

Dispersion for point sources

CE 524

January 2010

Concentration

- Air pollution law in most industrial countries based on concentration of contaminants
 - NAAQS in US
- Need method to predict concentrations at any given location
 - Any given set of pollutant
 - Meteorological conditions
 - At any location
 - For any time period
- But even best currently available concentration models are far from ideal

Concentration

- Commonly express concentration as ppm or $\mu\text{g}/\text{m}^3$
- Parts per million (ppm) = 1 volume of
 - 1 ppm = $\frac{1 \text{ volume gaseous pollutant}}{10^6 \text{ volumes (pollutant + air)}}$
- $\mu\text{g}/\text{m}^3 = \text{micrograms/cubic meter}$

Factors that determine Dispersion

- Physical nature of effluents
- Chemical nature of effluents
- Meteorology
- Location of the stack
- Nature of terrain downwind from the stack

Stack Effluents

- Gas and particulate matter
- Particles $< 20 \mu\text{m}$ behave same as gas
 - Low settling velocity
- Particle $> 20 \mu\text{m}$ have significant settling velocity
- Only gases and Particles $< 20 \mu\text{m}$ are treated in dispersion models
- Others are treated as particulate matter
- Assumes effluents leave the stack with sufficient momentum and buoyancy
 - Hot gases continue to rise

Assumptions

- Effluents leave the stack with sufficient momentum and buoyancy
 - Hot gases continue to rise
- Plume is deflected along its axis in proportion to the average wind speed (u)

Gaussian or Normal Distribution

- Gaussian distribution model
- Dispersion in y and z directions uses a double gaussian distribution -- plumes
- Dispersion in (x, y, z) is three-dimensional
- Used to model instantaneous puff of emissions

Gaussian or Normal Distribution

- Pollution dispersion follows a distribution function
- Theoretical form: gaussian distribution function

Gaussian or Normal Distribution

$$f(x) = \frac{1}{\sigma(2\pi)^{1/2}} \exp\left[-\frac{(x-x_0)^2}{2\sigma^2}\right] \quad (4-3)$$

- x = mean of the distribution
- σ = standard deviation

Gaussian distribution used to model probabilities, in this context formula used to predict steady state concentration at a point down stream

Gaussian or Normal Distribution

What are some properties of the normal distribution?

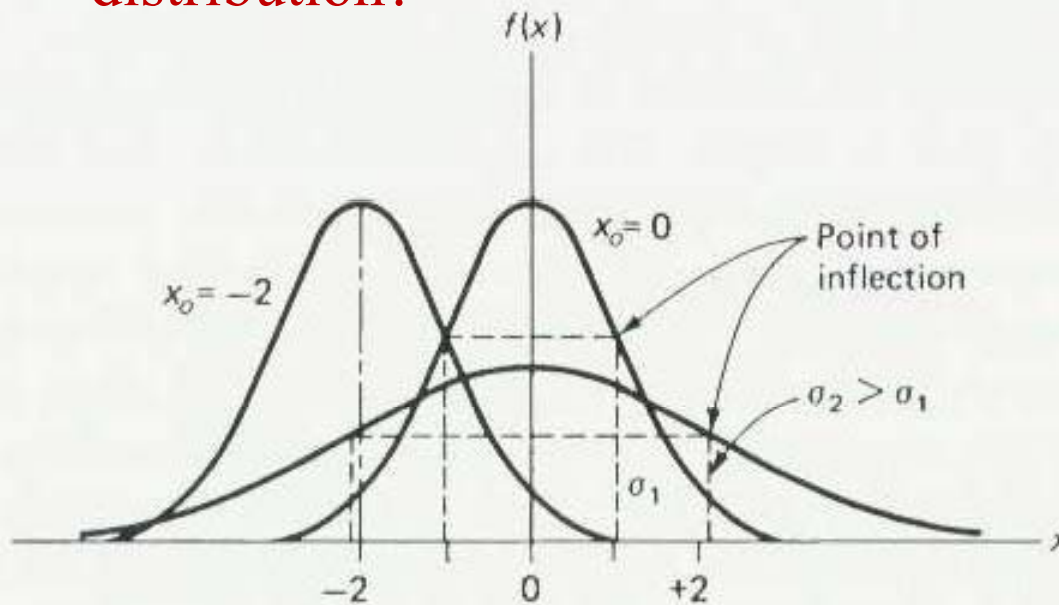


FIGURE 4-1 The Gaussian or normal distribution function for different values of x_0 and σ_0 .

$f(x)$ becomes concentration, maximum at center of plume

Gaussian or Normal distribution

- **68%** of the area fall within 1 standard deviation of the mean ($\mu \pm 1 \sigma$).
- **95%** of area fall within 1.96 standard deviation of the mean ($\mu \pm 1.96 \sigma$).
- **99.7%** of the area fall within 3 standard deviations of the mean ($\mu \pm 3 \sigma$)

Gaussian dispersion model

- Dispersion in y and z directions are modeled as Gaussian
- Becomes double Gaussian model
- Why doesn't it follow a Gaussian distribution in the x direction?
 - Direction of wind

Gaussian Dispersion Model

- For localized point sources – stacks
- General appearance
- Plume exits at height, h_s
- Rises an additional distance, Δh
 - buoyancy of hot gases
 - called plume rise
 - reaches distance where buoyancy and upward momentum cease
- Exit velocity, V_s
- Plume appears as a point source emitted at height $H = h_s + \Delta h$
- Emission rate Q (g/s)
- Assume wind blows in x direction at speed u
 - u is independent of time, elevation, or location (not really true)

Gaussian Dispersion Model

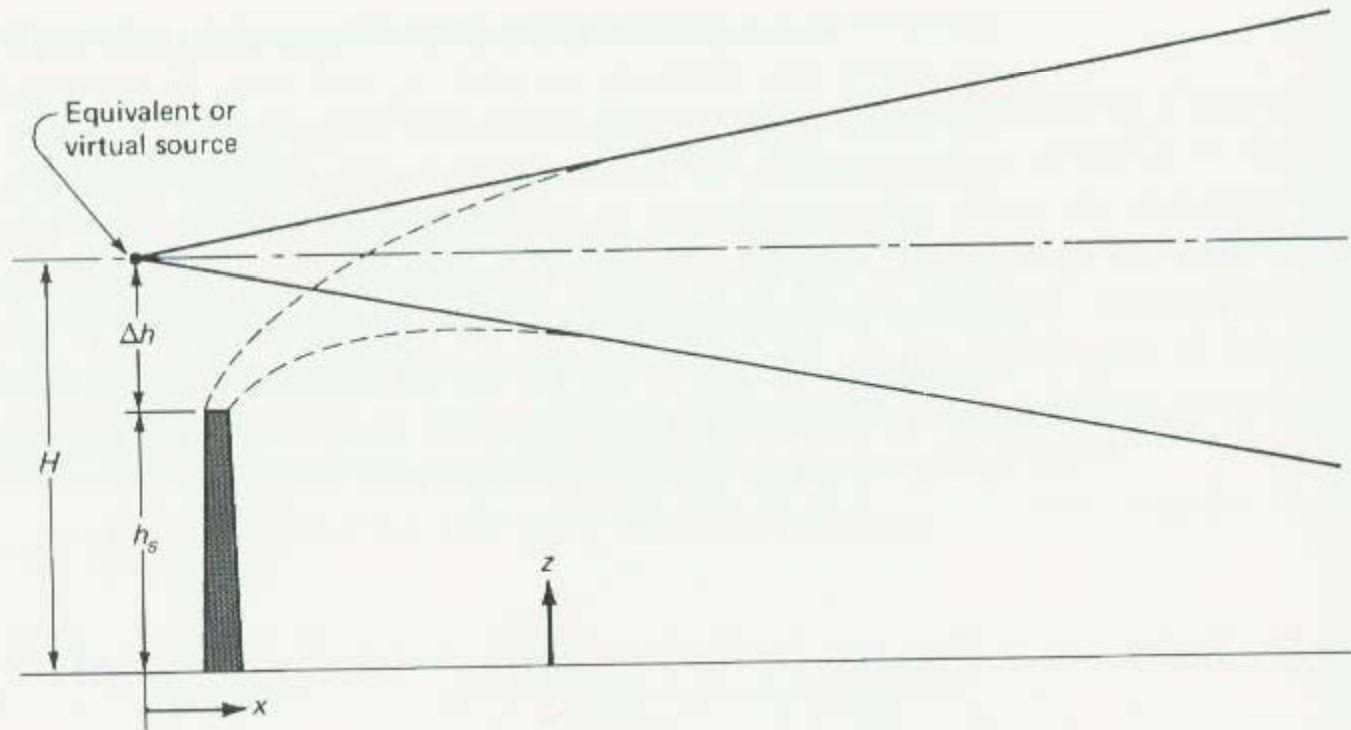


FIGURE 4-2 A dispersion model with virtual source at an effective stack height H .

