BM Respirometry
applied to a novel control strategy of nitrification in a wastewater biological treatment

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Abstract

In wastewater treatment plants, the biological nitrogen removal (BNR) has acquired critical importance, which makes that in the majority of the cases the overall process control largely depends on the control of this treatment. The normal aerobic process of nitrification is performed by specific aerobic living microorganisms and a lack of information on their bioactivity may be cause of confusion in terms of control and monitoring criteria. For this reason, the application of the BM Respirometry, for the goal of getting a determined performance within the frame of energy optimization, has achieved an important role for essential information about the actual nitrification situation but also in other situations under different conditions for the process development.

1. Introduction

The nitrification processes control must be based on a sufficient removal substrate rate to fit the actual hydraulic retention time of the biological reactor available for nitrification: Nitrification rate = ammonium-nitrogen uptake rate (AUR)

Either the nitrification rate is the correct on which the process has to run, the plant operator should find its value. He also has to know if it is enough or not; and in case of not enough, he has to find out the causes and the possible solutions.

For that purpose, a BM respirometer can be the perfect instrument to measure the actual nitrification rate and also to analyze if this has a higher or lower value than it is required in any specific process. By other side, assuming that we cannot control de pH and temperature, the nitrification drivers are the dissolved oxygen and the sludge age (SRT) and these parameters should be well determined within the frame of the energy optimization.

2. BM respirometer

BM respirometers series include three main models: BM-T+, BM-EVO and BM-Advance.
Any of those can perform the application of the nitrification control; but, because of the pH control feature in the BM-Advance, it is probably this model the most indicated for it.

Figure 1. BM-Advance respirometer

2.1. Main BM-Advance features

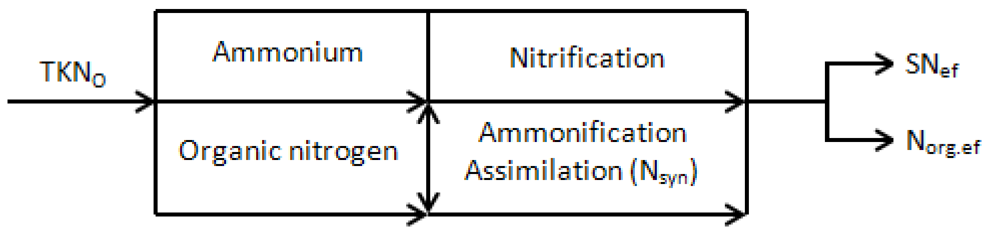
- Compact analyzer, with very low maintenance and user friendly operation
- Direct oxygen measurements from a maintenance-free oxygen sensor
- No oxygenation restriction during test performance
- Full control and results by means a powerful software already loaded in the PC
- Automatic software update versions from internet
- Capacity for test conditions setting and modify them throughout the test performance.
- Three different operation modes: R, OUR and Cyclic OUR
    1. R mode: Modified LFS system - Automatic measurements of Rs (exogenous respiration rate), CO (consumed oxygen), bCOD (biodegradable and readily biodegradable COD), U (COD utilization rate) and q (specific U)
    2. OUR mode: LSS system - OUR (oxygen uptake rate) & SOUR (specific OUR)
    3. OUR cyclic: Cyclic LSS system - OUR & SOUR within a continuous sequential chain of measurements
- Last, minimum, maximum and moving average results at any time during the test
- Several results at any time during the test and option to see them simultaneously on tabular or graphic modes
- Option to open several stored tests and compare their results
- Automatic temperature control integrated in the own console
- pH monitoring and automatic control system
- Package of measurements at any moment during test performance
- Capacity for different respirograms and their simultaneous overlying
- BM respirometers measure data that can be directly input into modeling – simulating software
- Option for a special reactor assembly for moving beds bio-films (MBBR)

3. Basic parameters

3.1. 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 can be calculated as follows:

Figure 2. Ammonium-nitrogen to nitrify



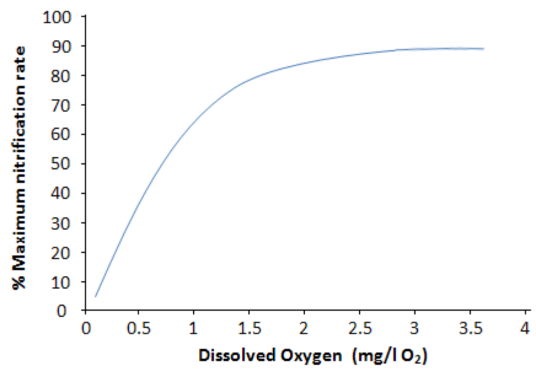
SN = $TKN_o - SNr_{ef} - N_{org.ef}$

SN: Ammonium-nitrogen to nitrify (mg NH_4-N/L)
TKN_o: Total Kjeldahl Nitrogen in the influent to biological reactor (mg N/L)
SNr_{ef}: Required Ammonium-nitrogen in effluent (mg NH_4-N/L)
$N_{org.ef}$: Soluble organic nitrogen in effluent (mg N_{org}/L)

3.2. Respiration rate due to nitrification for a DO range 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.

Figure 3. Maximum nitrification rate vs dissolved oxygen

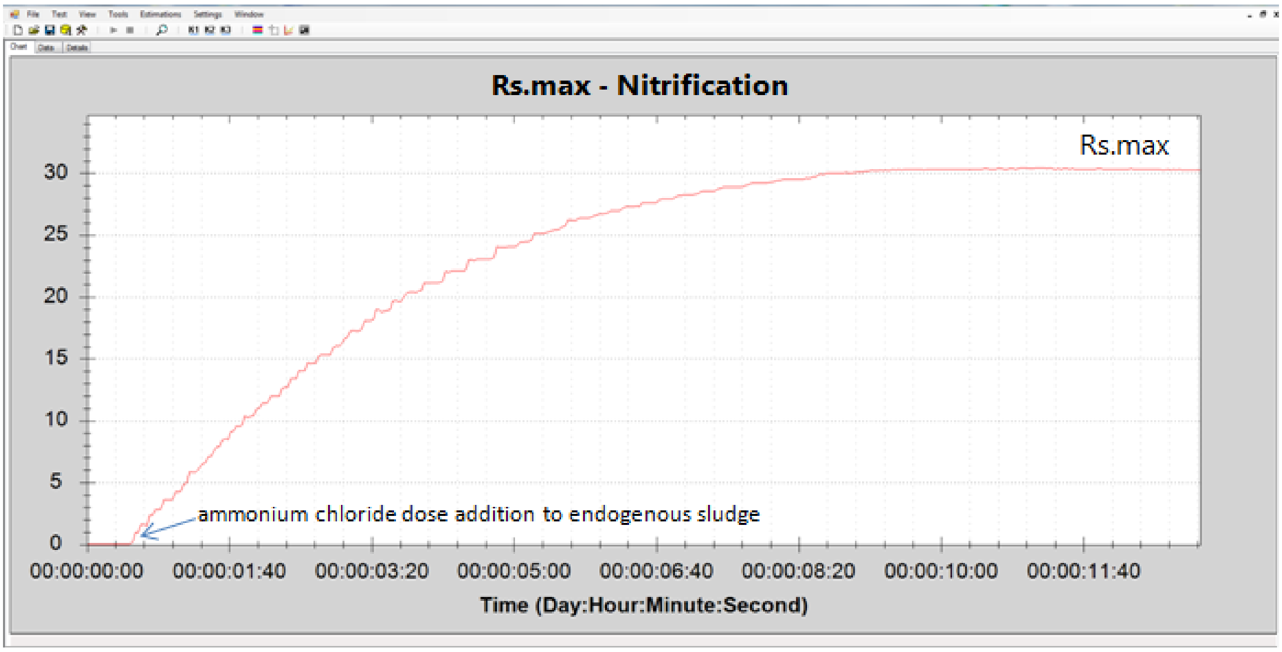


We can assume that the respiration rates values, under same conditions of pH and temperature, are not getting significant variations and we can get a maximum representative exogenous respiration rate by performing one R mode test with a DO > 3 mg/L

To carry out this R test, we will make use of the endogenous sludge from the effluent of the biological reactor and ammonium chloride as ammonium-nitrogen substrate on equivalent concentration (*)

(*) Here, we will have into account that each mg of NH_4Cl corresponds to 0.26 mg of NH_4-N.
$[NH_4Cl]$ (mg/L) = SN (mg/L) / 0.26

Figure 4. Rs_{max} respirogram due to nitrification



3.3. Nitrification rate for a specific DO

Based on Monod equations, the K_{OA} constant is used to calculate the nitrification rate (AUR) corresponding to any determined DO value (DO) on which the process could operate.

