Energy optimization by BM Respirometry

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BM respirometry systems

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Multi-purpose Respirometers BM™ Series

BM-Respirometers are laboratory analyzers specially developed for practical and efficient biological wastewater treatment management, design and research

Comparative table of BM respirometers

Comparative items	BM-T+	BM EVO	BM EVO2	BM Advance	BM Advance2	BM Advance Pro	Comments
Automatic measurements: **OUR** (mg/l.h) **SOUR** (mg/g.h) **OUR & SOUR cíclico** **Rs dinámica** (mg/l.h) **Rsp** (mg/g.h) **CO** (mg/l) **bCOD** (mg/l) **rbCOD** (mg/l) **U** (mg DQO/l.h) **q** (mg DQO/mgSS.d)	✓	✓	2 x ✓	✓	2 x ✓	✓	From the automatic measurements we can go to the applications.
Thermo system in the analyzer		✓	2 x ✓	✓	2 x ✓	✓	Cooling (Peltier) + Heating system included
External thermo unit	✓						External unit (separated unit) formed by Cooling (Peltier) + Heating system.
Easy transportable system	✓						Analyzer + case → 20 kg D-40 + case → 5 kg
Padded aluminium cases for easy transportation	✓						1 case for analyser + 1 case for the thermo-unit. D-40
pH measurement and control				✓	2 x ✓	✓	Especially important in all nitrification tests.
ORP measurement						✓	Redox
Possibility to set conditions and be able to modify them during the test	✓	✓	2 x ✓	✓	✓	✓	Important to carry out studies to analyze the influence of the conditions (pH, OD, Temp.)
BM software update from Internet	✓	✓	2 x ✓	✓	✓	✓	BM software is automatically updated.
Capability for biomass-carrier reactor	✓	✓	2 x ✓	✓	2 x ✓	✓	For MBBR and granular biomass

BM operation modes

Operation modes and automatic parameters

BM Respirometry Operation Modes

OUR & Cyclic OUR modes

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 mode

Rs: **Dynamic Exogenous 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 Exogenous 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.

BM Advance Respirometry system

BM-Advance Pro model

Key points of the components and control systems included in the BM - Respirometers

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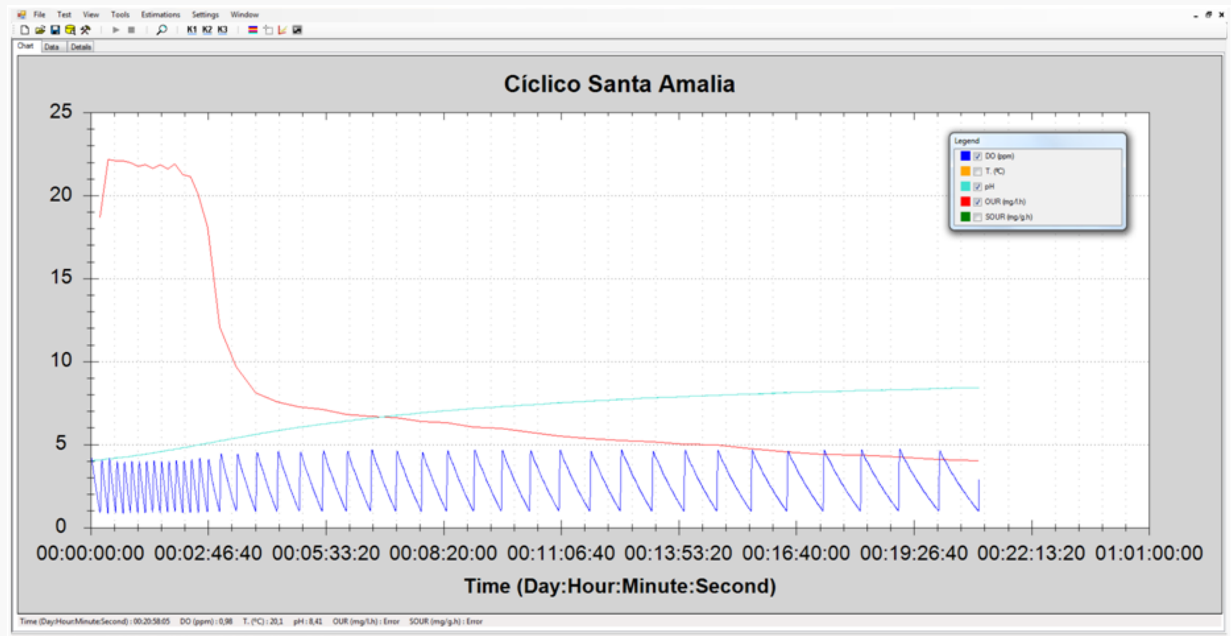
List of some key points concerning the components and systems included in the BM respirometers that make the difference

- Direct oxygen measurements from a maintenance-free oxygen sensor
- No oxygenation restriction during test performance
- pH control system in the BM-Advance system
- pH control and ORP measurements in the BM-Advance Pro system
- Automatic solid-state device for heating & cooling
- Option for a special reactor assembly to simulate a Moving Bed Biofilm Reactor (MBBR)
- Double reactor in model in BM-Advance2

