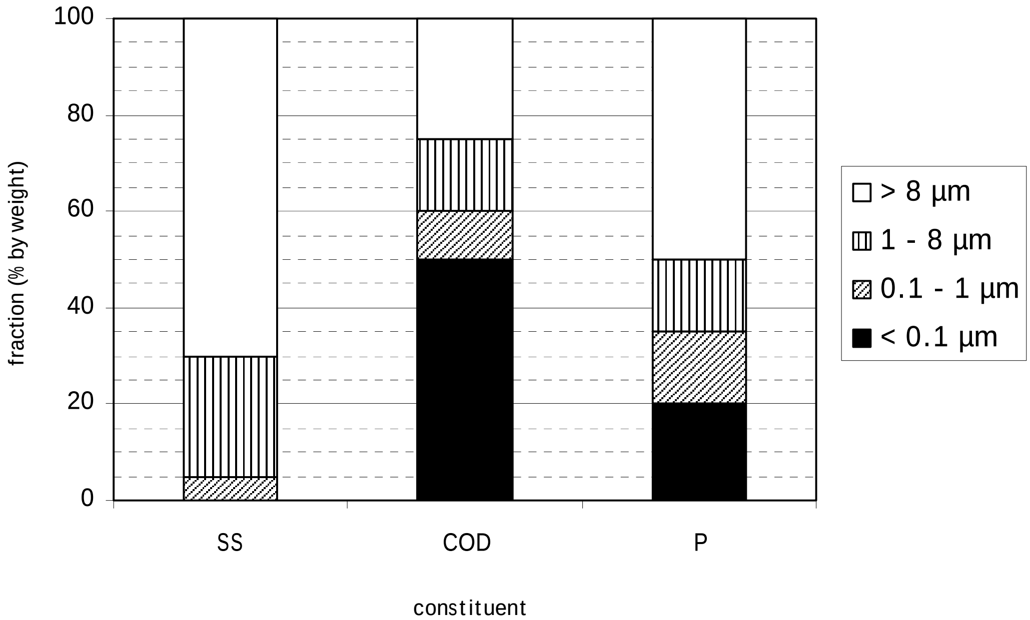
Write clearly; several questions consist of two or more subquestions.

1. Effluent filtration with a sand filter

An effluent of a WWTP has the following characteristics:

- SS concentration (> 0.1 µm): 42 mg/L
- Total COD concentration: 83 mgO_2/L
- Total P concentration: 1.8 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 10 % (by weight)
- fraction 1 – 8 µm, average removal of SS 55 % (by weight)
- fraction > 8 µm, average removal of SS 95 % (by weight)

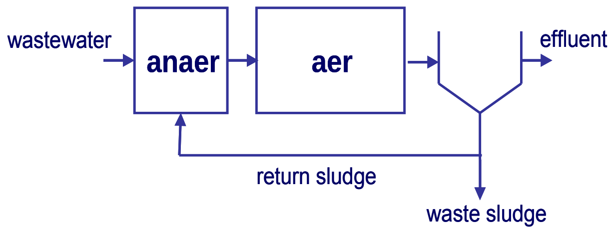
Estimate (by calculation) removal efficiencies and filtrate concentrations of:

- Suspended solids
- P

2. P removal in wastewater treatment

2.1 Explain the principle of bio-P removal in an activated sludge plant.

A wastewater has the following characteristics
- COD: 450 mg/l
- Biodegradable COD (bCOD): 300 mg/l
- Biodegradable soluble COD (bsCOD): 75 mg/l
- PO_4^{3-}–P: 9.5 mg/l



The kinetic constants and other characteristics are:

Sludge Yield 'Y'	0.45 g VSS/g COD
K_d	0.08 d^{-1}
SRT (θ_x)	6 d
P in PAO	0.32 g P / g VSS
P in others	0.02 g P/ g VSS
Effluent VSS	10 mg/l

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: $$X = \frac{Y(S_i - S)}{(1 + k_d \theta_x)}$$

2.2. 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.

2.3 Calculate the P removal efficiency.

3. Sludge Treatment

A flow of 750 m^3/day of waste sludge (1% SS of which is 70% organic matter) is thickened to a SS-concentration of 50 gSS/L by gravity. The thickened sludge is pumped to a digester. In the digester 50% of the organic matter is degraded to biogas. The digested sludge is dewatered to 25% SS (no chemicals are needed for dewatering).

3.1 How many trucks with a capacity of 30 tons are needed per week to transport the dewatered sludge to the central incineration plant?

