BM RESPIROMETRY APPLICATIONS GUIDE

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Chapters Index

This manual is made on the approach to get the necessary guidelines for the main respirometry tests and applications. It was not intended to describe closed and strict procedures; on the contrary, we have to take into account that BM respirometers are not closed systems and normally the user could carry out his own applications by making use of these guidelines and taking advantage of the wide field of possibilities that BM software is offering.

Measurements
&
Automatic tests

Automatic measurements and calculations

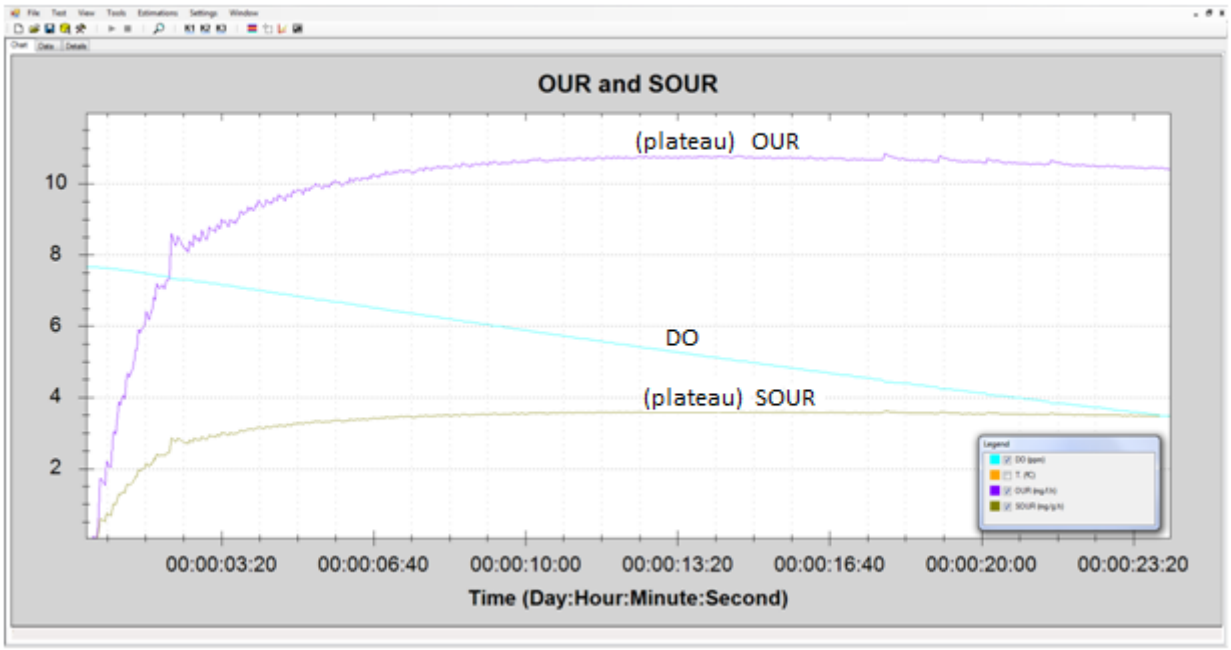
The main assays and measurements that with BM-Advance can be carried out on automatic form are the following:

OUR Static & Cyclic modes

OUR Oxygen uptake rate, in mixed liquor (mg O_2/L.h)
SOUR Specific OUR (mg O_2/g.h)

Normally the reference temperature for all these tests is 20ºC, and should be carried out within the same pH, temperature conditions and MLVSS concentration as the actual process.

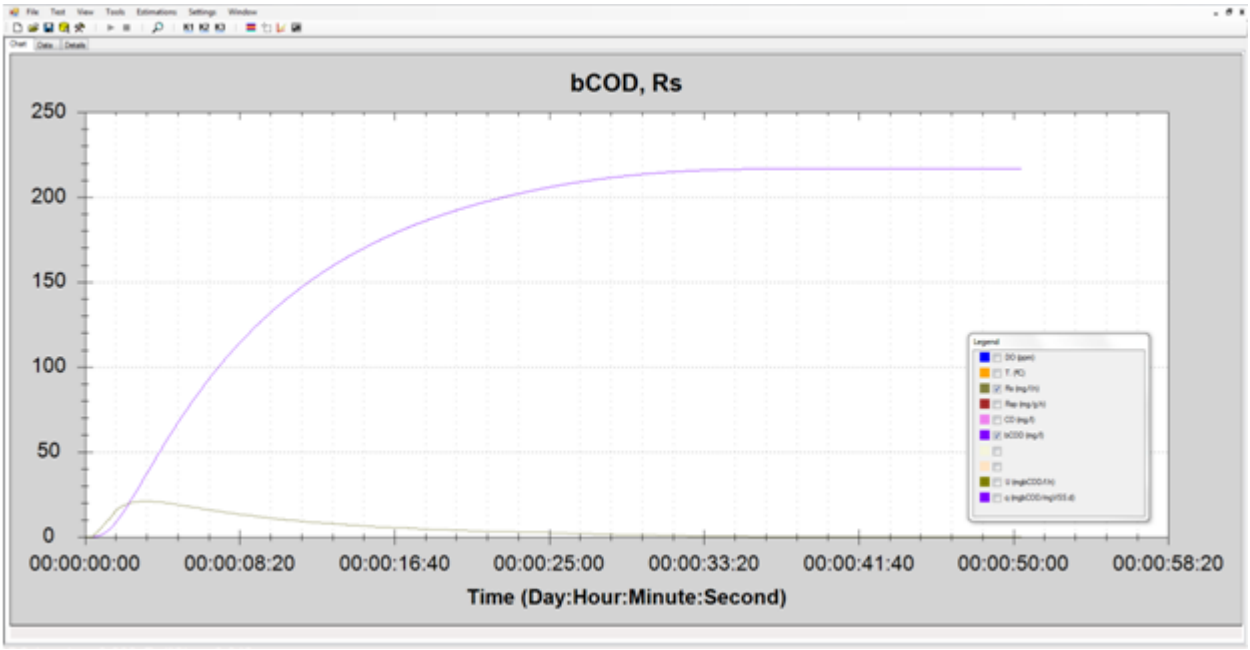
In a OUR test, it is assumed that the representative OUR & SOUR values correspond to their maximum values, which are normally reached within the plateau in the respirogram.



R mode – Dynamic

Normally R test must carry out with activated sludge of 2 – 5 g/l of MLVSS concentration; and in case that this concentration cannot be achieved we can make use of the returned activated sludge (RAS) by diluting it if necessary.

Rs Actual dynamic exogenous respiration rate (mg/l.h)
Rsp Specific Rs (mg O_2/g VSS.h)
CO Consumed oxygen in the wastewater (mg/l)
bCOD COD biodegradable fraction of the wastewater (mg/l)
U COD utilization rate (mg COD/h)
q Specific COD utilization rate (mg COD/mgVSS.d)



OUR & SOUR types

Depending on the sampling point we can distinguish several types of OUR & SOUR.

FED - UNFED OUR & SOUR

FED OUR & SOUR: OUR & SOUR from the starting process sampling point in the biological reactor of the plant.

In the BM-respirometers, we prepare the instrument by adjusting the aeration level to 80 and puma speed at 3 for high loading and 55 and 2 for normal and low loading.

For an extremely loaded process, we can also obtain the mixed liquor by making an equivalent mixture from influent wastewater to reactor + returned activated sludge (RAS).

Qi/Qr = V (influent) / V (RAS)
Mixed liquor = V (influent) + V (RAS)
Qi: Influent flow to reactor (m^3/h)
Qr: Recirculation sludge flow to reactor (m^3/h)

UNFED OUR & SOUR: OUR & SOUR from the process end sampling point (outlet of the reactor)

The mixed-liquor could also be obtained by a mixture of effluent wastewater + returned sludge within equivalent proportions to the actual mixed liquor.

Qe/Qr = V (effluent) / V (RAS)
Mixed liquor = V (effluent) / V (RAS)

Basic OUR

OUR_b & $SOUR_b$: OUR & SOUR from sludge that might content some rest of COD slowly biodegradable, but it could be maintained stable along relatively long time. This type of liquor could be qualified as sludge under Basic respiration.

Normally, in conventional ASP (Activated Sludge Process) with more than 85% of efficiency, the sludge from the process end can reach the basic respiration (sometimes also endogenous respiration) after > 4 hours of being uninterruptedly aerated.

In extended aeration systems, where the HRT is very high, the sludge from the process end used to be very near to endogenous and we can take it and directly use in a test.

Sludge under basic respiration could be utilized for a sludge source for R test as an alternative to endogenous sludge. Sometimes is even better, because the better nutrients ratio conservation.

Total endogenous respiration rate

OUR_{end}: Total OUR from sludge under endogenous respiration.

When an activated sludge remains under endogenous respiration, it has not any biodegradable COD (bCOD) or ammonium
The necessary time to reach the endogenous respiration can be very much variable (from a couple of hours until > 24 hours) and depends of the process type, actual loading rate state, physic-chemical conditions, biodegradable character of the material under treatment.

To check if the sludge is already under endogenous respiration, place it in the reactor vessel of the respirometer, set to ON stirrer, aeration (55) and pump. Then, check for a stable DO reading. If DO is still going up is because it is not yet under endogenous and will need more time to be aerated.

Once we get the sludge under endogenous state, we can perform a normal OUR test to get the OURend.

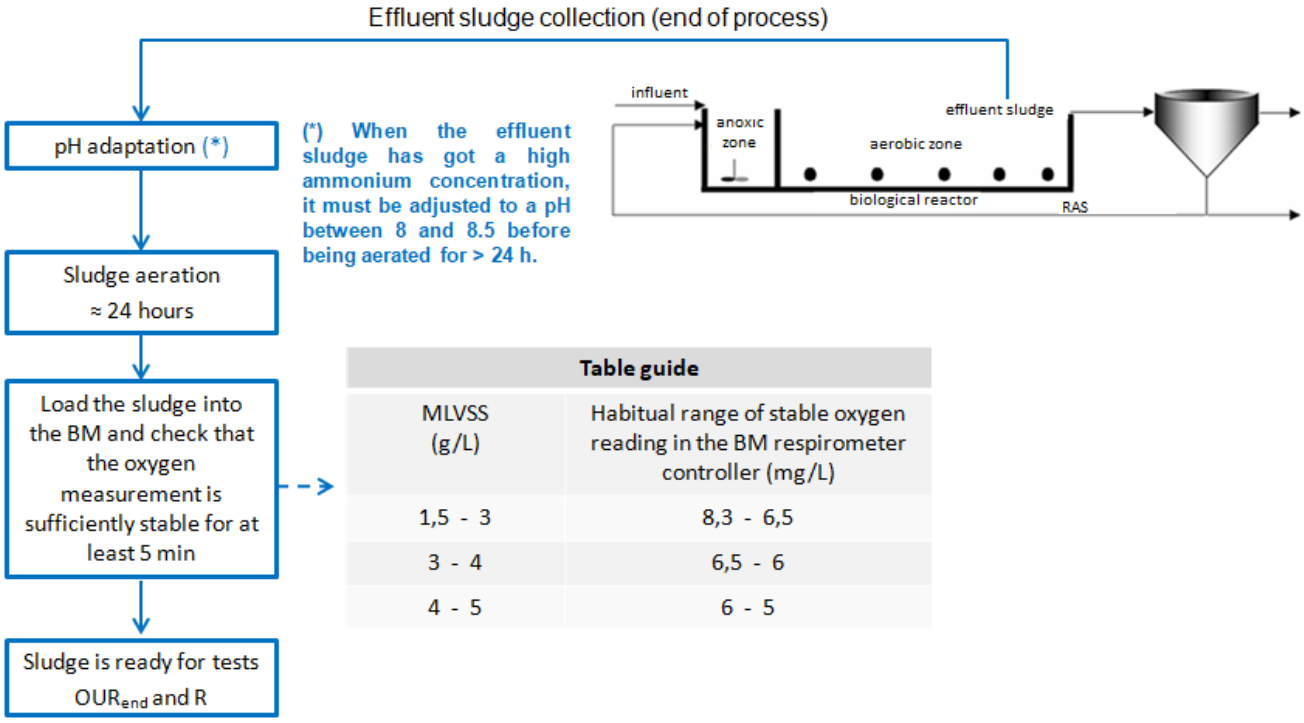


Table guide	
MLVSS (g/L)	Habitual range of stable oxygen reading in the BM respirometer controller (mg/L)
1,5 - 3	8,3 - 6,5
3 - 4	6,5 - 6
4 - 5	6 - 5

Endogenous respiration rate of the heterotrophic biomass

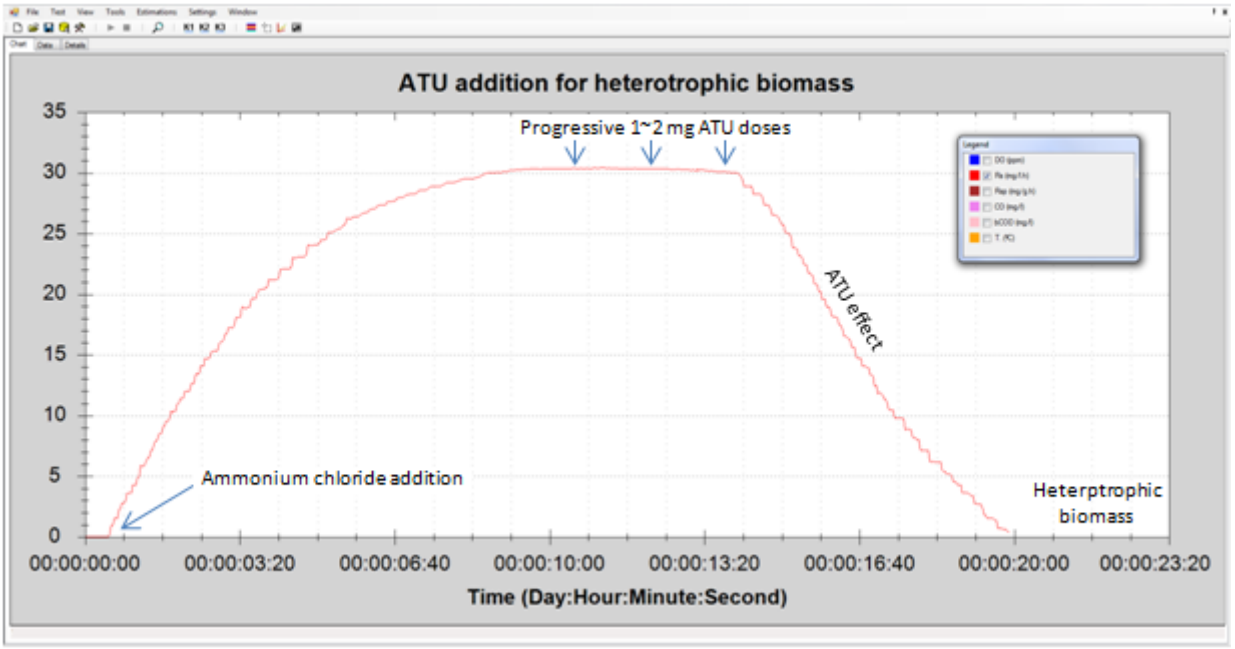
$OUR_{end.H}$: OUR of the sludge for the heterotrophic biomass

In a process with nitrification

In case there are active heterotrophic and autotrophic bacteria, the first thing to do is to eliminate the autotrophic in order to get a type of sludge where there are only heterotrophic microorganisms.

