ENV 504: Remediation of soil and groundwater
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Problem set #5: adsorption processes
SOLUTION

Problem 1:

$Q = 2\ \mathrm{m^3/min}$

$C_0 = 300\ \mu\mathrm{g/L}$ $\qquad$ $C_{target} = 3\ \mu\mathrm{g/L}$

$L = 15\ \mathrm{m}$

$v_0 = 5\ \mathrm{m/h}$

$d_g = 1.5\ \mathrm{mm}$

$\rho_b = 425\ kg/m^3$

$\epsilon_b = 0.35$

a -

$\mathrm{EBCT} = \frac{V_T}{Q}$ and $V_T = A_b * L$

$$A_b = \frac{Q}{V_0} = \frac{2\ \mathrm{m^3/min} * 60\ \mathrm{min/h}}{5\ \mathrm{m/h}} = 24\ m^2$$

$V_T = 24\ m^2 * 15\ m = 360\ m^3$

$$\mathrm{EBCT} = \frac{360\ m^3}{120\ m^3/h} = 3h$$

b- $A_b = \pi\ {d_b}^2/4 \Rightarrow d_b = \sqrt{\frac{4\ A_b}{\pi}} = 5.5\ \mathrm{m}$

c - $\qquad Q_{in}.C_{in}.t_b = C_s^e.\rho_b.V_{bed,used}$

$$t_b = \frac{C_s^e.\rho_b.V_{bed,used}}{Q_{in}.C_{in}}$$

Need to calculate: $\qquad V_{bed,used} = V_T.0.75 = 270\ m^3$

Need to calculate: $\qquad C_s^e = 250.C_{in}^{0.003} = 254.3\ \frac{\mu g_{atrazine}}{g_{AC}} = \frac{mg_{atrazine}}{kg_{AC}}$

$$C_{in} = 300\ \frac{\mu g_{atrazine}}{L\ GW} = 300\frac{mg_{atrazine}}{m^3 GW}$$

So, $t_b = \dfrac{254.3\ \frac{mg_{atrazine}}{kg_{AC}}.425\frac{kg_{AC}}{m^3_{AC}}.270\ m^3_{AC}}{120\frac{m^3}{h}.300\ \frac{mg_{atrazine}}{m^3}} = 810\ hr \sim 34\ days$

To calculate bed volumes, need EBCT:

$$\frac{t_b}{EBCT} = \theta_b = \frac{810\ hr}{3\ hr} = 270\ bed\ volumes$$

d- We are looking for: $\frac{kilogram\ of\ AC}{m^3 of\ water\ treated\ until\ regeneration/disposal}$

$$rate_{AC} = \frac{M_{AC}}{Q * t_b}$$

$$M_{AC} = V_T * \rho_b = 360m^3 * 425\ \frac{kg}{m^3} = 153{,}000\ kg$$

$$Q * A_b = 120\frac{m^3}{h} * 810\ h = 97{,}200\ m^3$$

$$rate_{AC} = \frac{153{,}000\ kg}{97{,}200\ m^3} = 1.5\ \frac{kg_{AC}}{m^3{}_{water}}$$

Problem 2:

Q = 5 L/min

possible sorbents: SIA or Actinomycetes 50 kg of sorbent

Waste stream 1: pH 4

influent concentration: 2 mg/L Cu^{2+} 2 mg/L Cd^{2+} 2 mg/L Zn^{2+}

desired effluent concentration: 600 µg/L

Waste stream 2: pH 6

influent concentration: 1.2 mg/L Cd^{2+} 1.5 mg/L Zn^{2+}

desired effluent concentration: 600 µg/L

Mass balance (for each sorbent/contaminant):

$$M_{sorbent} * C_s^e = Q * C_{aq} * t_b$$

$M_{Sorbent}$ = mass of sorbent available (g)

C^e_S = sorbed mass at equilibrium (µg metal/g sorbent)

Q = volume of liquid treated per time (L/d)

