A pilot scale study of a sequencing batch reactor treating municipal wastewater operated via the UP-PND process

M. Kornaros, C. Marazioti and G. Lyberatos

ABSTRACT

SBRs are usually preferred as small and decentralized wastewater treatment systems. We have demonstrated previously that using a frequent enough switching between aerobic and anoxic conditions and a specific to the treated wastewater aerobic to anoxic phase ratio, it is possible to bypass the second step of nitrification (i.e. conversion of nitrite to nitrate nitrogen). This innovative process for nitrate by-pass has been branded as UP-PND (University of Patras-Partial Nitrification Denitrification) (WO 2006/129132). The proved methodology was successfully transferred from a lab-scale SBR reactor treating synthetic wastewater to a pilot-scale SBR system treating real wastewater. In this work we present the results from the operation of this pilot-scale SBR, constructed in the Wastewater Treatment Plant of Patras (Greece), using 6-hour, 8-hour and 12-hour cycles. It is demonstrated that three pairs of aerobic/anoxic phases with a relative duration of 1:2 (8-hour cycle) and 2:3 (12-hour cycle) secures the desired by-pass of nitrate production.

Key words | municipal wastewater, partial nitrification-denitrification, SBR

INTRODUCTION

Biological nitrification–denitrification is the most common process for nitrogen removal from wastewaters. Operational costs of the biological nitrogen removal process are to a great extent related to the oxygen and organic matter requirements for nitrification and denitrification, respectively. Because the organic carbon present naturally in the wastewater is quite limited, the complete removal of nitrogen from wastewaters (especially those that contain high nitrogen concentration) requires a large amount of an added carbon source for denitrification.

These were what drove the investigation for new low-cost biotreatment processes and several different operational strategies. Many of them are based on partial nitrification of ammonium to nitrite. This process is based on the fact that nitrite is an intermediate compound in both nitrification and denitrification steps.

By carrying out partial nitrification up to nitrite and then denitrification starting from nitrite, the PND process (Partial Nitrification Denitrification) avoids the unnecessary steps of nitrification of nitrite to nitrate and denitrification of nitrate back to nitrite, with significant advantages such as (Abeling & Seyfried 1992): (1) 40% reduction of the COD demand during denitrification, (2) 63% higher rate of denitrification, (3) 25% reduction of oxygen demand for nitrification compared to complete oxidation to nitrate and (4) 30% lower biomass yield during anoxic growth.

Among the various methods that have been proposed for partial nitrification, exploitation of the time-lag is by far preferable, as it does not require any addition of chemicals, but a simple manipulation of the operating conditions. We have demonstrated (Katsogiannis et al. 2003) that using a frequent enough switching between aerobic and anoxic conditions and a specific to the treated wastewater aerobic to anoxic phase ratio, it is possible to by-pass the second step of nitrification (i.e. conversion of nitrite to nitrate nitrogen). This innovative process for nitrate by-pass has been branded as UP-PND (University of Patras-Partial Nitrification Denitrification) (WO 2006/129132). An SBR operated via the
UP-PND process partially oxidizes ammonia to nitrite (aerobically), which is then subsequently reduced to nitrogen gas (under anoxic conditions), without producing nitrate. The success of this process has been attributed to the fact that nitrite oxidizers exhibit a long lag phase under aerobic conditions following an anoxic phase (Dokianakis 2006).

The proved methodology was successfully transferred from the lab-scale SBR reactor treating synthetic wastewater to a pilot-scale SBR system treating real wastewater. In this work we present the results from the operation of this pilot-scale SBR, constructed in the Wastewater Treatment Plant of Patras (Greece), using 6-hour, 8-hour and 12-hour cycles.

METHODS

The pilot-scale reactor (Figure 1) with a working volume of 2 m$^3$ was operated in the sequence of fill (10 min), react (240 min for 6-hour, 600 min for 12-hour and 360 min for 8-hour), a final aerobic phase (15 min), settle (90 min) and draw/idle (5 min) phases. The total cycle times that were investigated were of 6, 8 and 12 hours. The seeding sludge was obtained from the aerobic basin of the wastewater treatment plant of the City of Patras, Greece.

Wastewater samples were collected directly from the reactor at regular intervals. The mixed liquor portion taken from the reactor was filtered through a 0.2 μm pore size filter. The filtrate was analyzed for ammonium-, nitrate- and nitrite-nitrogen concentration according to the phenate method (APHA/AWWA/WEF 1995), to ion chromatography (DX300, Dionex Corp.) and to the colorimetric sulfanilamide method (APHA/AWWA/WEF 1995), respectively. Measurements for pH (Ingold, Type 465), total suspended solids and volatile suspended solids (APHA/AWWA/WEF 1995) were also taken at regular intervals during the SBR cycle. The filtrate was also analyzed for chemical oxygen demand (APHA/AWWA/WEF 1995). Finally, the dissolved oxygen (DO) was monitored via a steam sterilizable galvanic (Johnson & Borkowski) type oxygen electrode.

