

# SOLUTIONS MANUAL

## INTRODUCTION TO ENVIRONMENTAL ENGINEERING and SCIENCE

SECOND EDITION

GILBERT M. MASTERS

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To consume about 80% of the resource corresponds to  $\pm 1.3\sigma$ :  
 $t_{80\%} = 2 \times 1.3 \sigma = 2 \times 1.3 \times 133 = 346 \text{ yrs}$

**3.10** At current rates  $P_0$  it would take 100 yrs to add  $Q$  tons of CFC to the already existing  $Q$  tons. That is,

$$100 P_0 = Q \quad \text{or} \quad \frac{Q}{P_0} = 100$$

Then using (3.16), the time required to add those  $Q$  tons and double CFCs is

$$T = \frac{1}{r} \ln \left( \frac{rQ}{P_0} + 1 \right) = \frac{1}{0.02} \ln(0.02 \times 100 + 1) = 54.9 \text{ yrs}$$

**3.11** Bismuth half life is 4.85 days so using (3.8) the corresponding reaction rate  $K$  is

$$T_{1/2} = \frac{\ln 2}{K} \quad \text{so,} \quad K = \frac{\ln 2}{T_{1/2}} = \frac{\ln 2}{4.85 \text{d}} = 0.143 / \text{day}$$

After 7 days the initial 10 g is reduced to

$$N = N_0 e^{-Kt} = 10 \text{g} e^{-0.143 \times 7} = 3.68 \text{g}$$

**3.12** Reaction rate  $K = 0.2/\text{day}$ , so from (3.8) the half-life is

$$T_{1/2} = \frac{\ln 2}{K} = \frac{\ln 2}{0.2/\text{d}} = 3.466 \text{ days}$$

The fraction remaining after 5 days is

$$\frac{N}{N_0} = e^{-Kt} = e^{-0.2/\text{d} \times 5\text{d}} = 0.368 \text{ that is, about 37\% of the sewage remains}$$

**3.13** Using the logistic curve (3.26) starting with  $N_0=6.3$  billion in 2000, growing at  $R_0=0.015/\text{yr}$  to a maximum of  $K=10.3$  billion, first find growth rate  $r$

$$r = \frac{R_0}{\left(1 - \frac{N_0}{K}\right)} = \frac{0.015}{\left(1 - \frac{6.3}{10.3}\right)} = 0.0386$$

To reach 9 billion, we need first to find  $t^*$  the time when size is  $K/2=5.15$  billion:

$$t^* = \frac{1}{r} \ln \left( \frac{K}{N_0} - 1 \right) = \frac{1}{0.0386} \ln \left( \frac{10.3}{6.3} - 1 \right) = -11.7 \text{ yrs before 2000 (that is, 1988)}$$

We can use (3.27) to find when will it reach 9 billion:

$$10^{-6} = \frac{20 \text{ m}^3/\text{d} \times C \text{ mg/m}^3 \times 350 \text{ d/yr} \times 30 \text{ yr}}{70 \text{ kg} \times 365 \text{ d/yr} \times 70 \text{ yr}} \times \frac{2.9 \times 10^{-2}}{\text{mg/kg} \cdot \text{d}}$$

$$C = \frac{10^{-6} \times 70 \times 365 \times 70}{20 \times 350 \times 30 \times 2.9 \times 10^{-2}} = 2.9 \times 10^{-4} \text{ mg/m}^3$$

d. vinyl chloride in water, risk  $10^{-4}$ , potency 2.3:

$$10^{-4} = \frac{2 \text{ L/d} \times C \text{ mg/L} \times 350 \text{ d/yr} \times 30 \text{ yr}}{70 \text{ kg} \times 365 \text{ d/yr} \times 70 \text{ yr}} \times \frac{2.3}{\text{mg/kg} \cdot \text{d}}$$

$$C = \frac{10^{-4} \times 70 \times 365 \times 70}{2 \times 350 \times 30 \times 2.3} = 3.7 \times 10^{-3} \text{ mg/L}$$