Gaussian Dispersion Model

- Stack gas transported downstream
- Dispersion in vertical direction governed by atmospheric stability
- Dispersion in horizontal plane governed by molecular and eddy diffusion
- x-axis oriented to wind direction
- z-axis oriented vertically upwards
- y-direction oriented transverse to the wind
- Concentrations are symmetric about y-axis and z-axis

Gaussian Dispersion Model

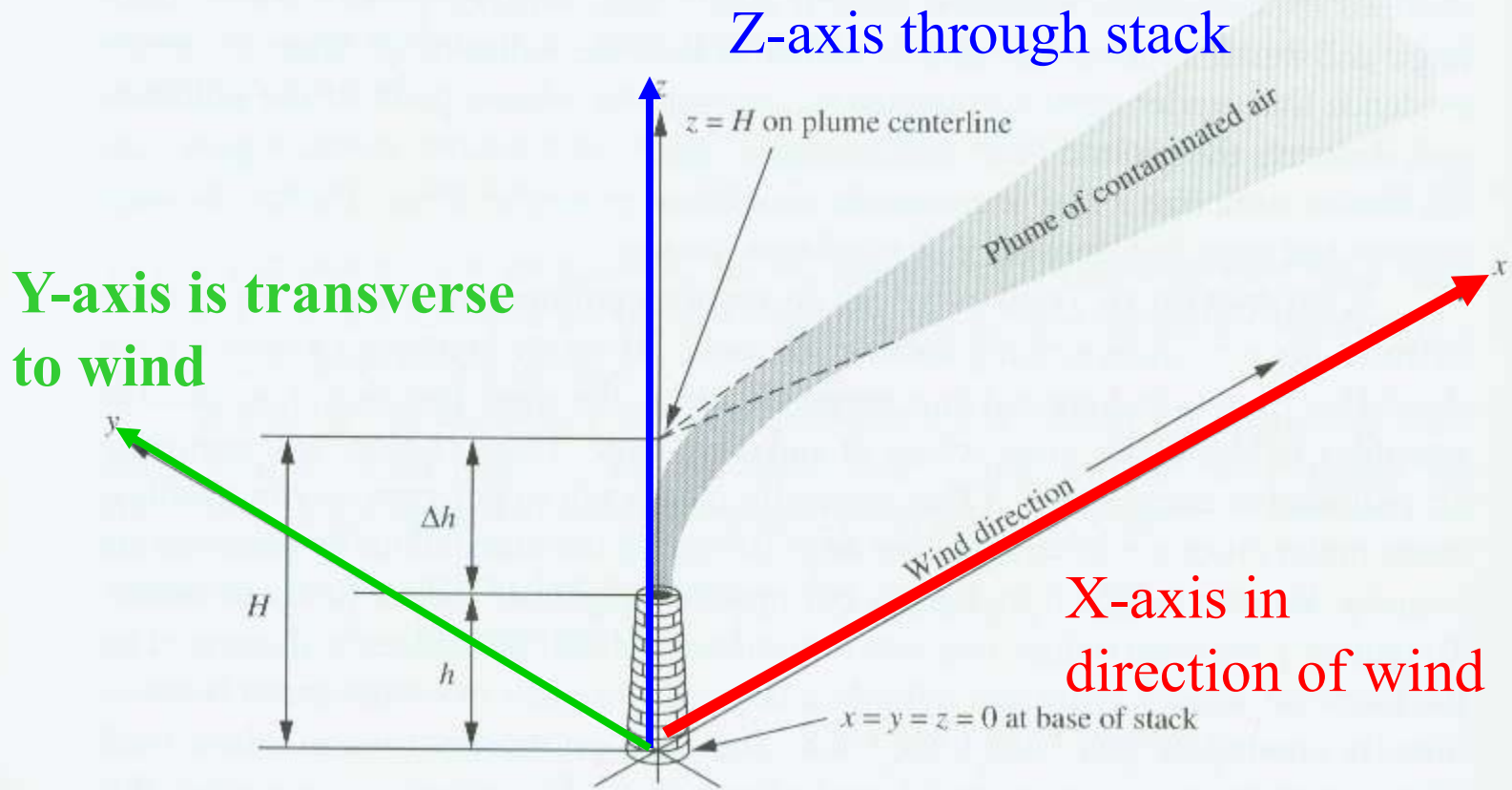
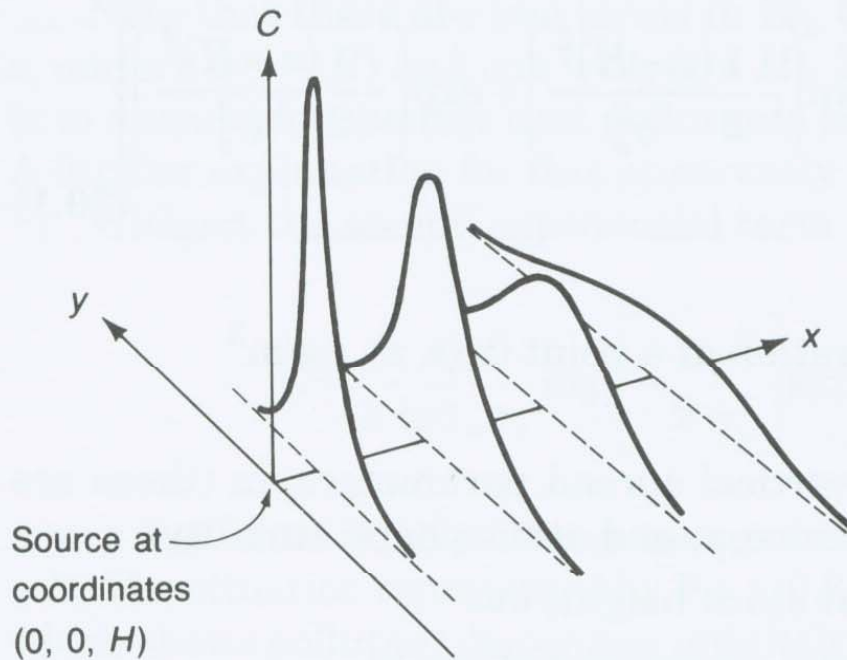


FIGURE 6.3

Coordinate system and nomenclature for the Gaussian plume idea.



As distance
increase so does
dispersion

Figure 20.3

Behavior of the downwind, elevated transverse concentration profiles as a function of distance downward.

