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Control of the biomass content in the packed bed reactors of Compartment III

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Draft	0	20/12/00	Original Version
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1. Introduction

The preliminary work carried out in the MELISSA Pilot Plant with the third compartment bioreactor has been focused on its physical characterisation and definition of the control system (TN 25.310, TN 25.330).

The nitrifying pilot reactor has been running throughout a first period of operation of approximately one year. During this period of time a set of experiments was carried-out, and both transient and steady states were studied in different situations (TN 37.42.): different conditions of ammonium input load with steps in both influent ammonium concentration and flow-rate were investigated, providing an important amount of results on the stability and high conversion of the influent to nitrate. Nevertheless, the operation of the third compartment of the MELISSA Pilot Plant had to be stopped due to the clogging of the packed bed. This fact is particularly negative due to the long period of time required to re-start the reactor operation.. The problems that caused the clogging of the reactor need to be analysed and treated to solve these important obstacles that would make unsuitable the operation of the nitrifying pilot reactor.

The biofilters in which the support material is less dense than the medium (like Biostyr the polystyrene beads used in compartment III of MELISSA) are called floating bed reactors. One of the advantages of this type of materials is their lower operational cost because less energy is necessary for pumping the medium through the filters. Another advantage of this kind of system is that backwashing is facilitated (Lazarova *et al.*, 1994; Meaney *et al.*, 1994). This possibility will be used to release the excess of biofilm over the support to avoid its clogging. For this, a series of modifications have been introduced in the reactor hardware.

2.- Clogging of the packed-bed

The first period of operation of the pilot reactor had to be stopped mainly due to two reasons: the deformation of the solid support for cell attachment (expanded polystyrene beads, Biostyr), and the high growth of the two strains of bacteria onto the surface of the beads, that decreased the void fraction of the bed causing the increase of the pressure drop of the packed bed. In figure 1 it can be observed the evolution of the aspect of the bottom part of the bed during the first period of operation. Clearly, bed compactation over the one year of operation is important. In table 1 the estimation of the variations in bed porosity during the operation of the nitrifying pilot reactors, both at bench and scale are given. In this table, the solid fraction includes the volumes of biofilm and beads. The solid fraction in the bed increases with operation time mainly due to both biofilm proliferation and deformation of the support beads. The deformation of the beads decreases the bed height and therefore, the bed volume, assuming that this deformation does not produce variations in the biofilm volume, the deformation of support beads leaves to an increase of solid fraction (1-ε), therefore to a decrease of the bed porosity or bed free fraction (ε).

These two problems must be avoided during the operation of the bioreactor in order to prevent serious problems in the long-term operation of this compartment of the MELISSA loop.

Initial reorganisation

Deformation of the support and biofilm development

<u>BENCH COLUMN</u>	**After 2-3 weeks**	**After 6 months**	**After more than 1.5 year**
Variation of the height of the bed	-3 cm	-4.5 cm	-7cm
Solid fraction, including support beads and mature biofilm	0.48	0.74	0.77

Table 1a.- Variation of bed solid fraction in bench columns (initial bed height 27 cm).

Initial reorganisation

Deformation of the
support and biofilm
development

PILOT REACTOR	**After 2-3 weeks**	**After 6 months**	**After 1 year**
Variation of the height of the bed	-5 cm	-9 cm	-21cm (clogging)
Solid fraction, including support beads and mature biofilm	0.69	0.77	0.80

Table 1b.- Variation of bed solid fraction in pilot reactor (initial bed height 56 cm).

