Procedure to analyze the effect of endogenous respiration on the oxygen requirement in an activated sludge process with nitrification

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Summary

It is well known that, when biological wastewater treatment includes nitrification, the operating parameters must be directed towards this process within the framework of the best energy optimization for a given performance.

The main pillars on which the nitrification process is based are the sludge age (SRT), dissolved oxygen (DO) and temperature (Temp.) Of these, the control parameters are sludge age and dissolved oxygen and, therefore, the determination of the influence of these parameters on the operation of the nitrification process becomes essential.

The general guideline is to try to optimize energy savings by trying to operate with as little oxygen as possible while maintaining the performance assigned to the process. However, it should be noted that oxygen handling must be accompanied by a change in sludge age; and, since the SRT is proportional to the concentration of the volatile suspended solids in mixed liquor (MLVSS), the endogenous respiration of its active biomass (OUR_{end}) also becomes a key parameter for the monitoring and evaluation of the energy optimization of the process.

1. Introduction

Nitrifying bacteria grow slowly and are also sensitive to environmental changes (pH, temperature, toxic compounds and inhibitors, etc.). Therefore, the SRT of a plant with biological treatment for nitrogen removal must be long enough to ensure the nitrification process and for biomass reproduction.

Here it is important to note that SRT equally affects heterotrophic bacteria and inert solids, which can cause a critical increase in the amount of MLVSS.

For a process with a limited hydraulic retention time (HRT), the average level of nitrification efficiency is linked to the nitrification rate and therefore to the respiration rate due to nitrification (RsN). For that reason, to maintain the nitrification efficiency, the nitrification rate should also be maintained. This respiration rate depends on the temperature, dissolved oxygen and concentration of nitrifying active biomass in the MLVSS. Thus, in order to maintain the assigned RsN for a given nitrification performance, the possible drop in the oxygen set point must be followed by an increase in the SRT and therefore in the MLVSS which in turn will cause an increase in its corresponding endogenous respiration rate (OUR_{end})

The fact is that, this endogenous respiration rate will generate an oxygen requirement (OR_{end}) which can reach an important percentage of the total oxygen requirement in the overall process.

All this generates the need for a procedure that allows analyzing the result of the comparison of the oxygen requirement between the current situation and the hypothetical one, where it is intended to program a dissolved oxygen set point at a value lower than the current one and raise the SRT in order to keep the same nitrification efficiency.

3.2. Parameters in play

It is a group of parameters that are needed for the development of the procedure that include data from the current process, parameters obtained by respirometry and theoretical data calculated for a supposed process where the dissolved oxygen is lower than the current one (Table1.)

Table 1. **Key parameters**

Data of the actual process	
V (m^3)	Volume of the aerobic biological reactor
Q (m^3/d)	Infuent flow
DO (mg/L)	Actual dissolved oxygen
MLVSS (mg/L)	Mixed liquor volatile suspended solids
SRT (d)	Sludge age
RsN_{max} (mg O_2/L.h)	Maximum respiration rate due to the actual nitrification
RsN (mg O_2/L.h)	Respiration rate due to the actual nitrification
OUR_{end} (mg O2/L/h)	Actual endogenous respiration rate
$OR_{OD,end}$	Actual oxygen requirement from DO and OUR_{end}
Data of a hypothetical process with a DO lower than the actual one	
MLVSS' (mg/L)	Mixed liquor volatile suspended solids
SRT' (d)	Sludge age
DO'(mg/L)	Dissolved oxygen - lower that DO -
RsN' (mg O_2/L.h)	Respiration rate due to the nitrification
OUR'_{end} (mg O2/L/h)	endogenous respiration rate
$OR'_{DO,end}$	Oxygen requirement from DO' y OUR'_{end}

2. BM multipurpose respirometer

The most appropriate respirometer for the procedure to be described may be any of the models of BM multifunction respirometry systems from Surcis (Figure 1.); since the technology of BM respirometry systems allows it to be adapted to different conditions of pH, Temperature, Oxygen and sample/sludge ratio. This respirometer also allows the possibility of entering certain data that can participate in automatic calculations of fundamental parameters in the treatment processes.

