Performance of the sequencing batch reactor to promote poultry wastewater nitrogen and COD reduction

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Abstract: *Nitrification and denitrification of poultry wastewater treated in a sequencing batch reactor was studied. The reactor was constructed with a glass tube, having a useful volume of 4 L, with a jacket for temperature control, and with porous stone at the bottom to promote aeration. The experimental results showed that the best operational strategy occurred when the following conditions were used: 500 mL of thickened sludge to simulate the treatment end, feed flow rate of 1.1 L/h, dissolved oxygen concentration of up to 5 mg/L during the aerobic reaction, and next to zero at the anoxic phase. Thus the cycle consisting of the following phases: 4 h aerated fill, 7.25 h aerated reaction, and 1 h settling. In this conditions, the reduction of ammonia, nitrite, nitrate, COD, and phosphorus were 87%, 67%, 75%, 74% and 86% at 25^o C, respectively.*

Key words: *Sequencing batch reactor (SBR), nitrification and denitrification, poultry wastewater*

Resumo: *Foram estudados os processos de nitrificação e desnitrificação no reator batelada seqüencial para tratar água residuária avícola. O reator foi construído com um tubo de vidro, (volume útil de 4 L) encamisado, para controlar a temperatura, contendo pedras porosas no fundo, para promover aeração. Os resultados experimentais mostraram que a melhor estratégia operacional ocorreu sob as seguintes condições: 500 mL de lodo, para simular o final do tratamento; vazão de alimentação de 1,1 L/h e concentração de oxigênio dissolvido até 5 mg/L durante a fase de reação aeróbia e próximo de zero na fase anóxica. Assim, o ciclo completo consistia das seguintes fases: 4 h de alimentação aerada; 7,25 h de reação* *aerada e 1 h de sedimentação. Nestas condições, a redução de amônia, nitrito, nitrato, DQO e fósforo, a 25º C, foram de 87%, 67%, 75%, 74% e 86%, respectivamente.*

Palavras-chave: *Reator Batelada Seqüencial (RBS), nitrificação e desnitrificação, água residuária avícola*

1 Introduction

Several wastewaters require care in their treatment to remove excess phosphorus and nitrogen, such as in the case of poultry wastewaters, which are highly polluted with nitrogen. These macronutrients promote plant and algae growth in rivers and lakes, which can cause eutrophication, and also the algae can confer disagreeable odours to the water, chloramine formation, toxicity, etc. Recently there has been increasing preoccupation about reducing these macronutrients in treated effluents by low cost means (FERRAZ *et al.*, 1994).

The use of the sequencing batch reactor has been emphasised due to some economic advantages, but the operational sequence must be adjusted to promote carbon consumption and ammonia, nitrite, nitrate and phosphate reduction. Some authors have obtained very good results such as 93% of COD and nitrogen reduction together with 95% of phosphorous reduction (BORTONE *et al.*, 1992; GERMIRLI *et al.*, 1993). Peavy *et al.* (1985) reported that the dissolved oxygen, pH, sludge age, aeration period, and carbon/nitrogen relation are important parameters that must be controlled to obtain good results for pollutant reduction. Under anaerobic or anoxic conditions, nitrite and nitrate are reduced to gaseous nitrogen.

Culp *et al.* (1978) observed that under anaerobic or anoxic conditions, nitrate was reduced to gaseous nitrogen. This fact suggested an operational sequence to promote nitrogen removal: reactor feeding and aerated steps to promote the oxidation of carbonaceous matter and nitrogenous compounds to nitrate, an agitated step to promote denitrification, and finally a sedimentation step followed by effluent and sludge excess discharge. At the end of the aeration step, such nitrification takes place, the pH reaching values between 8 and 8,8.

Experiments were conducted to study and compare nitrogen transformations occurring under both aerobic digestion and aerobic/anoxic (A/A) digestion. The process performance was examined at different sludge residence times (STRs), temperatures, and anoxic cycles. Both modes of operation gave comparable solids reduction results. However, introduction of anoxic periods to aerobic sludge digestion appears to be a promising alternative to control pH during digestion through endogenous nitrate respiration (ENR). Operating an aerobic digester with an anoxic phase to achieve complete denitrification would also improve supernatant quality over that achieved solely by aerobic digestion. The A/A digestion of mixed primary waste activated sludge achieved up to 43.7% reductions in volatile suspended solids, 33.7% removal of total nitrogen, and a specific ENR rate of 5.75×10^{-2} mg NO_3-N/mg VSS d. Optimum results were obtained at 10 d SRT, 30º C temperature, and 50% anoxic cycle length (AL-GHUSAIN *et al.* 2002).

