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SOLUTIONS MANUAL

INTRODUCTION TO ENVIRONMENTAL ENGINEERING and SCIENCE

SECOND EDITION

GILBERT M. MASTERS

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INTRODUCTION TO ENVIRONMENTAL ENGINEERING and SCIENCE

SECOND EDITION

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To consume about 80% of the resource corresponds to $\pm 1.3\sigma$:

$t_{80\%} = 2 \times 1.3\ \sigma = 2 \times 1.3 \times 133 = 346$ yrs

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

$$100\ P_o = Q \qquad \text{or} \qquad \frac{Q}{P_o} = 100$$

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

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

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/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

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

3.13 Using the logistic curve (3.26) starting with N_o=6.3 billion in 2000, growing at R_o=0.015/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:

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$$10^{-6} = \frac{20\ m^3/d \times C\ mg/m^3 \times 350\ d/yr \times 30\ yr}{70\ kg \times 365\ d/yr \times 70\ yr} \times \frac{2.9\times10^{-2}}{mg/kg-d}$$

$$C = \frac{10^{-6} \times 70 \times 365 \times 70}{20 \times 350 \times 30 \times 2.9\times10^{-2}} = 2.9\times10^{-4}\ mg/m^3$$

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

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

$$C = \frac{10^{-4} \times 70 \times 365 \times 70}{2 \times 350 \times 30 \times 2.3} = 3.7\times10^{-3}\ mg/L$$

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

Risk = CDI x Potency

$$10^{-4} = \frac{20m^3/d \times C\ mg/m^3 \times 250\ d/yr \times 25\ yr}{70\ kg \times 365\ d/yr \times 70\ yr} \times \frac{1.3\times10^{-2}}{mg/kg-d}$$

$$C = \frac{10^{-4} \times 70 \times 365 \times 70}{20 \times 250 \times 25 \times 1.3\times10^{-2}} = 0.11\ mg/m^3$$

To convert to ppm, we need the molecular weight of C_2Cl_3H, which is $2\times12 + 3\times35.5 + 1 = 131.5$ g/mol. From (1.8):

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

4.17 Benzene in fish = C (mg/L) in river x BCF (L/kg); From Table 4.12, BCF = 5.2 L/kg

Risk = CDI x Potency

$$10^{-6} = \frac{C\ mg/L \times 5.2\ L/kg \times 0.054\ kg/d \times 350\ d/yr \times 30\ yr}{70\ kg \times 365\ d/yr \times 70\ yr} \times \frac{2.9\times10^{-2}}{mg/kg-d}$$

$$C = \frac{10^{-6} \times 70 \times 365 \times 70}{5.2 \times 0.054 \times 350 \times 30 \times 2.9\times10^{-2}} = 0.021\ mg/L$$

4.18 DDT in fish = C (mg/L) x BCF (L/kg); from Table 4.12, BCF = 54,000 L/kg

Risk = CDI x Potency

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

4.19 Hazard index = Sum of the hazard quotients:

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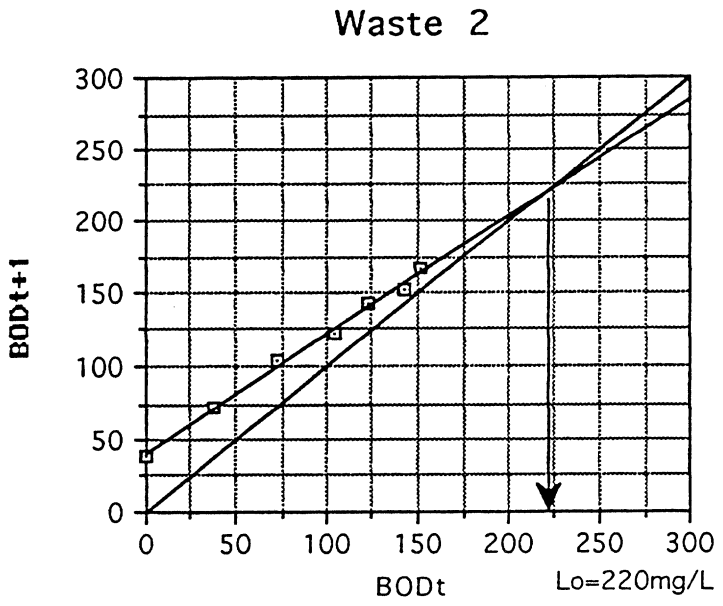

