Exercises VI (answers): Treatment of wastewater solids II

Applied wastewater engineering

Exercise 1: Thickening of sludge

The wastewater treatment plant of Marrakech currently has 1'200'000 population equivalents with a maximum two-hourly dry weather flowrate entering the primary treatment of 9'000 m^3/h. The primary clarification is composed of three basins of 3'600 m^3 each. The sludge extracted from the primary clarifiers has a total solids content of 1.0 % and is thickened to 4.0 % by three gravity thickeners with a total surface area of 550 m^2. The overflow is returned to the primary treatment.

a) Gravity thickening

1. Draw a scheme for exercise a).

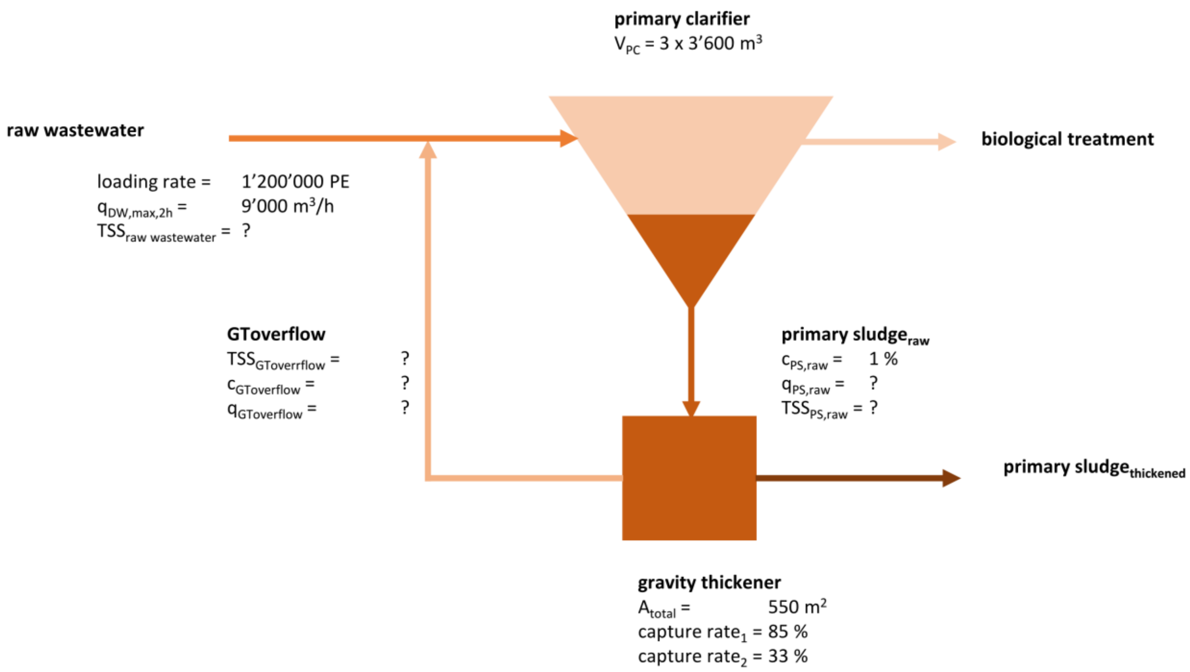

Figure 1 : Scheme of exercise 1 a).

2. What is the minimal residence time in the primary clarifier at the maximum dry weather flowrate? What is the yield of TSS removal of the primary clarifier?

$$residence\ time = \frac{volume\ of\ clarifiers}{q_{DW,max,2h}} = \frac{3 \times 3'600m^3}{9'000m^3/h} = \mathbf{1.2h}$$

The yield of the primary clarifier at a residence time close to 1 hour is equal to 50 %.

3. Assume that the gravity thickeners have a capture rate of 85 %, compute the solids loading rate (kg TSS/m^2·d) and the maximum overflow rate (m^3/m^2·d). Take into account the return flow of the gravity thickener.
   Use the TSS removal yield you determined for the primary clarifiers and not the sludge production for your calculations. Do both values respect design parameters given in the course?

Figure 1 shows the sludge thickening system in Marrakech. Conducting a mass flowrate equation (mass balance expressed in TSS/d), we can write the following equations for this system:

$$\left(TSS_{raw\ wastewater} + TSS_{GToverflow}\right) \times 50\% = TSS_{PS,raw} = TSS_{primary\ clarified\ wastewater}$$

$$TSS_{GToverflow} = TSS_{PS,raw} \times (100\% - capture\ rate_1) = TSS_{PS,raw} \times (100\% - 85\%)$$