The piggery waste characteristics greatly vary with types of manure collections and the amount of water used. If solids are separated well, the waste strength will be greatly reduced resulting in lower TCOD/TKN ratio of 4. If solids are separated by a mechanical scraper, some solids will remain and the waste strength will be increased with a TCOD/TKN ratio of 7. This study was conducted to find an optimum operating condition for nitrogen removal with these two rations. Nitrite nitrification was targeted because it could be a short cut process for savings in oxygen for nitrification and carbon requirements for denitrification. The study results indicated that nitrogen loading rate and pH were the most important factors to be considered for stable nitrite nitrification (EUM and CHOI, 2002).

Several bacteria such as *Pseudomonas, Micrococcus, Achromobacter,* and *Bacillus* promote denitrification during the agitated step, when 7.14 mg of alkalinity are removed per mg of ammonia. In this step the pH reaches values between 6.5 and 7.5 and the dissolved oxygen concentration must be reduced to near zero. Diamadopoulos *et al.* (1997) obtained almost 99% of nitrate removal from landfill leachate treated by SBR. In the anoxic step, however the total nitrogen removal was only 50%. Lee *et al.* (1997) obtained 90% of nitrogen and 89% of phosphorus removal, but they filled the reactor so fast that it would not be possible in real situations.

2 Materials and methods

The wastewater and biological sludge samples were collected in a poultry industry always at the same points, after the primary treatment steps and at the recycle line of the secondary treatment, respectively. The reactor was constructed with a glass tube having a useful volume of 4 L with a jacket for temperature control and with porous stone at the bottom to promote aeration. The samples of the reactor were filtered and analyses of ammonia, nitrite, nitrate, COD, alkalinity, phosphorus and total suspend solids were done according to APHA (1995). At the beginning of the experiment, the reactor started with 500 mL of compacted sludge mixed or not with 1,500 mL of raw wastewater, in these cases to get an initial sludge concentration around 2,500 mg/L MLSS. At the anoxic phase beginning it was fed 50 mL of acetate solution (190 mg/L COD) or 350 mL of raw wastewater as carbon source to promote the nitrate concentration reduction. The filling of the reactor and duration of each operational step were adjusted to reach the best conditions to reduce the COD, ammonia, nitrite, and nitrate concentrations.

3 Results and discussion

In the poultry industry where the samples were collected the wastewater treatment was carried out in an activated sludge plant without the addition of nutrients, with good COD reduction attending the concentrations allowed for discharge into waterways. However after several analyses, it was possible to observe that in some samples the phosphorus concentration was not sufficient to maintain sludge growth.

Due to the long time taken for the phosphorus determination before starting the experiment, experiments were done without phosphorus supplementation to observe the COD, ammonia, nitrite, nitrate and phosphorus removal (Table 1).

Parameter	Concentration (mg/L)
COD	1774 ± 190
TKN	94.0 ± 4.7
Organic nitrogen	85.4 ± 6.5
Inorganic nitrogen	8.6 ± 2.5
Phosphorus	3.7 ± 2.3
Fat and oils	266 ± 120
Alkalinity	944 ± 120
Chloride	152 ± 8
Total solids	2133 ± 620
Suspended solids	882 ± 60
Dissolved solids	1251 ± 600
Temperature	23.7 ± 1.1^0C
pH	6.93 ± 0.12

Table 1: Poultry wastewater characterization

The results of the experiment shown in Figures 1 and 2 started with 500 mL of compacted industrial sludge, and 1,500 mL of wastewater. The feed flow rate was 0.775 L/h and the reactor was filled up to 4 L with aeration, followed by the aerated and agitated reaction step for 11 hours, 5 hours agitated reaction step without aeration and 1 hour settling.

