

Unit Operations and Processes in Environmental Engineering (2nd Edition)

Chapter 13, Problem 6P

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Problem

An industrial wastewater containing 205 mg/l Cd+2 is to be treated by an ion exchange column, and the allowable effluent concentration is 5% C₀. A breakthrough curve has been obtained using a small laboratory column on the sodium cycle. Data concerning the column are as follows: inside diameter = 1.3 cm, mass of resin = 45.28 gm on a moist basis, moisture content = 48%, bulk density of the resin = 738 gm/l on a moist basis, and liquid flowrate = 1.120 l/d. The following throughput volumes in liters at the respective effluent cadmium concentrations in mg/l were obtained: 5.0, 0.0; 10.0, 0.0; 11.0, 14.07; 11.5, 26.43; 12.0, 42.17; 12.5, 68.60; 13.0, 104.59; 13.5, 141.70; 14.0, 163.07; 15.0, 196.81; 15.5, 202.43; 16.0, 205.00; and 16.5, 205.00. The design column will have a flowrate of 2.63 l/s, the allowable breakthrough time is 7 days of flow, and the resin depth is approximately twice the column diameter. Using the kinetic approach to design determine:

- The kilograms of resin required.
- The column diameter and depth.
- The height of the adsorption zone.

Step-by-step solution

Step 1 of 14

a)

Determine the amount of resin required.

List the throughput volumes *V* with their respective concentrations of divalent cadmium ion *C* in a table, which can be used to construct a breakthrough curve. Also list alongside them the parameters required for kinetic analysis: *C*/*C*₀, *C*₀/*C*, *C*₀/*C* − 1, and ln(*C*₀/*C* − 1). The goal is to use this laboratory data to determine the mass of the resin on the large scale.

*C*₀ is given as 205 mg/L.

<i>V</i> (liters)	<i>C</i> (mg/L)	<i>C</i> / <i>C</i> ₀	<i>C</i> ₀ / <i>C</i>	<i>C</i> ₀ / <i>C</i> − 1	ln(<i>C</i> ₀ / <i>C</i> − 1)
5.0	0.00	0.0000			
10.0	0.00	0.0000			
11.0	14.06	0.0686	14.580	13.580	2.609
11.5	26.43	0.1289	7.756	6.756	1.910
12.0	42.17	0.2057	4.861	3.861	1.351
12.5	68.60	0.3346	2.988	1.988	0.687
13.0	104.59	0.5102	1.960	0.960	-0.041
13.5	141.70	0.6912	1.447	0.447	-0.806
14.0	163.07	0.7955	1.257	0.257	-1.358
15.0	196.81	0.9600	1.042	0.042	-3.179
15.5	202.43	0.9875	1.013	0.013	-4.366
16.0	205.00	1.00	1.00	0	

Comment

Step 2 of 14

Construct a breakthrough curve of the data with the volume *V* on the on the horizontal axis and the concentration *C* on the vertical axis.

Comment

Step 3 of 14

It appears that the breakthrough occurs after the throughput volume reaches 10 liters, so the first point at *V* = 5 liters can be neglected for resolving the kinetics of the system. Construct a kinetic plot by plating the troughput volume on the horizontal axis, and the natural log of (*C*₀/*C* − 1) on the vertical axis.

Comment

Step 4 of 14

The equation of the line is displayed on the kinetic plot. Use the equation on the plot to determine the various parameters of equation (1). This is done to determine the constants *k*₁ and *q*₀, which allow the modeling of the actual treatment plant.

$$\ln\left(\frac{C_0}{C} - 1\right) = k_1 q_0 M - \frac{k_1 C_0 V}{Q} \quad \text{..... (1)}$$

The slope of the line is −1.5066 L^{−1} which corresponds to:

$$-1.5066 \text{ L}^{-1} = -\frac{k_1 C_0}{Q}$$

Substitute 205 mg/L for *C*₀ and 1.120 L/day for *Q*.

$$k_1 = (1.5066 \text{ L}^{-1}) \left(\frac{1.120 \text{ L/day}}{205 \text{ mg/L}} \right) \left(\frac{\text{day}}{86400 \text{ s}} \right) \left(\frac{10^6 \text{ mg}}{1 \text{ kg}} \right)$$

$$= .0953 \text{ L/kg-s}$$

Comment

Step 5 of 14

The ln(*C*₀/*C* − 1) intercept on the plot is 19.399, which corresponds to:

$$19.399 = k_1 q_0 \frac{M}{Q}$$

Substitute 0.04528 kg for *M*, 1.120 L/day for *Q*, and 0.0953 L/kg-s for *k*₁.

$$q_0 = \frac{19.399 \left(1.120 \frac{\text{L}}{\text{day}} \right) \left(\frac{\text{day}}{86400 \text{ s}} \right)}{(.0953 \text{ L/kg-s})(0.04528 \text{ kg})}$$

$$= 0.0583$$

It is important to note that the *q*₀ calculated is for *moist* resin, and, to compute dry resin, the moisture content of the resin must be considered.

Comment

Step 6 of 14

The mass of the resin in the full-scale plant *M* must be determined.

Calculate the allowable effluent concentration *C*.

The allowable concentration *C* is 5% of *C*₀.

Substitute 5% for *C*₀

$$C = 0.05(C_0)$$

$$= 0.05(205 \text{ mg/L})$$

$$= 10.25 \text{ mg/L}$$

Comment

Step 7 of 14

Calculate the allowable throughput volume.

