

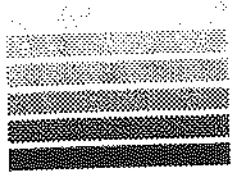
Instructor's Manual

UNIT OPERATIONS AND PROCESSES IN ENVIRONMENTAL ENGINEERING

Second Edition



Reynolds/Richards



Instructor's Manual

UNIT OPERATIONS AND PROCESSES IN ENVIRONMENTAL ENGINEERING

Second Edition

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¹ No quantitative problems in Chapter 6 or Chapter 24 - hence no worked solutions

Problem 1.1

$$\text{Na}^+ \quad \underline{\text{AW} = 23} \quad \text{Eq. wt.} = 23/1 = 23 \text{ gm}$$

$$\text{Ca}^{+2} \quad \underline{\text{AW} = 40} \quad \text{Eq. wt.} = 40/2 = 20 \text{ gm}$$

$$\text{Na}^+ \text{ meq wt} = 23 \text{ mg}$$

$$\text{Meqs} = (102 \text{ mg/L}) \div 23 \text{ mg/meq} = \underline{4.43 \text{ meq/L}}$$

$$\text{Ca}^{+2} \text{ meq wt} = 20 \text{ mg}$$

$$\text{Meqs} = (68 \text{ mg/L}) \div 20 \text{ mg/meq} = \underline{3.40 \text{ meq/L}}$$

Problem 1.2

$$\text{Ca Cl}_2 \text{ MW} = 40 + 2(35) = 110$$

$$\text{Meg wt} = 110/2 = 55 \text{ mg}$$

$$\text{Megs} = (168 \text{ mg/L}) \div 55 \text{ mg/meg} = \underline{3.05 \text{ meg/L}}$$

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Problem 1.3

1 ppm = 1 mg/L if specific gravity = 1.00

134 parts per million = 134 mg/L

Problem 1.4

$$pH = 7.6$$

$$pH = \log \frac{1}{[H^+]}$$

$$[H^+] = \underline{10^{-7.6} \text{ moles/l}}$$

$$[H^+][OH^-] = 10^{-14}$$

$$[10^{-7.6}][OH^-] = 10^{-14}$$

$$[OH^-] = \underline{10^{-6.4} \text{ moles/l}}$$

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Problem 1.5

It goes to completion because an insoluble product is formed.

Problem 1.6

Carbonate CO_3^{-2}

Bicarbonate HCO_3^{-}

Hydroxyl OH^{-}

Problem 1.7

$$\text{CaCl}_2 \text{ meq wt} = [40 + 12 + 3(16)]^{1/2} = 50$$

$$\text{Meq/l} = (185 \text{ mg/l}) \div 50 \text{ mg/meq} = \underline{3.70 \text{ m.}}$$

Problem 1.8

$$\text{CaCO}_3 \text{ Meg wt} = [40 + 12 + 3(16)] \frac{1}{2} = 50$$

$$\text{Meg/l} = (225 \text{ mg/l}) \div 50 \text{ mg/meg} = \underline{4.50 \text{ meg}}$$

Problem 1.9

a. Second

b. Zero

c. First

Problem 1.10

- a. Assume a first-order reaction. A plot of $\ln C = \ln C_0 - kt$ is shown in Figure 1. Since it is a straight line, it's first order.
first-order reaction

