Chemical Biochemical and Engineering Thermodynamics 5th edition Sandler Solutions Manual

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2.1 $$\frac{d(C\cdot \mathrm{V})}{dt}=\frac{dM}{dt}=\dot{M}_{\mathrm{IN}}-\dot{M}_{\mathrm{OUT}}$$

a) at steady state

$$\dot{M}_{\mathrm{IN}}=1\frac{\mathrm{g}}{\min}=\dot{M}_{\mathrm{OUT}}=C\cdot\text{volumetric flow rate out}$$

$$1\frac{\mathrm{g}}{\min}=C\times\frac{10\mathrm{m}^3}{\min} \qquad C=\frac{1}{10}\frac{\mathrm{g}}{\mathrm{m}^3}=0.1\frac{\mathrm{g}}{\mathrm{m}^3}$$

b) $$\mathrm{V}\frac{dC}{dt}=\dot{M}-C\times 10\frac{\mathrm{m}^3}{\min} \qquad \mathrm{V}\frac{dC}{dt}=\dot{M}-C-10\frac{\mathrm{m}^3}{\min}$$

$$\mathrm{V}=6\times6\times3=108\ \mathrm{m}^3 \qquad \mathrm{V}=6\times6\times3=108\ \mathrm{m}^3$$

$$108\mathrm{m}^3\frac{dC}{dt}=1\frac{g}{\min}-C\times\frac{10\mathrm{m}^3}{\min}$$

$$\frac{dC}{dt}=\frac{1}{108}\frac{g}{\mathrm{m}^3\min}-C\frac{10}{108}\mathrm{m}^{-1}$$

or for C in g/m^3

$$108\frac{dC}{dt}=-(10C-1) \qquad 10.8\frac{dC}{(C-0.1)}=-dt$$

$$10.8\ \ln\frac{(\mathrm{C}\text{-}0.1)}{(\ \ \text{-}0.1)}=-t$$

For $C = 0.95 * 0.1 = 0.095$ $$10.8\ \ln\left(\frac{-0.005}{-0.1}\right)=-t$$

$108 \ln 20 = t$ $\qquad$ $t = 32.35$ minutes

2.2 $$\frac{dC}{dt}=-kC \qquad \ln\frac{C_f}{C_i}=-kt$$

If $C_f = 0.5\ C_i$ $\qquad$ $\ln 0.5 = -kt$ or $k=\frac{\ln 2}{t}$

for a half life of seven years $\qquad$ $k = 0.099$ years^{-1}

so that

$$\ln\frac{\mathrm{C_f}}{22}=-\mathrm{k}\ 25=-0.099\times25=-2.475$$

$$\mathrm{C_f}=22\exp(-2.475)=1.85\ \mathrm{ppm}$$

2.3 Basis: 2-liter vessel = 2000 cm^3 = $2\times10^3\times10^{-6}\frac{\mathrm{m}^3}{\mathrm{cm}^3}=2\times10^{-3}\ \mathrm{m}^3$

Initial moles of phosphine = $5\ \frac{\mathrm{kmol}}{\mathrm{m}^3}\times10^3\frac{\mathrm{mol}}{\mathrm{kmol}}\times2\times10^{-5}\mathrm{m}^3$ = 10 mol

a) Mass balance from stoichiometry

Species	Initial	Final
PH_3	10	$10 - 4X = 7$
P_4	0	X
H_2	0	$6X$

Since $10 - 4X = 7$ $\quad 3 = 4X \quad X = 3/4$

$\Rightarrow P_4 = 0.75$ moles

$H_2 = 6$ moles

b) C_{PH_3} at any time $= \dfrac{(10\text{-}4X)\text{ moles}}{2\times10^{-3}\text{m}^3} = (5\text{-}2X)\times10^{-3}\dfrac{\text{moles}}{\text{m}^3}$

Therefore

$$\frac{dC_{PH_3}}{dt} = 3.715\times10^{-6} C_{PH_3}$$

$$-2\times10^{-3}\frac{dX}{dt} = -3.715\times10^{-6}(5\text{-}2X)\times10^{-3}$$

$$\frac{dX}{dt} = 3.715\times10^{-6}(2.5\text{-}X)$$

$$-\frac{dX}{2.5-X} = \frac{d(2.5\text{-}X)}{2.5\text{-}X} = -3.715\times10^{-6}dt$$

$$\ln(2.5\text{-}X)_t - \ln(2.5\text{-}X)_0 = -3.715\times10^{-6}t$$

$$\frac{2.5\text{-}X}{2.5} = e^{-2.715\times10^{-6}t}$$

$$2.5\text{-}X = 2.5\, e^{2.715\times10^{-6}t}$$

$$X = 2.5\left(1\text{-}e^{-2.715\times10^{-6}t}\right)$$

Therefore

$$\text{Moles } PH_3 = 10\text{-}4X = 10\text{-}10\left(1\text{-}e^{-2.715\times10^{-6}t}\right) = 10\, e^{-2.715\times10^{-6}t}$$

$$\text{Moles } PH_4 = 2.5\left(1\text{-}e^{-2.715\times10^{-6}t}\right)$$

$$\text{Moles } H_2 = 15\left(1 - e^{-2.715\times10^{-6}t}\right)$$

Time required for 3 moles to react = time for $X = 0.75$

$$X = 2.5\left(1\text{-}e^{-2.715\times10^{-6}t}\right) = 0.75$$

$$T = 1.314\times10^{5}\text{ sec} = 36.49\text{ hours}$$

2.4 $\quad 2\,NO + O_2 \rightarrow 2\,NO_2$

a) 0.5 moles NO produces 0.5 moles NO_2

b)

Species	Initial Conc	Conc. at X
NO	1	$1-2X$
O_2	3	$3-X$
NO_2	0	$6X$
		$4-X$

$$\frac{dC_{NO}}{dt} = -1.4\times10^{-4}C_{NO}^2 C_{O_2}$$

$$\frac{d(1-2X)}{dt} = -1.4\times10^{-4}(1\text{-}2X)^2(3\text{-}X) = -2\frac{dX}{dt}$$

$$\Rightarrow \qquad \frac{dX}{dt}=0.7\times10^{-4}\left(1\text{-}2X\right)^2\left(3\text{-}X\right)$$

$$0.7\times10^{-4}\,t=\frac{1}{5\left(1\text{-}2X\right)}+\frac{1}{25}\ln\frac{\left(2X\text{-}1\right)}{\left(X\text{-}3\right)}$$

Now for 0.5 mole of NO to react $\Rightarrow$ $1-2X=0.5$ $X=0.25$

$$0.7\times10^{-4}t=\frac{1}{5\times0.5}+\frac{1}{25}\ln\left(0.5/2.75\right)=0.332$$

$$t=\frac{0.332}{0.7}\times10^{4}=0.474\times10^{4}\text{sec}=1.317\text{ hrs}$$