

Results interpretation and evaluation in BM Respirometry



<https://youtu.be/UeMvk7U5ZMo>

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Measurements & Parameters

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Automatic measurements in BM Respirometry

BM Model	Automatic measurements	Description	Programming capability
T+ EVO, EVO2 Advance, Advance2 Advance Pro	DO (mg O ₂ /L)	Dissolved oxygen disuelto	Programmable threshold in Cyclic operation mode
EVO, EVO2 Advance, Advance2, Advance Pro	Temperature (°C)	Temperature	Programmable
Advance, Advance2, Advance Pro	pH	pH	Programmable
Advance Pro	ORP (mV)	Redox potential	No-programmable

All programmable measurements can be set before and during the respirometry test

Parameters automatically calculated in BM Respirometry

Parámetro	Descripción
OUR (mg O ₂ /L.h)	Oxygen Uptake Rate
SOUR (mg O ₂ /g VSS.h)	Specific Oxygen Uptake Rate = OUR / MLVSS
Rs (mg O ₂ /L.h)	Exogenous oxygen uptake rate due to the effect of the biological reaction of the substrate in the endogenous activated sludge
Rsp (mg O ₂ /gVSS.h)	Specific exogenous uptake rate = Rs / MLVSS
CO (mg O ₂ /L)	Consumed Oxygen in the biological oxidation of a determined substrate = $\int R_s$
bCOD (mg O ₂ /L) rbCOD (mg O ₂ /L)	Biodegradable COD Readily biodegradable (soluble) COD – By using soluble wastewater sample -
U (mg DQO/L.h)	COD uptake rate
q (mg DQO/mg SSV.d)	Specific COD uptake rate = U / VSS

Operation modes

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Usual chemical reagents used in BM Respirometry

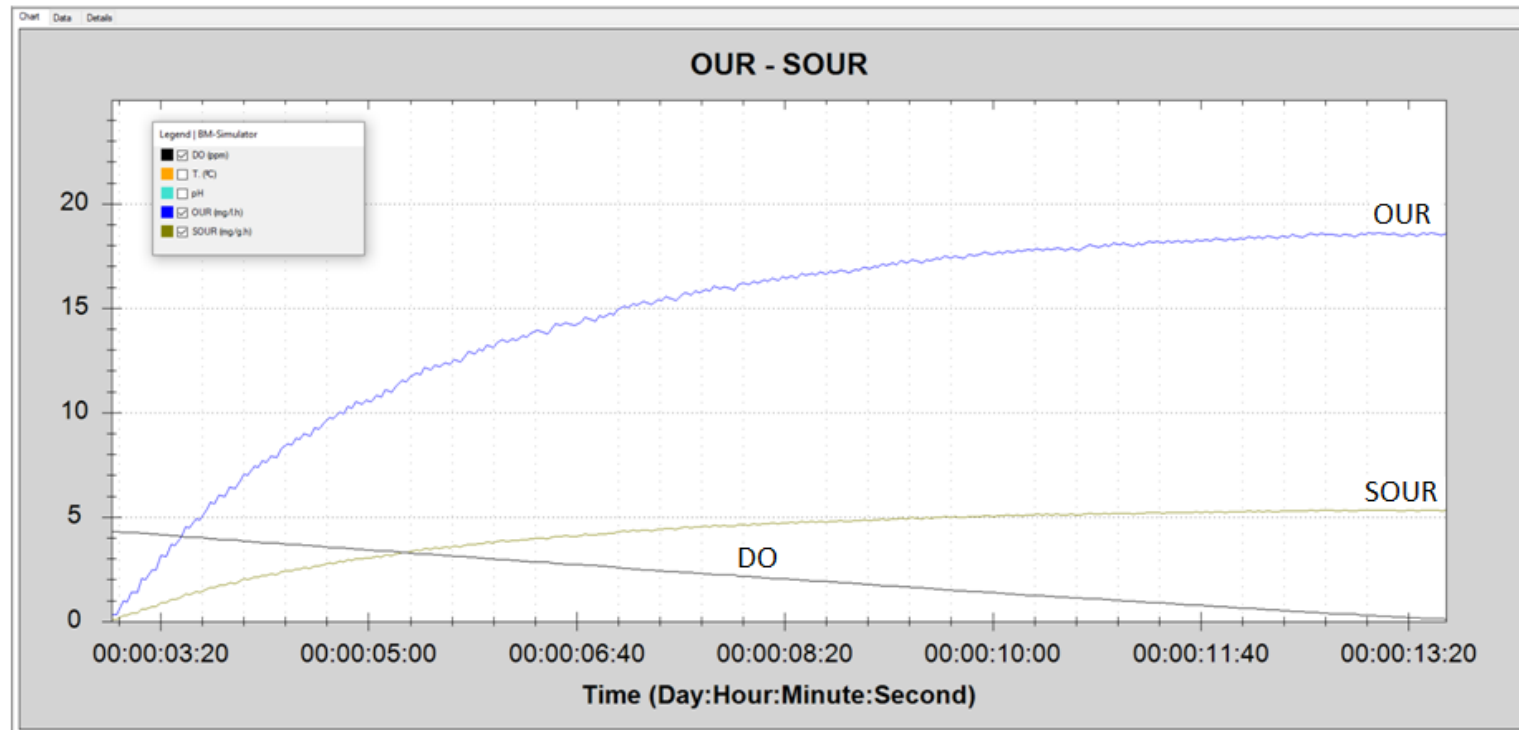
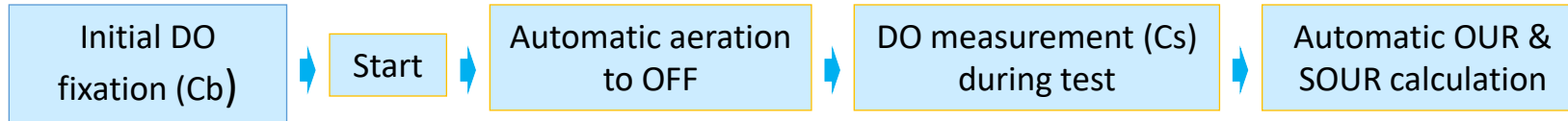
Reactivo	Aplicaciones	Comentarios
Sodium acetate	Organic standard for reference Yield coefficient determination for heterotrophic biomass (Y_H) Bioactivity reference	It could gather other applications.
Allyl Thiourea (ATU)	Nitrification Inhibition	It is prepared with a solution of 100 mg ATU in 100 mL distilled water. In this way, each mL dosed corresponds to 1 mg ATU.
Ammonium Chloride	Ammonium nitrogen standard for nitrification tests [1 mg $\text{NH}_4\text{Cl} \approx 0.26 \text{ mg NH}_4\text{-N}$]	Only needed when the process has nitrification or to check if there is nitrification in it.

Operation modes in BM Respirometry

Mode	Respirometry tests
OUR	OUR & SOUR
Cyclic OUR	Series of chained tests of the type OUR & SOUR
R	Test measuring a chained series of Rs measurements (exogenous respiration rate in endogenous sludge) and automatic calculation of derived parameters

OUR mode (I)

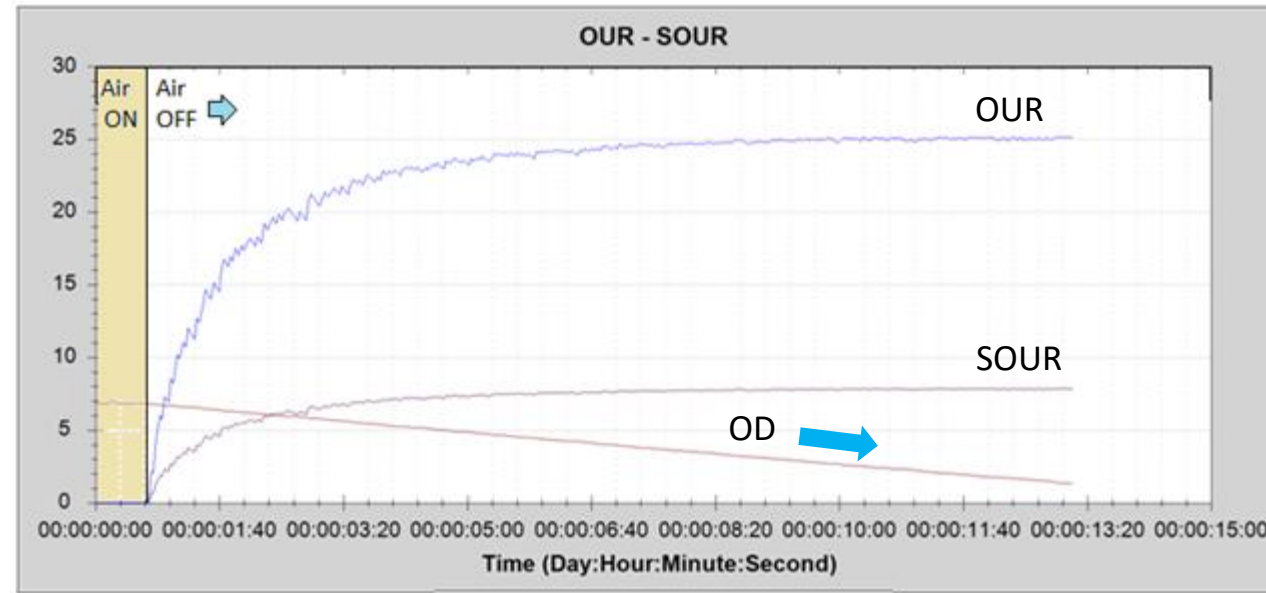
It is based on the traditional batch type respirometry where the operation mode is optimized by means one-sense membrane device that is able to isolate measuring chamber from the atmosphere to avoid the possible outside air interference and bubbles.



Simultaneous respirogram for DO, OUR, SOUR

OUR mode (II)

From the mixed-liquor in the biological reactor the OUR & SOUR parameters are determined for a certain test time – normally the result is valid when it has reached its more stable maximum value.



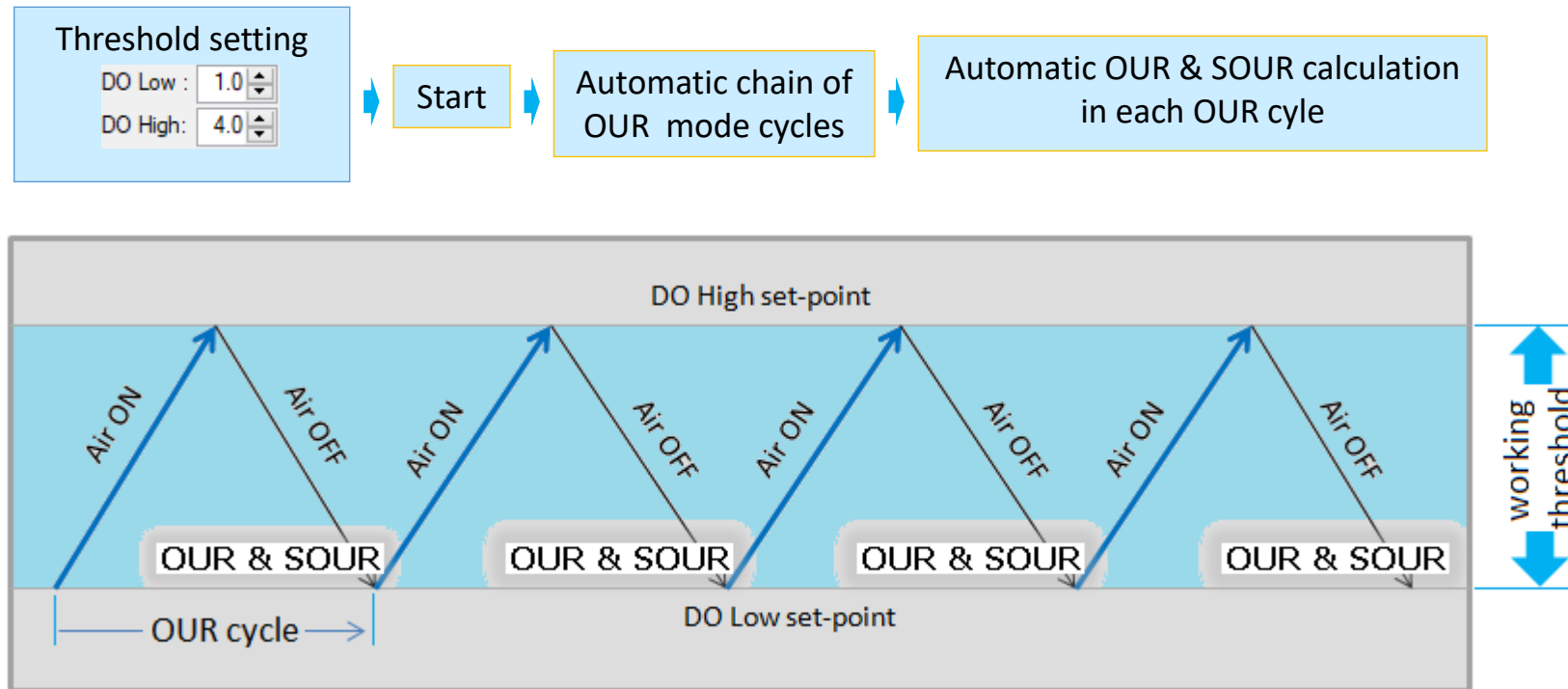
Respirogramas OUR, SOUR y OD

Oxygen uptake rate (mg O ₂ /l.h)	OUR
Specific OUR (mg O ₂ /g VSS.h)	SOUR = OUR / VSS

