Course « Water and wastewater treatment », Fall 2020

Part I « Wastewater treatment » by Prof. Holliger

Homework 5

Homework 5-1 : « Design of WWT plant Bern without nitrogen removal by SBRs »

The WWTP of Bern treats since several years its wastewater with so-called biofilters. The treatment of the sludge digester effluent by SBRs has been taken into account in the design of the biofilters. At present, there are 16 biofilter cells, each with a surface of 132 m^2 and a volume of 400 m^3. The WWTP has been designed for 350'000 person equivalents and a dry weather flow rate Q_{DW} = 1500 L s^{-1}. The WWTP has to respect an effluent concentration of $N_{tot,eff}$ = 15 mg_N L^{-1}, which is equivalent to a nitrogen removal of 55% which is achieved by a pre-denitrification in the biofilter system.

a) What would have been the consequence for the size of the secondary treatment by biofiltration if this part of the WWTP would also had to treat the nitrogen at present removed by the SBRs ?

b) Which parameters would one have had to verify if one would have wanted to realize this treatment by the biofilters knowing that the primary clarifier removes 80% of the COD ?

In order to be able to answer to (a) one has to make the following assumptions :

- *the nitrogen load treated by the SBRs is equivalent to 43% of the nitrogen load treated at present by the biofilters.*
- *the SBRs remove 100% of this nitrogen by nitritation-denitritation, hence the effluent nitrogen concentration of the SBRs can be considered to be zero.*
- *the discharge of the SBR effluents is already included in Q_{DW}, hence the treatment of the sludge digester effluent by the biofilters would only increase the nitrogen load but not the flow rate.*

Solution

a) One has first to determine the nitrogen load treated by the biofilters :

Q_0 = 1.5 m^3 s^{-1} x 60 x 60 x 24 = 129'600 m^3 d^{-1}, $N_{tot,inf}$ = 15/0.45 = 33.3 g_N m^{-3} →

B_{Ntot} = 4320 kg_N d^{-1}

The SBRs treat 0.43 x 4320 = 1858 kg_N d^{-1}, and all that would have to be eliminated by the biofilters. According to the parameters given in the slides on biofilters, one can treat 0.6-1.0 $kg_{N\text{-}NO3}$ m^{-3} d^{-1} by pre-denitrification and nitrify 0.6-1.5 $kg_{N\text{-}NH4}$ m^{-3} d^{-1}.

Hence, one needs between 1858-3096 m^3 for denitrification and between 1239-3096 m^3 for nitrification.

In total, one would need between 3096-6192 m^3 additonal biofilter volume, which corresponds to a secondary treatment by biofiltration that is 50-100% larger than the existing one.

b) For pre-denitrification one uses the organic matter present in the WWTP influent. Since a large percentage of the COD is already removed by the primary clarifiers, there might be a lack of substrate needed for denitrification.

Another important parameter to verify is alkalinity. If not sufficiently high, one might have pH problems during nitrification.

Homework 5-2 : « N mass balance in WWTP with DEMON process and aeration savings »

A WWTP based activated sludge has to remove 80% of the influent nitrogen from wastewater and therefore installed nitrification - denitrification. Waste sludge (WS) produced on-site and waste sludge from other WWTPs (40% of total treated waste sludge) are treated in an anaerobic digester. Digested sludge is dewatered by centrifugation. Half of the nitrogen contained in the fresh waste sludge is leaving the WWTP by the dewatered digested sludge (incinerated elsewhere), the rest is present mainly as ammonium in the digester effluent. Before 2008, the resulting ammonium-rich digester effluent was redirected in the biological wastewater treatment. Since 2008, the digester effluent is pretreated in a separate DEMON sequencing batch reactor (SBR), a system that combines partial nitritation of ammonium and anaerobic ammonium oxidation (analog to SHARON-Anammox). The DEMON system removes 85% of the nitrogen contained in the digester effluent. The DEMON effluent is directed to the activated sludge tanks (AT).