On that purpose, we will follow this procedure:

1. Get 1 litre of endogenous sludge for a R test.
2. Prepare a solution of 100 mg of ATU (Allyl Thiourea) in 100 ml of distilled water. In this way for 1 ml of solution would correspond 1 mg AEU.
3. Prepare an amount of ammonium chloride on 60 mg per g of MLVSS basis.
4. Prepare the dose of the ammonium chloride amount diluted in a small volume of distilled water (5~10 ml)
5. Program the R test, taking into account the temperature and pH, but not taking into account the Vf, Vm and Solids settings (you can leave the default values)
6. In the respirometer, be sure about the DO stability of the endogenous sludge.
7. Start the R test and, when "insert sample in the reactor" displays, add the ammonium chloride dose to the reactor.
8. Observe the respirogram and wait until it reaches a plateau of maximum Rs measurements.
9. As the plateau is formed, start adding the solution of ATU by doses of 1 ml every 20 seconds (approx.) until the Rs value in the plateau starts to decrease clearly. – The amount of ml you have added will give you the amount of mg of ATU necessary to inhibit the nitrifiers activity -
10. Wait until Rs value fall completely until reaching the base-line (horizontal axis)
11. Stop the test.



Now we have an endogenous sludge without nitrifiers and you can carry out an OUR test with this sludge that you get in the reactor.

NOTE1: Once you know the amount of ATU needed for a specific sludge, it would be not necessary to repeat the R test with ammonium chloride.

NOTE2: In the R test with ammonium chloride, the maximum value of Rs (in the plateau) would correspond to the representative respiration rate due to nitrification on the conditions in which the test was done. With this Rs value, we can calculate the corresponding nitrification rate (AUR)

NOTE3: It could be possible that we were not sure if the activated sludge has or not active nitrifier biomass. In this case this R test with ammonium chloride we will confirm if there is nitrification or not. So that, the absence of very poor Rs generation when we were adding the ammonium chloride would indicate the absence of nitrifier biomass and it would be not necessary to add any ATU dose to get the heterotrophic biomass.

In a process without nitrification

In this case the total OUR_{end} will coincide with the $OUR_{end.H}$

$OUR_{end.H} = OUR_{end}$

Endogenous respiration rate of the autotrophic biomass

The endogenous respiration rate for nitrifiers can be obtained by the difference between the total OUR_{end} and the $OUR_{end.H}$

$OUR_{end.A} = OUR_{end} - OUR_{end.H}$

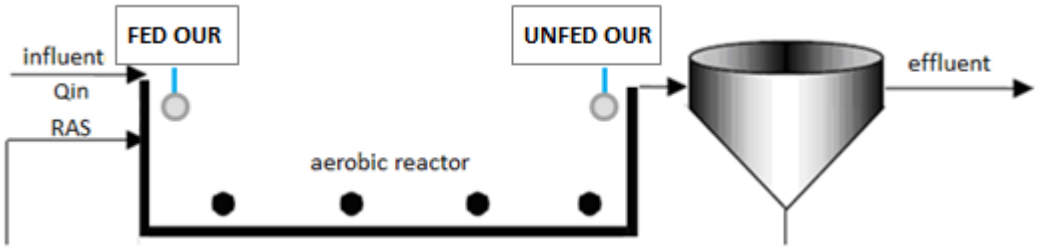
Applications

1.
Pulse to the process

Early evaluation of the treatment process

Taking the pulse by means the Loading Factor (LF)

The one-day pulse of the process can be taken by means the assessment of the ratio of two OUR tests corresponding to the influent sludge (FED OUR) and effluent sludge (UNFED OUR)



Loading Factor: **LF = FED OUR / UNFED OUR)**

LF	Assessment
LF < 1	Inhibition / Toxicity already present in reactor
1 < LF < 2	Low efficiency or low BOD loading
2 < LF < 5	Good process performance
LF < 5	Overloading

Taking the pulse by means the UNFED SOUR

This is a representative SOUR test of the effluent activated sludge in the biological reactor.

Throughout this test we can obtain a fast qualitative assessment of how the process is performing and sludge health.

In a plug-flow process, the sludge can be directly collected from the end of the reactor within a representative loading period.

Reference guide-table

Process type	F/M (BOD/SS.d)	SRT (d)	UNFED SOUR ref ($mgO_2/gVSS.h$)
High loading	> 0.4	4	10 - 15
Medium loading	0.2 – 0.4	4 - 10	7 - 10
Low loading	0.07 – 0.2	10 - 30	3 - 7
Very low loading (extended aeration)	< 0.7		

⟺

Actual UNFED SOUR Vs. UNFED SOUR ref. (Table)	Assessment
>> ref	Overloading
= or +/- ref	Good performance
< ref	Low loading
<< ref	Very low loading or Toxicity symptoms

To assess the results, we compare the UNFED SOUR from the test with the UNFED SOUR ref. in the guide-table.

The values of the guide-table should not be understood on the criterion that the result can vary within the showed range, but on the way that a determined process has its specific range which normally would be included within the range in the guide-table.

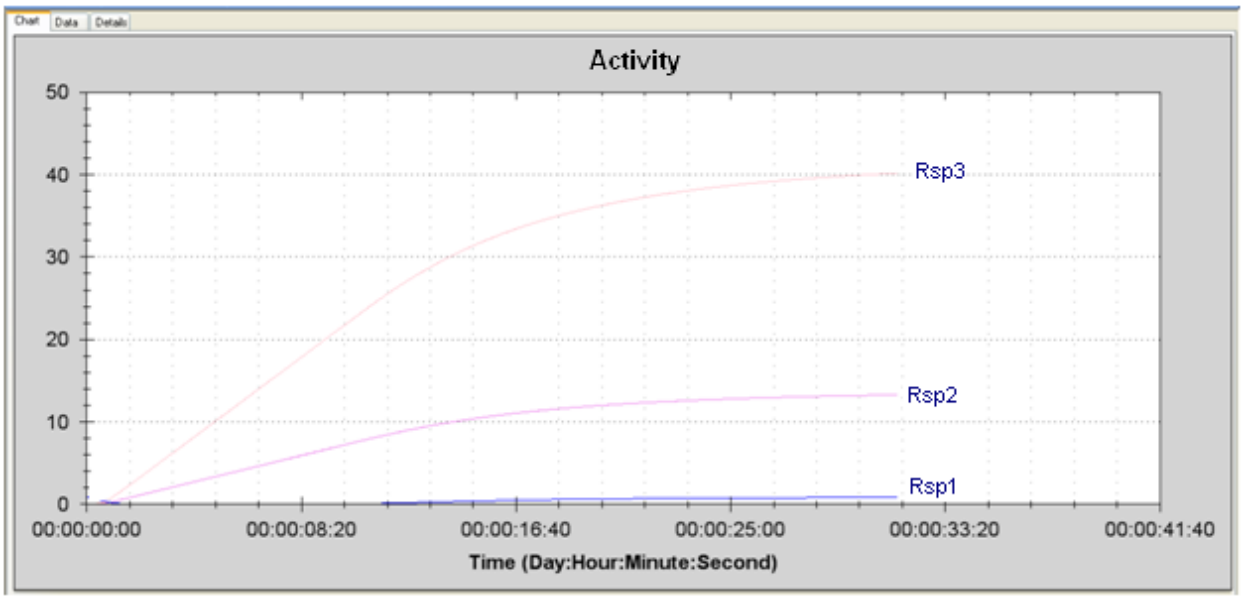
Rsp as bioactivity indicator (R mode test)

Rsp for a fixed time is proportional to the maximum COD removal rate.

For bioactivity indicator we make use of a standard sample: 200 mg sodium acetate as organic standard, and 500 mg of Ammonium Chloride in 1 litre of distilled water.

R-tests can be run periodically by utilizing the same standard, volume and temperature.

In the respirograms, in Legend we only select to see Rsp
Diagnostic must come up on the base that, under same conditions, the increasing trend of Rsp will indicate a bioactivity growing and, on the opposite way, a decreasing Rsp will indicate bioactivity loos.



2.
Stoichiometric coefficients of the heterotrophic biomass

Yield coefficient of heterotrophic biomass referred to oxygen demand

$Y_{H,COD}$: Yield coefficient of heterotrophic biomass (mg CO{bact.}/mg COD{soluble.})

Note: Y value corresponds to Y that is showed in the assay Configuration as 0,67. In case that we determine a different value, it should be modified in each R assay.

The $Y_{H,COD}$ value is specific for each ASP (activated sludge process)

$Y_{H,O2}$ is determined from an R assay where the activated sludge should prepared in optimal conditions:

- Free of big / hard solids in activated sludge. For that is convenient to filter the sludge by means a narrow bandwidth cook strainer.
- Activated sludge in basic or endogenous phase.
- The process should be without any symptom of inhibition or toxicity.

Most effective method for YH determination is by a R test with sodium acetate as standard sample.

In any case, there are some observations we have to take into account:

$Y_{H,COD}$ determination from sodium acetate

$Y_{H,COD}$ determination from acetate is more approached to rbCOD, and we can go to this method in case we have to test the soluble readily biodegradable COD of different samples and in case we do not have current COD data from the ASP.

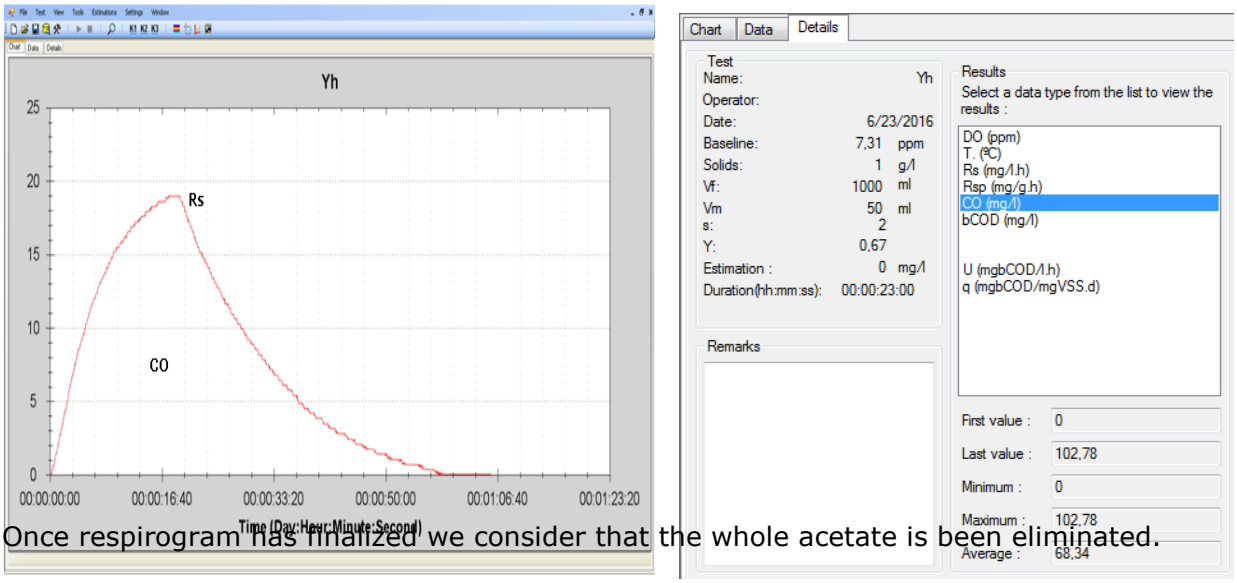
First thing is to make a solution of 400 mg of sodium acetate in 1 litre of distilled water. For this solution, we must obtain (from the lab.) the actual COD value (COD_{ac} ≈ 300 mg/l

The sample volume should be in between 30 and 50 ml and peristaltic pump flow at 2.

We carry out an R assay in order to determine CO.

CO: Consumed oxygen = Δ O_2 (mg/l)

We can make use of sample volume in between 50 and 100 ml. and pump speed to 2



Once respirogram has finalized we consider that the whole acetate is been eliminated.

$Y_{H,COD} = 1 - CO / COD_{ac}$

$Y_{H,COD}$: Heterotrophic yield coefficient (mg O_2/mg COD)

Yield coefficient of heterotrophic biomass referred to the biomass concentration

$\mathbf{Y_{H,VSS}} = Y_{H,COD} / f_{cv}$

$Y_{H,VSS}$: Heterotrophic yield coefficient referred to the biomass concentration (mg VSS / mg CODs)
f_{cv} = DQOrb {bact.} / VSS = 1.42 (mg DQO/mg VSS) - (normal value commonly accepted)

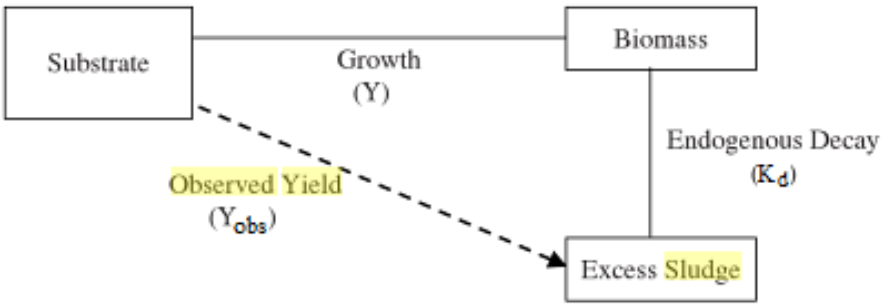
Source: The Activated Sludge Resource Book - K.C. Landrea - La Trobe University, Bendigo (Australia)

Typical values

Coefficient	Unit	Range	Typical	Remark
$\mathbf{Y_H}$	g MLSS/g COD	0.4-0.6	0.5	Convertible each other assuming COD/BOD=2 and MLVSS/MLSS=0.8 for municipal wastewater
	g MLVSS/g COD	0.3-0.5	0.4	
	g MLSS/g BOD	0.8-1.2	1.0	
	g MLVSS/g BOD	0.6-1.0	0.8	

Observed yield coefficient

Observed yield (Y_{obs}) is the observed amount of total biomass generated per unit amount of substrate utilized. As opposed to the true growth yield (Y), this coefficient is not a constant and it is inversely proportional with the sludge age (SRT). The main application of the observed yield is the calculation of the excess sludge production.