**4.16** Trichloroethylene in an industrial facility; risk  $10^{-4}$ :

Risk = CDI x Potency

$$10^{-4} = \frac{20 \text{ m}^3/\text{d} \times C \text{ mg/m}^3 \times 250 \text{ d/yr} \times 25 \text{ yr}}{70 \text{ kg} \times 365 \text{ d/yr} \times 70 \text{ yr}} \times \frac{1.3 \times 10^{-2}}{\text{mg/kg} \cdot \text{d}}$$

$$C = \frac{10^{-4} \times 70 \times 365 \times 70}{20 \times 250 \times 25 \times 1.3 \times 10^{-2}} = 0.11 \text{ mg/m}^3$$

To convert to ppm, we need the molecular weight of  $\text{C}_2\text{Cl}_3\text{H}$ , which is  $2 \times 12 + 3 \times 35.5 + 1 = 131.5 \text{ g/mol}$ . From (1.8):

$$\text{ppm} = \frac{24.465 \times C (\text{mg/m}^3)}{\text{mol wt}} = \frac{24.465 \times 0.11}{131.5} = 0.02 \text{ ppm}$$

**4.17** Benzene in fish =  $C (\text{mg/L})$  in river x BCF (L/kg); From Table 4.12, BCF = 5.2 L/kg

Risk = CDI x Potency

$$10^{-6} = \frac{C \text{ mg/L} \times 5.2 \text{ L/kg} \times 0.054 \text{ kg/d} \times 350 \text{ d/yr} \times 30 \text{ yr}}{70 \text{ kg} \times 365 \text{ d/yr} \times 70 \text{ yr}} \times \frac{2.9 \times 10^{-2}}{\text{mg/kg} \cdot \text{d}}$$

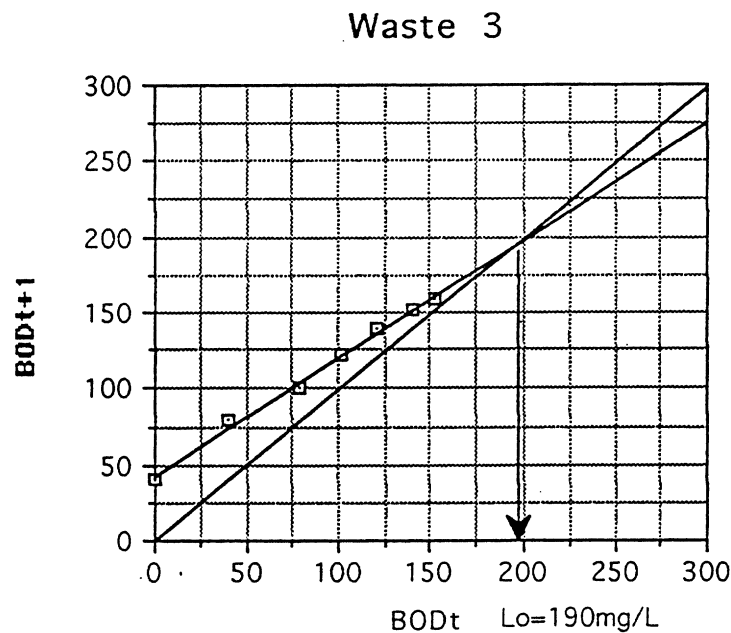
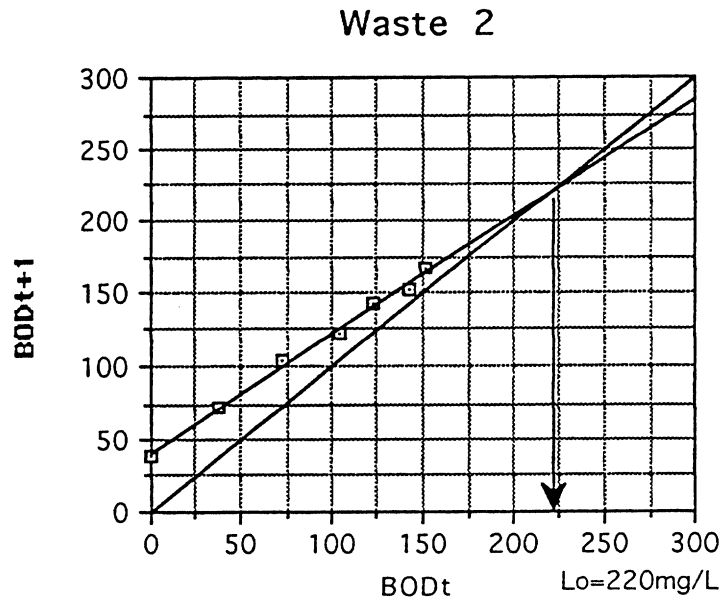
$$C = \frac{10^{-6} \times 70 \times 365 \times 70}{5.2 \times 0.054 \times 350 \times 30 \times 2.9 \times 10^{-2}} = 0.021 \text{ mg/L}$$