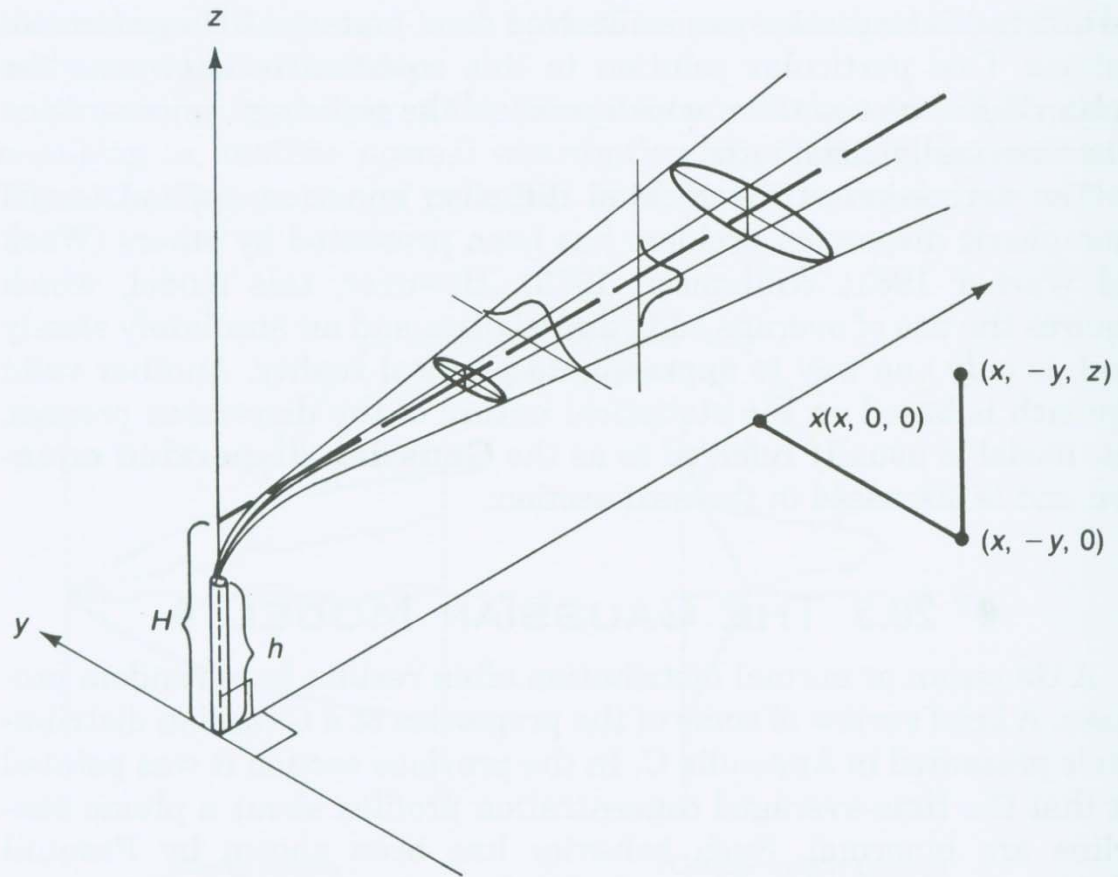


Figure 20.4

Coordinate system showing Gaussian distributions in the horizontal and vertical.

(Adapted from Turner, 1970.)

Point Source at Elevation H

- Assumes no interference or limitation to dispersion in any direction

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left[\frac{-(y - y_0)^2}{2\sigma_y^2}\right] \exp\left[\frac{-(z - z_0)^2}{2\sigma_z^2}\right] \quad (4-6)$$

x_0 and z_0 are location of centerline of plume

y_0 taken as base of the stack

z_0 is H

Q = emission strength of source (mass/time) – g/s

u = average wind speed thru the plume – m/s

C = concentration – g/m³ (**Notice this is not ppm**)

σ_y and σ_z are horizontal and vertical standard deviations in meters

Wind Velocity Profile

- Wind speed varies by height
- International standard height for wind-speed measurements is 10 m
- Dispersion of pollutant is a function of wind speed at the height where pollution is emitted
- But difficult to develop relationship between height and wind speed

Point Source at Elevation H without Reflection

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left[-\frac{(y - y_0)^2}{2\sigma_y^2}\right] \exp\left[-\frac{(z - z_0)^2}{2\sigma_z^2}\right] \quad (4-6)$$

- 3 terms
 - gives concentration on the centerline of the plume
 - gives concentration as you move in the sideways direction ($\pm y$ direction), direction doesn't matter because $(\pm y)^2$ gives a positive value
 - gives concentration as you move in the vertical direction ($\pm z$ direction), direction doesn't matter because $(\pm (z - H))^2$ gives a positive value
- Concentrations are symmetric about y-axis and z-axis
- Same concentration at $(z-H) = 10$ m as $(z-H) = -10$ m
- Close to ground symmetry is disturbed

Point Source at elevation H without reflection

- Equation 4-6 reduces to

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\left[\frac{y^2}{\sigma_y^2} + \frac{(z-H)^2}{\sigma_z^2}\right]\right) \quad (4-8)$$

Note in the book there are 2 equation 4-8s
(2 different equations just labeled wrong)

This is the first one

Gaussian Plume Example

- A factory emits 20 g/s of SO₂ at height H (includes plume rise)
- Wind speed = 3 m/s (u)
- At a distance of 1 km downstream, σ_y and σ_z are 30 m and 20 m (given, otherwise we would have to look up)
- What are the SO₂ concentrations at the centerline of the plume and at a point 60 meters to the side and 20 meters below the centerline

Gaussian Plume Example

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\left[\frac{y^2}{\sigma_y^2} + \frac{(z-H)^2}{\sigma_z^2}\right]\right) \quad (4-8)$$

$$Z - H = 0$$

- $Q = 20$ g/s of SO_2
- $u = 3$ m/s (u)
- σ_y and σ_z are 30 m and 20 m
- $y = 0$ and $z = H$
- So reduces to:

So second half of equation goes to 0

$$C(x,0,0) = \frac{20 \text{ g/s}}{2(\pi * 3 * 30 * 20)} = \underline{\underline{0.00177 \text{ g/m}^3}} = \underline{\underline{1770 \mu \text{ g/m}^3}}$$

At centerline y and Z are 0

Gaussian Plume Example

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\left[\frac{y^2}{\sigma_y^2} + \frac{(z-H)^2}{\sigma_z^2}\right]\right) \quad (4-8)$$

$$c = \frac{Q}{2\pi u \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left[\frac{(-y)^2}{\sigma_y^2} + \frac{(z-H)^2}{\sigma_z^2}\right]\right]$$

$$= \frac{20 \text{ g/s}}{2\pi \cdot 3 \cdot (30)(20)} \exp\left[-\frac{1}{2}\left[\frac{(-60\text{m})^2}{(30\text{m})^2} + \frac{(-20\text{m})^2}{(20\text{m})^2}\right]\right] =$$

$$(0.00177 \text{ g/m}^3) * (\exp^{-2.5}) = \underline{\underline{0.000145 \text{ g/m}^3 \text{ or } 145.23 \mu \text{ g/m}^3}}$$

At 20 and 60 meters

Evaluation of Standard Deviation

- Horizontal and vertical dispersion coefficients -- σ_y σ_z are a function
 - downwind position x
 - Atmospheric stability conditions
- many experimental measurements –charts have been created
 - Correlated σ_y and σ_z to atmospheric stability and x

Pasquill-Gifford Curves

- Concentrations correspond to sampling times of approx. 10 minutes
- Regulatory models assume that the concentrations predicted represent 1-hour averages
- Solid curves represent rural values
- Dashed lines represent urban values
- Estimated concentrations represent only the lowest several hundred meters of the atmosphere

