DISPERSION PROBLEMS

When accidents or accidental emissions occur, particularly when accompanied by fires and/or explosions, toxic/hazardous chemicals can be discharged to the environment. These releases are of increasing concern to society as the reported catastrophic incidents continue to rise. In addition, adverse publicity has further led to greater concern on the potential consequences of these chemical releases to the environment. This concern has sparked interest in the development and application of emergency response dispersion models and dispersion models in general. There is therefore a need to reliably predict dispersion in the environment and to more fully and accurately evaluate the impact from these accidental releases of chemicals. Since today's main concerns are with discharges into the air, the primary thrust of the ten problems in this section is with atmospheric, rather than water and/or soil dispersion. Although the problems concentrate on dispersion in the atmosphere from accidental discharges, much of the material can also be used in planning the location, i.e., siting of a future source of pollutants, such as, a hazardous or municipal waste incinerator.

DISPERSION 1

Emission Rates (Empirical)

Introduction

When a liquid chemical is spilled on land, the evaporation rate needs to be computed in order to estimate the source term for input to a dispersion model. A number of evaporation models have been developed that have different levels of complexity that range from nomograms to iterative solutions on mainframe computers. Many of the emergency response models undertake a number of modelling techniques to refine the evaporation estimates by including formulations to calculate the initial liquid flow rates from containers (e.g., Bernoulli equations) as well as pool evaporation. One of the simpler models is the Illinois Environmental Protection Agency (ILEPA) emergency response model. The model is basically designed to provide rapid and easy estimates for evacuation zones in case of an accident. The basic evaporation rate for each of approximately 500 chemicals was pre-computed using the following formula:

$$E = 0.0012\ c\ P_v/(760 - d\ P_v)$$

where: E = source flux, g/cm^2-sec
c = molecular weight/28.9
$d = 1 - c$
P_v = vapor pressure at 20 °C, mmHg.

The equation estimates the relative degree of volatility of the chemicals. Together with an Excursion Threshold Limit Value (ETLV) which represents a safe level for acute human exposure during chemical emergencies, the volatility is used to place each chemical in the categories of highly volatile and at least moderately toxic, or moderately volatile and severely toxic. This consideration of chemical properties and health effects serves as the primary basis for listing the chemical in the ILEPA's Hazardous Materials Response Guide.

Problem Statement and Data

A reflux line on a distillation column at a refinery is damaged by a severe tornado. The pipe line failure results in a leak that leaves 23,000 lbs of a volatile petroleum fraction on the ground. The ground may be considered a sandy soil. Estimate:

a. Spill area affected,
b. The hydrocarbon emission rate from the ground, and
c. The time for total evaporation.

The specific gravity, average molecular weight and approximate vapor pressure at ambient conditions for the hydrocarbon are 0.91, 154, and 375 mmHg, respectively.

Solution

1. First, calculate the volume, V, of the hydrocarbon leaked in ft^3.	$V = M/[(SG_{HC})(\text{density of water})]$. See Basic Operation 1.
2. Calculate the spill area in ft^2.	Assume that the spill occurs radially in cylindrical form. Thus, the spill radius may be estimated by the following equation: $r_s = (V/[(\pi)(\text{thickness})])^{0.5}$ Assume that the thickness of the hydrocarbon is given by the average for soils and sands (see **Comment** below).
3. In order to calculate the emission rate, first calculate the emission flux, E, using ILEPA's equation.	$E = 0.0012\, c\, P_v/(760 - d\, P_v)$ where: c = molecular weight/28.9 $= 154/28.9$ $d = 1 - c$ $P_v = 375$ mmHg.
4. Calculate the mass emission (or evaporation) rate, m, in g/sec.	$m = (E)(A)$
5. Calculate the time (in seconds) for total evaporation.	$t = M/m$ Make sure to use consistent units.

Comment

Information on liquid spill spread on/in soils and water is not readily available. If a known volume of liquid is released during an accident, the physical spread may be assumed to take a form of a cylinder of radius r (centered at the point of discharge) and height or thickness h. Some rough estimates on the spill thickness are given below.

- Soils - 1.0 inch,
- Sand - 0.5 inch,
- Concrete - 0.25 inch,
- Smooth metal surface - 0.15 inch,
- Lake water surface - 0.1 inch, and
- River, estuary or ocean water - 0.05 inch.

