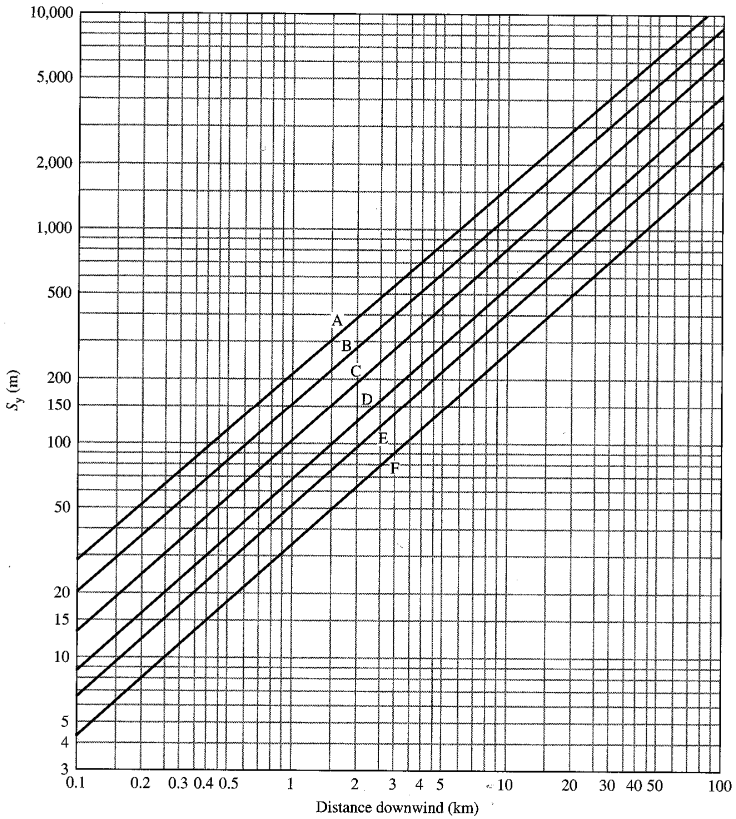
Holland's formula

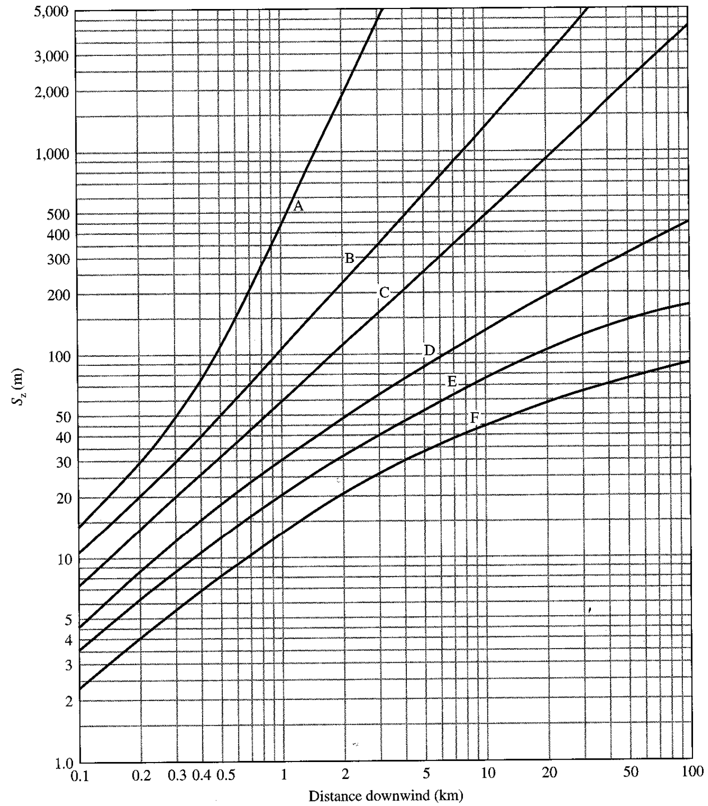
Recap 3

$$\sigma_y = a\,x^{0.894}$$

$$\sigma_z = cx^d + f$$

- Estimation of horizontal dispersion (s_y and s_z)

