

Exercises VII (answers): Treatment of wastewater solids III

Applied wastewater engineering

Exercise 1: Anaerobic digestion

The A.I.M.L (Association intercommunale de Lucens et Moudon) is thinking about the extension of their wastewater treatment plant to 51'000 population equivalents. The plant will employ an enhanced primary treatment with an expected yield equal to a classical primary treatment with a minimal residence time during dry weather conditions of 2.0 h even though the residence time is shorter. The wastewater shall be further treated with a nitrifying biology (sludge age of 10 days). The minimal water temperature is 10°C, this temperature should be used for the sludge production (maximal sludge production). The primary and secondary sludges are mixed and then thickened to 6 % TS with a gravity-belt thickener.

- a) The A.I.M.L. contracts you to determine whether their current digesters (2x365 m³) are large enough for the extension project (as a first approximation you can neglect the return sludge of the gravity-belt thickener). If not, they would like to know how much extra volume will be necessary.

Primary sludge production:

$$\text{sludge production}_{PS} = nPE \times \frac{m_{PS,q85\%}}{PE \times d} = 51'000PE \times \frac{40gTSS}{PE \times d} \times \frac{kg}{1'000g} = 2'040 \text{ kgTSS/d}$$

$$\begin{aligned} \text{sludge production}_{PS,TVSeasily\ degradable} &= \text{sludge production}_{PS} \times \text{content}_{TVS,PS} \times \text{content}_{easily\ degradable} \\ &= 2040 \text{ kgTSS/d} \times 0.75 \frac{TVS}{TSS} \times 0.70 \frac{TVSeasily\ degradable}{TVS} \\ &= 1'070 \text{ kgTVSeasily\ degradable/d} \end{aligned}$$

Waste activated sludge production:

$$\begin{aligned} \text{sludge production}_{WAS} &= nPE \times \frac{m_{WAS,q85\%}}{PE \times d} = 51'000PE \times \frac{29gTSS}{PE \times d} \times \frac{kg}{1'000g} \\ &= 1'480 \text{ kgTSS/d} \end{aligned}$$

$$\begin{aligned} \text{sludge production}_{WAS,TVSeasily\ degradable} &= \text{sludge production}_{WAS} \times \text{content}_{TVS,WAS} \times \text{content}_{easily\ degradable} \\ &= 1'480 \frac{kgTSS}{d} \times 0.72 \frac{TVS}{TSS} \times 0.45 \frac{TVSeasily\ degradable}{TVS} \\ &= 480 \text{ kgTVSeasily\ degradable/d} \end{aligned}$$

Total sludge flowrate entering digesters:

$$\begin{aligned} \text{flowrate}_{thickened\ sludge,PS+WAS} &= \frac{\text{sludge production}_{PS} + \text{sludge production}_{WAS,TVS}}{c_{thickened\ sludge}} \\ &= \frac{(2'040 + 1'480) \text{ kgTSS/d}}{0.06 \text{ kg/l}} \times \frac{\text{m}^3}{1'000\text{l}} = 59 \text{ m}^3/\text{d} \end{aligned}$$

Minimal required size of digester (I assume that the minimal sludge age is sufficient for a stable operation):

$$V_{\text{sludge age, digester}} \geq \text{flowrate}_{\text{thickened sludge, PS+WAS}} \times \text{required sludge age} = \frac{59\text{m}^3}{d} \times 18d$$

$$= 1'060\text{m}^3$$

$$V_{\text{TVS}_{\text{easily degradable}} \text{ loading factor}} \geq \frac{\text{sludge production}_{\text{TVSeasily degradable}}}{\text{TVS}_{\text{easily degradable}} \text{ loading factor}}$$

$$= \frac{\text{sludge production}_{\text{PS,TVSeasily degradable}} + \text{sludge production}_{\text{WAS,TVSeasily degradable}}}{\text{TVS}_{\text{easily degradable}} \text{ loading factor}}$$

$$= \frac{1'070 \text{ TVS}_{\text{easily degradable}}/d + 480 \text{ TVS}_{\text{easily degradable}}/d}{1.5 \text{ kgTVS}_{\text{easily degradable}}/\text{m}^3d} = 1'030\text{m}^3$$

The volume determined with the sludge age is slightly higher than that determined with the $\text{TVS}_{\text{easily degradable}}$ loading factor and is therefore retained.

$$V_{\text{extra}} = V_{\text{needed}} - V_{\text{existing}} = (1'060 - 2x365)\text{m}^3 = 330\text{m}^3$$

The volume of the existing digester is too small and a minimal extra volume of 330 m³ will be required for the extension project.

