27 Atmospheric Science and Meteorology

Content in blue refers to the *NCEES Handbook*.

PRACTICE PROBLEMS

1. A 60 m tall stack emits a plume at a temperature of 28°C. The air temperature at ground level is 17°C. The ambient lapse rate up to an elevation of 210 m is 0.0081°C/m. Above 210 m the ambient lapse rate is −0.0053°C/m. The maximum mixing depth is most nearly

(A) 730 m

(B) 1700 m

(C) 1900 m

(D) 2600 m

2. Hydrocarbons at a concentration of 3.1×10^9 μg/m^3 are emitted through a stack with an effective height of 110 m. The gas flow at the stack is 3.8 m^3/s, and the average wind speed 10 m above grade is 6.1 m/s. Atmospheric stability conditions are Class C. The maximum ground level concentration of hydrocarbons at 200 m crosswind of the stack is most nearly

(A) 1.6×10^3 μg/m^3

(B) 8.4×10^3 μg/m^3

(C) 1.1×10^4 μg/m^3

(D) 1.7×10^5 μg/m^3

3. An air pollutant is emitted at 4.3 kg/s through a stack with an effective height of 260 m. The wind speed at 10 m above grade is 5 m/s, and atmospheric stability conditions are Class D. The maximum ground-level concentration along the plume centerline is most nearly

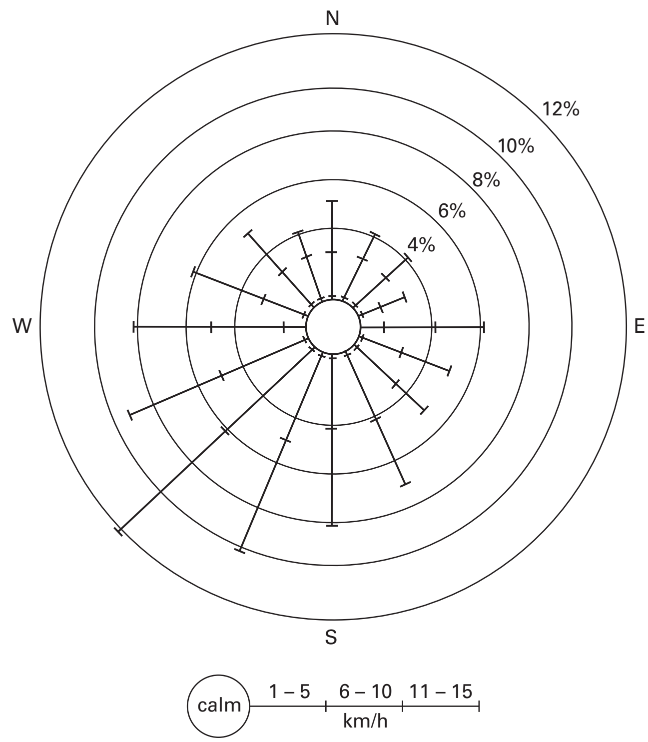
(A) ~~5.5×10^3~~ μg/m^3 6.1 x 10^2

(B) ~~5.9×10^4~~ μg/m^3 5.5 x 10^3

(C) 6.9×10^4 μg/m^3

(D) 1.8×10^5 μg/m^3

4. A typical wind rose is shown in the figure.



The percent of the time that the wind blows to the west is most nearly

(A) 2%

(B) 4%

(C) 6%

(D) 8%

Air

SOLUTIONS

1. The plume cools at the dry adiabatic lapse rate as it rises, and will stop rising when the plume and air temperatures are equal. The dry adiabatic lapse rate is 0.98°C/100 m (−0.0098°C/m). [Selected Properties of Air]

Calculate the plume temperature at 210 m.

$$28°\text{C} + \left(-0.0098\ \frac{°\text{C}}{\text{m}}\right)(210\ \text{m} - 60\ \text{m}) = 26.53°\text{C}$$

The air warms at the ambient lapse rate of +0.0081°C/m, up to an elevation of 210 m. Calculate the air temperature at 210 m.

$$17°\text{C} + \left(0.0081\ \frac{°\text{C}}{\text{m}}\right)(210\ \text{m}) = 18.70°\text{C}$$

The air cools above 300 m at the ambient lapse rate of −0.0053°C/m.