DISPERSION 2

Emission Rates (Semi-theoretical)

Introduction

If the partial pressure of a diffusing liquid is zero at a vertical height z from a liquid surface, the molar flux (rate of liquid evaporating per unit time per unit area) may be approximated by:

$$N_A = (D_{AB}/RT)\ P_A/z$$

where: N_A = molar flux of A, gmole/cm^2-sec
D_{AB} = diffusivity of A in B, cm^2/sec
R = ideal gas law constant, consistent units
T = temperature, °K
P_A = liquid vapor pressure of A at T, consistent pressure units
z = height above liquid where the partial pressure of A is zero, cm.

In lieu of a satisfactory empirical model, the equation above may be used to estimate the emissions (in terms of the flux, N_A, with units of moles/time-area) from a liquid source into a relatively stagnant body of gas (usually air). This equation may not be employed to estimate these emissions if the air is moving across the surface of the liquid with a steady velocity of u. The equation below is recommended if the wind speed u is very slow, as in laminar flow.

$$N_A = 0.0021\ (u/L)^{0.5}\ [(D_{AB})^{0.5}\rho\ /(Sc)^{0.167}]\ (P_A/P_o)$$

where: N_A = molar flux of A, consistent units, gmole/cm^2-sec
D_{AB} = diffusivity of A in B, cm^2/sec
u = wind speed, cm/sec
L = characteristic length of the pool (e.g., effective spill diameter), cm
Sc = Schmidt number = $\mu/\rho D_{AB}$ (μ is vapor viscosity and ρ is vapor density)
P_A = vapor pressure of liquid at temperature in question, atm
P_o = atmospheric pressure, atm.

Problem Statement and Data

A container of ethanol drops on the floor in a chemical laboratory, causing the liquid to form a spill with a characteristic length of 10 cm. Air slowly breezes over this spill at a speed of 4 cm/sec and at 298 °K and 1.0 atmosphere. Calculate the molar flux (or emission flux) of the ethanol into the air in g/m^2-hr. The vapor pressure, density, viscosity, and diffusivity of ethanol at 298 °K are 0.0789 atm, 1.174 kg/m^3, 1.8462 X 10^{-5} kg-m/sec, and 1.32 X 10^{-5} m^2/sec, respectively.

Solution

1. Since the wind speed is low, the flow may be assumed to be laminar and the second equation applies. First calculate the Schmidt number.

$Sc = \mu / \rho D_{AB}$
Be sure to use consistent units; the resulting Schmidt number should be dimensionless.

2. Using the second equation and the input values given, calculate the molar flux in kg/m^2-sec.

Once again be sure to use consistent units.

3. Convert the molar flux calculated above to g/m^2-hr.

Use appropriate conversion factors.

Comment

For turbulent flow conditions, either of the following two equations is recommended.

$$N_A = 0.0012\ (D_{AB}/L)^{0.2}\ [(u)^{0.8}\rho\ /(Sc)^{0.47}](P_A/P_o)$$

or

$$N_A = 0.0292\ [(u)^{0.78}/(L)^{0.11}\rho(Sc)^{0.67}](P_A/RT)$$

where (for latter equation only): u = wind speed, m/hr
L = spill diameter, m
R = 0.082 atm-m^3/kmole-°K
T = temperature, °K
N_A = molar flux, kmole/hr-m^3.

The equations presented in this problem may be used for estimating emissions from "pools" of liquid if no satisfactory empirical or experimental data is available. A safety factor of 10 is recommended with these equations to account for deviations from ideality, experimental error (if applicable), etc.

DISPERSION 3

Water Systems

Introduction

Enormous amounts of waste dumped into water systems are degrading water quality and causing increased human health problems. In assessing this pollution, there are two distinct problem areas. The first, and the worst, is in marine estuaries and associated coastal waters. As fewer and fewer alternatives remain for land disposal, wastes are finding their way more often into water. The second problem concerns the oceans themselves, although it is believed that currently not much of a problem exists, because relatively little waste is dumped directly in the ocean. Although municipal sewage and agricultural runoff are major concerns for water pollution, industry has received the brunt of the blame for toxic pollution in marine waters. In the aggregate, industrial discharges represent the largest source of the toxic pollutants entering the marine environment. In addition to the normal, every day pollutant emissions into water systems is the ever present threat of an accidental and/or emergency discharge. The dispersion and ultimate fate of these pollutants is a major concern to the environmental engineer.

Problem Statement and Data

A large concentration of toxic waste has been "accidentally" dumped into a stationary body of water in a long shallow straight canal. The dumped waste, which may be assumed to be at a concentration of 0.23 lbmole/ft^3, is initially located uniformly through a 100 ft section of the canal. Calculate the concentration of the waste 25 ft away from the center of the initial dumping location after 8 hours if the "effective" diffusivity for the waste/water system may be assumed to be 61 ft^2/hr.