No oxygenation restriction during test performance

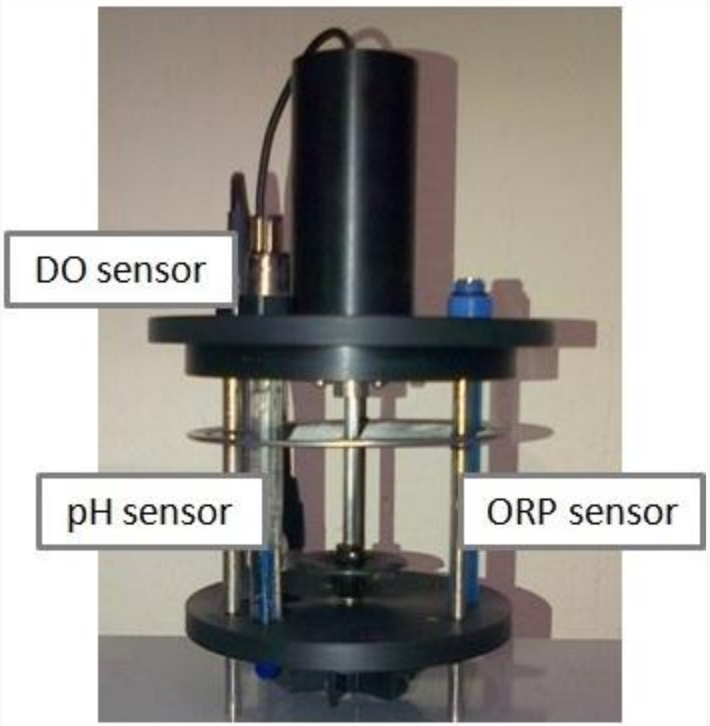
The air supplied to the reaction vessel comes from a small compressor which can be controlled in the settings board by fixing the percentage of the total air-flow.

Reactor assembly



Respirometry Cyclic OUR test of more than 20 h

High reliability Sensors



DO sensor – All models

40 ppb to saturation

0 – 60 ºC

Electrochemical oxygen sensor

Patented **OPTIFLOW** membrane – specially dsigned for harsh ambient -

100% maintenance-free sensor: membrane and electrolyte don't need to be replaced.

Response time is fast and independent of flow.

Very stable under harsh ambient conditions.

pH sensor – Advance and Advance Pro models

pH 0 to 14

0 – 135 ºC

Almost drift-free measurement.

Reference electrolyte factory prepressurized for a clog-free diaphragm potentials.

Everef-F Reference cartridge for silver-free electrolytes.

Poison resistant "PHI" pH glass.

ORP sensor – Advance Pro model

Set to -1000 mV to + 1000 mV

0 – 130 ºC

ORP element: Pt wire

Maintenance-free sensor.

High-performance ceramic diaphragms to reduce the effect of flow potentials.

pH control in the BM-Advance models

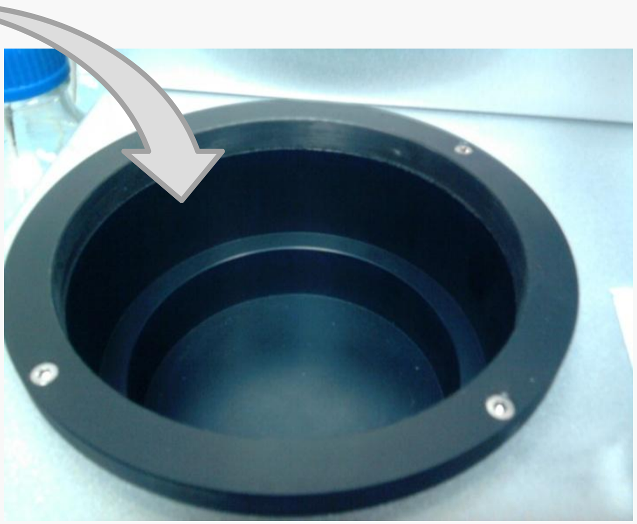
pH control system

Automatic pH buffers dosage in the reactor

Automatic heating-cooling system

Solid-state system based on peltier technology for temperature control (heating & cooling). This heating and cooling system is built into the same analyzer console without the need of using any water bath.

Reactor is carried to the heating-cooling site



Heating-cooling assembly

Optional reactor for MBBR

BM respirometers are the only respirometers on the market that can offer the possibility of making use of one special bio-reactor assembly (designed by Surcis) for respirometric tests simulating moving bed bio-film reactors (MBBR type) and granular biomass.

Biomass-carriersot granular loading
in the reactor-cage

Biomass-carriers + mixed-liquor
loaded in the reactor vessel

Reactor installed in the system
and ready for the test performance

Energy optimization by BM Respirometry

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Preliminary

BM Respirometry systems can undertake dozens of applications with the automatic parameters they provide, process data and possible other complementary parameters. One of these applications is energy optimization.

This presentation describes several procedures for energy optimization that can be obtained with a defined strategy based on lowering the air flow rate, lowering the dissolved oxygen and reducing the sludge age in the biological treatment process.

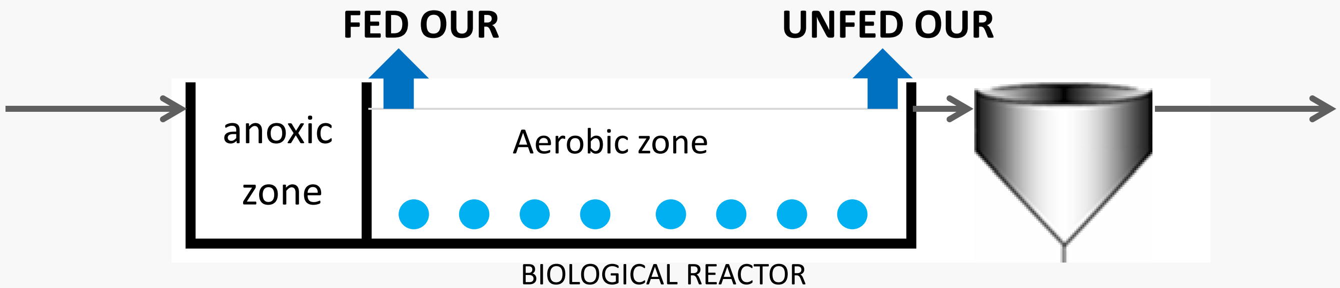
However, BM Respirometry is an open system, where different variables can be programmed to give enough flexibility for the user to compose his own applications and, thus, lead to some new procedure related to energy optimization and others.