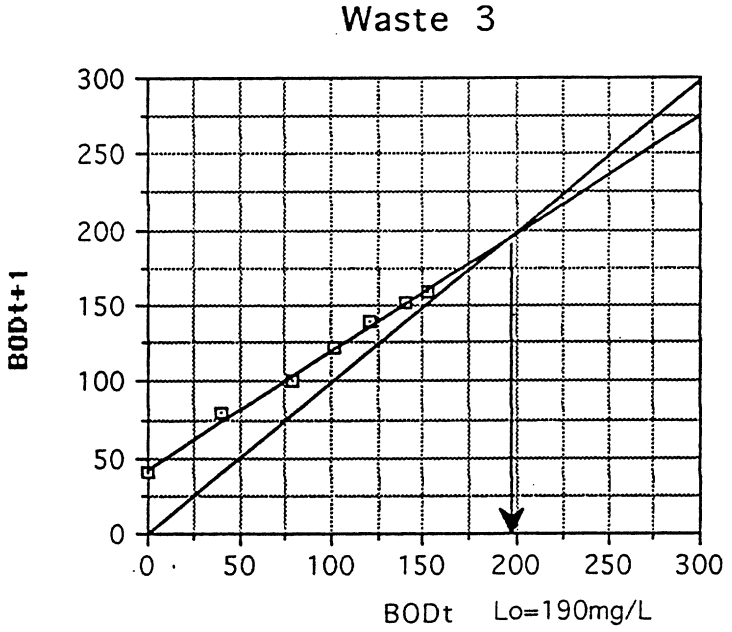

5.15 Show $BOD_{t+1} = a\,BOD_t + b$,that is, that it is linear:

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

now add and subtract e^{-k}

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

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

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

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7.9

$$RO\bullet + O_2 \rightarrow HO_2\bullet + R'CHO \qquad (7.19)$$

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

$$RO\bullet + O_2 \rightarrow HO_2\bullet + HCHO$$

for the reaction to balance , R = CH_3

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

7.10 RH = 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:

$$C_3H_6 + OH\bullet \rightarrow C_3H_5\bullet + H_2O$$
$$C_3H_5\bullet + O_2 \rightarrow C_3H_5O_2\bullet$$
$$C_3H_5O_2\bullet + NO \rightarrow C_3H_5O\bullet + NO_2$$
$$C_3H_5O\bullet + O_2 \rightarrow HO_2\bullet + C_2H_3CHO$$

The end product is acrolein, CH_2CHCHO.

7.11 U. S. Power plants:

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

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

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

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

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

7.12 Derivation for the dry adiabatic lapse rate:

$$dQ = dU + dW \qquad \text{where } dU = C_v dt \text{ and } dW = PdV$$
$$dQ = C_v dt + PdV \qquad (1)$$

ideal gas law says PV = nRT

so, d(PV) = PdV + VdP = nRT

or, PdV = nRT - VdP

plugged into (1) gives:

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b. $GWP_{100} = 1630 \cdot \dfrac{42\left(1 - e^{-100/42}\right)}{43.1} = 1440$

c. $GWP_{500} = 1630 \cdot \dfrac{42\left(1 - e^{-500/42}\right)}{138} = 495$

8.21

years	gas	rate(10^9kg)	GWP	GWPxrate	fraction
20	CO_2	44,700	1	44,700	0.65
20	CH_4	320	56	17,920	0.26
20	N_2O	22	280	6,160	0.09
100	CO_2	44700	1	44,700	0.77
100	CH_4	320	21	6,720	0.11
100	N_2O	22	310	6,820	0.12
500	CO_2	44700	1	44,700	0.88
500	CH_4	320	6.5	2,080	0.04
500	N_2O	22	170	3,740	0.07

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

$$\Delta T_{realized} = 0.6^oC = 0.75\ \Delta T_{equilibrium}$$

so, $\Delta T_{equilibrium} = 0.6/0.75 = 0.8^oC$

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

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

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

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. avg C intensity = 0.25x24.2 + 0.45x 19.7 + 0.20x13.8 + 0.10x0 = 17.68 gC/MJ

b. Coal replaced by non-carbon emitting sources:

avg C intensity = 0.25x0 + 0.45x 19.7 + 0.20x13.8 + 0.10x0 = 11.63 gC/MJ

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