# ADVANCED CONTROL SYSTEM OF ACTIVATED SLUDGE PROCESSES USING IN-SITU AMMONIUM AND NITRATE PROBES

**AZIS K.[1], MELIDIS P.[1], NTOUGIAS S.[1] and KOKKINIS P.[1]**

[1]Laboratory of Wastewater Management and Treatment Technologies, Department of Environmental Engineering, Democritus University of Thrace, Vas. Sofias 12, 67100 Xanthi, Greece
E-mail: pmelidis@env.duth.gr

## ABSTRACT

Nowadays, effluent quality of Wastewater Treatment Plants (WWTP) has to meet stringent environmental regulations. The aim of this study was to assess the dynamic control efficiency of nitrification and denitrification process using a pilot-scale intermittently aerated and fed bio-reactor (IAFB). On-line monitoring of nitrification and denitrification processes was achieved using in situ ammonium and nitrate probes and a programmable control system. The aeration requirements for organic carbon and ammonia oxidation were controlled by setting ammonia effluent concentration at 2, 3 or 4 mg $L^{-1}$ $NH_4^+$-N. Denitrification phase length was set by reaching the lowest nitrate effluent concentration (1 mg $L^{-1}$ $NO_3^-$-N).

The average nitrification time was 52 and 21 min for the oxidation of 6 and 3 mg $L^{-1}$ $NH_4^+$-N, respectively. The denitrification period needed for the reduction of 6 and 11 mg $L^{-1}$ $NO_3^-$-N was 7 and 71 min, respectively. Two distinct nitrification rates (Nr), i.e. 0.15 ± 0.05 and 0.08 ± 0.03 g $g^{-1}$ VSS $d^{-1}$, were detected, depending on the initial ammonium concentration of the influent. Three denitrification rates (DNr) were observed during anoxic phase, which were equal to 0.43 ± 0.09, 0.09 ± 0.02 and 0.04 ± 0.02 g $NO_3^-$-N $g^{-1}$ VSS $d^{-1}$. The control strategy of the activated sludge process resulted in COD, BOD, TKN, $NH_4^+$-N and $NO_3^-$-N removal efficiencies of 90, 94, 89, 94 and 99%, respectively.

**Keywords**: alternate nitrification/denitrification, system control, in-situ ammonium and nitrate probes

## 1. Introduction

Biological nitrogen removal can be achieved by successive oxic and anoxic phases at the same bioreactor (Chai and Lie, 2008; Haimi *et al*., 2013). The optimization of the activated sludge processes is accomplished with control strategies (Marsili-Libelli and Giunti, 2002). Some of the control strategies have been previously reported (Battistoni *et al*., 2003; Ingildsen and Olsson, 2002; Ingildsen and Wendelboe, 2003; Caraman *et al*., 2007 and Melidis *et al*., 2013). Ammonia and nitrate nitrogen monitoring can decrease total operational cycle period, minimizing the operational costs.

The aim of the current study is the control of nitrification and denitrification processes in an intermittently aerated and fed activated sludge bioreactor (IAFB) using in situ ammonium and nitrate sensors.

### 1.1. IAFB operation

The intermittent aeration can enhance nutrient removal in a different way applied for conventional systems (Battistoni *et al*., 2003). As a result of the direct loading of the total quantity of wastewater into the reactor, the sludge is fed with easily biodegradable organic matter (Martins *et al*., 2003; Kantartzi *et al*., 2010). Moreover, filamentous bacterial growth is inhibited and energy cost for aeration is minimized (Jianhua *et al*., 2007).

## 2. Model description

The whole study was conducted in a pilot-scale bioreactor (Figure 1) receiving wastewater from the University Campus in Xanthi. The reactor (45 L volume) was operated under different organic loading rates and anoxic/oxic phases. The aeration tank was equipped with an air–compressor, providing oxygen at a rate of 90 L $h^{-1}$. The DO concentration was measured by a DO probe, while a mechanical stirrer was used for mixing the influent with the activated sludge. Thus, this activated sludge system was a nonconventional pilot plant, which was operated under intermittent feeding and aeration conditions. The influent was entered in each cycle at the beginning of the anoxic phase. The experiments were conducted for a period of 7 months. The control of nitrification and denitrification processes was performed by obtaining continuous online measurements of ammonium and nitrate concentrations.