Assume that the waste is initially bounded by two parallel planes 2a units of length apart at a concentration C_{A0} equal to 0.23 lbmole/ft^3. Also assume that this region is located at the midpoint of the canal which can be assumed to have an infinite length and the remainder of the canal is initially toxic free. The actual dispersion process may be approximately described by a one-dimensional unsteady state mass transfer equation. The describing equation, in rectangular coordinates (with y representing the longitudinal direction of the canal), and the corresponding solution is provided by Theodore, et al., "Accidental and Emergency Management" (Wiley-Interscience, NYC, 1989). The solution is given below.

$$\begin{aligned} C_A(y,t) &= (C_{A0}/\sqrt{\pi})\{(\sqrt{\pi}/2)\ \mathrm{erf}[(y+a)/\sqrt{4Dt}] - (\sqrt{\pi}/2)\ \mathrm{erf}[(y-a)/\sqrt{4Dt}]\} \\ &= (C_{A0}/2)\{\mathrm{erf}[(y+a)/\sqrt{4Dt}] - \mathrm{erf}[(y-a)/\sqrt{4Dt}]\} \end{aligned}$$

where: C_A = concentration of toxic A at location y and time t, lbmole/ft^3
C_{A0} = initial concentration of A, lbmole/ft^3
y = longitudinal distance from initial dumping location, ft
t = time, hr
D = diffusivity, ft^2/hr
a = one-half initial width of contaminated region, ft
erf = error function or probability integral (see Appendix I for tabulated values of the error function).

Solution

1. First calculate the values of $(y + a)/\sqrt{4Dt}$ and $(y - a)/\sqrt{4Dt}$.	Be dimensionally consistent.
2. Determine the two values of the error function, i.e., erf $[(y + a)/\sqrt{4Dt}]$ and erf $[(y - a)/\sqrt{4Dt}]$.	See Appendix I. Note that erf (x) approaches 1.0 as x approaches infinity. For example, erf(2) = 0.99532.
3. Calculate the concentration of the toxic waste (in lbmole/ft^3) using the equation given previously.	Let y and t equal to 25 ft and 8 hr, respectively.

Comment

Note that the solution to the problem was obtained based solely on theoretical considerations. Predictive models of this type are used in practice if accurate and meaningful experimental data are not available.

DISPERSION 4

Atmospheric Plume Rise

Introduction

For atmospheric dispersion calculations, the calculational sequence begins by first estimating the "effective" height of the emission employing an applicable plume rise equation. The effective height of an emission rarely corresponds to the physical height of the source or the stack. If the plume is caught in the turbulent wake of a stack or a building in the vicinity of the source or stack, the effluent will be mixed rapidly downward toward the ground. If the plume is emitted free of these turbulent zones, a number of emission factors and meteorological factors influence the rise of the plume. The effective stack height (equivalent to the effective height of the emission) is usually considered as the sum of the actual stack height, the plume rise due to the velocity (momentum) of the issuing gases, and the buoyancy rise, which is a function of the temperature of the gases being emitted and the atmospheric conditions. Several plume rise equations are available. Briggs used the following equations to calculate the plume rise.

$$\Delta h = 1.6\ (F)^{1/3}\ (u)^{-1}\ (x)^{2/3}\ ;\ \text{if } x < x_f$$
$$\Delta h = 1.6\ (F)^{1/3}\ (u)^{-1}\ (x_f)^{2/3}\ ;\ \text{if } x >= x_f$$
$$x^* = 14\ (F)^{5/8}\ ;\ \text{when } F < 55\ m^4/sec^3$$
$$x^* = 34\ (F)^{2/5}\ ;\ \text{when } F >= 55\ m^4/sec^3$$
$$x_f = 3.5\ x^*$$

where: Δh = plume rise, m
F = buoyancy flux, $m^4/sec^3 = 3.7 \times 10^{-5}\ (Q_H)$
Q_H = heat emission, cal/sec
u = wind speed, m/sec
x = downward distance, m
x^* = distance of transition from first stage of rise to the second stage of rise, m
x_f = distance to final rise, m.

If the term Q_H is not available, the term F may be estimated by:

$$F = (g/\pi)(Q)(T_s - T)/T_s$$

where: g = gravity term, 9.8 m/sec
Q = stack gas volume flow, m^3/sec (actual conditions)
T_s, T = stack gas and ambient air temperature, respectively, °K.