$\mathbf{Y_{obs}} = Y / (1 + K_d * SRT)$

Y_{obs}: Observed Yield (MLVSS/DQO)
$Y \approx Y_{H.VSS}$ (0.42 VSS/COD – Typical value)
K_d (d^{-1}): Biomass fraction per day, oxidized during endogenous respiration ($K_d \approx 0.06$ – Typical value)
SRT (d^{-1}): Sludge residence time (Sludge age)

Typical values

SRT	Y_{obs}		MLVSS/ MLSS	F/M
days	g VSS/ g COD	g MLSS/ g COD		g COD/ g VSS/d
2	0.477	0.558	0.855	1.048
5	0.384	0.461	0.833	0.521
10	0.329	0.396	0.831	0.304
20	0.298	0.358	0.832	0.168
30	0.268	0.328	0.817	0.124

Source: Cicek, 2001; Macomber, 2005

3.
Sludge production

Procedure for the calculation of sludge production

1) 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.

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

2) 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.

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

P_X: Sludge production (kg SSV/d)

This parameter represents the net growth of biomass expressed in suspended volatile suspended solids.

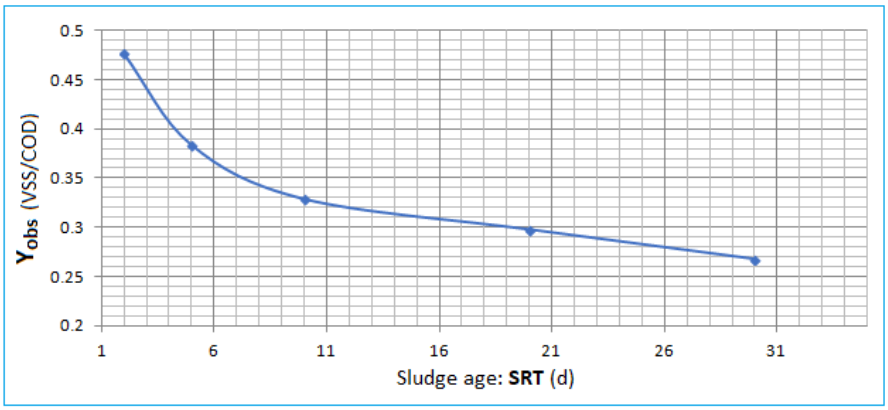
$$\mathbf{P_X} = Y_{obs} * Q * bCOD_e / 1000$$

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 à bCOD effluent ≈ 1,6 * BOD effluent

Estimated calculation of the sludge production

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



4.
Kinetic parameters for heterotrophic biomass

Total active biomass concentration calculated from endogenous respiration

X = 24 * OUR_{end} / (f_{cv} * b)

X: Total Active biomass concentration (mg/l)
OUR_{end}: Endogenous respiration (mg/l.h) - (see page 6)
f_{CV}: Oxygen uptake per unit of biomass = 1.42 (O_2/X_V)
b: Decay rate of biomass in endogenous respiration (estimated value) = 0,3

Source: Respirometry for Environmental Science and Engineering – James G. Young & Robert M. Cowan. 200

Active biomass concentration assessment

The active biomass concentration, determined from the respirometric tests, presents a variable percentage in the range of 14–35 %) of the total amount of MLVSS in the activated sludge sample.

If the OUR_{end} result is significantly lower than the habitual range, the most probable is that there is a low active biomass concentration, and the probable causes could be the following ones:

1. The process is operating on too much low F/M (the biomass is in lack of food)
2. One or more process conditions (T, DO, pH) are out of range.
3. Nutrients deficit.
4. Under toxicity or the process has got a recent toxicity

Total biomass fraction per day oxidized during endogenous respiration

$SOUR_{end}$ (mg O_2/g VSS.h) x 24/1000 = $SOUR_{end}$ (Kg O_2/ Kg VSS.d)

K_d = 0.024 * $SOUR_{end}$ / f_{vc}

K_d: biomass fraction per day oxidized in endogenous respiration (d^{-1})
f_{CV}: Oxygen uptake per unit of biomass = 1.42 (O_2/X_V)

Source: "Tratamiento de Aguas Residuales" R.S. Romalho 1991

For K_d estimation or assessment, we can make use of the following table guide:

F/M	0,03	0,05	0,1	0,15	0,20	0,25	0,30	0,40	0,50	0,60	0,70	0,80	1,00
Kd	0,024	0,041	0,067	0,080	0,092	0,1	0,109	0,118	0,123	0,128	1,131	0,133	0,136

Source: Curso de Tratamiento Biológico Aguas Residuales (CSIC) – Dr. Fco. Colmenarejo Morcillo

Decay rate of the heterotrophic biomass referred to endogenous respiration

Estimated formula

b_H = 0,24. $1.04^{(t-20)}$ (d^{-1})

t: Temperature in process (ºC)

THIS FORMULA CAN ONLY BE APPLIED WHEN THE OURend IS MAINTAINED WITHIN NORMAL RANGE VALUES

Ekema method

$\mathbf{b_H} = K_d / [1 - Y_{H,COD} (1 - fp)]$

b_H : Decay rate of heterotrophic biomass (d^{-1})
fp: Particulate biomass fraction = 0,08

Source: Ekama et al. (1986)

Active heterotrophic biomass concentration

Active heterotrophic biomass concentration from $OURe_{nd.H}$

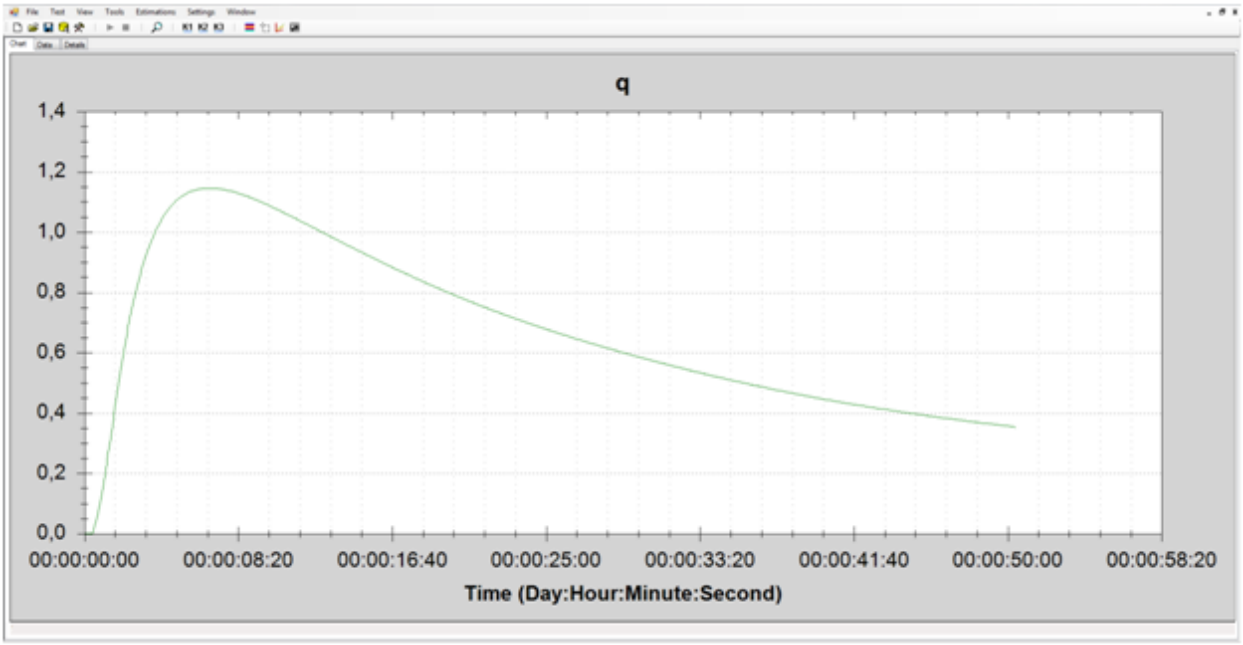
$\mathbf{X_H} = 24 * OUR_{end.H} / (f_{cv} * b_H)$

X_H: Active heterotrophic biomass (mg/l)
OUR_{end}: Endogenous respiration (mg/l.h) - (see page 6)
f_{CV}: Oxygen uptake per unit of biomass = 1.42 (O_2/X_v)

The active heterotrophic biomass concentration, determined from the respirometric tests, presents a variable percentage in the range of 30%–37% of the total amount of MLVSS in the activated sludge sample.

Soluble substrate utilization rate and specific utilization rate

We are making use of soluble sample to determine the velocity at which the readily biodegradable COD is being removed.



Then, the BM software will automatically calculate the parameters U, and q throughout the test performance.

Normally are the the maxium q (q') and U (U') the parameters to take into account.

U = U' * [DO / (K_{DO} + DO)]

q = q' * [DO / (K_{DO} + DO)] (COD/VSS.d)

U': Maximum value of the substrate utilization rate (mg CODs/h) in the test
Q': Maximum value of the specific substrate utilization rate (mg CODs/mg VSS.d) in the test
DO = Actual DO average in the process (mg/l)
K_{DO} = 0.2 (mg/l) - (commonly accepted value)

Fast method to determine the maximum specific COD uptake rate and half-saturation coeficient

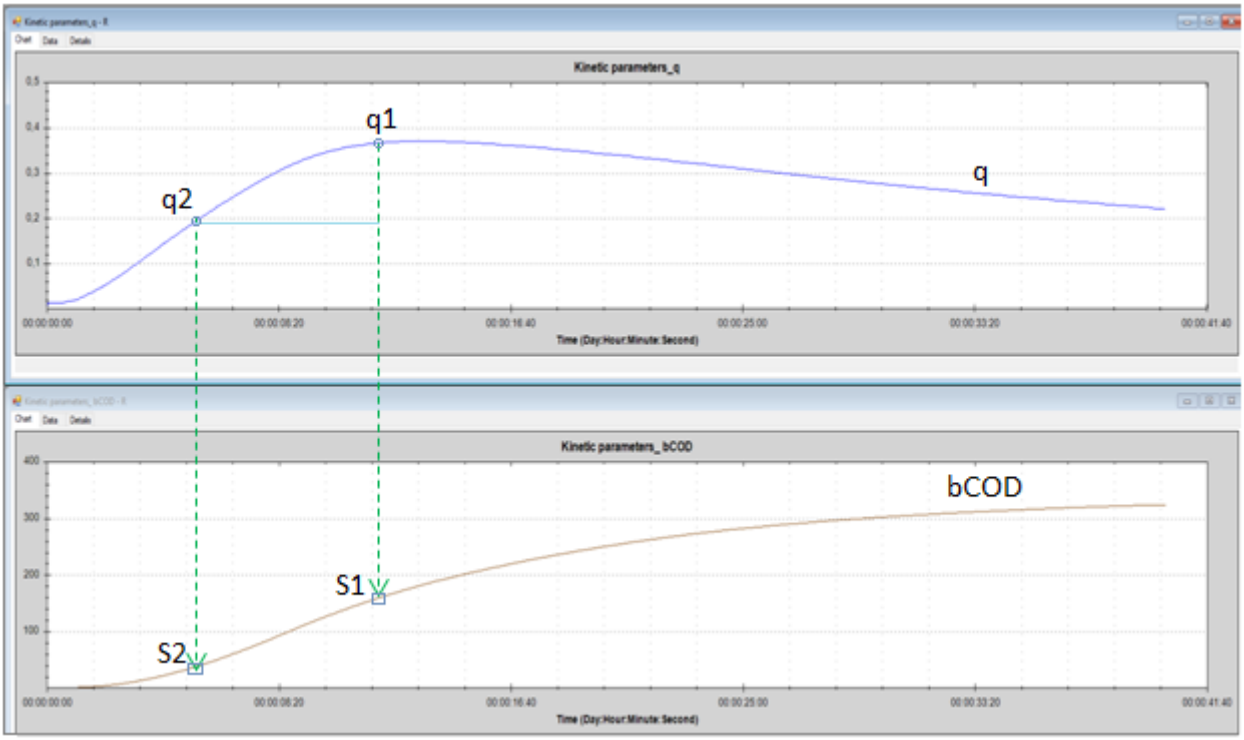
By making use of soluble wastewater sample or a solution of sodium acetate (*), we carry out one R test for bCOD.

(*): For design purposes, we can make use of a soluble standard compound (sodium acetate)

With the q respirogram of the test, we make use of the PC mouse.

With the mouse we click on the q respirogram line over the highest q value (q1) and in the low tool-bar we will see the corresponding bCOD removed (S1).