- b) At a meeting you explain them your design of the digesters of the extension project. They ask you about the sludge loading factor with easily degradable TVS of your project for the current situation (37'000 PE) and the future situation (51'000 PE).

Sludge loading with easily degradable TVS for the current situation (37'000 PE):

$$\text{loading factor}_{\text{TVSeasily degradable}} = \frac{\text{sludge production}_{\text{TVSeasily degradable, 51'000PE}} \times \frac{37'000\text{PE}}{51000\text{PE}}}{V_{\text{digesters, total}}}$$

$$= \frac{(\text{sludge production}_{\text{PS,TVSeasily degradable}} + \text{sludge production}_{\text{WAS,TVSeasily degradable}}) \times \frac{37'000\text{PE}}{51000\text{PE}}}{1'060\text{m}^3}$$

$$= \frac{(1'070 \text{ TVS}_{\text{easily degradable}}/d + 480 \text{ TVS}_{\text{easily degradable}}/d) \times \frac{37'000\text{PE}}{51000\text{PE}}}{1'060\text{m}^3}$$

$$= 1.06 \text{ kg TVS}_{\text{easily degradable}}/(\text{m}^3d)$$

Sludge loading with easily degradable TVS for future situation (51'000 PE):

$$\begin{aligned}
 \text{loading factor}_{TVS \text{ easily degradable}} &= \frac{\text{sludge production}_{TVS \text{ easily degradable}, 51'000 PE}}{V_{\text{digesters, total}}} \\
 &= \frac{(\text{sludge production}_{PS, TVS \text{ easily degradable}} + \text{sludge production}_{WAS, TVS \text{ easily degradable}})}{1060 m^3} \\
 &= \frac{(1'070 TVS_{\text{easily degradable}}/d + 480 TVS_{\text{easily degradable}}/d)}{1'060 m^3} \\
 &= \mathbf{1.46 \text{ kg } TVS_{\text{easily degradable}}/(m^3 d)}
 \end{aligned}$$

The sludge loading factor with easily degradable TVS is 1.06 kg/(m³d) for the current situation with the new digester in operation and 1.46 kg/(m³d) for the future situation.

- c) Furthermore, they would like to know how much gas they will produce in average per day once the plant reaches 51'000 PE. Assume a reduction of 85 % of easily degradable TVS.

gas production

$$\begin{aligned}
 &= \text{sludge production}_{PS, TVS \text{ easily degradable}} \times TVS_{\text{easily degradable removal}}_{PS} \\
 &\quad \times \frac{0.95 Nm^3}{TVS_{\text{removed}, PS}} \\
 &+ \text{sludge production}_{WAS, TVS \text{ easily degradable}} \times TVS_{\text{easily degradable removal}}_{WAS} \\
 &\quad \times \frac{0.85 Nm^3}{TVS_{\text{removed}, PS}} \\
 &= 1'070 \frac{kg TVS_{\text{easily degradable}, PS}}{d} \times 0.85 \frac{TVS_{\text{removed}, PS}}{TVS_{\text{easily degradable}, PS}} \times \frac{0.95 Nm^3}{TVS_{\text{removed}, PS}} \\
 &+ 460 \frac{g TVS_{\text{easily degradable}, WAS}}{d} \times 0.85 \frac{TVS_{\text{removed}, WAS}}{TVS_{\text{easily degradable}, WAS}} \times \frac{0.85 Nm^3}{TVS_{\text{removed}, PS}} \\
 &= \mathbf{1'200 Nm^3/d}
 \end{aligned}$$

The plant will produce about 1'200 Nm³ of gas per day once it reaches 51'000 PE. This corresponds to 23.5 l/PE.

Exercise 2: Dewatering of sludge

A wastewater treatment plant is planning to renew their sludge dewatering units. The primary and secondary sludge is anaerobically digested before being dewatered and transported to an incineration plant. After analysing the data of their operation system, you computed the following numbers concerning the digested sludge:

Parameter	Unit	Quantile 50 %	Quantile 85 %
Dry solids content in digested sludge	% TS	4.2	4.6
Mass loading rate of stratified digester	kg TS/day	1'100	1'400

The community contracts you to work on the project and asks you to answer the following questions taking into account an estimated increase of 20 % in sludge production in the next 15 years.

