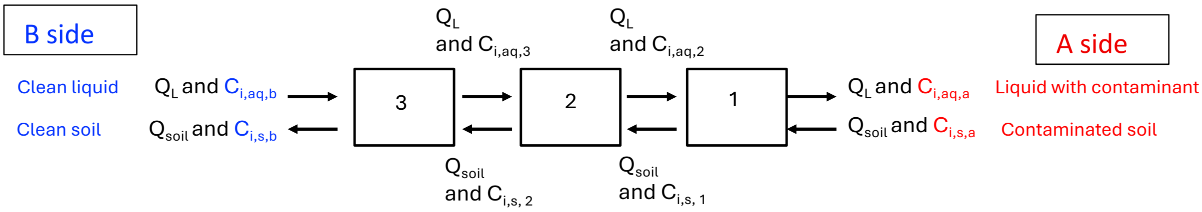
Lecture Notes week 7

Slide 17 – Soil washing example

Simplified scheme with three stages



First, we consider pH = 2 (K = 0.02 L/kg):

	Soil inlet / liquid effluent (A side)	Soil outlet / liquid influent (B side)	
initial conc.	$C_{i,s,a} = 3.5 * 10^{-4} \frac{kg}{kg}$	$C_{i,aq,b} = 5 * 10^{-8} \frac{kg}{L}$	
	$C_{i,aq,a} = 10^{-5} \frac{kg}{L}$	$C_{i,s,b} = 1.2 * 10^{-7} \frac{kg}{kg}$	final conc.

$$\frac{Q_{soil}}{Q_L} = 0.025 \frac{kg}{L}$$

Equilibrium on the soil inlet (A) side: $C^*_{i,s,a} = KC_{i,aq,a} = 0.02 * 10^{-5} = 2 * 10^{-7} \frac{kg}{kg}$

Equilibrium on the soil outlet (B) side: $C^*_{i,s,b} = KC_{i,aq,b} = 0.02 * 5 * 10^{-8} \frac{kg}{kg} = 1.0 * 10^{-9} \frac{kg}{kg}$

$$N = \frac{\ln\left(\frac{C_{i,s,a} - C^*_{i,s,a}}{C_{i,s,b} - C^*_{i,s,b}}\right)}{\ln\left(\frac{1}{K} * \frac{Q_L}{Q_{soil}}\right)} = 36$$

Slide 27 – Fixed bed activated carbon (Example 1)

$$C_{i,s} = KC_{i,aq}$$

Field case:

400 L of water – 0.05 g/L of contaminant A - Activated carbon (AC) removes 99% of contaminant.

The questions are:

1) How much of the compound of interest can be adsorbed?
2) What is the concentration in the solution?
3) For the full scale, how much adsorbent do you need?

To determine the adsorption constant K, we use a lab study.

Lab case:

1 L of water – 0.95 g/L of contaminant A – 3 g of AC - AC removes 96% of contaminant.

1) Determination of K using lab case

$$V_L = 1L\,; M_{AC} = 3\ g\,; m_A = 0.05\frac{g}{L} * 1L = 0.05\ g$$

$$C_{A,aq}^0 = 0.05\frac{g}{L};$$

96% of contaminant is removed from the water: $C_{A,aq}^{eq} = (1 - 0.96) * 0.05 = 0.002\frac{g}{L}$

Mass balance:

$$m_A = C_{A,s}^{eq} M_{AC} + C_{A,aq}^{eq} V_L = C_{A,aq}^{eq}(M_{AC}K + V_L) \qquad (\boldsymbol{eq\ 1})$$

$$\Rightarrow\ K = \frac{\frac{m_A}{C_{A,aq}^{eq}} - V_L}{M_{AC}} = \frac{\frac{0.05}{0.002} - 1}{3} = 8\frac{L}{g_{AC}}$$

8 L of water can be treated per gram of AC for a removal of 96%

2) Application to the field

$$V_L = 400\ L\,; M_{AC} = ?\,; m_A = 0.05 * 400 = 20\ g$$

99% of contaminant is removed from the water: $C_{A,aq}^{eq} = (1 - 0.99) * 0.05 = 0.0005\frac{g}{L}$