Figure 1 shows that the ammonia concentration increased as consequence of the COD reduction and excess nitrogen present in the substrate, while nitrite and nitrate decreased after the feeding step. A possible explanation for the increase in ammonia concentration was that the ammonia generation rate was higher than the nitrate production from nitrite and denitrification rates. There is also the possibility that a fraction of the nitrite and nitrate is used as nitrogen source for some microorganisms present in the original sludge, the phosphorus was totally removed. From the higher concentration at the end of the reactor filling step, nitrite and nitrate reduction reached 53% and 61%, respectively, but the COD reduction only reached 60%, about 50 mg/L of ammonia and 1 mg/L of phosphorus remaining at the experiment end.

Figures 3 and 4 show the results of another experiment, which started with 500 mL of thickened sludge and a feed flow rate of 1.1 L/h. To the contrary of what is observed in Figure 1.1, the COD concentration increased during the reactor feeding step as a consequence of a higher sludge concentration at the beginning of the experiment. Ammonia, nitrate and nitrite were present in the raw wastewater and their concentration decreased throughout the experiment, showing that all generated ammonia was continuously transformed in nitrite and nitrate resulting in a removal efficiency of 87%, 67% and 75%, respectively. With the exception of phosphorus all the parameters showed concentrations at the experiment end higher than those allowed for discharge into waterways. At the beginning of the sedimentation step a rapid decrease in all parameter concentrations was observed, showing the importance of this fact, that was also observed by LEE *et al.* (1997).

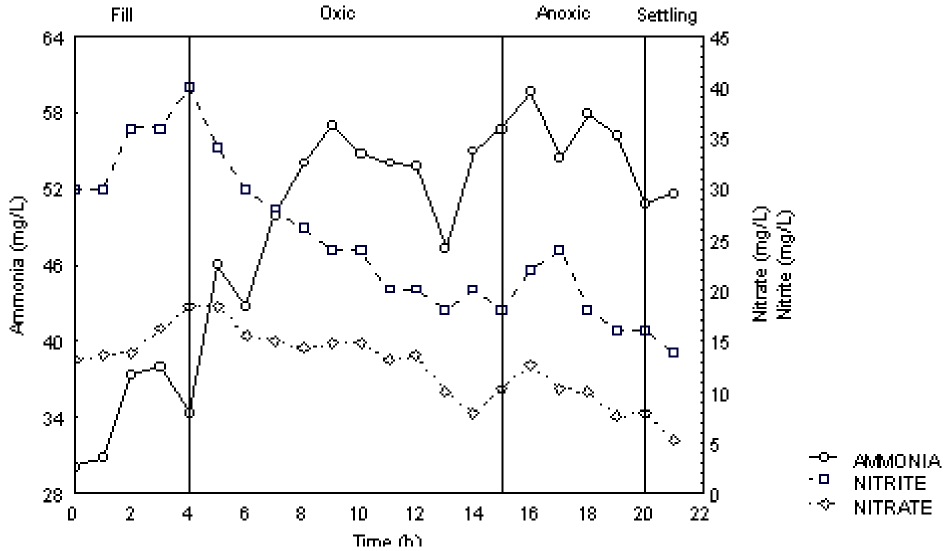

Figure 1. Variation of ammonia, nitrite and nitrate concentrations in SBR supplemented with acetate during experiment 1-Start condition: 500 mL of sludge and 1500 mL of raw wastewater (MLSS=2092 mg/L).