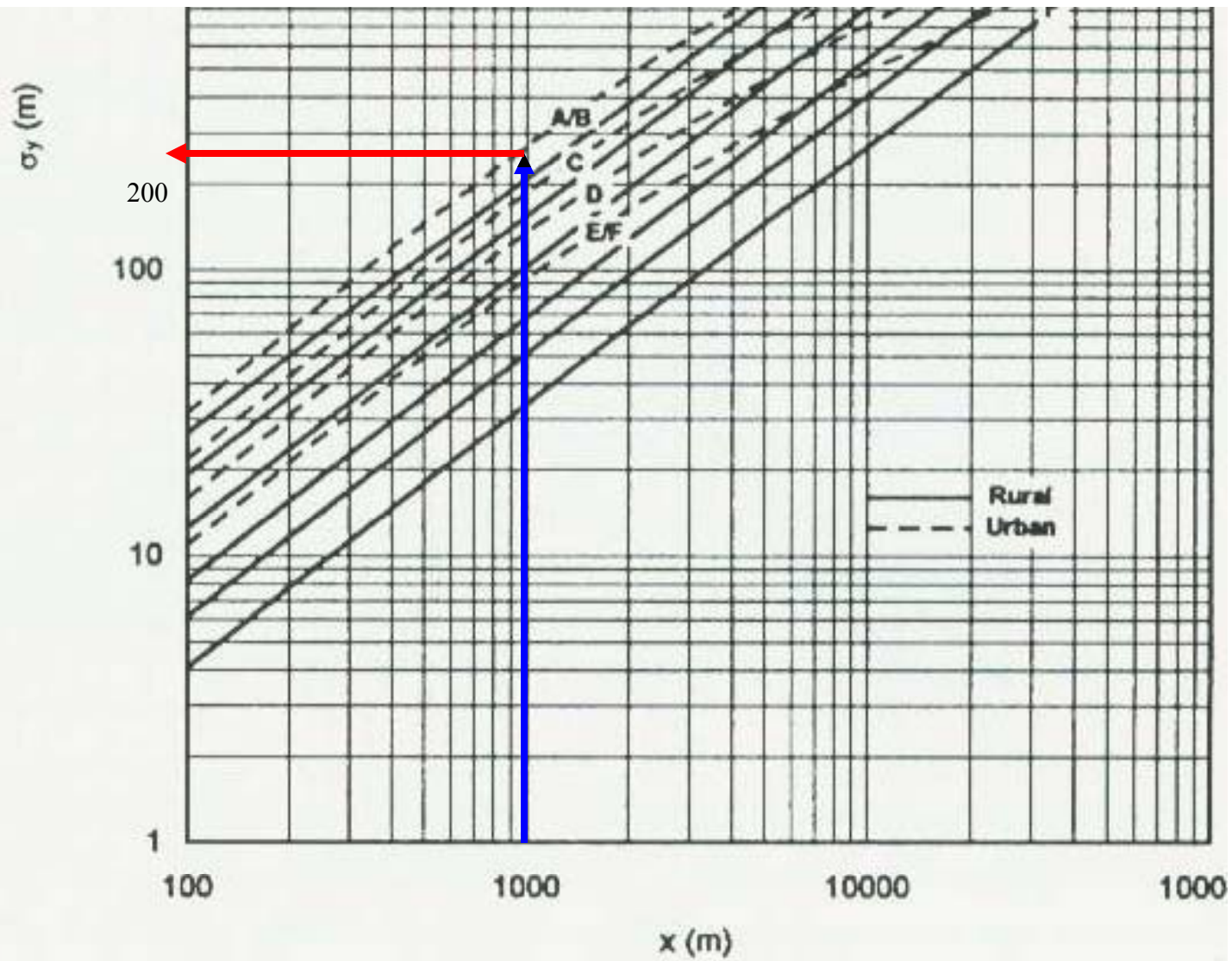
Pasquill-Gifford Curves

- σ_z less certain than σ_y
 - Especially for $x > 1$ km
- For neutral to moderately unstable atmospheric conditions and distances out to a few kilometers, concentrations should be within a factor of 2 or 3 of actual values
- Tables 3-1: Key to stability classes

Example

For stability class A, what are the values of σ_y and σ_z at 1 km downstream (assume urban)

From Tables 4-6 and 4-7



$\sigma_y \sim 220$ m

FIGURE 4-6 Rural and urban horizontal dispersion coefficients (σ_y) as a function of stability category. (Graph prepared by S.M. Claggett [20].)

$\sigma_z \sim 310 \text{ m}$

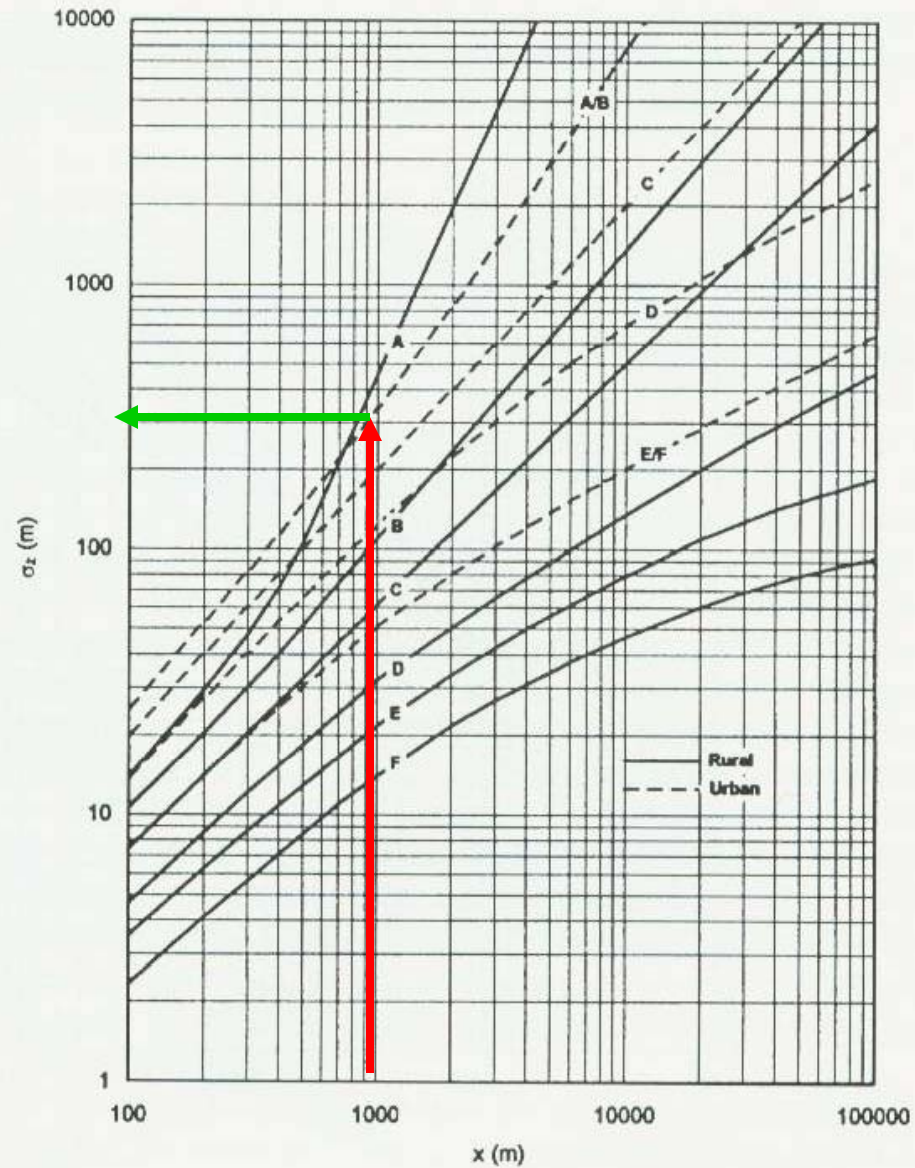


FIGURE 4-7 Rural and urban vertical dispersion coefficients (σ_z) as a function of stability category. (Graph prepared by S.M. Claggett [20].)

Example

For stability class A, what are the values of σ_y and σ_z at 1 km downstream

From Tables 4-6 and 4-7

$$\sigma_y = 220 \text{ m}$$

$$\sigma_z = 310 \text{ m}$$

Empirical Equations

- Often difficult to read charts
- Curves fit to empirical equations

$$\sigma_y = cx^d$$

$$\sigma_z = ax^b$$

Where

x = downwind distance (kilometers)

a, b, c, d = coefficients from Tables 4-1 and 4-2

Example: what are values of σ_y and σ_z at 1 km downstream for stability class A using equations rather than charts?

$$\sigma_y = cx^d$$

$$\sigma_z = ax^b$$

Using table 4-1 for stability class A

$$c = 24.1670$$

$$d = 2.5334$$

TABLE 4-1 Parameters Used to Calculate Pasquill-Gifford σ_y

<i>Pasquill Stability Category</i>	<i>c</i>	<i>d</i>
A	24.1670	2.5334
B	18.3330	1.8096
C	12.5000	1.0857
D	8.3330	0.72382
E	6.2500	0.54287
F	4.1667	0.36191

Example: what are values of σ_y and σ_z at 1 km downstream for stability class A using equations rather than charts?

$$\sigma_y = cx^d$$

$$\sigma_z = ax^b$$

Using table 4-2 where $x = 1$ km

$$a = 453.850$$

$$b = 2.11660$$

TABLE 4-2 Parameters Used to Calculate Pasquill-Gifford σ_z

Pasquill Stability Category	x (km)	a	b
A*	<.10	122.800	0.94470
	0.10 – 0.15	158.080	1.05420
	0.16 – 0.20	170.220	1.09320
	0.21 – 0.25	179.520	1.12620
	0.26 – 0.30	217.410	1.26440
	0.31 – 0.40	258.890	1.40940
	0.41 – 0.50	346.750	1.72830
	0.51 – 3.11	453.850	2.11660
	>3.11	**	**

