Proceedings of the 10th International Chemical and
Biological Engineering Conference - CHEMPOR 2008
Braga, Portugal, September 4-6, 2008
E.C. Ferreira and M. Mota (Eds.)

Denitrification in an anoxic rotating biological contactor under two carbon/nitrogen ratios

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Keywords: anoxic rotating biological contactor, C/N ratio, denitrification
Topic: Environmental engineering and management

Abstract

The aim of the present work was to compare the performance of an anoxic bench-scale rotating biological contactor (RBC), in terms of the denitrification process, applied to treat synthetic wastewater under two carbon/nitrogen (C/N) molar ratios (1.5 and 3). The average removal efficiency in terms of nitrogen-nitrate was of about 90.4% at a C/N=1.5 lowering to 73.7% at a C/N=3. Considering carbon-acetate removal an overall efficiency of 82.0% and 63.6% was attained at a C/N ratio of 1.5 and 3, respectively. These results evidence that, for the tested conditions, the use of C/N=1.5 is advantageous.

The increase of nitrogen-nitrate and carbon-acetate influent concentrations, keeping C/N constant, and the decrease of hydraulic retention time (HRT) had a slight negative effect in terms of substrate removal.

The accumulation of nitrite was observed in both experiments, which could probably be lowered with an increase in phosphorus influent concentration.

Results show that an anoxic RBC using acetate as a carbon source is a convenient and reliable process for the removal of nitrate from wastewater.

1 Introduction

Nowadays, the presence of nitrate in wastewater is considered a critical problem. The processes used for treating nitrate-rich wastewater include reverse osmosis, ion exchange, electrodialysis and biological nitrate reduction (denitrification). Denitrification has been shown to be more economical and practical and the most promising and versatile approach among all (Mateju et al., 1992). In this process, microorganisms first reduce nitrate (NO_3^-) to nitrite (NO_2^-) and then produce nitric oxide (NO), nitrous oxide (N_2O), and, finally, nitrogen gas (N_2), in the absence of dissolved oxygen (DO) or under limited DO concentrations (Tchobanoglous and Burton, 1991).

Most denitrification processes rely on heterotrophic bacteria so, when the wastewater does not contain biodegradable organic carbon compounds, these have to be added (Beaubien et al., 1995). Acetate has been reported to give high denitrification rates in most cases (Hallin et al., 2006).

Cervantes et al. (1999) reported that for high denitrifying efficiencies the carbon to nitrogen ratio was the main parameter of control to achieve a dissimilative respiratory process.

A rotating biological contactor is an attached growth bioreactor that offers an alternative technology to the conventional activated sludge process and is used for both municipal and

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industrial wastewater treatment. A RBC unit typically consists of a series of closely spaced discs that are mounted on a common horizontal shaft and are partially or completely submerged in wastewater. The shaft continually rotates and a biofilm is established onto the entire surface area of the media, which metabolizes the organic materials contained in the wastewater. Due to its advantages: simplicity of operation, short hydraulic retention time (HRT), low land area requirement, low operating and maintenance cost and high biomass concentration per reactor volume, RBCs constitute a very unique and superior alternative technology for carbon oxidation, nitrification, denitrification and phosphorus removal. Although in the last decade RBCs tightly closed to avoid air entrance have started to be used for denitrification, few studies have still been conducted with anoxic RBCs (Cortez et al. 2008).

In this study the denitrification efficiency of an anoxic bench-scale RBC was followed under two carbon/nitrogen (C/N) molar ratios: 1.5 and 3, with acetate as carbon source.

2 Materials and methods

2.1 Anoxic rotating biological contactor and operation

The anoxic RBC single-stage system consisted of 8 polymethylmethacrylate (PMMA) discs (diameter = 130 mm, thickness = 3 mm, 20 mm interspace) mounted on a horizontal shaft, having a working volume of 2.5 L. The rotating biological contactor was operated at a rotational speed of 4 rpm and the temperature was maintained at 28 ºC by means of a heating jacket. The submergence of the discs was 93.5%. Prior to continuous operation the reactor was inoculated with microorganisms, acclimatized to acetate and nitrate, collected from an activated sludge tank from a wastewater treatment plant. Microbial attachment onto the discs was allowed to occur in batch mode and a visible attachment of biomass on the discs was noticed after 4 days of inoculation. On day 6, the anoxic RBC mixed liquor was removed, the reactor was re-filled and started to be fed continuously with synthetic wastewater. The time “zero” of operation was considered when the hydraulic retention time was adjusted to 10 hours. Two days after that, samples started to be collected.