Cyclic OUR mode (I)

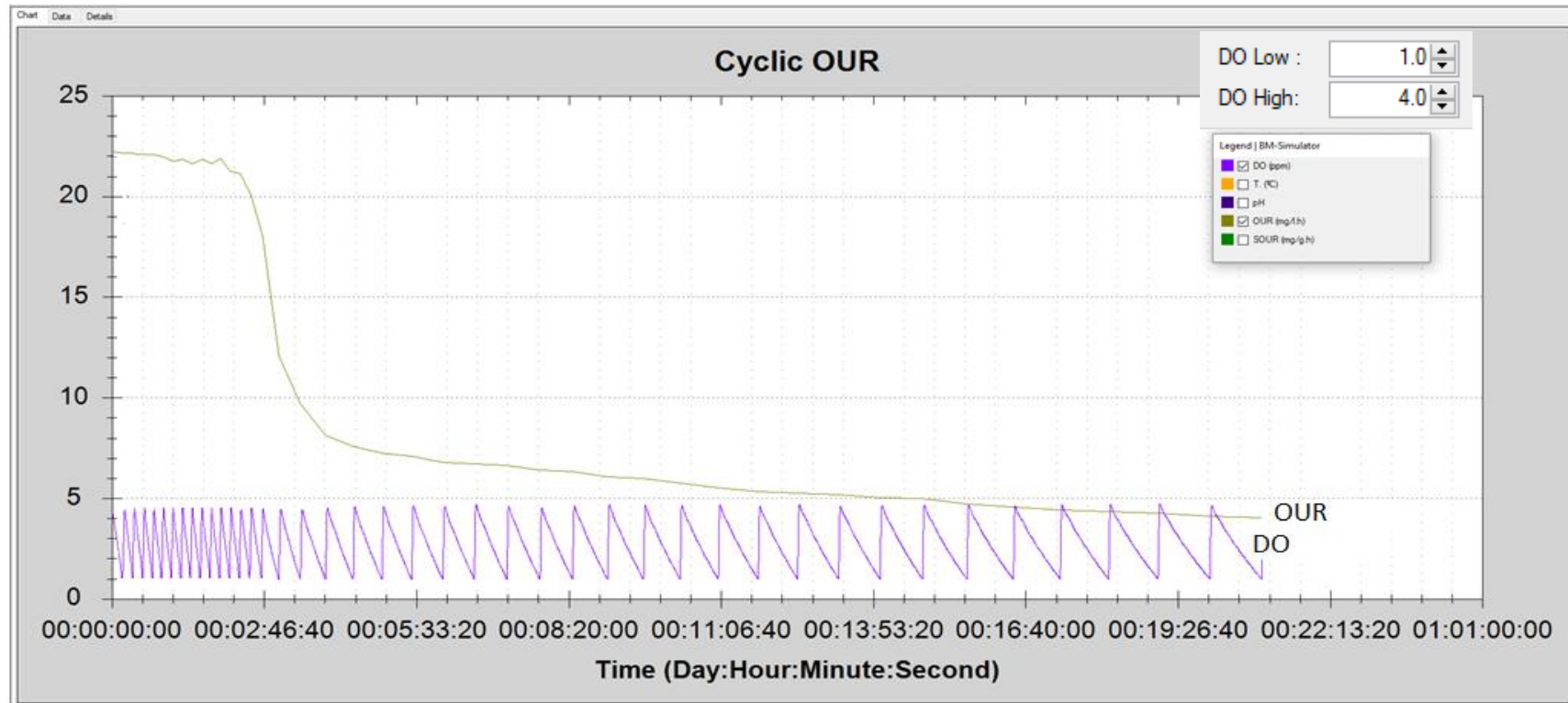
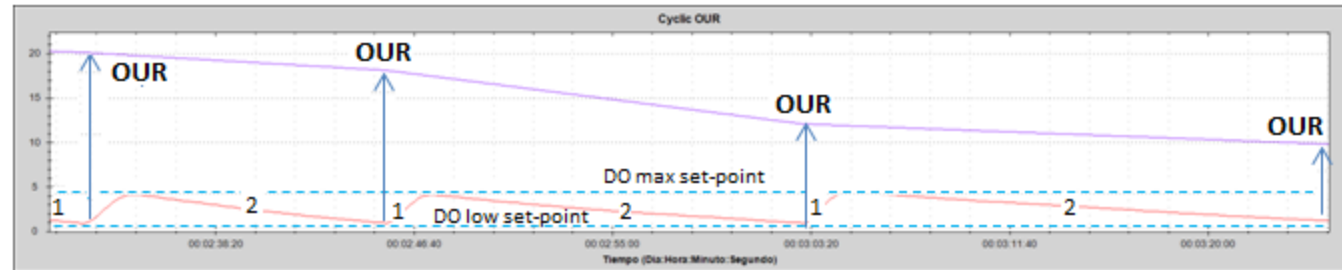
Cyclic OUR mode is a an automatic continuous chain of OUR & SOUR measurements.

On this mode a threshold between two DO limits in which we want to carry out the cyclic test is set by going to **DO Low** and **DO High**.



The DO measurement is jumping in between the programmed **DO High** and **DO Low** set-points and, for each cycle, one automatic **OUR & SOUR** measurement is made (just when it reaches the DO Low sp.)

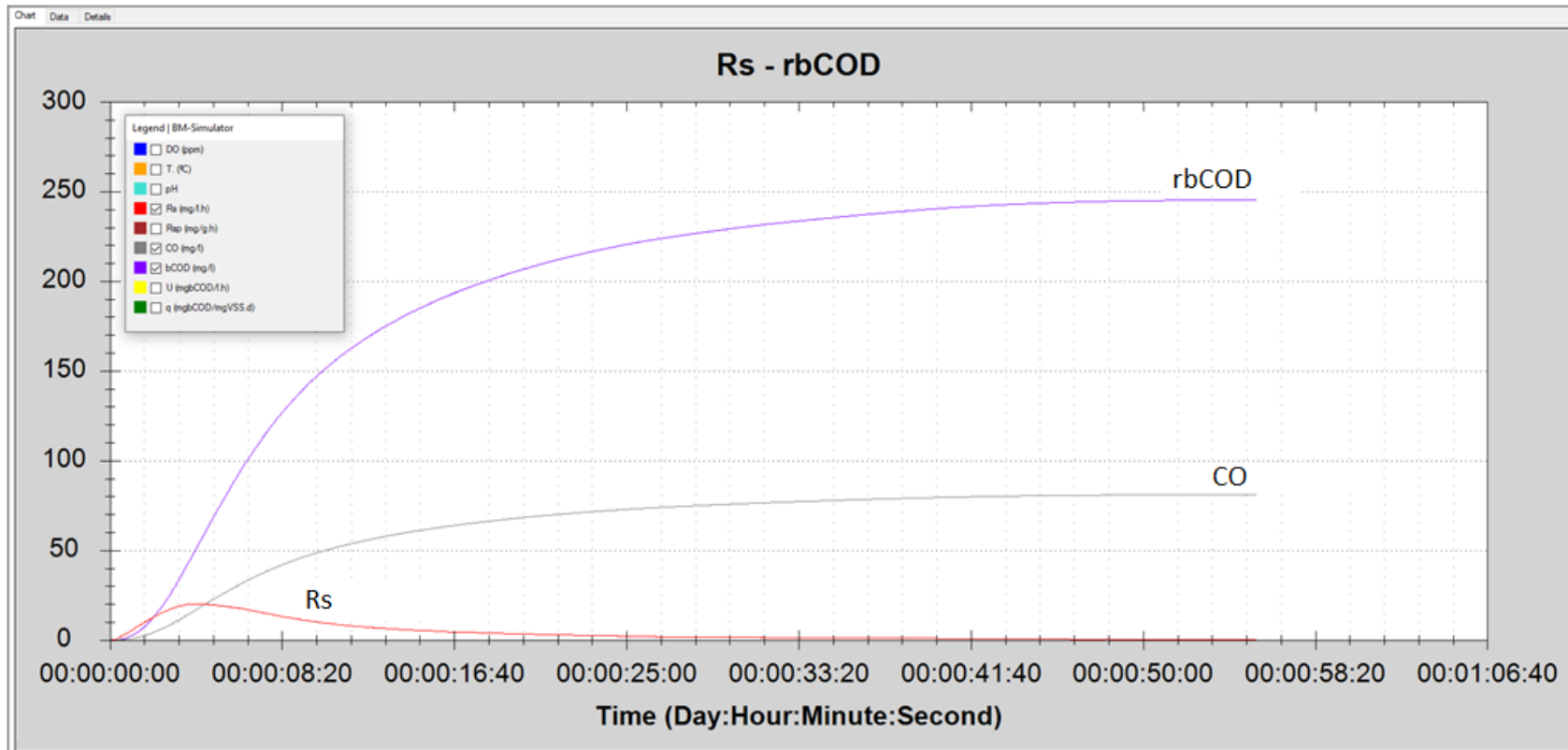
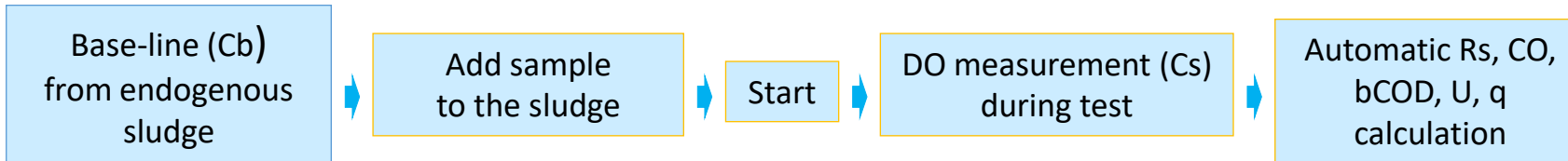
Cyclic OUR mode (II)



OUR & DO Respirograms

R Mode

Once the base-line (initial oxygen) is stored, we add the programmed volume (V_m) of sample and the test will start giving out results and plotting one or several graphical diagrams (respirograms) of any of the simultaneous parameters automatically measured during the test performance



R_s , CO , $rbCOD$ simultaneous respirograms

Results presentation

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Results and chart presentation

From the Chart, Data, Details tabs, the software can display the respirograms and results for any partial or final time of the test, as well as the final, mean, maximum and minimum value.