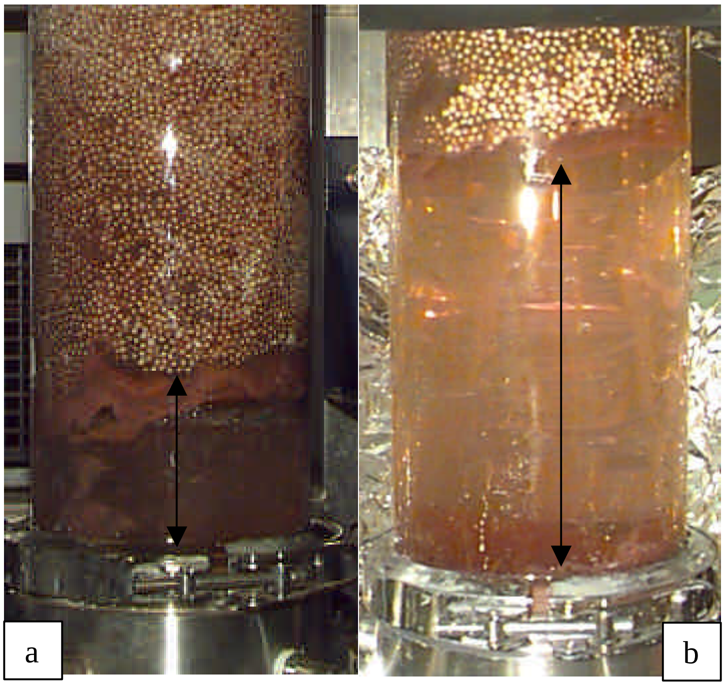

Figure 1.- First period of operation. Compression of the support particles: after 6 months of operation (a) and after 1 year (b).

The expanded polystyrene beads are very sensible to changes in the head pressure of the reactor. This fact is the starting point to the deformation phenomena that suffered the support during this first period of operation that concluded with the clogging of the bed. Due to the low mechanic resistance of Biostyr, the head pressure of the reactor was the responsible of compression of the support. To this problem, a second factor is added: the increase of biofilm due to cell growth. The combination of the two factors represents a real problem in the operation of this reactor. In this way, an important increase in the pressure drop complicates the circulation of the both liquid and gas phases through the bed.

To solve these important problems, three important actions were taken:

- Place non-return valves in the critical points where problems had been detected.
- Decrease the maximal head pressure of the control loop.
- Design a biofilm control protocol to eliminate part of the biomass attached onto the beads.

The non-return valves (HOKE, Creskill, N.J. USA), that allow conventional sterilisation, were placed in the inlets of liquid and gas to the reactor, and in the recirculation and acid/base lines (see figure 2 to know the exact position), to avoid liquid in the gas loop and in general to prevent the risk of accidents.

The maximal head pressure allowed in the pressure control loop was decreased from 200 mbar to 50 mbar, to avoid any effect over the support beads due to oscillation in the pressure of the gas loop.

The last measure taken to improve the long term operation in the reactor without clogging problems was to design a biofilm control protocol based on the principle of backwashing, process usually employed to control the amount of biomass in this kind of biological reactors. As the problem of biofilm excess had been detected also in the bench scale nitrifying reactors, first this protocol has been tested in these reactors and when its efficiency has been demonstrated, it has been transferred to pilot scale reactor. The detailed protocol to control biofilm extension is given in the next point.

The variable that is proposed to use to follow the decrease of the bed free fraction during the operation of the nitrifying reactors is the bed pressure drop. In the actual configuration of the nitrifying reactors, this variable is not measured directly. Nevertheless, important variations of the bed pressure drop can be detected in the case of the pilot reactor following the gas flow rate and the pressure of the manometer of the rotameter (reference number 405 in figure 2).

3.- Biofilm control protocol

The protocol consists on the following steps (see also figure 3):

- Switch all the control loops to manual operation, to avoid problems during the backwashing process.
- Close the aeration flow-rate.
- Close the input liquid flow-rate.
- Stop the recirculation pump.
- Invert the direction of the recirculation loop, using the backwashing loop.
- Increase the recycling flow-rate progressively to achieve a turbulent flow enough to detach fragments of biofilm to the liquid phase (see figure 4).
- Once the excess of liquid has been eliminated from the top section of the column, close the output of liquid.

A total time of 20 minutes before returning to the initial conditions has been tested for the bench scale reactors and 1 hour for the pilot reactor. After this period of time, the operating conditions of the reactor must be established again with exception of the feed flow-rate, which should be returned to the normal values in a progressively way.

In the nitrifying reactors a specific backwashing loop has been implemented in order to avoid accidents in the recirculation loop that is used during the normal operation of the reactor (as can be observed in figure 3). This backwashing loop includes its own non-return valve and a peristaltic tube with a higher diameter to provide a higher flow rate required for this process (for the bench scale reactors the flow-rate used was 40 mL/min, and for the pilot reactor 100 mL/min).