Problem Statement and Data

If a waste source emits a buoyancy flux of 50 m^4/sec^3, and the wind averages 4 m/sec, find the plume rise at a distance of 750 m downward from a stack that is 50 m high under unstable atmospheric conditions.

Solution

1. First calculate x_f since it is necessary to determine which plume equation applies.	The value of x_f is an important consideration.
a. In order to calculate x_f, x^* must be calculated first.	Using the value of F provided, select the appropriate x^* equation.
b. Calculate x_f.	Use the equation $x_f = 3.5\ x^*$
2. Calculate the plume rise in meters using the appropriate equation.	Compare x with x_f and select the appropriate equation.

Comment

Many more plume rise equations may be found in the literature. The USEPA is mandated to use Brigg's equations to calculate plume rise. In past years, industry has preferred to use the Holland or Davidson-Bryant equation. The Holland equation is shown below.

$$\Delta h = d_s\ (v_s/u)\ [1.5 + (2.68 \times 10^{-3})\ P\ (\ T/T_s)\ d_s]$$

where: d_s = inside stack diameter, m
v_s = stack exit velocity, m/sec
u = wind speed, m/sec
P = atmospheric pressure, mbar
T_s, T = stack gas and ambient temperature, respectively, °K.
$\Delta T = T_s - T$
Δh = plume rise, m

The Davidson-Bryant equation is given below.

$$\Delta h = d_s\ (v_s/u)^{1.4}\ [1.0 + (T_s + T)/T_s]$$

DISPERSION 5

Atmospheric Dispersion Coefficients

Introduction

Graphical values of dispersion coefficients in predicting downwind concentrations from emissions (see later problems in this section) are provided in Appendix II. Most researchers and meteorologists have assumed the downstream profiles to be normally distributed because;

1. This provides some flexibility for refinements in future work.
2. Most of the available experimental data refer to normally distributed profiles.

The literature suggests equations for dispersion coefficients, σ_y and σ_z, of the form:

$$\sigma_y = b(y)\ x^{a(y)}$$
$$\sigma_z = b(z)\ x^{a(z)}$$

where: σ_y = dispersion coefficient in the y direction (in the horizontal plane perpendicular to the downwind direction), m
σ_z = dispersion coefficient in z (vertical) direction, m
a, b = empirically determined constants that depend on the stability of the atmosphere
x = downwind distance, m.

If isotropic conditions exist,

$$\sigma_y = \sigma_z$$

Problem Statement and Data

As a part of an Accident & Emergency Management project, Dr. Theodore is required to develop mathematical equations (for use in a dispersion computer program) describing the dispersion coefficient σ_y as a function of downwind distance x for six stability categories (see the **Comment** section of this problem). Tied up by other nonessential departmental assignments, he has chosen to hire you as a subcontractor on the project to obtain this information. Also develop equations for the dispersion coefficient σ_z.

Solution

1. For stability category A, obtain σ_y values for the downwind distances, x, listed below.	Refer to Appendix II.

x (m)	σ_y (m)
200	
4000	
6000	
60000	

2. Linearize the equation $\sigma_y = b(y)\ x^{a(y)}$.	Take the natural logarithm of both sides of the equation. The equation should now be of the form: $Y = A + B\ X$ where: $Y = \ln \sigma_y$ $A = \ln b(y)$ $B = a(y)$ $X = x$.
3. Regress the above data (4 data points) using the method of least squares and generate the linear equation coefficients A and B.	The method of least squares requires that the sum of the errors squared between data and model is minimized.
4. Obtaine the constants a(y) and b(y).	Take the inverse natural logarithm of A to obtain b(y).
5. Repeat the above steps for stability categories B, C, D, E, and F. For category B: a(y) = b(y) = For category C: a(y) = b(y) = For category D: a(y) = b(y) = For category E: a(y) = b(y) = For category F: a(y) = b(y) =	Note that the numerical values of the constants a and b will vary with the number and numerical value of data point readings from the graph in Appendix II.

6. Repeat the all of the above steps for dispersion coefficient σ_z.

The above comment again applies.

For category A: a(z) =
b(z) =
For category B: a(z) =
b(z) =
For category C: a(z) =
b(z) =
For category D: a(z) =
b(z) =
For category E: a(z) =
b(z) =
For category F: a(z) =
b(z) =

Comment

It is important to note that these dispersion coefficients are the product of a long history of field experiments, and empirical judgments and extrapolations of the data from those experiments. There are few knowledgeable practitioners in the dispersion modeling field who would dispute that the coefficients could easily have an inherent uncertainty of +/- 25%. The six applicable stability categories for these coefficients are shown below.