ChartDataDetails

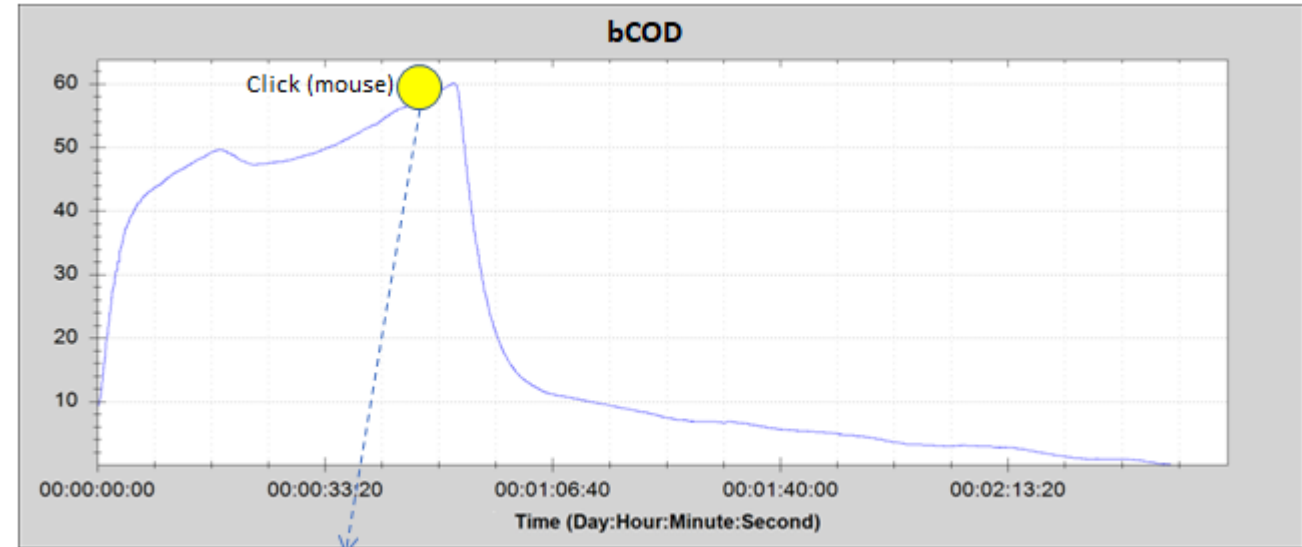
Test
Name:Rs - rbCOD
Operator:
Date:6/11/2020
Baseline:6.48 ppm
Solids:1 g/l
Vf:1000 ml
Vm50 ml
s:2
Y:0.67
Estimation : 0 mg/l
Duration(hh:mm:ss): 00:00:55:29

Results
Select a data type from the list to view the results :
DO (ppm)
T. (°C)
pH
Rs (mg/l.h)
Rsp (mg/g.h)
CO (mg/l)
bCOD (mg/l)
U (mgbCOD/l.h)
q (mgbCOD/mgVSS.d)

First value : 0
Last value : 245.01
Minimum : 0
Maximum : 245.01
Average : 195.09

Remarks

Last, minimum, maximum and average result



T. (°C) : 35,9 pH : 7.96 Rs (mg/l.h) : 60.091 CO (mg/l) : 17737.47925 bCOD (mg/l) : 53749.93712 U (mgbCOD/l.h) : 145.216

Rs respirogram for bCOD test

Chart	Data	Detail:							
Time	DO (ppm)	T. (°C)	pH	Rs (mg/l.h)	Rsp (mg/g.h)	CO (mg/l)	bCOD (mg/l)	U (mgbCOD/l.h)	q (mgbCOD/mgVSS.d)
00:00:01:09	7,1	25	8,16	7,77	0,39	2,05	3,94	5,02	0,01
00:00:01:11	7,1	25	8,16	7,77	0,39	2,23	4,28	5,3	0,01
00:00:01:13	7,02	25	8,16	8,94	0,45	2,43	4,68	5,62	0,01

Display of t current measurements

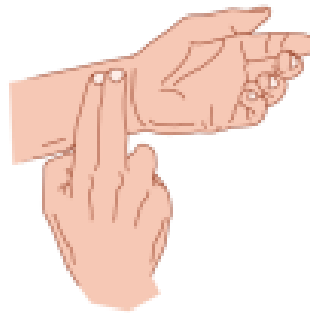
Results interpretation / evaluation

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Typical applications

- Actual oxygen requirement (AOR) and energy optimization
- COD fractionation and specific biodegradability to the activated sludge
 - Activated sludge toxicity: global and specific to nitrification
- Optimization of operational parameters in the context of energy savings
 - Nitrification: Nitrification Rate, Minimum DO and SRI for Nitrification
 - Denitrification: Nitrate removal rate (NUR), COD for denitrification
- Influence of process conditions on biological activity and treatment capacity
 - Bioaugmentation follow up
 - Nutrient ratio optimization (C/N/P)
 - Stoichiometric and kinetic parameters
 - Respirometry for MBBR processes and granular biomass
 - SBR process cycles control
 - Support for simulation programs such as GPS-X, BioWin, ...
 - Other

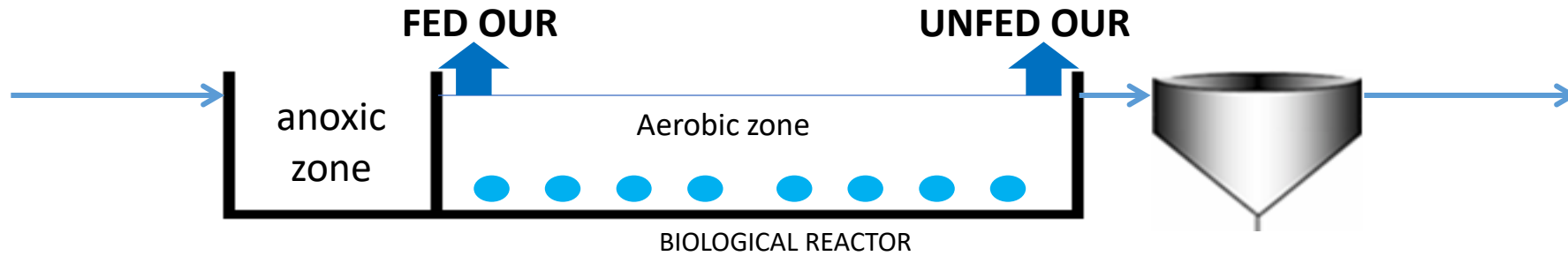
Taking the pulse of the process



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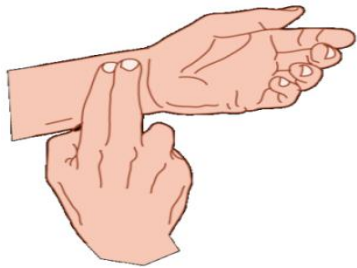
Taking the pulse of the process by the Loading Factor

The ASP can be assessed by means the relationship between the values of two OUR tests: one from the influent sludge (FED OUR) and another form the effluent sludge (UNFED OUR)



Loading factor (LF)

$$LF = \text{FED OUR} / \text{UNFED OUR}$$

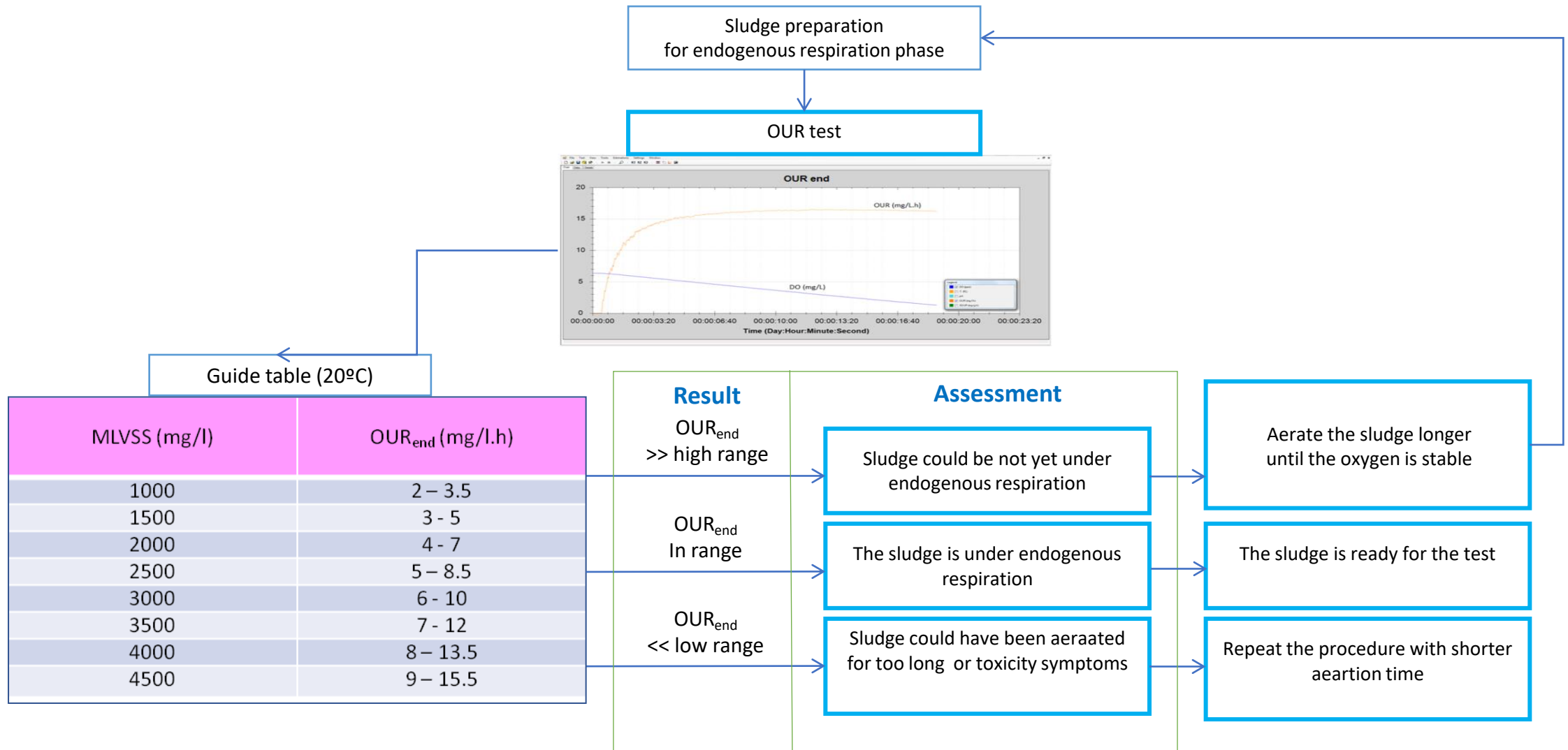


LF	Assessment
$FC \leq 1$	Inhibition / Toxicity
$1 < CF < 2$	Low efficiency or very low loading rate
$2 < FC < 5$	Good performance & Normal loading rate
$FC \geq 5$	Abnormal high loading rate

Endogenous oxygen uptake rate

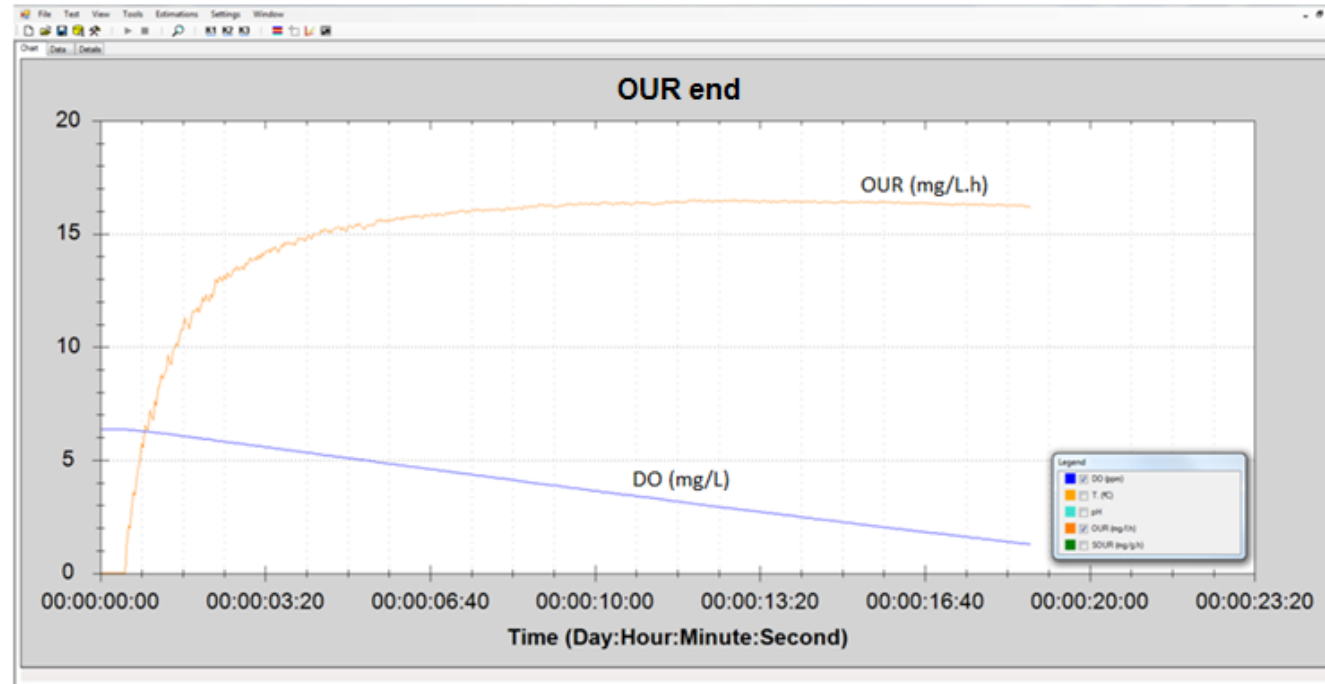
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Evaluation of the endogenous OUR results (OUR_{end})



The endogenous OUR is directly proportional to the concentration of the active biomass

The endogenous respiration rate (OUR_{end}) is just obtained from the activated sludge in the absence of any type of substrate. Therefore, as it depends exclusively on microorganisms, it is directly proportional to the concentration of active biomass (X)