Solving for $TSS_{PS,raw}$, we find the following equation:

$$\left(TSS_{raw\ wastewater} + TSS_{PS,raw} \times 15\%\right) \times 50\% = TSS_{PS,raw}$$

$$TSS_{raw\ wastewater} \times 50\% = TSS_{PS,raw} \times (1 - 15\% \times 50\%)$$

$$sludge\ extracted\ from\ primary\ clarifier\ per\ day = TSS_{PS,raw} = \frac{TSS_{raw\ wastewater} \times 50\%}{1 - 15\% \times 50\%}$$

$$= \frac{nPE \times specific\ daily\ loading\ rate \times 50\%}{1 - 15\% \times 50\%}$$

$$= \frac{1'200'000 \times \frac{70gTSS}{PE \times d} \times 50\%}{1 - 15\% \times 50\%} \times \frac{kg}{1'000g} = 45'400kgTSS/d$$

The solids loading rate of the thickener is then equal to:

$$solids\ loading\ rate = \frac{TSS_{PS,raw}}{surface\ of\ thickener} = \frac{45'400kgTTS/d}{550m^2} = \mathbf{83\ kgTSS}/(\boldsymbol{m^2 d})$$

This value is below 100 kg TSS/d so it respects the design parameters.

The flowrate of extracted primary sludge (density ≈ 1) is equal to

$$flowrate_{PS} = \frac{TSS_{PS,raw}}{concentration_{PS,raw}} = \frac{45'400kgTTS/d}{0.01kg/l} \times \frac{m^3}{1'000l} = 4'540m^3/d$$

Hence, the overflow rate of the thickener is equal to

$$overflow\ rate_{gravity\ thickener} \leq \frac{flowrate_{PS,raw}}{surface\ area_{gravity\ thickener}} = \frac{4'540m^3/d}{550m^2} = \mathbf{8.3m/d}$$

This value is below 15 m/d and hence respects our design criteria. Note that we did not compute the exact hydraulic overflow, as we had to subtract the flowrate of the thickened primary sludge from the *flowrate of the raw primary sludge. However, as the value is already smaller than 15 m/d, we do not need to make this additional step to provide a clear answer to the question.*

4. You visit the installation and the operator tells you that he has great difficulties with the gravity thickeners: their capture rate is currently only 33%. He asks you whether the design parameters (same as in 2.) are still respected.

We repeat the same calculation but using 33 % instead of 85 % for the capture rate.

$$sludge\ extracted\ from\ primary\ clarifier\ per\ day = TSS_{PS,raw}$$
$$= \frac{TSS_{raw\ wastewater} \times 50\%}{1-(100\% - capture\ rate_2)\times 50\%} = \frac{TSS_{raw\ wastewater} \times 50\%}{1-(100\% - 33\%)\times 50\%}$$
$$= \frac{nPE \times specific\ daily\ loading\ rate \times 50\%}{1-67\% \times 50\%}$$
$$= \frac{1'200'000 \times \frac{70gTSS}{PE \times d} \times 50\%}{1-67\%\times 50\%} \times \frac{kg}{1'000g} = 63'200kgTSS/d$$

The solids loading rate of the thickener is then equal to:

$$solids\ loading\ rate = \frac{TSS_{PS,raw}}{surface\ of\ thickener} = \frac{63'200kgTSS/d}{550m^2} = \mathbf{115\ kgTSS/(m^2 d)}$$

This value is above 100 kg/d so it does not respect the design criteria, which explains at least partially why the capture rate of the gravity thickener is so low.

The flowrate of extracted primary sludge is equal to

$$flowrate_{PS} = \frac{TSS_{PS,raw}}{concentration_{PS,raw}} = \frac{63'200kgTSS/d}{0.01kg/l} \times \frac{m^3}{1'000l} = 6'320m^3/d$$

Hence, the overflow rate of the thickener is equal to

$$overflow\ rate_{gravity\ thickener} \leq \frac{flowrate_{PS,raw}}{surface\ area_{gravity\ thickener}} = \frac{6'320m^3/d}{550m^2} = \mathbf{11.5m/d}$$

This value is below 15 m/d and hence respects our design criteria. Note that we did not compute the exact hydraulic overflow, as we had to subtract the flowrate of the thickened primary sludge from the flowrate of the raw primary sludge. However, as the value is already smaller than 15 m/d, we do not need to make this additional step to provide a clear answer to the question.

Hence, even though the overflow rate respects the design criteria, the solids loading rate is above the design criteria, which explains at least partially the low capture rate of the gravity thickener.

b) Mechanical thickening: The community of Marrakech is considering replacing the gravity thickeners by gravity-belt thickeners. The capture rate is estimated to be at least 92 %.