Figure 1. BM respirometer and automatic measurements performed by the software

3. Procedure

The purpose of the procedure that will be described in this paper is to compare and evaluate the change in the actual oxygen requirement in an activated sludge process with a limited HRT for nitrification, where nitrification efficiency (E_N) must be maintained, when it is decided to lower the level of dissolved oxygen in the belief that in this way energy savings will be achieved.

With this, two situations come into play:

1) the actual situation with its dissolved oxygen (DO), sludge age (SRT), volatile suspended solids (MLVSS) and a fixed nitrification efficiency (E_N)

2) the hypothetical situation in which the process operates with lower dissolved oxygen (DO); and therefore the age of the sludge (SRT') and the corresponding volatile suspended solids (MLVSS') must be raised to maintain the same nitrification efficiency as the actual one (E_N)

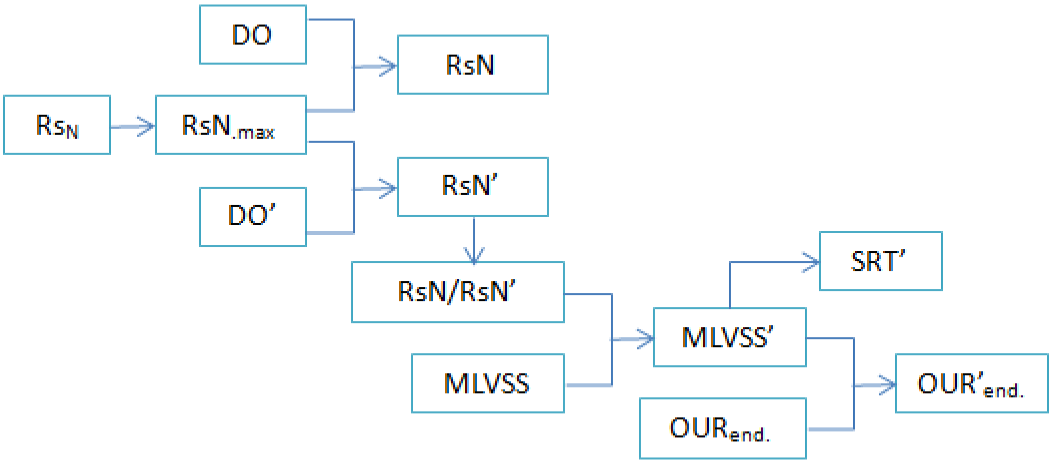
This procedure will show that, when oxygen decreases, the SRT and therefore MLVSS has to be increased to maintain the nitrification efficiency. Increased MLVSS leads to increased endogenous respiration of the corresponding active biomass and so will also the oxygen requirement for this concept.

The result of the comparison between the oxygen requirement from the DO and endogenous respiration ($OR_{DO,end}$) within the actual situation and the oxygen requirement from the OD' and endogenous respiration within the hypothetical situation ($OR'_{DO,end}$) will demonstrate that the hypothetical situation gives way to a critical increase in oxygen needs (Figure 2.)