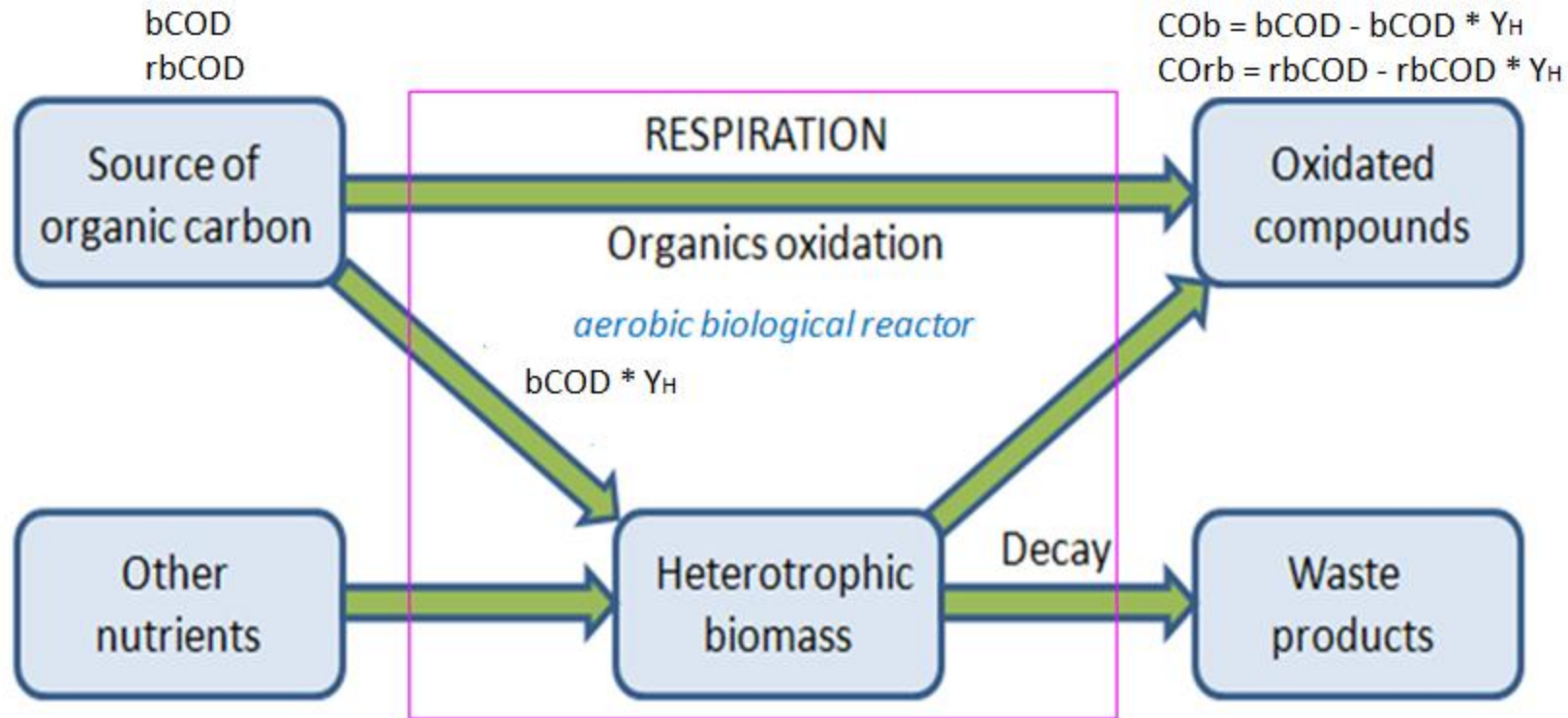
DO and OUR respirogram for OUR_{end}

LMVSS (mg/l)	Normal range OUR_{end} (mg/l.h)
1000	2 – 3.5
1500	3 - 5
2000	4 - 7
2500	5 – 8.5
3000	6 - 10
3500	7 - 12
4000	8 – 13.5
4500	9 – 15.5

OUR_{end} LOWER THAN ITS NORMAL RANGE MEANS A LOW ACTIVITY ~ LOW ACTIVE BIOMAS

Yield coefficient for heterotrophic biomass

Yield coefficient for heterotrophic biomass (Y_H) (II)



CO_b : Consumed Oxygen for biodegradable COD ($bCOD$)
 CO_{rb} : Consumed Oxygen for readily biodegradable COD ($rbCOD$)

$$Y_{H,02} (OC/DQO) = 1 - CO / DQO_{ac}$$

COD_{ac} : COD of sodium acetate solution dose

Yield coefficient for heterotrophic biomass test settings

One of the best ways to determine the Y_H is from a standard compound (sodium acetate) by means of an R-type test.

The test conditions are the typical for an R test, where sludge is used in endogenous phase and 30 ~ 50 ml (normally 50) of sample from a sodium acetate solution of 400 mg in 1 liter of distilled water with an approximate COD of 300 mg.

New Test | BM-Simulator

Test type:
OUR
Cyclic OUR

Name: Yh
Operator: JC
Filename: C:\Users\Usuario\Documents\Surcis\Re Search
Data interval: 2 s.

Vf: 1000,00 ml
Vm: 50,00 ml
fd: Auto 21

Solids: 1,80 g/L
Y: 0,67
☒ Readings < 0
☐ Force Cb: 5,29

CO: 126,05
DO Low: 2,0
DO High: 6,0

Board control settings during test

Temperature control
20,00
OFF ON

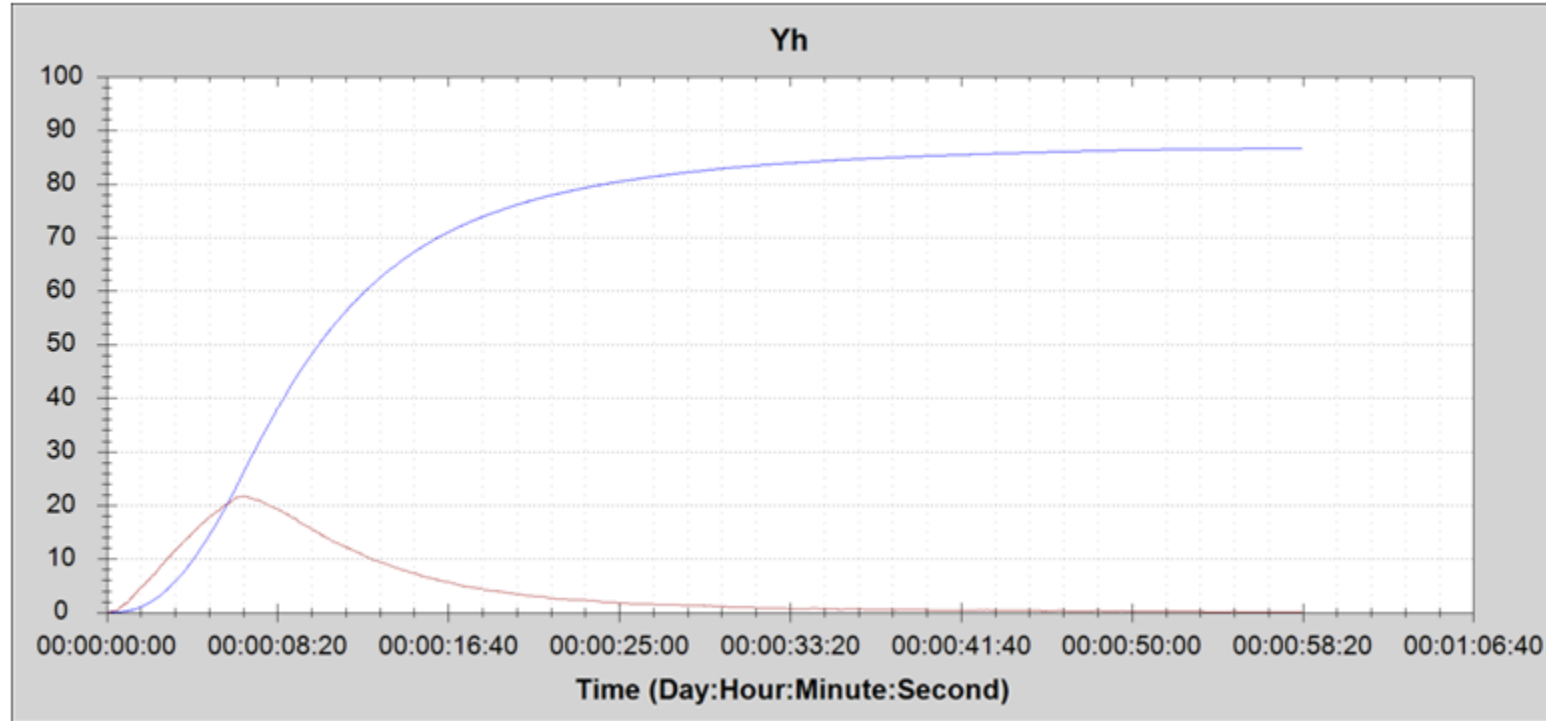
PH Control
7,30 Hysteresis: 0,10
OFF ON

Peristaltic pump
2
OFF ON

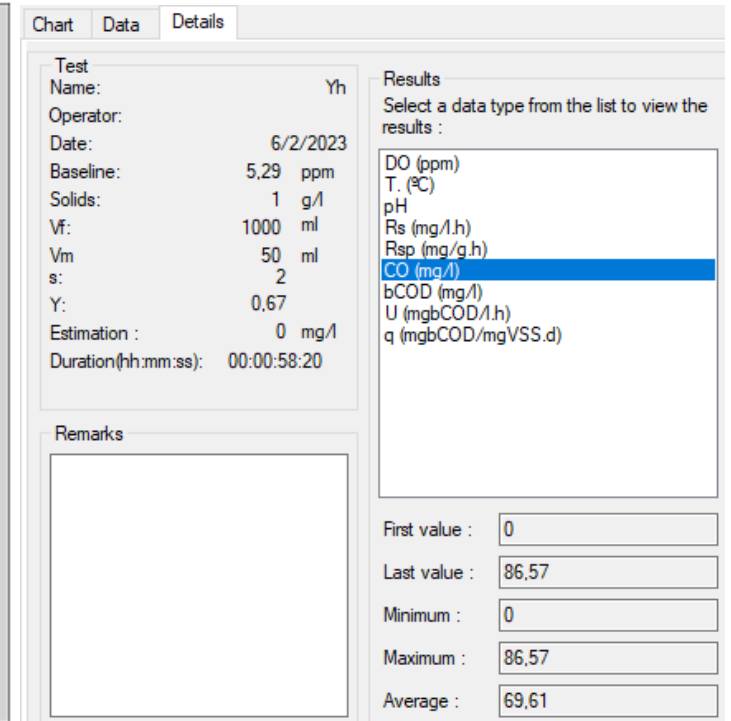
Aeration
55
OFF ON

Cancel Accept

Yield coefficient for heterotrophic biomass calculation from respirogram and CO result



Simultaneous respirograms RS and CO, after adding the sodium acetate sample



CO result (maximum)

$$Y_H = 1 - OC / COD_{ac}$$

COD_{ac}: COD of the sodium acetate solution ≈ 300 mg/L

Evaluation of the Y_H result

The determination of Y_H by respirometry, in addition to being part of the calculation of COD, complements the taking of the pulse of the process by assessing the health of the heterotrophic biomass.