- a) Will the current stratified digester of 500 m³ be large enough to keep the digested sludge (density ≈ 1) for at least 10 days? If not, how much larger should it be?

$$t_{residence} = \frac{V_{stratified\ digester}}{flowrate_{sludge,q85\%}} = \frac{V_{storage\ tank}}{\frac{mass\ loading\ rate_{q85\%} \times sludge\ production\ increase}{c_{sludge}}}$$

$$= \frac{500m^3}{\frac{1'400kg\ TS/d \times 1.2}{0.046\ kg\ TS/l}} \times \frac{1000l}{m^3} = \mathbf{13.7\ days}$$

The future residence time in the stratified digester will be 13.7 days (> 10 days). Hence, the current stratified digester will be large enough.

- b) What flowrate (L/min) and mass loading rate (kg/h) will the new dewatering unit have to treat? They only want to operate it 5 days a week and 8 hours per day.

$$flowrate = \frac{flowrate_{sludge,q85\%} \times sludge\ production\ increase \times \frac{7d}{week}}{time\ of\ operation\ per\ week} =$$

$$\frac{\frac{mass\ loading\ rate_{q85\%} \times population\ increase}{c_{sludge}} \times \frac{7d}{week}}{\frac{8\ hours}{d} \times \frac{5d}{week}} = \frac{\frac{1'400kg\ TS/d \times 1.2}{0.046\ kg\ TS/l} \times \frac{7d}{week}}{\frac{8\ hours}{d} \times \frac{5d}{week}} \times \frac{h}{60min}$$

$$= \mathbf{107L/min}$$

$$mass\ loading\ rate = \frac{mass\ loading\ rate_{sludge,q85\%} \times sludge\ production\ increase \times \frac{7d}{week}}{time\ of\ operation\ per\ week}$$

$$= \frac{mass\ loading\ rate_{q85\%} \times population\ increase \times \frac{7d}{week}}{\frac{8\ hours}{d} \times \frac{5d}{week}}$$

$$= \frac{1'400kg\ TS/d \times 1.2 \times \frac{7d}{week}}{\frac{8\ hours}{d} \times \frac{5d}{week}} = \mathbf{294kg\ TS/h}$$

The new dewatering unit should be able to treat a flowrate of digested sludge of 107 l/min and a mass loading rate of digested sludge of 294 kg TS/h.

- c) They ask you to suggest a dewatering technology for the replacement and to justify your choice. Discussing with the operator of the treatment plant you notice that he wants as little odour generation as possible as his office is in the same building. He also tells you that the community would like to see a dewatering technology implemented requiring little energy.

I would suggest them a screw press because it requires little maintenance and generates little odours. The low odour potential is important as the dewatering unit is in the same building as the office of the operator. Furthermore, a screw press consumes little energy as compared to other dewatering technologies, which seems to be an important argument to the community.

- d) How much polymer will be required per year (maximum expected)?

polymer required per year

$$\begin{aligned}
 &= \text{mass loading rate}_{q_{50\%}} \times \text{sludge production increase} \times 365d \\
 &\times \frac{\text{kg polymer required}_{\text{screw press,max}}}{\text{t TS treated}} \\
 &= \frac{1'100\text{kg TS}}{d} \times 1.2 \times \frac{365d}{\text{year}} \times \frac{12 \text{ kg}}{\text{t TS treated}} \times \frac{t}{1000\text{kg}} = \mathbf{5'800\text{kg/year}}
 \end{aligned}$$

The maximal quantity of polymer required is 5'800 kg/year if a screw press will be installed (6'700 kg/year in the case a centrifuge will be installed).

- e) What quantity of sludge (t TS/year and t/year) will have to be transported to the incineration plant? You estimated the density of the dewatered sludge equal to 1.1 t/m³ (make your computation based on an average expected TS content).

$$\begin{aligned}
 \text{quantity of TS produced per year} &= \text{mass loading rate}_{q_{50\%}} \times \text{population increase} \times 365d \\
 &= \frac{1'100\text{kgTS}}{d} \times 1.2 \times \frac{365d}{\text{year}} \times \frac{t}{1000\text{kg}} = 480 \text{ t TS/year}
 \end{aligned}$$

total quantity of dewatered sludge to evacuate produced per year

$$\begin{aligned}
 &= \frac{\text{mass loading rate}_{q_{50\%}} \times \text{sludge production increase} \times \frac{365d}{\text{year}}}{C_{\text{dewatered sludge,average}}} \\
 &= \frac{\frac{1'100\text{kgTS}}{d} \times 1.2 \times \frac{365d}{\text{year}}}{0.24\text{kgTS/kg sludge}_{\text{dewatered}}} \times \frac{t}{1000\text{kg}} = 2'000\text{t sludge}_{\text{dewatered}}/\text{year}
 \end{aligned}$$

The wastewater treatment plant will have to transport 480 t TS and 2'000 t of dewatered sludge per year to an incineration plant.