b. $K = \frac{\ln 135 - \ln 10}{8 \text{ hrs}}$

$= \underline{0.325 / \text{hr}}$

Problem 1.10

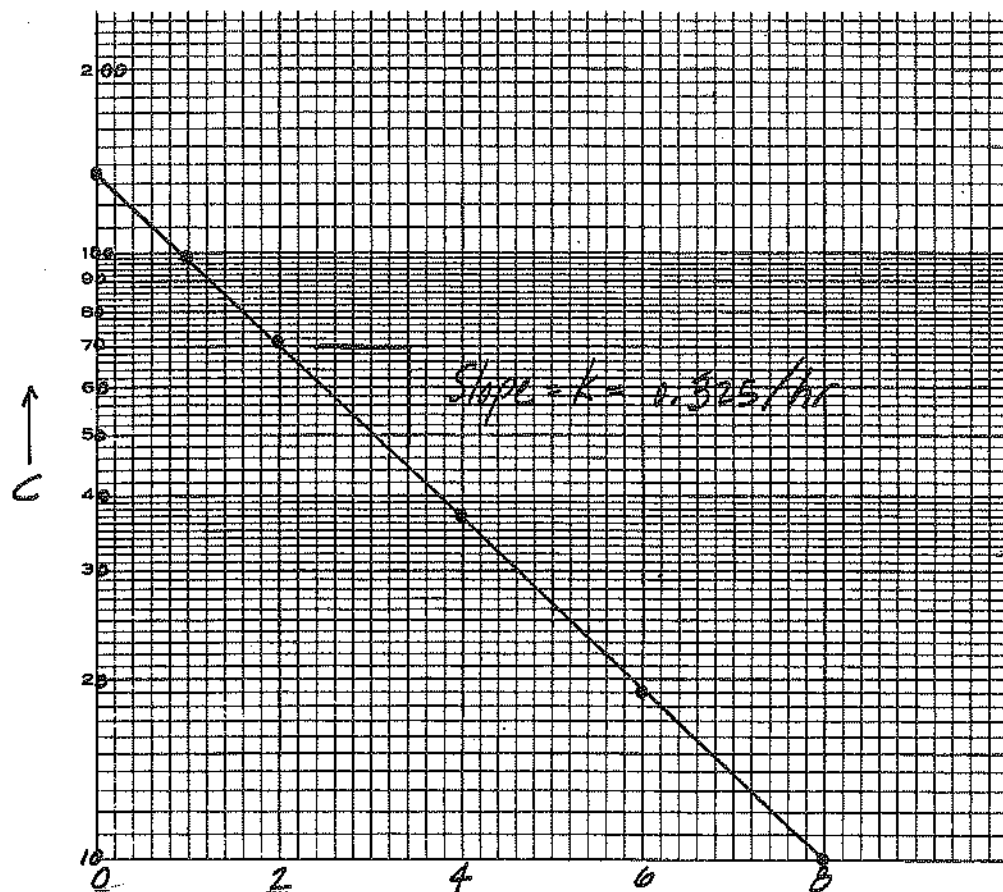
 $t, \text{hrs} \rightarrow$

Figure 1

Problem 1.11

a. Assume a second-order reaction. Plot is

$$\frac{1}{C} = \frac{1}{C_0} + kt$$

Reduced data is

Time, t (hr)	C (mg/l)	$1/C$ (l/mg)
0	135	0.0074
1	53	0.0189
2	33	0.0303
3	24	0.0417
4	19	0.0526
5	15	0.0667
6	13	0.0769
7	11	0.0909
8	10	0.100

The plot is a straight line in Figure 4, so it is a second order reaction

$$\begin{aligned}
 \text{b. Slope} = K &= \frac{(0.10 - 0.0074) \text{ l/mg}}{8 \text{ hr}} \\
 &= \underline{0.011575 \text{ l/mg-hr}}
 \end{aligned}$$

Problem 1.11

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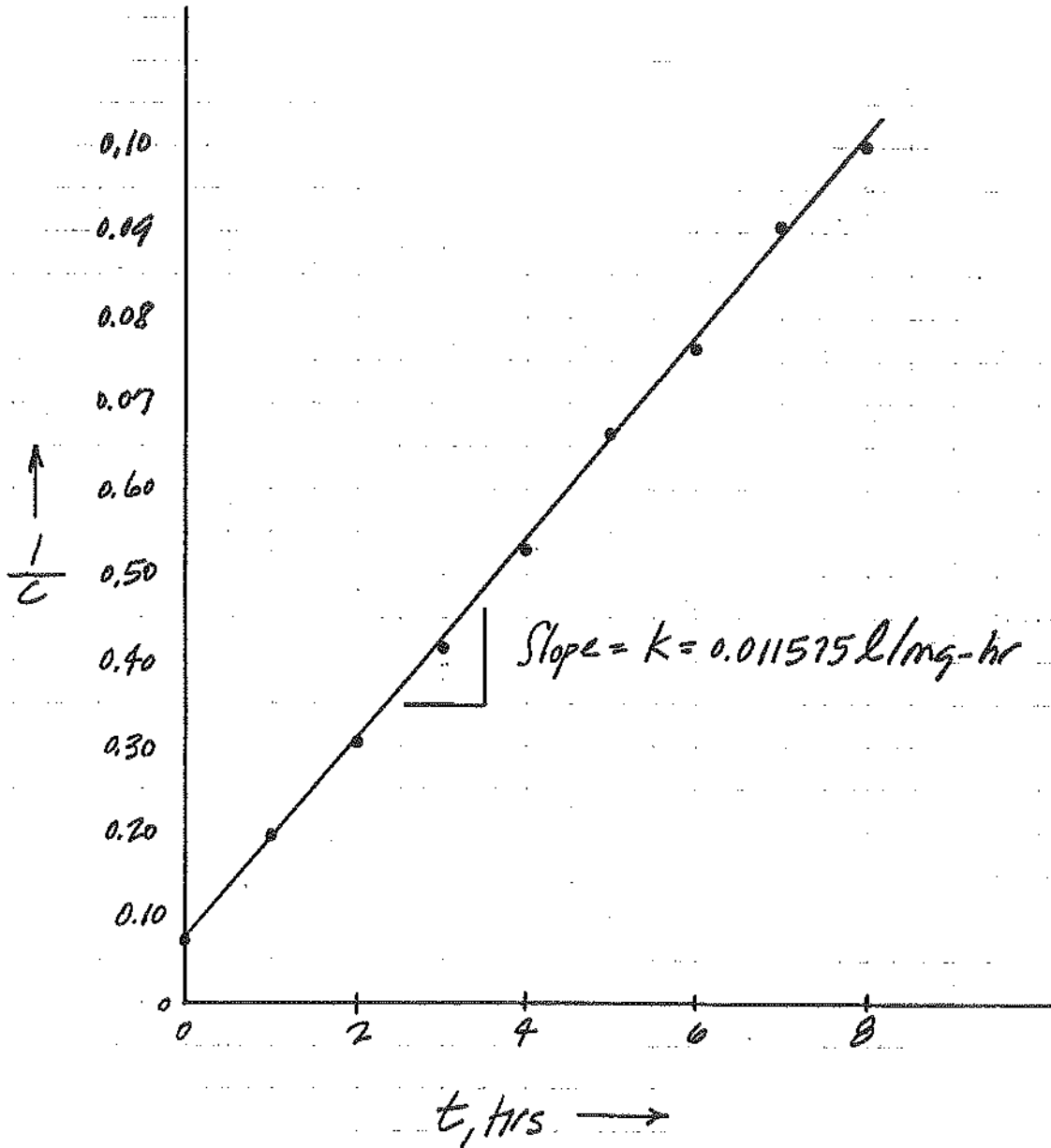