Y_{H,O_2}	Assessment
$Y_H > 0.8$	There could be a high % of rbCOD High heterotrophic biomass production in the activated sludge
<u>In range</u> $0.6 < Y_H < 0.8$	Normal heterotrophic biomass growth
$0.5 < Y_H < 0.6$	Low heterotrophic biomass growth There could be a high % of refractory COD (nbCOD) or slowly biodegradable COD (sbCOD)
$Y_H \ll 0.5$	Possible inhibition / toxicity, already present in the activated sludge

COD fractionation

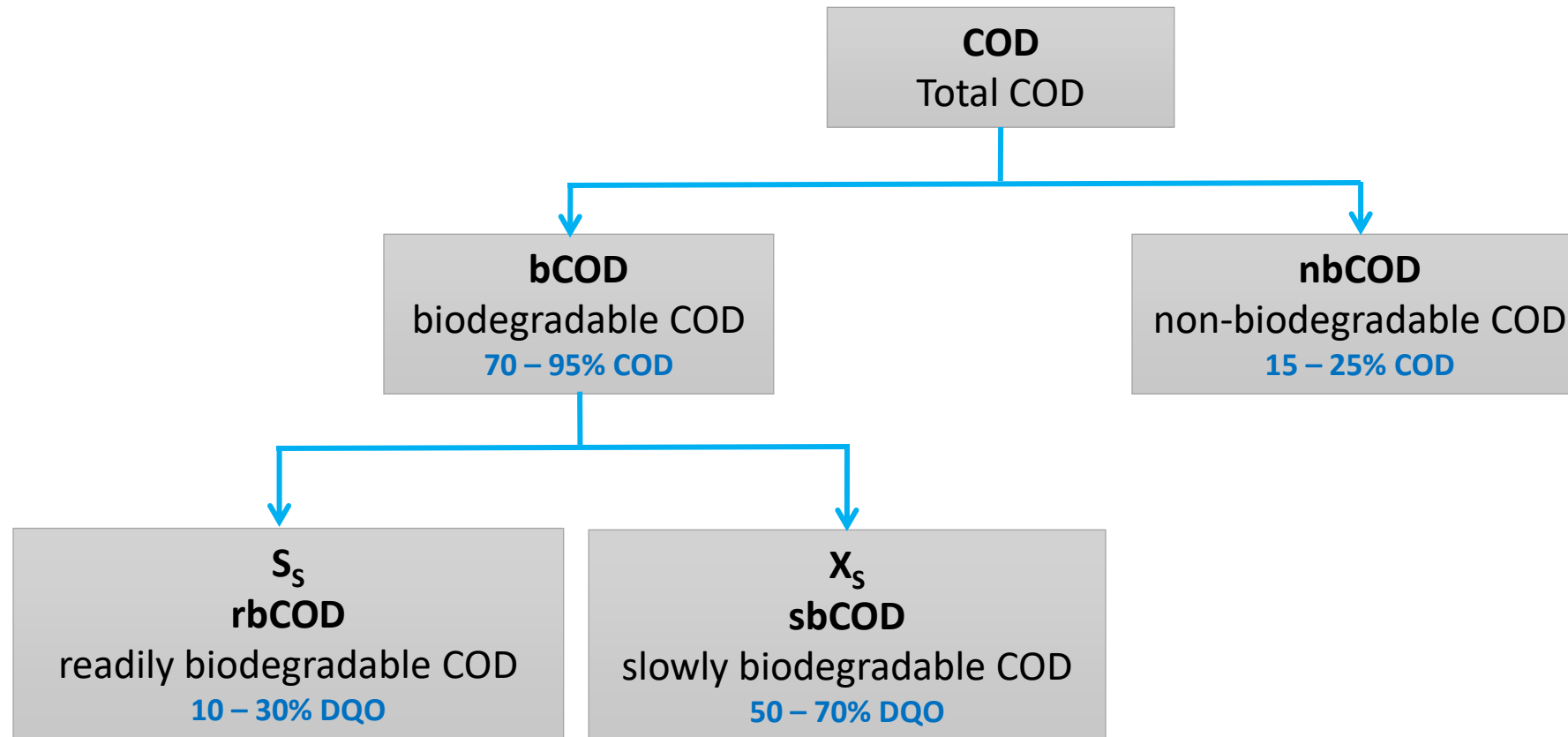
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Important requirements for BM respirometry tests to obtain the COD fractions

1. A valid endogenous respiration, sufficiently proven.
2. A stable base-line ~ stable oxygen reading.
3. Inhibition of the nitrifier biomass by means the addition of Allyl-Thiourea (ATU)- 3 to 4 mg per g MLVSS -
4. Stable dissolved oxygen and temperatures readings for at least 10 minutes before starting the test.
5. Absence of toxicity or inhibitory compounds or conditions in the activated sludge.
6. MLVSS equal or lower than 5 g/L (*)

(*) In case the sludge has a MLVSS concentration $\gg 5$ g/L, it should be diluted with distilled water to get a concentration in between 3 to 4 g/L – This dilution will not affect the CO for the Y_H determination -

Main COD fractions



Why COD fractionation in the activated sludge process ?

It mainly serves to obtain the following:

Determine the amount of COD that can be biologically treated ? bCOD

$$\text{Biodegradability to the sludge (\%)} = 100 * \text{bCOD} / \text{COD}$$

Determine the amount of COD that cannot be biologically treated ? Non-biodegradable: nbCOD = COD – bCOD

$$P_{nb} = 100 * \text{nbCOD} / \text{COD}$$

Explain a possible poor performance due to a slow biodegradation ? Slowly biodegradable COD: sbCOD = bCOD – rbCOD

$$P_{sb} = 100 * \text{sbCOD} / \text{COD}$$

Parameters associated with COD fractions

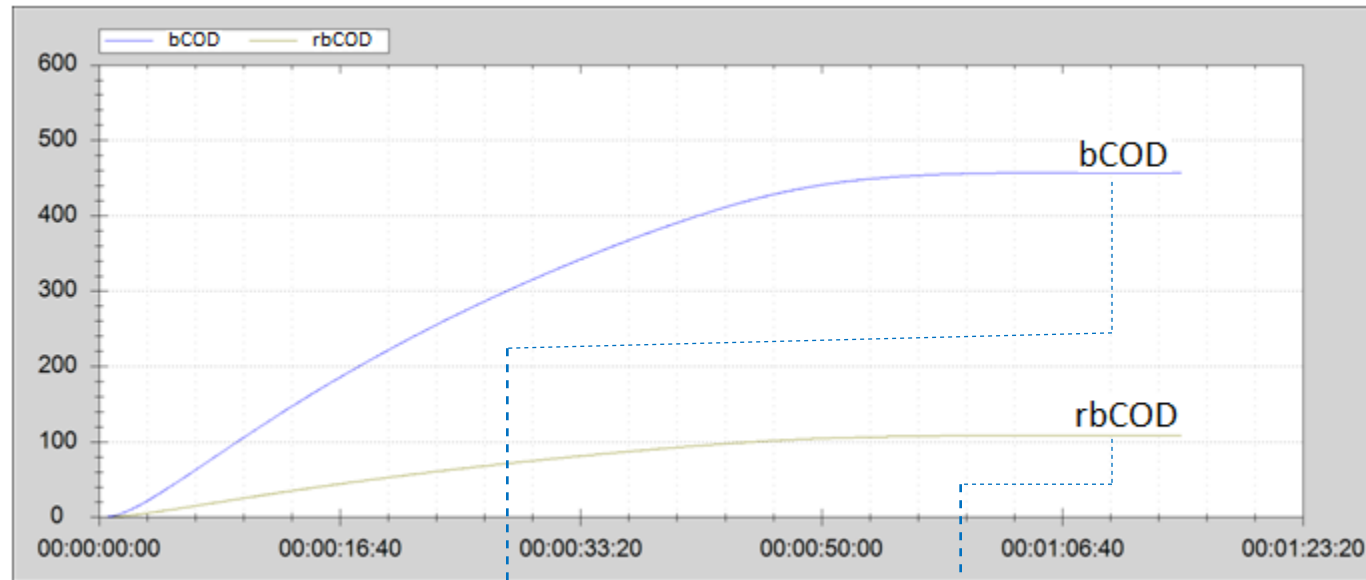
Biomass production performance coefficient (Y_H), Consumed Oxygen, COD removal rate (q, U)

Applications

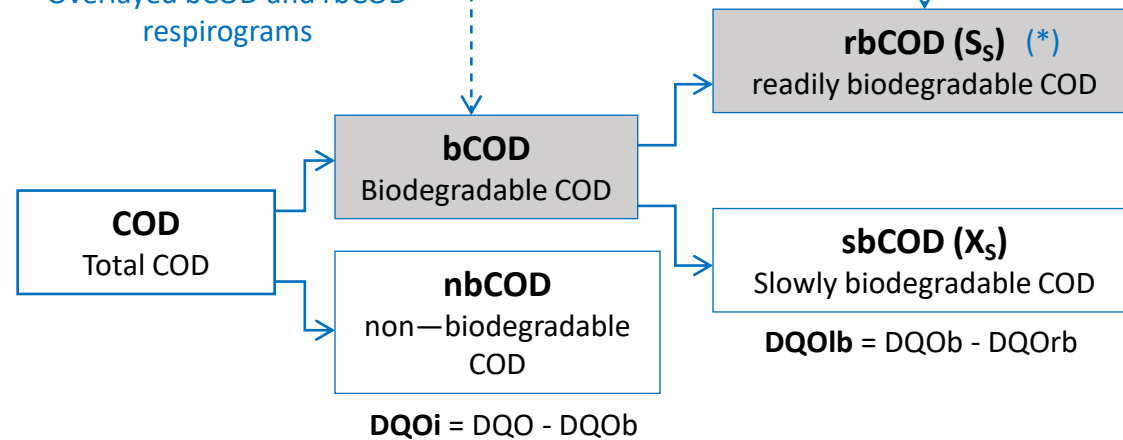
Support to Simulation Programs, COD Loading Rate analysis, Organic Oxygen Requirement, Nutrient Ratio, Inhibition Symptoms, Necessary COD for denitrification,

....

Main COD fractions just obtained from two R respirometry tests



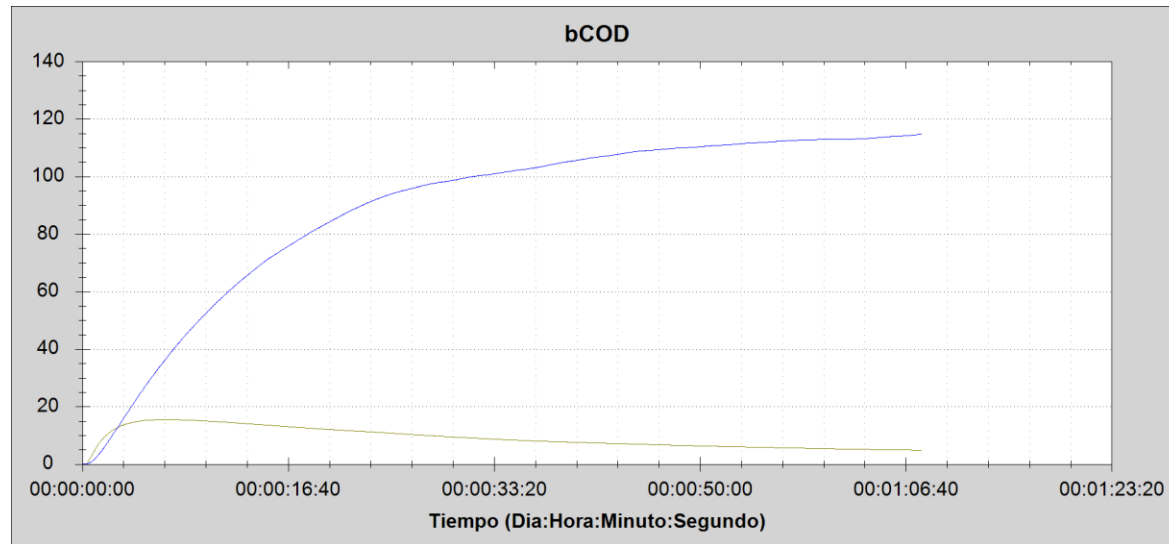
Overlaid bCOD and rbCOD respirometry curves



(*) rbCOD (S_s): Normally refers to the biodegradable COD of a truly soluble sample

COD uptake rate: U, q

Simultaneously to the determination of COD, the BM Respirometry software automatically calculates the rate and the specific rate (referred to VSS) with which COD is being eliminated: U (mg COD / L.h), q (mg COD / mg VSS.d)



Simultaneous respirograms bCOD, U

Results Select a data type from the list to view the results : DO (ppm) T. (°C) pH Rs (mg/l.h) Rsp (mg/g.h) CO (mg/l) bCOD (mg/l) U (mgbCOD/l.h) q (mgbCOD/mgVSS.d)	Results Select a data type from the list to view the results : DO (ppm) T. (°C) pH Rs (mg/l.h) Rsp (mg/g.h) CO (mg/l) bCOD (mg/l) U (mgbCOD/l.h) q (mgbCOD/mgVSS.d)	Results Select a data type from the list to view the results : DO (ppm) T. (°C) pH Rs (mg/l.h) Rsp (mg/g.h) CO (mg/l) bCOD (mg/l) U (mgbCOD/l.h) q (mgbCOD/mgVSS.d)
First value : 0	First value : 0	First value : 0
Last value : 114,74	Last value : 4,83	Last value : 0,06
Minimum : 0	Minimum : 0	Minimum : 0
Maximum : 114,74	Maximum : 15,44	Maximum : 0,2
Average : 88,36	Average : 9,12	Average : 0,12

From the value of the U we can know if with the current HRT there is time to sufficiently eliminate the current COD:

$$\text{HRT} = \text{bCOD} / \text{U}$$

From q we can assess de actual COD Loading Rate (F/M)