Example: what are values of σ_y and σ_z at 1 km downstream for stability class A using equations rather than charts?

$$\sigma_y = cx^d$$

$$\sigma_z = ax^b$$

$$c = 24.1670$$

$$a = 453.850$$

$$d = 2.5334$$

$$b = 2.11660$$

Solution

$$\sigma_y = cx^d = 24.1670(1 \text{ km})^{2.5334} = \underline{24.17 \text{ m}}$$

$$\sigma_z = ax^b = 453.85(1 \text{ km})^{2.11660} = \underline{453.9 \text{ m}}$$

Point Source at Elevation H with Reflection

- Previous equation for concentration of plumes a considerable distance above ground
- Ground damps out vertical dispersion
- Pollutants “reflect” back up from ground

Point Source at Elevation H with Reflection

- Accounts for reflection of gaseous pollutants back into the atmosphere
- Reflection at some distance x is mathematically equivalent to having a mirror image of the source at $-H$
- Concentration is equal to contribution of both plumes at **ground level**

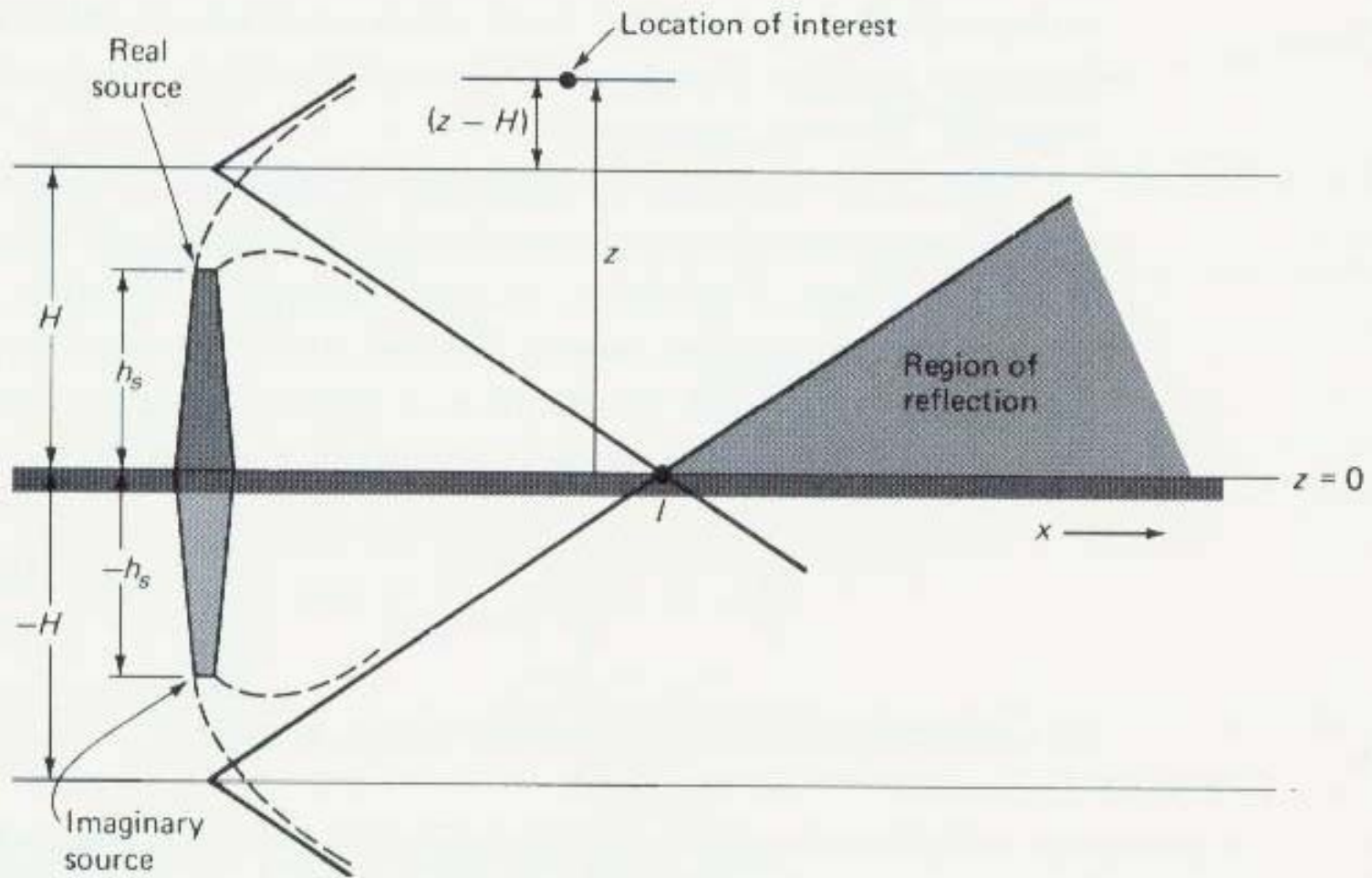


FIGURE 4-3 Use of an imaginary source to describe mathematically gaseous reflection at the surface of the earth.

Point Source at Elevation H with Reflection

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \left[\exp - \left(\frac{y^2}{2\sigma_y^2} \right) \right] \left\{ \exp \left[\frac{-(z-H)^2}{2\sigma_z^2} \right] + \exp \left[\frac{-(z+H)^2}{2\sigma_z^2} \right] \right\} \quad (4-8)$$

Notice this is also equation 4-8 in text,
it is the second equation 4-8 on the
bottom of page 149

Example: Point Source at Elevation H with Reflection

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \left[\exp - \left(\frac{y^2}{2\sigma_y^2} \right) \right] \left\{ \exp \left[\frac{-(z-H)^2}{2\sigma_z^2} \right] + \exp \left[\frac{-(z+H)^2}{2\sigma_z^2} \right] \right\} \quad (4-8)$$

Nitrogen dioxide is emitted at 110 g/s from stack with $H = 80$ m

Wind speed = 5 m/s

Plume rise is 20 m

Calculate ground level concentration 100 meter from centerline of plume (y)

Assume stability class D so $\sigma_y = 126$ m and $\sigma_z = 51$ m

Example: Point Source at Elevation H with Reflection

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \left[\exp - \left(\frac{y^2}{2\sigma_y^2} \right) \right] \left\{ \exp \left[\frac{-(z-H)^2}{2\sigma_z^2} \right] + \exp \left[\frac{-(z+H)^2}{2\sigma_z^2} \right] \right\} \quad (4-8)$$

$$Q = 110 \text{ g/s} \quad H = 80 \text{ m} \quad u = 5 \text{ m/s} \quad \Delta h = 20 \text{ m} \quad y = 100 \text{ m}$$

$$\sigma_y = 126 \text{ m} \text{ and } \sigma_z = 51 \text{ m}$$

$$\text{Effective stack height} = 80 \text{ m} + 20 \text{ m} = 100 \text{ m}$$

$$\sigma_y = 126 \text{ m} \text{ and } \sigma_z = 51 \text{ m}$$

$$\text{Solving in pieces } \frac{100 \text{ g/s}}{2\pi * 5 * 126 * 51} = 0.000496$$

$$2\pi * 5 * 126 * 51$$

Example: Point Source at Elevation H with Reflection

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \left[\exp - \left(\frac{y^2}{2\sigma_y^2} \right) \right] \left\{ \exp \left[\frac{-(z-H)^2}{2\sigma_z^2} \right] + \exp \left[\frac{-(z+H)^2}{2\sigma_z^2} \right] \right\} \quad (4-8)$$

$$Q = 110 \text{ g/s} \quad H = 80 \text{ m} \quad u = 5 \text{ m/s} \quad \Delta h = 20 \text{ m} \quad y = 100 \text{ m}$$

$$\sigma_y = 126 \text{ m} \text{ and } \sigma_z = 51 \text{ m}$$

$$\text{Solving in pieces } \exp - \left[\frac{100^2}{2 * 126^2} \right] = 0.726149$$

$$\text{Solving in pieces } \exp - \left[\frac{(0-100\text{m})^2}{2 * 51^2} \right] = 0.146265$$