**4.18** DDT in fish =  $C (\text{mg/L})$  x BCF (L/kg); from Table 4.12, BCF = 54,000 L/kg

Risk = CDI x Potency

$$\text{Risk} = \frac{0.020 \text{ mg/L} \times 54,000 \text{ L/kg} \times 0.002 \text{ kg/d}}{70 \text{ kg}} \times \frac{0.34}{\text{mg/kg} \cdot \text{d}} = 0.01$$

**4.19** Hazard index = Sum of the hazard quotients:



**5.15** Show  $BOD_{t+1} = a BOD_t + b$ , that is, that it is linear:

$$BOD_{t+1} = L_0(1 - e^{-k(t+1)}) = L_0(1 - e^{-kt}e^{-k})$$

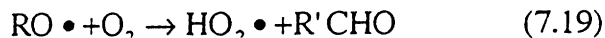
now add and subtract  $e^{-k}$

$$BOD_{t+1} = L_0(1 - e^{-kt}e^{-k} + e^{-k} - e^{-k}) = L_0[e^{-k}(1 - e^{-kt}) + 1 - e^{-k}]$$

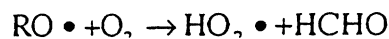
$$BOD_{t+1} = e^{-k}L_0(1 - e^{-kt}) + L_0(1 - e^{-k}) = e^{-k}BOD_t + L_0(1 - e^{-k})$$

$$BOD_{t+1} = a BOD_t + b \quad \text{where } a = e^{-k}, \text{ and } b = L_0(1 - e^{-k})$$

7.9



for  $R'CHO$  to be  $HCHO$ ,  $R'$  must be  $H$  so that

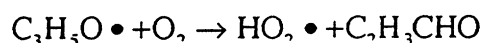
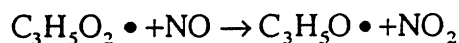
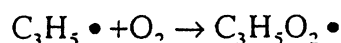
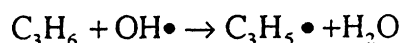


for the reaction to balance,  $R = CH_3$

which says  $RH$  in (7.16) must be  $CH_4$  (methane)

7.10  $RH = \text{propene} = CH_2=CH-CH_3 = C_3H_6$  so,  $R = C_3H_5$

so the sequence of reactions (7.16) to (7.19) are:



The end product is acrolein,  $CH_2CHCHO$ .

