CT4485 Wastewater Treatment
Tuesday, 31st January 2012, 14.00 – 17.00

Write clearly; several questions consist of two or more subquestions.
Please use a new examination paper, stating name and student number for every new topic

Topic I: Membrane bioreactors for wastewater treatment

(no answers provided by guest lecturer: answers can be found in lecture material)

1.

a) Describe 3 advantages and 3 constraints of membrane bioreactor technology by comparison with conventional activated sludge systems.

b) Define membrane fouling and explain how it is controlled in practice.

c) What is the activated sludge filterability? Why is filterability relevant for membrane bioreactor technology?

d) Considering the current knowledge, what are the main factors affecting sludge filterability?

2.
A water board is deciding between membrane bioreactor and sand filtration to upgrade the effluent quality of an existing wastewater treatment plant. The characteristics of the existing WWTP are:

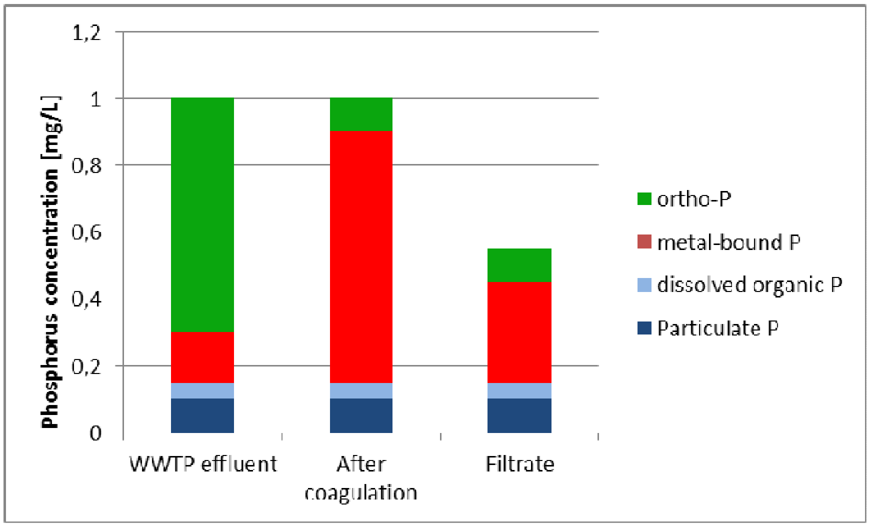
- Treatment of domestic influent coming from 10.000 inhabitants;
- Technology consist of conventional activated sludge treatment for carbon and nutrient removal;
- Located in an agricultural area;
- Effluent discharged in a sensitive area, where swimming is allowed.

a) Will membrane bioreactor and sand filtration technology provide similar effluent quality? Explain why?, why not.

b) A neighboring waterboard wants to extend a conventional activated sludge system by 4000 p.e. using MBR technology. Would you construct the MBR in series or/and in parallel with the conventional activated sludge treatment? Explain why.

Topic II Filtration

3.
A dual media filter (sand and anthracite layer) is used for simultaneous phosphorus and nitrogen removal from wastewater treatment plant effluent. The filtration velocity is 15 m/h, which results in a flocculation time of 7 minutes. For phosphorus removal 3 mol/mol $FeCl_3$ is added and for the denitrification 4 g methanol/g NOx-N and 0.8 g methanol/g O_2. Phosphorus distributions are made to investigate the phosphorus removal (see graph).



a) The discharge limit for total phosphorus is 0.15 mg/L. Evaluate the results of the provided phosphorus distribution. Briefly discuss what should be improved in order to reach 0.15 mg/L.

The activated sludge flocs are too small or break in the filterbed (1 point). The floc size could be influenced by increasing the dosage to 4 mol/mol (for example) or by increasing the flocculation time. Hence, in thet case the filtrationvelocity will be too high, so then it is most probable that the flocs will break due to too much energy in the filterbed. So the filtrationvelocity should decrease, to 10 m/h, which in the same time increases the flocculation time (BONUS POINT for this combination).

b) This filter operates with simultaneous phosphorus and nitrogen removal. Mention 2 advantages and 2 constraints of simultaneous removal.

