

CHAPTER 7 SOLUTIONS

7-1 Density of oxygen

Given: Temperature = 273.0 K, pressure = 98.0 kPa

Solution:

- a. Assume 1 gram mole of oxygen

From inside front cover of book GMW of O = 16.00

For O₂ = 2(16.00) = 32.00 g/mole

- b. Calculate density (Equation 7-1)

$$\rho = \left(\frac{1}{8.3143 \text{ J/K} \cdot \text{mole}} \right) \left(\frac{(98.0 \text{ kPa})(1 \text{ mole})(32.00 \text{ g/mole})}{273 \text{ K}} \right) \left(\frac{1000 \text{ Pa}}{\text{kPa}} \right) \left(\frac{10^{-3} \text{ kg}}{\text{g}} \right)$$

$$\rho = 1.382 \text{ kg/m}^3$$

7-2 Density of Carbon monoxide (CO)

Given: Temperature = 298.0 K, pressure = 102.0 kPa

Solution:

- a. Assume 1 gram mole of CO

From inside front cover of book find GMW of C = 12.01 and O = 16.00
CO = 28.01 g/mole

- b. Calculate density (Equation 7-1)

$$\rho = \left(\frac{1}{8.3143 \text{ J/K} \cdot \text{mole}} \right) \left(\frac{(102.0 \text{ kPa})(1 \text{ mole})(28.01 \text{ g/mole})}{298.0 \text{ K}} \right) \left(\frac{1000 \text{ Pa}}{\text{kPa}} \right) \left(\frac{10^{-3} \text{ kg}}{\text{g}} \right)$$

$$\rho = 1.153 \text{ kg/m}^3$$

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7-3 Density of methane (CH₄)

Given: Temperature = 273.0 K, pressure = 101.325 kPa

Solution:

a. Assume 1 gram mole of CH₄

From inside front cover of book find GMW of C = 12.01 and H = 1.008

$$\text{CH}_4 = 16.042 \text{ g/mole}$$

b. Calculate density (Equation 7-1)

$$\rho = \left(\frac{1}{8.3143 \text{ J/K} \cdot \text{mole}} \right) \left(\frac{(101.325 \text{ kPa})(1 \text{ mole})(16.042 \text{ g/mole})}{273 \text{ K}} \right) \left(\frac{1000 \text{ Pa}}{\text{kPa}} \right) \left(\frac{10^{-3} \text{ kg}}{\text{g}} \right)$$

$$\rho = 5.954 \text{ kg/m}^3$$

7-4 Show one mole = 22.414 L at STP

Given: STP = 273.16 K, 101.325 kPa

Solution:

a. Solve Eqn. 7-2 for V. Note that J = (N)(m) and that Pa = N/m² so that units are

$$V = \frac{(\text{mole}) \left(\frac{\text{N} \cdot \text{m}}{\text{K} \cdot \text{mole}} \right) (\text{K})}{\frac{\text{N}}{\text{m}^2}} = \text{m}^3$$

b. Using Equation 7-2 with n = 1

$$V = \frac{(1 \text{ mole})(8.3143 \text{ J/K} \cdot \text{mole})(273.16 \text{ K})}{(101.325 \text{ kPa})(1000 \text{ Pa/kPa})} (1000 \text{ L/m}^3)$$

$$V = 22.414 \text{ L}$$

7-5 Volume occupied by 1 mole

Given: T = 25.0 °C, 101.325 kPa

Solution:

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a. Solve Eqn. 7-2 for V. Note that $J = (N)(m)$ and that $\text{Pa} = \text{N}/\text{m}^2$ so that units are

$$V = \frac{(\text{mole}) \left(\frac{\text{N} \cdot \text{m}}{\text{K} \cdot \text{mole}} \right) (\text{K})}{\frac{\text{N}}{\text{m}^2}} = \text{m}^3$$

b. Using Eqn. 7-2 with $n = 1$

$$V = \frac{(1 \text{ mole})(8.3143 \text{ J/K} \cdot \text{mole})(298.0 \text{ K})(1000 \text{ L/m}^3)}{(101.325 \text{ kPa})(1000 \text{ Pa/kPa})}$$

$$V = 24.453 \text{ L}$$

7-6 Partial pressures of oxygen and nitrogen

Given: STP, oxygen = 8.583 moles/m³, nitrogen = 15.93 moles/m³, 1.0 m³ of air

Solution:

a. Solve Eqn. 7-2 for P. Note that $J = (N)(m)$ and that $\text{Pa} = \text{N}/\text{m}^2$ so that units are

$$P = \frac{(\text{mole}) \left(\frac{\text{N} \cdot \text{m}}{\text{K} \cdot \text{mole}} \right) (\text{K})}{\text{m}^3} = \frac{\text{N}}{\text{m}^2} = \text{Pa}$$

b. Partial pressure of oxygen (Equation 7-2)

$$P_{\text{O}_2} = \frac{(8.563 \text{ mole/m}^3)(8.3143 \text{ J/K} \cdot \text{mole})(273.16 \text{ K})(10^{-3} \text{ kPa/Pa})}{1.0 \text{ m}^3}$$

$$P_{\text{O}_2} = 19.45 \text{ kPa}$$

b. Partial pressure of nitrogen (Equation 7-3)

$$P_{\text{N}_2} = \frac{(15.93 \text{ mole/m}^3)(8.3143 \text{ J/K} \cdot \text{mole})(273.16 \text{ K})(10^{-3} \text{ kPa/Pa})}{1.0 \text{ m}^3}$$

$$P_{\text{N}_2} = 36.18 \text{ kPa}$$

7-7 Partial pressures of oxygen, nitrogen, carbon dioxide

Given: $T = 25.0\text{ }^\circ\text{C}$, oxygen = 8.32 moles, nitrogen = 16.40 moles, carbon dioxide = 16.15 moles, 1.0 m^3 tank

Solution:

a. Solve Eqn. 7-2 for P. Note that $J = (N)(m)$ and that $\text{Pa} = \text{N}/\text{m}^2$ so that units are

$$P = \frac{(\text{mole}) \left(\frac{\text{N} \cdot \text{m}}{\text{K} \cdot \text{mole}} \right) (\text{K})}{\text{m}^3} = \frac{\text{N}}{\text{m}^2} = \text{Pa}$$

b. Convert temperature to K

$$T = 25.0 + 273 = 298\text{ K}$$

c. Partial pressure of oxygen (Eqn. 7-2)

$$P_{\text{O}_2} = \frac{(8.32\text{ mole})(8.3143\text{ J/K} \cdot \text{mole})(298\text{ K})}{1.0\text{ m}^3} (10^{-3}\text{ kPa/Pa})$$

$$P_{\text{O}_2} = 20.61\text{ kPa}$$

d. Partial pressure of nitrogen (Eqn. 7-2)

$$P_{\text{N}_2} = \frac{(16.40\text{ mole})(8.3143\text{ J/K} \cdot \text{mole})(298\text{ K})}{1.0\text{ m}^3} (10^{-3}\text{ kPa/Pa})$$

$$P_{\text{N}_2} = 40.63\text{ kPa}$$

e. Partial pressure of carbon dioxide (Eqn. 7-2)

$$P_{\text{CO}_2} = \frac{(16.15\text{ mole})(8.3143\text{ J/K} \cdot \text{mole})(298\text{ K})}{1.0\text{ m}^3} (10^{-3}\text{ kPa/Pa})$$

$$P_{\text{CO}_2} = 40.01\text{ kPa}$$

7-8 Moles of O_2 , N_2 , and CO_2

Given: $P_{\text{O}_2} = 45.39\text{ kPa}$, $P_{\text{N}_2} = 40.63\text{ kPa}$, $P_{\text{CO}_2} = 15.24\text{ kPa}$, $V = 1.000\text{ m}^3$, $T = 25.0\text{ }^\circ\text{C}$

Solution:

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a. Solve Equation 7-2 for moles/m³ for O₂

Note: J/K-mole = Pa-m³/K-mole

$$n = \frac{(45.39\text{kPa})(1.0\text{m}^3)}{(8.314\text{J/K} \cdot \text{mole})(298\text{K})} (10^3 \text{ Pa/kPa})$$

$$n = 18.32 \text{ moles}$$

b. For N₂

$$n = \frac{(40.63\text{kPa})(1.0\text{m}^3)}{(8.314\text{J/K} \cdot \text{mole})(298\text{K})} (10^3 \text{ Pa/kPa})$$

$$n = 16.40 \text{ moles}$$

c. For CO₂

$$n = \frac{(15.24\text{kPa})(1.0\text{m}^3)}{(8.314\text{J/K} \cdot \text{mole})(298\text{K})} (10^3 \text{ Pa/kPa})$$

$$n = 6.15 \text{ moles}$$

7-9 Volume of carbon dioxide

Given: carbon dioxide = 5.2 kg, P = 152.0 kPa, T = 315.0 K

Solution:

a. Compute number of moles

$$\text{GMW} = 12.011 + 2(16.00) = 44.0098$$

$$n = \frac{5200\text{g}}{44.0\text{g/mole}} = 118.18\text{moles}$$

b. Compute volume as in Problem 7-5

$$V = \frac{(118.18\text{mole})(8.3143\text{J/K} \cdot \text{mole})(315.0\text{K})}{(152.0\text{kPa})(1000\text{Pa/kPa})} (1000\text{L/m}^3)$$

$$V = 2,036 \text{ L}$$

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7-10 Mass of oxygen

Given: volume = 5.0 m^3 , pressure = 568.0 Pa , temp. = 263.0 K

Solution:

a. Solve Eqn. 7-2 for n

$$n = \frac{PV}{RT} = \frac{(568.0 \text{ Pa})(5.0 \text{ m}^3)}{(8.314 \text{ J/K} \cdot \text{mole})(263.0 \text{ K})}$$

$$n = 1.2988 \text{ moles}$$

b. Compute mass

$$M_{\text{O}_2} = (1.2988 \text{ moles})(31.9988 \text{ g/mole}) = 41.562 \text{ g}$$