Example: Point Source at Elevation H with Reflection

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \left[\exp - \left(\frac{y^2}{2\sigma_y^2} \right) \right] \left\{ \exp \left[\frac{-(z-H)^2}{2\sigma_z^2} \right] + \exp \left[\frac{-(z+H)^2}{2\sigma_z^2} \right] \right\} \quad (4-8)$$

$$Q = 110 \text{ g/s} \quad H = 80 \text{ m} \quad u = 5 \text{ m/s} \quad \Delta h = 20 \text{ m} \quad y = 100 \text{ m}$$

$$\sigma_y = 126 \text{ m} \text{ and } \sigma_z = 51 \text{ m}$$

Solving in pieces both sides of z portion are same so add

$$c = 0.000496 * 0.726149 * (2 * 0.14625) = \underline{0.000116 \text{ g/m}^3} \text{ or } \underline{116.4 \text{ } \mu\text{g/m}^3}$$

Ground Level Concentration with reflection

- Often want ground level
 - People, property exposed to pollutants
- Previous eq. gives misleadingly low results near ground
- Pollutants “reflect” back up from ground

Ground Level Concentration

- Equation for ground level concentration
- $Z = 0$

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \left[\exp - \left(\frac{y^2}{2\sigma_y^2} \right) \right] \left\{ \exp \left[\frac{-(z-H)^2}{2\sigma_z^2} \right] + \exp \left[\frac{-(z+H)^2}{2\sigma_z^2} \right] \right\} \quad (4-8)$$

1 + 1 cancels 2

Reduces to at ground level

$$C(x, y, 0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp \left(\frac{-H^2}{2\sigma_z^2} \right) \exp \left(\frac{-y^2}{2\sigma_y^2} \right) \quad (4-9)$$

Ground Level Example

C- stability class

H = 50 m

Q = 95 g/s

Wind speed is 3 m/s

What is ground level concentration at 0.5 km downwind,
along the centerline?

From Figure 4-6, $\sigma_y = 90$ m,

From Figure 4-7, $\sigma_z = 32$ m

$$C = \frac{95 \times 10^6 \mu\text{g/s}}{\pi (3 \text{ m/s})(90 \text{ m})(32 \text{ m})} * \frac{\exp[-(50^2)] \exp [0]}{[2(32)^2]} = \underline{1023.3 \mu\text{g/m}^3}$$

Maximum Ground Level Concentration

- Effect of ground reflection increases ground concentration
- Does not continue indefinitely
- Eventually diffusion in y-direction (crosswind) and z-direction decreases concentration

Maximum Ground Level Concentration

$$\left(\frac{Cu}{Q}\right)_{\max} = \exp[a + b(\ln H) + c(\ln H)^2 + d(\ln H)^3] \quad (4-15)$$

Values for a, b, c, d are in Table 4-5

Alternative to Eq. 4-15

- For moderately unstable to neutral conditions

$$\sigma_z = 0.707H$$

$$C_{\text{max, reflection}} = \frac{0.1171Q}{u \sigma_y \sigma_z}$$

Max. Concentration Example

What is maximum ground level concentration and where is it located downstream for the following?

- Wind speed = 2 m/s
- H = 71 m
- Stability Class B
- Q = 2,500,000 $\mu\text{g/s}$

Solution:

$$\sigma_z = 0.707H = 0.707(71\text{m}) = 50.2 \text{ m}$$

From Figure 4-7, this occurs at **x = 500 m**

$$\sigma_z = 50.2 \text{ m}$$

From Figure 4-7, this occurs at $x = 500 \text{ m}$

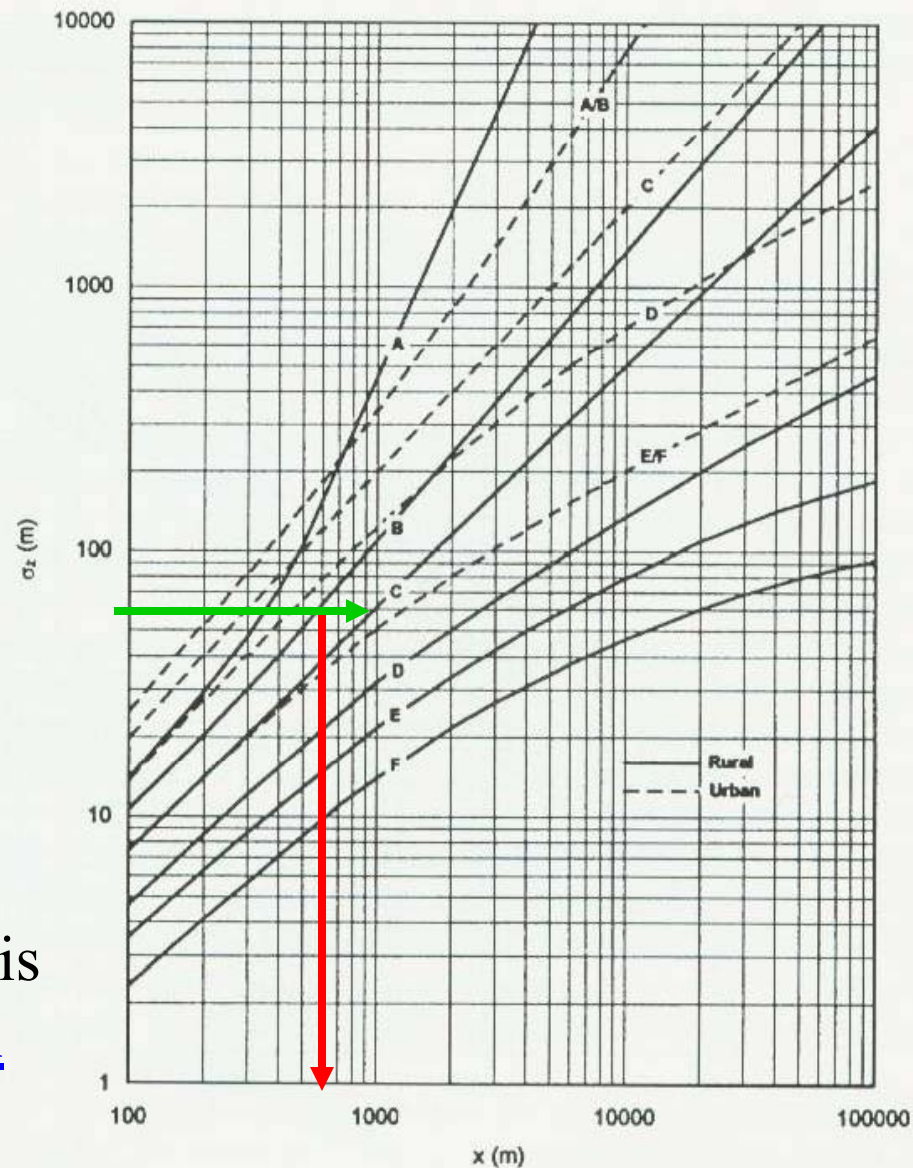


FIGURE 4-7 Rural and urban vertical dispersion coefficients (σ_z) as a function of stability category. (Graph prepared by S.M. Claggett [20].)

