Practical BM Respirometry for biological nitrogen removal in a wastewater treatment

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BM Respirometry

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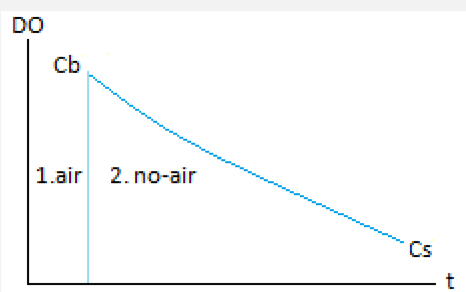
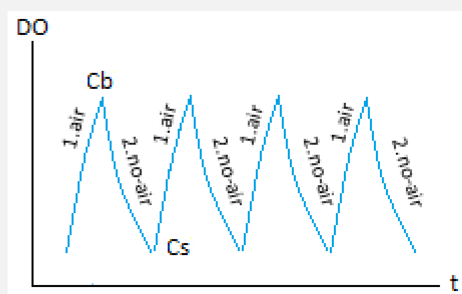
Three different operation modes

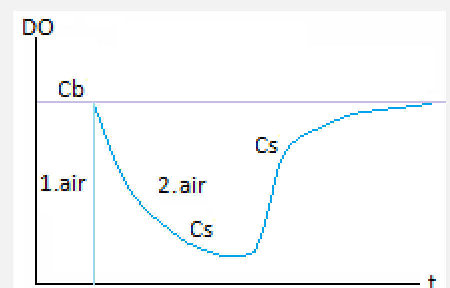
While most of the respirometers on the market offer only one operation mode, the BM respirometers have three different operation modes: OUR mode, Cyclic OUR mode, and R mode. Each mode develops different respirograms for automatic parameters including D.O., Temperature, and pH (in BM-Advance) from where specific applications can be made.

In a single batch reactor, the measuring system can work as LSS and LFS batch respirometry. The system is optimized by a one-sense membrane device, that together with a dividing plate, is able to isolate the measuring chamber and avoid bubbles against the DO sensor.

OUR	Cyclic OUR	R
This mode is making use of the LSS respirometry type. The OUR mode consists of a single test to measure the OUR and/or SOUR parameters (by manually setting the MLVSS concentration). It also has the option the get a partial SOUR for any period within the respirogram.	The cyclic OUR mode consists of a progressive sequence of OUR measurements, generated from the DO trajectory when it fluctuates between the DO. Low and DO. High set-points that were set at the start of the test.	The R mode corresponds to a modified LFS respirometry type test. The measuring system can be considered as a completely mixed batch reactor. In this mode, we get the important advantage to work with a small volume of samples in order to minimize the test time for an important package of several simultaneous parameters measurement.







Main automatic parameters in BM respirometer for the different operations modes

BM Operation modes

OUR & Cyclic OUR

OUR: **Oxygen Uptake Rate** (mg O_2/L.h)

It measures the oxygen uptake rate for only one measurement or serial o measurements.

SOUR: **Specific OUR** (mg O_2/g VSS.h)

Specific OUR related to MLVSS. SOUR = OUR / MLVSS

R

Rs: **Dynamic Respiration Rate** (mg O_2/L.h)

It measures the oxygen uptake rate from the mixture of the activated sludge and certain amount of wastewater sample or compound within a continuous chain of measurements.

Rsp: **Dynamic specific respiration Rate** (mg O_2/g VSS.h)

Specific Rs referred to MLVSS. Rsp = Rs / MLVSS

bCOD: **Biodegradable COD** (mg O_2/L)

Biodegradable or soluble readily biodegradable COD fraction, based on Rs measurements integration from a mixture of activated sludge and biodegradable sample.

U: **COD removal rate** (mg COD/L.h)

Speed at which the COD is being removed.

q: **Specific COD removal rate** (mg COD/ mg VSS.d)

Specific U referred to MLVSS concentration.

Nitrification

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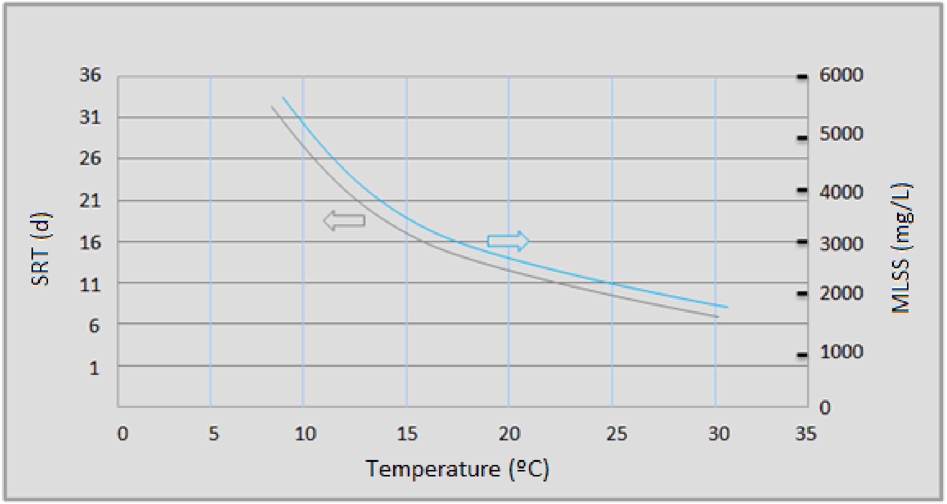
Optimal nitrification conditions