3.2 What is the daily biogas production, assuming 1,000 L biogas per kg degraded organic matter?

4. Membrane bioreactors (MBR) for wastewater treatment

4.1 Explain the two main advantages and the two main disadvantages of MBR technology, compared to activated sludge for sewage treatment.

4.2 Which pore sizes are generally applied in the membranes of MBR reactors and which compounds are retained by such membranes?

4.3 Explain the difference between reversible, irreversible and irrecoverable fouling.

4.4 According to the current insights, what is governing the filtration characteristics of MBR sludge

5. Decentralised Sanitation / source separation

5.1 Give an indication of the volume and mass fractions of COD, N and P associates with fecal matter and urine.

5.2 What are the major incentives for the development of sanitation approaches that are based on the separation of household waste streams.

5.3 If only separate collection of urine would be considered for over 50% of the Netherlands. What would be the main effect on the currently used centralized activated sludge plants?

6. Agricultural reuse of urban effluents

6.1 Mention 5 key-pollutants or contaminents of concern when the use of urban effluents for agricultural production is considered. Briefly discuss why removal of these pollutants is important.

6.2 South of Fortaleza in the poor North-East area of Brazil the use of the treated sewage in agriculture is considered. What type of additional disinfection technology do you propose and why.

6.3 From the various alternatives a local contractor proposes to construct a pond system for post-treating the effluent. What type of system, a plug-flow pond, a mixed pond or a series of mixed ponds would you prefer and why?

6.4 Calculate the hydraulic retention time of both:
a) a plug flow pond system and
b) a series of 5 mixed ponds with identical dimensions

Pathogen removal in an ideal plugflow pond follows a first order decay rate:

$$\frac{dN}{dt} = -k_d \cdot N$$

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 = 50,000 m^3/day
- $N_{infl.}$ = 2.8 x 10^7
- K_d = 0.8 / day
- The preceding wastewater treatment step already removes 99% of the incoming pathogens.
- Effluent must comply with WHO standards: $N_{effl.}$ = 10^3 for unrestricted irrigation.

6.5 Give a rough design sketch of the chosen system, including dimensions, assuming a depth of 1m and decide whether you would choose for the same option.

7. Disinfection of effluents with chlorine

Owing to land constraints, chemical disinfection of the effluents from the previous question are being evaluated. For disinfection with chlorine in a batch reactor the Chick and Watson equation is:

$$\ln\left(\frac{N_t}{N_0}\right) = -10.5 \cdot C^{1.2} \cdot t$$ (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), respectively
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

7.1 Estimate (by calculation) the time required to reach 1.10^3 pathogenic coliforms starting from 2.8×10^5 (or a kill of at least 99.64%) working with a chlorine dosage of 0.1 mg/L at 30ºC and pH = 7.0. Estimate the required volume of the contact tank treating the above flow of 50,000 m^3/day.

7.2 Comparing the pond solution and the chlorine solution for disinfection, give at least 2 advantages and disadvantages for both systems.

8 Anaerobic treatment

A food industry discharges wastewater with a flow of 4500 m^3/day and a concentration of 4000 mg COD/l. The biodegradability of the wastewater was estimated to be 95%. The industry is evaluating anaerobic treatment and is interested in using the biogas for energy supply.

8.1 Calculate the required volume of the anaerobic reactor, applying an organic loading rate of 30 kg COD/m^3.day. Do you propose a UASB reactor or an expanded bed high-rate reactor for this loading?

8.2. The reactor is dimensioned for an upflow velocity of 8 m/h. Calculate the height and diameter of the anaerobic reactor.

8.3 Calculate the daily methane production and the electric energy recovery assuming that all biodegradable COD is converted and a 40% efficiency combined heat power (CHP) generator is used.

- oxidation of methane: $CH_4 + 2\ O_2 \rightarrow 2CO_2 + 2\ H_2O$
- 1 mol gas = 22.4 l at standard temperature and pressure;
- C, H, and O have a molar weight of 12, 1 and 16, respectively
- theoretical energy content of 1 m^3 CH_4 equals 10,95 kWh.

8.4 What will be the daily benefit calculating with an energy price of 0.09 €/kWh and assuming that the energy requirement of 1 kWh/kg COD of the alternative activated sludge plant is saved.

8.5 Explain what happens with the biogas production if suddenly the influent also contains 1 kg SO_4 /m^3? Calculate the impact on the daily biogas production assuming that no SO_4 will be in the effluent of the anaerobic reactor and 2 moles of COD is needed to fully reduce SO_4 (molecular weight of S = 32).