Surface wind speed at 10 m (m/sec)	Day			Night	
	Incoming solar radiation			Thinly overcast or >4/8 low cloud	<3/8 cloud
	Strong	Moderate	Slight		
2	A	A - B	B	-	-
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
6	C	D	D	D	D

Note that A, B, C refer to daytime with unstable conditions; D refers to overcast or neutral conditions at night or during the day. E and F refer to night time stable conditions and are based on the amount of cloud cover. "Strong" incoming solar radiation corresponds to a solar altitude greater than 60 ° with clear skies (e.g., sunny midday in midsummer); "slight" insolation (rate of radiation from the sun received per unit of earth's surface) corresponds to a solar altitude from 15 to 35 ° with clear skies (e.g., sunny midday in midwinter). For the A-B, B-C, and C-D stability categories, one should use the average of the A and B values, B and C values, and C and D values, respectively.

DISPERSION 6

Pasquill - Gifford Model

Introduction

The coordinate system used in making atmospheric dispersion estimates, as suggested by Pasquill and modified by Gifford, is described below. The origin is at ground level or beneath the point emission, with the x axis extending horizontally in the direction of the mean wind. The y axis is in the horizontal plane perpendicular to the x axis, and the z axis extends vertically. The plume travels along or parallel to the x axis (in the mean wind direction). The concentration, C, of gas or aerosol at (x, y, z) from a continuous source with an effective height, H_e, is given by:

$$C\ (x,y,z,H_e) = (m/2\pi\,\sigma_y\,\sigma_z\,u)[\exp(-0.5(y/\sigma_y)^2)]\,[\exp(-0.5((z-H_e)/\sigma_z)^2) + \exp(-0.5((z+H_e)/\sigma_z)^2)]$$

where: H_e = effective height of emission (sum of the physical stack height, H_s, and the plume rise, Δh), m
u = mean wind speed affecting the plume, m/sec
m = emission rate of pollutants, g/sec
σ_y, σ_z = dispersion coefficients or stability parameters, m
C = concentration of gas, g/m^3
x, y, z = coordinates, m.

The assumptions made in the development of the above equation are: (1) the plume spread has a Gaussian distribution in both the horizontal and vertical planes, with standard deviations of plume concentration distribution in the horizontal and vertical directions of σ_y and σ_z, respectively; (2) uniform emission rate of pollutants, m; (3) total reflection of the plume takes place at the earth's surface; and (4) the plume moves downstream (horizontally in the x direction) with mean wind speed, u. Although any consistent set of units may be used, the cgs system is preferred. For concentrations calculated at ground level (z = 0), the equation simplifies to:

$$C\ (x,y,0,H_e) = (m/\pi\,\sigma_y\,\sigma_z\,u)[\exp(-0.5(y/\sigma_y)^2)]\,[\exp(-0.5(H_e/\sigma_z)^2)]$$

If the concentration is to be calculated along the centerline of the plume (y = 0), further simplification gives:

$$C\ (x,0,0,H_e) = (m/\pi\,\sigma_y\,\sigma_z\,u)[\exp(-0.5(H_e/\sigma_z)^2)]$$

In the case of a ground level source with no effective plume rise (H_e= 0), the equation further simplifies to:

$$C\ (x,0,0,0) = (m/\pi\,\sigma_y\,\sigma_z\,u)$$

Problem Statement and Data

A power plant burns 12 tons of 2.5% sulfur content coal per hour. The effective stack height is 120 meters and the wind speed is 2 m/sec. At one hour before sunrise, the sky is clear. A risk analysis requires information on the approximate distance of the maximum concentration under these conditions (Hint: calculate concentrations for downward distances of 0.1, 1.0, 5, 10, 20, 25, 30, 50, and 70 km.)

Solution

1. First calculate the sulfur dioxide emission rate, m, in g/sec.

Note that a unit mass of sulfur produces 2 unit mass of sulfur dioxide.

2. Select the stability category.

See the table in the Comment section of Dispersion problem 5.

3. Determine the values of σ_y and σ_z for each downward distance, x, for the stability category selected in step 2.

Refer to Appendix II.

x = 0.1 km; σ_y = m, σ_z = m
x = 1.0 km; σ_y = m, σ_z = m
x = 5 km; σ_y = m, σ_z = m
x = 10 km; σ_y = m, σ_z = m
x = 20 km; σ_y = m, σ_z = m
x = 25 km; σ_y = m, σ_z = m
x = 30 km; σ_y = m, σ_z = m
x = 50 km; σ_y = m, σ_z = m
x = 70 km; σ_y = m, σ_z = m

4. Select the appropriate dispersion equation.

Note that the maximum concentration occurs along the centerline of the plume, i.e., y = 0.

