Exercises for final exam preparation (answers)

Applied wastewater engineering

Exercise 1: Backwashing of sand filters of organic micropollutants treatment

A wastewater treatment plant with 60’000 inhabitants connected to it is currently treating a COD-load (determined by the 85th percentile of the influent loads) of 8’500 kg/d. Each population equivalent generates 120 L of wastewater per day. Furthermore, the wastewater contains 40 % infiltration water. The maximum wastewater flowrate which can be accepted at the WWTP is 3.5 times the average dry-weather flowrate (dry weather includes infiltration water).

The treatment train of the wastewater treatment plant is as follows: pre-treatment, primary clarifier, biofilters, ozonation contactor, sand filters. The six sand filters are currently operated at a maximal filtration rate of 14 m/h (excluding the return of the backwash water). The sand filters are backwashed every second day (half of the sand filters per night) and generate 5.5 m^3 backwash water per square meter of filter surface area. The backwash water is pumped back to the primary clarifier at a constant flowrate from 22:30 until 6 am.

a) Draw a scheme containing all information required for solve exercise 3.

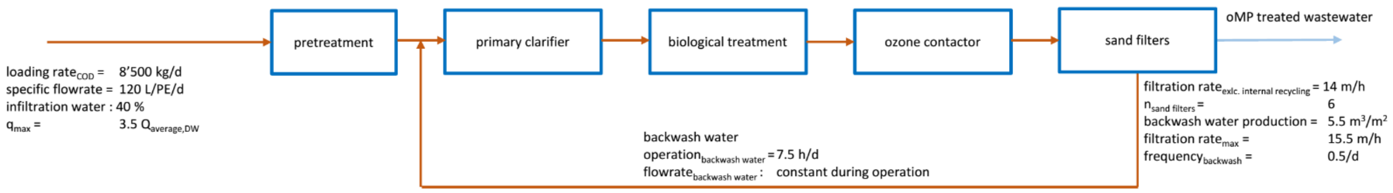

Figure 1: Scheme of exercise 1.

b) What is the average dry weather and the maximum rain weather flowrate entering the wastewater treatment plant (both expressed in m^3/h)?

$$nPE = \frac{loading\ rate_{COD,85\%}}{specific\ loading\ rate_{COD}} = \frac{8'500kgCOD/d}{120gCOD/PE} \times \frac{1000g}{1kg} = 71'000PE$$

$$Q_{average,DW} = \frac{nPE \times specific\ flowrate}{(1 - fraction_{infiltration\ water})} = \frac{71'00PE \times 120L/PE/d}{(1 - 0.4)} \times \frac{m^3}{1000L} \times \frac{d}{24h} = \mathbf{590m^3/h}$$

$$Q_{max} = 3.5 \times Q_{average,DW} = 3.5 \times 590m^3/h = \mathbf{2'070m^3/h}$$

The average dry weather and the maximum rain weather flowrate entering the wastewater treatment plant are 590 m^3/h and 2’070 m^3/h, respectively.

c) Compute the total surface area and the surface area of each sand filter.

$$total\ S_{sand\ filters} = \frac{Q_{max}}{filtration\ rate_{max}} = \frac{2'070m^3/h}{14m/h} = \mathbf{148m^2}$$

$$S_{sand\ filter} = \frac{total\ S_{sand\ filters}}{n_{sand\ filters}} = \frac{148m^2}{6} = \mathbf{25m^2}$$

The total surface area of the sand filters is 148 m^2 and each sand filter has a surface area of 25 m^2.

d) How much backwash water is generated each day? What is the maximum flowrate of backwash water entering the primary clarifier? Express both values in percent as compared to average daily dry weather flowrate and maximum rainy weather flowrate, respectively.

$$\frac{Q_{backwash\ water,average}}{Q_{average,DW}} \times 100\% = \frac{total\ S_{sand\ filters} \times frequency_{backwash} \times backwash\ water\ production}{Q_{average,DW}} \times 100\% = \frac{148m^2 \times 0.5/d \times 5.5m^3/m^2}{590m^3/h} \times \frac{d}{24h} \times 100\% = \mathbf{2.9}\%$$

$$\frac{Q_{backwash\ water,max}}{Q_{max}} \times 100\% = \frac{\frac{total\ S_{sand\ filters} \times frequency_{backwash} \times backwash\ water\ production}{operation_{backwash\ water}}}{Q_{max}} \times 100\% = \frac{\frac{148m^2 \times 0.5/d \times 5.5m^3/m^2}{7.5h/d}}{2'070m^3/h} \times 100\% = \mathbf{2.6}\%$$