CONDITIONS FOR ENERGY OPTIMISATION

1. **The process should not be under toxicity / inhibition condition**
2. **The active biomass concentration should not be below the normal range**
3. **The aeration system must be sufficient for the actual oxygen requirement**
4. **The treatment process must meet the necessary conditions for nitrification and denitrification**
5. **Aeration system should be in good maintenance condition**

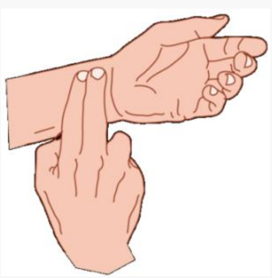
Detection of toxicity already present in the biological reactor

The ASP can be assessed by means the relationship betrween the values of two OUR tests from composite sludge samples or enough representative sample: one from the influent sludge (FED OUR) and another form the effluent sludge (UNFED OUR)



Loading factor (LF)

LF = FED OUR / UNFED OUR



LF	Assessment
LF ≤ 1	**Inhibition / Toxicity**
1 < LF < 2	**Low efficiency or very low loading rate or toxicity**
2 < LF < 5	Good performance & Normal loading rate
LF ≥ 5	Abnormal high loading rate

A toxicity already present in the biological reactor is detected when the LF falls below 1, and may be likely when the LF falls below 2.

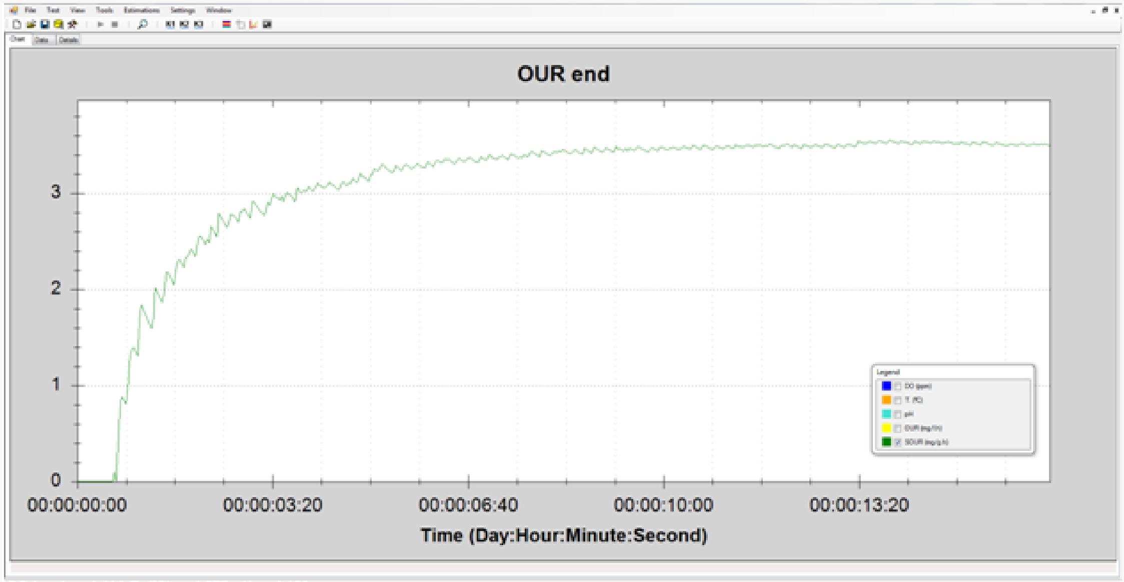
Detection of toxicity already present in the biological reactor by endogenous respiration rate evaluation

The pulse of actual biomass can be taken by performing the endogenous OUR test (OUR_{end}) from outlet sludge, aerated during > 24 hours (*), to get it into endogenous phase (without any substrate)

(*) For low loading processes , the endogenous phase is usually reached just after aerating the effluent sludge for 2 ~ 4 hours.

Table guide for OUR_{end} (20 ºC)

MLVSS (mg/l)	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 respirogram

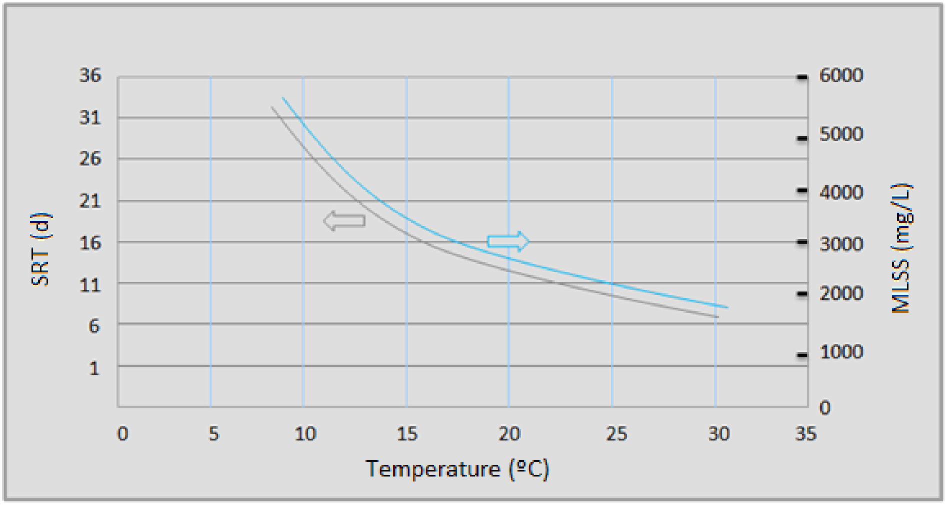
Reasons for which the OUR end value could be below its normal range

1. Low active biomass concentration
2. **Toxicity already present in the biological reactor**
3. Nutrients deficiency
4. Process conditions (Temperature, pH, Operative parameters) out of the normal operation range

Conditions for the nitrification process

Nitrification conditions	
pH	7.3 a 8 (optimal)
T	> 15 to 28 ºC
OD	1.5 to 3 ppm
CODe/TKNe	< 5
SRT	5 to 30 d
Sufficient capacity in the reactor for nitrification	
Without any inhibitor nor toxic compounds	

Coherent SRT & MLSS vs Temperature



Conditions for the denitrification process

Denitrification 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	

When can energy be optimized ?

