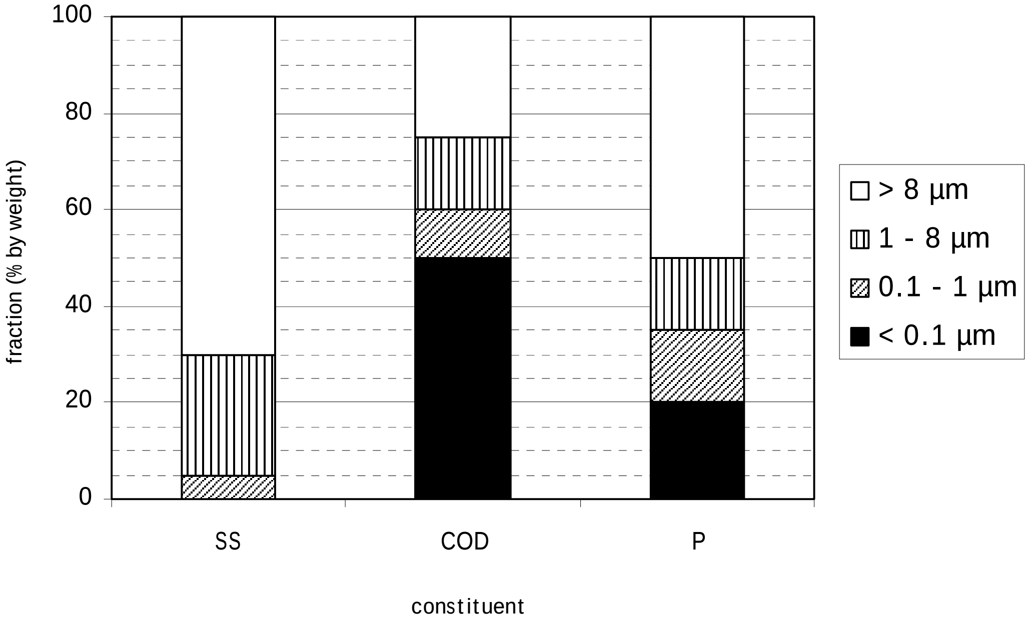
Write clearly; several questions consist of two or more subquestions.

1. Effluent filtration with a sand filter

An effluent of a WWTP has the following characteristics:

- SS concentration (> 0.1 µm): 30 mg/L
- Total COD concentration: 45 mgO_2/L
- Total P concentration: 2.4 mgP/L

The results of fractioning of the effluent are illustrated in the following graph:



This effluent is filtered over a sand filter with the following removal efficiencies:

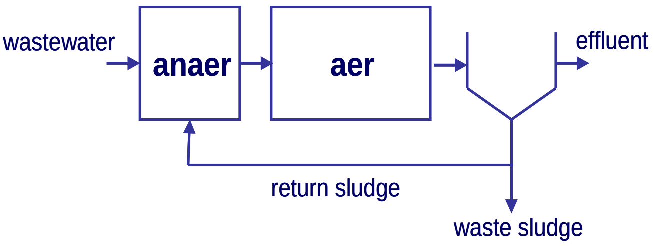
- fraction 0.1 – 1 µm, average removal of SS 5 % (by weight)
- fraction 1 – 8 µm, average removal of SS 60 % (by weight)
- fraction > 8 µm, average removal of SS 95 % (by weight)

1.1 Estimate (by calculation) removal efficiencies and filtrate concentrations of:
- Suspended solids
- P

1.2 Explain the differences between particle size distribution (nominal) (PSD), particle volume distribution (PVD), cumulative volume distribution (PVD-cum) and relative cumulative volume distribution (PVD-rel-cum).

2. Biological P removal

A wastewater has the following characteristics
- COD: 300 mg/l
- Biodegradable COD (bCOD): 200 mg/l
- Biodegradable soluble COD (bsCOD): 50 mg/l
- PO_4^{3-}–P: 6 mg/l



Y	0.40 gVSS/g COD
k_d	0.08 d^{-1}
SRT	5 d
P in PAO	0.30 gP/gVSS
P in others	0.02 gP/gVSS
effluent VSS	8 gm^{-3}
f_d	0

The wastewater is treated with the above activated sludge plant optimized for Bio-P removal. Other required kinetic parameters and process values are tabulated above.

Biomass growth is given by: $$X = \frac{Y(S_i - S)}{(1 + k_d \theta_x)}$$

2.1. Estimate the effluent soluble P concentration in the above system, assuming that all influent P is available for P accumulating organisms (PAO). Assume that all bCOD is removed in the system.

2.2 Calculate the P removal efficiency.

3. Advanced phosphorous removal.

For the extensive removal of phosphorus from a WWTP plant effluent with sand filtration an iron chloride ($FeCl_3$) solution, with 75 g Fe^{3+}/L is used. The pilot installation treats 10 m^3/h, with an average orthophosphorus concentration of 0.8 mg P_{ortho}/L. The optimal metal/P_{ortho} dosing ratio is 4 mol/mol. Molar mass for Fe^{3+} is 56 g/mol and for PO_4-P is 31 g/mol.

3.1 Calculate the dosage of iron chloride solution in L/h.

3.2 Which process parameters are of importance for advanced phosphorus removal? Mention at least 5 parameters. How do these process parameters influence the phosphorus removal?