7-11 Volume of $235 \mu\text{g}$ of O_3

Given: 1.00 m^3 of air; STP: 273.15 K , 101.325 kPa

Solution:

a. Calculate number of moles of O_3

GMW of O = 16.00 from inside cover of book

GMW of O_3 = $(3)(16.00) = 48.00 \text{ g/mole}$

$$n = \frac{(235 \mu\text{g})(10^{-6} \text{ g}/\mu\text{g})}{48.00} = 4.896 \times 10^{-6} \text{ moles}$$

b. From ideal gas law with $T = 273.15 \text{ K}$

$$V = \frac{(4.896 \times 10^{-6})(8.314)(273.15)}{101.325} = 1.097 \times 10^{-4} \text{ L}$$

c. Volumetric ratio

$$\frac{V_p}{V_{\text{air}}} = \frac{(1.097 \times 10^{-4} \text{ L})(10^{-3} \text{ m}^3/\text{L})}{1.0 \text{ m}^3} = 1.097 \times 10^{-7} \text{ V/V}$$

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7-12 Partial pressure of H₂S

Given: 250 mg/L of H₂S, Temperature = 0 °C, pressure = 108.26 kPa

Solution:

a. Compute number of moles

$$\text{GMW} = 2(1.0079) + 32.06 = 34.07 \text{ g/mole}$$

$$n = \frac{250 \text{ mg/L}}{34.07 \text{ g/mole} (10^3 \text{ mg/g})} = 0.0073366 \text{ mole/L}$$

b. Solve Eqn. 7-2 for P (see Problem 7-7)

$$P_{\text{H}_2\text{S}} = \frac{(0.0073366 \text{ moles})(8.314 \text{ J/K} \cdot \text{mole})(273.0 \text{ K}) \left(\frac{1000 \text{ L}}{\text{m}^3} \right) \left(\frac{\text{kPa}}{1000 \text{ Pa}} \right)}{1.0 \text{ L}}$$

$$P_{\text{H}_2\text{S}} = 16.7 \text{ kPa}$$

7-13 Partial pressures of CH₄, N₂, and CO₂

Given: 28 L volume, Temperature = 300 K, 11 g methane, 1.5 g nitrogen, 16 g carbon dioxide

Solution:

a. Compute moles of each gas

$$\text{GMW}_{\text{CH}_4} = 12.011 + 4(1.0079) = 16.04 \text{ g/mole}$$

$$n = \frac{11 \text{ g}}{16.04 \text{ g/mole}} = 0.6856 \text{ moles}$$

$$\text{GMW}_{\text{N}_2} = 2(14.0067) = 28.013 \text{ g/mole}$$

$$n = \frac{1.5 \text{ g}}{28.013 \text{ g/mole}} = 0.05355 \text{ moles}$$

$$\text{GMW}_{\text{CO}_2} = 12.011 + 2(15.9994) = 44.01$$

$$n = \frac{16\text{g}}{44.01\text{g/mole}} = 0.6856\text{moles}$$

b. Compute partial pressures (Eqn. 7-2)

$$P_{\text{CH}_4} = \frac{(0.6857\text{moles})(8.314\text{J/K} \cdot \text{mole})(300.0\text{K})}{28.0\text{L}} \left(\frac{1000\text{L}}{\text{m}^3} \right) \left(\frac{\text{kPa}}{1000\text{Pa}} \right)$$

$$P_{\text{CH}_4} = 61.08 \text{ or } 61 \text{ kPa}$$

$$P_{\text{N}_2} = \frac{(0.05355\text{moles})(8.314\text{J/K} \cdot \text{mole})(300.0\text{K})}{28.0\text{L}} \left(\frac{1000\text{L}}{\text{m}^3} \right) \left(\frac{\text{kPa}}{1000\text{Pa}} \right)$$

$$P_{\text{N}_2} = 4.77 \text{ or } 4.8 \text{ kPa}$$

$$P_{\text{CO}_2} = \frac{(0.3633\text{moles})(8.314\text{J/K} \cdot \text{mole})(300.0\text{K})}{28.0\text{L}} \left(\frac{1000\text{L}}{\text{m}^3} \right) \left(\frac{\text{kPa}}{1000\text{Pa}} \right)$$

$$P_{\text{CO}_2} = 32.36 \text{ or } 32 \text{ kPa}$$

7-14 Moles of gas present in Problem 7-13

Given: See Problem 7-13

Solution:

a. Compute moles of each gas

(Note: this is essentially a repetition of part of Problem 7-12 computed here with significant figures equal to that given)

$$\text{GMW}_{\text{CH}_4} = 12.011 + 4(1.0079) = 16.04 \text{ g/mole}$$

$$n = \frac{11\text{g}}{16.04\text{g/mole}} = 0.688\text{moles}$$

$$\text{GMW}_{\text{N}_2} = 2(14.0067) = 28.013 \text{ g/mole}$$

$$n = \frac{1.5\text{g}}{28.013\text{g/mole}} = 0.054\text{moles}$$

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$$\text{GMW}_{\text{CO}_2} = 12.011 + 2(15.9994) = 44.01$$

$$n = \frac{16\text{g}}{44.01\text{g/mole}} = 0.364\text{moles}$$

7-15 Gram molecular weight of air

Given: 22.414 L volume of air at STP, $P_{\text{O}_2} = 21.224 \text{ kPa}$, $P_{\text{N}_2} = 79.119 \text{ kPa}$, $P_{\text{Ar}} = 0.946 \text{ kPa}$, $P_{\text{CO}_2} = 0.036 \text{ kPa}$

Solution:

a. Compute number of moles of each gas

Oxygen

$$n = \frac{PV}{RT} = \frac{(21.224\text{kPa})(10^3 \text{ Pa/kPa})(22.414\text{L})(10^{-3} \text{ m}^3/\text{L})}{(8.314\text{J/K} \cdot \text{mole})(273.15\text{K})}$$

$$n = 0.20947 \text{ moles}$$

Nitrogen

$$n = \frac{PV}{RT} = \frac{(79.119\text{kPa})(10^3 \text{ Pa/kPa})(22.414\text{L})(10^{-3} \text{ m}^3/\text{L})}{(8.314\text{J/K} \cdot \text{mole})(273.15\text{K})}$$

$$n = 0.78086 \text{ moles}$$

Argon

$$n = \frac{PV}{RT} = \frac{(0.946\text{kPa})(10^3 \text{ Pa/kPa})(22.414\text{L})(10^{-3} \text{ m}^3/\text{L})}{(8.314\text{J/K} \cdot \text{mole})(273.15\text{K})}$$

$$n = 0.00934 \text{ moles}$$

Carbon dioxide

$$n = \frac{PV}{RT} = \frac{(0.036\text{kPa})(10^3 \text{ Pa/kPa})(22.414\text{L})(10^{-3} \text{ m}^3/\text{L})}{(8.314\text{J/K} \cdot \text{mole})(273.15\text{K})}$$

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$$n = 0.00036 \text{ moles}$$

b. Compute mass of each gas

$$M_{O_2} = (n)(GMW) = 0.209469(32.00) = 6.703$$

$$M_{N_2} = 0.78086(28.02) = 21.880$$

$$M_{Ar} = 0.009336(39.95) = 0.37297$$

$$M_{CO_2} = 0.000355(44.01) = 0.01562$$

c. Molecular weight of air

$$M_{O_2} + M_{N_2} + M_{Ar} + M_{CO_2} = 28.972 \text{ or } 28.97 \text{ g/mole}$$

7-16 GMW or air at 500 °C

Given: Temperature = 500 °C, Pressure = 101.325 kPa

Solution:

a. Compute the moles of each gas.

Note: P is standard pressure and $T = 273.15 + 500 = 773.15 \text{ K}$

Oxygen

$$n = \frac{PV}{RT} = \frac{(21.224 \text{ kPa})(10^3 \text{ Pa/kPa})(22.414 \text{ L})(10^{-3} \text{ m}^3/\text{L})}{(8.314 \text{ J/K} \cdot \text{mole})(773.15 \text{ K})}$$

$$n = 0.07401 \text{ moles}$$

Nitrogen

$$n = \frac{PV}{RT} = \frac{(79.119 \text{ kPa})(10^3 \text{ Pa/kPa})(22.414 \text{ L})(10^{-3} \text{ m}^3/\text{L})}{(8.314 \text{ J/K} \cdot \text{mole})(773.15 \text{ K})}$$

$$n = 0.27588 \text{ moles}$$

Argon

$$n = \frac{PV}{RT} = \frac{(0.946 \text{ kPa})(10^3 \text{ Pa/kPa})(22.414 \text{ L})(10^{-3} \text{ m}^3/\text{L})}{(8.314 \text{ J/K} \cdot \text{mole})(773.15 \text{ K})}$$

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$$n = 0.00330 \text{ moles}$$

Carbon dioxide

$$n = \frac{PV}{RT} = \frac{(0.036 \text{ kPa})(10^3 \text{ Pa/kPa})(22.414 \text{ L})(10^{-3} \text{ m}^3/\text{L})}{(8.314 \text{ J/K} \cdot \text{mole})(773.15 \text{ K})}$$

$$n = 0.00013 \text{ moles}$$

b. Compute mass of each gas

$$M_{\text{O}_2} = (n)(\text{GMW}) = (0.07401)(32.00) = 2.368$$

$$M_{\text{N}_2} = (0.27588)(28.02) = 7.7282$$

$$M_{\text{Ar}} = (0.00330)(39.95) = 0.1318$$

$$M_{\text{CO}_2} = (0.00013)(44.01) = 0.0055189$$

c. Molecular weight of air

$$M_{\text{O}_2} + M_{\text{N}_2} + M_{\text{Ar}} + M_{\text{CO}_2} = 8.102 \text{ g/mole}$$