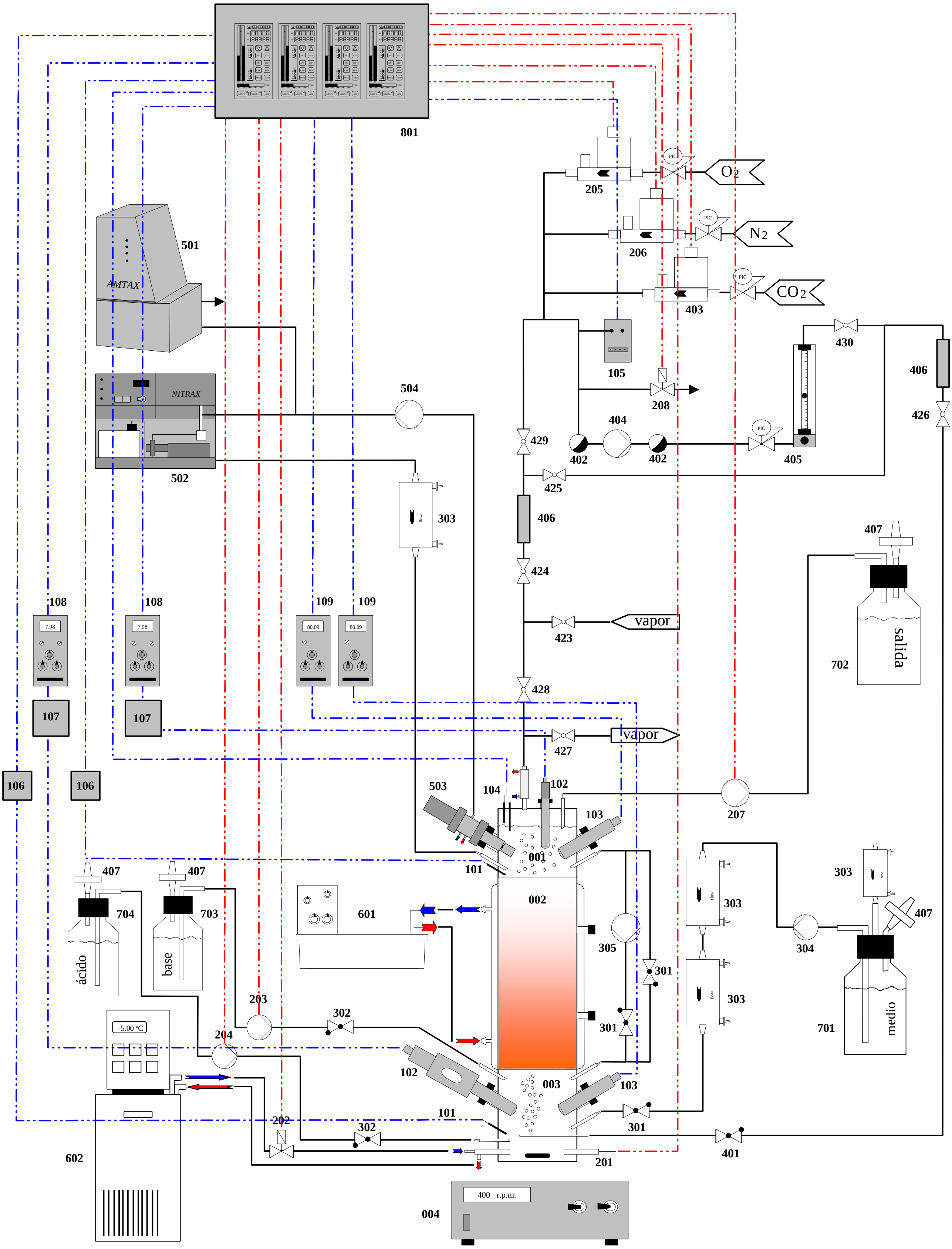

Figure 2.- Schematic representation of the third compartment. The non-return valves introduced in the set-up are the reference numbers: 301, 302 and 401.