WWTP parameters: $Q_0 = 50'000\ m^3\ d^{-1}$; $S_{BOD5,0} = 180\ gO_2\ m^{-3}$; $N_{tot,eff} = 5\ gN\ m^{-3}$.

a) Nitrogen mass balance: Calculate the nitrogen loads ($kgN\ d^{-1}$) and fill in the mass balance flow scheme below. Give the details of all calculations with adequate units on the next page.

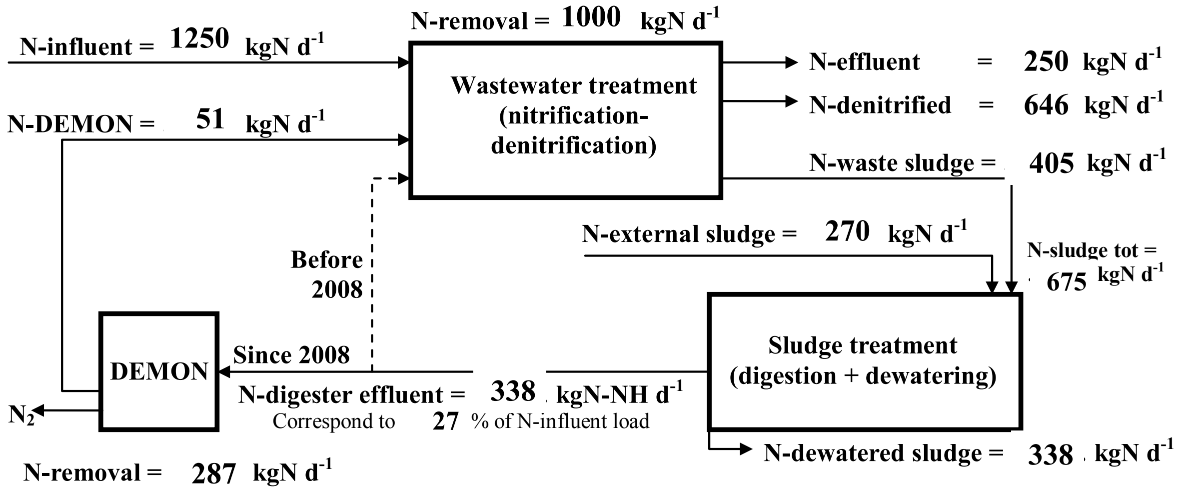
Hint: Start load calculations by determining first the load for N-waste sludge.

b) Aeration savings: With the implementation of the separate DEMON treatment, calculate the annual savings in comparison to full nitrification if you consider an aeration cost of CHF 0.25 per kgO_2.

Solution

a) Nitrogen mass balance calculations

1) N-waste sludge = $180\ gBOD5\ m^{-3} \cdot 0.045\ gN\ gBOD5^{-1} \cdot 50'000\ m^3\ d^{-1} = 405\ kgN\ d^{-1}$
2) N-sludge tot = $405\ kgN\ d^{-1} / 0.60\ (-) = 675\ kgN\ d^{-1}$
3) N-external sludge = $675\ kgN\ d^{-1} \cdot 0.40\ (-) = 270\ kgN\ d^{-1}$
4) N-digester effluent = $675\ kgN\ d^{-1} \cdot 0.50 = 338\ kgN\ d^{-1}$
5) N-dewatered sludge = $675\ kgN\ d^{-1} \cdot 0.50 = 338\ kgN\ d^{-1}$ = N-digester effluent
6) N-removal DEMON = $338\ kgN\ d^{-1} \cdot 0.85\ (-) = 287\ kgN\ d^{-1}$
7) N-effluent DEMON = $338\ kgN\ d^{-1} \cdot 0.15\ (-) = 51\ kgN\ d^{-1}$
8) N-effluent AST = $5\ gN\ m^{-3} \cdot 50'000\ m^3\ d^{-1} \cdot 10^{-3}\ kg\ g^{-1} = 250\ kgN\ d^{-1}$
9) N-influent WWTP = N-effluent AST / 0.20 (-) = $1'250\ kgN\ d^{-1}$
10) N-removal (inf-eff) = N-influent WWTP – N-effluent AST = $(1'250 – 250)\ kgN\ d^{-1} = 1'000\ kgN\ d^{-1}$
11) N-tot inlet AST = N-influent WWTP + N-effluent DEMON = $(1'250 + 51)\ kgN\ d^{-1} = 1'301\ kgN\ d^{-1}$
12) Total N-removal AST = N-tot inlet AST – N-effluent AST = $(1'301 – 250)\ kgN\ d^{-1} = 1'051\ kgN\ d^{-1}$
13) N-denitrified = N-tot inlet AST – N-waste sludge – N-effluent AST = (1'301 – 405 – 250) = 646 $kgN\ d^{-1}$
14) N-digester effluent corresponds to: $338\ kgN\text{-}NH\ d^{-1} / 1'250\ kgN\ d^{-1}$ = 27% of N-influent WW.