7-17 Micrograms/m³ to ppm for SO₂

Given: 80 μg/m³ of SO₂, T = 25 °C, P = 101.325 kPa

Solution:

a. Compute GMW of SO₂

$$\text{GMW} = 32.06 + 32.00 = 64.06$$

b. Convert to ppm using Eqn. 7-7

$$\text{ppm} = \frac{\left(\frac{80}{64.06}\right)(22.414)\left(\frac{298}{273}\right)\left(\frac{101.325}{101.325}\right)}{(1.0)(1000)}$$

$$\text{ppm} = 0.030555 \text{ or } 0.031$$

7-18 ppm to $\mu\text{g}/\text{m}^3$ for NO_2

Given: 0.55 ppm of NO_2 , $T = -17.7^\circ\text{C} = 255.45\text{ K}$, $P = 100.0\text{ kPa}$

Solution:

a. Compute GMW of NO_2

$$\text{GMW} = 14.01 + 32.00 = 46.01$$

b. Convert to $\mu\text{g}/\text{m}^3$ using Eqn. 7-7

Note: Temperature = $273.15 - 17.7 = 255.45$

$$M_p = \frac{(0.55)(1000)(46.01)}{(22.414) \left(\frac{255.45}{273.15} \right) \left(\frac{101.325}{100.0} \right)}$$

$$M_p = 1191.45 \text{ or } 1191 \mu\text{g}/\text{m}^3$$

7-19 Convert ppm CO_2 to $\mu\text{g}/\text{m}^3$

Given: 370 ppm CO_2 at 20°C and 101.325 kPa

Solution:

a. Compute GMW of CO_2

$$\text{GMW} = 12.01 + 2(16.00) = 44.01$$

b. Convert to $\mu\text{g}/\text{m}^3$

$$M_p = \frac{(370)(1000)(44.01)}{(22.414) \left(\frac{293.15}{273.15} \right) \left(\frac{101.325}{101.325} \right)}$$

$$M_p = 676,932 \text{ or } 677,000 \mu\text{g}/\text{m}^3$$

7-20 Stability of atmosphere based on temperature profiles

Given: Elevations and temperatures

Solution:

Case a.

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Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(-6.21^{\circ}\text{C}) - (-3.05^{\circ}\text{C})}{318\text{m} - 2\text{m}} = -0.0100^{\circ}\text{C}/\text{m}$$

Lapse rate per 100 m is $-1.00^{\circ}\text{C}/100\text{ m}$

Compare with neutral condition and find that the atmosphere is neutral.

Case b.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(3.09^{\circ}\text{C}) - (6.00^{\circ}\text{C})}{202\text{m} - 10\text{m}} = -0.0152^{\circ}\text{C}/\text{m}$$

Lapse rate per 100 m is $-1.52^{\circ}\text{C}/100\text{ m}$

Compare with neutral condition and find that the atmosphere is unstable.

Case c.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(16.71^{\circ}\text{C}) - (14.03^{\circ}\text{C})}{286\text{m} - 18\text{m}} = +0.0100^{\circ}\text{C}/\text{m}$$

Lapse rate per 100 m is $+1.00^{\circ}\text{C}/100\text{ m}$

Compare with neutral condition and find that the atmosphere is stable. In fact, it is an inversion.

7-21 Stability of atmosphere based on temperature profiles

Given: Elevations and temperatures

Solution:

Case a.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(0.10^\circ\text{C}) - (-4.49^\circ\text{C})}{339\text{m} - 1.5\text{m}} = 0.0136^\circ\text{C}/\text{m}$$

Lapse rate per 100 m is 1.36 °C/100 m

Compare with neutral condition and find that the atmosphere is stable. In fact, it is an inversion.

Case b.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(19.67^\circ\text{C}) - (28.05^\circ\text{C})}{279\text{m} - 12\text{m}} = -0.0314^\circ\text{C}/\text{m}$$

Lapse rate per 100 m is -3.14 °C/100 m

Compare with neutral condition and find that the atmosphere is unstable.

Case c.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(18.93^\circ\text{C}) - (19.55^\circ\text{C})}{339\text{m} - 8\text{m}} = -0.00187^\circ\text{C}/\text{m}$$

Lapse rate per 100 m is -0.187 °C/100 m

Compare with neutral condition and find that the atmosphere is stable.

7-22 Stability of atmosphere based on temperature profiles

Given: Elevations and temperatures

Solution:

Case a.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(4.52^\circ\text{C}) - (5.00^\circ\text{C})}{50\text{m} - 2\text{m}} = -0.0100^\circ\text{C}/\text{m}$$

Lapse rate per 100 m is -1.00 °C/100 m

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Compare with neutral condition and find that the atmosphere is neutral.

Case b.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(5.00^\circ\text{C}) - (5.00^\circ\text{C})}{50\text{m} - 2\text{m}} = 0.00^\circ\text{C}/\text{m}$$

Lapse rate is 0.00 °C/100 m

Compare with the neutral condition and find that the atmosphere is stable. It is also isothermal.

Case c.

Compute lapse rate

$$\frac{\Delta T}{\Delta Z} = \frac{(-25.17^\circ\text{C}) - (-21.01^\circ\text{C})}{50\text{m} - 2\text{m}} = -0.08667^\circ\text{C}/\text{m}$$

Lapse rate is -8.67 °C/100 m

Compare with the neutral condition and find that the atmosphere is unstable.

7-23 Stability of atmosphere based on “Key”

Given: Time of year, time of day and wind speed

Solution:

Case a.

Because of late sunrise in winter, at 9:00 AM would expect solar insolation to be “slight.” With wind speed of 5.5 m/s the stability class would be D.

Case b.

The neutral class (D) is selected for all overcast conditions. See footnote to Table 7-8.

Case c.

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A clear winter night means $< 3/8$ cloud cover. With a wind speed of 2.8 m/s, select stability class F.

Case d.

At 11:30 AM in the summer we would expect the solar insolation to be strong. With a wind speed of 4.1 m/s, select stability class B.

7-24 Stability of atmosphere based on “Key”

Given: Time of year, time of day and wind speed

Solution:

Case a.

At 1:00 PM on a clear summer afternoon we would expect the solar insolation to be strong. With a wind speed of 1.6 m/s select stability class A.

Case b.

The neutral class (D) is selected for all overcast conditions. See footnote to Table 7-8.

Case c.

At 9:30 AM on a clear winter morning we would expect the solar insolation to be slight. With a wind speed of 6.6 m/s, select stability class D.

Case d.

Use the “thinly overcast” column and a wind speed of 2.4 m/s to select a stability class of E.

7-25 Stability of atmosphere based on “Key”

Given: Time of year, time of day, wind speed, and cloud cover

Solution:

Case a.

At 1:00 PM on a clear summer day we would expect solar insolation to be strong. With a wind speed of 5.6 m/s, select stability category C.

Case b.

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A clear summer night means “ $\leq 3/8$ cloud”. With a wind speed of 2.1 m/s, select stability category F.

Case c.

Overcast conditions have a default stability category of D. See footnote to Table 7-8.

Case d.

See the notes below Table 7-8. For broken clouds “strong” solar insolation (as expected on a clear summer afternoon) is reduced to “moderate” with a wind speed of 5.2 m/s, select class C-D.

7-26 Downwind distance to inversion layer (x_L)

Given: Time of year, time of day and wind speed, inversion base at 667 m

Solution:

a. Stability class

Because of late sunrise, solar insolation will be slight. With a wind speed of 2.6 m/s, select a stability class of C.

b. Compute S_z with Eqn. 7-24

$$S_z = 0.47(667) = 313.5 \text{ m}$$

c. Use Figure 7-23 with stability class C and $S_z = 313.5$ to locate x_L at 5.8 km. (Some allowance for graph reading should be given.)

7-27 Downwind distance to inversion layer (x_L)

Given: Time of year, time of day and wind speed, inversion base at 369 m

Solution:

a. Stability class

The neutral class (D) is selected for all overcast conditions. See footnote to Table 7-8.

b. Compute S_z with Eqn. 7-24

$$S_z = 0.47(369) = 173.43 \text{ m}$$

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- c. Use Figure 7-23 with stability class D and $S_z = 173.43$ to locate x_L at 14 km. (Some allowance for graph reading should be given.)

7-28 Distance downwind plume will begin mixing downward

Given: Time of year, time of day, wind speed, inversion base of 265 m, effective stack height of 85 m

Solution:

- a. Stability class

For overcast conditions, pick stability class D. See footnote to Table 7-8

- b. Compute S_z

$$S_z = 0.47(265 - 85) = 84.6 \text{ m}$$

- c. Using Figure 7-23, find $x_L = 4.5$ km

(Some allowance for graph reading should be given.)

7-29 Downwind concentration of SO_2

Given: Example 7-4, inversion base at 200 m, point downwind 4 km and 0.2 km perpendicular to plume

Solution:

- a. First check to see if Eqn. 7-25 should be used. Stability class D is given in Example 7-4.

$$S_z = 0.47(200) = 94.0 \text{ m}$$

Using Figure 7-23, we find $x_L = 5.5$ km and that the inversion form of the equation would apply beyond $2(5.5) = 11$ km. Since the concentration is to be calculated at 4 km, use Eqn. 7-19.

