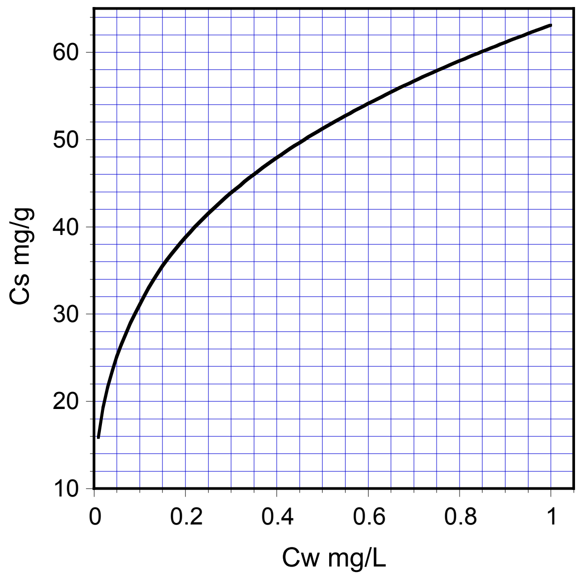
Water and wastewater treatment - Homework 10 – Solutions

1. Adsorption

An adsorption isotherm for the adsorption of atrazine on activated carbon has been determined and is shown in the graph below.

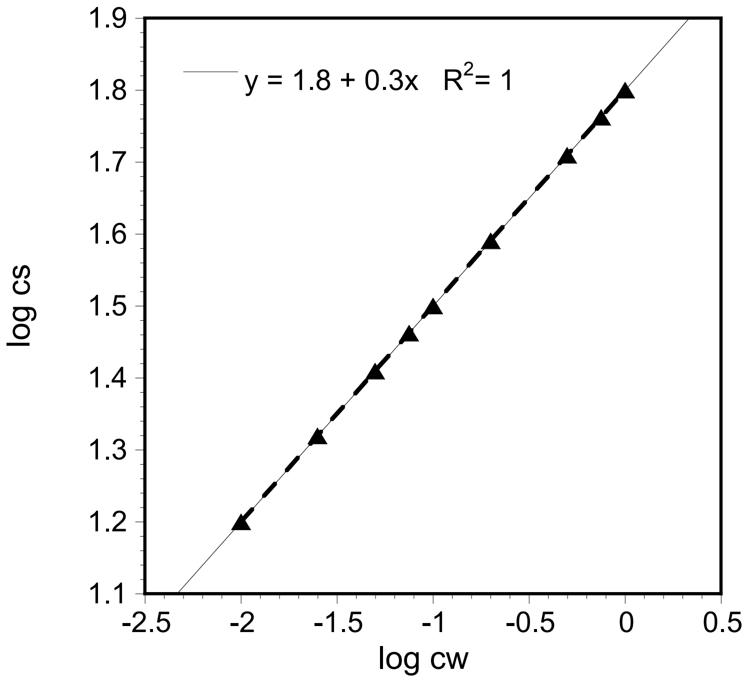
a) Determine the parameters (K, 1/n) for a Freundlich isotherm.



Answer

Cw mg/L	Cs mg/g
0.0100000	15.849
0.025000	20.863
0.050000	25.686
0.075000	29.008
0.10000	31.623
0.20000	38.932
0.50000	51.250
0.75000	57.879
1.0000	63.096

Based on the Freundlich equation ($\log C_s = \log K + 1/n \log C_w$), a plot of the log Cs versus log Cw yields K and 1/n.



logK = 1.8 => K= 63

1/n= 0.3

b) An activated carbon filter should be used to remove atrazine. The specifications are as follows:

Carbon type F400: $\rho_F = 450$g/L

Influent concentration 1 mg/L

Flow rate 50 m^3/h

EBCT 20 min

(i) Calculate the minimum GAC usage rate and the maximum specific throughput

Answer

$$\text{Minimum CUR} = \frac{M_{GAC}}{Qt_b} = \frac{C_{inf}}{q_e} = \frac{C_{inf}}{K(C_{inf})^{1/n}}$$

$$= \frac{1\,\text{mg/L}}{\left[63\ (\text{mg}^{0.7}\text{L}^{0.3}\text{g}^{-1})\right](1\,\text{mg}/\text{L})^{0.3}} = 0.016\ \text{g GAC/L}\ H_2O\ \text{treated}$$

$$\text{Maximum specific throughput} = \frac{1}{\text{GAC usage rate}} = \frac{1}{0.016\ \text{g/L}} = 62.5\ \text{L/g GAC}$$

(ii) How much water can be treated before the compound breaks through?

Answer

The mass of carbon in the filter can be calculated as follows:

$$M_{GAC} = Q \times EBCT \times \rho_F = 833\ \text{L/min} \times 20\ \text{min} \times 450\ \text{g/L} = 7.5 \times 10^6\text{g}$$

Water that can be treated until breakthrough:

$$\frac{\text{mass of activated carbon in filter bed}}{\text{GAC usage rate}} = \frac{7.5 \times 10^6\text{g}}{0.016\ \text{g/L}} = 4.7 \times 10^8\text{L} = 470000\ \text{m}^3$$

(iii) What is the filter bed life (lifetime of filter before compound breaks through)?

Answer

$$\text{Filter bed life} = \frac{\text{volume of water before breakthrough}}{Q}$$

$$= \frac{470000\ \text{m}^3}{50\ \text{m}^3/\text{h}} = 9400\ \text{h} = 391\ \text{days}$$

2. Membrane fouling

The water authority decides to operate the membranes in a dead-end mode, with intermittent back-flushing. The flux is kept at a constant value of 70 L m^{-2} h^{-1}. Pilot experiments show a typical pressure diagram of the filtration cycles as shown in Figure 1.

