

**Example 5.1**

Determine the maximum influent phosphorus concentration that can be removed in an activated sludge system with an anaerobic zone that has an influent substrate concentration of 500 mg COD.l<sup>-1</sup> in the form of acetate. Assume a temperature of 20°C and a sludge age of 10 days. Compare the total sludge mass in the system with that of a conventional system.

**Solution:**

Observe that in the calculation presented below  $S_{bi}$  equals  $S_{ti}$ , as all organic material is biodegradable. Assuming that a PAO culture will be established and that the utilisation of the organic material is complete, one has:

$$\begin{aligned} mX_{ap} &= Y \cdot R_s / (1 + b_p \cdot R_s) \\ &= 0.45 \cdot 10 / (1 + 0.04 \cdot 10) = 3.2 \text{ mg VSS} \cdot \text{mg}^{-1} \text{ COD} \cdot \text{d}^{-1} \text{ and} \end{aligned}$$

$$\begin{aligned} mX_{ep} &= f_{ep} \cdot b_p \cdot R_s \cdot mX_{ap} \\ &= f_{ep} \cdot b_p \cdot R_s \cdot Y \cdot R_s / (1 + b_p \cdot R_s) = 0.32 \text{ mg VSS} \cdot \text{mg}^{-1} \text{ COD} \cdot \text{d}^{-1} \end{aligned}$$

The discharge of phosphorus with the excess sludge per unit mass of daily applied COD is:

$$\begin{aligned} mP_i &= (f_{pp} \cdot mX_{ap} + f_p \cdot mX_{ep}) / R_s \\ &= (0.38 \cdot 3.2 + 0.025 \cdot 0.32) / 10 = 0.12 \text{ mg P} \cdot \text{mg}^{-1} \text{ COD}. \end{aligned}$$

For the influent COD concentration of 500 mg.l<sup>-1</sup>, the value of  $P_i$ , the concentration of phosphorus that theoretically can be removed from the influent with the excess sludge is  $0.12 \cdot 500 = 60 \text{ mg P} \cdot \text{l}^{-1}$ . For comparison, in a conventional system the value of  $P_i$  is only:

$$\begin{aligned} P_i &= f_p \cdot [(1 + f \cdot b_h \cdot R_s) \cdot C_r / R_s] \cdot S_{ti} & (3.62) \\ &= 0.025 \cdot [(1 + 0.2 \cdot 0.24 \cdot 10) \cdot (0.45 \cdot 10 / (1 + 0.24 \cdot 10)) / 10] \cdot 500 \\ &= 0.0049 \cdot 500 = 2.5 \text{ mg P} \cdot \text{l}^{-1} \end{aligned}$$

The ratio between  $P_i$  in the enhanced system (60 mg P.l<sup>-1</sup>) and in the conventional system (2.5 mg P.l<sup>-1</sup>), i.e.  $60/2.5 = 24$ , is even more than could be expected based on the difference in phosphorus content of the different sludges: i.e.  $0.38/0.025 = 15$ . This is due to the lower decay rate of the PAO compared to that of the other heterotrophs. For this reason, the active fraction in the excess sludge is much higher for PAO sludge than for conventional sludge:  $mX_{ap} = 3.2$  against  $mX_a = 1.3 \text{ mg VSS} \cdot \text{mg}^{-1} \text{ COD} \cdot \text{d}^{-1}$ .

In both cases it should be noted that due to imperfections in the solid-liquid separation in the final settler, part of  $P_i$  will be present in the effluent instead of in the excess sludge. The consequences of this model simplification will be discussed in Section 5.1.3.4. The volatile excess sludge production of the PAO can be calculated as:

$$mE_{vp} = (mX_{ap} + mX_{ep}) / R_s = (3.2 + 0.32) / 10 = 0.35 \text{ mg VSS} \cdot \text{mg}^{-1} \text{ COD}$$

The total excess sludge production is given by:

$$\begin{aligned} mE_{tp} &= (mX_{ap}/f_{vp} + mX_{ep}/f_v) / R_s \\ &= (3.2/0.46 + 0.32/0.8) / 10 \\ &= 0.75 \text{ mg TSS} \cdot \text{mg}^{-1} \text{ COD} \end{aligned}$$

In the conventional activated sludge system the volatile and total excess sludge production are:

$$\begin{aligned}mE_v &= (1 + f \cdot b_h \cdot R_s) \cdot C_r / R_s \\ &= 1.48 \cdot 1.32 / 10 \\ &= 0.20 \text{ mg VSS} \cdot \text{mg}^{-1} \text{COD and}\end{aligned}$$

$$mE_t = mE_v / f_v = 0.20 / 0.80 = 0.25 \text{ g TSS} \cdot \text{mg}^{-1} \text{COD}$$

It is concluded that under the specified conditions, the excess sludge production in a system with biological excess phosphorus removal =  $0.75 / 0.25 = 3$  times higher than in a conventional activated sludge system.