Checks: IN = OUT (no accumulation), across the AST boundaries and across the WWTP site boundaries

Over the activated sludge tank

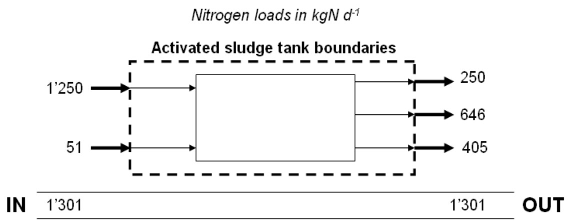
N-influent WW + N-effluent DEMON = N-effluent AST + N-denitrified + N-waste sludge

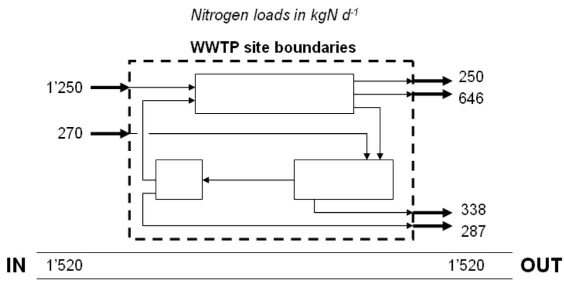
(1'250 + 51) kgN d^{-1} = **1'301 kgN d^{-1}** = (250 + 646 + 405) kgN d^{-1} → **Balance OK**

Over the whole WWTP

N-influent WW + N-external sludge = N-effluent AST + N-denitrified + N-dewatered sludge + N- removal DEMON

(1'250 + 270) kgN d^{-1} = **1'520 kgN d^{-1}** = (250 + 646 + 338 + 287) kgN d^{-1} → **Balance OK**





b) Aeration savings

Full nitrification (*first approximation by considering only catabolism*)

-1 NH_4^+ **- 2** O_2 + 1 NO_3^- + 1 H_2O + 2 H^+

2 mol O_2 consumed per 1 mol N-NH consumed → *2 mol O_2 mol^{-1} N-NH*

Partial nitritation (*first approximation by considering only catabolism*)

50% NH_4^+ converted into NO_2^-, 50% remaining for subsequent anammox process

-2 NH_4^+ **- 1.5** O_2 + 1 NH_4^+ + 1 NO_2^- + 1 H_2O + 2 H^+

1.5 mol O_2 consumed per 2 mol N-NH consumed → *0.75 mol O_2 mol^{-1} N-NH*

Oxygen savings with partial nitritation

ΔO_2 = (2-0.75) mol O_2 = 1.25 mol O_2 1.25 mol O_2 / 2 mol O_2 = 62.5% O_2-savings

Savings = 1.25 mol O_2 mol^{-1} N-NH ·32 gO_2 mol O_2^{-1} /14 gN mol N-NH^{-1} ·338 kgN-NH d^{-1} ·365 d y^{-1} x 0.25 CHF kgO_2^{-1}

Savings = 965 kgO_2 kgN-NH^{-1} x 365 d y^{-1} x 0.25 CHF kgO_2^{-1} = 352'486 kgO_2 y^{-1} x 0.25 CHF kgO_2^{-1} = 88 kCHF

Full nitrification	141 kCHF y^{-1} (100%)
Partial nitritation	53 kCHF y^{-1} (37.5%)
Δ = Savings	88 kCHF y^{-1} (62.5%)