RESULTS AND DISCUSSION

6-hour cycle

For the 6-hour cycle 3 pairs of aerobic/anoxic phases and 1:1, 1:2 and 1:3 aerobic/anoxic ratio were investigated. For all cases a complete removal of ammonia and soluble COD was observed.

Figure 2 presents the profiles of ammonium, nitrates and nitrites during the 6-hour cycle with 3-pairs of aerobic/anoxic phases and an aerobic/anoxic ratio of 1:2. The wastewater feed characteristics were: 50.55 mg NH$_4$-N/l, 0.048 mg NO$_2$-N/l, 2.19 mg NO$_3$-N/l, total COD 261 mg/l, soluble COD 89.53 mg/l, temperature 24°C, pH 7.37, TSS 0.02 g/l and a Sludge Retention Time (θc) = 16 d.

8-hour cycle

For the 8-hour cycle 3 pairs of aerobic/anoxic phases and 1:1, 1:2, 2:3 and 1:3 aerobic/anoxic ratio were investigated.
For all cases a complete removal of ammonia and soluble COD was observed.

Figure 3 presents the profiles of ammonium, nitrates and nitrites during the 8-hour cycle with 3-pairs of aerobic/anoxic phases and an aerobic/anoxic ratio of 1:2. The wastewater feed characteristics were: 24.3 mg NH4-N/l, 0.3 mg NO2-N/l, 0.9 mg NO3-N/l, total COD 381 mg/l, soluble COD 101 mg/l, temperature 19.4°C, pH 7.3, TSS 0.02 g/l and a Sludge Retention Time (u) = 16 d. During this 8-hour cycle the biological nitrogen removal was achieved via nitrites (by-passing nitrates). Ammonium nitrogen was completely removed at the end of the cycle, while the concentration of nitrates and nitrites in the end of the cycle was almost zero. The concentration of soluble COD was below the legal limits for disposal to sensitive water receptors.

12-hour cycle

For the 12-hour cycle 3 pairs and 1 pair of aerobic/anoxic phases and 2:3 aerobic/anoxic ratio were investigated. For all cases a complete removal of ammonia and soluble COD was observed.

Figure 4 presents the profiles of ammonium, nitrates and nitrites during the 12-hour cycle with 3-pairs of aerobic/anoxic phases and an aerobic/anoxic ratio of 2:3. The wastewater feed characteristics were: 36.5 mg NH4-N/l, 0.5 mg NO2-N/l, 0.5 mg NO3-N/l, total COD 506 mg/l, soluble COD 95 mg/l, temperature 12.6°C, pH 7.8, TSS 0.99 g/l and a Sludge Retention Time (u) = 16 d. During this 12-hour cycle the biological nitrogen removal was achieved via nitrites (by-passing nitrates). Ammonium nitrogen was completely removed at the end of the cycle (99.8%), the concentration of nitrates and nitrites in the end of the cycle was almost zero and the concentration of soluble COD was under the legal limits for disposal.
The characteristics of the effluent for all cases studied are presented in Table 1. In the last column the process is characterized as a PND process or not.

## CONCLUSIONS

It is demonstrated that three pairs of aerobic/anoxic phases with a relative duration of 1:2 (8-hour cycle) and 2:3 (12-hour cycle) secures the desired by-pass of nitrate production. Moreover, a complete removal of soluble COD was achieved, while denitrification took place without the addition of an external carbon source. The nitrification-denitrification process in the pilot SBR was however achieved with a lower rate than that observed in the lab-scale system. This might be attributed to the lower temperature and the composition of the raw wastewater treated in the pilot system, compared with the operating conditions of the lab-scale SBR system (synthetic wastewater treated at 25°C).

The 6-hour cycle exhibited a complete removal of ammonia and soluble COD, but without the desired by-pass of nitrate production. At the end of the 6-hour cycle, nitrates were not completely consumed as it was the case with the 8-hour and 12-hour cycles.

The 8-hour cycle with 3 pairs of aerobic/anoxic phases and an aerobic/anoxic ratio of 1:2 showed similar results with the 12-hour operation. However, the benefit of the 8-hour cycle over the 12-hour cycle is the increased throughput of treated wastewater in the reactor.

## REFERENCES