The average and maximum backwash water flowrate corresponds to 2.9 % and 2.6 % as compared to average and maximum flowrate of the wastewater treatment plant, respectively.

e) What is the maximal filtration rate of the sand filters if one sand filter is being backwashed? Take into account that the backwash water is returned back into the primary clarifier at the same time.

$$maximal\ filtration\ rate_{one\ filter\ being\ backwashed} = \frac{Q_{max} + Q_{recycle}}{S_{filters\ in\ operation}} = \frac{Q_{max} \times (1 + \frac{Q_{backwash\ water,max}}{Q_{max}})}{n_{filters\ in\ operation} \times S_{sand\ filer}} = \frac{2'070m^3/h \times (1 + 0.026)}{5 \times 25m^2} = \mathbf{17m/h}$$

The maximal possible filtration rate of the sand filters is 17 m/h if one filter is under backwash (out of operation) and if the return of the backwash water is considered.

Exercise 2: Chemical conditioning

1. In sludge treatment, when is chemical conditioning required?

a) For mechanical thickening using natural gravity force, chemical conditioning is necessary in order for it to work properly. In contrast, gravity/centrifuge/flotation thickening can be done without chemical conditioning.
b) The dewatering process always requires prior chemical conditioning.

2. a) What are the most important substances used for chemical conditioning?

The most important substances used for chemical conditioning are polymers.

b) What is particular about these substances?

The particularity about polymers is their huge molecular weight, which allows them to bind to different particles (e.g. bacteria) and bring them in contact (flocculation process).

c) What is important for their correct preparation and use

The polymers are purchased in either solid or liquid from. The first step before use is always the dilution of these concentrated forms into a more dilute solution. Once diluted it is essential to allow the polymers to maturate (maturation period). Once maturation period is finished, the solution should be used ideally within hours and at least within one day.

Exercise 3: Chemical scrubbers for waste air treatment

A municipality operates chemical scrubbers for the waste air treatment at their wastewater treatment plant. It treats 220'000 m^3/h of waste air, which has an average density of 1.2 kg/m^3. The waste air contains an average concentration of 20 mg sulphide/m^3. The scrubbant density is 1.0 kg/L.

a) Estimate the volume of the packing material of the basic chemical scrubber. You know that the design was done using conservative values.

Based on the design values given in the course, I chose a conservative gas residence time in the packing of 2.0 s for my computation.

$$V_{packing} = flowrate_{air} \times residence\ time_{air} = 220'000 m^3/h \times 2.0 s \times \frac{h}{3600 s} = \mathbf{120\ m^3}$$

My estimation of the volume of the basic chemical scrubber packing material is about 120 m^3.

b) How much scrubbant water (dilute caustic soda) has to be pumped back up to the tower (m^3/h)? Compute this based on average design values (kg air flow through the scrubbant).

An average design parameter for the quantity of scrubbant required is 2.0 kg H_2O/kg air flow. Hence:

$$flowrate_{scrubbant} = \frac{flowrate_{air} \times density_{air} \times mass\ required_{scrubbent}}{density_{scrubbent}}$$

$$= \frac{220'000m^3/h \times 1.2kg\ air/m^3 \times 2.0kgH_2O/kg\ air}{1.0kg\ H_2O/L} \times \frac{m^3}{1000L} = \mathbf{530m^3/h}$$

About 530 m^3 of scrubbant water (dilute caustic soda) have to be pumped back up to the scrubber tower per hour.

c) What is the average yearly consumption of caustic soda (NaOH) in t/year (to simply your computation you can assume a 100 % removal of sulphides in the scrubber)?

The average caustic soda dose can be estimated with 2.5 kg NaOH/kg sulphide removed:

$$consumption_{NaOH,yearly} = flowrate_{air,yearly} \times c_{sulphide} \times dose_{sulphide}$$

$$= \frac{220'000m^3}{h} \times \frac{24 \times 365h}{year} \times 20\frac{mg\ sulfide}{m^3} \times \frac{kg\ sulfide}{1000'000mg\ sulfide}$$

$$\times 2.5\frac{kg\ NaOH}{kg\ sulphide} \times \frac{t\ NaOH}{1000kg\ NaOH} = \mathbf{96t/y}$$

Each year the basic scrubber consumes in average 96t of caustic soda.