- b. Find plume standard deviations from Figures 7-22 and 7-23: $S_y = 230$ m, $S_z = 78$ m.

$$\text{By Eqn 7-22, } S_y = 68(4)^{0.894} = 234.8$$

$$\text{By Eqn 7-23, } S_z = 44.5(4)^{0.516} - 13 = 77.99.$$

- c. Calculate concentration (using $S_y = 230$ m, $S_z = 78$ m)

$$\chi = \frac{1656.2}{(\pi)(230)(78)(4.50)} \exp\left[-\frac{1}{2}\left(\frac{200}{230}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{128}{78}\right)^2\right]$$

$$\chi = (0.00653) \exp[-0.378] \exp[-1.346] = 1.16 \times 10^{-3} \text{ g/m}^3$$

Slightly different answer will result if Eqns. 7-22 and 7-23 are used.

7-30 Emission rate of TSP

Given: Stack parameters, atmospheric conditions and downwind concentration of 1,520 $\mu\text{g/m}^3$

Solution:

a. Determine stability class (Table 7-8)

Solar insolation will be strong on a clear summer afternoon. With a wind speed of 3.2 m/s, select stability class B.

b. Select Eqn. 7-19 because no inversion is specified.

c. Calculate plume rise (Eqn. 7-21)

$$\Delta H = \frac{(12.0)(1.50)}{3.20} \left[1.5 + \left(2.68 \times 10^{-2} (100.0) \left(\frac{595 - 301}{595} \right) (1.5) \right) \right] = 19.6 \text{ m}$$

d. Calculate effective stack height (Eqn. 7-20)

$$H = 75.0 + 19.6 = 94.6 \text{ m}$$

e. With stability class B and downwind distance of 2 km

$$\text{By Eqn 7-22, } S_y = 156(2)^{0.894} = 289.898$$

$$\text{By Eqn 7-23, } S_z = 108.2(2)^{1.098} - 2 = 233.61$$

f. Solve Eqn. 7-19 for E

$$E = \frac{(1520 \times 10^{-6})(\pi)(289.898)(233.61)(3.20)}{\exp\left[-\frac{1}{2}\left(\frac{500}{289.898}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{94.6}{233.61}\right)^2\right]}$$

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$$E = 4,970.91 \text{ or } 5,000 \text{ g/s}$$

7-31 Downwind concentration of SO₂

Given: Stack parameters, emission rate, 1976 g/s of SO₂, wind speed = 2.5 m/s, 1:00 AM on clear winter night, effective stack height = 85 m, inversion layer at 185 m

Solution:

a. Determine stability class

Based on clear sky at night and wind speed = 2.5 m/s, select stability category F

b. Check x_L

$$S_z = 0.47(185 - 85) = 47 \text{ m}$$

With stability class F and S_z = 47, find x_L ≅ 10 km in Figure 7-23

$$2x_L \cong 20 \text{ km}$$

Because 30 km > 20 km use Equation 7-25

c. Calculate S_y using Table 7-9 and Equation 7-22

$$S_y = 34(30)^{0.894} = 711.26$$

d. Calculate downwind concentration

$$\chi = \frac{1976}{\sqrt{2\pi}(711.26)(2.5)(185)} = 2.4 \times 10^{-3} \text{ g/m}^3$$

7-32 Maximum SO₂ concentration

Given: Coal specifications, stack data and meteorological conditions

Solution:

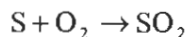
a. Computations to set up spreadsheet

(1) Select stability class

From Key at “thinly overcast” and wind speed = 3.8 m/s, select category D

(2) Calculate emission rate

Note: 95% conversion efficiency (see Example 7-2)



GMW: 32 32 64

Thus, 1 g of S in coal yields:

$$(1\text{g})\left(\frac{64}{32}\right) = 2\text{g } SO_2$$

From burning rate and 2.80% S in coal and 95% conversion efficiency:

$$E = (28.82 \times 10^6 \text{ g/h})\left(\frac{1}{3600\text{s/h}}\right)(0.0280)\left(\frac{64}{32}\right)(0.95)$$

$$E = 425.90 \text{ g/s}$$

(3) Calculate effective stack height (Eqn. 7-21). Note T is absolute temp in K

$$\Delta H = \frac{(10.5)(1.8)}{3.8} \left[1.5 + (2.68 \times 10^{-2})(103.285) \left(\frac{570 - 262}{570} \right) (1.8) \right] = 20.84\text{m}$$

$$H = 40.0 \text{ m} + 20.84 \text{ m} = 60.84 \text{ m}$$

(4) Estimate downwind distance to switch from Eqn. 7-19 to Eqn. 7-25

(a) Calculate S_z

$$S_z = 0.47(170.0 - 60.84) = 51.3 \text{ m}$$

(b) From Figure 7-23 at stability class D and $S_z = 51.3 \text{ m}$, read

$$x_L = 2.1 \text{ km}$$

(c) Switch from Eqn. 7-19 to Eqn. 7-25 at $2(2.1) = 4.2 \text{ km}$

b. See following spreadsheet calculations

Stability class	D
Emission rate	425.9 g/s
Effective stack height	60.84 m
Inversion base =	170 m
x_L	2.1 km
$2x_L$	4.2 km
Wind speed	3.8 m/s

continued on following page

Distance	s_y	s_z	First Term	Exponential	χ
0.1	8.679784	4.553715	0.902608	1.7316E-39	1.563E-39
0.2	16.12983	8.636769	0.25609	1.6776E-11	4.296E-12
0.3	23.1769	12.16919	0.12649	3.7357E-06	4.725E-07
0.4	29.9744	15.38565	0.077358	0.00040227	3.112E-05
0.5	36.59216	18.3859	0.053027	0.00419052	0.0002222
0.6	43.07012	21.22439	0.039027	0.01643321	0.0006413
0.7	49.43409	23.93505	0.030152	0.03953478	0.001192
0.8	55.70207	26.54089	0.024132	0.07226988	0.001744
0.9	61.88733	29.05841	0.019838	0.11171336	0.0022162
1	68	31.5	0.016655	0.15486397	0.0025793
1.5	97.70898	41.85587	0.008723	0.34769913	0.0030331
2	126.3659	50.63433	0.005576	0.48584348	0.0027089
3	181.5747	65.44307	0.003002	0.64912067	0.0019489
4	234.8284	77.99614	0.001948	0.73769109	0.0014369
5	286.6739	89.10066	0.001397		0.0009176
6	337.4241	99.17241	0.001066		0.0007796
7	387.2813	108.4593	0.000849		0.0006792
8	436.3866	117.1231	0.000698		0.0006028
9	484.8437	125.2767	0.000587		0.0005426
10	532.7322	133.0024	0.000504		0.0004938
20	989.9875	195.7812	0.000184		0.0002657
30	1422.51	244.368	0.000103		0.0001849
40	1839.715	285.554	6.79E-05		0.000143
50	2245.888	321.9874	4.93E-05		0.0001171
60	2643.481	355.0324	3.8E-05		9.951E-05
70	3034.077	385.5021	3.05E-05		8.67E-05
80	3418.782	413.9278	2.52E-05		7.695E-05
90	3798.409	440.6795	2.13E-05		6.926E-05
100	4173.582	466.027	1.83E-05		6.303E-05

c. Use highest value of χ on spreadsheet to calculate ppm using Eqn. 7-7

$$\text{ppm} = \frac{\left(\frac{0.0030331 \text{ g/m}^3 (1000000 \mu\text{g/g})}{64} \right) (22.414) \left(\frac{101.325}{103.285} \right) \left(\frac{262}{273} \right)}{1.0(1000)}$$

$$\text{ppm} = 1.00$$

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7-33 Ventilation rate to reduce concentration to 0.05 ppm

Given: Steady-state conditions, $\text{CH}_2\text{O} = 0.28 \text{ ppm}$, outdoor air = 0.0 ppm, $V = 148 \text{ m}^3$, $k = 1.11 \times 10^{-4} \text{ s}^{-1}$

Table 7-11 p. 598

Solution:

a. Calculate Q in m^3/h

$$Q = \text{ventilation rate} = (0.56 \text{ ach})(148 \text{ m}^3) = 82.88 \text{ m}^3/\text{h}$$

b. Estimate emission rate (E) in ppm/h

$$k = (1.1 \times 10^{-4} \text{ s}^{-1})(3600 \text{ s/h}) = 0.3996 \text{ h}^{-1}$$

$$0.28 = \frac{(82.88 \text{ m}^3/\text{h})(0.0) + E}{82.88 \text{ m}^3/\text{h} + (0.3996 \text{ h}^{-1})(148 \text{ m}^3)}$$

$$E = 39.77 \text{ ppm/h}$$

c. Estimate new ventilation rate

$$0.05 = \frac{0 + 39.77 \text{ ppm}}{Q + (0.3996 \text{ h}^{-1})(148 \text{ m}^3)}$$

$$Q = 736.11 \text{ m}^3/\text{h}$$

d. In air changes per hour

$$\text{ach} = \frac{736.11 \text{ m}^3/\text{h}}{148 \text{ m}^3} = 4.97 \text{ or } 5 \text{ ach}$$

7-34 Set point for CO alarm

Given: Furnace emits 3 mg/s of CO, $V = 540 \text{ m}^3$, $C = 10 \text{ mg/m}^3$, $k = 0.0$, $Q = 100 \text{ m}^3/\text{h}$

Solution:

Indoor Air Quality - Carbon Monoxide		
E	3	mg/s
V	540	m ³
C _a	10	mg/m ³ =NAAQS 8 hour std
Q	0.0278	m ³ /s =100 m ³ /h
k	0.00E+00	s ⁻¹
C ₀	1	mg/m ³

