Course « Water and wastewater treatment », Fall 2020
Part II « Wastewater treatment » by Prof. Holliger

Homework 2

Homework 2-1 : « BOD due to nitrification »

Nitrification consumes oxygen and has to be taken into consideration in WWTPs where a low ammonium effluent concentration has to be achieved.

a) Calculate the nitrogenous oxygen demand NOD for normal, concentrated and diluted wastewaters (see lecture slides) by neglecting biomass production by nitrifyers and compare it to BOD_5 of these wastewaters.

b) How would this oxygen demand change if one takes into consideration biomass production by nitrifyers with ammonium as nitrogen source ?

Solution

a) For normal, concentrated and diluted wastewater, 37.5 $g_{N\text{-}NH4}$ m^{-3}, 62.5 $g_{N\text{-}NH4}$ m^{-3}, and 22.5 $g_{N\text{-}NH4}$ m^{-3} have to be nitrified because the rest of the total nitrogen is removed by the waste sludge (see slide 14 in Nutrient Removal 1).

According to equations on the slides 15 &16, 1 mole of NH_4^+ consumes 2 moles of O_2. This is equivalent to 4.57 g_{O2} $g_{N\text{-}NH4}^{-1}$.

Hence, the BOD_{NH4} is 171.4 g_{O2} m^{-3}, 285.6 g_{O2} m^{-3}, and 102.8 g_{O2} m^{-3} for normal, concentrated and diluted wastewater.

This is 69%, 82%, and 69% of the BOD_5 present in these wastewaters.

b) According to the equation that includes biomass production (slide 17), 1 mole of NH_4^+ consumes only 1.86 moles of O_2. This is equivalent to 4.25 g_{O2} $g_{N\text{-}NH4}^{-1}$.

Hence, the BOD_{NH4} would then be 159.4 g_{O2} m^{-3}, 265.6 g_{O2} m^{-3}, and 95.6 g_{O2} m^{-3} for normal, concentrated and diluted wastewater.

The oxygen demand would thus decrease, and this by 7%.

Homework 2-2 : « Nitrification in a specific WWTP »

For the design of nitrifying activated sludge plants, a security factor can be taken into account that is defined as:

$SF = \mu \times \theta_X$

with SF = security factor
μ = growth rate of nitrifyers
θ_X = solids retention time / sludge age

If SF is < 1.0, it is very probable that the plant does not nitrify.

A WWTP was designed to nitrify at 15°C with an oxygen concentration of 2 g m^{-3} and a sludge age of 5 days. The pH of the wastewater is between 7.0 – 7.5.

Does that WWTP nitrify according the security factor concept at 15°C ?

Hints: 1. Use the information on growth rates presented on the lecture slides. The half-saturation constant K_{O2} for nitrifiers is 0.5 – 1.0 g_{O2} m^{-3}.

2. The norm for N-NH_4 is 2 g m^{-3} and the aeration tank is designed as a completely stirred tank reactor.

Solution

We have to take the following equations and parameters into account from slides 18-21:

- equations for μ_{max} (T) (slide 18) and μ dependence on NH_4, DO, and pH (slide 21).
- $\mu_{max}(T_{20}) = 0.85\ d^{-1}$ (slide 19)
- $K_{O2} = 0.5 – 1.0\ g_{O2}\ m^{-3}$
- $\theta_T = 0.106$ for Nitrosomonas since it is this the rate limiting process (slide 18)

For the equation on slide 19, we need μ_{max} at 15°C. We can calculate that with the formula of slide 16 and μ_{max} at 20°C:

$$\mu_{max}(T_{15}) = 0.85 \text{ x } e^{0.106(15-20)} = 0.50\ d^{-1}.$$

The growth rate is also influenced by the NH_4^+ concentration, the oxygen concentration and pH.

For the NH_4^+ concentration, we can take 2 $g_{N\text{-}NH4}$ m^{-3} by supposing that it is a completely stirred tank reactor and therefore nitrification takes place at effluent concentration.

For the oxygen concentration, we can choose a typical value controlled by the aeration system, e.g. 2 g_{O2} m^{-3}.

For the pH, we can consider a value between 7.0 – 7.5 and as optimal value 7.2.

With K_{O2} of 0.5 g_{O2} m^{-3}, pH of 7.0 and the equation for the calculation of growth rates of slide 21, we get a growth rate $\mu = 0.277\ d^{-1}$, with K_{O2} of 1.0 g_{O2} m^{-3} and pH of 7.5 the growth rate is $\mu = 0.208\ d^{-1}$.

Independent of the affinity of the biomass for oxygen and the sensitivity to pH, the WWTP will nitrify because the SFs for both K_{O2} values and pHs are > 1.0 (1.39 and 1.04, respectively; calculated by multiplying the growth rates with the given sludge age (5 days)).

<u>Homework 2-3 : « Biomass production due to aerobic and denitrifying heterotrophs and nitrifyers »</u>

An average wastewater has a COD concentration of 340 g_{O2} m^{-3}, a BOD_5 concentration of 170 g_{O2} m^{-3}, and a TKN concentration of 30 g_N m^{-3}. The aerobic heterotrophs have a growth yield of 0.5 g_X g^{-1} organic matter, the nitrifyers produce biomass according the equation given on a lecture slide, and denitrifyers according the equation on another slide with the assumption that enough nitrate is available to oxidize all organic matter. Compare the biomasses produced by either aerobic and denitrifying heterotrophs and by the nitrifyers ?