5. Calculate the concentration of sulfur dioxide at the same downward distances by completing the table below.

Be dimensionally consistent.

x (km)	C (g/cm^3)
0.1	
1.0	
5	
10	
20	
25	
30	
50	
70	

6. Determine the maximum concentration and its location.

Estimate these two numbers from the calculated results generated in the table in step 5.

Comment

The Pasquill-Gifford equation is valid where diffusion in the direction of the wind can be neglected (i.e., no diffusion in the x direction). This is a valid assumption if the release is continuous or if the duration of the release is equal to or greater than the travel time (x/u) from the source to the location of interest.

DISPERSION 7

Lines Sources

Introduction

The development on atmospheric dispersion in the previous problem was limited to emissions from a "point" (e.g., stack) source. Although most dispersion applications involve point sources, there are instances where the location of the emission can be more accurately described physically and mathematically by a line source or an area source.

Line source applications are generally confined to roadways and streets along which there are well defined movements of motor vehicles. For these types of line sources, data are required on the width of the roadway and its center strip, the types and amounts (g/sec-m) of pollutant emissions, the number of lanes, the emissions from each lane, and the height of emissions. In some situations, e.g., a traffic jam at a tollbooth, or a series of industries located along a river, or heavy traffic along a straight stretch of highway, the pollution problem may be modeled as a continuous emitting infinite line source. Concentrations downwind of a continuous emitting infinite line source, when the wind direction is normal to the line, can be calculated from:

$$C\ (x,y,0,H_e) = (2q/\sqrt{2\pi}\,\sigma_z\ u)\ [\exp\ (-0.5(H_e/\sigma_z)^2)]$$

where: q = source strength per unit distance, g/sec-m
H_e = effective stack or discharge height, m
u = wind speed, m/sec
σ_z = vertical dispersion coefficient, m.

Note that the horizontal dispersion coefficient, σ_y, does not appear in this equation, since it is assumed that lateral dispersion from one segment of the line is compensated by dispersion in the opposite direction from adjacent segments. Also, y does not appear since the concentration at a given x is the same for any value of y.

Problem Statement and Data

A six story hospital building is located 300 meters east and downwind from an expressway. The expressway runs north-south and the wind is from the west at 4 m/sec. It is 5:30 in the afternoon on an overcast day. The measured traffic flow is 8,000 vehicles per hour during this rush hour and the average vehicle speed is 40 miles/hr. At this speed the average vehicle is expected to emit 0.02 g/sec of total hydrocarbons. Concentrations at the hospital are required as part of risk assessment study. How much lower, in percent, will the hydrocarbon concentration be on top of the building (where the eldery patients are housed) as compared with the concentration estimated at ground level? Assume a standard floor to be 3.5 meters in height.

Solution

1. First determine the stability category.	See the table in the Comment section of Dispersion problem 5.
2. Calculate the source strength per unit distance, q.	Be sure to use consistent units.
a. First calculate the number of vehicles per meter, n.	There are 1609 meters per mile.
b. Calculate the source strength per unit length, q.	Use n calculated in step 2a and the emission rate per vehicle.
3. Obtain the vertical dispersion coefficient, σ_z, under the stability category determined in step 1.	Refer to Appendix II.
4. Determine the height of the building.	It is a six story building.
5. Calculate the concentration 300 m downwind at ground level conditions.	Note that the exponential term in the dispersion equation becomes 1.0 if $H_e = 0$.
6. Calculate the concentration 300 m downwind at the top of the building.	Select an appropriate value of H_e.
7. Determine how much lower, in percent, the concentration at the top of the building will be.	The percent difference should be based on the result calculated in step 5.

Comment

Concentrations from infinite line sources, when the wind is not perpendicular to the line, can also be approximated. If the angle between the wind direction and line source is ϕ,

$$C\ (x,y,0,H_e) = (2q/\sin(\theta)\sqrt{2\pi}\ \sigma_z\ u)[\exp(-0.5(H_e/\sigma_z)^2)]$$

This equation should not be used where ϕ is less than 45°. When the continuously emitting line source is reasonably short in length or "finite", one can account for the edge effects caused by the two ends of the source. If the line source is perpendicular to the wind direction, then it is convenient to define the x-axis in the direction of the wind and also passing through the sampling point downwind. The ends of the line source then are at two positions in the crosswind direction, y_1 and y_2, where y_1 is less than y_2. The concentration along the x-axis at ground level is then given by the expression below:

$$C\ (x,0,0,H_e) = (2q/\sqrt{2\pi}\ \sigma_z\ u)[\exp(-0.5(H_e/\sigma_z)^2)] \int_{p_1}^{p_2} [(1/\sqrt{2\pi})\exp(-0.5p^2)\ dp]$$

where: $p_1 = y_1/\sigma_y$
$p_2 = y_2/\sigma_y$.