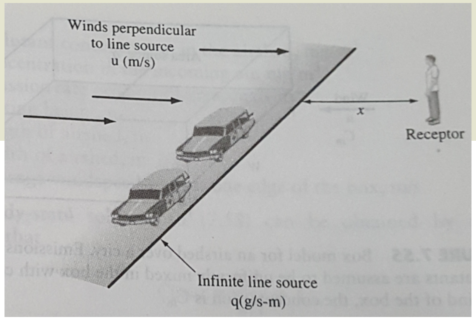




- Estimation of wind speed at stack height
- Model uncertainty could be up to 50%

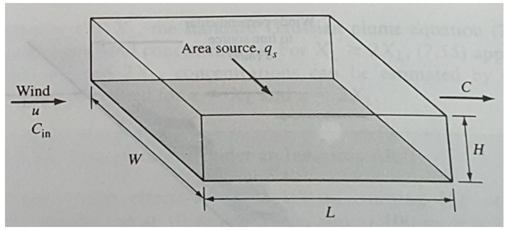
$$u_2 = u_1\left(\frac{z_2}{z_1}\right)^p$$

Recap 4



- When source is distributed along a line with continuous emissions, ground level conc. of pollutant at a perpendicular distance x can be obtained by:

$$C(x) = \frac{2q}{\sqrt{2\pi}\,\sigma_z u}$$



- For distributed sources spread over an area, box model can be used, assuming uniform mixing in the box, rate of change of pollutants in the box:

$$LWH\frac{dC}{dt} = q_s LW + WHuC_{in} - WHuC$$

$$C(\infty) = \frac{q_s L}{uH} + C_{in}$$

$$C(t) = \left(\frac{q_s L}{uH} + C_{in}\right)\left(1 - e^{-ut/L}\right) + C(0)e^{-ut/L}$$

Today's Learning Objective !

- To learn about air quality modeling methods

Box Model: Example !

In a square city of 15 km a side, there are 20,000 cars on the road, each driven 30 km between 4-6pm, and each emitting 3 g/km of CO. It's a clear winter evening with radiation inversion restricting mixing height to 20 m. The wind is bringing clean air at a steady rate of 1.0 m/s, along an edge of the city. Using box model estimate CO at 6 pm if there was no CO in air at 4 pm, and only source of CO is cars. Assume CO is conservative and uniform mixing in the box.

First, calculate the CO emissions, q_s (in units of mass/area-time):

$$q_s = \frac{2000 cars \times 30\, km / car \times 3\, g / km}{(15 \times 10^3 m)^2 \times 3600 s / hr \times 2 hr}$$

$$= 1.1 \times 10^{-5} \; g / s - m^2$$

Box Model: Example !

In a square city of 15 km a side, there are 20,000 cars on the road, each driven 30 km between 4-6pm, and each emitting 3 g/km of CO. It's a clear winter evening with radiation inversion restricting mixing height to 20 m. The wind is bringing clean air at a steady rate of 1.0 m/s, along an edge of the city. Using box model estimate CO at 6 pm if there was no CO in air at 4 pm, and only source of CO is cars. Assume CO is conservative and uniform mixing in the box.

$$C(t) = \left(\frac{q_s L}{uH} + C_{\text{in}}\right)(1 - e^{-ut/L}) + C(0)e^{-ut/L}$$

Hence,

$$C(t) = \frac{q_s L}{uH}(1 - e^{-ut/L})$$

$$C(2hr) = \frac{1.1\times10^{-5}\, g/s-m^2 \times 15\times10^3\, m}{(15\times10^3\, m)^2 \times 3600 s/hr \times 2hr}\left[1-\exp\left(\frac{-1.0 m/s \times 7200 s}{15\times10^3\, m}\right)\right]$$

$$= 3.2\times10^{-3}\ \ g/m^3$$

Indoor Box Model

- Similar to urban airshed, a box model can be used for indoor environments
- e.g. a basic mass balance for pollution in the building/ room, assuming well-mixed conditions:

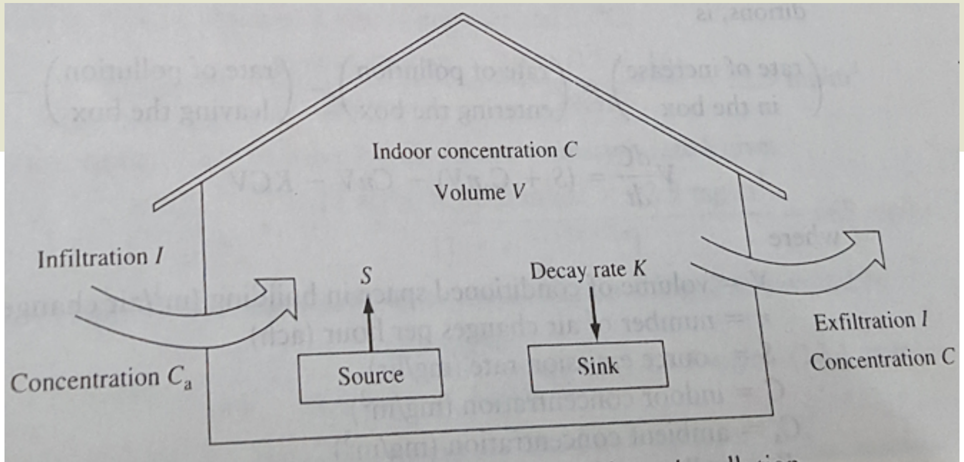


FIGURE 7.65 Box model for indoor air pollution.

$$\begin{pmatrix}\text{rate of increase}\\ \text{in the box}\end{pmatrix} = \begin{pmatrix}\text{rate of pollution}\\ \text{entering the box}\end{pmatrix} - \begin{pmatrix}\text{rate of pollution}\\ \text{leaving the box}\end{pmatrix} - \begin{pmatrix}\text{rate of decay}\\ \text{in the box}\end{pmatrix}$$

$$V\frac{dC}{dt} = (S + C_a nV) - CnV - KCV$$

where

V = volume of conditioned space in building (m^3/air change)
n = number of air changes per hour (ach)
S = source emission rate (mg/hr)
C = indoor concentration (mg/m^3)
C_a = ambient concentration (mg/m^3)
K = pollutant decay rate or reactivity (1/hr)

Indoor Box Model

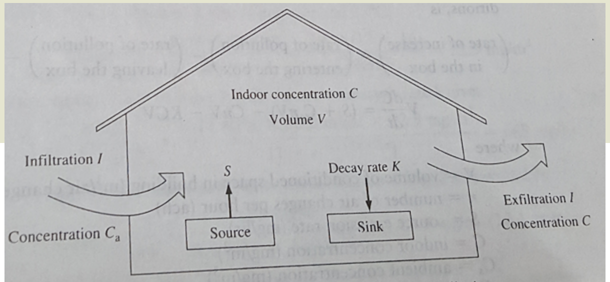


FIGURE 7.65 Box model for indoor air pollution.

- Steady-state indoor pollutant conc., by setting dC/dt = 0, will be:

$$C(\infty) = \frac{(S/V) + C_a n}{n + K}$$

- Time-dependant variation of indoor pollutant conc. can be obtained by:

$$C(t) = \left[\frac{(S/V) + C_a n}{n + K}\right]\left[1 - e^{-(n+K)t}\right] + C(0)e^{-(n+K)t}$$

- For pollutants such as CO and NO_2, which can be treated as conservative (K=0), also, if ambient conc. is negligible (C_a=0), and before a source is operated indoors (C(0)=0), then:

$$C(t) = \left(\frac{S}{nV}\right)(1 - e^{-nt})$$

Quiz time !!!