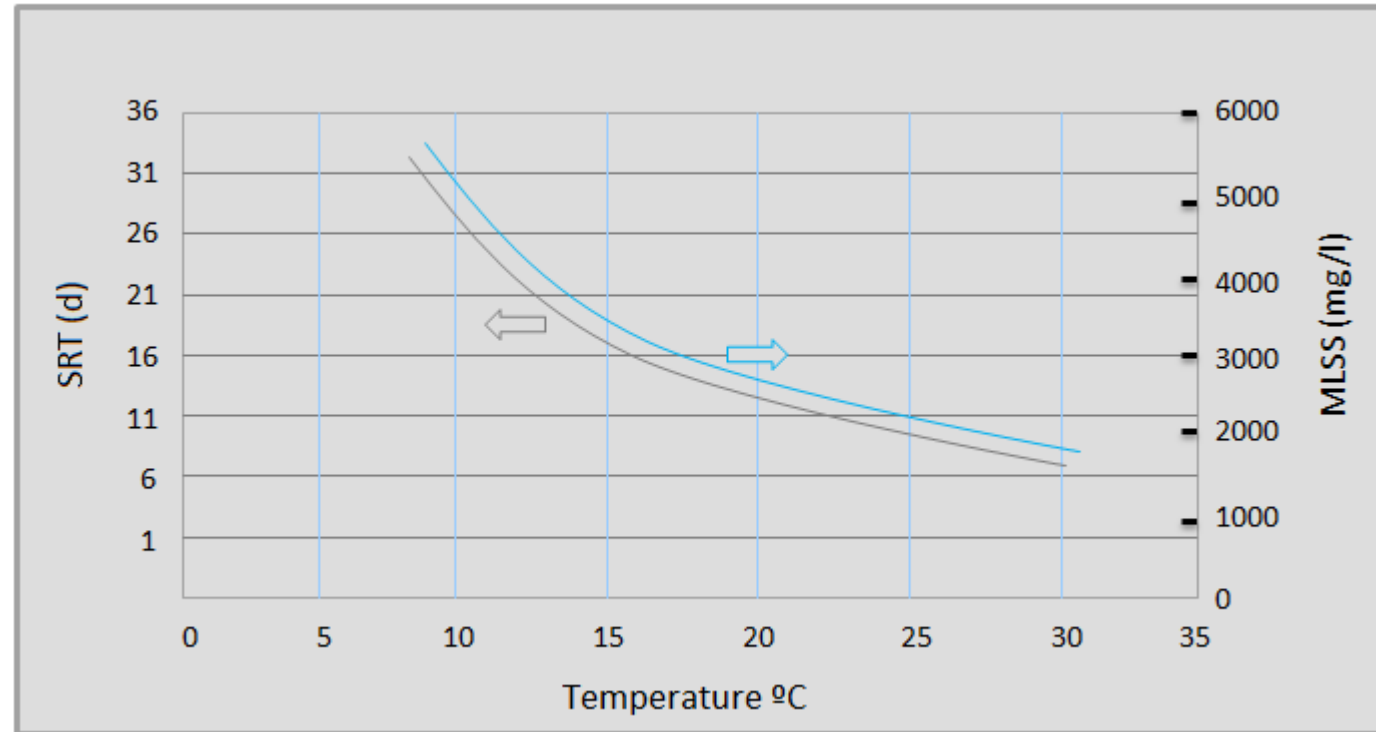
Nitrification

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Initial conditions for nitrification

Condiciones	
pH	7.3 a 8 (optimal)
T	> 15 to 28 °C
OD	1.5 to 3 ppm
BOD/TKN	< 5
SRT	5 to 30 d
Sufficient capacity in the reactor for nitrification	
Without any inhibitor nor toxic compounds	

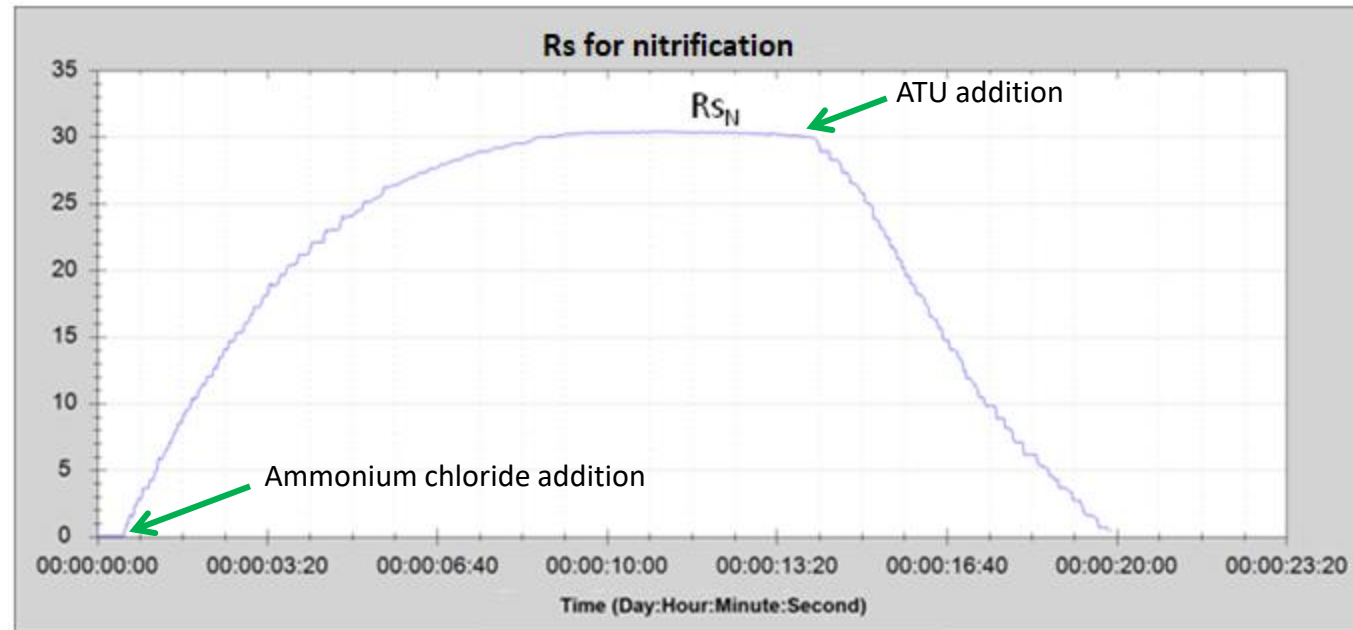
Recommended SRT & MLSS for a nitrification process vs Temperature



Nitrification rate (AUR)

We will use ammonium chloride with an equivalent ammonium concentration ($C_{NH4} = N-NH_4 / 0.26$) in an R test, under equivalent temperature and pH conditions until reaching the maximum value)(Rs_N)

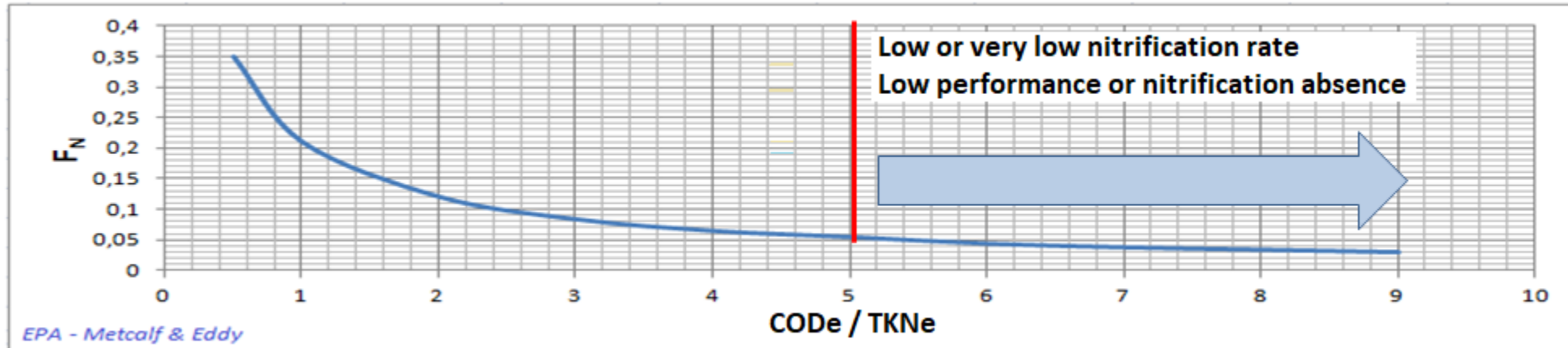
Once the maximum value is reached, successive doses of ATU (3 to 4 mg / g VSS) are added until the nitrifying biomass is inhibited. In this way, this sludge will serve us for the determination of bCOD and rbCOD.



Rs respirogram for nitrification

Oxygen uptake rate due to nitrification (mg O_2 /l.h)	Rs_N
Nitrification rate (mg N- NH_4 /l.h)	$AUR = [Rs_N / 4.57] * DO / (K_{DO} + DO)$ DO : Dissolved Oxygen in the nitrification process (mg/l) : K_{DO} : Correction factor due to DO $\approx 0,5$ (Usual value by default)

Estimation of the nitrifier biomass concentration and corresponding SRT for nitrification



CODE: eliminated COD in the aerobic process

TKNe: eliminated TKN in the aerobic process

$$X_A = F_N * MLVSS$$

$$SRT = X_A / (2.4 * AUR)$$

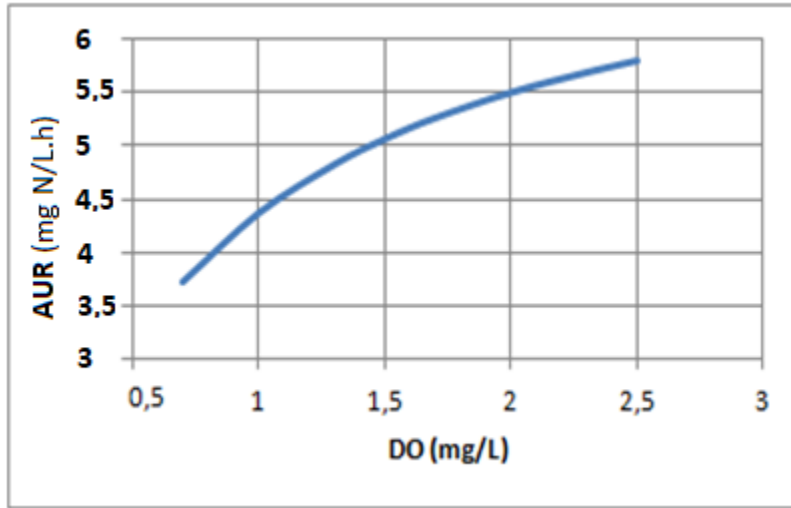
X_A : Active nitrifier biomass (mg/l)

SRT: Minimum sludge age for nitrification (d)

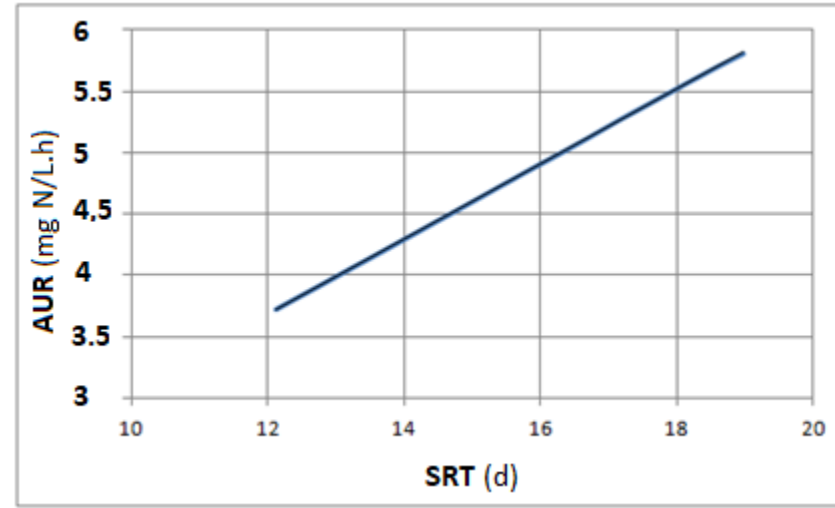
Possible causes of poor nitrification performance

1. The process is operating with a very low OD (< 1 ppm) and very fair conditions
2. The sludge age (SRT) is less than the minimum at which the process should be operating
3. COD/TKNe ratio $\gg 5$
4. Low temperature ($< 15^{\circ}\text{C}$)
5. Presence of any inhibitor or toxicant
6. Other

Dissolve Oxygen (DO) and/or Sludge Age (SRT) for nitrification



$$\text{AUR} = [\text{R}_{\text{S}_\text{N}} / 4.57] * \text{OD} / (\text{K}_{\text{OD}} + \text{OD})$$