General Equation	
E/V	0.005555556
C _a Q/V	0.000514815
Q/V	5.14815E-05
First term	117.9136691
Exp Pwr	5.14815E-05

t _{allowed} [hours]	C _i [mg/m ³]	t [hours]	Safety factor
8	10	0.43	0.054027143
1	30	1.54	1.538204091
0.5	60	3.79	7.580744826
0.25	100	10.12	40.48644032

7-35 Slope of equilibrium curve for HCl

Given: Pressure and corresponding liquid concentrations

Solution:

- a. Convert to mole fractions (example)

$$x^* = \frac{38.9}{\frac{36.46 \text{GMW} \cdot \text{HCl}}{38.9} + \frac{100}{18.015}} = 0.1612$$

$$y^* = \frac{0.6533}{101.325} = 0.006477$$

- b. The following table was calculated in a similar fashion

x*	y*
0.1612	0.006477
0.1351	0.000859
0.1099	0.000269

- c. Perform a linear regression to find $m = 0.120$, $b = 0.139$ and $y = 0.120x - 0.0139$

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7-36 Slope of equilibrium line for SO₂

Given: Pressures and water concentrations

Solution:

a. Convert to mole fractions as in Problem 7-35

b. Tabulation of mole fractions

x*	y*
0.0028	0.1039
0.0020	0.0684
0.0014	0.0474
0.0008	0.0259

c. By least squares linear regression

$$m = 39.71$$

7-37 Height of packed tower to remove H₂S

Given: Operating conditions for tower

Solution:

a. Compute mole fractions at inlet and outlet

Since operating temperature is 25 °C, the density of air is 1.185 kg/m³.

$$y_1 = \frac{\frac{0.100 \text{ kg/m}^3}{34.07 \text{ GMW} \cdot \text{H}_2\text{S}}}{\frac{1.185 \text{ kg/m}^3}{28.97 \text{ GMW} \cdot \text{air}}} = 0.071755$$

$$y_2 = \frac{\frac{0.005 \text{ kg/m}^3}{34.07 \text{ GMW} \cdot \text{H}_2\text{S}}}{\frac{1.185 \text{ kg/m}^3}{28.97 \text{ GMW} \cdot \text{air}}} = 0.003587$$

$$x_2 = 0.0$$

b. Compute the value of A (see example 7-7)

$$A = \frac{5.522 \left(\frac{5 \text{ kg/s air}}{28.97 \text{ GMW} \cdot \text{air}} \right)}{\frac{20 \text{ kg/s H}_2\text{O}}{18.015 \text{ GMW} \cdot \text{H}_2\text{O}}} = 0.858464$$

c. Number of gas transfer units (Eqn. 7-46)

$$N_{\text{og}} = \frac{\ln \left[\frac{0.071755 - 5.522(0)}{0.002587 - 5.522(0)} (1 - 0.8584) + 0.8584 \right]}{1 - 0.8584} = 9.233$$

d. Height of individual gas transfer unit (Eqn. 7-47)

$$H_{\text{og}} = 0.444 + 0.8584(0.325) = 0.723$$

e. Height of tower (Eqn. 7-45)

$$Z_t = (9.233)(0.723) = 6.6 \text{ or } 7 \text{ m}$$

7-38 Height of packed tower to reduce H₂S concentration to 0.0002 mg/L

Given: Problem 7-37, initial concentration = 0.100 kg/m³, final concentration = 0.0002 mg/L

Solution:

a. Compute mole fractions at inlet and outlet with operation temp. = 25 °C, air density = 1.185 kg/m³

Note: (0.0002 mg/L)(10³ L/m³)(10⁻⁶ kg/mg) = 2 x 10⁻⁷ kg/m³

$$y_1 = \frac{\frac{0.100 \text{ kg/m}^3}{34.07 \text{ GMW} \cdot \text{H}_2\text{S}}}{\frac{1.185 \text{ kg/m}^3}{28.97 \text{ GMW} \cdot \text{air}}} = 0.071755$$

$$y_2 = \frac{\frac{2 \times 10^{-7}}{34.07 \text{GMW} \cdot \text{H}_2\text{S}}}{\frac{1.185 \text{ kg/m}^3}{28.97 \text{GMW} \cdot \text{air}}} = 1.4351 \times 10^{-7}$$

$$x_2 = 0.0$$

b. Compute the value of A

$$A = \frac{5.522 \left[\frac{5 \text{ kg/s air}}{28.97 \text{GMW} \cdot \text{air}} \right]}{\frac{20 \text{ kg/s H}_2\text{O}}{18.015 \text{GMW} \cdot \text{H}_2\text{O}}} = 0.858464$$

c. Number of gas transfer units

$$N_{\text{og}} = \frac{\ln \left[\frac{0.071755 - 5.522(0)}{1.4351 \times 10^{-7} - 5.522(0)} (1 - 0.8584) + 0.8584 \right]}{1 - 0.8584} = 78.87$$

d. Height of individual gas transfer unit

$$H_{\text{og}} = 0.444 + (0.8584)(0.325) = 0.723$$

e. Height of tower $Z_t = (78.87)(0.723) = 57.02$ or 57 m

Obviously an impractical solution!

7-39 Height of packed tower to remove Cl_2

Given: Operating conditions for tower

Solution:

a. Compute mole fractions at inlet and outlet

Since operating temperature is 20°C , the density of air is 1.205 kg/m^3 (see example problem for calculation).

$$y_1 = \frac{\frac{10.0 \text{ mg/m}^3 (10^{-6} \text{ kg/mg})}{70.906 \text{ GMW} \cdot \text{Cl}_2}}{\frac{1.205 \text{ kg/m}^3}{28.97 \text{ GMW} \cdot \text{air}}} = 3.39 \times 10^{-6}$$

$$y_2 = \frac{\frac{2.95 \text{ mg/m}^3 (10^{-6} \text{ kg/mg})}{70.906 \text{ GMW} \cdot \text{Cl}_2}}{\frac{1.205 \text{ kg/m}^3}{28.97 \text{ GMW} \cdot \text{air}}} = 1.00 \times 10^{-6}$$

$$x_2 = 0.0$$

b. Compute the value of A

$$A = \frac{6.820 \left[\frac{3 \text{ kg/s air}}{28.97 \text{ GMW} \cdot \text{air}} \right]}{\frac{15 \text{ kg/s H}_2\text{O}}{18.015 \text{ GMW} \cdot \text{H}_2\text{O}}} = 0.848203$$

c. Number of gas transfer units

$$N_{\text{og}} = \frac{\ln \left[\frac{3.39 \times 10^{-6} - 6.820(0)}{1.00 \times 10^{-6} - 6.820(0)} (1 - 0.8482) + 0.8482 \right]}{1 - 0.8482} = 2.039$$

d. Height of individual gas transfer unit

$$H_{\text{og}} = 0.662 + 0.8482(0.285) = 0.9037$$

e. Height of tower

$$Z_t = (2.039)(0.9037) = 1.84 \text{ or } 2 \text{ m}$$

7-40 Langmuir Constants for hydrogen sulfide (H_2S)

Given: Partial pressures and mass adsorption data

Solution:

a. Calculate equilibrium concentration of gas

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Assume standard atmospheric pressure = 101.325 kPa

$$C^* = \left(\frac{P_{H_2S}}{101.325} \right) \left(\frac{GMW \cdot H_2S}{GMW \cdot air} \right)$$

$$C^* = \left(\frac{0.840}{101.325} \right) \left(\frac{34.08}{28.97} \right) = 0.009752$$

b. Complete table of C^* and C^*/W

P_{H_2S}	C^*	W	C^*/W
0.840	0.009752	0.082	0.1189
1.667	0.01935	0.1065	0.1817
2.666	0.03095	0.118	0.2623
3.333	0.03869	0.122	0.3171

c. From plot on following page

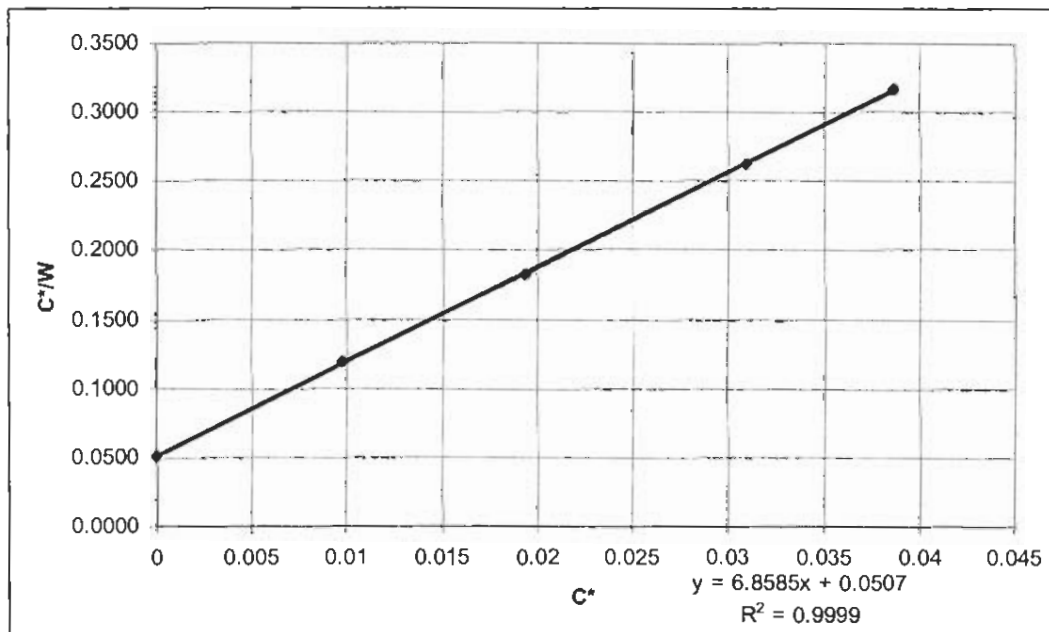


Figure S-7-40: Plot to determine Langmuir constants for H_2S on molecular sieve

$$\text{Intercept} = \frac{1}{a} = 0.0507$$

$$a = 19.72 \text{ or } 20$$

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$$\text{Slope} = \frac{b}{a} = 6.8583$$

$$b = (6.8583)(19.72) = 135.25 \text{ or } 135$$

7-41 Langmuir Constants for benzene (C_6H_6)