1. **Over-aeration detection**

2. **Lack of cleaning or replacement need of the air diffusers**

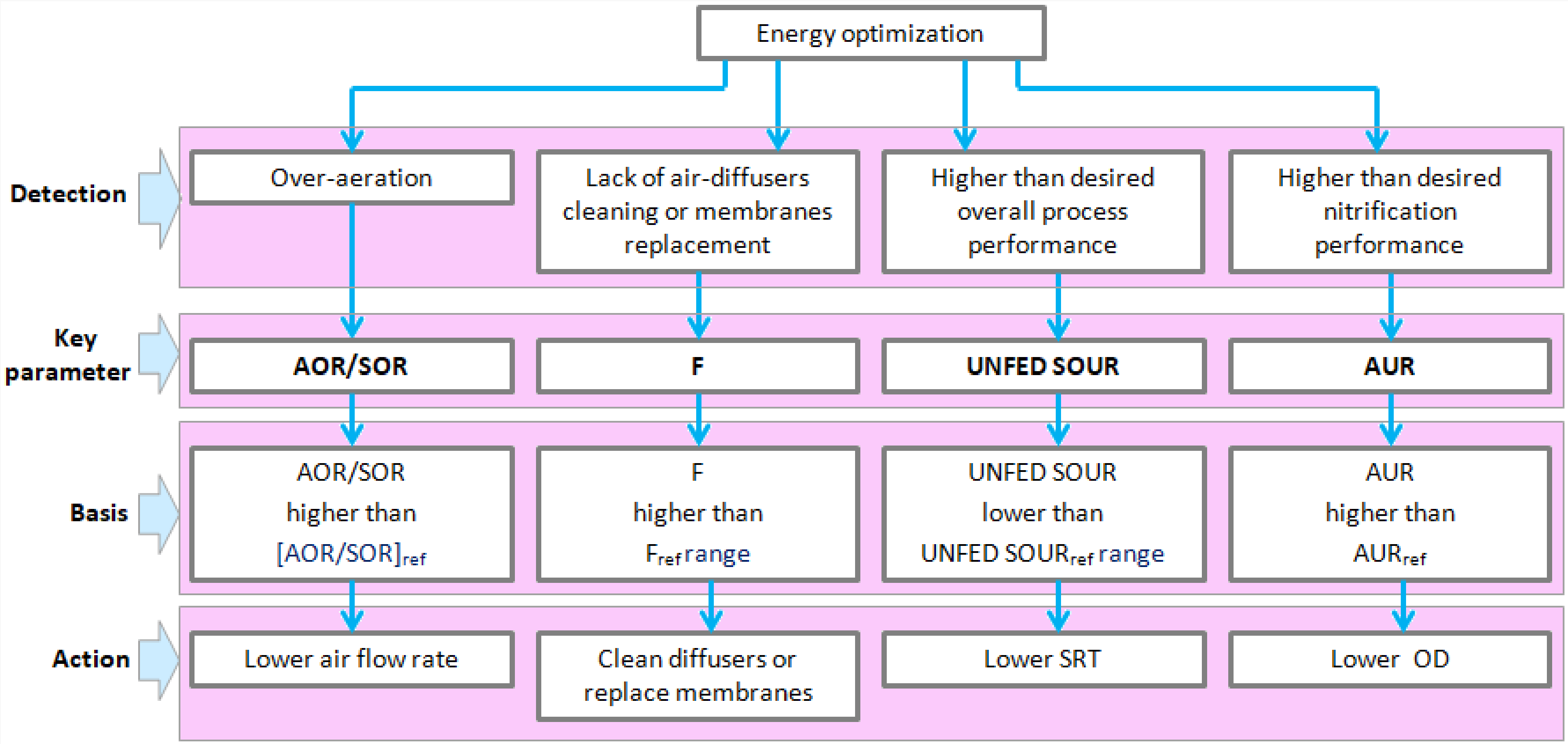
3. **Overall current treatment performance higher than the desired performance**

4. **Nitrification performance higher than the desired performance**

Parameters used in the energy optimization procedures

Parameter	Description
AOR	Actual oxygen requirement (kg O_2/d)
SOR	Standard oxygen requirement (kg O_2/d) for new diffusers
AOR/SOR	Relationship between AOR and SOR
$[AOR/SOR]_{ref}$	AOR/SOR reference : Fine bubble dif. = 0.33 - Coarse bubble dif. = 0.5 Sources: University of Idaho, Civil Engineering, 2003 - Bengtson, Harlan H – 2017 - Phil Korth - 2013
F	Fouling factor: Normal range = 0.7 to 0.9
F_{ref}	Fouling factor reference range: 0.7 to 0.9
UFED SOUR	Specific Oxygen Uptake Rate (mgO_2/gSVSS/h)
UFED $SOUR_{ref}$	UNFED SOUR reference (mgO_2/gSVSS/h) – It depends of the actual F/M and SRT
AUR	Nitrification rate (mg NH_4/L/h)
AURr	Required AUR for a desired nitrification performance (mg NH_4-N/L/h)

Basic diagram for procedures on energy optimization by BM Resperimetry



AOR	Actual oxygen equirement (kg O_2/d)	**SOR**	Standard oxygen requirement for new diffusers (kg O_2/d)
AOR/SOR	AOR / SOR ratio	**$[AOR/SOR]_{ref}$**	AOR/SOR reference: Fine bubble diffusers = 0.33 - Coarse bubble diffusrs = 0.5
F	Fouling factor	**F_{ref}**	Fouling factor reference - range: 0.7 to 0.9
UNFED SOUR	Specific Oxygen Uptake Rate (mgO_2/gVSS/h)	**UNFED $SOUR_{ref}$**	UNFED SOUR reference - Range on table related to F/M & SRT
AUR	Nitrification rate (mg NH_4/L/h)	**AURr**	Required AUR for a desired nitrification performance