The synthetic wastewater contained nitrate, acetate as carbon source, a phosphorus concentration of 10 mg P/L and trace elements.

To evaluate the reactor efficiency, during the assay, nitrogen-nitrate concentration was doubled at the 8th day of operation and carbon-acetate concentration was adjusted to keep the ratio C/N constant (according to the experiment, C/N=1.5 or C/N=3). In both experiments the hydraulic retention time was also changed and reduced from 10.00 h to 5.68 h, as shown in Table 1.

Table 1. Operation parameters of the anoxic RBC.

Days of operation	HRT (h)	N-NO_3^- (mg/L)
0 - 8	10.00	50
8 - 15	10.00	100
15 - 22	6.84	100
22 – 28	5.68	100

The study was conducted for a period of 28 days (for each C/N ratio). The nitrogen-nitrate range selected is typical of concentrations found in agricultural and industrial wastewaters (Bickers and Oostrom, 2000).

2.2 Sampling and analysis

During the course of continuous operation, samples of the RBC influent and effluent were collected routinely and analysed for various parameters such as nitrate, acetate and nitrite. In order to remove interfering suspended particles samples were filtered over a 0.2 µm membrane filter. Nitrate and acetate concentrations were measured by HPLC in an organic acids column (*Varian Metacarb*, type 67H, 9 µm, 300 mm long, 6.5 mm internal diameter). Nitrite was determined by a colorimetric method using N-(1-naphthyl)-ethylene-diamine, according to the standard methods (APHA, 1989). Periodically, gas samples were analysed by gas chromatography.

3 Results and discussion

Variations in the removal efficiencies of nitrogen-nitrate ($N\text{-}NO_3^-$) and carbon-acetate ($C\text{-}CH_3COO^-$) as a function of operating time are shown in Figure 1 (a) and (b), respectively.

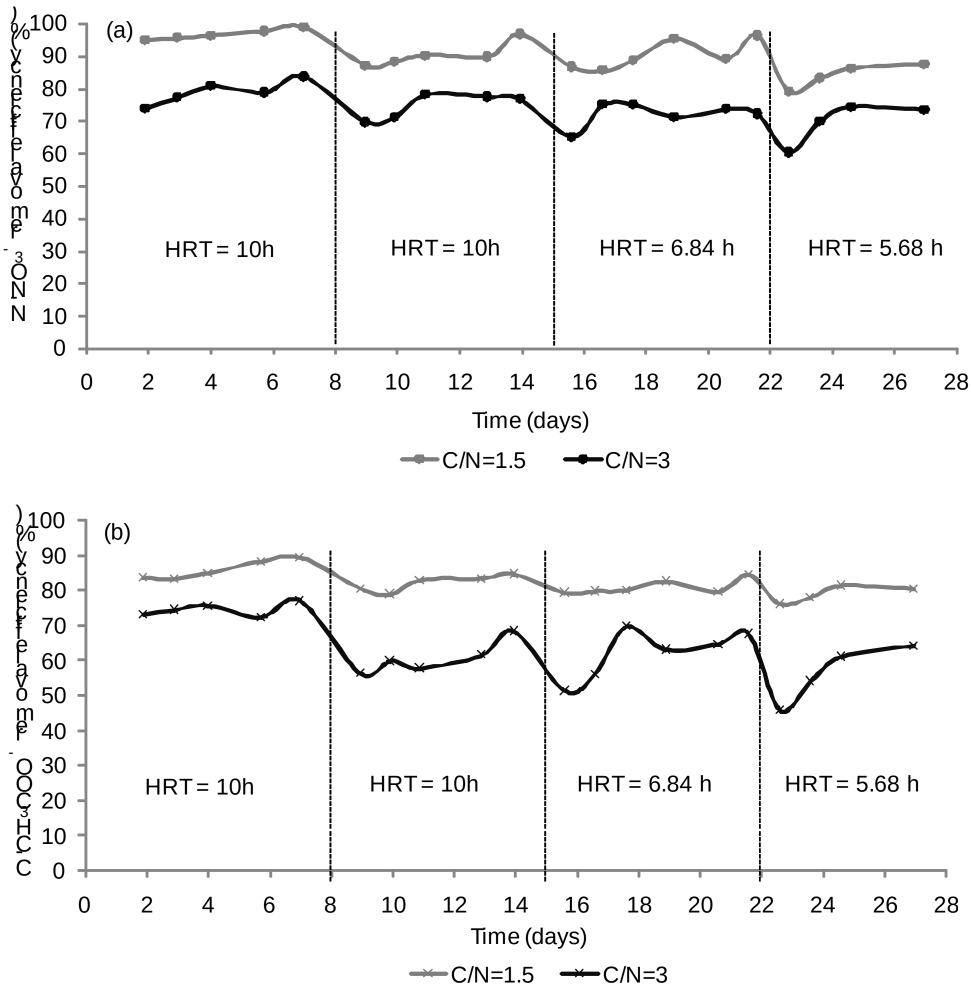

Figure 1. Nitrogen-nitrate (a) and carbon-acetate (b) removal efficiency along the time at two C/N ratios: 1.5 and 3.