C_{aq}^i= influent concentration (µg metal/L)

t_b= time at breakthrough

Example calculation: Copper SIA vs Actino at pH 4 (waste stream 1)
Looking at the isotherms, we see that for SIA:

At Cu^{2+}= 600 µg/L => C_S = 6 mg/g sorbent (read on graph)

But at Cu^{2+} = 2,000 µg/L => C_S = 15 mg/g sorbent (read on graph)

For Actinomycetes:

At Cu^{2+}= 600 µg/L => C_S = 6.5 mg/g sorbent (read on graph)

But at Cu^{2+} = 2,000 µg/L => C_S = 10 mg/g sorbent (read on graph)

We see that at equilibrium, at high concentrations, more copper is adsorbed onto SIA but at low concentrations, Actinomycetes do better.

The isotherms are obtained for batch systems, so the initial concentration decreases over time until it reaches the equilibrium concentration. So, if this exercise were about a batch system, it would make sense to select Actinomycetes.

However, we are considering a packed system (like activated carbon but with a different sorbent). Therefore, at breakthrough, most of the bed will have a porewater with a concentration of C_{in}.

Therefore, the solid phase concentration at exhaustion (which means that the solid phase is exhausted, it cannot bind any more compound) should be calculated in equilibrium with the influent concentration. This is because (unlike batch), more contaminant is continuously coming in, reaching the maximum load given the influent concentration.

We can calculate

$$Cu^{2+}\ on\ SIA \Rightarrow t_{b_{sorbent}} = \frac{C_S^e M_{sorbent}}{Q * C_{aq}^i} = \frac{15\frac{mg}{g} * \frac{10^3 g}{kg} * 50\ kg}{5\frac{L}{min} * 2\ \frac{mg}{L}} = 72\ days$$

$$Cu^{2+}\ on\ Actino \Rightarrow t_{b_{sorbent}} = \frac{C_S^e M_{sorbent}}{Q * C_{aq}^i} = \frac{10\frac{mg}{g} * \frac{10^3 g}{kg} * 50\ kg}{5\frac{L}{min} * 2\ \frac{mg}{L}} = 50\ days$$

Then, do the same for all conditions:

		SIA				Actinomycetes		
		Cu. pH 4	Cd. pH 4	Zn. pH 4		Cu. pH 4	Cd. pH 4	Zn. pH 4
Mass	kg	50	50	50		50	50	50
Cs	mg/g	14.5	5.5	1		10	3.25	1
Q	L/min	5	5	5		5	5	5
Cin	mg/L	2	2	2		2	2	2
Cout	mg/L	0.6	0.6	0.6		0.6	0.6	0.6
Time	days	72	27	5		50	16	5

		SIA			Actinomycetes	
		Cd. pH 6	Zn. pH 6		Cd. pH 6	Zn. pH 6
Mass	kg	50	50		50	50
Cs	mg/g	15	13		3	1.5
Q	L/min	5	5		5	5
Cin	mg/L	2	2		2	2
Cout	mg/L	0.6	0.6		0.6	0.6
Time	days	74	64		15	7

waste stream #1	pH = 4	C_S (mg/g)	days till breakthrough
SIA	Cu	14.5	72
	Cd	5.5	27
	Zn	1	5

Actinomycetes	Cu	10	50
	Cd	3.25	16
	Zn	1	5

waste stream #2	pH = 6	C_S	days till breakthrough
SIA	Cd	15	74
	Zn	13	64

Actinomycetes	Cd	3	15
	Zn	1.5	7

To determine which sorbent is better, we need to consider the metal that breaks through the fastest within a set but the slowest to compare the two sorbents.

ws #1 Zn^{2+} breaks through first (of the three metals) after 5d (SIA and Actino)=> best option is either sorbent

ws #2 the fastest breakthrough is for Zn^{2+} for Atinomycetes (7 days).

SIA is the best option here by far as the breakthrough is at 64 days for Zinc.