ENV-405 | Water and Wastewater Treatment

Lecture 4. Rapid sand filtration and ultrafiltration

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Exercice #1 | Rapid sand filtration

A deep bed rapid filter consists of 1 m with an average diameter of sand grains of 0.5 mm. The filtration rate is 10 m/h.

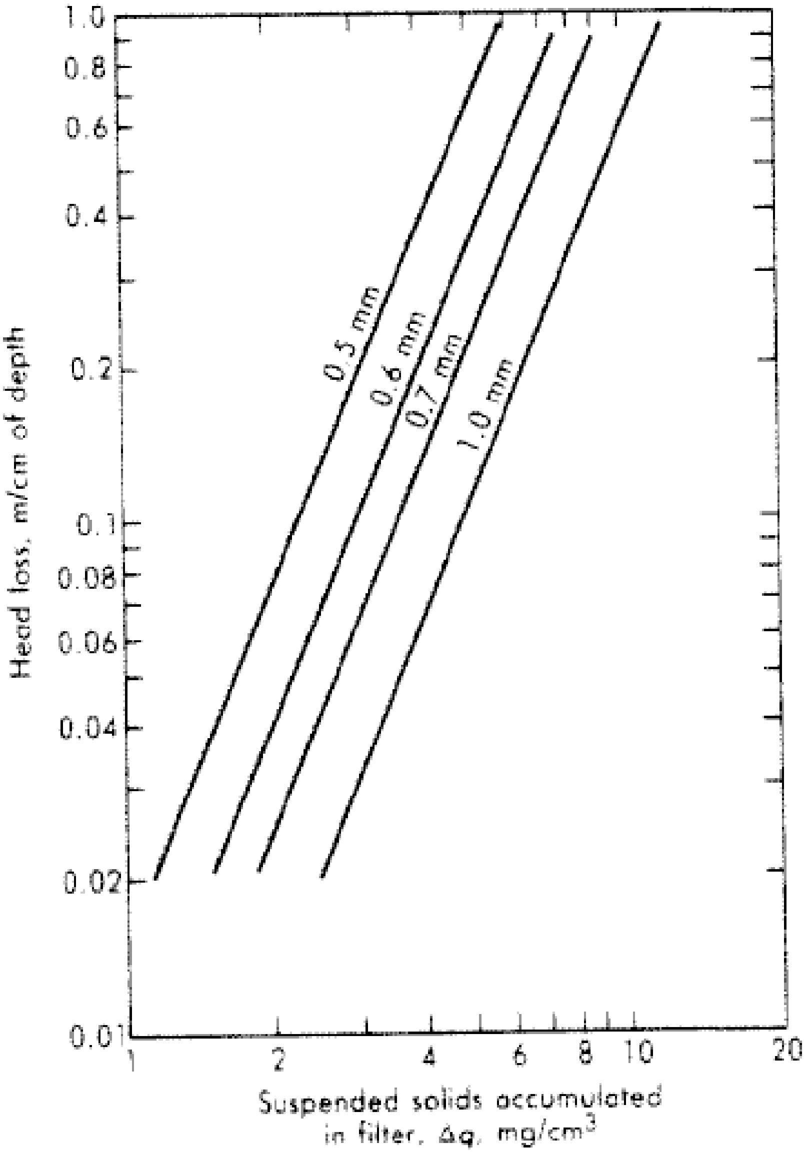
Q1. Calculate the clean-bed head loss for a temperature of 5°C. Use average values for k_V, k_I and ε from the lecture notes. Dynamic viscosity could be found in Homework #3 (Table C-1).

Q2. Plot the head loss as a function of porosity (using the parameters above). Determine the porosity decrease for a 30% increase of the head loss (assuming that other parameters remain constant)? If you failed at Q1, use 1.15 m for the clean-bed head loss.

Q3. Calculate the total head loss after 2h of operation for a non-homogeneous deposition of particles. The influent water contains 5×10^5 particles/L with a diameter of 50 µm and a density of 2000 kg/m^3. The relative removal in each layer of the filter after 2h is described in the table below.

