Mathematical model of nitrification-denitrification in one stage under anoxic conditions

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Introduction

A typical bioprocessing technology for managing high strength ammonium wastewater is anaerobic digestion followed by aerobic treatment. Anaerobic digestion consumes mainly the incoming carbon leaving at the outlet high nitrogen amounts which are removed in two stages during the aerobic treatment. The first step requires strong oxidized conditions, so that the organic nitrogen is converted to nitrate (nitrification) and the second stage requires anoxic conditions in order the nitrate to be reduced to nitrogen gas (denitrification). Critical parameters for these two stages are the dissolved oxygen (DO), the redox potential (ORP) and the COD/TKN ratio of the influent. If the DO levels are low and close to 1 mg O_2/L (Wiesman, 1994, Ciudad *et al*, 2005), the redox potential is also low resulting in the assimilation of carbon to the denitrification step. If the dissolved oxygen is above 2 mg O_2/L, then the assimilation of carbon takes place during the nitrification step. In our study, the DO remains in anoxic levels (under 2 mg O_2/L) throughout the aeration stage.

The influent COD/TKN ratio shows the availability of organic carbon for the aerobic processes. At high COD/TKN ratios (>12) the denitrification step is promoted, while low COD/TKN ratios favor the nitrification process (Pan *et al*, 2017). The combination of anoxic conditions and low COD/TKN ratio could result to nitrite accumulation and production of molecular nitrogen, bypassing the nitrate accumulation. In this case, the tCOD/TKN ratio range was 3.9-28.2 and the sCOD/TKN ratio was 0.7-21.5.

This study presents a mathematical model for the kinetics of a nitrification-denitrification method in one stage under anoxic conditions. Application of the model can result in low aeration costs and effective nitrogen fixations. The model can be applied either on a continuous flow or a batch system. Then a validation process was carried out in an industrial Sequencing Batch Reactor (SBR) treating potato industry wastewater with high nitrogen concentration.

Materials and Methods

The monitoring of the biological treatment was performed in the facilities of the potato industry TASTYFOODS.SA, in Agios Stefanos, in the region of Attikis. The biological treatment system is based on the combination of an anaerobic and an aerobic reactor that operate in series. During a cycle, the following operations are occurred: the feeding of the SBR (30 minutes), the aeration period (240 minutes), the stirring of the waste in anoxic conditions (30 minutes), the sedimentation of the sludge (120 minutes), and finally, the decanting of the supernatant (60 minutes).

During each cycle, the DO values, pH and Redox Potential (ORP) were recorded continuously. Samples were taken every half hour for further analysis. The soluble chemical oxygen demand (sCOD), ammonia (NH_3-N), nitrate, total suspended solids (TSS), volatile suspended solids (VSS) and volatile solids as percentage of total solids were measured. Also, in the inlet and outlet of the reactor, pH, TSS, VSS, sCOD, Total Kjeldahl Nitrogen (TKN) and concentrations of NH_3-N and NO_3^-N were analyzed.

An unstructured model so as to predict the behavior of the most important variables during the cycle of SBR was developed. The model was based on the most important biochemical reactions that take place during the SBR cycle. In Figure 1, the two different bioroutes (route 1 and route 2) of the consumption of TOC are illustrated together with the bioconversion of TKN to N_2. Route 1 requires oxygen while route 2 is activated in anoxic conditions.

Results and Discussion

Table 1 shows the average experimental values of the most important variables at the inlet and outlet of the SBR. The pH inlet has a typical value of a liquid effluent coming out from a UASB digester. The pH is then stabilized at 7.7-7.8, as a result of the nitrification bacteria action. The rapid increase in TSS after initiation of aeration is the result of mixing the feeding with the aerobic sludge while during the precipitation stage TSS are reduced to zero. Regarding the carbon assimilation (C), it seems that the COD inlet is easily degradable, and hence, its removal remains at high percentages throughout the SBR cycle (>92%). Similar behavior is noticed on the assimilation of nitrogen (N), as the % removal of TKN reached 88%.

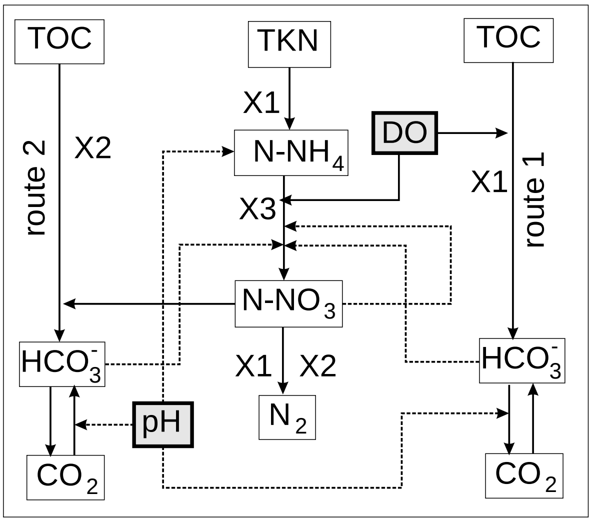

Figure 1 The different bioroutes for assimilating TOC and TKN in the examined SBR system.

Table 1. Characteristics of the feeding in the SBR

Parameters	TSS (mg/L)	VSS (mg/L)	tCOD (mg/L)	sCOD (mg/L)	TKN (mg/L)	NH_4^+-N (mg/L)	NO_3^--N (mg/L)	pH
	958	635	1890	851	130.8	54.2	8.8	6.99

Conclusions

A mathematical model was constructed in order to show the kinetics of a nitrification-denitrification method in one stage under anoxic conditions. The model was then applied on an industrial SBR in order to be validated. The results showed that the model can describe the performance of a real semi batch system that converts ammonia to nitrogen gas bypassing nitrate accumulation and under low DO levels and COD/TKN ratios.

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