Application of advanced Respirometry in the Nitrification assessment for different levels of Temperature, pH and Oxygen

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Abstract

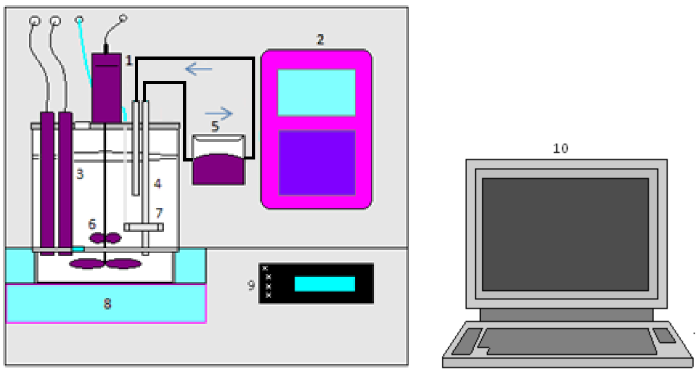
Environmental factors control the rate of nitrification.
For a determined substrate concentration, the most significant environmental factors are temperature, pH and oxygen availability. The well known critical influence of those factors on the nitrification are here analyzed by making use of a specific software and advanced respirometry based on a dynamic LFS system, where the test conditions can be set in the corresponding test-settings board and their levels modified throughout the test performance. In this way, it is possible to get and asses the trajectory of the dynamic exogenous respiration rate coming from the ammonia removal for different levels of temperature, pH and oxygen. Then, from each respiration rate value the nitrification rate and nitrification capacity are determined.

For a better understanding, the present study is conducted by means the summary of three different real cases of study related with the nitrification process for each of the those critical factors. On each of the cases, by making use of the advanced software, we can get the correspondent respirograms and results, to be precisely analyzed and assessed.

1. Materials and Methods

Respirometer

The methods and cases of study described in this paper were carried out with parameters and calculations resulting from respirometric tests performed by means a BM-Advance respirometer (from Surcis, S.L.)



1. Stirring motor - 2.Oxygen & pH controller - 3.Oxygen & pH sensors - 4.Inlet & Outlet recirculation tubes – 5.Peristaltic pump - 6.Stirring paddles - 7.Air diffuser - 8.Automatic cooling and heating system - 9. Display – 10.PC with BM software.

Figure 1. BM-Advance respirometry system

This respirometer is able to conduct tests within different ranges of temperature, pH and DO; and, if required, it also gives the option to modify the values of those variables during the test performance.

The analyzer can be programmed on three different operation modes: OUR, Cyclic OUR and R.
In the present study only the R mode was used.

The R mode is based on a modified LFS batch respirometry type where the dissolved oxygen is measured in liquid media which is continuously aerated, stirred and recirculated.
The exclusive feature of the R operation mode is based on the fact that, when sludge under endogenous respiration is used, the stable resultant dissolved oxygen of the sludge without adding any substrate is taken as base line. Then, when substrate is added, the test actually begins and the software is able to calculate the exogenous respiration rate directly related to the biological substrate removal for a maximum DO concentration over time. When the substrate is a standard compound which contains an equivalent ammonium-nitrogen, the dynamic exogenous respiration rate is exclusively related to nitrification rate.

2. Nitrification rate and nitrification capacity

This study is mainly based on the determination of the nitrification rate and nitrification capacity, based on the following formulas:

AUR = Rs / 4.56 (3)
$\mathbf{N_C}$ = AUR * HRT_N (4)

Where

AUR: Actual nitrification rate (mg/L.h NH_4-N)
Rs: Actual respiration rate due to nitrification (mg/L.h O_2)
4.56: mgs of oxygen utilized per each mg of NH_4-N during nitrification
N_C: Nitrification capacity (mg/L NH_4-N)
HRT_N: Hydraulic retention time available for nitrification (h)

3. Case of study 1 - Influence of a low temperature range on the nitrification

In this case of study it is analyzed the influence of three different temperatures on the nitrification rate for a fixed pH and ammonia substrate concentration.