Energy optimization

based on the detection of

- **over-aeration**
- **lack of cleanliness**
- **membranes replacement**

in diffused aeration systems

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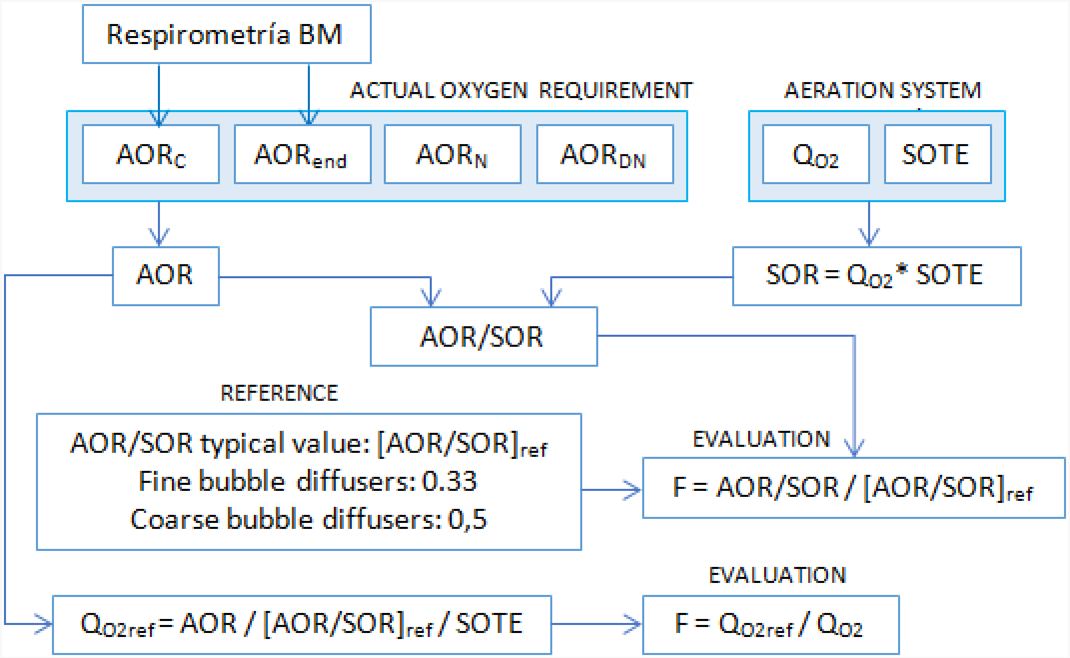
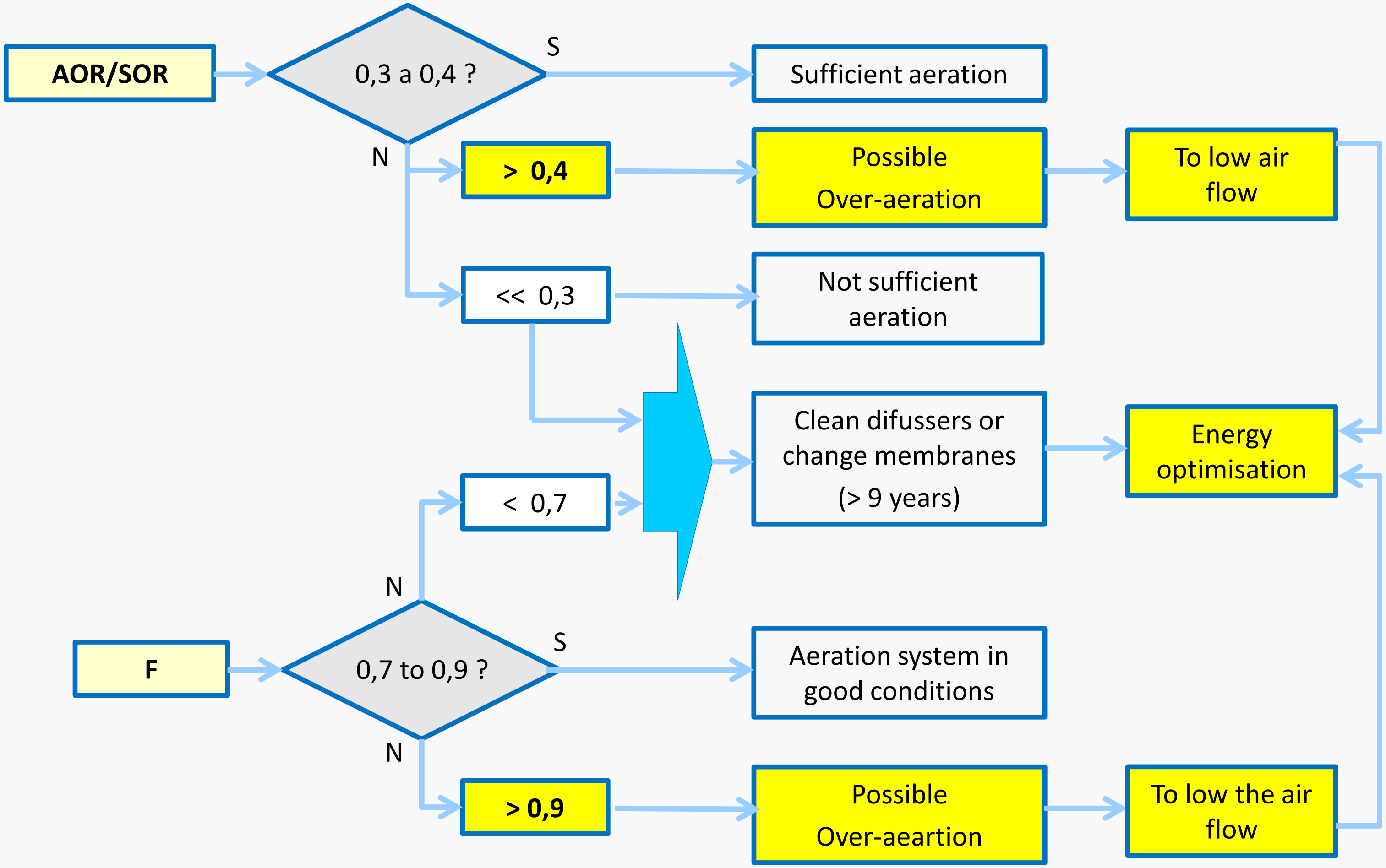
Practical procedure to evaluate a diffused aeration system