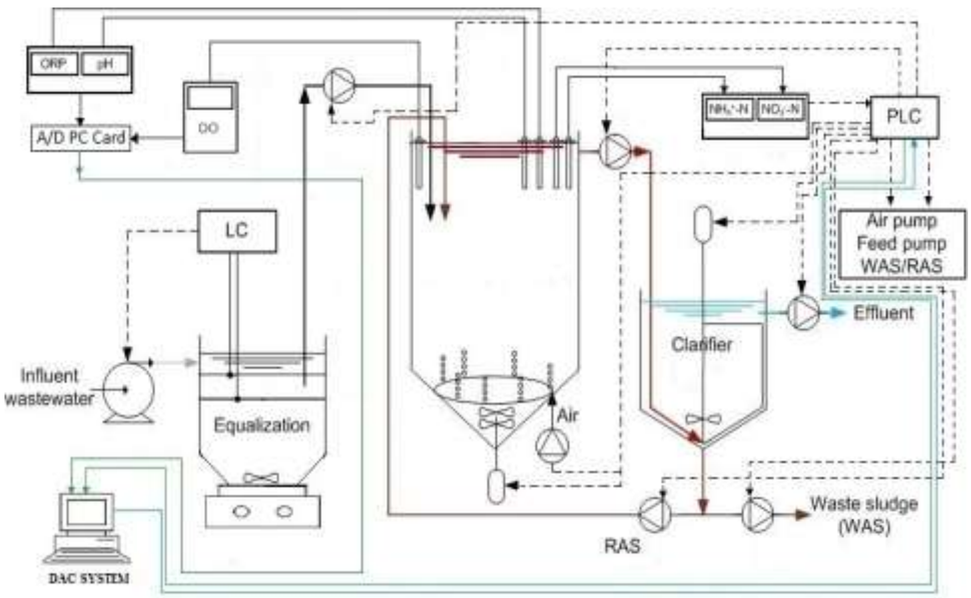


**Figure 1:** Schematic layout of an intermittently aerated and fed activated sludge pilot plant.

### 2.1. Composition of raw wastewater

The wastewater used was characterized by low carbon/nitrogen ratio. In this case, the organic carbon was insufficient to achieve denitrification and external carbon source addition was needed. Glycerol was added in the bioreactor to maximize nitrogen removal, when it was necessary. Tam *et al*. (1992) examined the effects of low ratio C/N or high nitrate concentration on the nitrogen removal process, showing that external carbon source such as methanol, acetic acid etc is needed. The physicochemical characteristics of the influent are illustrated in Table 1. Moreover, the operational characteristics are presented in Table 2.

**Tabe 1:** Physicochemical characteristics of influent sewage.

| Parameters | Mean ± Stdev | Mean ± Stdev (glycerol) |
|---|---|---|
| $tCOD_{inf}$ (mg $L^{-1}$) | 375 ± 72.7 | 1078 ± 193 |
| $sCOD_{inf}$ (mg $L^{-1}$) | 185 ± 68.9 | 865 ± 181 |
| $BOD_{inf}$ (mg $L^{-1}$) | 230 ± 33.2 | 938 ± 188 |
| $NH_4\text{-}N_{inf}$ (mg $L^{-1}$) | 77.5 ± 14.2 | |
| $TKN_{inf}$ (mg $L^{-1}$) | 98.6 ± 15.8 | |
| $SS_{inf}$ (mg $L^{-1}$) | 132 ± 39.12 | |
| $PO_4\text{-}P_{inf}$ (mg $L^{-1}$) | 5.87 ± 1.40 | |
| $pH_{inf}$ (mg $L^{-1}$) | 7.67 ± 0.19 | |
| $EC_{inf}$ (μS $cm^{-1}$) | 1318 ± 98.94 | |

**Table 2:** Bioreactor operational characteristics.

| Operational characteristics | Mean ± Stdev |
|---|---|
| Flow rate (L $d^{-1}$) | 36.3 ± 13 |
| $L_{org,,v}$ (gBOD $L^{-1}$ $d^{-1}$) | 16.1 ± 9.02 |
| F/M (gBOD $g^{-1}$VSS $d^{-1}$) | 0.31 ± 0.15 |
| $L_{N,VSS}$ ($gNH_4$-N $g^{-1}$VSS $d^{-1}$) | 0.06 ± 0.026 |
| HRT (h) | 35 ± 17 |
| MLSS (g $L^{-1}$) | 3.06 ± 0.64 |
| MLVSS (g $L^{-1}$) | 2.64 ± 0.57 |
| $MLSS_{RAS}$ (g $L^{-1}$) | 10.3 ± 3.54 |
| C/N | 9.9 ± 2.59 |
| SVI (mL $g^{-1}$) | 94.2 ± 43.6 |

### 2.2. Control of nitrification/denitrification process

The control of stages duration was automatically achieved by the PLC system that connected to a data acquisition and control (DAC) system. The DAC system was consisted of computer, interface cards, meters, transmitters, and solid state relays. Mapping-depiction was achieved by SCADA through an Indusoft Web Studio software. In situ ammonium and nitrate sensors were used for adjusting the oxic and anoxic phase duration.