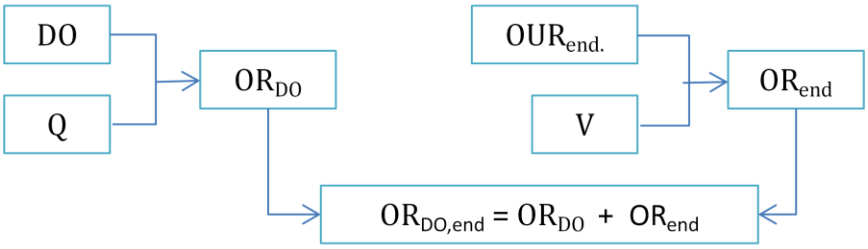
3.1. Procedure diagram

Figure 2. Procedure diagram

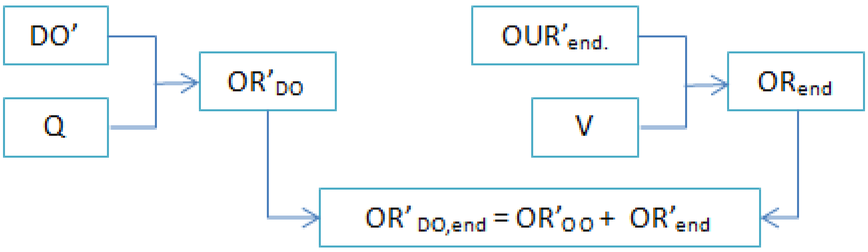
1. Determination of endogenous respiration (OUR'_{end}) and sludge age (SRT') in the hypothetical process.



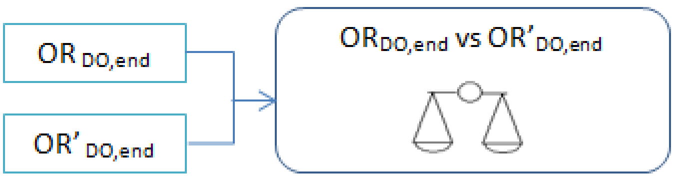
2. Determination of the oxygen requirement from dissolved oxygen and endogenous respiration in the actual process.



3. Determination of the oxygen requirement from dissolved oxygen and endogenous respiration in the hypothetical process.



4. Comparison and evaluation of OR from dissolved oxygen and endogenous respiration between the actual and hypotetical process.



With all this, to avoid this increase of oxygen requirement, the decision to low the dissolved oxygen must be accompanied by the condition of maintaining the SRT. And, above all, be fully aware that, the energy to be saved may be at the cost of a significant drop in nitrification efficiency.

3.1. Conditions

The procedure will be able to work in any case, but logically it will be more representative when nitrification is carried out within normal conditions for nitrification (Table 2.)

Table 2. Normal conditions for nitrification

Temperature	> 15 to 30 ºC
pH	7 - 8,5
DO	1 to 3 mg/L
CODe/TKNe	> 5
No inhibition, no toxicity	

In this procedure it is also assumed that the available HRT is limited for the assigned effciency.

3.4. Procedure performance

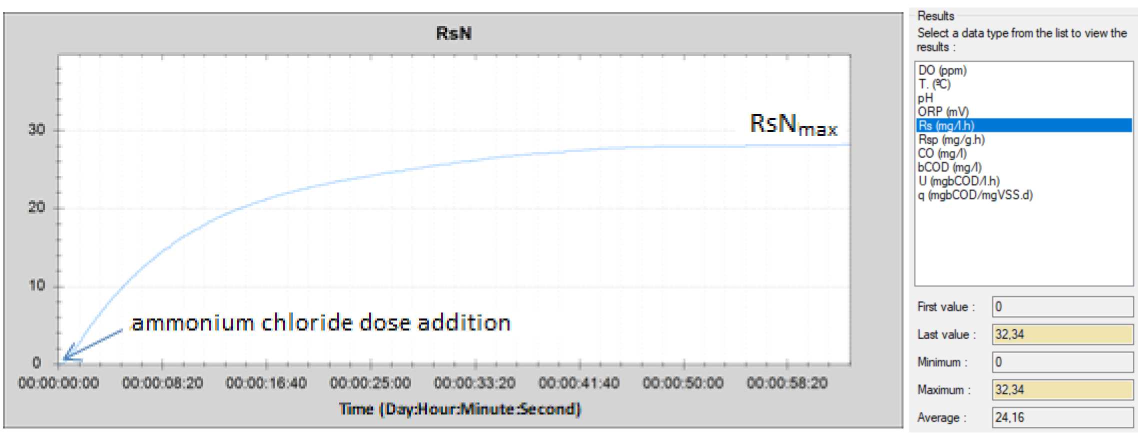
To carry out the procedure, we follow each of the parts specified in the diagram (Figure 2.)