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: Fine bubble dif. = 0.33 - Coarse bubble dif. = 0.5 **Sources: University of Idaho, Civil Engineering, 2003 - Bengtson, Harlan H – 2017 - Phil Korth - 2013**
F	Fouling factor: Normal range = 0.7 to 0.9

Energy optimization by the detection of over-areation in a fine-bubble diffuser aeration system

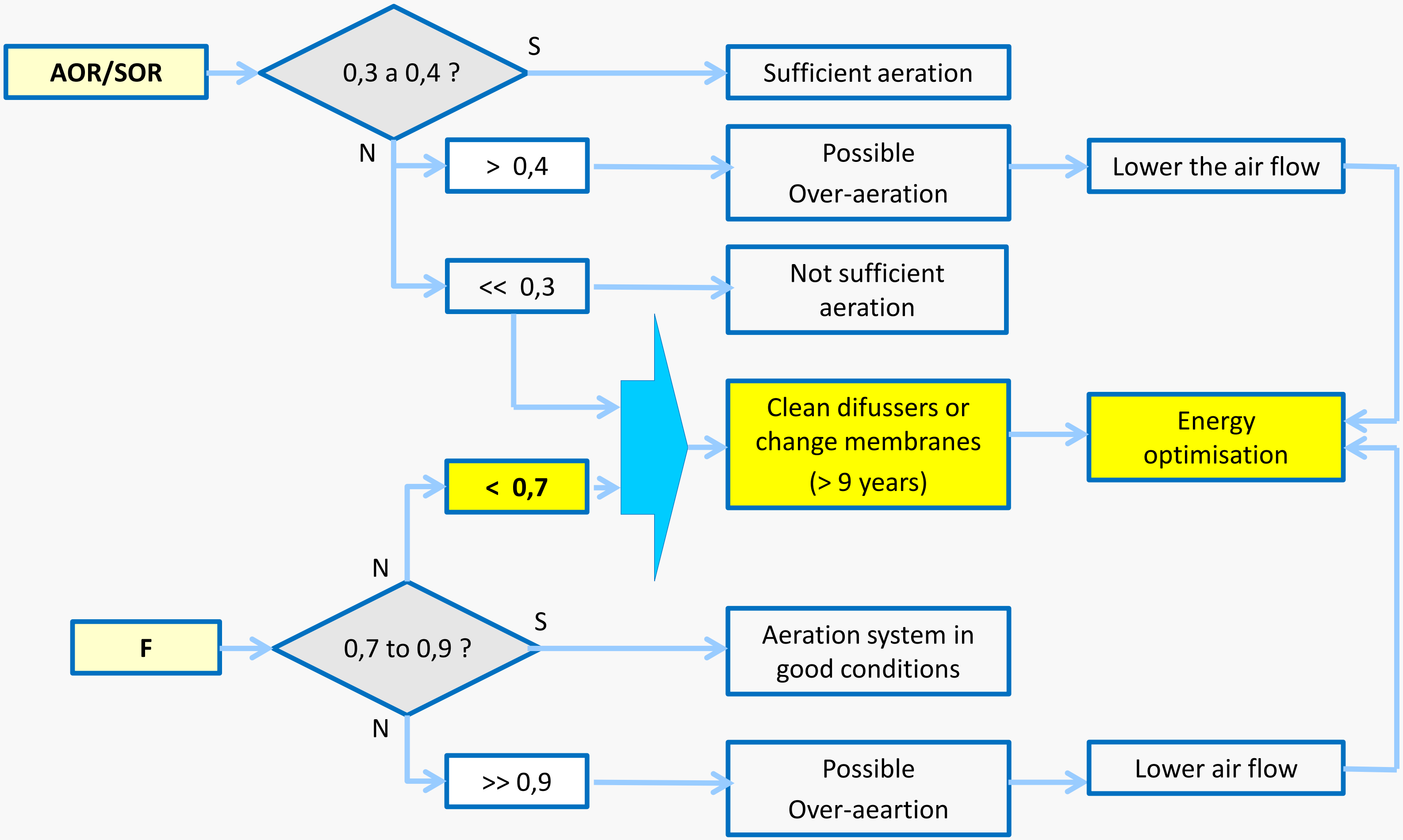
Over-aeration will be detected when the average AOR/SOR is significantly higher than 0.4 and/or when F is higher than 0.9



For other type of diffuser system the criteria will follow the same type of diagram

Energy optimization by detection of lack of cleaning or membranes replacement need in a fine-bubble diffuser aeration system

Failure to clean or replace membranes will be detected when AOR/SOR drops significantly below 0.3 and/or when F drops significantly below 0.7



For other type of diffuser system the criteria will follow the same type of diagram

Energy optimization

based on the detection of

an overall current treatment performance that is higher than the desired performance