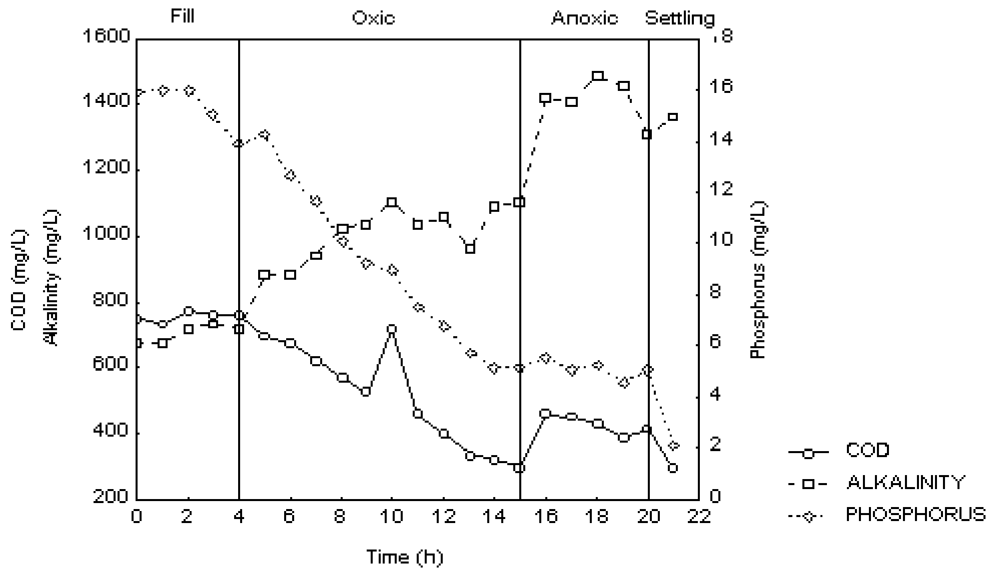

Figure 2. Variation of COD, alkalinity and phosphorus concentrations in SBR supplemented with acetate during experiment 1-Start condition: 500 mL of sludge and 1500 mL of raw wastewater (MLSS=2092 mg/L).

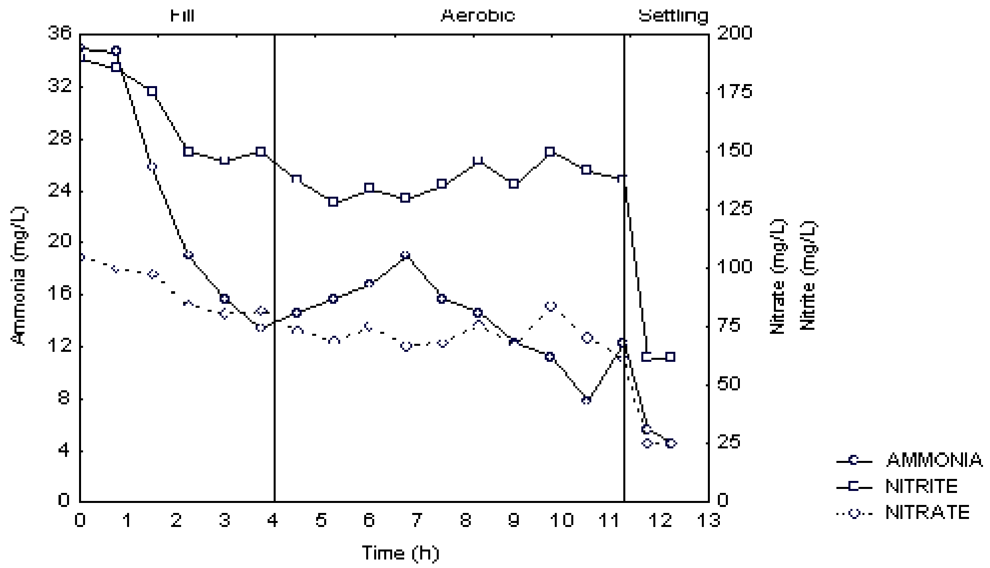

Figure 3. Variation of ammonia, nitrite and nitrate concentrations in SBR during experiment 2-Start condition: 500 mL of sludge.