Given: Partial pressures and mass adsorption data

Solution:

a. Compute C^* as in 7-40

$P_{C_6H_6}$	C^*	W	C^*/W
0.027	0.00072	0.129	0.00556
0.067	0.00178	0.170	0.01047
0.133	0.00354	0.204	0.01735
0.266	0.00708	0.240	0.02950

b. From plot

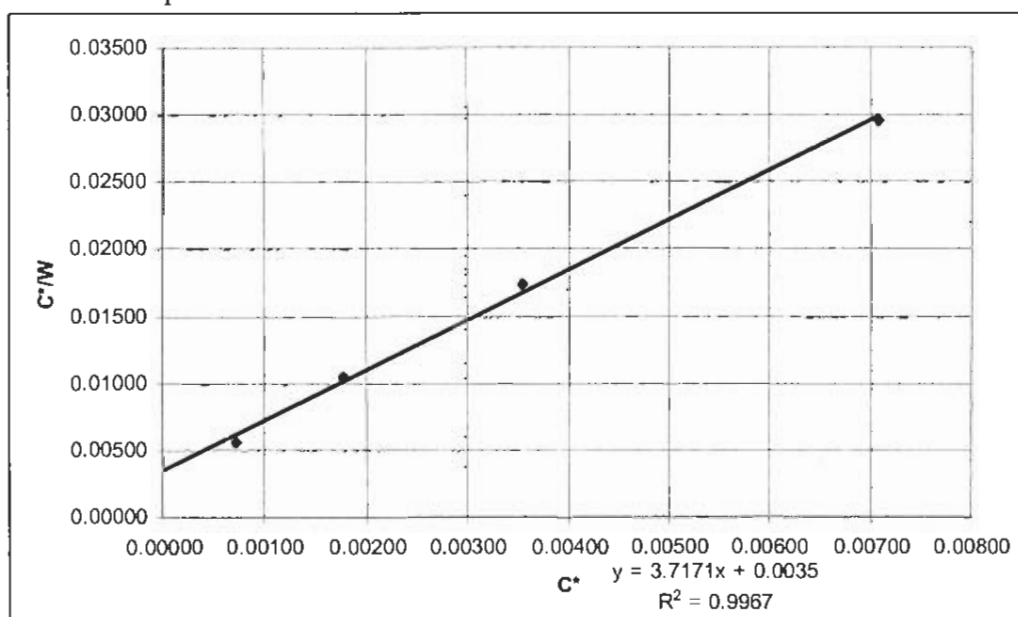


Figure S-7-41: Plot to determine Langmuir constants for C_6H_6

$$\text{Intercept} = \frac{1}{a} = 0.0035$$

$$a = 285.71 \text{ or } 286$$

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$$\text{Slope} = \frac{b}{a} = 3.7171$$

$$b = (3.7171)(285.71) = 1062.03 \text{ or } 1060$$

7-42 Freundlich constants

Given: Table of q_e vs. C_e

Solution:

C_e	q_e
70	520
170	550
700	640
1750	690
4000	740
7000	780

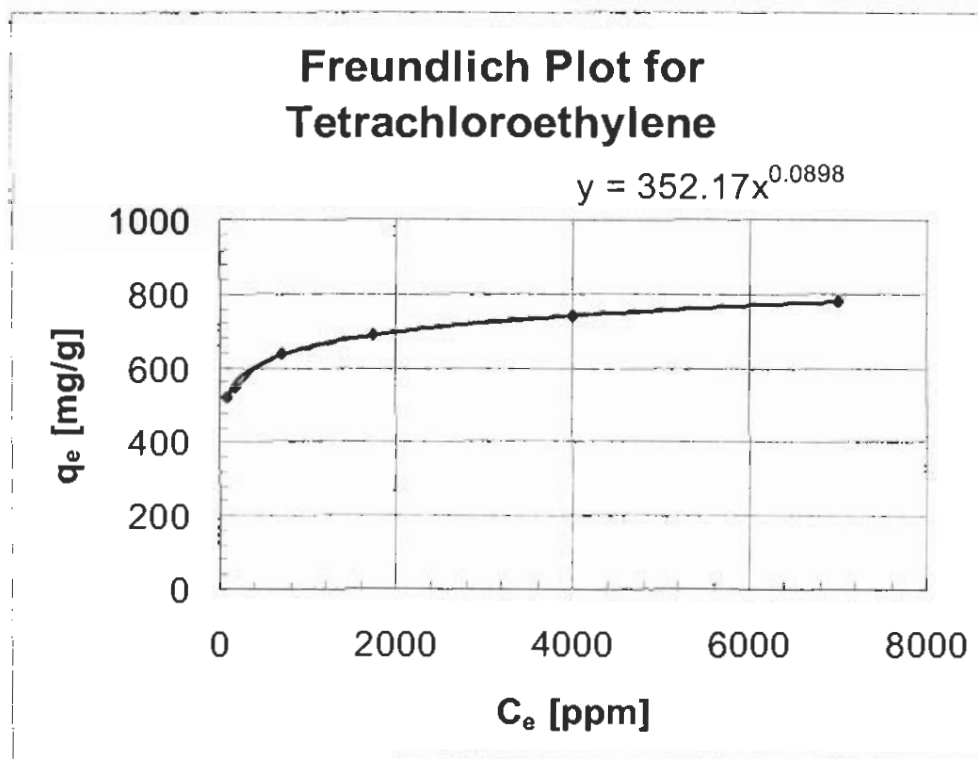


Figure S-7-42: Freundlich plot

From the curve fitting equation

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$$K = 352.17$$

$$n = 0.0898$$

7-43 Breakthrough time

Given: Carbon column design and operating data

Solution:

a. From Appendix A, $\rho_g = 1.185 \text{ kg/m}^3$

b. Face velocity (Eqn. 7-52)

$$v_r = \frac{(1.185 \text{ kg/m}^3)(1 + 3000(0.00350))}{(465)(450)(1.185 \text{ kg/m}^3)(5.0)} = 1.1 \times 10^{-5} \text{ m/s}$$

c. Breakthrough time

$$t_B = \frac{0.75\text{m} - 0.045\text{m}}{1.1 \times 10^{-5} \text{ m/s}} = 6.409 \times 10^4 \text{ s}$$

$$t_B = \frac{6.409 \times 10^4 \text{ s}}{3600 \text{ s/h}} = 17.8 \text{ h}$$

7-44 Thickness of adsorption bed

Given: Carbon column operating data

Solution:

a. Gas density at 25 °C and 105 kPa from Appendix A.

$$\text{Interpolate to find } \rho_g = 1.22685$$

b. From Dalton's law, partial pressure may be determined from ratio of volumes.

$$\text{Since pollutant concentration is 3000 ppm (V/V ratio): } 3000 \text{ ppm} = 0.30\% = 0.003$$

$$C^* = (0.003)(2.36 \text{ m}^3/\text{s})(1.22685 \text{ kg/m}^3) = 0.00869 \text{ kg/s}$$

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c. Calculate cross sectional area

$$A_c = \frac{\pi(3.00)^2}{4} = 7.0686\text{m}^2$$

d. Calculate face velocity

$$v_f = \frac{(2.36)(1.22685)(1 + 900(0.00869))}{(400)(390)(1.22685)(7.0686)} = 1.888 \times 10^{-5} \text{ m/s}$$

e. Solve for height of bed (Eqn. 7-50)

$$Z_t = (t_B)(v_f) + \delta$$

$$Z_t = (8 \text{ h})(3600 \text{ s/h})(1.888 \times 10^{-5} \text{ m/s}) + 0.028$$

$$Z_t = 0.5717 \text{ or } 0.57 \text{ m}$$

7-45 Catalyst dimensions to remove toluene

Given: $C_{in} = 1.87 \text{ g/m}^3$, $C_{out} = 0.00187 \text{ g/m}^3$, $Q_{in} = 16.33 \text{ m}^3/\text{s}$, Combustion air = $1.80 \text{ m}^3/\text{s}$, $T_{in} = 20 \text{ }^\circ\text{C}$, $T_{combustion} = 510 \text{ }^\circ\text{C}$, bed gas velocity = 7.5 m/s , $k = 120 \text{ s}^{-1}$

Solution:

a. Volumetric flow rate at $510 \text{ }^\circ\text{C}$

$$Q_T = (16.33 + 1.80) \left(\frac{510 + 273}{20 + 273} \right) = 48.45 \text{ m}^3/\text{s}$$

b. Cross sectional area to obtain 7.5 m/s velocity

$$\text{Area} = \frac{48.54 \text{ m}^3/\text{s}}{7.5 \text{ m/s}} = 6.46 \text{ or } 6.5 \text{ m}^2$$

c. Desired retention time (1^{st} order kinetics)

$$\frac{C_t}{C_0} = \frac{0.00187}{1.87} = 0.0010$$

$$0.0010 = \exp(-120(t))$$

$$\ln(0.0010) = -120(t)$$

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$$t = 0.0576 \text{ s}$$

d. Depth of catalyst

$$D = (7.5 \text{ m/s})(0.0676 \text{ s}) = 0.4317 \text{ or } 0.43 \text{ m}$$

7-46 Catalyst dimensions to remove hexane

Given: $C_{in} = 454 \text{ g/min}$, $C_{out} = 100 \text{ ppm}$ at STP, $Q_{in} = 7.1 \text{ m}^3/\text{s}$, $T_{in} = 315 \text{ }^\circ\text{C}$, $Q_{\text{combustion}} = 550 \text{ }^\circ\text{C}$, bed gas velocity = 9.5 m/s , $k = 55 \text{ s}^{-1}$