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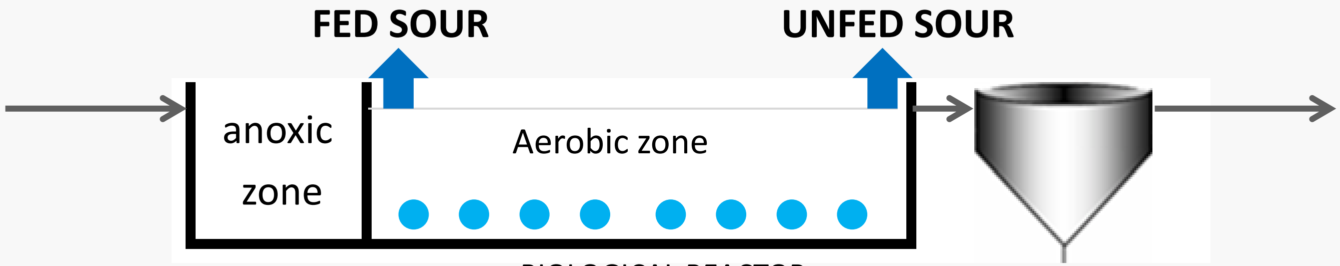
Energy optimization from the evaluation of the overall process performance by the UNFED SOUR evaluation

The UNFED SOUR is the SOUR value corresponding to a representative effluent sludge (end of aerobic process)



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Process type	F/M (BOD/SS.d)	SRT (d)	REFERENCE UNFED SOUR ref (mgO₂/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		

Source: Based on the "Operating Activated Sludge Using Oxygen Uptake" from Water Pollution Control Federation (USA) – Univ. Barcelona - Applications Manual of Surcis BM Respirometry

UNFED SOUR values below its minimum range mean higher than desired overall performance.

Energy optimization would be achieved by lowering the SRT when the UNFED SOUR falls below the minimum value of its corresponding range.

Energy optimization

based on the calculation of the minimum dissolved oxygen and sludge retention time for the nitrification process

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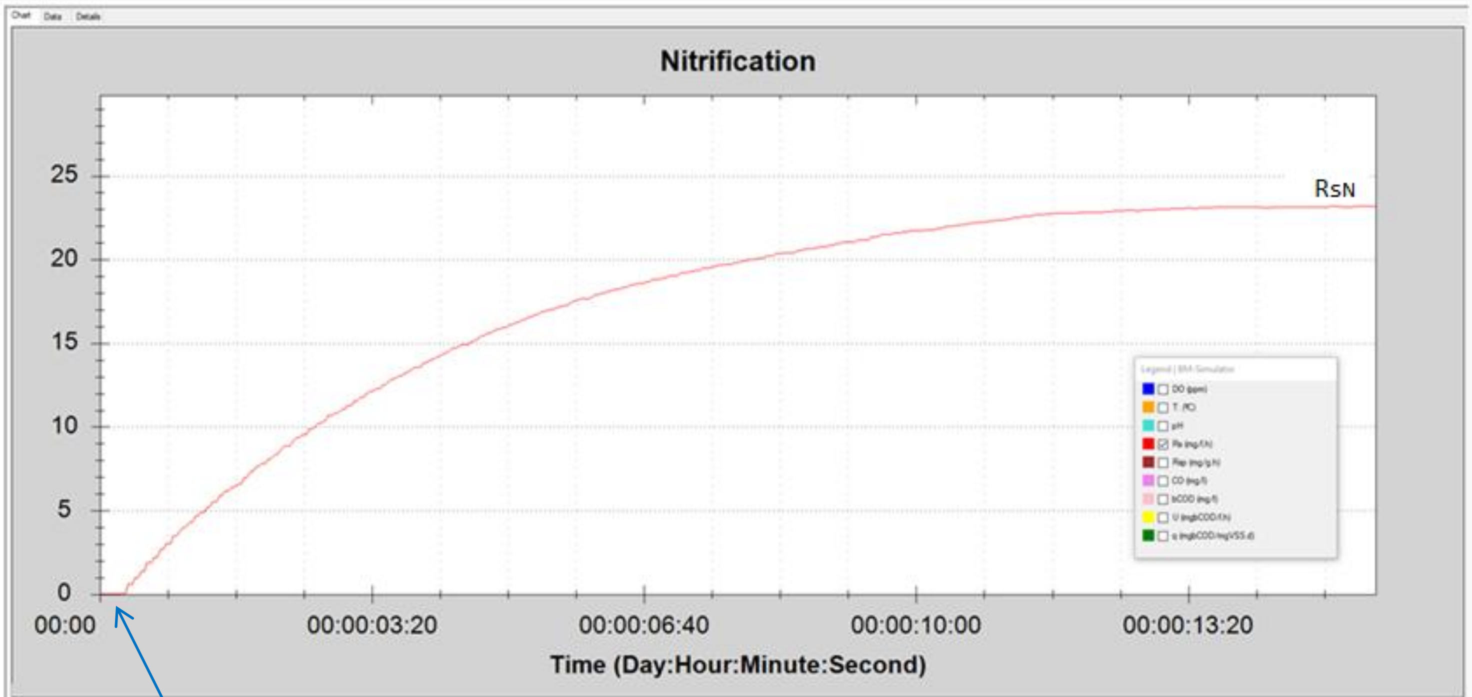
Actual nitrification rate

We carry out a R test with ammonium chloride on equivalent ammonium concentration, until we reach the representative Rs (Rs_N)



Rs respirogram

Ammonium chloride addition

Actual nitrification rate (mg N/l.h): **AUR** = (Rs_N / 4,57) * DO / (K_{OA} + DO)

Rs_N: Respiration rate due to nitrification (mg O_2/l.h)