3.4.1. Determination of endogenous respiration in the supposed theoretical process

Maxium respiration rate due to nitrification in the actual process: RsN_{max}

This maximum exogenous respiration rate is obtained with a respirometry test (in R mode) by adding to the activated sludge, under the endogenous respiration condition, a dose of ammonium chloride with an ammonia nitrogen concentration equivalent to that of the actual process.

Figure 3. Respirometry test for Rs_N



Actual respiration rate due to nitrification in the actual process : RsN

RsN (kg $O_2/m^3/d$) = (24 / 1000) * RsN_{max} * F_{DO}

Where:
F_{DO}: Correction factor from actual DO = DO / (K_{DO} + OD)
DO : Dissolved oxygen (mg O_2/L)
K_{DO} : Oxygen half saturation coeficient ≈ 0.5 (by default value, usually accepted)

Respiration rate due to nitrification in the hypothetical process : RsN'

RsN' (kg $O_2/m^3/d$) = (24 / 1000) * RsN_{max} * F'_{OD}

Where:
F_{DO}: Correction factor from the DO' in the hypothetical process = DO'/ (K_{DO} + DO')

MLVSS with which the hypotetical process must operate: MLVSS'

Volatile solids from activated sludge are in direct proportion to the respiration rate.

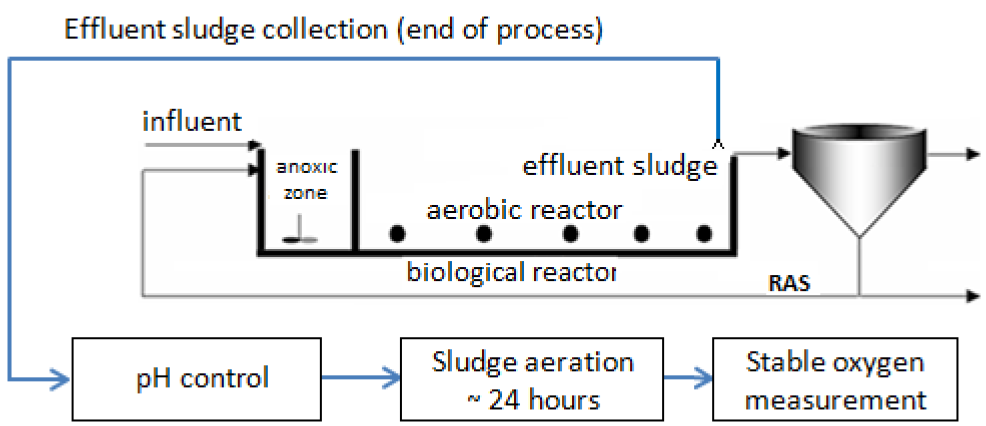
Therefore:
MLVSS' (mg/L) = (RsN / RsN') * MLVSS

Endogenous respiration rate in the actual process: OUR_{end}

It is the rate of respiration of the actual active sludge in the absence of any degradable substrate. Therefore, the consumption of oxygen over time is due solely and exclusively to the microorganisms contained in the sludge.

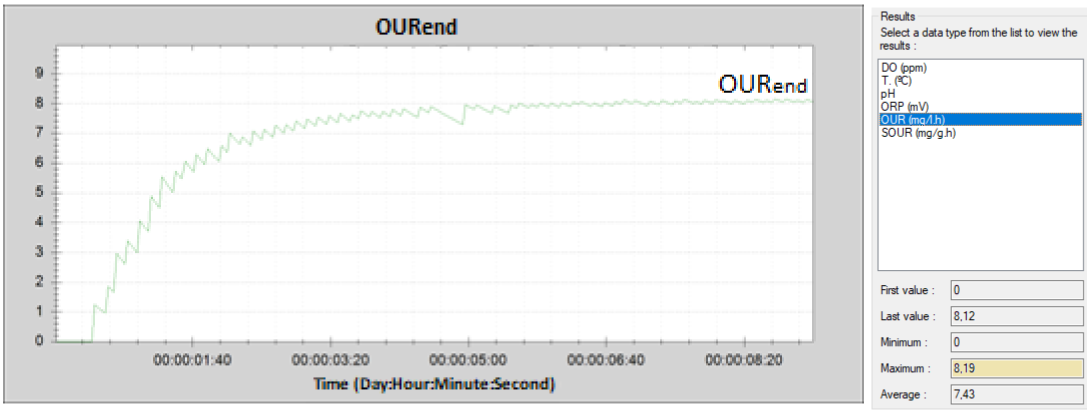
In a conventional activated sludge process, the endogenous sludge is normally achieved by collecting certain volume of effluent sludge and imposing it to a controlled aeration during ≥ 24 hours, under a normal pH control, until DO remain stable in the respiromer reactor (Figure 4.)