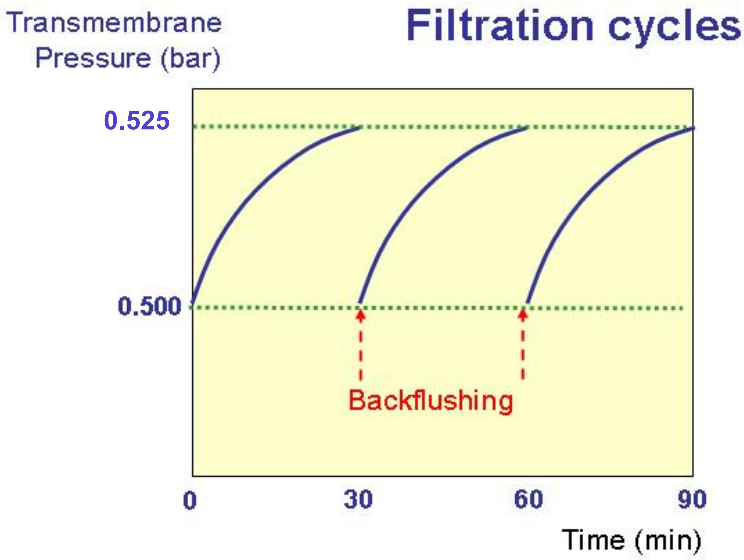


Figure 1: Trans-membrane pressure during filtration cycles

a) Discuss the mode of fouling (reversible vs irreversible).

Answer

After back-flushing, there is a full recovery of the original transmembrane pressure. Therefore, the fouling is fully reversible.

b) Observation above shows that the cake layer formed by deposition of the particulate fraction is effectively removed during backwashing. Calculate the thickness and porosity of the cake layer formed on the membrane. The concentration of particles is 600 mg/L, the average particle diameter 0.05 μm, and the particle density 1500 kg/m^3, T=20^{o}C, μ = 1.002 x 10^{-3} Ns/m^2, 1 bar = 10^5 Pa = 10^5 kg m^{-1}s^{-2}. Assume in a first approximation that the porosity can be neglected for the calculation of the thickness of the cake layer.

Answer

The thickness of the fouling layer, δ_c can be calculated as follows:

$$\delta_c = \frac{600 \text{ mg/L} \times 70 \text{ L m}^{-2} \text{ h}^{-1} \times 0.5 \text{ h}}{1.5 \times 10^9 \text{ mg/m}^3} = 1.4 \times 10^{-5} \text{ m}^3\text{m}^{-2} = 14 \ \mu\text{m}$$

The cake layer resistance is given by:

$$\Delta P = 0.025 \text{ bar} = 2.5 \times 10^3 \text{ kg m}^{-1}\text{s}^{-2}$$

$$J = 1.94 \times 10^{-5} \text{ m}^3\text{m}^{-2}\text{s}^{-1}$$

$$R_c = \frac{\Delta P}{\mu J} = 1.28 \times 10^{11} \text{ m}^{-1}$$

The porosity can now be calculated by solving the Carman Kozeny equation for ε.

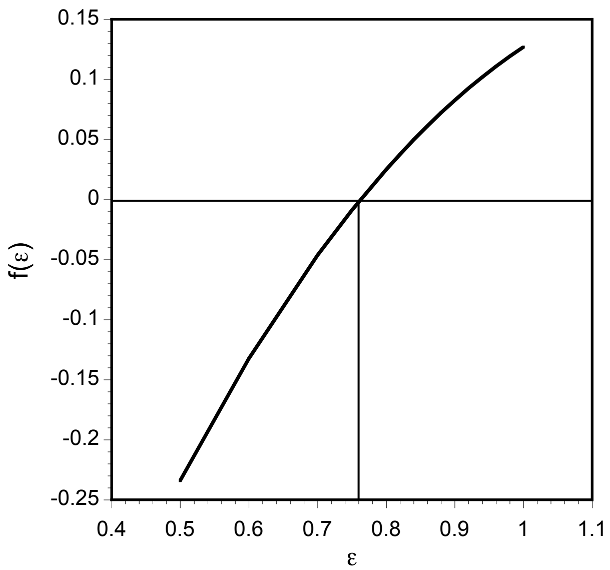
$$R_c = \frac{36 \times k_k (1-\varepsilon)^2 \delta_c}{\varepsilon^3 d_p^{\,2}}$$

$$R_c d_p^2 \varepsilon^3 = 36 \times k_k \delta_c (1-\varepsilon)^2$$

$$3.2 \times 10^{-4} \varepsilon^3 = 36 \times 5 \times 1.4 \times 10^{-5} (1-\varepsilon)^2 = 2.52 \times 10^{-3} (1-\varepsilon)^2$$

$$0.127\varepsilon^3 - \varepsilon^2 + 2\varepsilon - 1 = 0$$

The graphical solution (graph below) shows that the porosity of the fouling layer is 0.76.



c) In 3b) we have neglected the porosity. How does this result affect the fouling layer thickness and also the porosity (qualitative answer)?

Answer

Based on this result the fouling layer has to be recalculated, yielding 14 μm/0.24 = 58 μm. This value can then be used to recalculate the porosity (δ_c in Carman Kozeny equation) and based on this the fouling layer thickness can be recalculated. The two parameters are then obtained in an iterative process.

d) How does the calculated porosity from 3b) compare to deep bed filtration (ε=0.4)?

Answer

The porosity in sand filters is around 0.4. The porosity in the fouling layer is much higher!