1.

pH	7.3 to 8,3
T	> 15 to 28 ºC
OD	1 a 3 ppm
COD/TKN	< 5
Enough HRT for nitrification in the reactor	
Without any inhibitory or toxic compound	

2. Coherent SRT & MLSS vs Temperature:



Possible reasons from which the actual nitrifier biomass is lower than the reference value in the standard table

1. The process is not operating under one or more correct conditions of DO, pH, Temperature.

2. BOD/TKN > 5

3. BOD/TKN ≥ 5 + Low temperature (< 15ºC) for a long time.

3. Low temperature (< 15ºC) for a long period of time.,

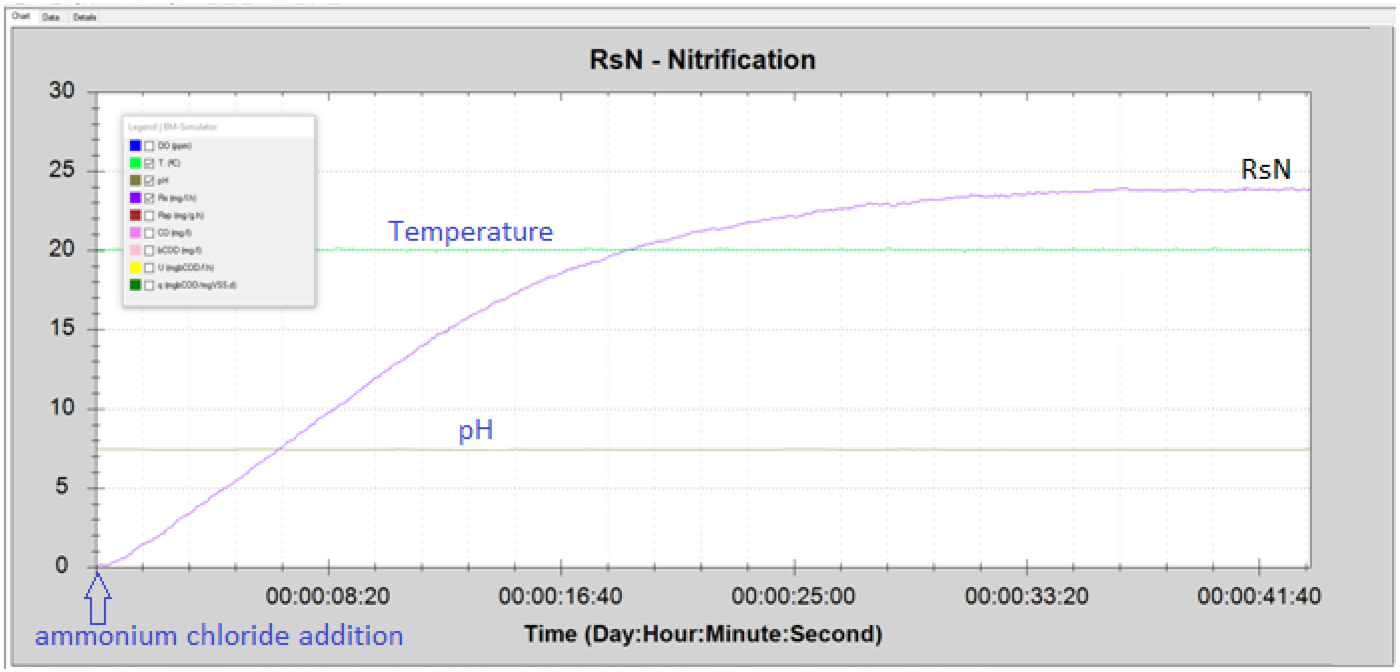
4. Presence of toxic compound in the influent wastewater.

5. Nutrients defficiency

6. Others.

Actual nitrification rate

To get the nitrification rate, we carry out a R test with ammonium chloride on equivalent concentration until reaching the maximum exogenous respiration rate. Then, Allyl Thiourea (ATU) could be added to inhibit the nitrifiers bacteria and get the endogenous sludge ready for organic matter tests where only the heterotrophic biomass is acting.