The analysis is carried out by means a single R respirometric test starting with a determined volume of activated sludge under endogenous respiration to which it was added one dose of ammonium chloride solution with equivalent ammonia concentration.

The test was initially set to a temperature of 6ºC and then, as the dynamic exogenous respiration rate (Rs) reached its maximum value, it was raised to 11 ºC and 16 ºC.

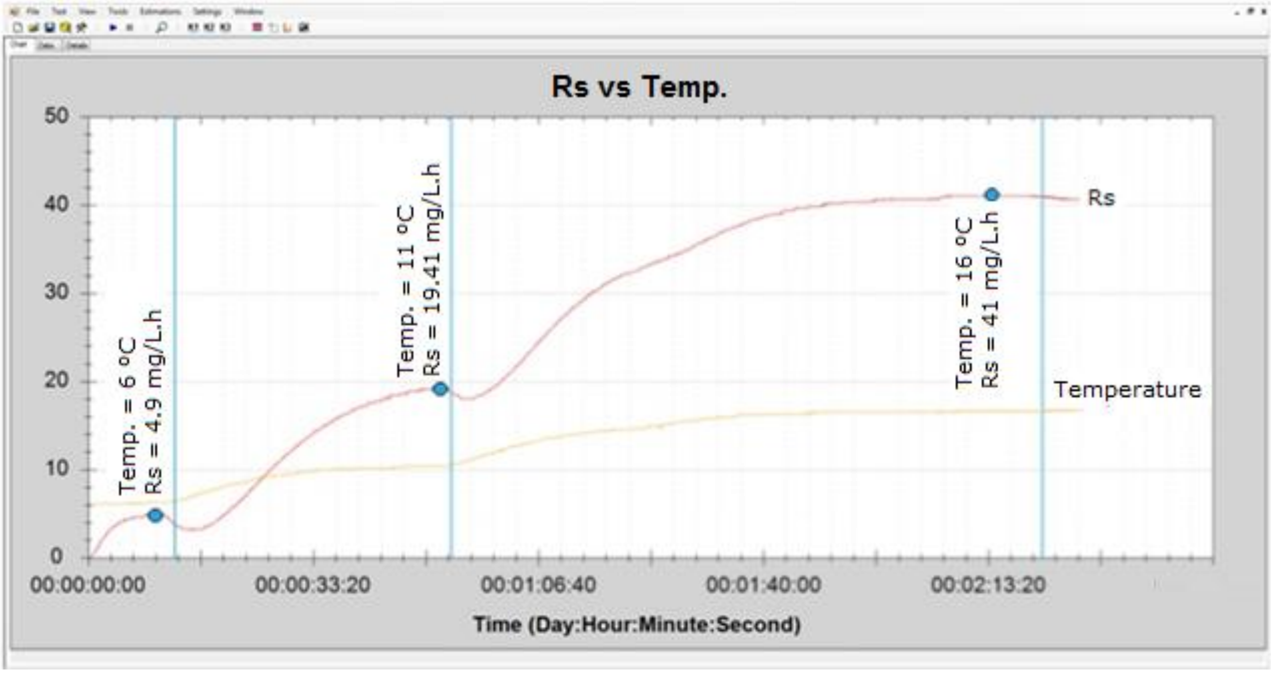


Figure 1. Respirogram of the R test to study the Influence of the temperature in the Rs due to nitrification

As we could see in the respirograms (Figure 1), the software allows the simultaneous display of the respiration rate (Rs) and temperature during the test performance over the time.

The Rs results are the calculation base of the corresponding nitrification rates (AUR) and nitrification capacities (N_C) for an operative hydraulic retention time (HRT_N) of 9 hours available in the nitrification ((Table 1.)

Parameter	Description	6ºC	11 ºC	16ºC
Rs (mg/L.h)	Exogenous respiration rate	4.9	19.41	41.02
AUR (mg/L.h NH_4-N)	Nitrification rate	1.07	4.24	8.97
N_C (mg/L NH_4-N)	Nitrification capacity	7.70	30.52	64.58

Table 1. Table of parameters figured out from the respirometric test Temperature-Rs due to nitrification.