The allowable throughput volume occurs at breaking point, which is assumed to occur after 7 days of flow:

$$V = (7 \text{ days})(2.63 \text{ L/s}) \left(\frac{86,400 \text{ s}}{\text{day}} \right)$$

$$= 1.59(10^6) \text{ L}$$

Substitute 0.0953 L/kg-s for *k*₁, 0.0583 gm/gm for *q*₀, 205 mg/L for *C*₀, 10.25 mg/L for *C*, 2.63 L/s 60,000 gal/day for *Q*, and 1.59(10⁶) L for *V* in equation (1).

$$\ln\left(\frac{C_0}{C} - 1\right) = \frac{k_1 q_0 M}{Q} - \frac{k_1 C_0 V}{Q}$$

$$\ln\left(\frac{205}{10.25} - 1\right) = \frac{(.0953 \text{ L/kg-s})(0.0583) M}{(2.63 \text{ L/s})} - \frac{(.0953 \text{ L/kg-s})(205 \text{ mg/L}) \left(\frac{\text{kg}}{10^6 \text{ mg}} \right) (1.59(10^6) \text{ L})}{(2.63 \text{ L/s})}$$

$$2.944 = 2.11(10^{-7}) M - 11.81$$

$$M_M = 6990 \text{ kg}$$

Comment

Step 8 of 14

Calculate mass of the dry resin by using the equation.

$$M_D = M_M(1 - 48)$$

Substitute 6990 kg for *M*_{*M*}

$$M_D = (6990 \text{ kg})(.52)$$

$$= 3630 \text{ kg}$$

Comment

Step 9 of 14

b)

Determine the column diameter *d* and depth *H*.

Determine volume of the column by using the equation.

$$V = \frac{M_M}{\rho}$$

Substitute 6990 kg for *M*_{*M*} and 738 gm/L for ρ

$$V = \frac{6990 \text{ kg}}{738 \text{ gm/L} \left(\frac{\text{kg}}{1000 \text{ gm}} \right) \left(\frac{1000 \text{ L}}{\text{m}^3} \right)}$$

$$= 9.472 \text{ m}^3$$

Comment

Step 10 of 14

Determine the depth and diameter by using the equation.

$$V = \frac{\pi d^2}{4} H \quad \text{..... (2)}$$

Substitute 2*d* for *H* and 9.472 m³ for *V*

$$V = \frac{\pi d^2}{4} (2d)$$

$$9.472 = \frac{\pi}{2} \left(\frac{9.472 \times 2}{\pi} \right)^{3/2}$$

$$d = 1.82 \text{ m}$$

Therefore, the diameter is 1.82 m.

Comment

Step 11 of 14

Substitute 1.82 m for *d* and 9.472 m³ for *V* into equation (2)

$$V = \frac{\pi d^2}{4} H$$

$$334.5 \text{ ft}^3 = \frac{\pi (6 \text{ ft})^2}{4} (H)$$

$$H = 3.64 \text{ m}$$

Therefore, depth of the column is 3.64 m.

Comment

Step 12 of 14

c)

Determine height of the sorption zone.

Determine volume associated with an effluent concentration of 0.95*C*₀

Calculate the concentration

$$C = (.95)(205 \text{ mg/L})$$

$$= 194.75 \text{ mg/L}$$

Substitute 0.343 L/gm-hr for *k*₁, 0.0583 gm/gm for *q*₀, 205 mg/L for *C*₀, 194.75 mg/L for *C*, 2.63 L/s for *Q*, 6990 kg 15400 lb for *M*_{*s*}, and *V*_{*s*} for *V* in equation (1).

$$\ln\left(\frac{205}{194.75} - 1\right) = \frac{(.0953 \text{ L/kg-s})(0.0583)(6990 \text{ kg})}{(2.63 \text{ L/s})} - \frac{(.0953 \text{ L/kg-s})(205 \text{ mg/L}) V_s \left(\frac{\text{kg}}{10^6 \text{ mg}} \right)}{(2.63 \text{ L/s})}$$

$$-2.944 = 14.766 - 7.428(10^{-4}) V_s$$

$$V_s = 2384000 \text{ L}$$

$$V_s = 2384 \text{ m}^3$$

Comment

Step 13 of 14

Calculate the value of *V*_{*s*} the different between the throughput volumes associated with 0.95*C*₀ and 0.05*C*₀.

Recall that the volume associated with 0.05*C*₀ is 420,000 gallons.

$$V_s = V_T - V_g$$

Substitute 2384 m³ for *V*_{*s*} and 1590 m³ for *V*_{*T*}.

$$V_s = 2384 \text{ m}^3 - 1590 \text{ m}^3$$

$$= 794 \text{ m}^3$$

Comment

Step 14 of 14

Calculate height of the adsorption zone by using the equation.

$$Z_s = H \left[\frac{V_s}{V_T - 0.5 V_s} \right]$$

Substitute 794 m³ for *V*_{*s*}, 2384 m³ for *V*_{*T*}, and 3.64 m for *H*.

$$Z_s = 3.64 \left[\frac{794}{2384 - 0.5(794)} \right]$$

$$= 1.45 \text{ m}$$

Therefore, height of the adsorption zone is 1.45 m.

Comment

Was this solution helpful?

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Recommended solutions for you in Chapter 13