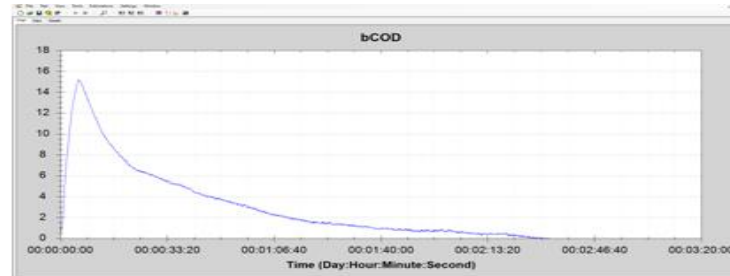
$$\text{SRT} = \text{X}_\text{A} / (2.4 * \text{AUR})$$

Denitrification

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Aerobic procedure to determine the denitrification rate (NUR) from the COD uptake rate (U)

1. Perform a complete R test for bCOD of wastewater entering the anoxic process.



2. Go to the Data tab obtained during the R test.

Time (D:H:M:S)	DO (ppm)	T. (°C)	pH	Rs (mg/l.h)	Rap (mg/g.h)	CO (mg/l)	bCOD (mg/l)	U (mgbCOD/l.h)	q (mgbCOD/mgVSS.d)
00:00:44:02	7,9	20	7,56	4,17	2,32	119,88	399,59	25,93	0,35
00:00:44:53	7,9	20	7,56	4,15	2,3	121,1	403,68	25,7	0,34
00:00:44:55	7,9	20	7,56	4,13	2,3	121,15	403,84	25,69	0,34

3. Find the **CO** value equal / similar to that of oxygen for denitrification CO_D , and the **U** value corresponding to the same time frame.
Where $CO_{DN} = 2,86 * [N-NH_4]$

CO (mg/l)	bCOD (mg/l)	U (mgbCOD/l.h)	q (mgbCOD/mgVSS.d)
121,15	403,84	25,69	0,34

6. Calculate the the dentrification rate (NUR):

$$NUR \text{ (mg N/L.h)} = [U (1-Y_{HD}) / 2.86] * K_{OD} / (K_{OD} + OD_D)$$

Y_{HD} : Yield coefficient in the anoxic zone (O_2/COD) = $0,85 * Y_H$

K_{OD} : Inhibition coefficient due to possible oxygen in the anoxic zone = 0.2 (mg/L) - Henze et al 1996 –

DO_D : Possible Dissolved Oxygen in the anoxic zone (mg O_2 /L) – Must be below **0.3 mg/L**

Specific denitrification rate

$$\text{SDNR} = 24 * \text{NUR} / X_v$$

SDNR: Specific denitrification rate (mg N-NO₃ / mg VSS.d)

Guide table

Estimated Specific Denitrification Rates

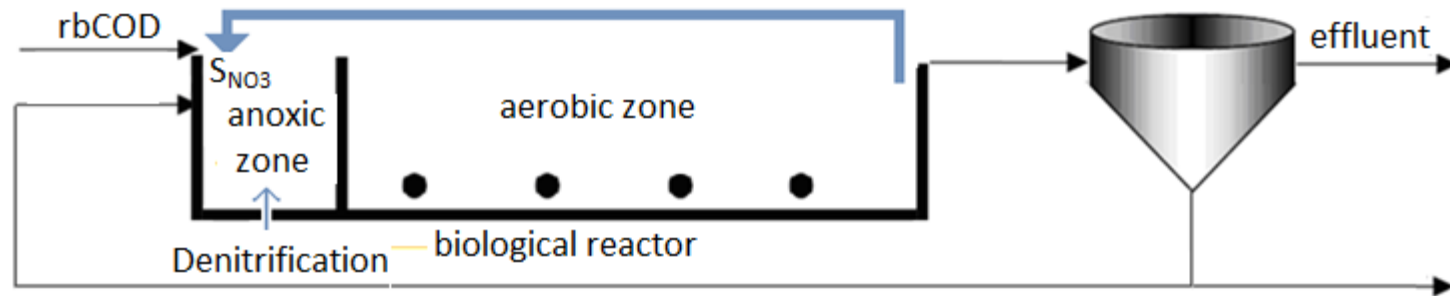
Temp ° C	Estimated SDNR	Temp ° C	Estimated SDNR
10	0.035	18	0.076
12	0.042	20	0.091
14	0.052	22	0.110
16	0.063	24	0.132

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 carbonaceous matter)
3. Anoxic zone is not gathering the anoxic condition (oxygen < 0.3 ppm)
4. The hydraulic 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

Required rbCOD for denitrification



$$\text{rbCOD}_D > 2.86 * S_{\text{NO}_3} / (1 - Y_{\text{HD}})$$

S_{NO_3} : Nitrate to denitrify (mg N-NO₃/L)

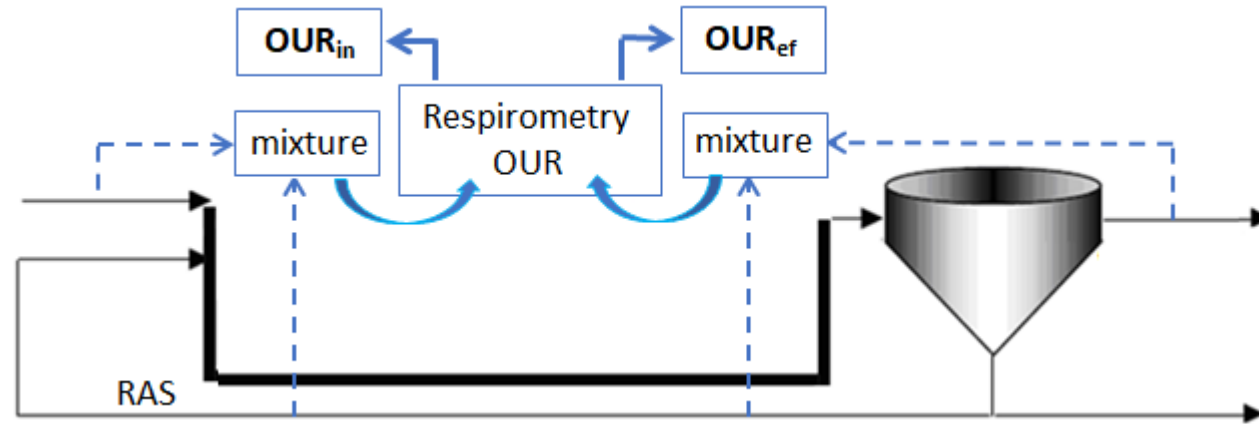
rbCOD_{DN} : Minimum readily biodegradable COD DQO required for denitrification (mg/L)

Y_{HD} : Yield coefficient of the heterotrophic biomass in the denitrification anoxic zone (mg O₂/mg COD) $\approx 0.83 * Y_{\text{H}}$

Toxicity

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Possible toxicity already present in the biological reactor



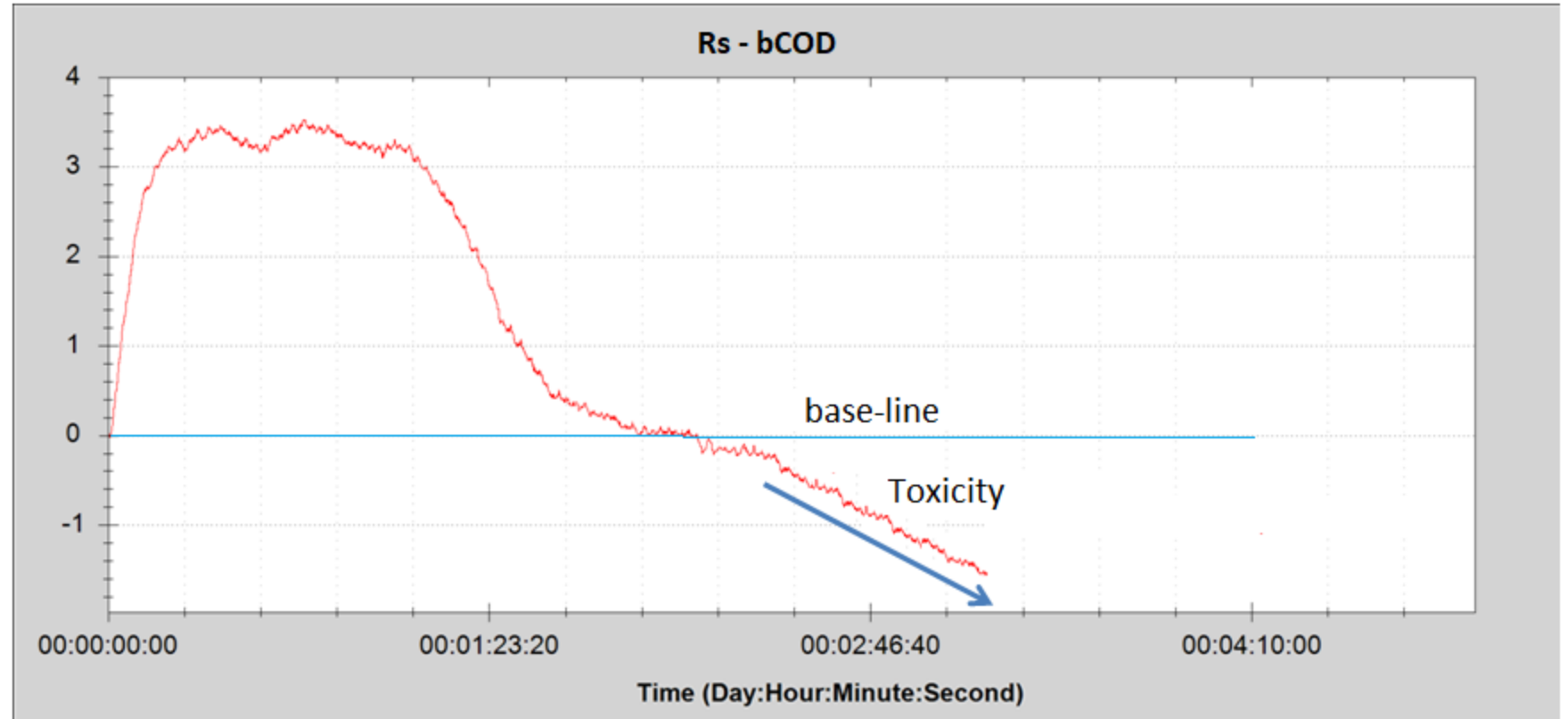
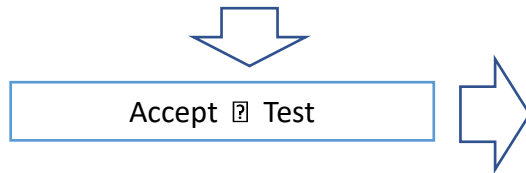
Loading Factor: $LF = OUR_{in} / OUR_{ef}$

LF	Evaluation
$LF < 1.3$	Inhibition / Toxicity – already present in the biological reactor

Toxicity detection from a bCOD test

When the R_s exceeds the baseline and falls with a clear progressive negative slope, the test is indicating the possibility of the presence of a toxicity caused by the sample for the V_m/V_f ratio in with which the test has been performed.