4,57: mg O_2 / mg Ammonium oxidized

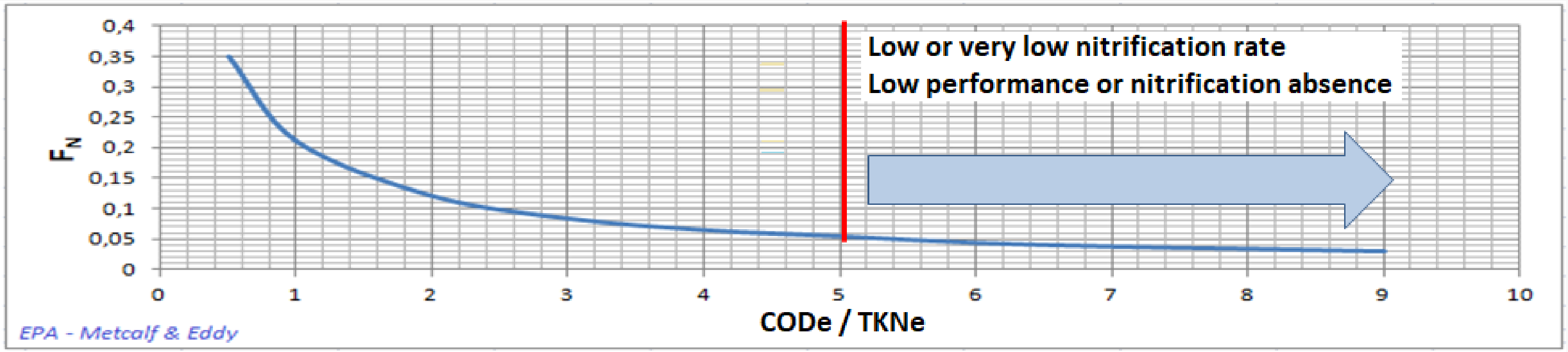
DO: Actual dissolved oxygen in the biological ractor

K_{OA}: Nitrification coefficient ≈ 0,5 (habitual default value)

Nitrifier biomass concentration and SRT for nitrification

When the rest of conditions are in nomal range, the autotrophic nitrifier biomass concentration (XA) depends of the ratio between eliminated COD and eliminated TKN

For a normal nitrifier biomass production and activity, this ration shoule be equal or lower than 5.



CODe: eliminated COD in the aerobic process
TKNe: eliminated TKN in the aerobic process

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

$$\mathbf{SRT} \approx X_A / (2.4 * \text{AUR})$$

X_A: Active nitrifier biomass (mg/l)
SRT: Minimum sludge age for nitrification (d)
2.4: Default value for ($Y_{A\text{-}VSS}$ * 24)

Required nitrification rate (AURr)

We can assume that the current nitrification performance is a direct consequence of the actual AUR and therefore, to meet any other performance, the first parameter we want to calculate the required AUR (AURr) that the process would need.

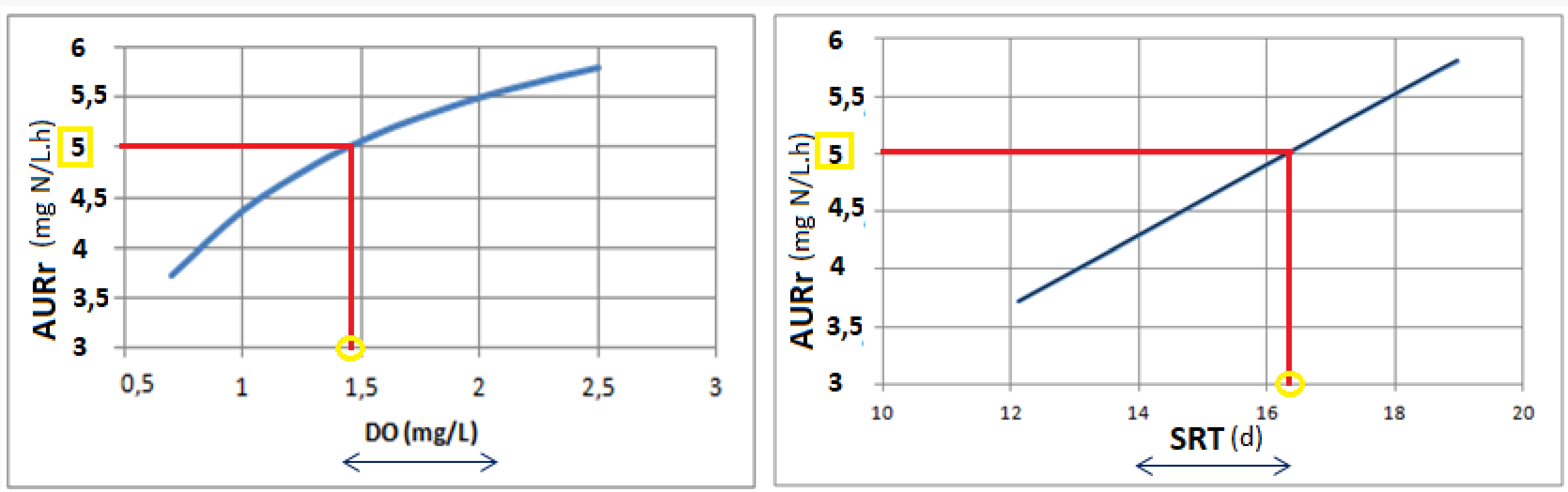
Under that purpose, assuming the nitrification performance is linked to the difference between the influent TKN and effluent ammonium nitrogen, the required AUR could be calculated as follows:

$$\mathbf{AURr = AUR\ (TKN_o - SNr_{ef})\ /\ (TKN_o - SN_{ef})}$$

AURr: Required AUR (mg NH_4-N/L/h)
AUR: Actual AUR (mg NH_4-N/L/h)
TKN_0: TKN in the influent (mg N/L)
SNr_{ef}: Required ammonium-nitrogen in the effluent (mg NH_4-N/L)
SN_{ef}: Actual Ammonium-nitrogen in the effluent (mg NH_4-N/L)

Energy optimisation by control of the Dissolved Oxygen (DO) and Sludge Age (SRT) for Nitrification

The way to save energy is based on the determination of the minimum oxygen in which the process must operate. It is based on obtaining an AURr vs OD graph based on the AUR equation in which, by varying the OD or SRT value, an AUR value equal (or close) to that of the AURr is obtained.



Example of minimum DO for AURr = 5 (mg NH_4/L/h)

AUR ≈ AURr = $[Rs_N / 4.57] * OD \Updownarrow / (K_{OD} + OD \Updownarrow)$

AUR ≈ AURr = $X_A / (2.4 * SRT)$

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