7.11 U. S. Power plants:

$$\text{heat input} = 685 \times 10^6 \text{ tons} \times 2000 \frac{\text{lb}}{\text{ton}} \times 10,000 \frac{\text{Btu}}{\text{lb}} = 1.37 \times 10^{16} \text{ Btu}$$

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{1400 \times 10^9 \text{ kWh} \times 3412 \text{ Btu/kWh}}{1.37 \times 10^{16} \text{ Btu}} = 0.349 \approx 35\%$$

At NSPS of 0.03 lb particulates per  $10^6$  Btu input, emissions would have been:

$$\text{emissions} = \frac{0.03 \text{ lb}}{10^6 \text{ Btu heat input}} \times 1.37 \times 10^{16} \text{ Btu in} \times \frac{1000 \text{ g}}{2.2 \text{ lb}} = 1.87 \times 10^{11} \text{ g}$$

$$\text{For comparison, } \frac{\text{emissions at NSPS}}{\text{actual emissions}} = \frac{1.87 \times 10^{11} \text{ g}}{0.39 \times 10^{12}} = 0.48 = 48\%$$

7.12 Derivation for the dry adiabatic lapse rate:

$$dQ = dU + dW \quad \text{where } dU = C_v dt \text{ and } dW = PdV$$

$$dQ = C_v dt + PdV \quad (1)$$

ideal gas law says  $PV = nRT$

$$\text{so, } d(PV) = PdV + VdP = nRT$$

$$\text{or, } PdV = nRT - VdP$$

plugged into (1) gives:



$$b. \text{GWP}_{100} = 1630 \cdot \frac{42(1 - e^{-100/42})}{43.1} = 1440$$

$$c. \text{GWP}_{500} = 1630 \cdot \frac{42(1 - e^{-500/42})}{138} = 495$$

8.21	years	gas	rate(10 <sup>9</sup> kg)	GWP	GWPxrate	fraction
	20	CO <sub>2</sub>	44,700	1	44,700	0.65
	20	CH <sub>4</sub>	320	56	17,920	0.26
	20	N <sub>2</sub> O	22	280	6,160	0.09
	100	CO <sub>2</sub>	44700	1	44,700	0.77
	100	CH <sub>4</sub>	320	21	6,720	0.11
	100	N <sub>2</sub> O	22	310	6,820	0.12
	500	CO <sub>2</sub>	44700	1	44,700	0.88
	500	CH <sub>4</sub>	320	6.5	2,080	0.04
	500	N <sub>2</sub> O	22	170	3,740	0.07

8.22 The actual  $\Delta T_{\text{realized}}$  is estimated to be about 0.6°C, which is 75% of the equilibrium  $\Delta T$

$$\Delta T_{\text{realized}} = 0.6^\circ\text{C} = 0.75 \Delta T_{\text{equilibrium}}$$

$$\text{so, } \Delta T_{\text{equilibrium}} = 0.6/0.75 = 0.8^\circ\text{C}$$

$$\text{but, } \Delta T_{\text{equilibrium}} = \lambda \Delta F_{\text{actual}} = 0.57 \times \Delta F_{\text{actual}} = 0.8$$

$$\text{that is, } \Delta F_{\text{actual}} = \frac{0.8}{0.57} = 1.40 \text{ W/m}^2$$

The direct forcing is 2.45 W/m<sup>2</sup>, so aerosols etc are 2.45 - 1.40 = 1.05 W/m<sup>2</sup>

8.23 Energy sources and carbon intensity:

Coal	25%	@ 24.2 gC/MJ
Oil	45%	@ 19.7 gC/MJ
Gas	20%	@ 13.8 gC/MJ
Other	10%	@ 0

$$a. \text{ avg C intensity} = 0.25 \times 24.2 + 0.45 \times 19.7 + 0.20 \times 13.8 + 0.10 \times 0 = 17.68 \text{ gC/MJ}$$

b. Coal replaced by non-carbon emitting sources:

$$\text{avg C intensity} = 0.25 \times 0 + 0.45 \times 19.7 + 0.20 \times 13.8 + 0.10 \times 0 = 11.63 \text{ gC/MJ}$$