

## Course « Water and wastewater treatment », Fall 2025

### Part II « Wastewater treatment »

## Homework 2

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### 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.

- Calculate the nitrogenous oxygen demand NOD for normal wastewaters ( $37.5 \text{ gN-NH}_4 \text{ m}^{-3}$ ) (Equations see lecture slides) by neglecting biomass production by nitrifiers and compare it to  $\text{BOD}_5$  ( $250 \text{ mg L}^{-1}$ ) of these wastewaters.
- How would this oxygen demand change if one takes into consideration biomass production by nitrifiers with ammonium as nitrogen source ?

### 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:

$$\text{SF} = \mu \cdot \theta_x$$

with SF = security factor

$\mu$  = growth rate of nitrifiers

$\theta_x$  = solids retention time / sludge age

If SF is  $< 1.0$ , it is very probable that the plant does not nitrify because nitrifiers will be washed out..

A WWTP was designed to nitrify at  $15^\circ\text{C}$  with an oxygen concentration of  $2 \text{ g m}^{-3}$  and a sludge age of 5 days. The pH of the wastewater is between  $7.0 - 7.5$ .  $\text{N-NH}_4$  is  $2 \text{ g m}^{-3}$   
 $K_{\text{O}_2} = 0.5 - 1.0 \text{ g O}_2 \text{ m}^{-3}$  (These are typical values)

Does this WWTP nitrify according the security factor concept at  $15^\circ\text{C}$  ?

*Influence of different environmental parameters on growth rates is described as below:*

$$\mu = \mu_{\max} \frac{[NH_4^+]}{10^{0.051T-1.158} + [NH_4^+]} \cdot e^{0.098(T-15)} \cdot \frac{[DO]}{K_{\text{O}_2} + [DO]} \cdot \left[1 - 0.833 \cdot |pH_{\text{opt}} - pH|\right]$$

with: T=temperature in  $^\circ\text{C}$

[DO]=dissolved oxygen concentration (mg/L)

$pH_{\text{opt}}$ =pH optimum equal to 7.2

$\mu_{\max}$ =maximal growth rate,

$\mu_{\max}(T=15^\circ\text{C}) = 0.60 \text{ d}^{-1}$  for *Nitrosomonas*, and  $0.50 \text{ d}^{-1}$  for *Nitrobacter*.

### **Homework 2-3 : « Biomass production due to aerobic and denitrifying heterotrophs and nitrifiers »**

A typical wastewater has a COD concentration of  $340 \text{ g}_{\text{O}_2} \text{ m}^{-3}$ , a  $\text{BOD}_5$  concentration of  $170 \text{ g}_{\text{O}_2} \text{ m}^{-3}$ , and a TKN concentration of  $30 \text{ g}_{\text{N}} \text{ m}^{-3}$ .

Assume:

The aerobic heterotrophs have a growth yield of  $0.5 \text{ g}_X \text{ g}^{-1}$  organic matter, the nitrifiers produce biomass according to the equation given in the lecture slide, and denitrifiers according to the equation given in the lecture slide with the assumption that enough nitrate is available to oxidize all organic matter (In other words, organic matter is stoichiometrically limiting), and a pre-denitrification process was used.

Compare the theoretical biomasses that could be produced by aerobic heterotrophs, denitrifying heterotrophs, and the nitrifiers using this water?

*Hint, COD can be converted to organic matter according to Homework 1.*

### **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  $5 \text{ eqv m}^{-3}$  (more than 5 mol of protons/acid is needed per  $\text{m}^3$  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  $4.1 \text{ eqv m}^{-3}$  before denitrification,  $25 \text{ g}_{\text{N-NO}_3} \text{ m}^{-3}$  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.*

### **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  $\text{BOD}_5$  for denitrification, how much less oxygen has to be provided for  $\text{BOD}_5$  removal if one has to denitrify  $20 \text{ g}_{\text{N-NO}_3} \text{ m}^{-3}$ . Assume that there is ammonium available as nitrogen source.

*Hints: - Use the empirical formula  $\text{C}_{18}\text{H}_{19}\text{O}_9\text{N}$  for OM and assume a growth yield for aerobic heterotrophs of  $0.5 \text{ g}_X \text{ g}_{\text{OM}}^{-1}$ .*

*- 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. Specifically, include biomass formation into the OM degradation stoichiometry equation.*