Course « Water and wastewater treatment », Fall 2025
Part II « Wastewater treatment »

Homework 4

Homework 4-1 : « Problem with biological phosphorous removal with A/O process »

An activated sludge WWTP has been designed to remove phosphorous biologically according the process A/O at temperatures as low as 10°C. The wastewater temperature fluctuates between 16-20°C and never reaches its design minimum. It is observed that the biological phosphorous removal does not really function. What could be the reason for the bad functioning of this microbiological process ?

Solution

Since the design has been made for 10°C and the wastewater never reaches these low temperatures, the WWTP is over-designed, too big. This could lead to regular nitrification in the aerated part of the treatment system which will result in an arrival of nitrate in the non-aerated part by the return sludge. The anaerobic part becomes anoxic which is not favorable for biological dephosphatation.

One could try to eliminate the aeration at the end of the aerobic part and thus create a denitrifying anoxic part in the activated sludge tank. This could lead to nitrate-free water that flows into the secondary clarifier and thus no nitrate would be brought into the non-aerated part by the return sludge.

Homework 4-2 : « Design of BOD-treating biological contactors »

A cheese manufacturing needs its own treatment of its wastewater and decided to install a small WWTP based on biological contactors. The wastewater contains mainly cheese whey (sugars equivalent to glucose; 3.5 g_{sugar} L^{-1}; 21 m^3 d^{-1}). You have been asked to design this small WWTP and you assume the following: the sludge biomass has the formula $C_5H_7O_2N$, the growth yield of the sludge is 0.375 g_x g_{sugar}^{-1} and there is sufficient nitrogen for the production of the sludge biomass. A module of biological contactors has a surface to be colonized of 2000 m^2. How many of these modules do you need for the construction of this WWTP if only BOD_5 has to be removed ?

Hint: Since you need the BOD_5 present in the wastewater, you must first estimate the BOD of glucose degradation.

Solution

To design this small WWTP based on biological contactors, one needs to first determine the BOD present in the wastewater:

- 1 mole of glucose = 180 g
- 1 mole of biomass = 113 g
- based on the growth yield, to produce 1 mole of biomass, one mole of biomass consumes 113/0.375 g of sugar = 301.3 g of sugar which is equivalent to 1.67 mole of glucose

$1.67\ C_6H_{12}O_6 + a\ O_2 + 1\ NH_3 \rightarrow 1\ C_5H_7O_2N + b\ CO_2 + c\ H_2O + d\ H^+$

b = 5,0, c= 8,0, d = 0, a = 5

$1,67\ C_6H_{12}O_6 + 5\ O_2 + 1\ NH_3 \rightarrow 1\ C_5H_7O_2N + 5\ CO_2 + 8\ H_2O + 0\ H^+$

The BOD of sugar is equal to 0.53 g_{O2} g_{sugar}^{-1}, and therefore the cheese whey wastewater contains 3.5x0.53 = 1.859 g_{BOD} L^{-1}.

Since the wastewater volume produced per day is 21 m^3, one has to treat 39 kg_{BOD5} d^{-1}.

The specific surface load for biological contactors is 12 g_{BOD5} m^{-2} d^{-1}, and therefore one needs 3253 m^2 of colonization surface to treat this wastewater efficiently.

Hence, one needs two modules of 2000 m^2, and an operation of the two modules in parallel would be an interesting option in case one treatment lane has a problem or needs maintenance.

Homework 4-3 : « Design of denitrifying biotrickling filter-based WWTP »

A WWTP which is equipped with biotrickling filters has been designed to eliminate part of the nitrogen by pre-denitrification. You are asked to verify whether the design has been done correctly.

The parameters used for the design were the following :

Q_0 = 5'000 $m^3\ d^{-1}$ $C_{0,BOD5}$ = 170 $g_{O2}\ m^{-3}$

$N_{TKN,inf}$ = 45 $g_N\ m^{-3}$ $N_{NO3,eff}$ = 15 $g_N\ m^{-3}$ $N_{NH4,eff}$ = 2 $g_N\ m^{-3}$

Denitrifying filters: 2 with Ø of 20.5 m and 4 m high, carrier with 140 $m^2\ m^{-3}$ surface; Recycling rate r = 1.30.

Nitrifying filters : 2 with Ø of 15.5 m and 4 m high, carrier with 180 $m^2\ m^{-3}$ surface.