Within the linear ramp-up section of the graph, we select now a value equal to half of q1 as q2 (q2 = q1 / 2) and, with the mouse, also calculate the corresponding bCOD removed (S2)



The principle of the Ks calculation is based on the Michaelis-Menten equation:

q_{max} = q (K_S + S) / S

Therefore:

q_{max} = q1 (K_S + S1) / S1 = q2 (K_S + S2) / S2

$q2 = q1/2 \rightarrow q1/q2 = 2$

$2 (K_S + S1) / S1 = (Ks + S2) / S2$

Matching the above equations and reducing, we obtain the following equation:

Ks = 1 / (1/S2 – 2/S1)

K_S: Half-saturation coeficient (mg/L)

Maximum specific substrate utilization rate

$\mathbf{q_{max}} = q (S + Ks) / S$

q_{max}: Maximum specific substrate utilization rate (mg CODs/mg VSS.d)

Growing rate of the heterotrophic biomass

Maximum net growing rate

$\mathbf{\mu_{H.max}} = Y_{H.VSS} * q_{max}$

$\mu_{H.max}$: Maximum growing rate of the heterotrophic biomass (d^{-1})
$Y_{H.VSS}$: Heterotrophic yield coefficient (VSS/CODs)

Net growing rate for a determined S (COD)

$\mathbf{\mu_H} = \mu_{H.max} \ S / (Ks + S)$

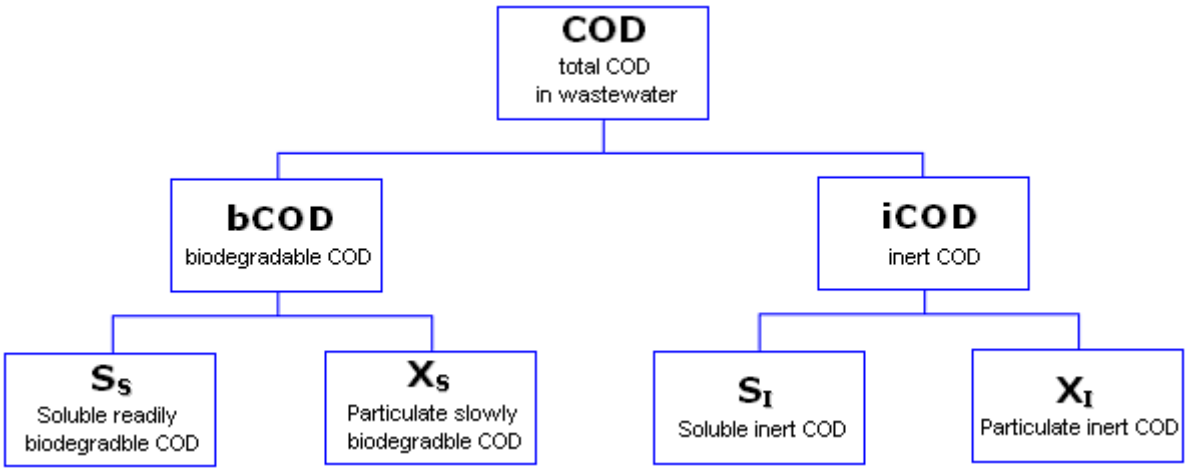
μ_{Hx}: Growing rate of the heterotrophic biomass (d^{-1})

5.
COD fractions

Main COD fractions

We can determine and estimate some fractions through the R mode. For that, we are making use of the Allil Thiourea for nitrification inhibition)

For COD fractioning we are making use of R mode assays. Here the BM analyser is carrying out the continuous Rs integration corresponding to the substrate oxidation in order to calculate the corresponding CO (mg/l) on timely basis.



For the assays related with COD fractioning we refer to the fractions that a determined activated sludge process is able to degrade.

Total biodegradable COD (bCOD) from R mode

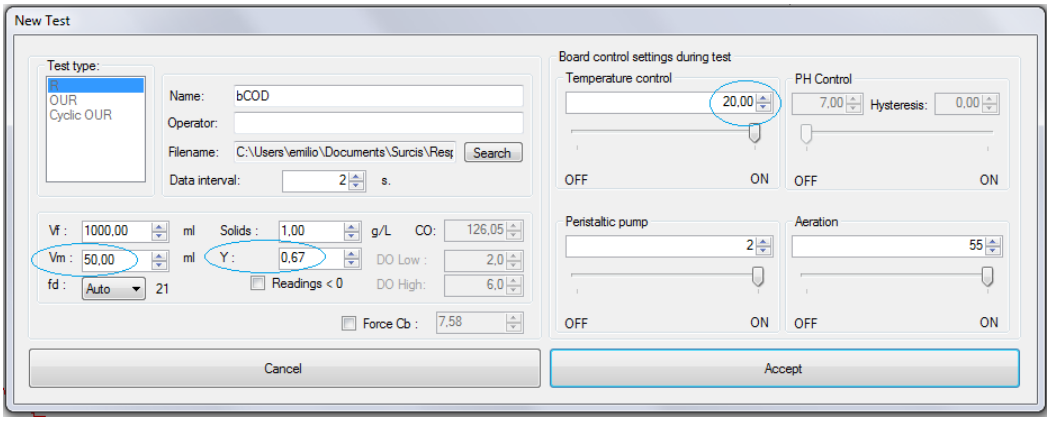
We can determine the total biodegradable COD (bCOD) by means one R test with influent wastewater to the biological reactor and endogenous sludge.

Only in case the process has nitrification, you must add a dose o Allyl Thiourea (ATU) to the endogenous sludge (stirring and aerating it) ½ hour before the test (2 to 3 mg ATU / g VSS)

If you do not use the Y default value (0.67), set the actual value of $Y_{H.COD}$ in the settings board of the bCOD test in the box for Y value.

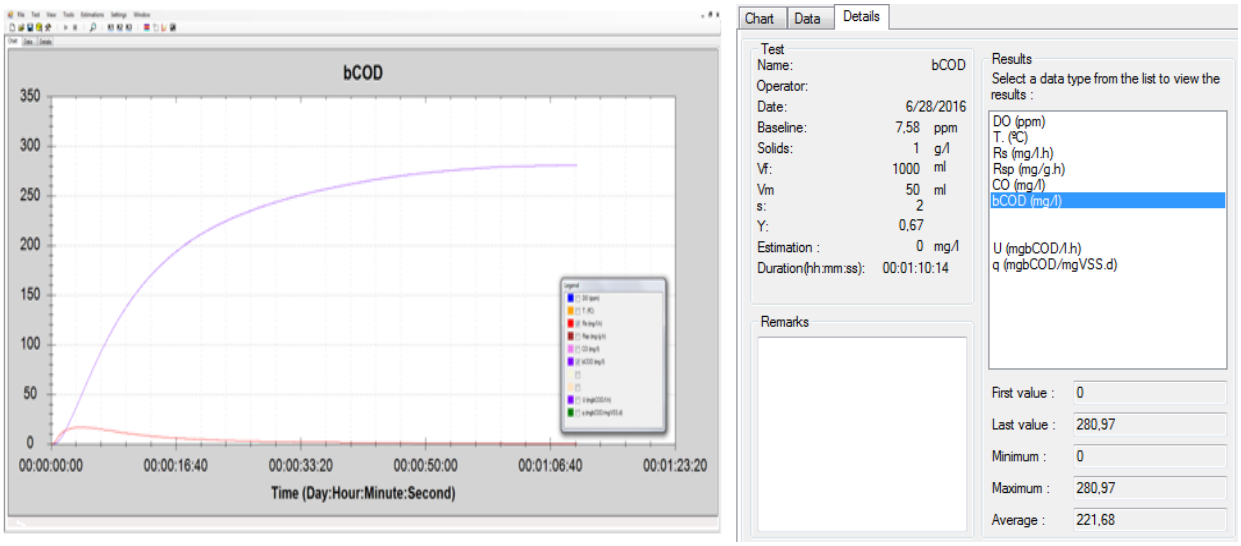
Normally we will place the peristaltic pump at 2 and the default value of aeration (55)
For the volume of sample, we should follow more or less the following guide table:

Total COD (mg/l)	Sample volume (ml)
< 500	50
500 – 5000	50 - 30
5000 - 10000	30 - 20
10000 – 25000	20 - 10
> 25000	10



IMPORTANT
R test must carry out with activated sludge of 2 – 5 g/l of MLVSS concentration. In case that this concentration cannot be achieved, we can make use of the returned activated sludge (RAS) by diluting it to get a concentration in between 2 – 5 g/l (if necessary)

BM-respirometer software will automatically calculate the on-going bCOD value by making use of the Y and the accumulated consumed oxygen (CO) It means that at any moment during the test performance we can see the bCOD that is being utilized.



Readily biodegradable COD determined by respirometry

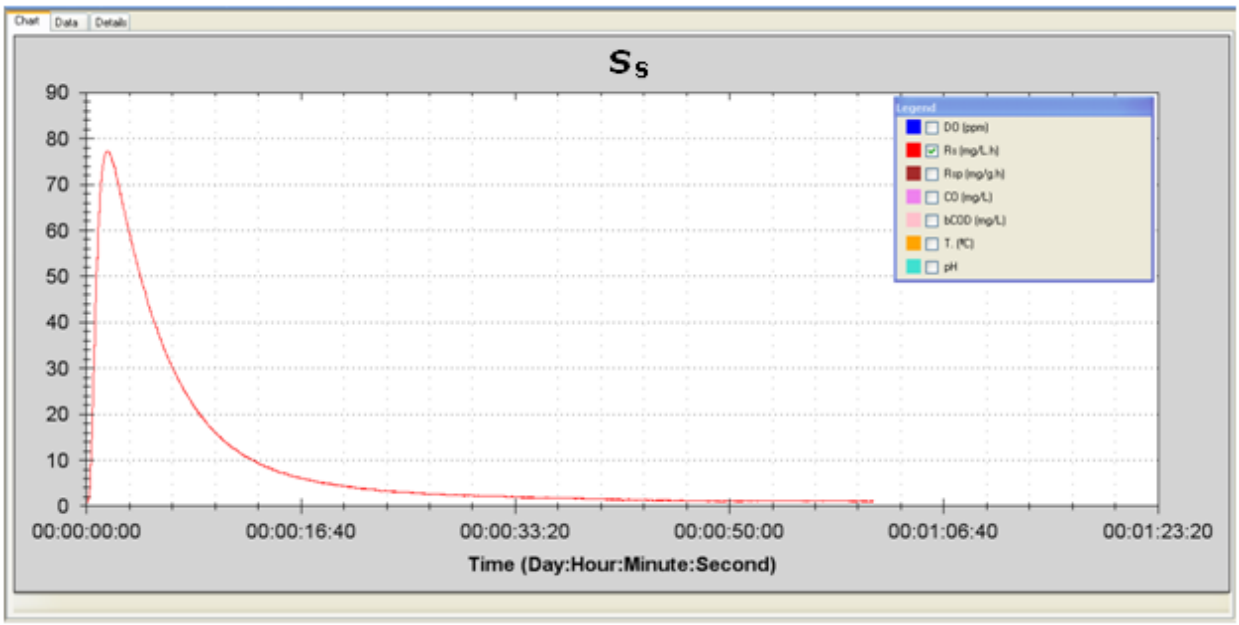
The readily biodegradable COD fraction is obtained from a truly soluble wastewater sample. Normally we can get this sample by making use of a coagulant compound (e.g. zinc sulphate: $ZnSO_4$) and then filtering the supernatant at 0.45 micron.

For test settings, we follow the same criteria as those used in the R test for bCOD (page 21)

$\mathbf{S_S} = CO / (1-Y_{H,O2})$

SS = rbCOD: Readily biodegradable COD (mg/l)
CO: Consumed oxygen in the current test (mg/L)

Note: In the following chapters, the soluble readily biodegradable COD can also be named **rbCOD**



Particulate slowly biodegradable COD

X_S = bCOD - S_S

X_S = sbCOD: Particulate slowly biodegradable COD (mg/l)

sbCOD is normally associated to particulate biodegradable COD. It corresponds to the slowly hydrolysable organic matter by the heterotrophic biomass.

Soluble inert COD

S_I = iCOD * Ss / bCOD

S_I: Soluble inert COD (mg/l)
COD_S : Soluble COD

Inert COD

X_I = iCOD - S_I

X_I: Particulate inert COD

Biodegradability for a specific activated sludge process

This biodegradability as seen from the activated sludge respirometry view, under equivalent conditions to the actual ASP, should be considered not only from the biodegradable character of the wastewater sample to be analyzed but also from the sludge activity health and sample adaptation to the biomass. For that reason, this type of biodegradability should be specific for the activated sludge responsible of the organic matter oxidation of the influent wastewater.

Here we compare the biodegradable fractions with the total COD.

bCOD / COD	Character
> 0.8	Very biodegradable
0.7 ~ 0.8	Biodegradable
0.3 ~ 0.7	Very little biodegradable
< 0.3	Unbiodegradable

Biodegradability (%) = 100 * bCOD/COD

6.
Operational parameters for organics removal

Operation parameters guide table

PROCESS	F/M	SRT	Volumetric load	MLSS	HRT	BOD perf.	r Qr/Q
	(kg DBO^5/kg MLSS * d)	(días)	(kg DBO^5/ m^3 * d)	(mg/l)	(horas)	(%)	(%)
PLUG FLOW	0,2 - 0,4	5 - 15	0,3 - 0,6	1500 - 3000	4 - 8	85-95	25-50
COMPLETE MIXING	0,2 - 0,6	5 - 15	0,8 - 2,0	3000 - 5000	3 -5	85-96	25-100
STEPPED FED.	0,2 - 0,4	5 - 15	0,6 - 1,0	2000 - 3500	3 - 5	85-97	25-75
EXT. AERATION	0,05 - 0,1	20 - 30	0,1 - 0,4	3000 - 6000	18 - 36	85-98	75-150
OXIDATION DITCH	0,05 - 0,1	20 - 30	0,1 - 0,4	3000 - 5000	19 - 36	85-99	75-150
CONTACT	0,2 - 0,6	5 - 15	1,0 - 1,2	Contacto:1000-3000	Contacto:0,5 - 1,0	80-90	25-100
STABILIZATION				Estabiliza:4000-8000	Estabiliza: 3,0 - 6,0		
DOUBLE STAGE	1ª etapa: 2,0 - 6,0	-	-	-	0,5 - 1,0	90-95	-
	2ª etapa: 0,2 - 0,4	-	-	-	3,0 - 7,0		-
(*) Con Nitrificación	0,05 - 0,2	-	-	-	2ª etapa: 10 - 30		-
PURE OXYGEN		8 - 20	1,6 - 3,3	3000 - 5000	1,0 - 3,0	85-95	25-50

Minimum sludge retention time for organic substrate removal in a process without nitrification

$\mathbf{SRT_{min}} = 1 / (Y_{H,VSS} * q_{H.max} - K_d)$

SRT: Minimum sludge retention time (d)
K_d can be neglected when $q_{H.max}$ value is below 0.1

SRT could be considered as MCRT (Mean cell retention time)

The actual SRT in the process should be > SRT_{min}

IMPORTANT:
In case of a process with nitrification, the SRT should always be determined in base of the nitrification rate (see chapter 9)

Specific loading rate

Actual specific BOD loading rate

$\mathbf{F/M}_{(BOD)} = BOD / (MLSS * HRT)$

$F/M_{(BOD)}$: Loading rate related to BOD (kg BOD/kg MLSS. d)
HRT: Hydraulic Residence Time (d) in the aeration tank

Actual specific rbCOD loading rate

To assess the loading to the biological reactor, it is very useful the value of F/M (rbCOD)

$\mathbf{F/M}_{(rbCOD)} = rbCOD / (MLSS * HRT)$

$F/M_{(rbCOD)}$: Loading rate related to rbCOD (kg rbCOD/kg MLSS. d)

Normally the F/M (rbCOD) is usually in the range of 60-70 % of the F/M (BOD)
Just in case the F/M (rbCOD) is >> 70% of the F/M (BOD) or << 60%, the process could run into problems (although the F/M (BOD) remains within its normal range)