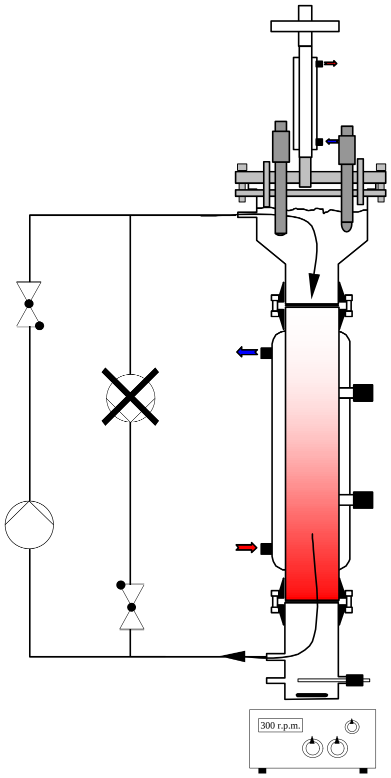

Figure 3.- Schematic representation of the backwashing loop in one of the nitrifying packed bed bioreactors.

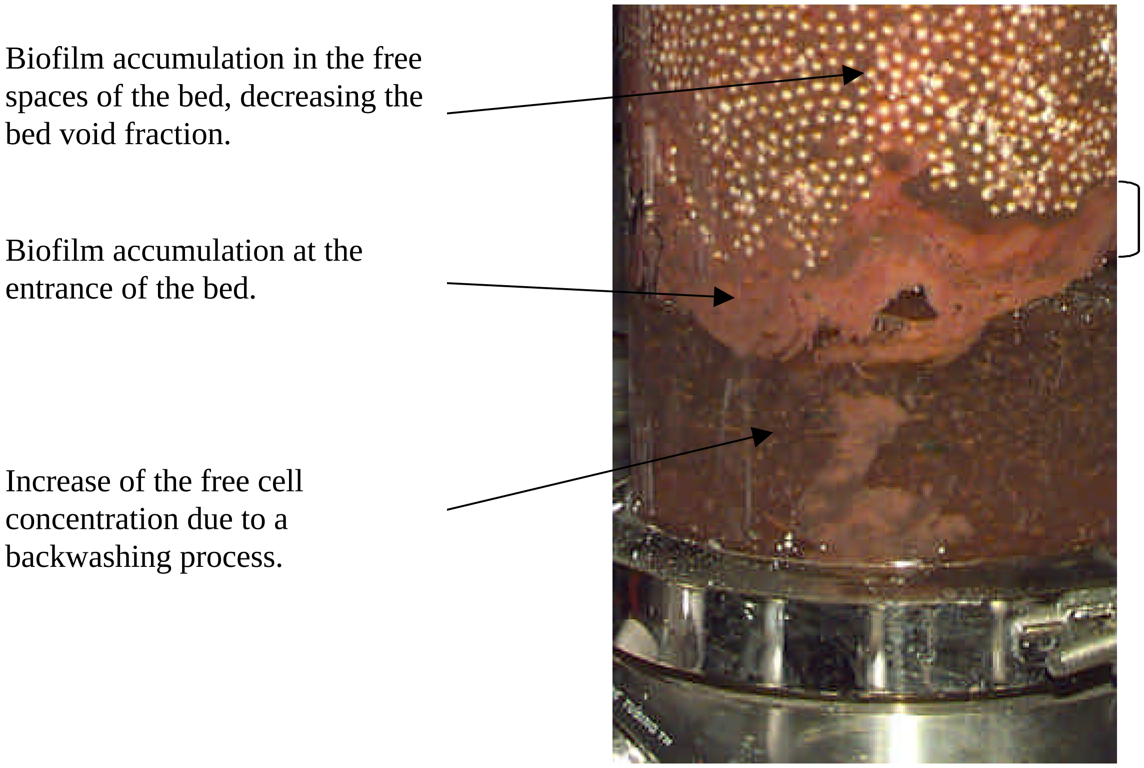

Figure 4.- Aspect of the bed and liquid phase during a backwashing process in the first period of operation. The increase of free cell concentration is removed of the reactor when the continuous operation of the reactor is restarted.

4.- Results obtained during the second period of operation

The nitrifying pilot reactor was restarted once the non-return valves and new head pressure limit in the control loop were introduced to improve the robustness of the third compartment. During this period of operation (after more than one year, corresponding to the operation period 10/1999 and 12/2000) the support particles have not suffered any deformation (see figure 5 to compare macroscopically the aspect of the bed after six months of operation in the two different periods of operation, before the modifications, and after the up-grade presented in this technical note). Also, it is important to note that, as a consequence of the introduced changes, the number of operational disturbances (mainly due the input of liquid to the gas loop) has been decreased to a very low figure. Indeed, in this second operation period of one year with the new improvements only one disturbance due to problems in P100 (SENSYCON, Hartman&Braun, Nanterre, France) temperature control happened, having only transient effects on the operation of the reactor, that recovered steady-state behaviour after a short period of operation (five days).