Solution

Design of denitrifying biotrickling filters :

- $C_{den,nec}$ = 40.5 + 0 – (0.045x127.5) – 2 – 15 = 17.76 $g_N\ m^{-3}$ (assuming that PC removes 10% of $N_{TKN,inf}$)
- $r_{den,nec}$ = 17.76 / 127.5 = 0.139 $g_N\ g^{-1}_{BOD5}$
- $B_{A,BOD5}$ = 2.93 $g_{BOD5}\ m^{-2}\ d^{-1}$
- A_{den} = (5000 x 127.5)/2.93 = 217’577 m^2
- $V_{fil,den}$ = 217‘577 / 140 = 1554 m^3, per biotrickling filter 777 m^3
- $A_{fil,den}$ = 777 / 4 = 194.3 m^2
- r = 7.86 m, **Ø = 15.7 m**

Design of nitrifying biotrickling filters :

- Denitrification consumes 3.77 g of organic matter per g of nitrate. With the BOD_5 for organic matter which is 0.72 $g_{O2}\ g_{OM}^{-1}$, this makes 2.71 $g_{BOD5}\ g_{NO3}^{-1}$ (see Homework 2-5).
- BOD_5 consumption by denitrifying filters = 17.76 x 2.71 = 48.13; there are still 79.4 $g_{BOD5}\ m^{-3}$ present in the effluent of these filters
- ammonium to nitrify : 40.5 – (0,045x127.5) – 2 = 32.76 $g_N\ m^{-3}$
- $A_{tot} = A_{BOD5} + A_{nit}$ = (5000x79.4)/4 + (5000x32.76)/0.9 = 84’000 + 207'000 = 281'250 m^2

  or (5000x79.4)/7 + (5000x32.76)/0.9 = 48’000 + 207'000 = 238’700 m^2
- $V_{fil,nit}$ = 281'250 / 180 = 1563 m^3, per filter 782 m^3

  or 238’700 / 180 = 1326 m^3, per filter 663 m^3
- $A_{fil,nit}$ = 782 / 4 = 195.5 m^2 or 663 / 4 = 166 m^2
- r = 7.26 m – 7.33 m, **Ø = 14.5 – 14.7 m**

Recirculation rate for pre-denitrification

r = (17.76 + 1)/(15-1) = **1.34**

The nitrifying biotrickling filters are designed correctly, but the denitrifying biotrickling filters are too big and the recirculation rate is perhaps a little too small.

Homework 4-4 : « Transform activated sludge WWTP into a "Moving bed" plant »

A WWTP that treats the wastewater of 15'000 capita has to be redesigned in order to treat wastewater of additional 10'000 capita. In addition, the WWTP is requested to completely nitrify the wastewater. One has proposed to transform the existing system into a moving bed. The existing installation has primary clarifiers and two aeration tanks of 1'100 m^3.

a) Did the existing installation already nitrify the wastewater of 15'000 capita ?

b) Is the existing aeration tank volume large enough in order to treat the additional wastewater with a moving bed ?

$Q_0 = 5500\ m^3\ d^{-1}$ $C_{0,BOD5} = 160\ g_{BOD5}\ m^{-3}$ $N_{TKN,inf} = 35\ g_N\ m^{-3}$ $C_{0,TSS} = 185\ g_{TSS}\ m^{-3}$

Solution

a) For the treatment of the BOD_5, the WWTP needs the following aeration tank volume :

$\mathbf{V_{AT}} = (Q_0 \times C_{0,BOD5} \times SP_c \times \theta_X) / X_{AT} = (5500 \times 0{,}12 \times 5 \times 0.99) / 3 = \mathbf{1089\ m^3}$

The WWTP has 2200 m^3 of V_{AT} available, hence 1100 m^3 too much. One can expect that the installation is big enough for complete nitrification.

Verification: $\mathbf{V_{AT}} = (Q_0 \times C_{0,BOD5} \times SP_c \times \theta_X) / X_{AT} = (5500 \times 0{,}12 \times 10 \times 0.89) / 3 = \mathbf{1958\ m^3}$

b) The values of the wastewater parameters have to be increased by a factor of 1.67 in order to get the values for 25'000 capita in total. For the design of a moving bed we can use the procedure of the course slides :

V_{nec} = daily load / volumetric loads

$V_{nec,BOD5} = (1100\ kg_{BOD5}/d) / (1{,}3\ kg_{BOD5}/m^3d) = 846\ m^3$

$V_{nec,NH4} = (320{,}8\text{-}49{,}5\text{-}18{,}3\ kg_N/d) / (0{,}193\ kg_{NH4}/m^3d) = 1310\ m^3$

In total, we need **2156 m^3** which means that the existing aeration tank volume of **2200 m^3** is large enough in order to treat the additional wastewater with a moving bed including full nitrification.