Once the limits of integration are established, the value of the integral may be determined from standard tables of integrals.

DISPERSION 8

Area Sources

Introduction

Area sources include the multitude of minor sources with individually small emissions that are impractical to consider as separate point or line sources. Area sources are typically treated as a grid network of square areas, with pollutant emissions distributed uniformly within each grid square. Area source information required are types and amounts of pollutant emissions, the physical size of the area over which emissions are prorated and representative stack height(s) for the area. In dealing with dispersion of pollutants in areas having large numbers of sources, e.g., as in fugitive dust from (coal) piles, a large number of automobiles in a parking lot, or a multi-stack situation, there may be too many sources to consider each source individually. Often an approximation can be made by combining all of the emissions in a given area and treating this area as a source having an initial horizontal standard deviation, σ_{yo}. A virtual distance, x_y, can then be found that will give this standard deviation. This is just the distance that will yield the appropriate value for σ_y from Appendix II. Values of x_y will vary with stability. The equation for point sources may then be used, determining σ_y as a function of $x + x_y$. This procedure effectively treats the area source as a cross-wind line source with a normal distribution; this is a fairly good approximation for the distribution across an area source. The initial standard deviation for a square area source can be approximated by $\sigma_{yo} = s/4.3$, where s is the length of a side of the area.

Problem Statement and Data

An inventory of emissions has been made in an urban location by square areas, 1524 meters on a side as part of an emergency planning and response study. The emissions from two such adjacent areas (source area B and D) are estimated to be 6 g/sec for each area. The effective stack height of the sources within each area is approximately 20 meters. The wind is 2.5 m/sec on a thinly overcast night and perpendicular to the two adjacent square areas (i.e., source areas B and D are aligned perpendicular to the wind). What is the percentage contribution of emissions from the two sources to the center point of next square area (point A) immediately downwind of the source area D?

Solution

1. Determine the stability category.	See the **Comment** section of Dispersion problem 5.

2. Calculate the initial standard deviation, σ_{yo}.	See the Introduction section.
3. Obtain the virtual point source distance, x_y.	Use the value of σ_{yo} calculated above. Refer to Appendix II.
4. Calculate the total distance, x_t.	For this distance, $x_t = x + x_y$
5. Obtain σ_y which corresponds to x_t calculated above.	Refer to Appendix II.
6. Determine the value of σ_z.	Since the area source can be assumed to be well mixed, σ_z may be obtained at 1524 m.
7. Calculate the concentration at point A because of point D.	Note that point A is directly downward of point D so that $y = 0$.
8. Calculate the concentration from point B.	Point A is not directly downwind of point B.
9. Calculate the ratio of the contribution to point A from points B and D.	If the areas are aligned parallel to the wind direction (B followed by D, followed by A), the reader is left with the exercise of showing that the contribution from B and D to A are 43 % and 57 %, respectively.

If the emissions within an area are from varying effective stack heights, the variation may be approximated by using a σ_{zo}. Thus, H would be the mean effective height of release and σ_{zo} the standard deviation of the initial vertical distribution of sources. A virtual distance, x_z, can then be found, and the point source equation is again used for estimating concentrations by determining σ_z as function of $x + x_z$.

DISPERSION 9

Instantaneous "Puff" Model

Introduction

A rather significant amount of data and information is available for sources that emit continuously. Unfortunately, little is available on instantaneous or "puff" sources. Other than computer models which are not suitable for classroom and/or illustrative example calculations - only USEPA Turner's "Workbook of Atmospheric Dispersion Estimates" provides an equation that may be used for estimation purposes. Cases of instantaneous releases, as from an explosion, or short-term releases on the order of seconds, are also and often of practical concern. To determine concentrations at any position downwind, one must consider both the time interval after the time of release and diffusion in the downwind direction, as well as lateral and vertical diffusion. Of considerable importance, but very difficult, is the determination of the path or trajectory of the "puff." This is most important if concentrations are to be determined at specific points. Determining the trajectory is of less importance if knowledge of the magnitude of the concentration for particular downwind distances or travel times is required without the need to know exactly at what points these concentrations occur. An equation that may be used for estimates of concentration downwind from a release from height, H, is:

$$C\ (x,y,0,H) = 2m_T/((2\pi)^{1.5}\ \sigma_x\ \sigma_y\ \sigma_z)[\exp(-0.5((x-ut)/\sigma_x)^2)]\\ [\exp(-0.5(H/\sigma_z)^2)][\exp(-0.5(y/\sigma_y)^2)]$$

where: m_T = total mass of the release
u = wind speed
t = time after release.