Calculate the distance, z, above 210 m where the air and plume temperatures are equal.

$$26.53°\text{C} + \left(-0.0098\ \frac{°\text{C}}{\text{m}}\right)z = 18.70°\text{C} + \left(-0.0053\ \frac{°\text{C}}{\text{m}}\right)z$$

$$z = \frac{26.53°\text{C} - 18.70°\text{C}}{0.0098\ \frac{°\text{C}}{\text{m}} - 0.0053\ \frac{°\text{C}}{\text{m}}} = 1740\ \text{m}$$

The maximum mixing depth is equal to how high the plume will rise.

$$210\ \text{m} + 1740\ \text{m} = 1950\ \text{m} \quad (1900\ \text{m})$$

The answer is (C).

2. Calculate the location of maximum ground-level concentration.

H = effective stack height, 110 m

Atmospheric Dispersion Modeling (Gaussian)

$$\sigma_z = \frac{H}{\sqrt{2}} = \frac{110\ \text{m}}{\sqrt{2}} = 78\ \text{m}$$

From a chart of standard deviations of a plume, for a standard deviation of 78 m and Class C atmospheric stability conditions, the downwind distance, x = 1300 m. [Vertical Standard Deviations of a Plume]

From a chart of standard deviations of a plume, for x = 1300 m and Class C atmospheric stability conditions, the standard deviation for the downwind distance, s_y = 160 m. [Horizontal Standard Deviations of a Plume]

Calculate the gas emission rate, Q.

$$Q = \left(3.8\ \frac{\text{m}^3}{\text{s}}\right)\left(3.1\times 10^9\ \frac{\mu\text{g}}{\text{m}^3}\right) = 1.18\times 10^{10}\ \mu\text{g/s}$$

Calculate the hydrocarbon concentration, C, at the monitoring station. The equation for the concentration is shown.

μ = wind speed = 6.1 m/s

z = vertical distance from ground level = 0 m

Atmospheric Dispersion Modeling (Gaussian)

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

For ground level concentration, the equation reduces to the following.

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

$$= \frac{1.18\times 10^{10}\ \frac{\mu g}{s}}{\pi\left(6.1\ \frac{\text{m}}{\text{s}}\right)(160\ \text{m})(78\ \text{m})} \times\exp\left(-\left(\frac{1}{2}\right)\frac{(200\ \text{m})^2}{(160\ \text{m})^2}\right)\exp\left(-\left(\frac{1}{2}\right)\left(\frac{(110\ \text{m})^2}{(78\ \text{m})^2}\right)\right)$$

$$= 8.4\times 10^3\ \mu\text{g/m}^3$$

The answer is (B).

3. Calculate the location of maximum ground-level concentration.

H = effective stack height, 260 m

Atmospheric Dispersion Modeling (Gaussian)

$$\sigma_z = \frac{H}{\sqrt{2}} = \frac{260\ \text{m}}{\sqrt{2}} = 184\ \text{m}$$

From a chart of standard deviations of a plume, for σ_z = 184 m and Class D atmospheric stability conditions, the downwind distance, x = 18 km. [Vertical Standard Deviations of a Plume]

From a chart of standard deviations of a plume, for x = 18 km and Class D atmospheric stability conditions, the standard deviation for the downwind distance, σ_y = ~~100~~ 900 m. [Horizontal Standard Deviations of a Plume]

Calculate the gas emission rate, Q, in units of μg/s.

$$Q = \left(4.3\ \frac{\text{kg}}{\text{s}}\right)\left(10^9\ \frac{\mu\text{g}}{\text{kg}}\right) = 4.3 \times 10^9\ \mu\text{g/s}$$