At 500 m, $\sigma_y = 120$ m

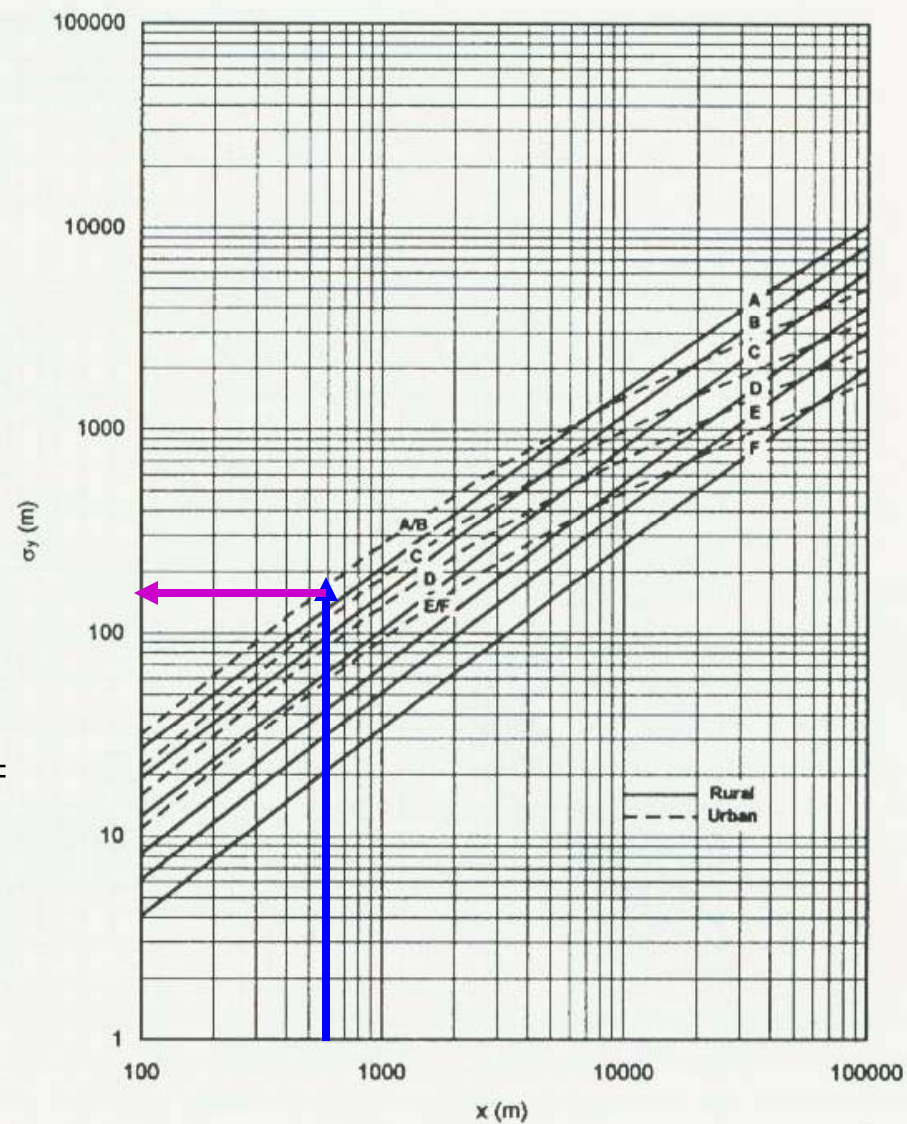


FIGURE 4-6 Rural and urban horizontal dispersion coefficients (σ_y) as a function of stability category. (Graph prepared by S.M. Claggett [20].)

Max. Concentration Example

What is maximum ground level concentration and where is it located downstream for the following?

- Wind speed = 2 m/s
- H = 71 m
- Stability Class B
- Q = 2,500,000 $\mu\text{g/s}$

Solution:

$$\sigma_z = 0.707H = 0.707(71\text{m}) = 50.2 \text{ m}$$

From Figure 4-7, this occurs at **x = 500 m**

From Figure 4-6, $\sigma_y = 120 \text{ m}$

$$C_{\text{max, reflection}} = \frac{0.1171Q}{u \sigma_y \sigma_z} = \frac{0.1171(2500000)}{(2)(120)(50.2)} = \underline{\underline{24.3 \mu\text{g/m}^3}}$$

Calculation of Effective Stack Height

- $H = h_s + \Delta h$
- Δh depends on:
 - Stack characteristics
 - Meteorological conditions
 - Physical and chemical nature of effluent
- Various equations based on different characteristics, pages 162 to 166

Carson and Moses

$$\Delta h = -0.029 \frac{V_s d_s}{u_s} + 2.62 \left(\frac{(Q_h)^{1/2}}{u_s} \right) \quad (4-18)$$

Where:

Δh = plume rise (meters)

V_s = stack gas exit velocity (m/s)

d_s = stack exit diameter (meters)

u_s = wind speed at stack exit (m/s)

Q_h = heat emission rate in kilojoules per second

Other basic equations

- Holland
- concawe

Example:

From text

Heat emission rate = 4800 kJ/s

Wind speed = 5 mph

Stack gas velocity = 15 m/s

Stack diameter at top is 2 m

Estimate plume rise

$$\Delta h = -0.029 \left[\frac{15(2)}{5} \right] + 2.62 \left[\frac{(4800)^{1/2}}{5} \right] = -0.1 + 36.3$$

= 36.2 m (Carson and Moses)

Concentration Estimates for Different Sampling Times

- Concentrations calculated in previous examples based on averages over 10-minute intervals
- Current regulatory applications use this as 1-hour average concentration
- For other time periods adjust by:
 - 3-hr multiply 1-hr value by 0.9
 - 8-hr multiply 1-hr value by 0.7
 - 24-hr multiply 1-hr value by 0.4
 - annual multiply 1-hr value by 0.03 – 0.08

Concentration Estimates for Different Sampling Times—Example

- For other time periods adjust by:
 - 3-hr multiply 1-hr value by 0.9
 - 8-hr multiply 1-hr value by 0.7
 - 24-hr multiply 1-hr value by 0.4
 - annual multiply 1-hr value by 0.03 – 0.08

Conversion of 1-hr concentration of previous example to an 8-hour average =

$$c_{8\text{-hour}} = 36.4 \mu\text{g}/\text{m}^3 \times 0.7 = 25.5 \mu\text{g}/\text{m}^3$$

Line Sources

- Imagine that a line source, such as a highway, consists of an infinite number of point sources
- The roadway can be broken into finite elements, each representing a point source, and contributions from each element are summed to predict net concentration

Line Sources

- When wind direction is normal to line of emission
- Ground level concentration downwind

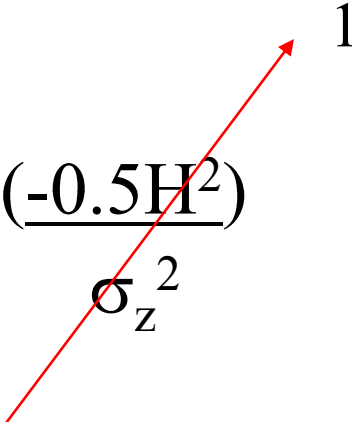
$$C(x,0) = \frac{2q}{(2\Pi)^{0.5} \sigma_z u} \exp\left(\frac{-0.5H^2}{\sigma_z^2}\right)$$

q = source strength per unit distance (g/s * m)

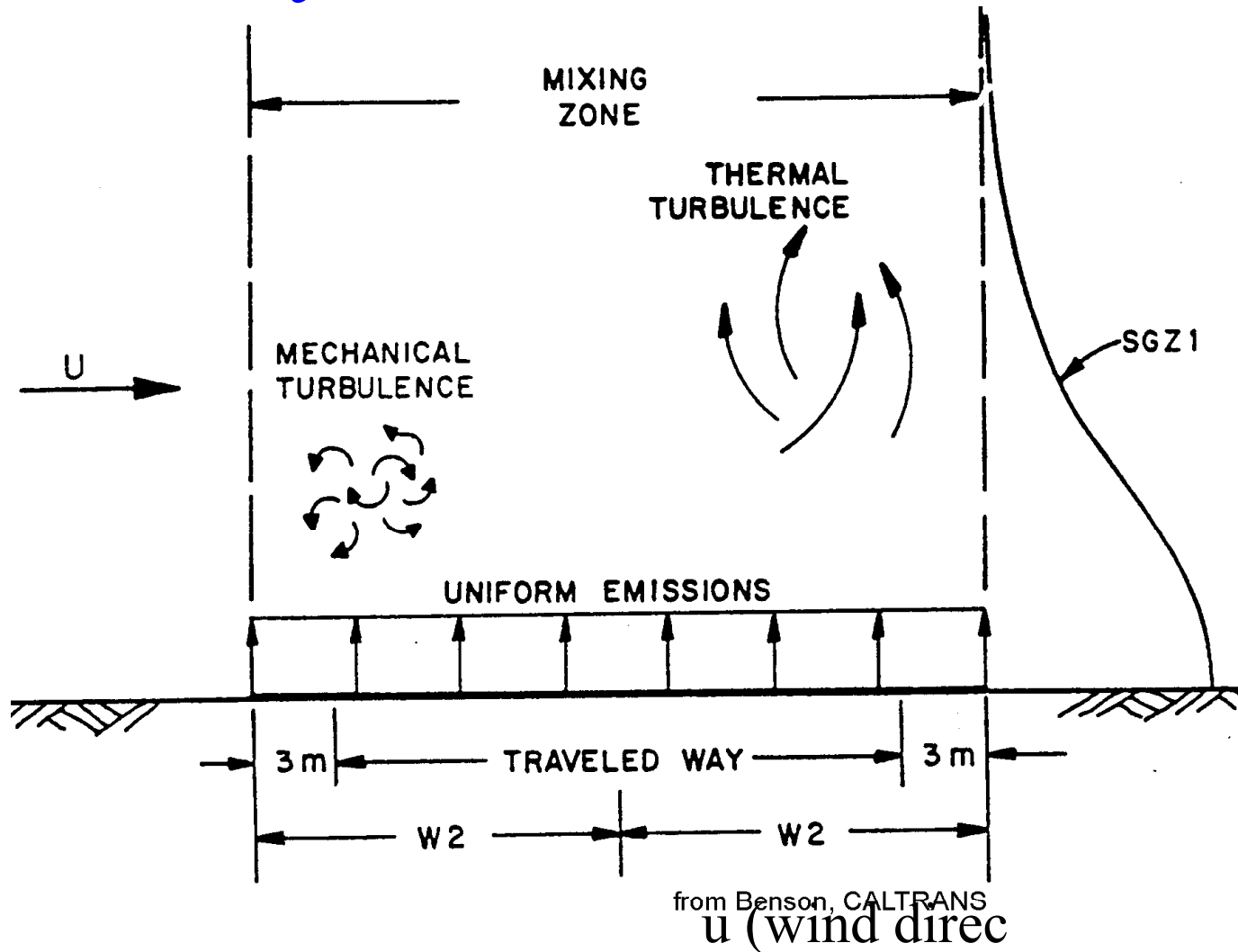
Concentration should be uniform in the y -direction at a given x