Solution:

a. Volumetric gas flow rate at $550 \text{ }^\circ\text{C}$

$$Q_{in} = (7.1) \left(\frac{550 + 273}{315 + 273} \right) = 9.94 \text{ m}^3/\text{s}$$

$$Q_{\text{combustion}} = (0.70) \left(\frac{550 + 273}{20 + 273} \right) = 1.97 \text{ m}^3/\text{s}$$

$$Q_T = 9.94 + 1.97 = 11.91 \text{ m}^3/\text{s}$$

b. Cross sectional area

$$\text{Area} = \frac{11.91 \text{ m}^3/\text{s}}{9.5 \text{ m/s}} = 1.25 \text{ m}^2$$

c. Convert 454 g/min to g/m^3 at STP

$$Q_{\text{gas}} = (7.1 \text{ m}^3/\text{s})(60 \text{ s/min}) = 426.0 \text{ m}^3/\text{min}$$

At STP

$$(426.0 \text{ m}^3/\text{min}) \left(\frac{273}{315 + 273} \right) = 197.79 \text{ m}^3/\text{min}$$

$$C_0 = \frac{454.0 \text{ g/min}}{197.79 \text{ m}^3/\text{min}} = 2.295 \text{ g/m}^3$$

d. Convert 1.0 ppm to g/m^3

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Solve Eqn. 7-7 for M_p

GMW Hexane (C_6H_{14})

$$6(12.01) + 14(1.008) = 86.172$$

$$M_p = \frac{(100\text{ppm})(1000)(86.172\text{ g/mole})}{(22.414)\left(\frac{273}{273}\right)\left(\frac{101.325}{101.325}\right)} = 3.845 \times 10^5 \mu\text{g/m}^3$$

e. Desired retention time (1st order kinetics)

$$\frac{C_1}{C_0} = \frac{3.845 \times 10^{-1} \text{ g/m}^3}{2.295 \text{ g/m}^3} = 0.168$$

$$0.168 = \exp(-55(t))$$

$$\ln(0.168) = -55(t)$$

$$t = 0.032 \text{ s}$$

f. Depth of catalyst

$$D = (9.5 \text{ m/s})(0.032 \text{ s}) = 0.309 \text{ m or } 0.3 \text{ m}$$

7-47 Cyclone efficiency for 1.0 m barrel

Given: 2.50 μm diameter particle, $\rho = 1250 \text{ kg/m}^3$, $Q_g = 2.80 \text{ m}^3/\text{s}$, $T = 25 \text{ }^\circ\text{C}$

Solution:

a. Using Figure 7-35 with $D_2 = 1.0 \text{ m}$

$$B = 0.25(1.0) = 0.250 \text{ m}$$

$$H = 0.5(1.0) = 0.50 \text{ m}$$

$$L_1 = L_2 = 2(1.0) = 2.0 \text{ m}$$

b. The number of turns is

$$\theta = \frac{\pi}{0.50} [2(2.0) + 2.0] = 37.7$$

c. From the gas temperature and Table A-3 the dynamic viscosity is $18.5 \mu\text{Pa}\cdot\text{s}$

d. The cut diameter is

$$d_{0.5} = \left[\frac{9(18.5 \times 10^{-6} \text{ Pa} \cdot \text{s})(0.250 \text{ m})^2 (0.50 \text{ m})}{(1250 \text{ kg/m}^3)(2.80 \text{ m}^3/\text{s})(37.7)} \right]^{1/2} = 6.28 \times 10^{-6} \text{ m}$$

$$= 6.28 \mu\text{m}$$

e. The ratio of particle sizes is

$$\frac{d}{d_{0.5}} = \frac{2.50 \mu\text{m}}{6.28 \mu\text{m}} = 0.398 \text{ or } 0.4$$

f. From Figure 7-36 the efficiency is about 14%

7-48 Cyclone efficiency for multiclone

Given: Data in Problem 7-47 and $D_2 = 0.10 \text{ m}$

Solution:

a. Using Figure 7-35 with $D_2 = 0.10 \text{ m}$

$$B = 0.25(0.10) = 0.025$$

$$H = 0.5(0.10) = 0.050$$

$$L_1 = L_2 = 2(0.10) = 0.20 \text{ m}$$

b. From the gas temperature and Table A-3 the dynamic viscosity is $18.5 \mu\text{Pa}\cdot\text{s}$

c. The cut diameter (with $Q = \frac{2.80 \text{ m}^3/\text{s}}{10} = 0.280 \text{ m}^3/\text{s}$)

$$d_{0.5} = \left[\frac{9(18.5 \times 10^{-6} \text{ Pa} \cdot \text{s})(0.025 \text{ m})^2 (0.05 \text{ m})}{(1250 \text{ kg/m}^3)(0.280 \text{ m}^3/\text{s})(37.7)} \right]^{1/2} = 6.28 \times 10^{-7} \text{ m}$$

$$= 0.628 \mu\text{m}$$

d. The ratio of particle sizes is

$$\frac{d}{d_{0.5}} = \frac{2.50 \mu\text{m}}{0.628 \mu\text{m}} = 3.98$$

e. From Figure 7-36 the efficiency is about 0.95 or 95%

7-49 Cyclone efficiency

Given: Cyclone in example 7-10; $\rho_p = 1000 \text{ kg/m}^3$; radii of 1.00, 5.00, 10.00, and 25.00 μm

Solution:

a. Determine cut diameter

$$d_{0.5} = \left[\frac{9(18.5 \times 10^{-6} \text{ Pa} \cdot \text{s})(0.125 \text{ m})^2 (0.25 \text{ m})}{(1000 \text{ kg/m}^3)(4.0 \text{ m}^3/\text{s})(37.7)} \right]^{1/2} = 2.08 \times 10^{-6} \text{ m}$$

$$= 2.08 \mu\text{m}$$

b. Ratio of particle sizes and efficiencies from Figure 7-36 remembering that $d = 2r$

Particle dia. [μm]	$d/d_{0.5}$	Efficiency
2	0.963026485	45
10	4.815132423	98
20	9.630264846	100
50	24.07566212	100

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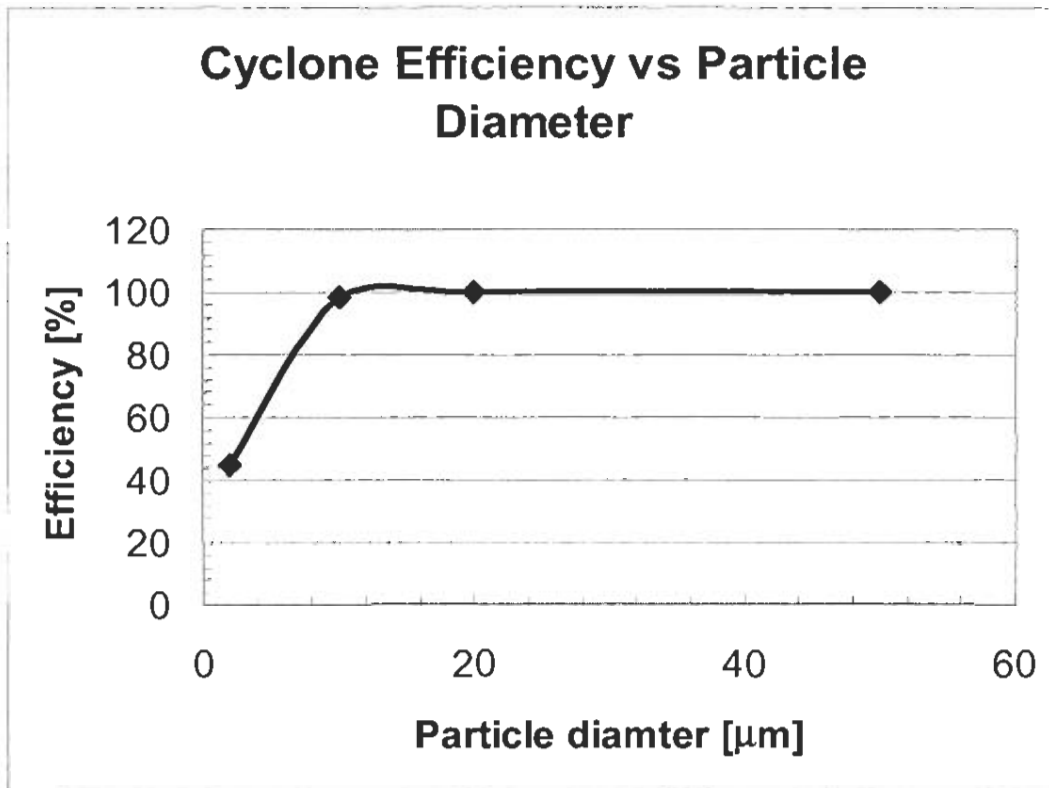


Figure S-7-49: Cyclone efficiency

7-50 Pulse-jet baghouse to replace mechanical shaker

Given: Example 7-11, 15 cm diameter x 5 m long bags, air to cloth ratio of 0.050 m/s