Figure 4. Steps to get the sludge under endogenous respiration



The respirometry test is performed with the endogenous sludge at pH and temperature equivalent to the actual process (Figure 5.)

Figure 5. Respirometry test for OUR_{end}



OUR_{end} (kg $O_2/m^3/d$) = (24/1000) * [max. stable result of OUR in the test]

<u>Endogenous respiration rate in the hypotetical process: OUR'_{end}</u>

The endogenous respiration rate is directly proportional to the MLVSS,
For this reason, it will vary proportionally.

OUR'_{end} = (MLVSS / MLVSS') * OUR_{end}

3.4.2. Oxygen requirement for dissolved oxygen and endogenous respiration in the actual process

Oxygen requirement (kg O_2/d): OR_{DO} = Q * DO / 1000
Oxygen requiremen for endogenous respiration (kg O_2/d): $OR_{end.}$= V * OUR_{end}

Combo OR from DO and endogenous respiration (kg O_2/d): $OR_{OD,end} = OR_{OD} + OR_{end}$

3.4.3. Oxygen requirement for dissolved oxygen and endogenous respiration in the hypothetical process

Oxygen requirement (kg O_2/d): OR'_{DO} = Q * DO' / 1000
Oxygen requiremen for endogenous respiration (kg O_2/d): $OR'_{end.}$= V * OUR'_{end}

Combo OR from DO and endogenous respiration (kg O_2/d): $OR'_{DO,end} = OR'_{DO} + OR'_{end}$

3.4.4. Comparison of the OR by dissolved oxygen and endogenous rerespiration between the real process and the hypothetical process under the assumption of the same nitrification efficiency in both cases

This comparison will show that, for the same nitrification performance [E_N], the OR' is higher than OR.

Comparison: $OR'_{DO,end}$ [E_N] > $OR_{DO,end}$ [E_N]

The reason for this is that, in the hypothetical process where the OD is lower than the current OD and where the efficiency of the process should be maintained, the age of the sludge and therefore also the endogenous respiration must be increased.

4. Example of what the lowering of the DO set point from the current value of 2.2 mg/L to a value of 1 mg/L would represent in a real plant.

By following the before described procedure, the strategy will be to compare the current process, which is operating with an DO of 2.2 mg/L, MLSSV of 3720 mg/L and SRT of 15 d with an assumed process operating with a DO of 1 mg/L in order to obtain the same nitrification performance in both cases.

4.1. Actual process

Data of the actual process [Courtesy of DAM company]

Type of the proctreatment system: Extended aeration plant
Temperature: 21 ºC
Dissoved oxygen: DO = 2.2 mg/L
Mixed liquor volatile suspended solids: MLVSS = 3720 mg/L
Sludge age: SRT = 15.3 d
Loading rate: F/M = 0.07
Nitrification afficiency: E_N = 97 %

Maximum respiration rate fue to nitrification: RsN

The following result are obtained from the respirometry R test:

RsN_{max} = 28 mg/L/h

$RsN = RsN_{max} * F_{DO} = 28 * 0.81 = 22.68$ mg N-NH_4/L/h

Where:
$F_{OD} = DO/(0.5 + DO) = 2.2 / (0.5 + 2.2) = 0.81$

Endogeous respiration rate: OUR_{end}

The following result are obtained from the respirometry OUR test:

OUR_{end} = 8 mg/L.h = 0.19 kg O_2/m^3.d

Oxygen requirement from DO and OURend: $OR_{DO,end}$

Oxygen requirement from DO: OR_{DO} = Q * DO / 1000 = 5500* 2,2 / 1000 = 12 kg O_2/d

Oxygen requirement from OUR_{end}: $OR_{end.}$= V * OUR_{end} = 8900 * 0.19 = 1691 kg O_2/d

$OR_{DO,end}$ = AOR_{OD} + AOR_{end} = 12 + 1691 = 1703 kg O_2/d

4.2. Hypothetical process

Dissolved oxygen: DO'

This is the starting point for the entire calculation of the rest of parameters.

OD' = 1 mg/L

Respiration rate due to nitrification: RsN'

RsN' = RsN.max * F'_{DO} = 28 * 0,67 =18.76 mg N-NH_4/L/h

F'_{DO} = DO'/(0,5 + OD') = 1 / (1 + 0,5) ≈ 0,67

MLVSS'

To maintain the current efficiency (E_N = 97%), the actual RsN should be maintained.
To do this, we take into account that the value of the RsN is proportional to the MLVSS and, therefore, the concentration of volatile solids in this hypothetical situation must be raised by applying the corresponding proportionality factor:

MLVSS' = (RsN/RsN') * MLVSS = (22.68/18.76) * 3720 ≈ 4500 mg/L

Loading rate: F/M'

The loading rate is inversely proportional to the concentration of the volatile suspended solids. Therefore:

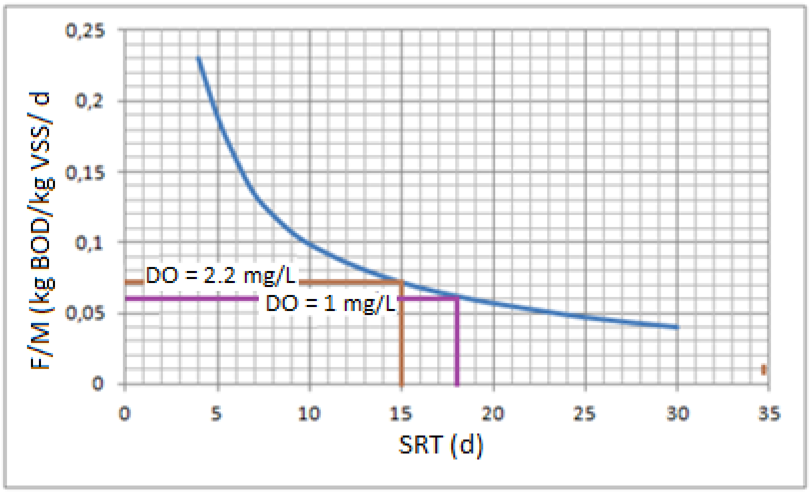
F/M' = (MLVSS / MLVSS) * F/M = (3720/4500) * 0.07 ≈ 0,06 kg BOD/kg VSS/d

Sludge age: SRT

The SRT to which the process must conform can be estimated from the graph in Figure 2

SRT’ ≈ 18 d

Figure 6. F/M vs SRT



Source: FUNDAMENTOS DE LOS FANGOS ACTIVADOS - E. Ronzano y J.L. Dapena

Endogenous respiration rate: OUR'_{end}

OURend will rise in the same proportion as that of the SSVLM':

OUR'_{end} = (RsN/RsN’) * OUR_{end} = (22.68/18.76) * 0,19 = 0.23 kg $O_2/m^3/d$

Summary of the results of the hypothetical process conditions

Dissoved oxygen: DO = 1 mg/L
Mixed liquor volatile suspended solids: MLVSS = 4500 mg/L
Sludge age: SRT = 18 d
Loading rate: F/M = 0.06
Nitrification afficiency: E_N = 97 %
Endogenous respiration rate: OUR'_{end} = 0.23 kg $O_2/m^3/d$