The dispersion coefficients above are not necessarily those evaluated with respect to the dispersion of a continuous source at a fixed point in space. This equation can be simplified for centerline concentrations and ground level emissions by setting $y = 0$ and $H = 0$, respectively. The dispersion coefficients in the above equation refer to dispersion statistics following the motion of the expanding puff. The σ_x is the standard deviation of the concentration distribution in the puff in the downwind direction, and t is the time after release. Note that there is no dilution in the downwind direction by wind speed. The speed of the wind mainly serves to give the downwind position of the center of the puff, as shown by examination of the exponential term involving σ_x. In general, one should expect the σ_x value to be about the same as σ_y. Unless another model is available for treating instantaneous sources, it is recommended that the above equation be employed. The use of appropriate values of σ for this equation is not clear cut. As a first approximation, the reader may consider employing the values of σ provided in Appendix II.

Problem Statement and Data

A 20 meter high tank in a plant containing a toxic gas suddenly explodes. Following the explosion, an emission of 400 g/sec for 3 minutes results. A school is located 200 meters west and 50 meters south from the plant. If the wind velocity is 3.5 m/sec from the east, how many seconds after the explosion will the concentration reach a maximum in the school? Humans will be adversely affected if the concentration of the gas is greater than 1.0 ug/l. Is there any impact on the students in the school? Assume that stability category D applies.

Solution

1. First determine the total amount of toxic gas released, m_T.	Be sure to be dimensionally consistent.
2. Determine the values of the three standard deviations.	Refer to Appendix II and the **Introduction** section of this problem.
3. Calculate the time at which the maximum concentration will occur at the school.	Use the equation, $t = x/u$
4. Calculate the maximum concentration at the school.	Note that the maximum concentration occurs at $x = ut$.
5. Convert the above concentration to ug/l.	Use appropriate conversion factors.
6. Is there any impact on the students in the school?	Compare the calculated concentration to 1.0 ug/l.

Yes _____
No _____

Comment

Quantifying the magnitude of the source term (m_T) in the above equation is a major problem that has yet to be resolved by industry and researchers.

DISPERSION 10

Instantaneous "Puff" Sources

Introduction

Wind speed may influence the dispersion indirectly because the dispersion parameters σ_x, σ_y, and σ_z may be functions of wind speed. The σ_y's and σ_z's for an instantaneous source are generally less than those given in Appendix II. Others have suggested values for σ_y and σ_z for quasi-instantaneous sources. These are given below:

	x = 100 m		x = 4 km	
	σ_y	σ_z	σ_y	σ_z
Unstable	10	15	300	220
Neutral	4	3.8	120	50
Very Stable	1.3	0.75	35	7

Problem Statement and Data

EPA considers it a health hazard if a particular chemical gas has a ground level concentration (GLC) greater than 1×10^{-9} g/m^3. An explosion in a chemical plant releases 1000 kg of this gas as a "puff" from ground level conditions. A residential community is located 4000 meters downwind and 1000 meters crosswind from the source of the explosion. If the wind speed is 6 m/sec and the stability category is "unstable", how much time do the residents have to "evacuate" the town?

Solution

1. First determine the values of the dispersion coefficients σ_y and σ_z.	Refer to the above table.
2. Assign a value to the dispersion coefficient σ_x.	Refer to Dispersion problem 9 for the relation between σ_x and σ_y.
3. Assign a value to the term H.	The explosion occurs at ground conditions.

4. Calculate the time to reach the health hazard concentration.	Set the LHS of the instantaneous "puff" equation to the maximum GLC allowed and solve for the time, t.

Comment

Strictly speaking, the "puff" equation provided in Dispersion problem 9 is not applicable to large initial puffs. The effect of the initial dimensions of the puff may be approximated by finding a virtual distance (similar to that for area sources) to give the appropriate initial standard deviation for each direction. Then σ_y will be determined as a function of $x + x_y$, σ_z as a function of $x + x_z$, and σ_x as a function of $x + x_x$.