Maximum specific loading rate for control and design purposes

$F/M_{max\ (BOD)}$ = $q_{H.max}$ * (BOD/rbCOD) * (MLVSS/MLSS)

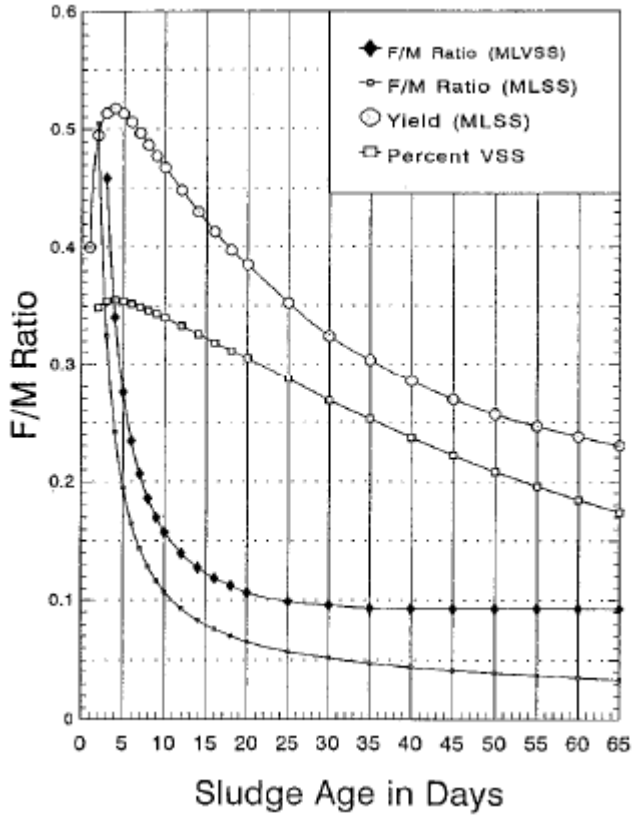
F/M_{max}: Maximum loading rate (BOD/MLSS.d)

Hydraulic retention time

HRT = 24 * BOD / (MLSS * $F/M_{max\ (BOD)}$)

HRT: Hydraulic retention time (h)

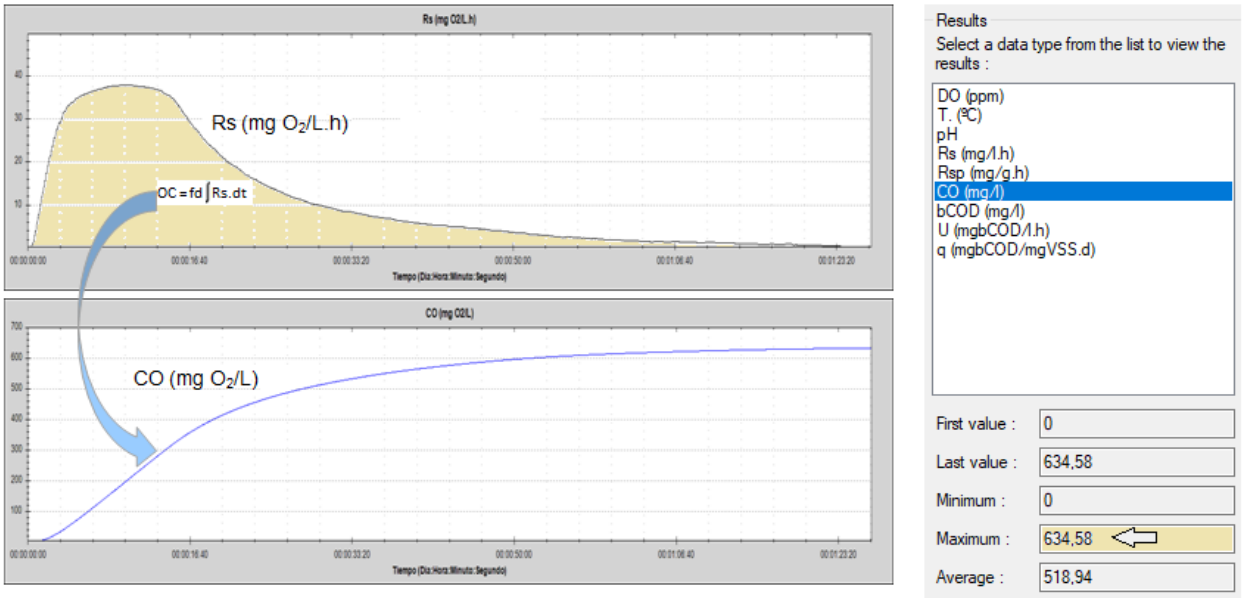
Graphics guide - reference



7.
Aeration - Oxygen needs

Actual Oxygen Requirement (AOR) calculation in a process with nitrification-denitrification

Requirement for the carbonaceous organic matter (kg O_2/d): **AOR_C** = Q * CO / 1000



R test for bCOD

Requirement for endogenus respiration (kg O_2/d): **AOR_{end}** = 24 * V * OUR_{end} / 1000

Requirement for nitrification (kg O_2/d): **AOR_N** = 4.57 * Q * N_n / 1000

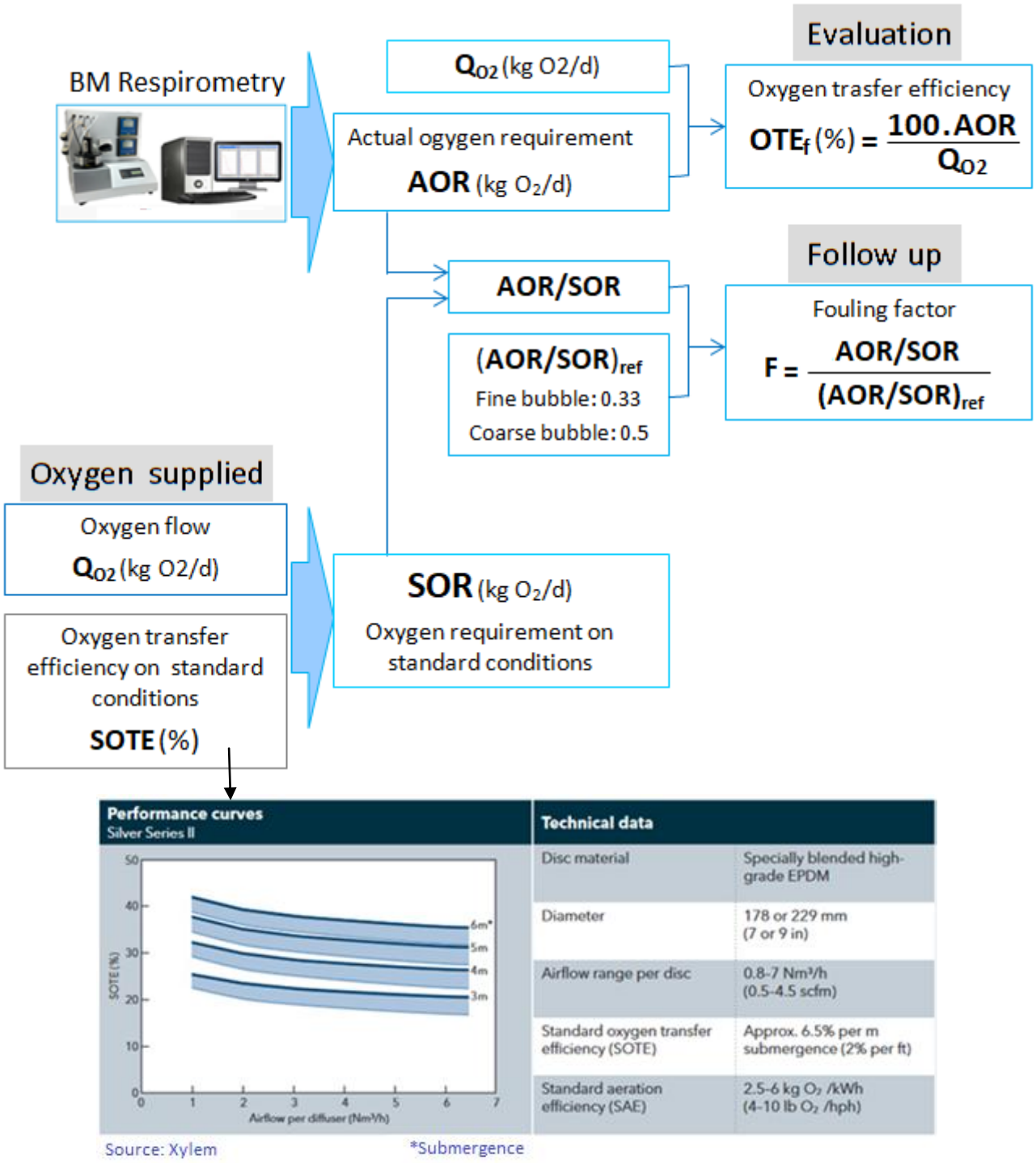
Requirement for denitrification (kg O_2/d): **AOR_{DN}** (kg O_2/d) = 2.28 * Q * N-NO_3 / 1000

Q: Influent flow (m^3/d)
CO: Consumed oxygen for the eliminated organic matter (m^3/d) - from R test for bCOD -
V: Aerobic reactor (m^3)
OUR_{end}: Oxygen uptake rate of the sludge under endogenous phase (mg O_2(L.h)
N_n: Ninitrogen for nitrification (mg N/L) ≈ NTK eliminated (mg N/L)
N-NO_3: Nitrate for denitrification (mg N-NO_3/L) ≈ N_N – N-NO_3 efluent

The oxygen requirement by denitrification (AOR_{DN}), performed under anoxic conditions, is presented as a credit against the total oxygen requirement.

AOR = AOR_C + AOR_{end} + AOR_N - AOR_N

Practical procedure to evaluate a diffused aeration system



When there is a progressive reduction of the OTE_f and the F is below 0.7 the diffuser aeration system needs maintenance for membrane cleaning or diffusers replacement (ijust n case they are more than 4 years old)

8.
Toxicity

Toxicity in activated sludge

The only one toxicity of our interest is the one that could damage or activated sludge process, and never any other one where the activated sludge is not present. For that reason, this toxicity can be only assessed from the own activated sludge of one specific process.

From this evidence we can approach the toxicity in two main ways:

- Possible toxicity already in the activated sludge process (aeration tank)
- Possible toxic reaction of a waste water or compound with the activated sludge; but toxicity is not in the activated sludge process (aeration tank)

Symptoms for inhibition or toxicity that is already in the activated sludge process

Besides the external physic symptoms, by respirometry we can guess that the ASP could be under inhibition or toxicity state when we detect the following:

FED OUR / UNFED OUR < 1,3

UNFED OUR < range; and however COD in the final effluent is high.

$\mathbf{q_H}$ << F/M (rbCOD)

Toxicity detection by progressive substrate concentration increasing

To the activated sludge we add a substrate (S) in order to create a maximum respiration rate as high reference level.

IMPORTANT
The reactor sludge must be free o f any kind of Toxicity.
In case the sludge has got any toxicity, the application should be carried out by means another healthy sludge (from another plant) of similar features.

For process with nitrification
S = [½ g acetate] / g VSS + 100 mg ClNH4, in 5 mL distilled water.

For a process without nitrification
S = [½ g acetate] / g VSS, in 5 mL distilled water.

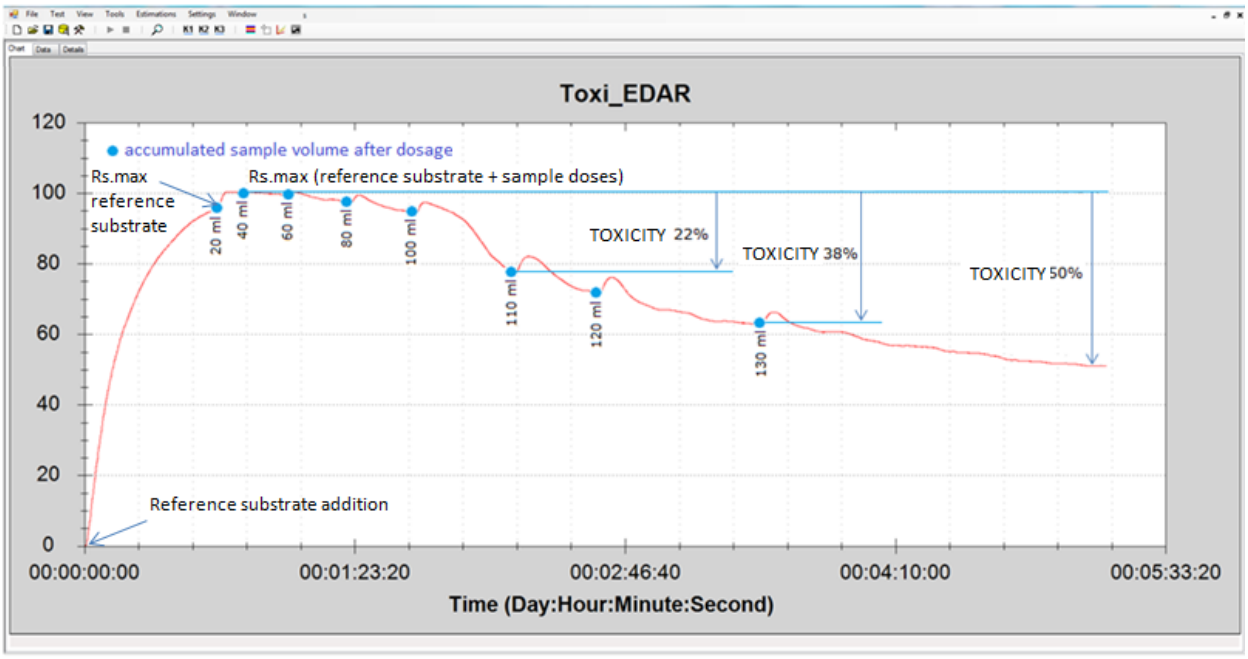
Once we have reached the maximum respiration rate (Rs.max from reference substrate) we add progressive doses of aliquot (*) in order to progressively increase the substrate concentration in the activated sludge.

(*) aliquot: sample --> starting with 1 mL sample + 5 mg acetate.

In case of toxicity, as we are sequentially adding a serial of doses: increasing progresivelly from 1 mL to 2 ---> 10 ---> 20 mL sample + 5 mg acetate.
It can happen that the Rs could increase at the begging. However, as soon as the toxic effect is detected, the respiration rates in the respirogram will start to decrease progressively.