Rs respirogram after adding the NH_4Cl dose

$$\mathbf{AUR} = AUR_{max} * [DO / (K_{OA} + DO)]$$

AUR: Actual nitrification rate (mg /L.h NH_4-N)

AUR_{max}: Nitrification rate for max. DO - 4,57: total mg O_2 consumed per mg NH_4 - N

Rs_N: Maximum value of exogenous respiration rate (Rs) due to nitrification

DO: Average bulk dissolved oxygen in the actual nitrification process

K_{OA}: Half saturation coefficient = 0.5 mg/l - Default value ASM2, ASM3, Henze et al 2000 - [when DO ≥ 3 mg/L → K_{OA} = 0]

Active nitrifier biomass concentration

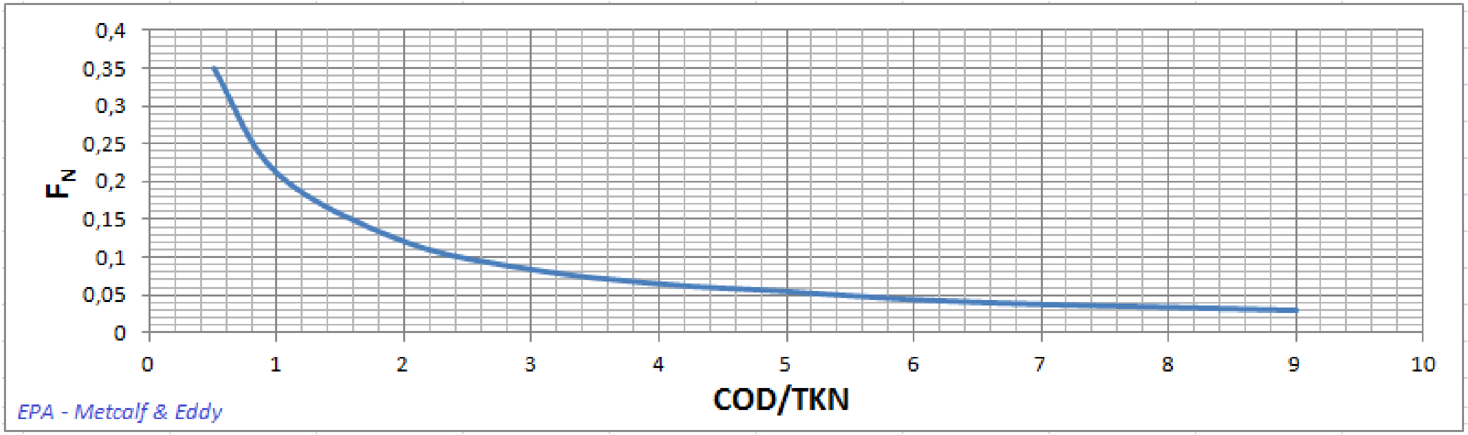
From the nitrification rate of an already existing nitrification process

$$\mathbf{X_A} = Y_A * 24 * AUR * SRT$$

X_A: Nitrifier biomass concentration (mg/l)
Y_A: Autotrophic yield coefficient ≈ 0.12 - Metcalf & Eddy
SRT: Actual sludge age on which the process is operating (d)

From standard table

This table can be applied for a process that is running without any inhibition problems, under an average temperature > 20ºC, pH in between 7 and 8.5 and DO ≥ 2 ppm.



Source: Metcalf & Eddy. 1995

COD: Elimnated COD (mg/L)
TKN: Eliminated TKN (mg N/L)

$$\mathbf{X_A} = F_N * MLVSS$$

Nitrogen for nitrification

Actual nitrogen being nitrified

$$\mathbf{S_n} = TKN_O - N_O - S_{sy} - S_{ne}$$

S_N: Actual ammonium-nitrogen concentration that is currently being nitrified (mg/l NH_4-N) by the actual AUR
TKN_O: Influent TKN (mg/L N)
N_O: Organic nitrogen in the effluent ≈ 2 mg N/L
N_{sy}: Nitrogen utilized in the cell synthesis = 0.05 * BOD
S_{Ne}: Actual ammonium-nitrogen concentration in the effluent (mg N-NH_4/L)

$$\mathbf{E_n} = 100 * (1 - S_{ne} / S_n)$$

E_n: Actual efficiency (%)

Required Nitrogen to be nitrified

$$\mathbf{S'_N} = TKN_O - N_O - S_{sy} - S'_{ne}$$

S'_N: Ammonium-Nitrogen concentration that should be nitrified (mg NH_4-N/L)
S'_{Ne}: Required ammonium-nitrogen concentration in the effluent (mg N-NH_4/L)

$$\mathbf{E'_n} = 100 * (1 - S'_{ne} / S_n)$$

E'_n: Required efficiency (%)