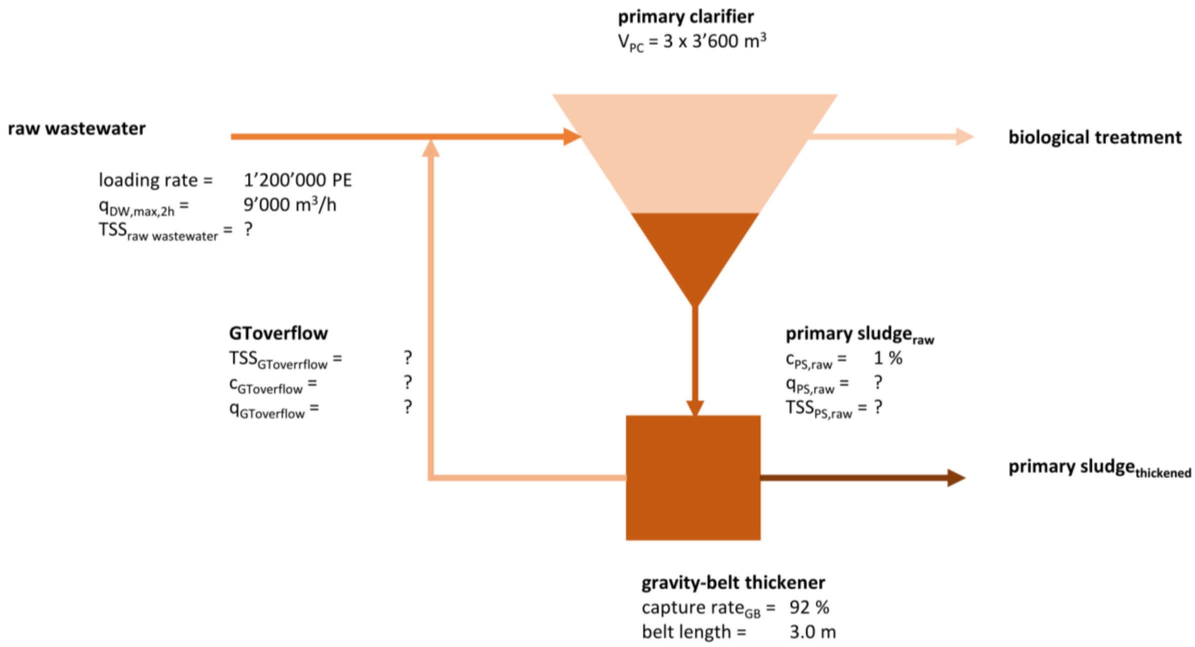

Figure 2 : Scheme of exercise 1b).

1. They want to know how many machines they would require with a belt size of 3.0 meters if they operate them 16 hours per day.

We repeat the same calculation but using 92 % instead of 85 % for the capture rate.

$$TSS_{PS,raw} = sludge\ extracted\ from\ primary\ clarifier\ per\ day$$
$$= \frac{TSS_{raw\ wastewater} \times 50\%}{1-(100\% - capture\ rate_{GB}) \times 50\%} = \frac{TSS_{raw\ wastewater} \times 50\%}{1-(100\%-92\%) \times 50\%}$$
$$= \frac{nPE \times specific\ daily\ loading\ rate \times 50\%}{1-8\% \times 50\%}$$
$$= \frac{1'200'000 \times \frac{70gTSS}{PE \times d} \times 50\%}{1-8\% \times 50\%} \times \frac{kg}{1'000g} = 43'800kgTSS/d$$

The flowrate of extracted primary sludge is equal to

$$flowrate_{PS,raw} = \frac{TSS_{PS,raw}}{concentration_{PS,raw}} = \frac{43'800kgTSS/d}{0.01kg/l} \times \frac{m^3}{1'000l} = 4'380m^3/d$$

$$flowrate_{16h} = flowrate_{PS,raw} \times \frac{1d}{16h} = 4'380m^3/d \times \frac{1d}{16h} \times \frac{1h}{3'600s} \times \frac{1'000l}{1m^3} = 76l/s$$

If we design our gravity belt-thickeners with a conservative 18 l/s for 16 hours per day:

$$number\ of\ units = \frac{flowrate\ of\ sludge}{flowrate\ per\ machine} = \frac{76 l/s}{18 l/s} = \mathbf{4.2}$$

Hence, in order to replace the gravity thickeners, the community had to purchase four gravity-belt thickeners with an effective belt size of 3.0 m and a maximal hydraulic loading slightly above 18 l/s.

2. They also ask you to design a sludge storage tank of untreated sludge. They would like to be able to stop the operation of the gravity-belt thickeners for at least 16 hours.

Hence, the minimal volume of the unthickened primary sludge storage tank is:

$$V_{storage\ tank,PS,raw} = flowrate_{PS,raw} \times time = \frac{4'380 m^3}{d} \times 16h \times \frac{d}{24h} = \mathbf{2'920 m^3}$$

Exercise 2: Sludge stabilisation

a) What are the main advantages of the anaerobic digestion compared to aerobic digestion?

- *Anaerobic digestion generates energy in form of gas (about 65 % methane), whereas aerobic digestion requires a lot of energy due to air injection.*
- *The aerobic digested biosolids have poorer dewatering characteristics than anaerobic digested biosolids.*

b) How does alkaline stabilisation 'stabilise' sludge?

Alkaline stabilisation increases the pH value of the sludge, which kills pathogens. The high pH value halts microbial reactions and hence avoids the putrefaction of the sludge. Furthermore, if quick lime is added to increase the pH value, the temperature also increases due to the hydration reaction. The increased temperature additionally helps to inactivate pathogens and other microorganisms.

However, the alkaline treated sludge remains stabilised only as long as the pH remains high.