<u>Solution</u>

Aerobic heterotrophs

In Homework 1, we have calculated the COD of organic matter (OM) to be 1.42 g_{O2} g_{OM}^{-1}. Hence, the COD of 340 g_{O2} m^{-3} corresponds to 239.4 g_{OM} m^{-3}. With a yield of 0.5 g_X g_{OM}^{-1}, the aerobic heterotrophs produce **119.7 g_X m^{-3}**.

Denitrifyers

The organic matter available is 239.4 g_{OM} m^{-3} which corresponds to 0.61 mol. This is exactly the amount needed to produce one mole of biomass (see equation for denitrification including biomass production, slide 23), hence, denitrifyers produce **113 g m^{-3}** if they oxidize all organic matter available.

Nitrifyers

The wastewater has a BOD_5 of 170 g_{O2} m^{-3}, and therefore about 7.65 g_N m^{-3} will be eliminated by the waste sludge (see slide 13). The remaining 22.35 g_N m^{-3} have to be nitrified.

The growth yield of nitrifiyers according to the specific equation (slide 17) is 0.161 g_X $g_{N\text{-}NH4}$. Hence, the nitrifyers produce **3.60 g_X m^{-3}**.

Hence, nitrifyers produce 31- to 33-times less biomass than denitrifying and aerobic heterotrophs, respectively.

Homework 2-4 : « Alkalinity change due to denitrification »

Alkalinity is measured by conventional titration with acid to an end pH of 4.5. The higher the value is, the greater the buffering capacity. Normally municipal wastewaters with an alkalinity over 5 eqv m^{-3} (more than 5 mol of protons/acid is needed per m^3 to reach pH 4.5) will not cause problems in connection with nitrification and simultaneous precipitation of phosphate.

Denitrification also influences alkalinity. If in a wastewater that has an alkalinity of 4.1 eqv m^{-3} before denitrification, 25 g_{N-NO3} m^{-3} are denitrified, what will be the alkalinity TAL after the denitrification process ?

Hints: *Assume that denitrification is done in a pre-denitrification process and that therefore ammonium is available as nitrogen source.*

Solution

- From the denitrification equation including biomass production (slide 23) it is found that 0.91 eqv alkalinity per mol $N\text{-}NO_3$ converted (4.15/4.54) are produced.
- 25 g_{N-NO3} m^{-3} = 1.79 mol $N\text{-}NO_3$ m^{-3} (25/14).
- The change in alkalinity ΔTAL is therefore

  $\Delta TAL = 0.91 \times 1.79 = 1.63$ eqv m^{-3}
- The alkalinity of the wastewater is thus 4.1 + 1.6 = 5.7 eqv m^{-3}, a level that can be considered non-problematic if nitrification and phosphorous precipitation follow.

Homework 2-5 : « Oxygen savings due to denitrification »

Denitrification consumes organic matter (OM) as carbon and energy source in order to reduce nitrate to dinitrogen gas. If one would use the influent BOD_5 for denitrification, how much less oxygen has to be provided for BOD_5 removal if one has to denitrify 20 $g_{N\text{-}NO3}$ m^{-3}.

Hints: - *Use the empirical formula $C_{18}H_{19}O_9N$ for OM and assume a growth yield for aerobic heterotrophs of 0.5 g_X g_{OM}^{-1}.*

- *Establish an equation for aerobic degradation of OM like the equation for denitrifying degradation of OM to be able to determine BOD for OM degradation.*

Solution

- The molecular mass of organic matter is 393 g (see Homework 1-1).
- According to the equation with biomass production with ammonium (slide 23), 3.77 g_{OM} are degraded per $g_{N\text{-}NO3}$ denitrified ((0.61x393) / (4.54x14)).
- We have to denitrify 20 $g_{N\text{-}NO3}$ m^{-3} and need for that 75.43 g_{OM} m^{-3} (20x3.77).
- Organic matter is aerobically degraded as follows:

  $a\ C_{18}H_{19}O_9N + b\ O_2 + c NH_3 \rightarrow d\ C_5H_7NO_2 + e\ CO_2 + f\ H_2O$

  where $\dfrac{d \times MW_X}{a \times MW_{OM}} = Y_{obs}$.

  We can set a = 1 and calculate d: $d = \dfrac{Y_{obs} \times a \times MW_{OM}}{MW_X} = \dfrac{0.5 \times 1 \times 393}{113} = 1.74$

- We can now write the equation for aerobic degradation of organic matter taking biomass production into account:

  $C_{18}H_{19}O_9N + 8.8\ O_2 + 0.74\ NH_3 \rightarrow 1.74\ C_5H_7NO_2 + 9.3\ CO_2 + 4.52\ H_2O$

  Note that *c* is the inorganic nitrogen needed in addition to the nitrogen present in organic matter to form the biomass. It has been obtained by subtracting *a* from *d.*

- The BOD of organic matter can now be calculated and is 0.72 g_{O2} g_{OM} (8.8x32/393).
- Since denitrification consumes 75.43 g_{OM} m^{-3} that would otherwise have to be degraded aerobically, we have to provide **54.31 g m^{-3} less O_2** by aeration for the BOD removal in the aerobic part of the WWTP.