Estimation of required nitrification rate

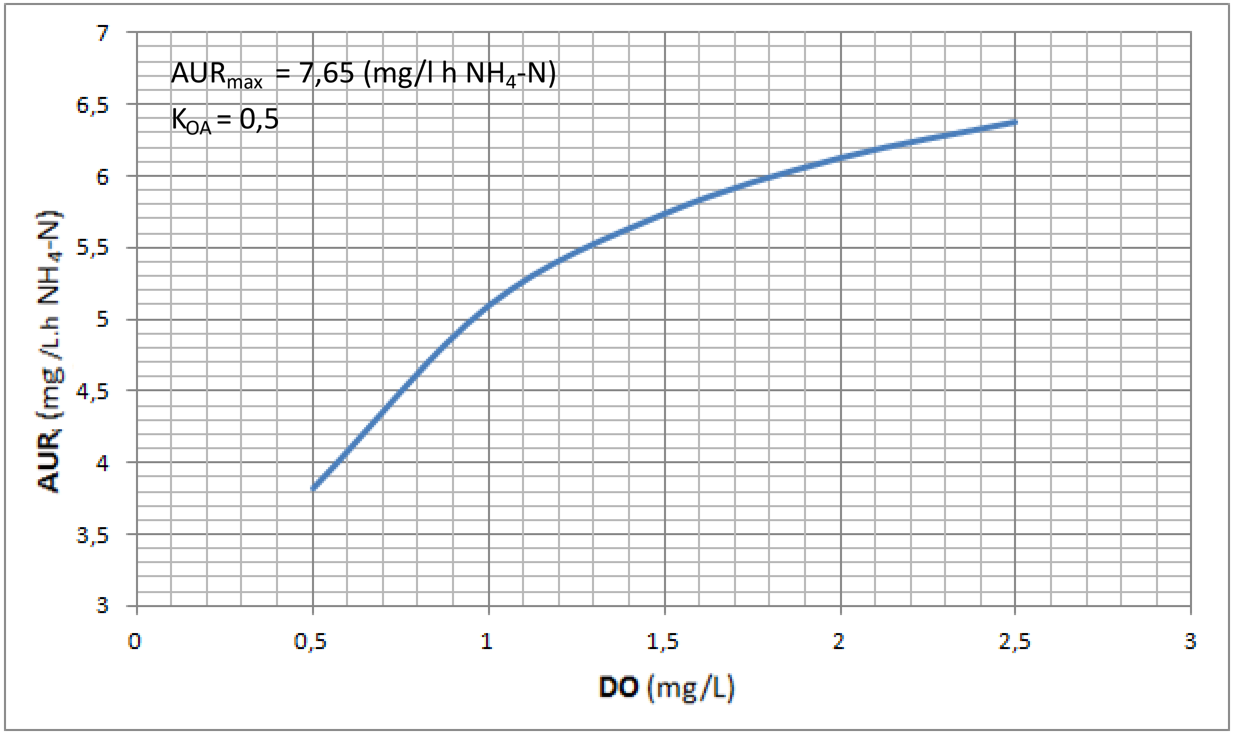
$$\mathbf{AUR'} = [1 + (E'_n - E_n) / 100] * AUR$$

AUR': Nitrification rate necessary to get the E'_n efficiency (mg NH_4-N /l.h)

Influence of dissolved oxygen on the nitrification rate

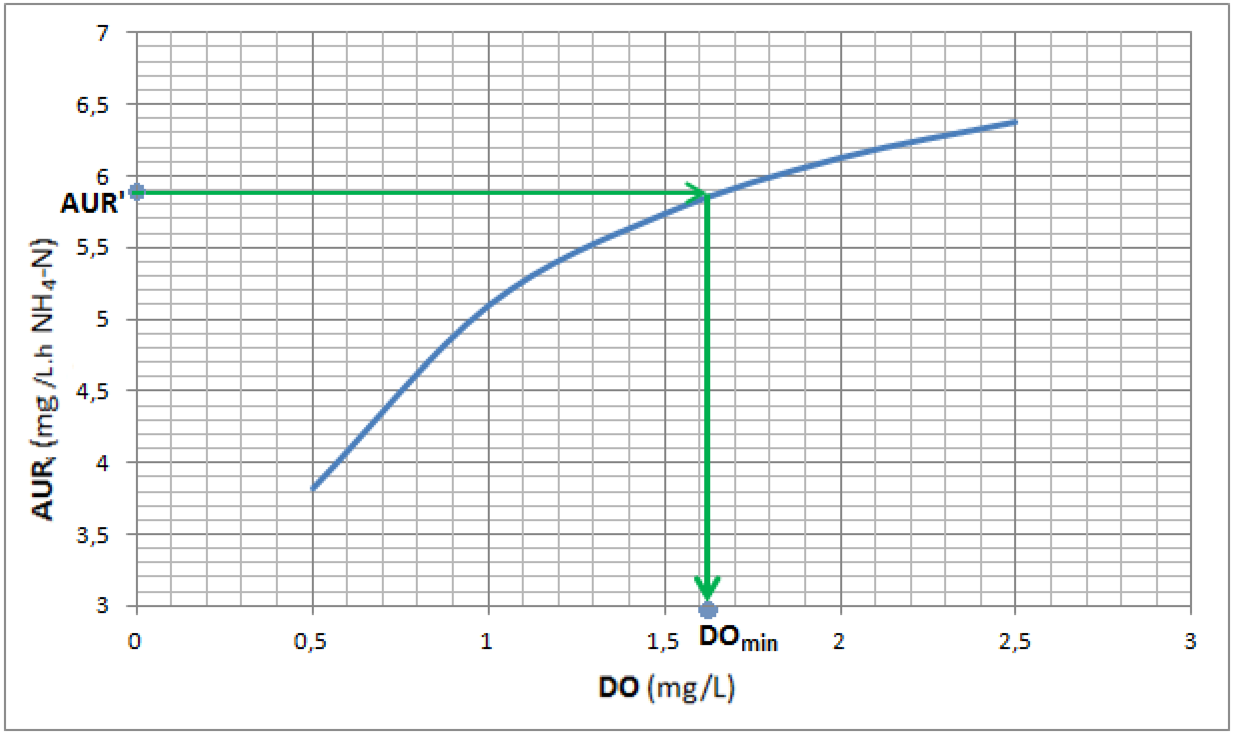
For different DO values , the actual AUR value can be plotted.