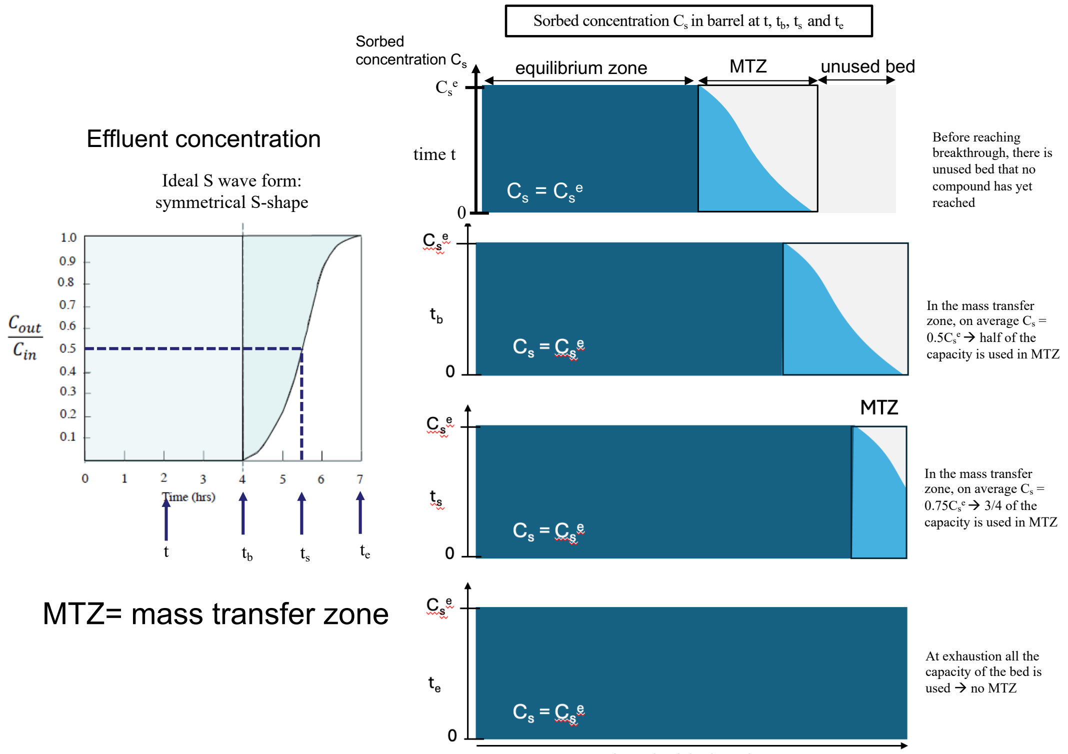
$$C_{A,s}^{eq} = 8 * 0.0005 = 4 * 10^{-3}\frac{g}{g}$$

Re-using eq 1:

$$M_{AC} = \frac{\frac{m_A}{C_{A,aq}^{eq}} - V_L}{K} = \frac{\frac{20}{0.0005} - 400}{8} = 4{,}950\ g = 4.95\ kg$$

Remark: here we are considering that 100% of the AC is useful, in reality, part is not usually not used and more AC is needed to reach the desired aqueous concentration.

Slide 29 – Fixed bed activated carbon (Example 2)



1) Determine breakthrough, exhaustion, and stoichiometric time

By reading on the graph:

$t_b = 4h$; $t_e = 7h$; $t_s = 5.5$ h

2) What is the fraction of unused capacity at breakthrough?

In the MTZ the average concentration is:

$C_{s,MTZ} = \frac{C_{out}}{2} = 0.5C_s^e$ → this means that half of the capacity is used in the MTZ

Let's calculate size of MTZ, and fully used bed, in time, meaning time it takes for the fluid to flow through these volumes:

The size of the MTZ is: $t_{MTZ} = t_e - t_b = 7 - 4 = 3h$

The size of the fully used (i.e., excluding the MTZ) is: $t_{used} = t_e - t_{MTZ} = t_b = 7 - 3 = 4h$

The flow of water is constant over time, so the time are proportional to the distance, meaning the length of bed used:

$$\%_{used,b} = \frac{t_{used} + 0.5t_{MTZ}}{t_e} = \frac{t_b + 0.5t_{MTZ}}{t_e} = \frac{4 + 0.5 * 3}{7} = 78\%$$

3) What fraction of the bed is used at stoichiometric time?