AUR = $(Rs_{max} / 4.57) * DO / (K_{OA} + DO)$

AUR: Nitrification rate (mg N/L/h)
4.57: mg of O_2 for each mg of nitrifying nitrogen to be oxidized
K_{OA}; Half saturation constant (mg/L) ≈ 0.5 (ASM3)

3.4. Actual nitrifier biomass concentration

Research confirmed that the endogenous respiration rate has a direct proportionality with the active biomass (Michael W. Barnett et al. 1998, Vanrolleghem & W. Verstraetet et al 1992)
Based on this principle, we can calculate the part of nitrifier biomass from the total MLVSS by performing two OUR test (Figure 5): One normal test from endogenous sludge and another one from a well acclimated endogenous sludge where we had added a dose of Allyl Thiourea (AUT) to inhibit the nitrifiers.

Endogenous OUR of the nitrifiers is obtained from the difference between the OUR results of those tests:

$OURend_A = OURend - OURend_H$

$OURend_A$: Endogenous OUR from nitrifier biomass
OURend: Endogenous OUR from total MLVSS
$OURend_H$: OUR end from the sludge with ATU

From here, now we calculate the ratio corresponding to the part (Fn) of nitrifier biomass in the total MLVSS.

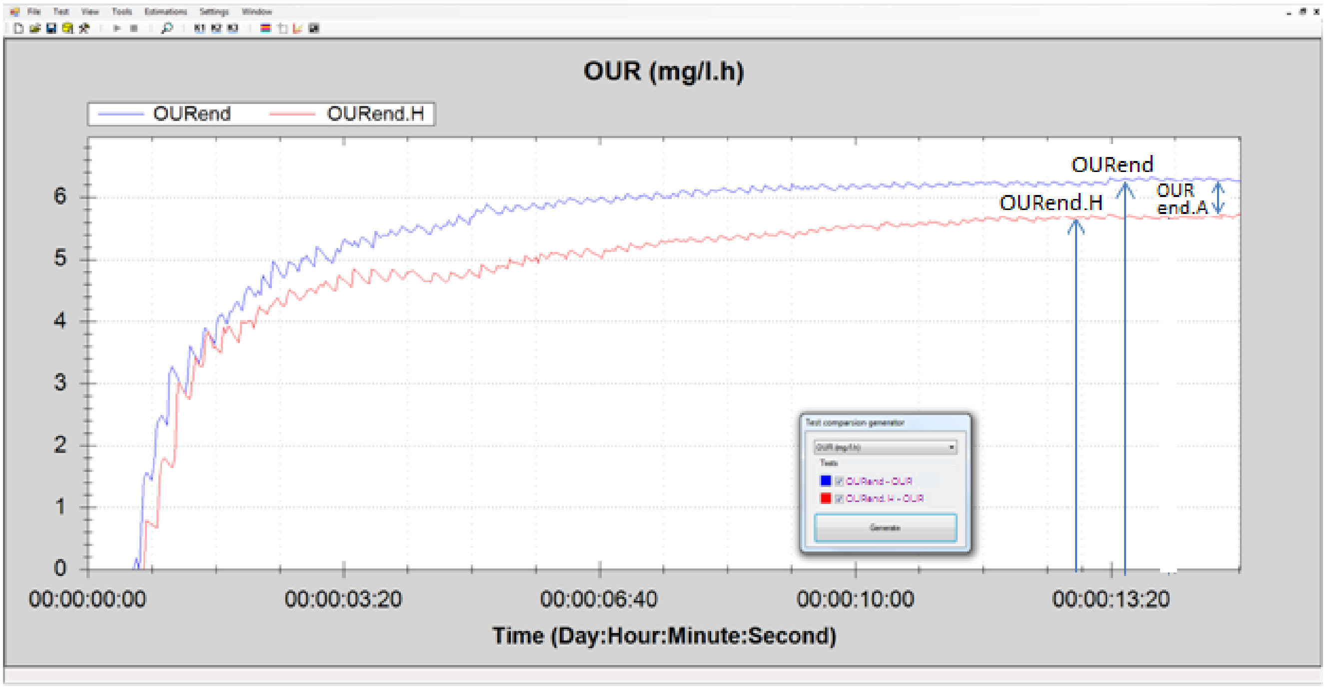
$Fn = OURend_A / OURend$

Now, multiplying Fn by the MLVSS concentration, the nitrifier biomass concentration is then obtained:

X_A = Fn * MLVSS

X_A: Actual concentration of the nitrifier biomass (mg//L)

Figure 5. OURend and $OURend_H$ respirograms overlaid for $OURend_A$ calculation



4. How to achieve a given performance in the nitrification process

Most of the times is the Water Agency or any other Official Water Institution who fix the ammonium for a limited restricted value in the effluent. As a result of this, plant operator must calibrate the process to meet the ammonia affluent under this restricted level.

In all these respects, it goes without saying that the nitrification performance is highly dependent from the nitrification rate and to the required ammonium nitrogen concentration in the effluent. From this principle, we can assume that for any specific performance it should be a required AUR and it would be in plant operator hands to play on some determined conditions and operative parameters to get this required nitrification rate.

Since most of the times is not `pssible to change some critical conditions such as the incoming pH and temperature, the tools to get the AUR value for a specific performance will lie on the DO and solids residence time (SRT) management.

4.1. Required AUR

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 is the required AUR that the process would need.

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

AURr = AUR (TKN_o – SNref) / (TKN_o – SNef)

AURr: Required AUR (mg NH_4-N/h)
AUR: Actual AUR (mg NH_4-N/L/h)
SNref: Required ammonium-nitrogen in the effluent
SNef: Actual Ammonium-nitrogen in the effluent

To achieve the AURr represents the first goal where control actions should be conducted

4.2. Procedures to get the required nitrification rate

Within the target of achieving a determined nitrification performance, we can get the corresponding required nitrification rate (AURr) be mean DO or MLSV concentration changes.

To choose one or the other way will depend of the priorities and power resources of the plant. If there is enough electrical power and there is enough capability for it, DO can be selected when the energy optimization of the plant is a critical point. But for when the range to play with the DO range is very low we should go to SRT.

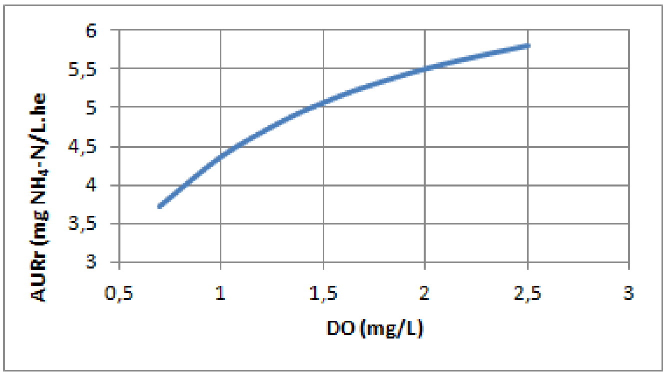
4.2.1. AURr calculation from DO

In this case the AUR equation is converted into AURr:

AURr = (Rs_{max} / 4.57) * DO / (K_{OA} + DO)

The strategy is to change the DO in the equation, within a set of coherent values on which the process could operate, in order to figure out the corresponding AURr (Figure 6)

Figure 6. Example of AURr vs DO



Temperature = 23 °C
K_{OA} = 0.7 mg/L
Rs max = 34 mg/L
Actual DO = 1.5 mg/L
Actual AUR = 5.07 mg NH_4-N/L.h

Then, once we have got the DO value, then we can fix it in the real process to make its effect after giving a coherent time to grow its nitrification activity.

The main advantage of this procedure is that making use of it we open the door to the ability of selecting the minimum DO for a sufficient nitrification performance and, in this way, go for the maximum possible energy saving in the aeration system of the biological reactor.