Figure 1

Problem 1.12

a. Assume a zero-order reaction. Plot is

$$C = C_0 - kt$$

Plot is shown in appropriate figure. Since it is straight line it is zero-order

b. Slope = $k = \frac{(135 - 10) \text{ mg/L}}{8 \text{ hr}} = \underline{15.625 \text{ mg/L-hr}}$

Problem 1.12

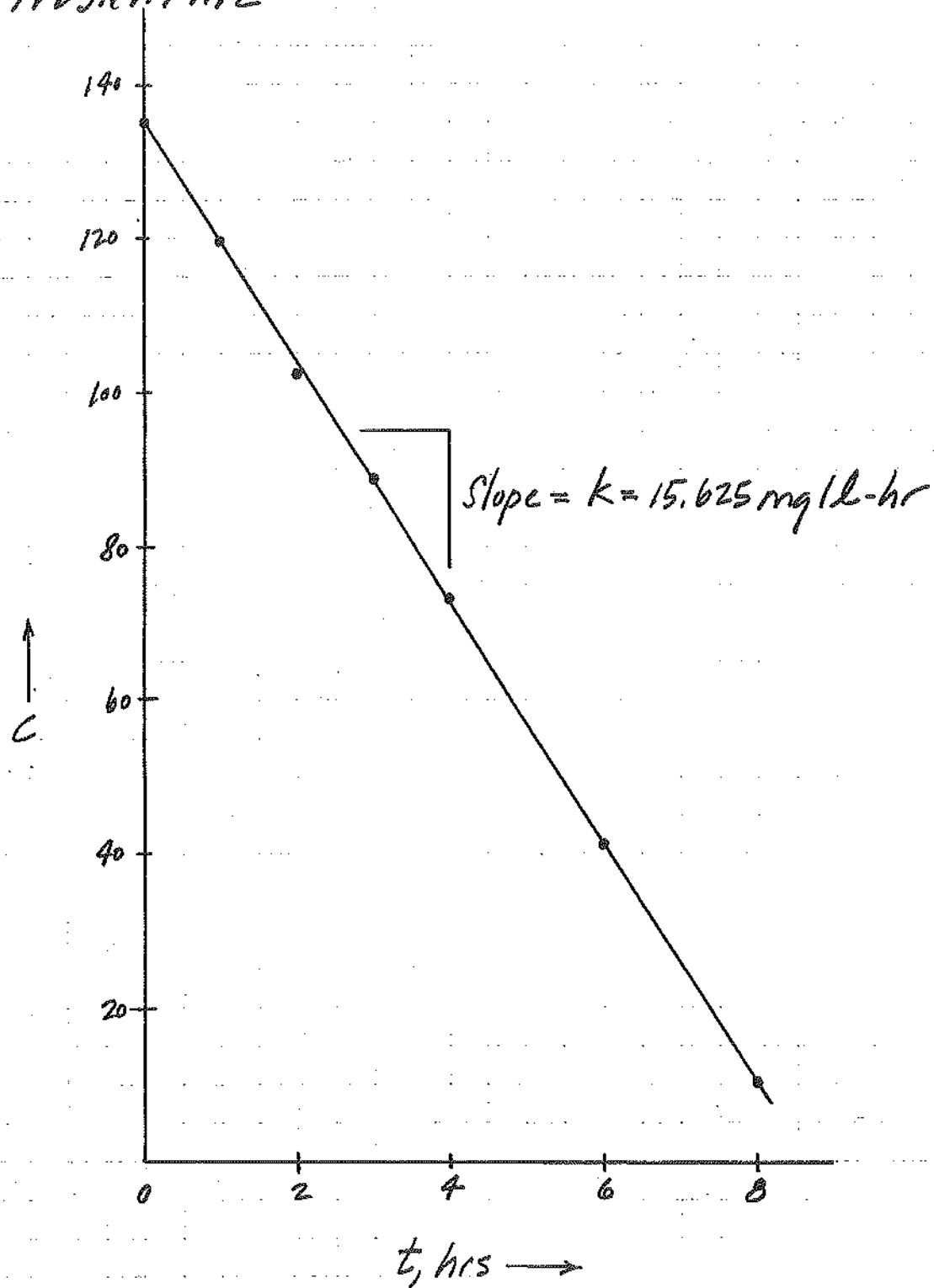


Figure 1

Problem 1.13

$$C_s = \text{Constant} \cdot P_g$$

$$C_s = 43.8 \text{ mg/l-atmospheres}$$

El. 1000	733 mm Hg
1500	X
2000	706 mm Hg

$$X = (733 + 706)^{1/2} = 719.5 \text{ mm}$$

$$\text{atmosphere}_1 = 719.5 / 760 = 0.9467$$

$$C_s = (43.8 \text{ mg/l-atm})(0.9467 \text{ atm.})(0.209)$$

$$= \underline{8.67 \text{ mg/l}}$$

Problem 1.14

$$C_s = 43.8 \text{ mg/l-atm} \times P_g$$

$$P_g = 0.80 \text{ atmospheres}$$

$$\begin{aligned} C_s &= (43.8 \text{ mg/l-atm})(0.80 \text{ atm}) \\ &= \underline{35.0 \text{ mg/l}} \end{aligned}$$

Problem 1.16

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$T_1 = T_2$$

$$P_1 V_1 = P_2 V_2$$

For USCS Units:

$$P_1 = 14.7 \text{ psi} + (10/12 \text{ ft})(\text{psi}/2.31 \text{ ft}) = 15.06 \text{ ps}$$

$$P_2 = 14.7 + 35 = 49.7 \text{ psia}$$

$$V_2 = \frac{P_1}{P_2} V_1 = \left(\frac{15.06}{49.7} \right) (162,000 \text{ ft}^3/\text{day})$$

$$= 49,089 = \underline{49,100 \text{ ft}^3/\text{day}}$$