Then we can stop the test as soon as we have reached the target inhibition %, or at any time we want.

This is normally a screening analysis but, by calculating the corresponding equivalence volumes with the plant reality, it can give us an idea of how much toxicant substrate can support our activated sludge.



I (%) = 100 (Rs.max – Rs.tox) / Rs.max

I: Toxicity (%)
Rs.max: Maximum Rs after adding the reference substrate and aliquot doses.
Rs.tox: Rs below Rs.max causing toxicity

Global toxicity in wastewater analysis by comparison of two or more mixed liquors with a reference by means R tests with standard.

The analysis is carried out by means of two mixed liquor preparation by returned sludge (running normal)

Equivalent mixed liquors should maintain the same ratio of the actual process.

Qo/Qr = V (sample) / V (RAS)
Qo: Influent flow to reactor (m^3/h)
Qr: Recirculation sludge flow to reactor (m^3/h)
RAS: Returned Activated Sludge

Preparations:

1 litre ML ref: V returned sludge (RAS) + V (ref)

1 litre ML sample: V returned sludge (RAS) + V (influent)

ML ref: Reference mixed liquor
ML sample: Mixed liquor to analyze
V returned sludge WWTP: Volume of returned sludge from WWTP
V (ref): Volume of distilled water + reference substrate (sodium acetate)
V: Volume of influent to be analyzed

IMPORTANT
The reactor and RAS sludge must be free of any kind of Toxicity.
In case the sludge has got any toxicity, the application should be carried out by means another healthy sludge (from another plant) of similar features.

V (ref) and V should have similar COD. If not, we add sodium acetate in order to readjust the value to the other. For that, we base our corresponding dose by taking into account that approximately 100 mg acetate / litre make 75 mg COD/L.

In order to get the endogenous respiration in ML (ref) and ML sample, we leave them aerating and mixing during at least 24 hours (it could be by means of a simple aquarium aeration system)

Procedure

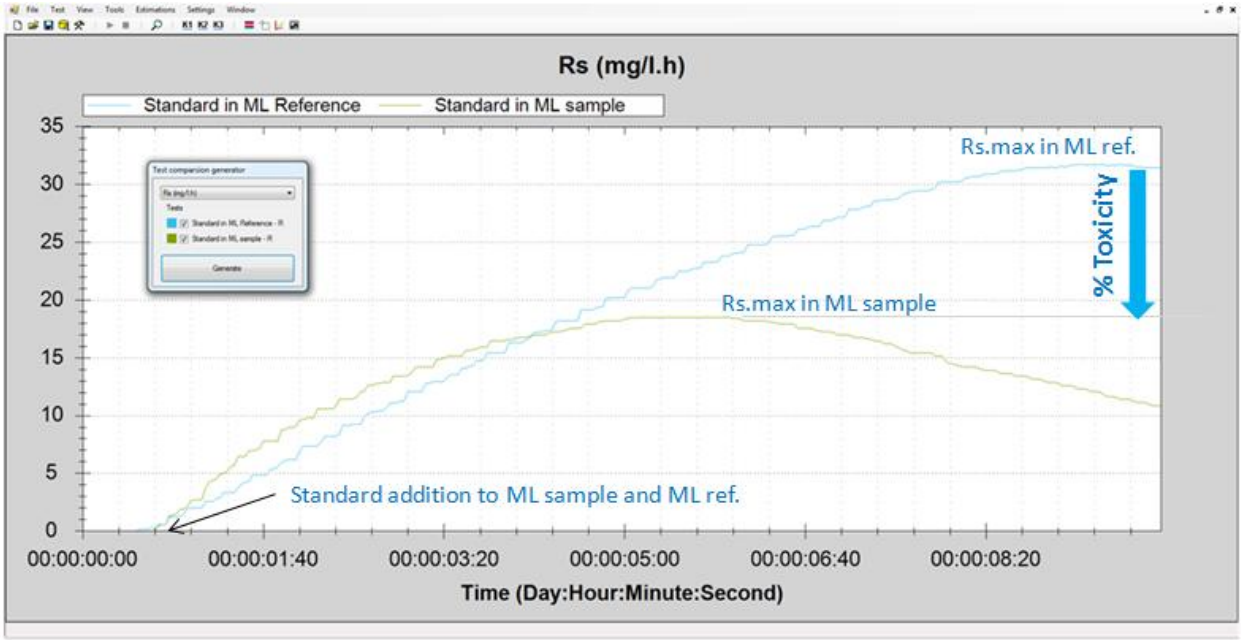
After the 24 hours of conditioning time, from ML (ref) and ML we carry out two R tests, by adding the same amount of a standard substrate (S)

S = [½ g acetate] / g VSS in 10 mL distilled water.

First, we do the reference R test [V returned sludge WWTP + V (ref) + S] and we stop the respirogram as it reaches its maximum respiration rate (Rs.max in ML ref)

Then, we do the sample respirogram [V returned sludge WWTP + V + S] and stop the respirogram as it gets the corresponding maximum respiration rate (Rs.max in ML sample)

Once obtained the corresponding respirograms, by making use of the BM software, we overlay them and analyze the Rs.max from reference on respect to the current Rs from sample test within the same time.



We calculate the % of inhibition / toxicity from the difference between RsMax in the reference test and the corresponding value of Rs in the sample test, at the same time.

I (%) = 100 (Rs.max ML ref. – Rs.max ML sample) / Rs.max ML ref.

Specific toxicity for nitrification

The procedure is practically the same as before, but instead of sodium acetate we have to make only use of ammonium chloride in a concentration similar to the one in actual process. For that, we take into account that to calculate the actual ammonium concentration we have to multiply the mg of ammonium chloride by 0,26.

Once we have left aerating both mixed-liquors during at least 12 hours, we carry out the R tests by adding a substrate (S) composed by ammonium chloride:

S = [100 mg ClNH4] / g VSS, in 10 mL distilled water.

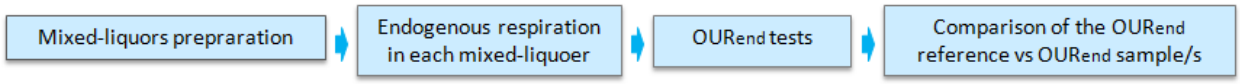
We calculate the % of inhibition / toxicity (I_N) specific for nitrification from the difference between Rs_{max} in the reference test and the corresponding value of Rs in the sample test, at the same time.

$$I_N = 100 * (1 - Rs/Rs_{max})$$

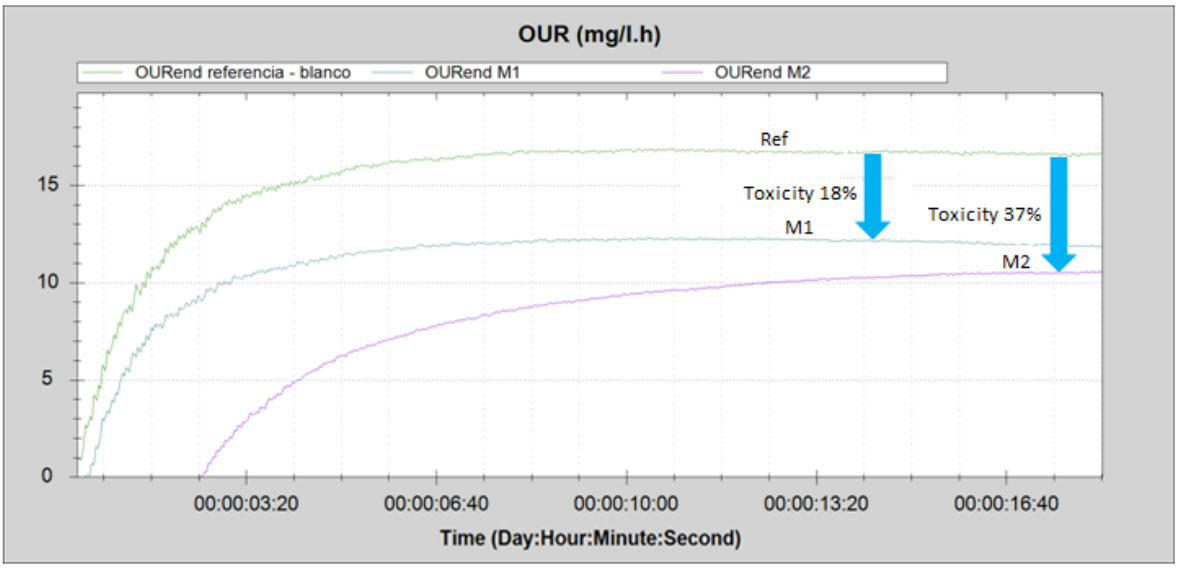
I_N: Nitrification toxicity (%)

Toxicity to the global biomass by OUR_{end} tests

With this procedure the global toxicity is assessed by comparison of the OURend of one o several mixed-liquors samples with the one for reference, all under endogenous respiration phase.



The preparations and procedure is similar to the global toxicity before described but doing endogenous OUR instead of R test and not adding any standard.

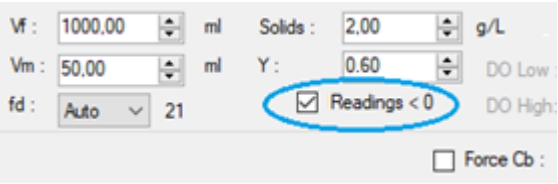


I (%) = 100 * (OURend.ref. – OURend sample M) / OURend.ref

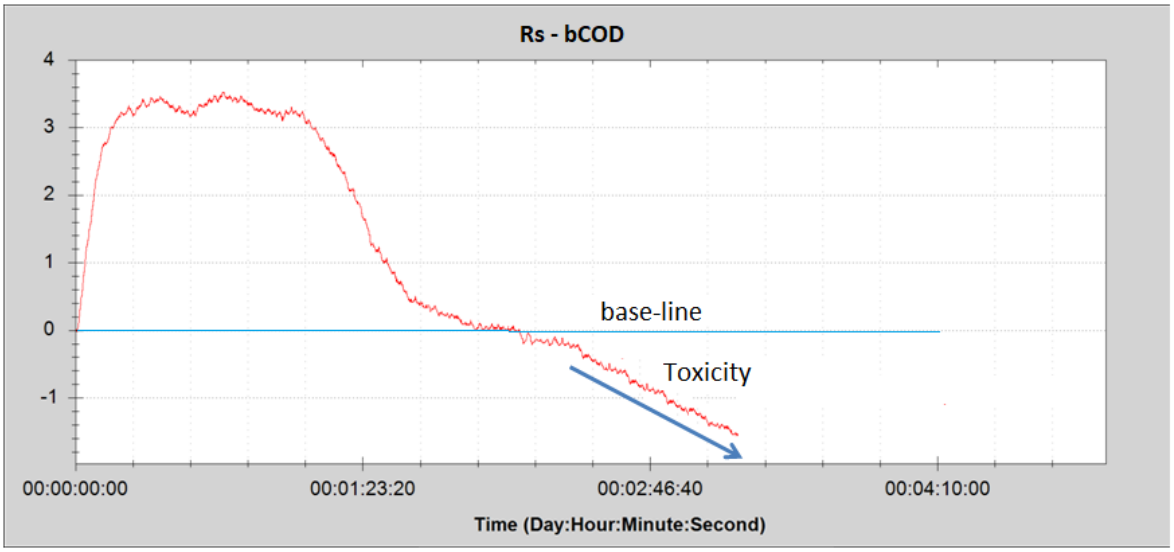
Toxicity detecion during a bCOD test

What theres is an abnormal low bCOD we can suspect that it could be a symptom of toxicity.

To check ths possibility we can modify the test by clicking od Test → set the Rs Readings < 0 → Accept and see ths pssible Rs vaiues below base line.



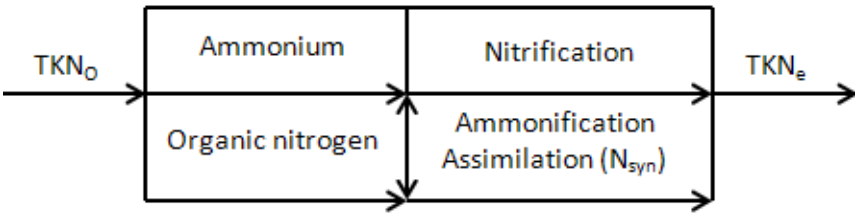
When the Rs exceeds the baseline and falls with a clear progressive negative slope, the test is indicating the possibility of the presence of a toxicity caused by the sample for the Vm/Vf ratio in with which the test has been performed.



9.
Kinetic parameters for autotrophic biomass

Ammonium nitrogen to nitrify in the biological process

Because of the ammonification process, where part of the organic nitrogen is going into ammonium form, the effective ammonium to nitrify must be calculated from the eliminated TKN from which we have to subtract the corresponding nitrogen directed to cell synthesis.



Actual ammonium that the process is currently nitrifying

$$\mathbf{S_N} = TKN_O - TKN_e - S_{sy}$$

S_N: Actual ammonium concentration to nitrify (mg/l NH_4-N)
TKN_O: Influent TKN (mg/l N)
TKN_e: Effluent soluble TKN (mg/l N)
S_{sy}: Nitrogen utilized in the cell synthesis = 0.05 * BOD

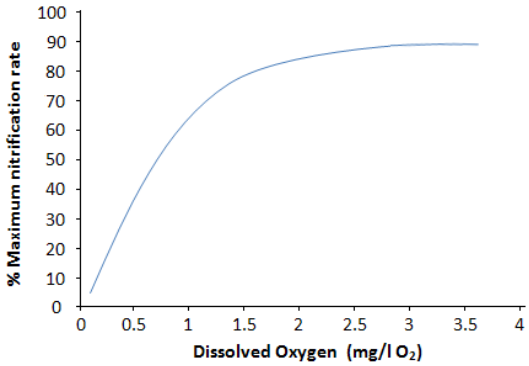
Ammonium that the process should nitrify

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

N_O: Organic nitrogen in effluent ≈ 2 mg N/L
S'_N: Ammonium concentration that the process should nitrify (mg/l NH_4-N)
S'_{Ne}: Maximum ammonium concentration permitted in the effluent (mg N-NH_4/l.h)

Respiration rate due to nitrification for maximum DO (higher than 3 mg/l)

Under practical terms, we can assume the maximum dissolved oxygen for nitrification is achieved when it is higher than 3 mg/l.