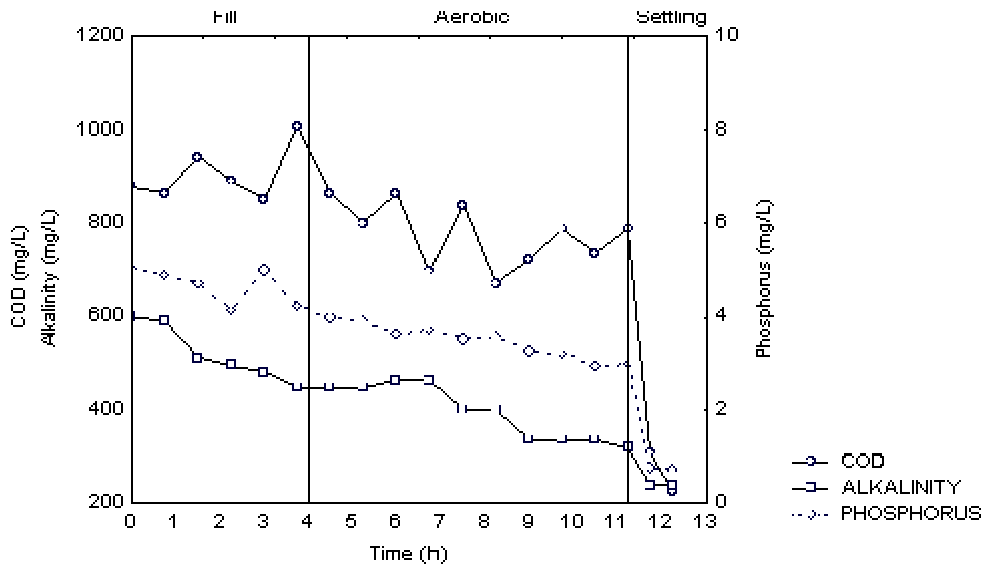

Figure 4. Variation of COD, alkalinity and phosphorus concentrations in SBR during experiment 2-Start condition: 500 mL of sludge.

In Figures 5 and 6 one can see the results of another experiment in which the initial volume was 2 L of a mixture of 500 mL of thickened sludge and 1,500 mL of wastewater. In this experiment the initial phosphorus concentration was the same as in the second, and the final COD and phosphorus concentration reached values that attended the allowed discharge parameters, although ammonia, nitrite and nitrate were not with these limits. In this experiment behaviour similar to that of the first experiment was observed that is, the ammonia concentration and alkalinity increased during the feeding and the beginning of the aeration steps. The efficiencies of COD, nitrite and nitrate reductions were 95%, 36% and 76%, respectively.

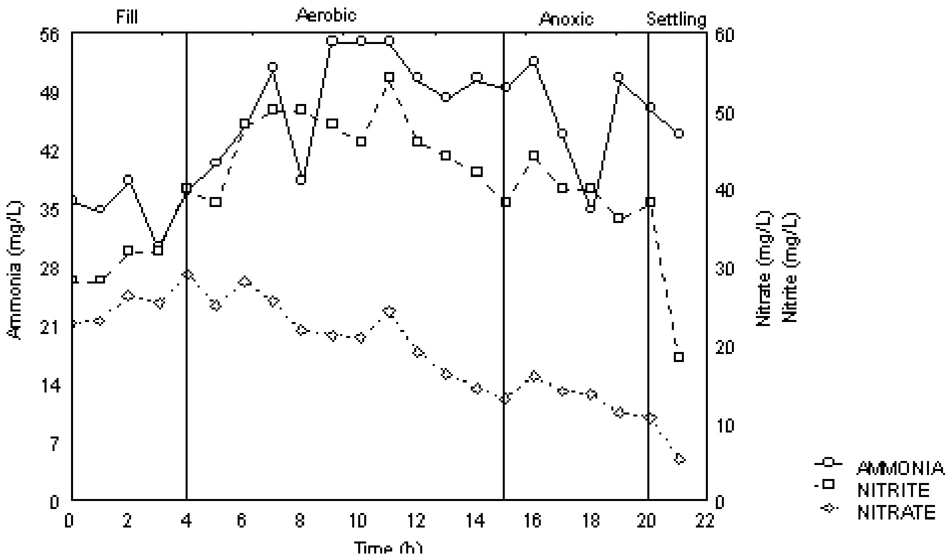

Figure 5. Variation of ammonia, nitrite and nitrate concentrations in SBR supplemented with wastewater during experiment 3-Start condition: 500 mL of sludge and 1500 mL of raw wastewater (MLSS=1842 mg/L).