$$\mathbf{AUR} = AUR_{max} * DO / (K_{OA} + DO)$$



Minimum oxygen for any required nitrification rate

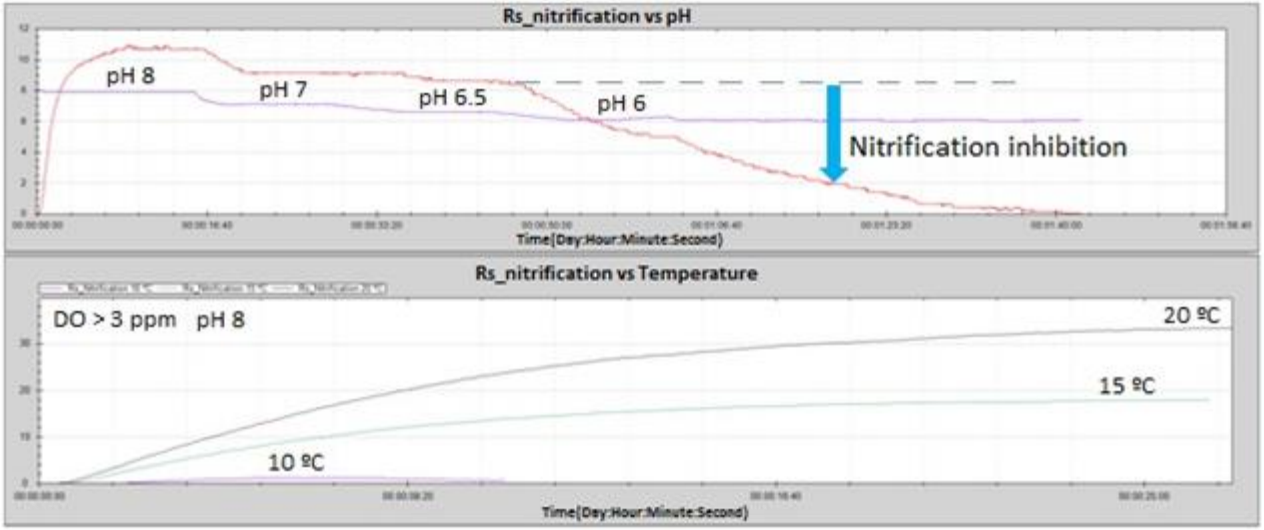
From the curve AUR vs DO, the minimum DO (DO_{min}), on which the nitrification could operate, can be figured out for any required nitrification rate AUR'.



$$\mathbf{DO_{min}} = K_{OA} / (AUR_{max} / AUR' - 1)$$

Influence of Temperature and pH on the nitrification rate

Nitrification rate depends of the corresponding exogenous respiration rate (Rs) as ammonia is being eliminated. Besides de oxygen influence, the temperature and pH have also a direct influence in the nitrification rate and therefore the knowledge of this should represent an essential data to get the actual nitrification rate.



In a BM Advance respirometer there is the option of be varying the pH during the test to analyze the different Rs and determine the break-level at which the inhibition starts

The pH influence can be analyzed on different temperature settings and it also could be analyzed the Temperature influence for a fixed pH level.