Now, for a determined concentration of ammonia (S_N) to be removed and by making use of the N_C values in Table 1, it is possible to assess if the actual process is able or not to remove it for a fixed performance. The logical condition to get the required performance would be that S_N is equal or lower than N_C.

4. Case of study 2 – Influence of the pH in the nitrification

This specific case analyzes not only the influence of different pH levels on the nitrification but also the maximum pH by which the process begins to lose its nitrification activity (*)

(*) In the same way, it would also be possible to determine the minimum pH by which the nitrification process starts to be inhibited.

The respirometric test follows similar procedure to that used in the temperature study, by making use of a dose of ammonium chloride solution with equivalent ammonia concentration.

The analysis of the pH influence is performed by going to different levels of pH within the own respirometric test and automatically obtaining the corresponding exogenous respiration rates (Rs) due to nitrification.

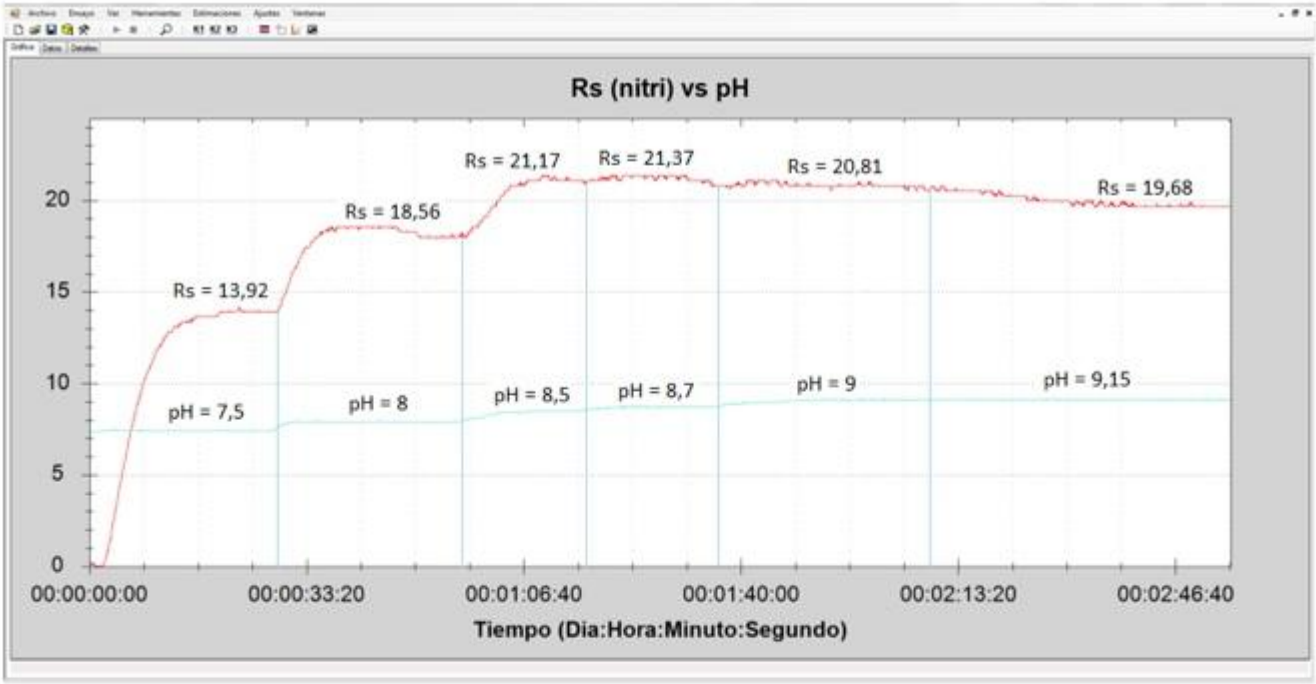


Figure 2. Respirogram of the test to study the influence of the pH in the Rs due to nitrification

In the same way as it has done in the Temperature case, from the different Rs values, we can now calculate the corresponding nitrification rates (AUR) and nitrification capacities (N_C) and make a table where we could apply the same condition for any required performance.