Adventages: smaller footprint/equal removal of nutrients in comparison with two step removal/ smaller particles can be removed (fixed-bed filter). Disadvantages: risk for phosphate limitation (nitrite production) and shorter running times.

Topic III: Aerobic Granular Sludge Technology

4.
In May this year, the first full scale Nereda wastewater treatment plant will be officially opened. This full scale treatment plant replaces a conventional activated sludge system of 59.000 population equivalent. The application of aerobic granular sludge aims at a compact sewage treatment plant, low energy use and high effluent quality (demands Ntotal < 5 mg/L and PO_4-P < 1 mg/L). Influent concentrations are standard for municipal sewage the Netherlands.

a) One of the key parameters from the Nereda technology is the use of a Sequencing Batch Reactor (SBR). Explain why this reactor technology is needed for good granule formation.

- Bio-P process needed for stability, so alternating anaerobic, aerobic period needed
- High feeding concentration during feeding to avoid COD concentration gradients in the granules (PHB storage throughout granule)
- Selection of fast settling granules
- no pumping of the granules from one tank to the other, since that ruins the structure

b) Explain which phases in the SBR cycle are needed to reach given effluent demands. Explain what happens in which phase as well and to which part of a conventional treatment plant this could be compared.

Anaerobic feeding and effluent extraction: plug flow: P release, COD uptake, effluent discharge – anaerobic tank.
Aerobic period: P uptake, simultaneous nitrification/denitrification – aeration tank
Anoxic period: additional denitrification – anoxic tank
Settling: to select fast settling granules – clarifier
(Sludge drain: surplus sludge flow after clarifier)
Effluent extraction could also be mentioned as separate phase (SBR cycle, not Nereda cycle)

c) All process parameters are set in such a way that nitrogen is sufficiently removed, and nitrate in the effluent is below 4 mg/L. Due to an unexpected event, the granules break up and the average granule diameter decreases from 2 mm to 0,5 mm. Explain what will happen to the ammonium and/or nitrate in the effluent, and which measures can be taken to solve this problem.

Smaller granules with same DO means that the oxygen penetration depth stays the same, so nitrification capacity stays the same, but the anoxic volume decreases, so denitrification decreases: nitrate will increase in the effluent. Lowering the DO to reach an optimal aerobic/anoxic granule volume would solve the problem

Topic IV: Anaerobic treatment

5.
Shell Moerdijk discharges discontinuously 10.000 m^3/day of a merely soluble acidified wastewater with a concentration of 3500 mg COD/l. The biodegradability of the wastewater is estimated to be 80%. The industry is evaluating anaerobic treatment and is interested in using the biogas for energy supply.

a) Explain the main differences between anaerobic and aerobic treatment

No aeration, organic matter converted in CO2 and CH4, energy production, low sludge yield, etc

b) What different steps can you distinguish in the anaerobic conversion process; describe each step shortly

Hydrolysis, acidification, acetogenesis, methanogenesis

c) Considering the wastewater characteristics, what unit steps do you advise for the anaerobic treatment system

Buffer tank + anaerobic system + gas treatment + sludge storage

d) Calculate the required volume of the proposed anaerobic reactor, applying an organic loading rate of 20 kg COD/m^3.day

Volume: $V = c \cdot Q/ r_v$ or: 3.5 kg/m^3 x 10000 m^3/day / 20 kg COD/m^3.day = 1750 m^3.

e) The reactor is dimensioned for a maximum liquid upflow velocity of 8 m/h. Calculate the height and diameter of the anaerobic reactor.