Possible reasons for which the actual nitrification rate could be less than the required nitrification rate

1. The process is not operating under one or more correct conditions of DO, pH, Temperature.

2. The sludge age (SRT) is lower than the one on which the process should be operating.

3. The concentration of the active nitrifier biomass is too low.

   This could be because of

   . BOD/TKN > 5

   . Conditions are out of normal range

   . Inhibition effect

5. Toxicity

6. Others

Actual nitrifier biomass growing rate

$$\mu_A = 24 * AUR * Y_A / X_A$$

μ_A : Nitrifier biomass growing rate (d^{-1})
Y_A: Yield coefficient ≈ 0,12 (Metcalf & Eddy)

Minimum sludge age for the actual nitrification

$$SRT_{min} = 1 / (\mu_A - b_A)$$

SRT_{min}: Minimum sludge age for nitrification (d)

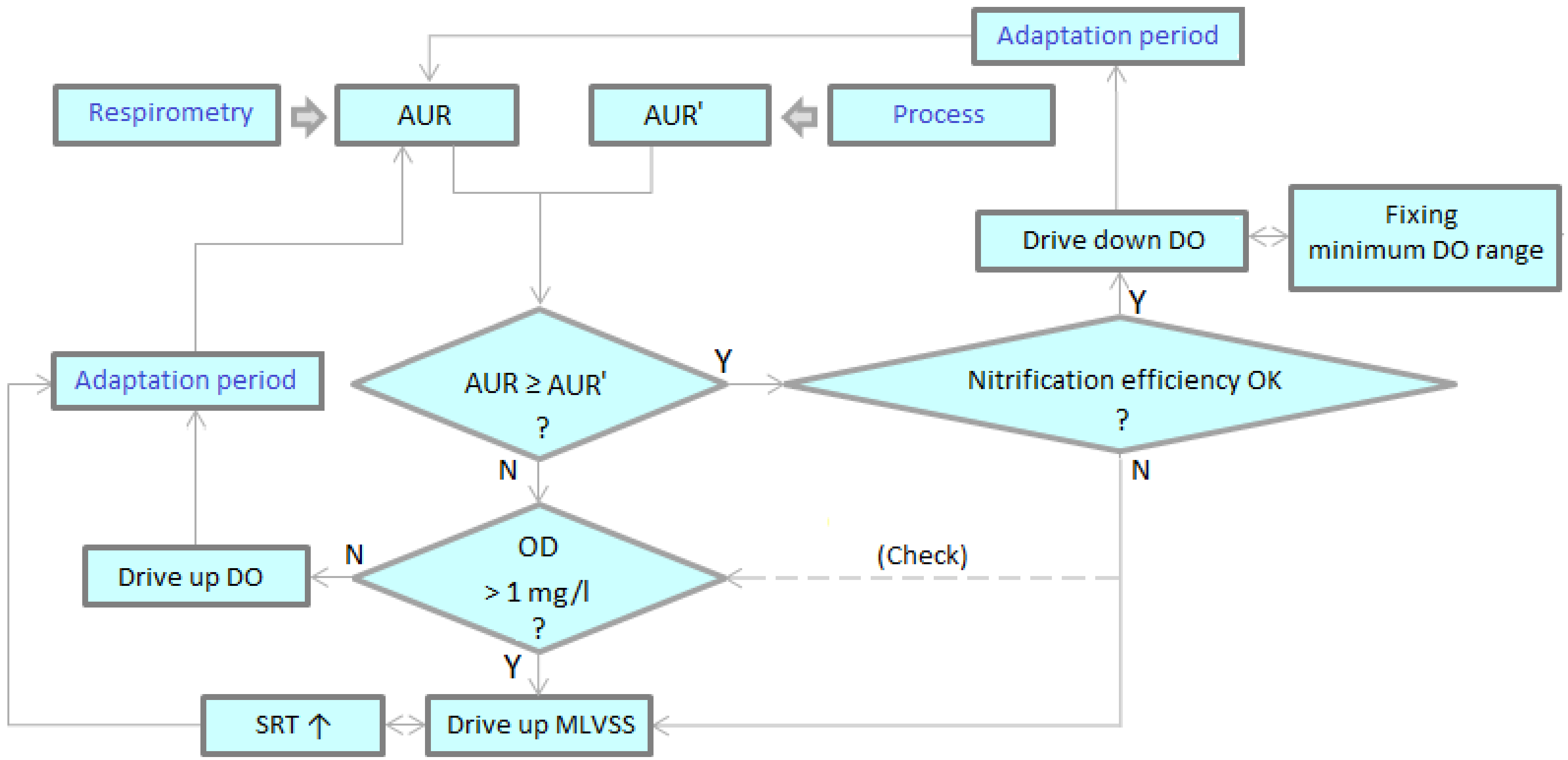
Temp	Death & Decay Rate b_A (days^{-1})
10°C	0.02
15°C	0.03
20°C	0.04
25°C	0.05

Source: EPA – Long Island. Sound Study, NY - 2000

Sludge age condition for nitrification ⟶ $SRT \geq SRT_{min}$

Practical operation protocol for the nitrification under energy optimization frame

In this protocol we asume the temperature and pH conditions are within the normal range and the process has the capability to control the DO level under the approach of its minimum range.