5.1. Case of study 3 - Influence of the dissolved oxygen in the nitrification and determination of the minimum oxygen for the process.

In this case of study, the concentration to nitrify was 45 mg/L NH_4-N, within a HRT of 9 hours, and an operative DO range in between 0.5 y 1.6 ppm.

This case is mainly approached to a degree of energy optimization by conducting the study to analyze the influence of different levels of oxygen in the nitrification to finally determine the minimum DO with which the process could operate within certain performance range.

The objectives of the study were done by following a procedure in which certain critical parameters have to be calculated.

5.1.1. DO half-saturation constant (K_{OA})

This constant can be calculated from a mass balance of the current process from the nitrification rate at maximum DO and current data of Oxygen, S_N and the HRT in the nitrification process.

$$\mathbf{K_{OA}} = DO_{act} (AUR_{DO.max} - S_N / HRT_N) / (S_N / HRT_N) \qquad (5)$$

Where:

K_{OA}: DO half-saturation constant (ppm)
$AUR_{DO.max}$: Nitrification rate at maximum DO (mg/L.h NH_4-N)
DO_{act}: Bulk liquid dissolved oxygen in the nitrification process (ppm)
HRT_N: Hydraulic retention time for nitrification (h)

5.1.2. Nitrification rate at maximum oxygen ($AUR_{DO.max}$)

This parameter can be obtained by means a single dynamic respirometry test with activated sludge under endogenous respiration and a dose of ammonium-chloride on equivalent concentration to the ammonia concentration to be nitrified.