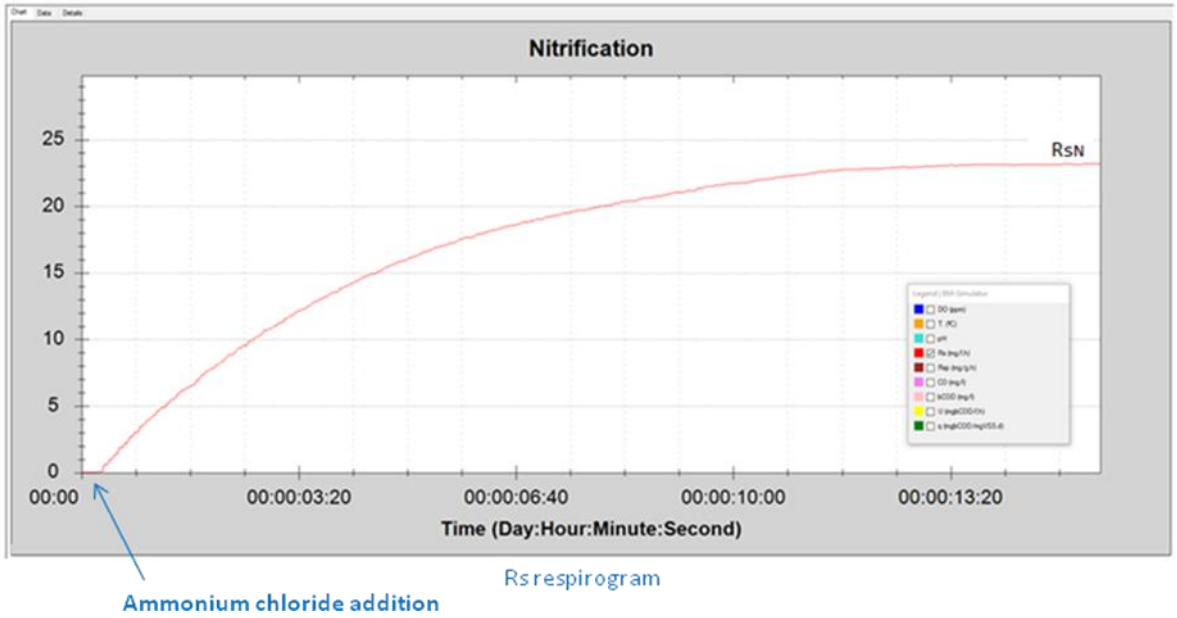
In this case, we assume that the respiration rates values, under same conditions of pH and temperature, are not getting significant variations and we can make use of a dynamic respiration rate under maximum DO (> 3 mg/l) level by means one R test.

To carry out this R test, we will make use of one litre of discharged mixed liquor from the end of the completed ASP under endogenous phase (1) and ammonium chloride (2)

(1) Regarding the activated sludge, we must be sure that organics degradation and nitrification are completed; if not, we must leave the activated sludge full aerated until the organics and ammonium oxidation process are completed.

(2) Here, we will have into account that each mg of NH_4Cl corresponds to 0.26 mg of NH_4-N. Therefore, by knowing the ammonium nitrogen concentration to nitrify we can calculate the corresponding amount of NH_4Cl:

$[NH_4Cl]$ (mg/L) = S_N (mg/L) / 0.26



Nitrification rate for the actual DO

AUR = (Rs_N / 4.57) * DO / (K_{OA} + DO)

AUR: Ammonium uptake rate at actual DO (mg/l.h NH_4-N)
Rs_N: Exogenous respiration rate at maximum DO (> 3 mg/l)
4.57: mg of O_2 needed by each mg of N-NH_4 for its oxidation
DO: Average DO in the process (mg/l)
K_{OA}: Oxygen half-saturation coefficient = 0.5 (default value)

Source: Advanced Biological Process – Lawrence K. Wang – 2008

Oxygen half-saturation constant for nitrification

From a mass balance

K_{OA} = DO (Rs_N/4,57 – S_N / HRT_N) / (S_N / HRT_N)

K_{OA}: DO half-saturation constant (mg/l)
DO: Average buk DO value in the nitrification process (mg/l)
HRT_N: Hydraulic retention time for nitrification (h)

Estimated value from a default value

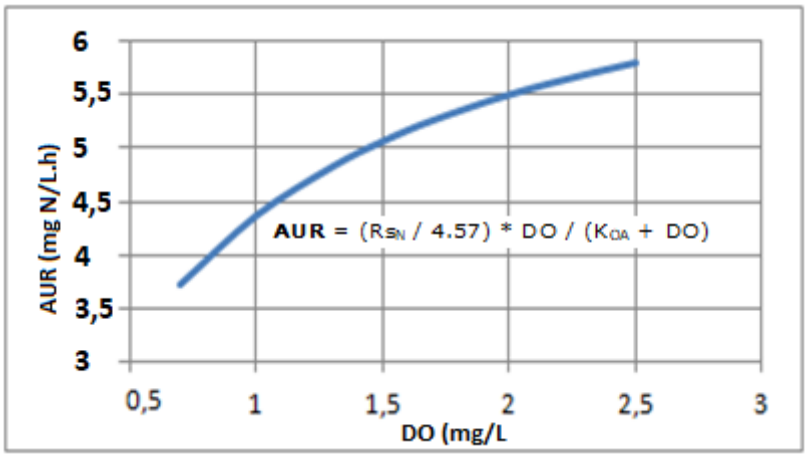
In bibliography it seems there is not any agreement between authors and researchers about a defined value for K_{OA}.

From Surcis experience the most coherent value is the following one:

K_{OA} ≈ 0.5 (recommended)

Estimation of the nitrification rate for any DO value in which the process could operate

When we determine the R_N and AUR tests on equivalent conditions of substrate, temperature and pH, by making use of the AUR equation, the nitrification rate corresponding to any determined DO value on which the process could operate can be graphically determined.



Specific ammonium uptake rate referred to MLVSS

This is a very common parameter to assess the nitrification activity, where we relate the nitrification rate to the total MLVSS in the activated sludge:

SAUR = 24 * AUR / VSS

AUR: Specific ammonium-nitrogen uptake rate (mg/l.d NH_4-N)

To get an assessment of this parameter we can also go to the reference curve that relates AUR vs the ratio BOD/ TKN.

SAUR can be considered as the easiest and fastest parameter to identify the nitrification process. That means, if by trial and error we get an efficient nitrification under certain AUR value, we can establish it as the specific reference parameter on which we have to go.

Autotrophic biomass concentration

<u>From the actual nitrification rate of a already existing processl</u>

$\mathbf{X_A}$ = 0.1 * 24 * AUR * SRT

X_A: Autotrophic biomass concentration (mg/l)
SRT: Actual sludge age on which the process is operating (d)

<u>From standard table</u>

This table should be only applied for a process that is running without problems under an average temperature > 20ºC, pH in between 7 and 8 and DO > 2 ppm.

COD/TKN	0.5	1	2	3	4	5	6	7	8	9
F_N	0.35	0.21	0.12	0.083	0.064	0.054	0.043	0.037	0.033	0.029

$\mathbf{X_A} = F_N * X_V$

Source: Metcalf & Eddy. 1995

From Eckenfelder formula

As first step, we are going to calculate the nitrifier biomass fraction (F_N) within the global volatile solids (X_v), by means the following mathematical formula:

$\mathbf{F_N} = Y_{A.VSS} * S_N / (Y_{H.VSS} * S_S + Y_{A.vss} * S_N)$

S_S: Actual eliminated COD in the biological process (mg/L)
$Y_{A.vss}$: Autotrophic yield coefficient ≈ 0,1
$Y_{H.VSS}$: Heterotrophic yield coefficient ≈ 0.45 (referred to VSS)

$\mathbf{X_A} = F_N * X_V$

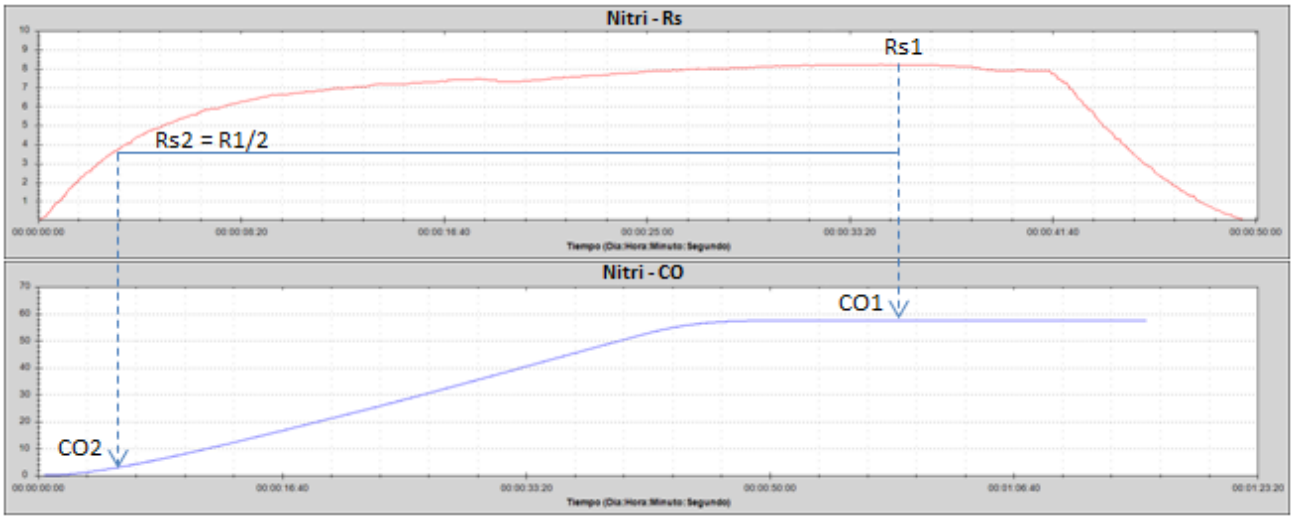
Source: Activated sludge treatment of industrial wastewater – W.W. Eckenfelder, J.L. Musterman - 1995

Determination of susbtrate half saturation constant for ammonium nitrogen removal in the Nitrification

Half saturation constant can be calculated from a R test and a solution of ammonium chloride with an equuivalent concentration of ammonium nitrogen as the actual nitrification process. The solution dose can go from 30 to 50 mL (Vm = 30 ~ 50)

$[NH_4\text{-}N] = [ClNH_4]/0.26$

The R-Test can be stopped as soon as the highest respiration rate (Rs1) is reached.



From Rs1 and Rs2 the corresponding values of consumed oxugen are selected: CO1, CO2

Then, from CO1 and CO2, the corresponding aliminated ammonium nitrogen (SN1, SN2) are calculated:

SN1 = CO1/4,57

SN2 = CO2/4,57

According to the Micahelis –Mente equuation:

Rs.max = Rs1 (SN1 + Kn) / SN1 = Rs2 (SN2 + Kn) / SN2

Taking into account Rs2 = Rs1 / 2 → Rs1/Rs2 = 2

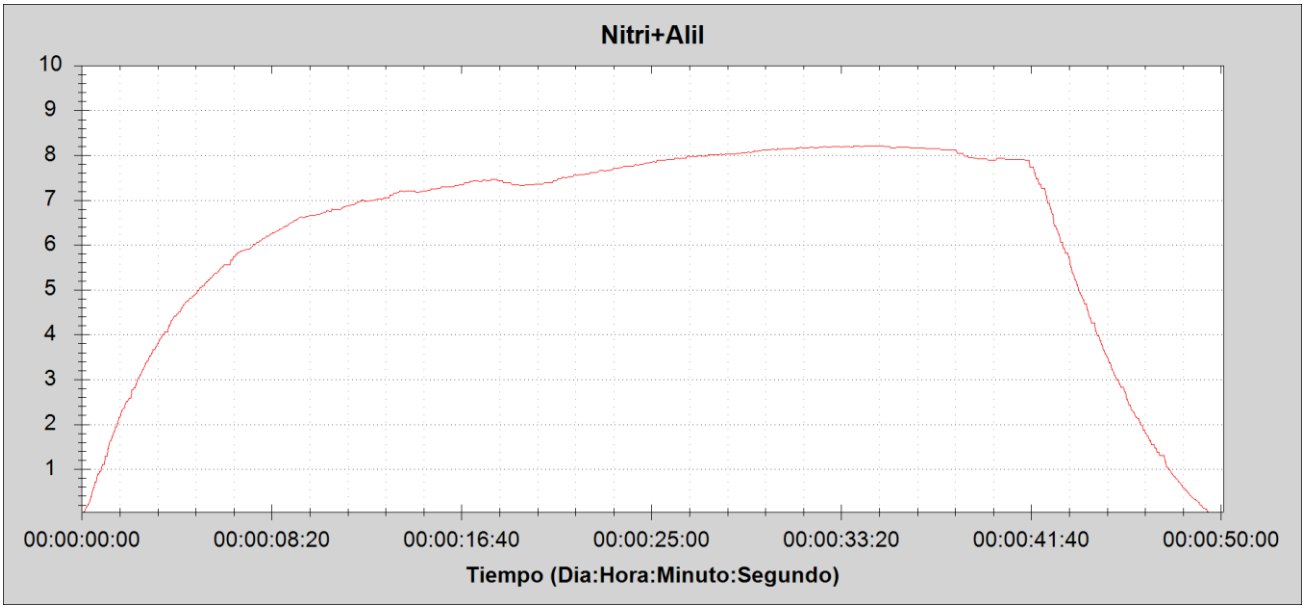
Matching the above equations and reducing, we obtain the following equation:

Kn = 1 / (1/SN2 – 2/SN1)

Kn: Half saturation coefficient (mg NH_4-N/L)

Actual and maximum nitrification rate

Those parameteres can be obtained from the same R test used for half saturation constant (previous point) and making use of the highest Rs (Rs1) and corresponding eliminated ammonium nitrogen (SN1)



AUR = Rs1 / 4,57

AUR_{max} = AUR (SN1 + Kn) / SN1

AUR1: Actual nitrification rate (mg NH_4-N/L.h)
AUR_{max}: Maximum nitrification rate (mg NH_4-N/L.h)

Actual and maximum specific nitrification rate

q_N = AUR * 24 / X_A

q_{Nmax} = AUR_{max} * 24 / X_A

q_N: Actual and maximum specific nitrification rate [NH_4-N/(VSS_A.d)]
q_{Nmax}: Maximum specific nitrification rate [NH_4-N/(VSS_A.d)]

SRT = 1 / μ_A

Stoichiomatric coefficient for autotrophic biomass

Option 1 (recommended)

$\mathbf{Y_{A.VSS}} = 1/ (TRC * q_N)$

Y_A: Stoichiometric coefficient of autottrophic biomass (VSS/N)
SRT: Sludge retention time (sludge age) (d)

Option 2

To avoid too long test, a solution of 200 mg of ammonium chloride is prepared in one litre of distilled water. Then a normal R test is carried out by adding a sample volume of 50 mL in the litre of endogenous activated sludge contained in the reactor vessel.