Denitrification

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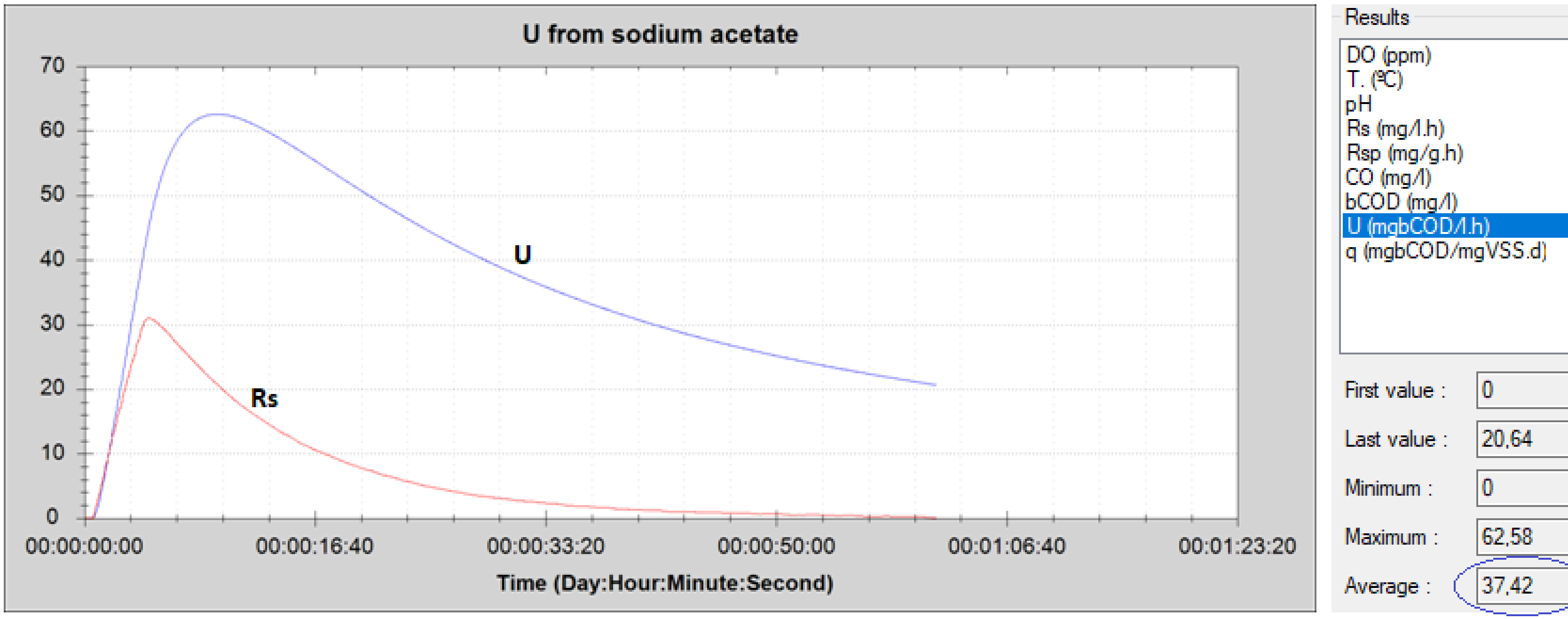
Conditions for denitrification process

Conditions	
pH	6.5 a 8 (optimal)
BOD/TKN	2.5 to 5
Soluble biodegradable COD/N-$NO_{3.DN}$	≥ 2.83
DO	< 0.3 mg/L
Denitrification zone with enough HRT to perform the process	
Without any inhibitor nor toxic compounds	

Determination of NUR by sodium acetate solution

Just as a thmb rule, the value of the estimated NUR could be determined by using the sodium acetate solution and taking the average of the COD utilization rate (U) in the R test.

Here, in order to make the corresponding COD solution, it should be taken into account that 1 mg sodium-acetate/l correspond approx. to a readily biodegradable COD (COD_{ac}) of 0,75 mg/l .