$A_{reactor} = Q/V_{upw}$, A= (10000/24)/8 = 52 m^2. Height is V/A = 1000/52 = 33.7 m….
Too high …!! Not possible!
Bonus points: reduce size to e.g. 20 m and increase diameter to 10.5 m; or h = 25 m and d = 9.5 m, liquid upflow velocity drops to 5-6 m/h, space for some recirculation.

f) Calculate the daily biogas and methane production assuming that all biodegradable COD is converted to methane, the sludge yield is about 10%, the average oxidation state of the organic matter is 0, and the reactor temperature is 30ºC.
- 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

methane production: 3.5 kg/m^3 x 10000 m^3/day x 80% x 0.35 x (273+30/273) x 0.9 = 9789 m^3/d
Biogas (theory): 9789/0.5 = 19,578; more realistic: 9789/0.7 = 13,984 m^3/d since CO2 will be partly bound to the liquid. A CO2 content of less than 50% should be considered

g) Calculate the biogas upflow velocity and decide whether an advanced or a conventional gas separator/ GLSS device must be mounted.

Assume: 70% CH4 and 30% CO2: biogas is 13,984 m3/d: in the reactor.
Vgas upw = 11.2 m/h, way too high for conventional settler.

h) Explain what happens with the biogas production if suddenly the influent also contains 0.5 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).

Sulphate gets reduced instead of carbon, thus a lower CH_4 production at the expense of H_2S production. H_2S may also be toxic for methanogens, reducing further the CH_4 production yield.
1 mol SO4 equals 2 mol COD
96 g SO4 = 64 g COD, 1 kg SO4 = 0.67 kg COD, so 0.5 kg SO4 = 0.335 kg COD.

The amount of COD converted to CH4 is reduced from (3.5 x 0.8 x 0.9) = 2.52 to 2.185 (2.2) kg / m^3
methane production: 2.185 kg/m^3 x 10000 m^3/day x 0.35 x 303/273 = 8488 m^3/day

i) Anaerobic treatment is widely applied for industrial wastewater. Is anaerobic treatment of domestic sewage also an option for the Netherlands? Explain your answer

No, with current state of the art it is no option:
- *Sewage temp is too low in winter*
- *Sewage is very dilute so by far largest fraction of produced CH4 is in effluent (difficult to capture / greenhouse gas)*
- *Anaerobic treatment only converts organics, so no soluble BOD left for denitrification and BioP removal*

Topic V: Decentralised Sanitation / source separation

6.

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

Volume urine + faeces: 1.5 l/cap/day
Contains 50-60% of COD, 90-95% of N, 70-80% of P

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

- *potentials for recovery of PO4 and NH4*
- *potential energy recovery*
- *prevention of priority pollutants emission to the environment (insufficient removed by CAS)*
- *potential recovery of grey waters*
- *prevention of pathogens emissions (via effluents or CSO)*

c) 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?

Less NH4 to CAS, meaning significant reduction in required nitrification and thus huge savings in energy costs.

Topic VI: Wastewater treatment-Sewer Interactions
(no answers provided by guest lecurer)

7.
A city of 100,000 inhabitants (no industry) has been provided with a combined sewer system for the collection of wastewater. This wastewater has to be treated in a new wwtp. The only suitable discharge location for effluent is a pristine river 10 km away. This receiving water is vulnerable with respect to ammonia toxicity. As the slope of the area is insufficient, a pressure main will be necessary to transport the wastewater.

The design characteristics of the WWTP are:

- capacity: 100,000 p.e.
- daily dry weather flow DWF = 12,000 m^3/day
- maximum dry weather flow DWF_{max} = 1,000 m^3/h
- maximum wet weather flow WWF = $3 \cdot DWF_{max}$
- diameter transport sewer = 1 m

a) What is the optimal location for the wwtp, near the city or near the river banks? Explain why.

A survey of the sewer system revealed that the sewer system is leaking and receives a considerable flow of infiltrating groundwater, increasing the average dry weather flow to 24.000 m^3/day. The maximum dry weather flow and wet weather flow remain the same.

b) What are the consequences of the additional extraneous water on the performance of the wwtp with respect to effluent quality and treatment efficiency for COD, N_{total}, ammonia and P_{total}