## 3. Calculations performed

Dynamic Process Control (DPC) strategy brought about COD, BOD, TKN, $NH_4^+$-N and $NO_3^-$-N removal percentages of 90, 94, 89, 94 and 99%, respectively. In any case, the legislative effluent limits were not exceeded. C/N ratio was 10, necessary for the nitrification. The mean ammonium oxidation was 3.5 mg/L within 33 min of the aerobic phase, reaching the set point of 2 mg/L. At the anoxic phase, the direct intermittent feeding method resulted in complete $NO_3$-N removal within 12 min, due to the higher carbon source available to the denitrifiers (Figure 2).

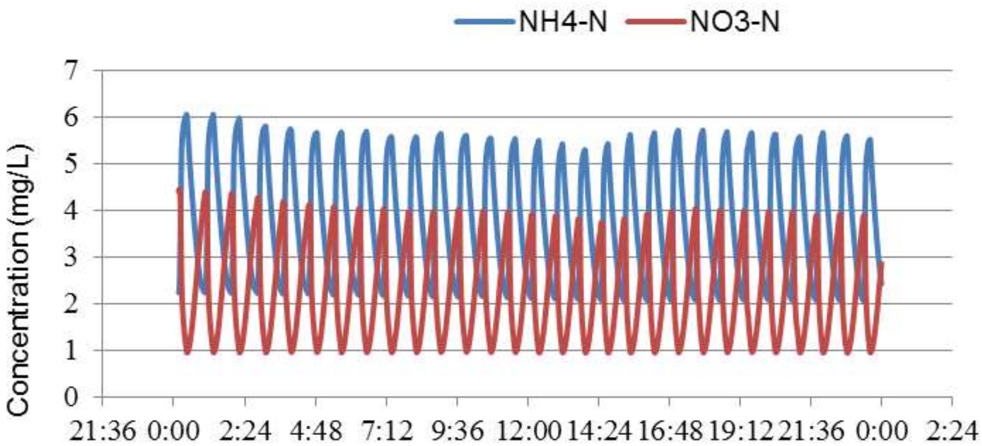


**Figure 2:** $NH_4$-N and $NO_3$-N cycle profiles during monitoring of the nitrification-denitrification process in intermittently aerated and fed bio-reactor.

## 4. Results

The efficiency of ammonium nitrate removal was 85.6% of total $NH_4$-N concentration within 21 min and 14% of residual ammonium concentration within 11 min of aerobic phase. Two nitrification rates (NRs) were formed at the aerobic phase, the first and fastest was ranged from 0.06 to 0.2 g $g^{-1}$ VSS $d^{-1}$ with an average of 0.15 g $g^{-1}$VSS $d^{-1}$ and the second from 0.03 to 0.12 g $g^{-1}$ VSS $d^{-1}$ with an average of 0.08 g $g^{-1}$VSS $d^{-1}$. Under every circumstance, the nitrification rates are greater than literature refers (Dytczak *et al*., 2008). At the same time, three denitrification rates (DNRs) were observed during the anoxic phase. The first rate was 0.1 to 0.58 g $g^{-1}$ VSS $d^{-1}$ with average 0.43 g $NO_3$-N $g^{-1}$VSS $d^{-1}$, the second rate was ranged from 0.02 to 0.12 g $g^{-1}$ VSS $d^{-1}$ with a mean of 0.09 g $NO_3$-N $g^{-1}$ VSS $d^{-1}$ and the third rate varied from 0.01 to 0.07 g $g^{-1}$ VSS $d^{-1}$ with average of 0.04 g $NO_3$-N $g^{-1}$VSS $d^{-1}$. The high denitrification rates were due to the increased amount of available carbon source (Carrera *et al*., 2004).

## 5. Conclusions

The control of aerobic and anoxic phases was achieved using a Programmable Logic Controller and measurements of ammonium and nitrate nitrogen concentrations with in situ located $NH_4$-N and $NO_3$-N sensors. Setting the minimum desired concentration of ammonia and nitrates as "target", the optimization of the nitrification and denitrification process was attained, respectively, according to the requirements of the incoming nitrogen load. Oxidation of 4 to 7 mg/L ammonium nitrogen lasted from 28 to 36 and the average nitrification time was 31 min. Complete denitrification (reduction of 7 mg $NO_3$-N/L) was achieved in a very short anoxic phase time of 21 min. The success of the control strategy is shown by the high removal efficiencies of ammonia and TKN (by 94 and 89%, respectively). The average removal efficiencies of BOD and COD were 94 and 90% respectively. The activated sludge also showed excellent settling ability.

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