Line Sources

- For ground level ($H = 0$), could also use breathing height

$$C(x,0) = \frac{2q}{(2\Pi)^{0.5} \sigma_z u} \exp\left(\frac{-0.5H^2}{\sigma_z^2}\right)$$


Roadway Emissions and Mixing



From Guensler, 2000

Instantaneous Release of a Puff

- Pollutant released quickly
- Explosion
- Accidental spill
- Release time \ll transport time
- Also based on Gaussian distribution function

$$C = \frac{Q_p}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\left(\frac{y-y_o}{\sigma_y}\right)^2\right) \exp\left(-\frac{1}{2}\left(\frac{x-x_o}{\sigma_x}\right)^2\right) \left[\exp\left(-\frac{1}{2}\left(\frac{z-z_o}{\sigma_z}\right)^2\right) + \exp\left(-\frac{1}{2}\left(\frac{z+z_o}{\sigma_z}\right)^2\right) \right] \quad (4-39)$$

Instantaneous Release of a Puff

- Equation 4-41 to predict maximum ground level concentration

$$C_{\max} = \frac{2Qp}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z}$$

Receptor downwind would see a gradual increase in concentration until center of puff passed and then concentration would decrease

Assume $\sigma_x = \sigma_y$

Figure 4-9 and Table 4-7

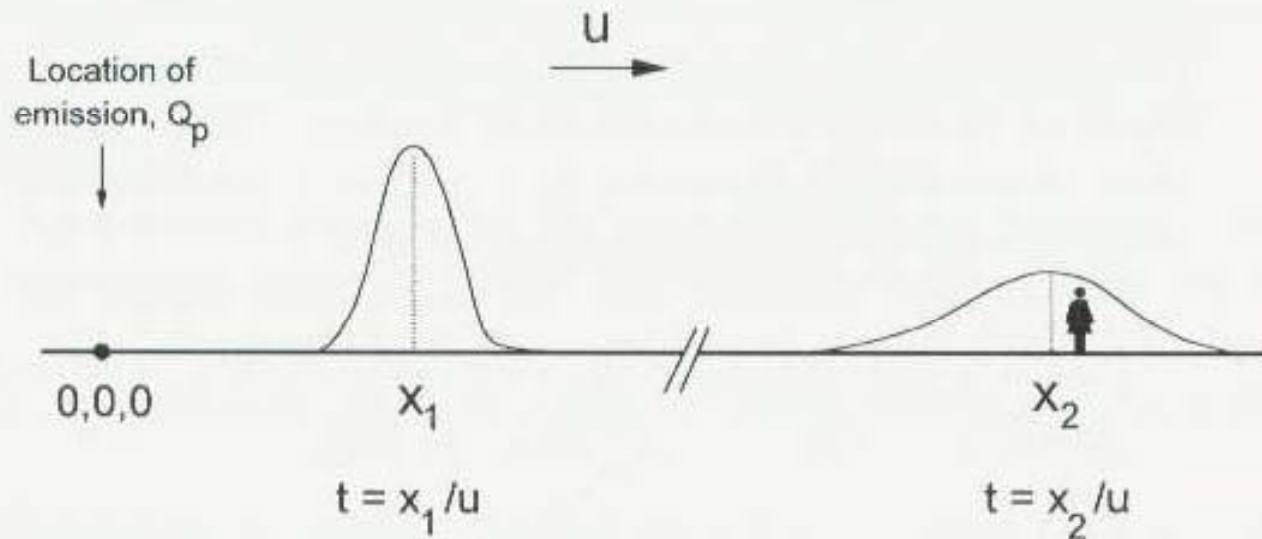


FIGURE 4-9 An instantaneous puff traveling downwind at windspeed, u .

Figure 4-9 and Table 4-7

TABLE 4.7 Instantaneous Values for σ_y and σ_z in meters [11]

Parameter	Stability Condition	Equation*
σ_y	Unstable	$\sigma_y = 0.14 (x)^{0.92}$
	Neutral	$\sigma_y = 0.06 (x)^{0.92}$
	Very Stable	$\sigma_y = 0.02 (x)^{0.89}$
σ_z	Unstable	$\sigma_z = 0.53 (x)^{0.73}$
	Neutral	$\sigma_z = 0.15 (x)^{0.70}$
	Very Stable	$\sigma_z = 0.05 (x)^{0.61}$

*x is the distance downwind in meters.

Puff Example

A tanker spill on the freeway releases 400,000 grams of chlorine. What exposure will vehicles directly behind the tanker (downwind) receive if $x = 100$ m? Assume very stable conditions.

From Table 4-7,

Figure 4-9 and Table 4-7

TABLE 4.7 Instantaneous Values for σ_y and σ_z in meters [11]

Parameter	Stability Condition	Equation*
σ_y	Unstable	$\sigma_y = 0.14 (x)^{0.92}$
	Neutral	$\sigma_y = 0.06 (x)^{0.92}$
	Very Stable	$\sigma_y = 0.02 (x)^{0.89}$
σ_z	Unstable	$\sigma_z = 0.53 (x)^{0.73}$
	Neutral	$\sigma_z = 0.15 (x)^{0.70}$
	Very Stable	$\sigma_z = 0.05 (x)^{0.61}$

*x is the distance downwind in meters.

Puff Example

A tanker spill on the freeway releases 400,000 grams of chlorine. What exposure will vehicles directly behind the tanker (downwind) receive if $x = 100$ m? Assume very stable conditions.

$$\text{From Table 4-7, } \sigma_y = 0.02(100\text{m})^{0.89} = 1.21$$

$$\text{From Table 4-7, } \sigma_z = 0.05(100\text{m})^{0.61} = 0.83$$

$$\sigma_x = \sigma_y = 1.21$$

Puff Example

A tanker spill on the freeway releases 400,000 grams of chlorine. What exposure will vehicles directly behind the tanker (downwind) receive if $x = 100$ m? Assume very stable conditions.

From Table 4-7, $\sigma_y = 0.02(100\text{m})^{0.89} = 1.21$

From Table 4-7, $\sigma_z = 0.05(100\text{m})^{0.61} = 0.83$

$$C_{\max} = \frac{2Q_p}{(2\pi)^{3/2} \sigma_x \sigma_y \sigma_z} = \frac{2(400000 \text{ g})}{(2\pi)^{3/2}(1.21)(1.21)(0.83)} = \underline{\underline{42,181 \text{ g/m}^3}}$$