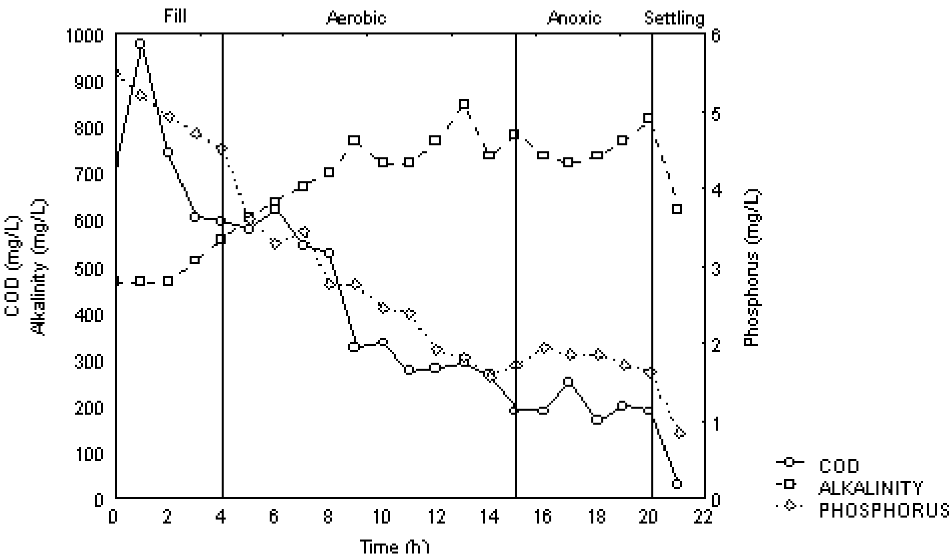

Figure 6. Variation of COD, alkalinity and phosphorus concentrations in SBR supplemented with wastewater during experiment 3-Start condition: 500 mL of sludge and 1500 mL of raw wastewater (MLSS=1842 mg/L).

4 Conclusions

These experiments show that it is possible to treat poultry wastewater using adapted sludge in a SBR, despite the low phosphorus concentration. However, it is the starting conditions and steps duration which determine the performance. It is obvious that phosphorus supplementation can improve the treatment, but, in order to check this in a proper way, it is necessary to use an average value of the phosphorus concentration to avoid an excess of phosphorus addition.

The nitrogen removal process is not so easy to understand since the nitrification reactions occur as nitrate consumption by microorganisms and ammonia generation by endogenous respiration in the aerated and agitated steps. The efficiency values present in the literature (including this work) that are calculated from the final and initial nitrogen concentrations are not so accurate. The total nitrogen and COD removal efficiencies should be calculated from the difference between the final and initial masses. At the moment experiments with phosphorus supplementation are carrying out.

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References

AL-GHUSAIN, I., HAMODA, M. F. and EL-GHANY, M.A. Nitrogen transformations during aerobic/anoxic sludge digestion. *Bioresource Technology*, v. 85, p. 147-154, 2002.

APHA, AWWA, WPCF, *Standard Methods for the Examination of Water and Wastewater*, 19th ed. New York, 1995.

BORTONE, G., GEMELLI, S., RAMBALDI, A. and TILCHE, A. Nitrification, denitrification and biological phosphate removal in SBRs treating piggery wastewater. *Water Science and Technology*, v. 26, p. 977-985, 1992.

CULP, R. L., WESNER, G. M. and CULP, G. L. *Advanced Wastewater Treatment*, 2nd ed. New York: Van Nostrand Reinhold Company, 1978.

DIAMADOPOULOS, E., SAMARAS, P., DABOU, X. and SAKELLAROPOULOS, G. P. Combined treatment of landfill leachate and domestic sewage in a sequencing batch reactor. *Water Science Technology*, v. 36, p. 61-68, 1997.

EUM, Y. and CHOI, E. Optimization of nitrogen removal from piggery waste by nitrite nitrification. *Water Science Technology*, v. 45, n. 12, p. 89-96, 2002.

FERRAZ, A. O., GOBBI, E. F., GAMA, A. F. S. and RUSSO, C. Modelo matemático do reator batelada sequencial-Parte 1: Nitrificação. *Revista Brasileira de Engenharia*, v. 11, p. 7-16, 1994.

GERMIRLI, F., BORTONE, G., ORHON, D. and TILCHE, A. Fate of residuals in nitrification-denitrification treatment of piggery wastewaters. *Bioresource Technology: Biomass, Bioenergy, Biowastes*, v. 45, p. 205-211, 1993.

LEE, S. I., PARK, J. H., KO, K. B. and KOOPMAN, B. Effect of fermented swine wastes on biological nutrient removal in Sequencing Batch Reactors. *Water Research*, v. 31, p. 1807-1812, 1997.

PEAVY, H. S., ROWE, D. R. and TCHOBANOGLOUS, G. *Environmental Engineering*, New York: McGRAW Hill, 1985.