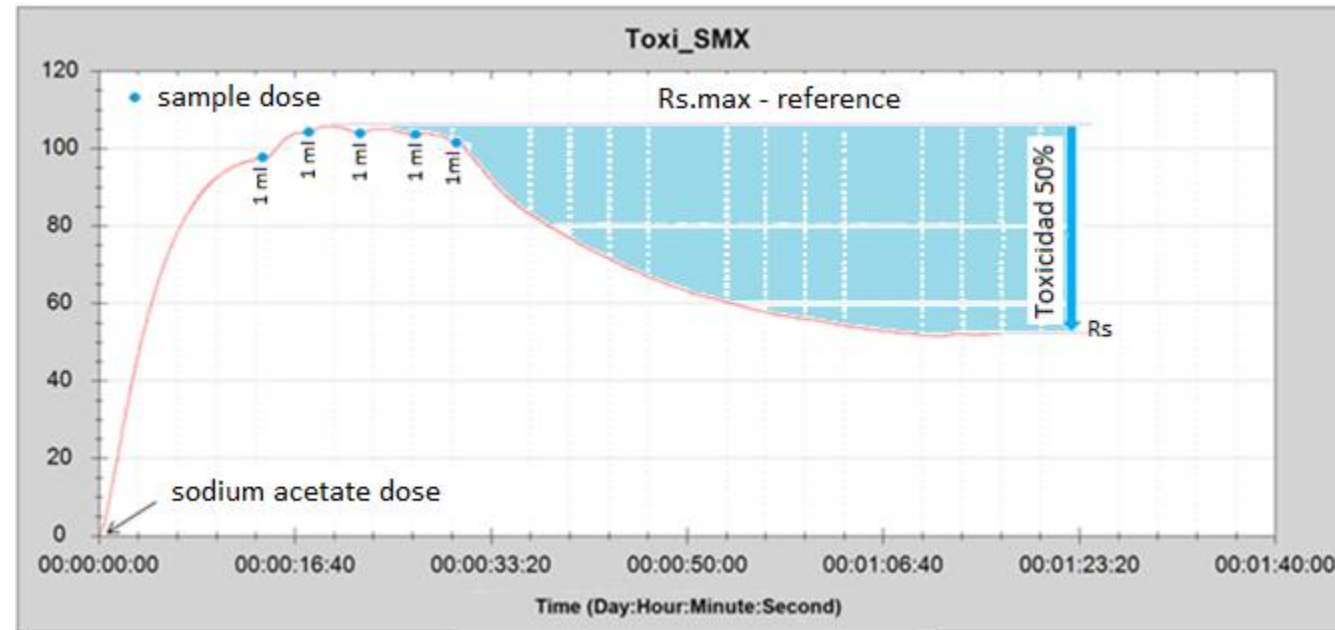
Wf : 1000,00 ml Solids : 2,00 g/L
Vm : 50,00 ml Y : 0,60 DO Low :
fd : Auto 21 ☒ Readings < 0 DO High :
☐ Force Cb :



Rs of the bCOD Respirogram

Fast- toxicity analysis by cumulative sample dose

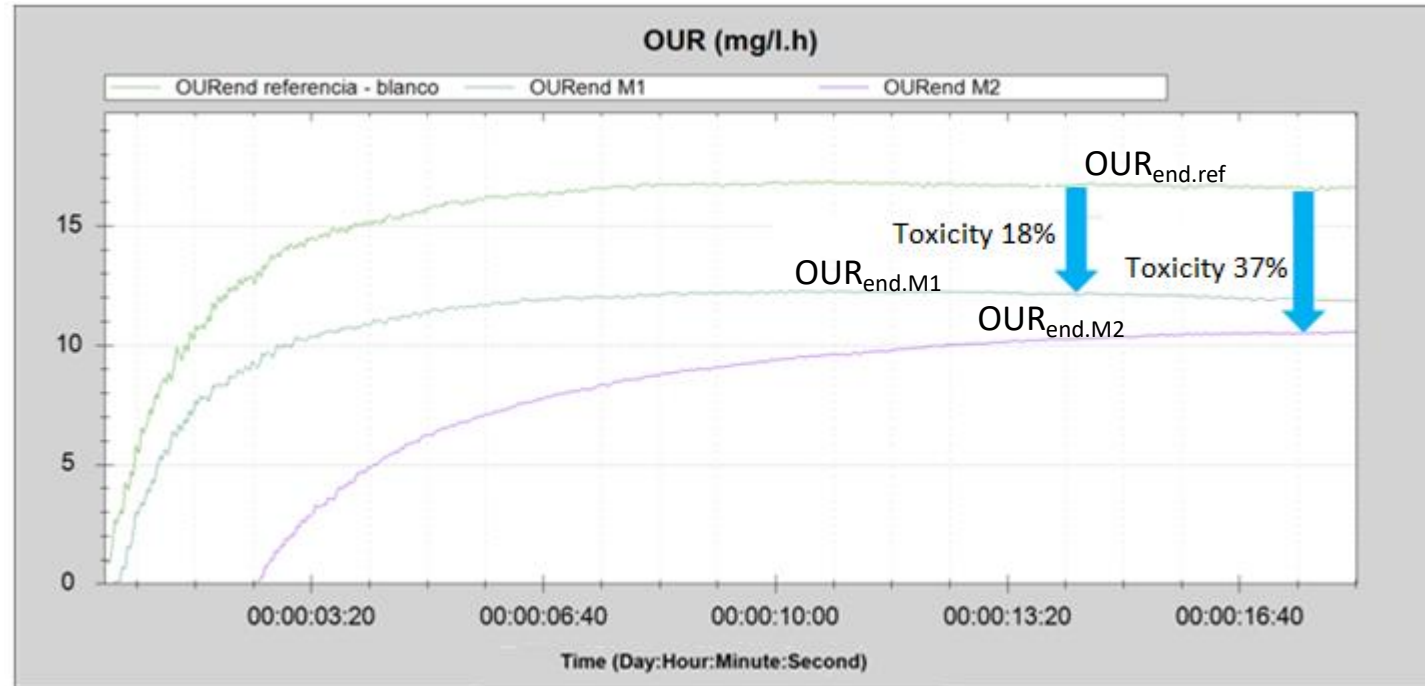
The objective on this application is to analyze a toxic effect that could occur in activated sludge by the progressive addition of wastewater sample doses over a maximum respiration rate caused by the addition of a reference substrate (sodium acetate, ammonium chloride, or both)



Rs respirogram for toxicity by cumulative doses of sample addition

Toxicity analysis for one or several samples by means endogenous our tests evaluation

With this procedure, toxicity is assessed by comparing the endogenous OUR value ($OUR_{end.M}$) of one or several mixtures prepared with sample/s + sludge vs the reference endogenous OUR ($OUR_{end.ref}$)



OURend overlayed respirograms for toxicity assessing of two samples

$$\text{Toxicity: I (\%)} = 100 * (OUR_{end.ref} - OUR_{end.M} / OUR_{end.ref})$$

Sludge production

SURCIS

Procedure for the determination of sludge production

Procedure: K_d \rightarrow Y_{obs} \rightarrow P_x

K_d : Coefficient of biomass decomposition in endogenous respiration phase (d^{-1})

This coefficient takes into account the loss of cell mass due to the oxidation of internal energy storage products for the maintenance of the cell in the endogenous respiration phase.

$$K_d = (24 / 1000) * SOUR_{end} / 1.42$$

Y_{obs} : Stoichiometric observed yield coefficient (VSS/ DQO)

This coefficient represents the ratio of net biomass accumulation to the amount of excess sludge. It is related to the K_d and age of the sludge age (SRT), thus accounting for the lysis (death) of bacterial cells and the predation of bacteria by other microorganisms.

$$Y_{obs} = Y_{H,VSS} / (1 + K_d * SRT)$$

P_x : Sludge production (kg SSV/d)

This parameter represents the net growth of biomass expressed in suspended volatile suspended solids. Its mathematical formula is as follows:

$$P_x = Y_{obs} * Q * bCOD_e / 1000$$

P_x : Sludge production (kg VSS/d)

Y_{obs} : Observed yield coefficient (VSS/COD)

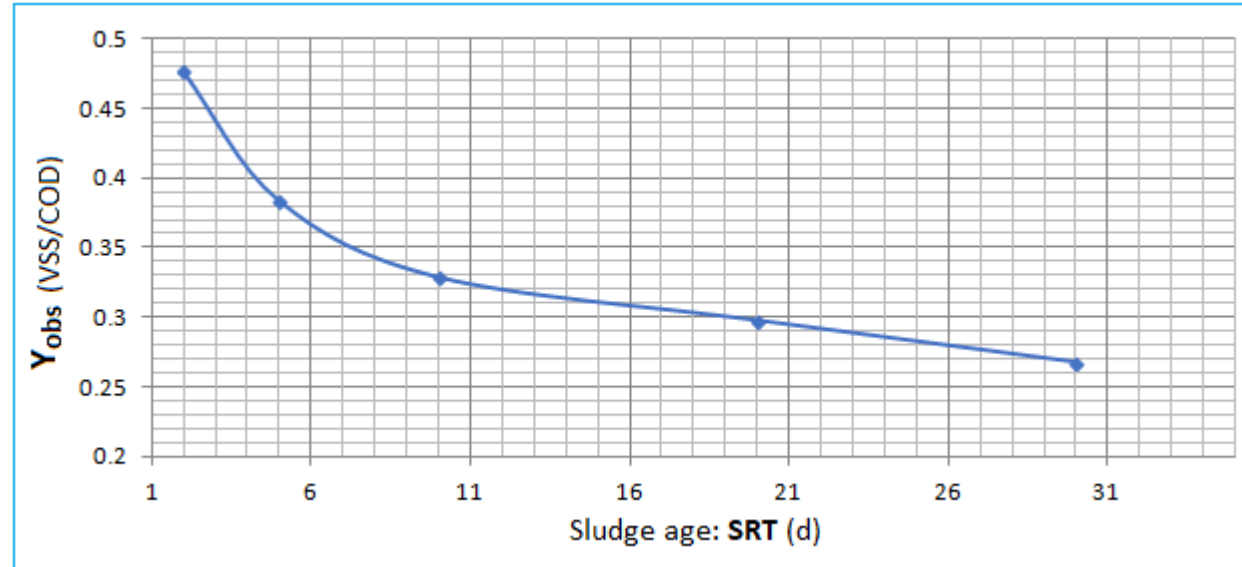
Q : Influent flow (m^3/d)

$bCOD_e$: Biodegradable COD eliminated ($mg\ bCOD/L$) = $bCOD\ influent - bCOD\ effluent$ $\rightarrow bCOD\ effluent \approx 1,6 * BOD\ effluent$

Estimated calculation of the sludge production: P_x

Y_{obs} (VSS/COD)	TRC (d)	F/M (COD/VSS.d)
0,477	2	1,048
0,384	5	0,521
0,329	10	0,304
0,298	20	0,168
0,268	30	0,124

Cicek, 2001; Macomber, 2005



$$P_x = Y_{obs} * Q * bCOD_e / 1000$$

P_x : Sludge production (kg VSS/d)

Y_{obs} : Observed yield coefficient (VSS/COD)

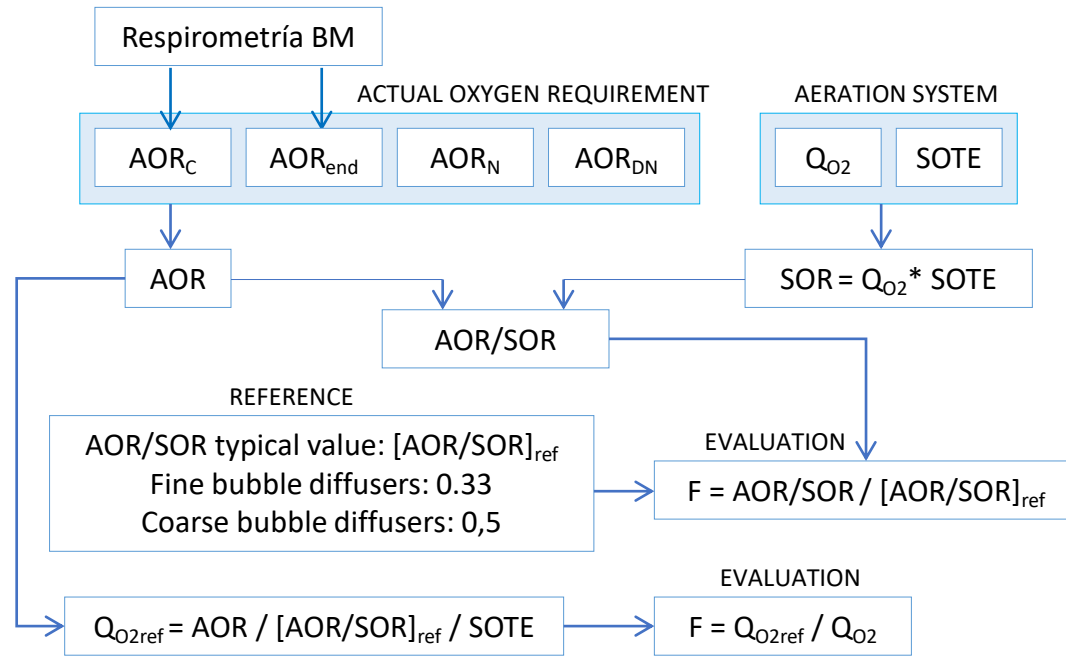
Q : Influent flow (m³/d)

$bCOD_e$: Biodegradable COD eliminated (mg bCOD/L) = bCOD influent – bCOD effluent \approx bCOD effluent \approx 1,6 * BOD effluent

Diffused aeration system follow-up

SURCIS

Essential parameters for evaluating a diffused aeration system



AOR	Actual oxygen requirement (kg O ₂ /d)
Q_{O2}	Oxygen flow rate supplied by the aeration system (kg O ₂ /d) = 6.84 * Q _{air} (Nm ³ /h)
SOTE	Standard oxygen transfer efficiency (%) - calculated from the curve provided by the manufacturer.
SOR	Standard oxygen requirement (kg O ₂ /d) for new diffusers
AOR/SOR	Relationship between AOR and SOR
[AOR/SOR]_{ref}	AOR/SOR reference & typical values for evaluation
F	Fouling factor

BM Respirometry is not limited



THERE IS ALWAYS THE POSSIBILITY OF DEVELOPING NEW APPLICATIONS