Solution:

a. Area required

$$A = \frac{20 \text{ m}^3/\text{s}}{0.050 \text{ m}^3/\text{s} \cdot \text{m}^2} = 400 \text{ m}^2$$

b. The net number of bags required is

$$\frac{400 \text{ m}^2}{\pi(0.15 \text{ m})(5 \text{ m})} = 169.77 \text{ or } 170 \text{ bags}$$

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7-51 Reverse air baghouse for coffee bean screening

Given: Emission = 0.75 g/m^3 , $Q = 3.3 \text{ m}^3/\text{s}$, bag diameter = 20 cm, length = 12 m, $A/C = 0.010$, bag cleaning = 0.5

Solution:

a. Area required

$$A = \frac{3.3 \text{ m}^3/\text{s}}{0.010 \text{ m}^3/\text{s} \cdot \text{m}^2} = 330 \text{ m}^2$$

b. Net number of bags

$$\frac{330 \text{ m}^2}{\pi(0.20 \text{ m})(12 \text{ m})} = 43.77 \text{ or } 44 \text{ bags}$$

c. With 50% off-line for cleaning, the additional number of bags is

$$\frac{44}{2} = 22$$

And the total number of bags is $44 + 22 = 66$ bags

d. Mass of particulate collected

$$M_p = (0.75 \text{ g/m}^3)(3.3 \text{ m}^3/\text{s})(86400 \text{ s/d})(0.99) = 211,702 \text{ g or } 210 \text{ kg/d}$$

7-52 Overall efficiency of venturi

Given: Example 7-12 and particle size distribution

Solution:

a. Calculate Cunningham correction factor for smallest particle to see if d_p term can be ignored.

$$C = 1 + \frac{(6.21 \times 10^{-4})(1.50)}{2.5} = 1.04 \text{ or } 1.0$$

Therefore for all particles $> 2.5 \mu\text{m}$ we can see that the term containing d_p will be small and can use the approximation $C = 1$.

b. Determine gas velocity at throat:

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$$v_g = \frac{94.4 \text{ m}^3/\text{s}}{1.0 \text{ m}^2} = 94.4 \text{ m/s}$$

c. Calculating psi in terms of d

$$\Psi = \frac{(1)(700)(94.4)(d_p)^2(10^{-12})}{18(100 \times 10^{-6})(2.38 \times 10^{-5})} = 1.54(d_p)^2$$

d. Taking the square root of Ψ and computing R as 0.13/94.40, the expression for efficiency as a function of diameter is then:

$$\eta = 1 - \exp[-0.342(d_p)]$$

e. Example calculation for diameter of 2.5 μm

$$\eta = 1 - \exp[-0.342(2.5)] \times 100\% = 57.47\%$$

f. Therefore mass efficiency

$$25\% \text{ total mass} \times 57.47\% = 14.36\%$$

g. Tabulated results:

Paricle Diameter [μm]	% of total mass	Efficiency	Mass Efficiency [%]
2.5	25	0.5747	14.37
7.5	20	0.9231	18.46
15	15	0.9941	14.91
25	15	0.9998	15.00
35	10	0.9999	10.00
50	15	0.9999	15.00
	100		87.74

h. Therefore the overall mass efficiency is = 88%

7-53 Venturi throat area to achieve efficiency = 99%

Given: $d_p = 2.50 \mu\text{m}$, $\rho_p = 1400 \text{ kg/m}^3$, $Q_g = 10.0 \text{ m}^3/\text{s}$, temperature = 180 °C, $Q_l = 0.100 \text{ m}^3/\text{s}$, $k = 200$, droplet diameter = 100 μm

Solution:

a. Solve Eqn. 7-58 for Ψ

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$$R = \frac{Q_l}{Q_g} = \frac{0.100}{10.0} = 0.01$$

$$0.99 = 1 - \exp[-(200)(0.01)(\Psi)^{1/2}]$$

$$0.99 = 1 - \exp[-(2)(\Psi)^{1/2}]$$

$$-0.01 = -\exp[-(2)(\Psi)^{1/2}]$$

$$\ln(0.01) = \ln(\exp[-(2)(\Psi)^{1/2}])$$

$$-4.6052 = -2.0(\Psi)^{1/2}$$

$$\Psi = 5.30$$

b. Cunningham correction factor ($T = 180 + 273 = 453$, $d_p = 2(1.25) = 2.50 \mu\text{m}$)

$$C = 1 + \frac{(6.21 \times 10^{-4})(453)}{2.5} = 1.11$$

c. Find μ from footnote in Table A-4 assuming $p = 101.325$

$$\mu = 17.11 + 0.0536(180) + 101.325/8280 = 26.77 \mu\text{Pa}\cdot\text{s}$$

d. Solve Eqn. 7-59 for v_g

$$v_g = \frac{(\Psi)(18)(d_d)(\mu)}{(C)(\rho_p)(d_p)^2}$$

$$v_g = \frac{(5.30)(18)(100 \times 10^{-6})(26.77 \times 10^{-6})}{(1.11)(1400)(2.50 \times 10^{-6})^2} = 26.3 \text{ m/s}$$

e. For $Q_g = 10.0 \text{ m}^3/\text{s}$

$$A = \frac{10.0 \text{ m}^3/\text{s}}{26.3 \text{ m/s}} = 0.38 \text{ m}^2$$

$$\text{Throat area} = 0.38 \text{ m}^2$$

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7-54 Overall mass efficiency

Given: particle size distribution and data from Problem 7-53

Solution:

Gas temperature	180 °C =	453 K
ρ_p	1400 kg/m ³	
Gas velocity	26.3 m/s	
Droplet diameter	100 μ m	
μ	26.77024 μ Pa-s	See Table A-4 footnote
k	200	
Q_i	0.1 m ³ /s	
Q_g	10 m ³ /s	
R	0.01	

Particle dia.[μ m]	C	ψ	Eta	Mass %	Mass Fraction	Mass Fraction Efficiency [%]
0.05	6.62626	0.0127	0.2014967	0.01	0.0001	0.00
0.3	1.93771	0.1333	0.5181334	0.21	0.0021	0.11
0.8	1.351641	0.661	0.8032923	0.78	0.0078	0.63
3	1.093771	7.5219	0.9958524	13	0.13	12.95
8	1.035164	50.623	0.9999993	16	0.16	16.00
13	1.021639	131.93	1	12	0.12	12.00
18	1.015629	251.44	1	8	0.08	8.00
80	1.003516	4907.5	1	50	0.5	50.00

Overall mass efficiency = 99.68 %

7-55 ESP Collection Efficiency

Given: Collection tube diameter = 0.300 m; L = 2.00 m; $d_p = 1.00 \mu\text{m}$; $Q_g = 0.150 \text{ m}^3/\text{s}$;
 $E_p = 100,000 \text{ V/m}$; $q = 0.300 \text{ fC}$; temp = 25.0 °C

Solution:

p. 760 \leftarrow A-4

a. From Appendix A, $\mu = 18.5 \times 10^{-6} \text{ Pa s}$

b. Calculate Cunningham correction factor (Eqn. 7-60)

$$C = 1 + \frac{(6.21 \times 10^{-4})(298)}{1.00} = 1.19$$

c. Calculate migration velocity (Eqn. 7-62)

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$$W = \frac{(0.300 \times 10^{-15})(1.0 \times 10^5)(1.19)}{(6)(\pi)(0.50 \times 10^{-6})(18.5 \times 10^{-6})} = 0.205 \text{ m/s}$$

d. Area of collection surface

$$A = \pi(0.300\text{m})(2.00\text{m}) = 1.885\text{m}^2$$

e. Efficiency

$$\eta = 1 - \exp\left[-\frac{(1.885)(0.205)}{0.150}\right] = 0.924$$

$$\text{Efficiency} = 92.4\%$$

7-56 ESP Collection Efficiency

Given: Problem 7-55

Solution:

a. All calculations from 7-55 remain same except last step

b. Efficiency

$$\eta = 1 - \exp\left[-\frac{(1.885)(0.205)}{0.075}\right] = 0.9942$$

$$\text{Efficiency} = 99.42\%$$

DISCUSSION QUESTIONS

7-1 Effect of change in pressure on ppm measurement

Given: Gas bag sample at 103.0 kPa with 0.02 ppm SO₂

Solution:

The concentration would remain the same because ppm in air pollution is a volume to volume measurement and the ratio of volumes would remain constant.

7-2 Strongest inversion conditions

Given: three choices

Solution:

Choice b - "Clear winter night with fresh snow cover." Because of snow cover radiative heating of the ground is minimized (the snow reflects the solar radiation). On a clear night, the radiative cooling of the ground is the greatest. This results in a very cold ground surface and, thus, the strongest inversion.

7-3 Selection of air pollution control device

Given: very hot cement kiln dust and three choices of control equipment

Solution:

Choice c - "Electrostatic precipitator." The nature of cement dust precludes wet collection, i.e. it will solidify the collection equipment. The very hot gas temperatures will damage the fabric of the bags in the bag house.

7-4 Photochemical oxidants and automobiles

Given: Photochemical oxidants are not directly attributable to people or natural sources. Why are autos singled out?

Solution:

Photochemical oxidants are the result of a reaction between volatile organic compounds and nitrogen dioxide in the presence of sunlight. Autos are singled out because, in major metropolitan areas, they are the major source of these two compounds.

7-5 Why PM_{2.5} standard is more appropriate than TSP

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Solution:

The PM_{2.5} standard restricts the concentration of particulate matter smaller than 2.5 μm in diameter. Particles in the range below 2.5 μm in diameter have the greatest potential to penetrate to the lower respiratory tract and, thus, damage the alveoli. TSP restricts the concentration of all particles but because larger particles contribute more mass, the standard does not protect the lung from large concentrations of fine particles.