For SI Units:

$$P_1 = 101.37 \text{ kPa} + (10/12 \text{ ft})(\text{psi}/2.31 \text{ ft})(6.8957 \text{ k})$$

$$= 101.37 + 2.49 = 103.84 \text{ kPa}$$

$$P_2 = 101.37 + 241 = 342.37 \text{ kPa}$$

$$V_2 = \left(\frac{103.84}{342.37} \right) (4590 \text{ m}^3/\text{d})$$

$$= 1392 = \underline{1390 \text{ m}^3/\text{d}}$$

Problem 1.15

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$T_1 = T_2, \text{ so}$$

$$P_1 V_1 = P_2 V_2$$

For USCS Units:

$$V_1 = 110,000 \text{ ft}^3$$

$$P_1 = 14.7 \text{ psi} + (10/12 \text{ ft}) \div 2.31 \text{ ft/psi} = 15.06 \text{ psi}$$

$$P_2 = 14.7 \text{ psi} + 30 \text{ psi} = 44.7 \text{ psi}$$

$$V_2 = \frac{P_1}{P_2} V_1$$

$$= \left(\frac{15.06}{44.7} \right) (110,000 \text{ ft}^3) = 37,060 = \underline{37,100 \text{ ft}^3}$$

For SI Units

$$P_1 = 101.37 \text{ kPa} + (10/12 \text{ ft}) (\text{psi} / 2.31 \text{ ft}) (6.8957)$$

$$= 101.37 + 2.49 = 103.84 \text{ kPa}$$

$$P_2 = 101.37 + 207 = 308.37 \text{ kPa}$$

$$V_2 = \left(\frac{103.84}{308.37} \right) (3,118 \text{ m}^3) = 104.9 = \underline{105 \text{ m}^3}$$

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Problem 1.17

$$\text{Driving force} = C_s - C_a$$

$$\text{Ratio} = \frac{9.0 - 6.0}{9.0 - 4.0} = \frac{3}{5} = \underline{0.60}$$