Calculate the pollutant concentration.

u = wind speed = 5 m/s

Atmospheric Dispersion Modeling (Gaussian)

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

$$= \frac{4.3 \times 10^9\ \frac{\mu\text{g}}{\text{s}}}{\pi\left(5\ \frac{\text{m}}{\text{s}}\right)(100\ \text{m})(184\ \text{m})}\exp\left(-\left(\frac{1}{2}\right)\frac{(260\ \text{m})^2}{(184\ \text{m})^2}\right)$$

$$= 5.5 \times 10^3\ \mu\text{g/m}^3$$

6.1 x 10^2

900

The answer is (A).

4. From the figure, the wind blows to the west 6% of the time.

The answer is (C).

5. Diagram (d) shows the ambient lapse rate to be greater than the dry adiabatic lapse rate. This illustrates subadiabatic atmospheric stability.

The answer is (D).

6. The prevailing lapse rate of −10.1°C/km is less than the dry adiabatic lapse rate of −9.8°C/km up to a height of 250 m, indicating superadiabatic conditions. Above 250 m, the prevailing lapse rate has a positive slope and an inversion is formed. When an inversion exists over superadiabatic conditions, a fumigation plume will be formed.

The answer is (C).

7. Water vapor in air will condense, and heat will be released as the air rises. Therefore, a dry adiabatic lapse rate will increase (be less negative) in a water-saturated atmosphere.

The answer is (A).

8. From a table of atmospheric stability under various conditions, for slightly unstable stability conditions use atmospheric stability C. [**Atmospheric Stability Under Various Conditions**]

From a graph of horizontal standard deviations of a plume, for $x = 1500$ m and stability class C, $\sigma_y = 180$ m. [**Horizontal Standard Deviations of a Plume**]

From a graph of vertical standard deviations of a plume, for $x = 1500$ m and stability class C, $\sigma_z = 90$ m. [**Vertical Standard Deviations of a Plume**]

Use the equation for finding a steady-state concentration at a point.

Atmospheric Dispersion Modeling (Gaussian)

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

$C_{x,y}$ = concentration, g/m^3, along plume centerline at distance $x = 1500$ m, and at crosswind distance $y = 200$ m. For a ground level concentration crosswind of the plume centerline, the vertical distance from the ground is zero, $z = 0$. The equation reduces to

$$C_{x,y} = \frac{Q}{\pi u \sigma_y \sigma_z}\exp\left(\left(-\frac{1}{2}\right)\frac{y^2}{\sigma_y^2}\right)\exp\left(\left(-\frac{1}{2}\right)\frac{H^2}{\sigma_z}\right)$$

$$C_{1500,200} = \frac{210\ \frac{\text{g}}{\text{s}}}{\pi\left(8\ \frac{\text{m}}{s}\right)(180\ \text{m})(90\ \text{m})} \times\exp\left(\left(-\frac{1}{2}\right)\frac{(200\ \text{m})^2}{(180\ \text{m})^2}\right)\exp\left(\left(-\frac{1}{2}\right)\frac{(175\ \text{m})^2}{(90\ \text{m})^2}\right)$$

$$= 0.000042\ \text{g/m}^3$$

Converting to micrograms gives

$$\left(0.000042\ \frac{\text{g}}{\text{m}^3}\right)\left(10^6\ \frac{\mu\text{g}}{\text{g}}\right) = 42\ \mu\text{g/m}^3$$

The answer is (A).

9. Diagram (c) shows the ambient lapse rate with a positive slope and the dry adiabatic lapse rate with a negative slope. This illustrates an inversion.

The answer is (C).

10. From the figure, the maximum velocity for winds originating from the south-southeast is between 11 and 15 km/h.

The answer is (C).

11. Find the Gaussian dispersion coefficient.

σ_z = Gaussian dispersion coefficient for vertical plume concentration at downwind distance x, m

H = effective stack height = 175 m

Air