The bench-scale RBC showed a high nitrate removal percentage in both experiments. $N\text{-}NO_3^-$ overall efficiency was of about 90.4% at a C/N=1.5 lowering to 73.7% at a C/N=3 (Figure 1 (a)). Considering carbon-acetate removal (Figure 1 (b)), an overall efficiency of 82.0% and 63.6% was attained at a C/N ratio of 1.5 and 3, respectively. These results evidence that, an increase in the C/N ratio from 1.5 to 3 was accompanied by a decrease in substrate removal efficiencies. Consequently, in the experiment at C/N=3 the biomass present in the anoxic RBC did not metabolize all the substrates and as a result they were accumulated along the time. For economical and environmental reasons the use of C/N=1.5 is advantageous.

The maximum substrate removal efficiencies were obtained in the first period of operation, with an influent nitrogen-nitrate concentration of 50 mg $N\text{-}NO_3^-$/L and a hydraulic retention time of 10 h. The removal efficiencies were slightly lowered by a twofold increase in nitrate and acetate loading rate and a decrease in HRT.

Data presented in Figure 2 show the accumulation of nitrogen-nitrite ($N\text{-}NO_2^-$). Accumulation of nitrite has been frequently found in biological denitrification processes. Several factors such as oxygen concentration, pH, temperature, biofilm composition, toxic substances, influent nitrate concentration, available and type of carbon source and carbon to nitrogen ratio influence nitrite accumulation (Moreno et al., 2005). It is very important to avoid nitrite accumulation because it can lead to inhibition of bacterial development. Moreover, high nitrite concentration is highly undesirable once nitrite is more toxic than nitrate (Hunter, 2003).

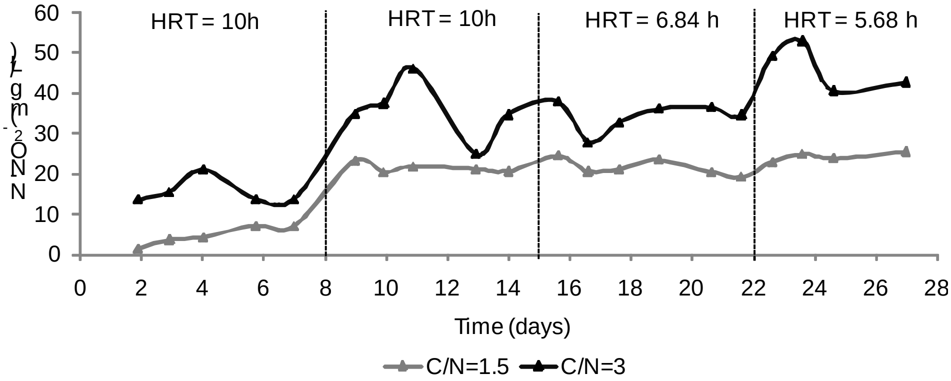

Figure 2. Nitrogen-nitrite effluent concentration along the time at two C/N ratios: 1.5 and 3.

An insufficient phosphate level also leads to nitrite accumulation (Reisinger et al., 1989). In order to reduce the formation of nitrite, Teixeira and Oliveira (2000) increased the phosphorus concentration tenfold (from 2 mg P/L to 20 mg P/L) which resulted in a drastically decrease in the accumulation of nitrite and induced a good RBC performance. It can be speculated that the influent phosphate concentration limited the conversion of nitrite to nitrogen gas. Alternatively, the accumulation of nitrite can result from the microbial population present inside the RBC rich in nitrate reducing bacteria.

4 Conclusions

The RBC had a very good performance at C/N=1.5, using acetate as carbon source, attaining a nitrate removal of about 90%, that could probably be enhanced with an increase in phosphorus concentration. As a general conclusion, the RBC proved to be very robust in coping with high nitrate loads and shock loads.

Acknowledgments

Susana Cortez and Pilar Teixeira fully acknowledge the financial support provided from Fundação para a Ciência e Tecnologia (FCT) through the grants SFRH/BD/24715/2005 and SFRH/BPD/26803/2006, respectively.

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