On the other hand, during the second period of operation the backwashing protocol had to be necessary only one time. The backwash operation was performed during 1 hour. The continuous operation of the reactor was started again, and it took 7 residence times (9 days) to recover 90 % of the conversion before the backwash step and 14 residence times (18 days) to recover full operation.

This action was taken after 12 months of operation, and mainly for prevention of any further clogging, since no real limiting conditions where observed at that time. Clearly, a further improvement of the reactor operation would be to incorporate an on-line measurement of the differential pressure between the top and bottom sections of the reactor, that could be use to monitor the degree of clogging of the packed bed and to take decisions on the times when a backwashing action is necessary. In absence of this measurement, it is recommended to apply this action periodically every 4-6 months as a maintenance routine, unless some clear compactation is observed before (following the bed height). In figure 6 the ammonium, nitrite and nitrate concentration are shown before and after the biofilm control process. It should also be noted in figure 6 that after the washing, residence time was changed from 32 to 23 hours, in order to re-start the normal operation of the reactor gradually, to avoid any important accumulation of ammonium or nitrite that could be inhibitory for nitrifying cells (Anthonisen *et al.*, 1976) .

If this process is applied in this way before any critical situation occurs, the long term operation of the reactor would be preserved and moreover, the pressure drop of the packed bed would not increase sufficiently as to produce deformation in Biostyr particles.