In case we are making the test in a BM-Advance, we have to prepare the corresponding buffer flasks and pumps for pH control, and in the "board control setting" we place the pH control into ON.

As soon as the respirogram of Rs reaches the baseline (or near to it), we can assume that all the ammonium is oxidized already. Then, we get the correspondent consumed oxygen from the test results.

$\mathbf{Y_{A.COD}} = 4.57 - CO_N / [NH_4\text{-}N]$

$Y_{A,COD}$: Autotrophic yield coefficient (O_2/NH_4-N)
CO_N (mg/l): Consumed oxygen for nitrification
$[NH_4\text{-}N]$ (mg/l): Concentration of ammonium utilized in the test

$\mathbf{Y_{A,VSS}} = Y_{A,COD} / 1.42$

Source: Water Environment Fundation - 2006

$Y_{A,VSS}$: Autotrophic yield coefficint referred to VSS_A (VSS_A/NH_4-N)
$Y_{A,VSS} \approx 0,1$ (common estimated value)

Actual and maximum growing rate in the autotrophic biomass

$\mathbf{\mu_A} = Y_{A,VSS} * q_N$

$\mathbf{\mu_{Amax}} = Y_{A,VSS} * q_{N.max}$

μ_A: Actual autotrophic growing rate coefficient (d^{-1})
$\mu_{.max}$: Net maximum autotrophic growing rate coefficient (d^{-1})

10.
Operative parameters for Nitrification

Typical design parameters for activated-sludge process modifications

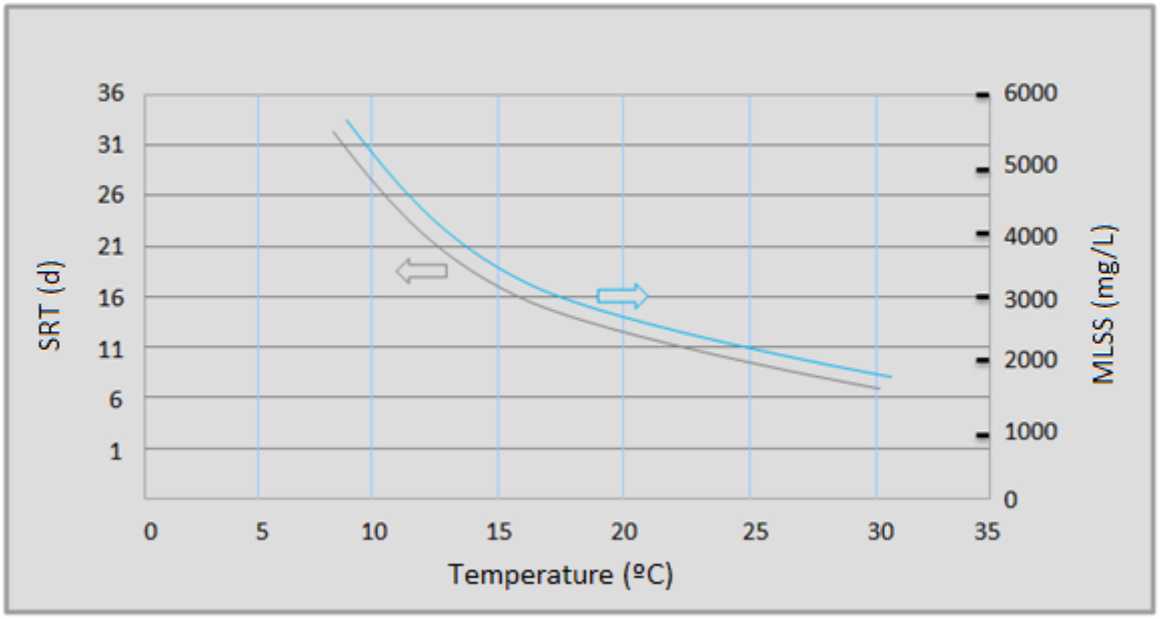
Process modification	SRT, days[a]	Food-to-microorganism	MLSS, mg/L	Aeration time, hours	Return flow-to-plant flow ratio
Conventional	5–15	0.2–0.4	1 500–3 000	4–8	0.25–0.75
Complete mix	5–15	0.2–0.6	2 500–4 000	3–5	0.25–1.0
Step feed	5–15	0.2–0.4	2 000–3 500	3–5	0.25–0.75
Modified aeration	0.2–0.5	1.5–5.0	200–1 000	1.5–3	0.05–0.25
Contact stabilization	5–15	0.2–0.6	1 000–3 000[c] 4 000–10 000[d]	0.5–1.0[c] 3–6[d]	0.5–1.50
Extended aeration	20–30	0.05–0.15	3 000–6 000	18–36	0.5–1.50
High-rate aeration	5–10	0.4–1.5	4 000–10 000	2–4	1.0–5.0
High-purity oxygen	3–10	0.25–1.0	2 000–5 000	1–3	0.25–0.5
Oxidation ditch	10–30	0.05–0.30	3 000–6 000	8–36	0.75–1.50
Single-stage nitrification	8–20	0.10–0.25 (0.02–0.15)[e]	2 000–3 500	6–15	0.50–1.50
Separate-stage nitrification	15–100	0.05–0.20 (0.04–0.15)[e]	2 000–3 500	3–6	0.50–2.00

Actual and minimum sludge retention time for nitrification

SRT = 1 / μ_A

SRT_{min} = 1 / μ_{Amax}

SRT: Actual sludge retention time (d)
SRT_{min}: Minimum sludge retention time (d)
$Y_{A,VSS}$ ≈ 0.1



11.
Denitrification

Denitrification rate (NUR)

Maximum denitrification rate by R test with sodium acetate

Based on bibliography, adapted to the R mode in the BM Respirometry

In principle, the advantage of this procedure is the relative shot time to get a reliable result

Procedure

Get 1 litre of sludge from the anoxic zone and pass it into endogenous phase (sludge should have a concentration in between 2 and 4 g/l MLVSS. If higher, the sludge should be diluted with distilled water.

Carry out the R test to obtain the yield coefficient (see procedure on page 13) and record the value (Y_H) – Optionally default value of 0,67 can be used -.

Make a solution of sodium acetate of 400 mg acetate in 1 litre of distilled water.

Take 50 mL of sample in a probe from the acetate solution.

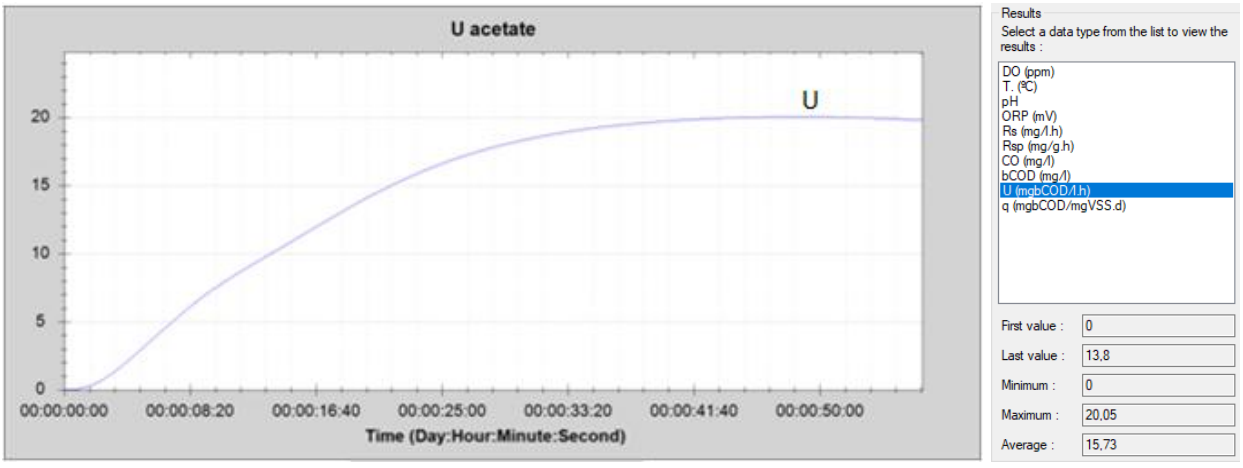
Prepare the R test by setting similar conditions of pH and Temperature as the real process.

Set sludge volume to 1000 (Vf = 1000) and sample volume to 50 (Vm = 50)

Start the test, taking special care of a stable initial baseline and adding (slowly) the 50 mL just at the time the test is asking for it.

Select the U value in the Legend option in order to obtin the respirogram of this parameter over time.

Stop the test when U (U) reaches its maximum value and record the result (it can be seen in the details window)



Calculate the NUR value, by applying the following formula:

$NUR_{max} = U_{max} (1 - Y_{HD}) / 2,86$

Y_{HD} = 0,83 * Y_H: Yield coefficient for denitrification - **Habitual value Y_{HD} = 0,55** (mg O_2/mg COD)

Actual denitrification rate

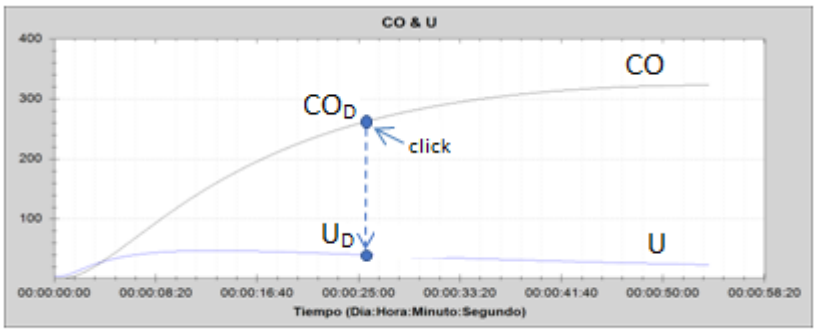
Same R respirometry test as for NUR_{max} is used for actual denitrificatio rate calculation.

In this case, the value of the cosumed oxygen should be first calculated:

$CO_D = 2.86 * S_{NO3}$

CO_D: Consumed oxygen for the actual denitrification (mg/L)
S_{NO3}: Nitrate to denitrify (mg NO_3/L)

From the bCOD test the CO and U respirogramas are overlied:



CO and U respirograms

By making use of the PC muse, in the CO curve we look for the previously calculated CO_D value, and then the corresponding U value (U_D) for the same periode of time. Both values will appear on the down bar (attached to the respirograms screen) – Those results can also be seen on the table values in the "Data" option -

The actual NUR is calculted as follows:

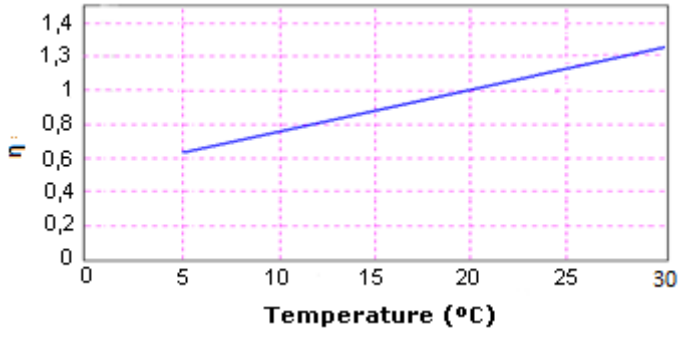
$NUR = U_D (1 - Y_{HD}) * KO_D / (KO_D + OD_D)$

Inhibition factor: $KO_D / (KO_D + OD_D)$
KO_D: Inhibition coefficient due to oxygen in the anoxic zone = 0,2 (mg/l) - Default value –
DO_D: Actual dissolved oxygen in the denitrification zone (mg O_2/L)

Sources: US-EPA, Henze et al 1987, Others

NUR correction by temperature factor

Just in case that the NUR has been previously determined at 20ºc to pass it to other temperatures, we can apply the temperature correction factor (η) by appluing the following graph:



$$NUR_{(Temp)} = \eta * NUR_{(20^oC)}$$

Sources: E.CHOI and R.DAEHWAN. 2000. Korea University - W.W. Eckenfekder & J.L. Musterman – 1995

However it is recommended to determine the NUR by setting the test at similar temperature to that of the actual process; and, in this way, no temperature correction should be necessary.

Specific denitrification rate

SNUR = 24 * NUR / VSS

SNUR: Specific denitrification rate [mg NO_3 –N / (mg VSS.d)] – SNUR is also called **SDNR** –
VSS: MLVSS (mg/L)

The SNUR or SDNR assessment can be done though the following reference 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)

Procedure to calculate the necessary rbCOD, BOD and COD for denitrification

!) Consumed oxygen for denitrification: CO_D

CO_D = 2.85 * S_{NO3}

S_{NO3}: Nitratate to denitrify (mg NO_3/L)

2) rbCOD for denitrification: $rbCOD_D$

$rbCOD_D$ = CO_D / (0.83 . Y_H)

3) BOD for denitrication: BOD_D

BOD_D =(BOD/rbCOD) * $rbCOD_D$

rbCOD: Readily biodegradable COD of the wastewater sampla (mg/L)
BOD: BOD_5 of the wastewater sample (mg/L)

4) COD for denitrification: COD_D

COD_D = (COD/rbCOD) * $rbCOD_D$

COD: Chemical Oxygen Demand of the wastewater sample (mg/L)

12.
Conclusion

Conclusion

On this manual there are not all the applications that can be carried out with a BM-Respiromer.

BM-Respirometers ace open systems and for the complexity of the different ASP types there are a huge number of applications that can be done and much more that you can discover or invent.

Each ASP is specific and many times we have to study the best daily and periodical protocol of tests in order to control and protect the process.

By means of the BM respirometer, we can also perform important studies, to develop specific control programs, D & R, support simulation software …

In case of interest of any application not related in this manual or any other consult related with BM-respirometry you can be in contact with SURCIS

By other side, SURCIS, besides manufacturing the BM analyzers, as Respirometry Engineering very much specialized in activated sludge processes, is in the best condition to act as Consulting to give a full technological customer support and perform Respirometry Services directly or associated with other or consulting, university or research centre.

SURCIS is also open to participate in any Research / Study Program, in agreement with any Organism or Research Centres related with wastewater treatment.

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Mystery is the most beautiful thing we can experience.
It is the source of all true art and science.
Albert Einstein