Oxygen requirement from DO' and OUR'$_{end}$: OR'$_{DO,end}$

Oxygen requirement from DO': OR_{DO} = Q * DO' / 1000 = 5500 * 1 / 1000 = 5.5 kg O_2/d

Oxygen requirement from OUR'$_{end}$: $OR_{end.}$= V * OUR_{end} = 8900 * 0.23 = 2047 kg O_2/d

OR'$_{DO,end}$ = OR'$_{OD}$ + OR'$_{end}$ = 5.5 + 2047 = 2052 kg O_2/d

Comparison of $OR_{DO,end}$ vs OR'$_{DO,end}$

OR'$_{OD,end}$ > $OR_{OD,end}$

Diference = AOR'$_{OD,end}$ – $AOR_{OD,end}$ = 2052 - 1703 = - 349 kg O_2/d

4.4. Conclusiones

In an activated sludge process with a hydraulic retention time, by adjusting the conditions (SRT and MLVSS) for the assigned efficincy to nitrification (97%), in this article it is shown that less oxygen is required operating with the current DO of 2.2 mg/L than operating with DO of 1 mg/L.

The reason for this is that, at 1 mg/L, to obtain a nitrification rate and equivalent efficincy to that achieved with the 2.2 DO, the SSVLM must be raised. This gives way to a higher rate of endogenous respiration and a higher oxygen requirement for oxygen.

An additional benefit of operating with 2.2 mg/L oxygen instead of 1 mg/L oxygen is to provide greater stability and homogenization of the mixed-liquor and better prevention of possible load peaks.

7. Follow-up

The follow up is essential to obtain a certain nitrification performance within the framework of energy optimization.

The basic parameter to initiate this monitoring is the nitrification rate required to obtain the assigned performance (E_N) and to set this nitrification rate as a reference (AUR_{ref})

Provided that the nitrification conditions and the aeration system allow it, the possible strategy can be based on the following points:

1)

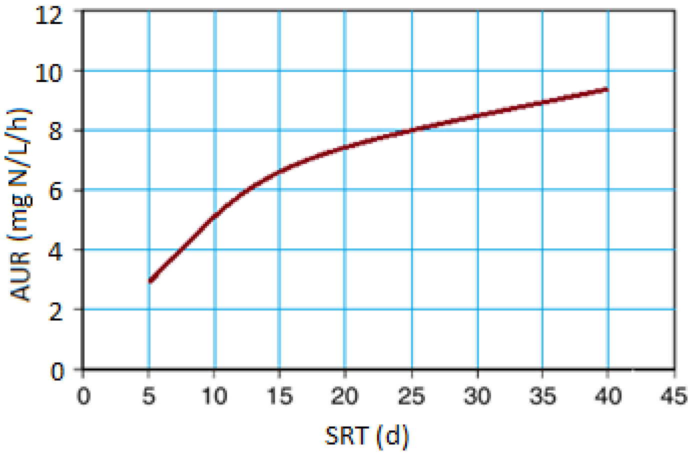
In practical terms, it is taken into account that the AUR is proportional to the nitrification efficiency. Therefore, the reference AUR (AUR_{ref}) can be calculated from the value of the current AUR (AUR), the current nitrification efficincy (E_N) and the one assigned for nitrification ($E_{N.ref}$)

$AUR_{ref} = AUR / (E_N / E_{N.ref})$

E_N (%): Actual nitrification efficiency.
$E_{N.ref}$ (%): Assigned reference nitrification afficieny.

2)
Set the SRT corresponding to AUR_{ref} (Figure 7.)

Figure 7. AUR vs SRT



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3)
Readjust the value by raising or lowering the OD, within its normal range, by including it in the correction coefficient on the current AUR_{max}.

$AUR_{ref} = AUR_{max} * (OD \updownarrow / 0.5 + OD \updownarrow)$

All this could be carried out with an Excel spreadsheet, and thus generate the corresponding graphs that will facilitate the development of the procedure operation.

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