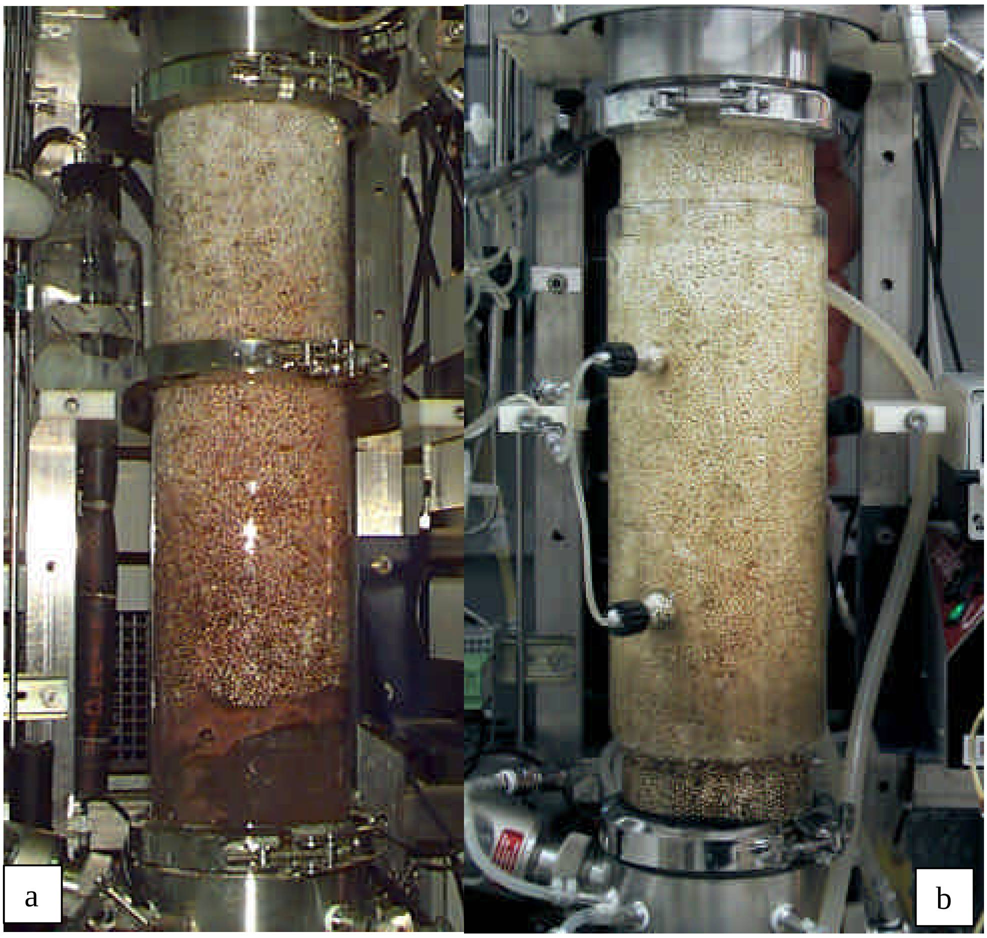

Figure 5.- Comparison between the external aspect of the pilot reactor during the two periods of operation: first period of operation (6 months of operation, photography ‘a’), second period of operation (10 months of operation, photography ‘b’).

Other point to include in this process should be to introduce a specific equipment to harvest biomass from the outlet flow from Compartment III, before it is fed to Compartment IV, because biomass concentration increases as a result of backwashing. As in the case of Compartment IV, possible equipments to be used successfully are: tangential filtration and disk stack centrifuge (TN 37.30), in this way, it would be possible to use the same equipment, because its utilization will be infrequently. Although in our case, the biomass concentration is considerably lower, and, on the other hand, to preserve the cells of any damage is not essential in this case, for this reason, any conventional method of separating cells could be used.

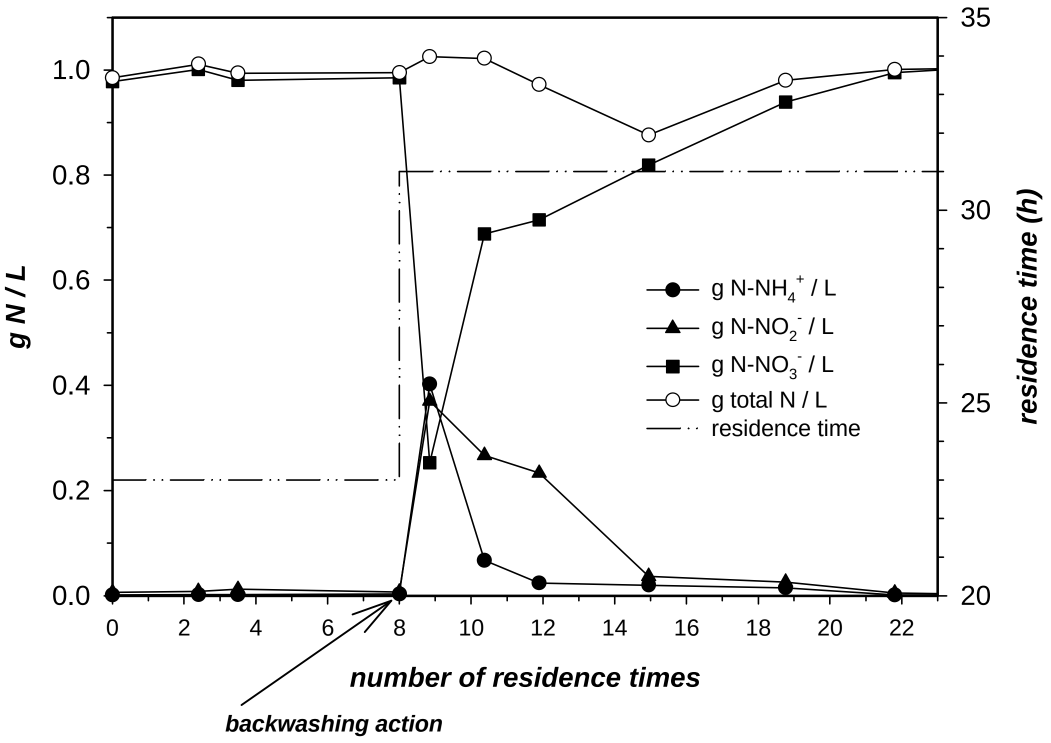

Figure 6.- Effect of a backwashing process in the pilot reactor. The input ammonium concentration was 1.0 gN/L.

5.- Conclusions

The improvements carried out in the pilot reactor have demonstrated an important delay in the phenomenon of deformation of Biostyr support particles. On the other hand, the designed backwashing protocol for the nitrifying packed bed reactors can be considered as a helpful tool to control the biofilm development during the long-term operation of these types of reactors.

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