4.2.2. AURr calculation from SRT

Here the goal is to calculate the SRT to meet a targeted AURr for a specific nitrification performance, and the procedure starts with the equation that links the SRT with X_A. In this, it is assumed that the SRT is practically the inverse of the nitrifier biomass growing rate (μ_A)

$$SRT \approx 1 / \mu_A$$

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

μ_A: nitrifier biomass growing rate (d^{-1})
$Y_A \approx$ yield coefficient $\approx$ 0.1 ($mgVSS_2/mg$ N)

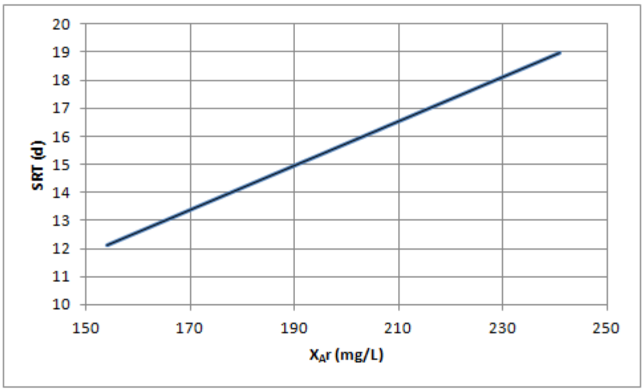
Fixing AUR as the actual nitrification rate, the formula can be arranged for STRr and X_Ar

$$SRTr = X_Ar / (Y_A * 24 * AUR)$$

X_At: X_A required (mg/L)

Now it is important to realize that the increase of SRTr includes the increase of MLVSS and so XAr. Then, it should be taken into account that, as the nitrifiers concentration goes up, the nitrification rate will also go up accordingly. Having said that, taking the actual AUR as a fixed value and the actual X_A as the starting reference, it can be plotted a graph SRTr vs X_Ar (Figure 7)

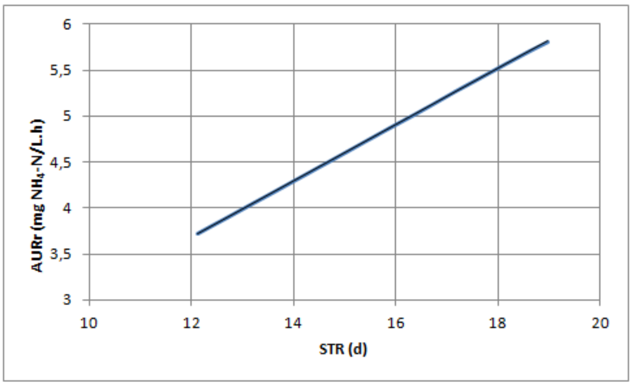
Figure 7. Example of SRTr vs X_Ar



Temperature = 23 °C
Actual AUR = 5.07 mg NH4-N/L.h
Actual X_A = 210 mg/L

Then, from the set of SRTr values, it is obtained a set of AURr values by keeping the same proportion as the corresponding values of X_Ar and then those values can also be plotted (Figure 8)

Figure 8. Example of SRTr vs AURr



Temperature = 23 °C
Actual SRT = 16.5 d
Actual X_A = 210 mg/L
Actual AUR = 5.07 mg NH_4-N/L.h

The described procedure permits operating under minimum SRT, and so the minimum the MLVSS in the reactor.

The important advantages to operate the process under minimum MVSS is that the energy of the aeration systems is optimized on the application of the oxygen requirement to the endogenous respiration in the microorganisms and, by other side, to reduce the sludge production..

5. Conclusions

The applications described in this paper demonstrates that by means three simple and short respirometric tests made by an advanced multipurpose respirometer, it is possible to carry out some critical applications addressed to calculate the minimum bulk DO and SRT to meet a determined nitrification performance.

The novel strategy based on linking a determined nitrification performance to a required nitrification rate (AURr) is conducted through two different methods addressed to find out the minimum DO and SRT on which the process could be operated to achieve this performance.

The procedure for the SRT includes a relative novel method, based on the endogenous respiration rates of the sludge, to get the nitrifier biomass concentration (X_A) that could be more simple and precise than others described in bibliography.

The important benefit from this strategy is to get the capability to plot some important graphs that allow setting the process under the better conditions to run within the frame of energy optimization and minimize the sludge production.

6. References

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