4. Physical-Chemical Pretreatment WWTP TU Delft

Given information of WWTP TU Delft
dwf = 1,000 m^3/h
rwf = 3,200 m^3/h
Q_{day} = 15,000 m^3/d
BOD = 180 g/m^3
TSS = 220 g/m^3
TUR = 250 NTU/l
$N_{kjeldahl}$ = 55 g/m^3
P_{total} = 9 g/m^3
P = 31 g/mol
Fe^{3+} = 56 g/mol
required Me^{3+}/P-ratio = 0.9 mol/mol

4.1 Calculate the surface of the sedimentation tank

4.2 Calculate the required metal salt addition for P-removal down to 1 mg P/l as g Fe^{3+}/m^3 and ton Fe^{3+}/year

4.3 Calculate the required PE addition (dosage 2 mg active PE/100 NTU/l) as g PE/m^3

4.4 Can we still apply proper pre-denitrification after chemically enhanced pre-sedimentation?

5. Sludge Treatment

5.1. Calculate the sludge volume reduction when excess sludge is thickened from 1% to 5%.

5.2. What technologies are generally used to dewater the sludge of digestion.

5.3. What TSS concentrations can be reached after dewatering?

6. Ultrafiltration of effluent

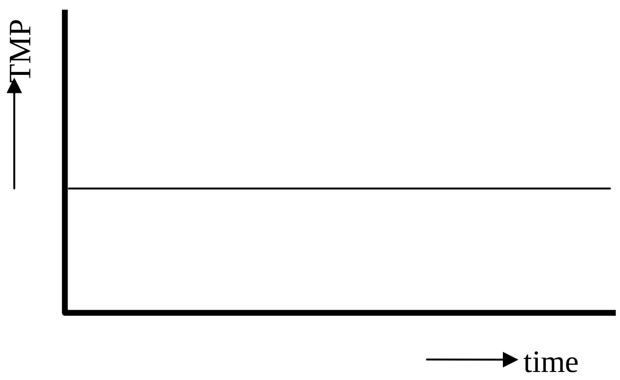
The relation between flux (J) and trans membrane pressure (TMP) is described according to Darcy's law:

$$J = \frac{TMP}{\eta \cdot R}$$

in which R is total resistance over membrane and fouling during filtration.

6.1 Describe the different types of resistance that occur during filtration.

6.2. When an ultra filtration installation is fed with a nonfouling effluent the relation between TMP and time (at constant flux) is according to the graph below.



Draw the relation between TMP and time in case of:
a. adequate pretreatment and periodic cleaning
b. inadequate pretreatment and inadequate periodic cleaning

7. Disinfection of effluents

For disinfection with chlorine in a batch reactor the Chick and Watson equation is:

$$\ln(\frac{N_t}{N_0}) = -10.5 \cdot C^{1.2} \cdot t$$ (conditions: 5 ºC and pH = 8.5)

with: N_t = number of surviving bacteria after contact time t (min)
N_0 = number of bacteria at t=0 min
C = chlorine dosage (mg/L)

The temperature relation is given by:

$$\ln\frac{t_1}{t_2} = \frac{E(T_2 - T_1)}{R \cdot T_1 \cdot T_2}$$

with: t_1, t_2 = time (min) for given % kill at temperatures T_1 and T_2 (K)
E = activation energy (J/mole) (see table)

R = gas constant = 8.3144 J/mole.K

Compound	pH	E (J/mole)
Aqueous chlorine	7.0	34,340
	8.5	26,800
	9.8	50,250
	10.7	62,810
Chloramines	7.0	50,250
	8.5	58,630
	9.5	83,750

7.1 Estimate (by calculation) the time required for 99.9% kill for a chlorine dosage of 0.1 mg/L at 15 ºC and pH = 7.0.

7.2 Give at least three advantages of disinfection with UV compared to disinfection with chlorine.

7.3 Give also at least three disadvantages.

8. Agricultural reuse: pathogen removal in pond systems.

Pathogen removal in an ideal plugflow pond follows a first order decay rate: **$dN/dt = - k_d * N$**
In mixed pond systems, pathogen removal is described by:

$$\frac{N_{effl}}{N_{inf}} = \frac{1}{(1 + k_d * \theta / n)^n}$$

with N = number of pathogenic organisms
k_d = decay rate
θ = hydraulic retention time
n = number of ponds

Given:
Q = 100,000 m^3/day
$N_{infl.} = 10^8$
K_d = 0.7 / day

8.1 Calculate the required hydraulic retention time for reaching the WHO requirements for unrestricted irrigation ($N_{effl.} = 10^3$) for the following 3 pond systems:

- Plug flow pond
- Completely mixed single (1) compartment pond
- Completely mixed pond series consisting of 5 compartments

8.2 Explain advantages and constraints of using treated effluents for agricultural usage

9 Anaerobic treatment

9.1 Explain why the pH of an anaerobic reactor will likely drop when the reactor is overloaded with non-acidified wastewater?

9.2. Will the pH also drop when the reactor is fed with only acetate? Explain Why / Why not.

9.3 Explain what happens with the biogas production if suddenly a substantial amount of sulphate (SO_4^{--}) is added to the influent. Why does this happen?

9.4 Why reactors with immobilised sludge are most successful in anaerobic treatment?