Filtration depth cm	C_x/C_o
0	1
5	0.85
10	0.78
15	0.72
20	0.68
30	0.65
40	0.62
60	0.62
80	0.62
100	0.62

You will start by calculating the total suspended solid concentration of the water (in mg/L). With that, you can determine the quantity of suspended solid accumulated (in mg/cm^3) in 2 h for each 5-cm layer of filter (the calculation is independent of the filter surface area). Finally, use the figure below to estimate the head loss for each layer and thus the total head loss.

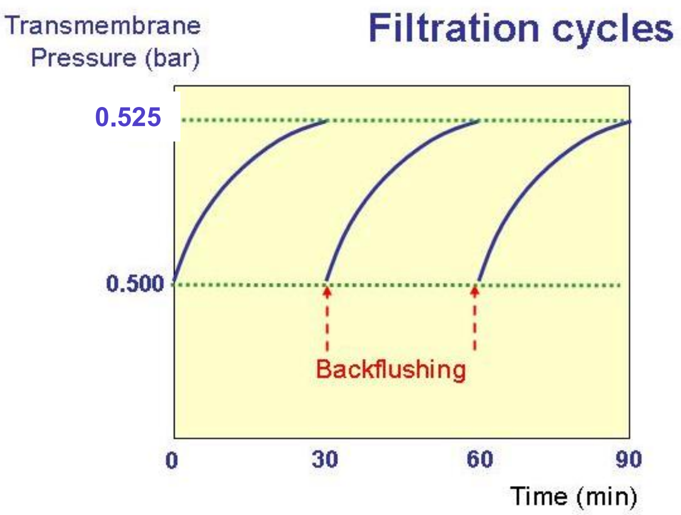

1.0
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
Head loss, m/cm of depth
0.5 mm
0.6 mm
0.7 mm
1.0 mm
1
2
4
6
8
10
20
Suspended solids accumulated
in filter, Δq, mg/cm3

Exercice #2 | Membrane fouling

A water utility decides to operate ultrafiltration membranes in a dead-end mode with intermittent backwashing to produce 1'000 m^3/h. The flux is kept at a constant value of 70 $L/m^2.h$.

Q1. Since the membrane surface area for 1 module is 60 m^2. How many modules should be used in their drinking water treatment plant?

Q2. The TMP increase was monitored, and a typical pressure diagram of the filtration cycles is shown below. Discuss if we observe a reversible or irreversible fouling.



Observation above shows that the cake layer formed by deposition of the particulate fraction is effectively removed during backwashing.

Q3. Calculate the cake layer thickness (δ_c) before backflushing with the following information

- Concentration of particles = 600 mg/L
- Average particle diameter = 0.05 µm
- Density = 1'500 kg/m^3
- T = 20°C
- $\mu = 1.002 \times 10^{-3}$ Ns/m^2
- 1 bar = 10^5 Pa = 10^5 $kg/m.s^2$
- In a first approximation, assume that the porosity can be neglected for the calculation of the thickness of the cake layer
- additional information can be found in the figure above

Q3. Calculate the cake layer resistance (Kc) with the following formula: $J = \Delta P / (\mu . K_c)$

Q4. Calculate the cake porosity solving the Kozeny equation:

$$\kappa_C = \frac{36\kappa_K (1-\varepsilon)^2 \delta_C}{\varepsilon^3 d_P^2}$$

where κ_C = cake layer resistance coefficient, m^{-1}

κ_K = Kozeny coefficient, unitless (typically 5)

ε = cake porosity, dimensionless

δ_C = thickness of cake layer, m

d_P = diameter of retained particles, m

Q5. In Q2, we neglected the porosity. How does this result affect the fouling layer thickness and the porosity (qualitative answer)?

Q6. Compare the porosity calculated in Q4 with a conventional porosity for a deep bed filter (ε = 0.4)