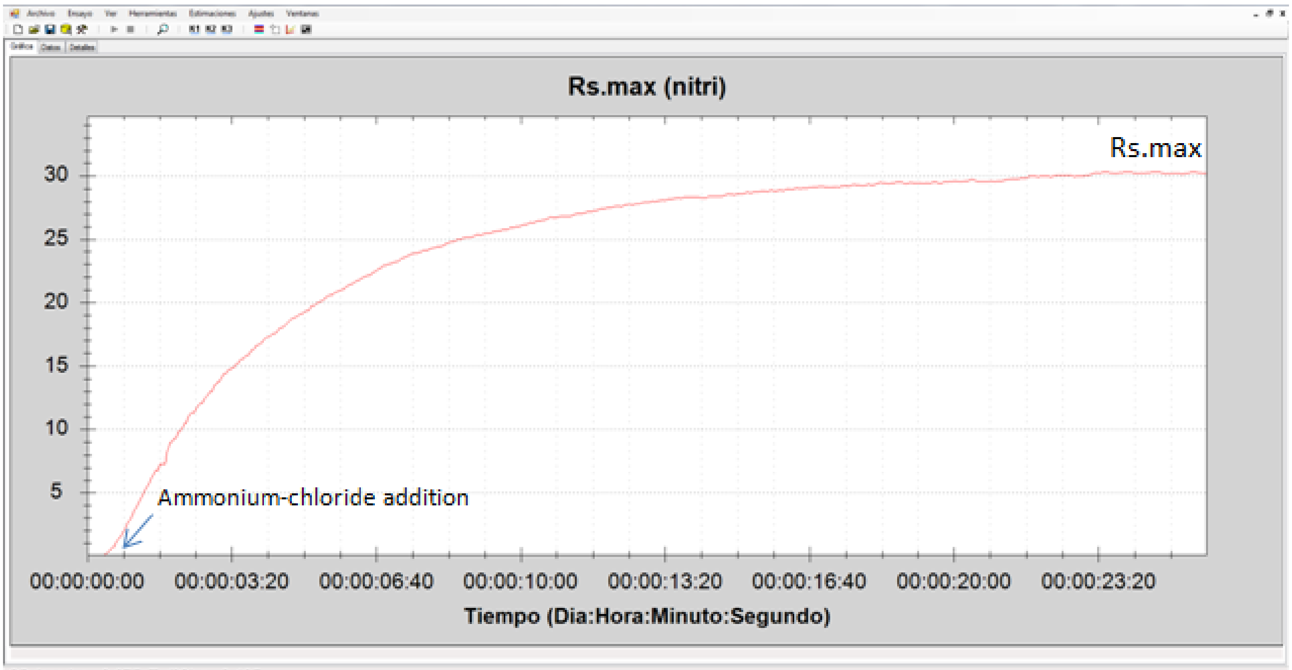


Figure 3. Respirogram of the test to get the maximum Rs due to nuitrification

5.1.3. AUR_{DO}

Once K_{OA} is determined, the AUR at maximum DO ($AUR_{DO.max}$) can be used as a pivot reference value to calculate the actual nitrification rate (AUR_{DO}) for different DO levels.

For this purpose it is used a formula based on Monod principle.

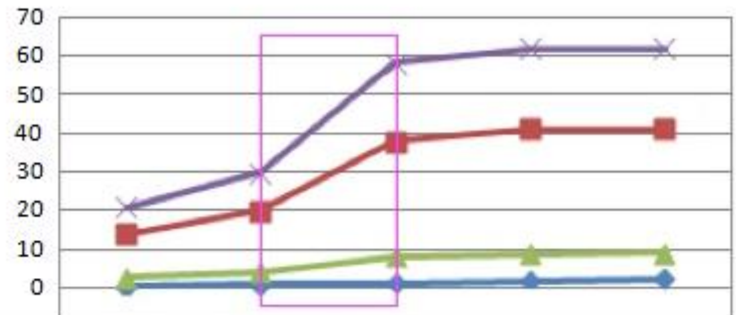
$$\mathbf{AUR_{DO}} = AUR_{DO}.max * DO / (K_{OA} + DO) \qquad (6)$$

5.1.4. Minimum DO with which the nitrification could operate

From the AUR_{OD} results, throughout the formula (6) and for different DO levels, the corresponding C_N were also calculated. Then, the way to get the minimum DO is based on selecting the nearest N_C above the ammonia to nitrify (45)

In our specific case we can realize that the nearest N_C above 45 is 58, and the corresponding DO for this concentration value is 1.5 ppm (Table 2)

Therefore a DO level of 1.5 ppm would correspond to the minimum DO with which the nitrification process could operate.



DO (ppm)	0.5	1	1.5	2	2.6
Rs (mg/L.h O_2)	14	20	38	41	41
AUR (mg/L.h NH_4-N)	3	4.37	8.31	8.97	9.97
N_C (mg/L NH_4-N)	21	30	58	62	62

Table 2. Rs, AUR and N_C results for different DO levels to determine the DO min.

Once obtained the minimum DO, this matrix could be used to figure out some other operative and bio-kinetic parameters.

6. Conclusions

By making use of an advanced BM respirometry system, different studies of Temperature, pH and Oxygen of a nitrification process could be perfectly carried out within a relatively short time.

In these studies, throughout the simultaneous display of the respirograms corresponding to the parameters of Temperature, pH, Oxygen and Respiration rates it was demonstrated the important effect that the different conditions can produce in the nitrification rate.

The key parameter is the nitrification capacity (N_C) which can be compared with the actual ammonia to nitrify (S_N). In this way, we could get an assessment under common criteria based on the condition where S_N should be equal or lower than N_C

Also by the generation of a NC table and graphics for different DO values it is also possible to determine the minimum oxygen with which the nitrification process could operate.

The BM respirometry not only allows a reliable picture of the actual process behavior but also to open the possibility for an effective energy optimization by the determination of the minimum oxygen to operate with which the nitrification could take place within its expected performance.

Note:
Last BM respirometers generation from Surcis, S.L., by making use of a special reactor, can also be applied to MBBR processes, tricking filters and granular biomass.

8. References

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