Similarly, as what we just did:

In the MTZ the average concentration is:

$C_{s,MTZ} = \frac{C_s^e + C_{out}}{2} = \frac{C_s^e + 0.5C_s^e}{2} = 0.75C_s^e$ → this means that ¾ of the capacity is used in the MTZ

In time, size of the MTZ is: $t_{MTZ} = t_e - t_s = 7 - 5.5 = 1.5h$

In time, size of the fully used (i.e., excluding the MTZ) is: $t_{used} = t_e - t_{MTZ} = t_s = 7 - 1.5 = 5.5h$

$$\%_{used,s} = \frac{t_{used} + 0.75t_{MTZ}}{t_e} = \frac{t_s + 0.75t_{MTZ}}{t_e} = \frac{5.5 + 0.75 * 1.5}{7} = 95\%$$

Slide 31 – Fixed bed activated carbon (Example 3)

$$C_S = \frac{0.05 * C_{aq}}{32.1 + C_{aq}}$$
$$Q = 1\frac{L}{min} = 0.001\frac{m^3}{min}$$
$$C_{in} = 100\frac{g}{m^3}$$
$$C_{out} = 1\frac{g}{m^3}$$
$$M_{AC} = 15\ kg$$

1) **How much TME is adsorbed when the breakthrough concentration reaches 1 g/m^3?**

$$C_S = C_s^e = \frac{0.05 * C_{in}}{32.1 + C_{in}} = 0.0379\frac{g_{TME}}{g_{AC}}$$

We assume that 75% is used at breakthrough (ideal S-wave shape as seen in example 2).

$$TME_{ads} = 0.0379 * 75\% * 15{,}000 = 426\ g$$

2) H**ow long will it take to reach this concentration?**

$$\rho_b V_{bed} = M_{AC}$$

$$t_b = \frac{C_s^{eq} M_{AC}}{Q_{in} C_{in}} = \frac{0.0379\ \left({}^{g_{TME}}/_{g_{AC}}\right) * 15{,}000\ (g_{AC}) * 0.75}{0.001\left({}^{m^3}/_{min}\right) * (100)\left({}^{g}/_{m^3}\right)} = 4{,}264\ \mathrm{min} \quad \sim 3\ days$$

<u>Slide 32 and 33 – Fixed bed activated carbon (Example 4)</u>

Groundwater with 5 mg/L of toluene → 100 µg/L

$$C_{i,s}[\frac{kg}{kg}] = \frac{0.04 * C_{i,aq}\left[\frac{mg}{L}\right]}{1 + 0.002C_{i,aq}\left[\frac{mg}{L}\right]}$$

H = 1 m ; D = 0.5 m ; ρ_b = 485 kg/m^3 ; Q = 140 L/min

$$V_{AC} = \pi * R^2 * H = 3.14156 * 0.25^2 * 1 = 0.196\, m^3$$

1) **How much toluene can each unit remove before the activated carbon is fully spent (exhaustion)?**

Activated carbon is fully spent means that we are at exhaustion, 100% is used.

$$C_{i,s}^{eq} = \frac{0.04 * 5}{1 + 0.002 * 5} = 0.2\frac{kg}{kg}$$

$$M_{AC} = V_{AC} * \rho_b = 0.196m^3 * 485\, {}^{kg}/_{m^3} = 95\, kg$$

$$m_{i,ads,max} = C_{i,s}^{eq} * M_{AC} = 0.2 * 95 = 19\, kg$$

Note: we always stop before exhaustion when outlet concentration reaches threshold value, if we were to stop at breakthrough for instance, assuming ideal wave form at **breakthrough,** about 75% of the carbon is used (see example 2):

$$m_{i,ads} = 0.75 * m_{i,ads,max} = 14.25\, kg$$

2) **How long until breakthrough (still assuming ideal wave form)?**

$$t_b = \frac{m_{i,ads}}{Q_{in}(C_{in} - C_{out})} = \frac{14.25\, kg * 10^6\, mg/kg}{140\, L/min * (5)mg/L} = 20{,}357\, min = \ 14.1\, d$$