CO Respirogram – sodium acetate solution sample

$$\mathbf{NUR} = (U\ \ (1 - Y_H) / 2{,}86) * K'_O / (K'_O + OD_{DN})$$

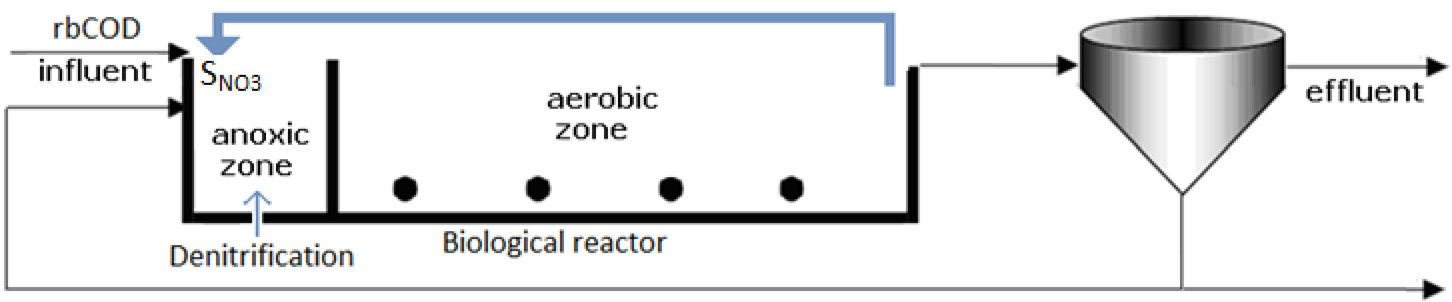
U: COD utilization rate (mg COD/l.h)

Y_H: Yield coefficient (mgO_2/COD) ≈ 0,63 (defaul value)
K'_O: Inhibition coefficient due to oxygen in the anoxic zone = 0,2 (mg/L) - Default value –
DO_{DN}: Dissolved oxygen in the denitrification zone (mg /L O_2)

rbCOD required for denitrification

When the anoxic denitrification process takes place just before the aerobic treatment, a possible critical situation could arise when there is very little rbCOD in the influent and it is completely removed in that zone. Thus, there would be no rbCOD left for the aerobic zone and only the slowly biodegradable COD (rbCOD) would be in the aerobic zone. Then, under that condition and due to of a possible lack of direct food, it may result in low biomass heterotrophic growth, weak flocculation and poor process performance.

For this reason, in many cases, it is important to exceed the minimum rbCOD required for a given nitrate concentration.



<u>rbCOD required for denitrification</u>

$$\mathbf{rbCOD_{DN}} > 2{,}86 * S_{NO3} / (1 - Y_H)$$

$rbCOD_{DN}$ Minimum readily biodegradable COD required for denitrification (mg/L)
Y_H: Heterotrophic yield coefficient (mg O_2/mg COD) ≈ 0,63 (usual default value for the
S_{NO3}: Nitrate to denitrify (mg NO_3-N/L)

If the required rbCOD is not met, it may be necessary to resort to the use of an external source of of readily biodegradable COD (normally methanol)

Calculation of methanol loading for a determined denitrification efficiency

PROCEDURE

1. **Calculation of the S_{NO3} and rbCOD present in the influent**
   - Calculation of the nitrate concentration to denitrify (S_{NO3})
   - Calculation of the rbCOD in the influent by mean a R test with filtered wastewater sample.

2. **Calculation of the methanol loading for maximum denitrification**
   - Methanol loading (m^3/d) = 2.86 * Nitrate loading - rbCOD loading

     Nitrate loading (kg S_{NO3}/d) = Q (m^3/d) * S_{NO3} (kg NO_3-N)/m^3

     rbCOD loading (kg COD/d) = = Q (m^3/d) * rbCOD (kg COD/m^3)
   - Methanol loading (L/d) = 1000 * Methanol loading (m^3/d)

     1 liter methanol = 1.2 Kg rbCOD
   - Methanol loading (kg/d) = Methanol loading (L/d) / 1.2

3. **Calculation of the methanol loading for a determined denitrification efficiency (E)**
   - E = 1 - S_{NO3e} / S_{NO3}

     E: denitrification efficiency

     S_{NO3e} : Nitrate expected in the effluent (mg NO_3-N/L)
   - Methanol loading’ = E x Methanol loading

     Methanol loading’: Methanol loading for E efficiency (liter/day)

In any case, the metahnol must be progressively acclimated to the sludge before applying the calculated methanol loading

Specific denitrification rate

SDNR = 24 * NUR / X_V

SDNR: Specific denitrification rate (mg N-NO_3 / mg VSS.d)

<u>Guide table</u>

Estimated Specific Denitrification Rates

Temp ° C	Estimated SDNR	Temp ° C	Estimated SDNR
10	0.035	18	0.076
12	0.042	20	0.091
14	0.052	22	0.110
16	0.063	24	0.132

Source: Long Island Sound Training – Nitrogen Removal - 2003 (EPA)

Possible reasons for which the actual specific denitrification rate could be less than the reference table value

1. The process is not operating under one or more correct conditions range.

2. The concentration of the readily biodegradable COD is too low (soluble organic cabonaceous matter)

3. Anoxic zone is not gathering the anoxic condition (oxygen < 0.3 ppm)

4. The hidraulc retention time in the denitrification zone is too short (it has not enough volume)

5. Presence of inhibitor or toxic compounds in the wastewater.

6. Others

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