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Nutrient removal from slaughterhouse wastewater in an intermittently aerated sequencing batch reactor

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Abstract

The performance of a 10 L sequencing batch reactor (SBR) treating slaughterhouse wastewater was examined at ambient temperature. The influent wastewater comprised 4672 ± 952 mg chemical oxygen demand (COD)/L, 356 ± 46 mg total nitrogen (TN)/L and 29 ± 10 mg total phosphorus (TP)/L. The duration of a complete cycle was 8 h and comprised four phases: fill (7 min), react (393 min), settle (30 min) and draw/idle (50 min). During the react phase, the reactor was intermittently aerated with an air supply of 0.8 L/min four times at 50-min intervals, 50 min each time. At an influent organic loading rate of 1.2 g COD/(L d), average effluent concentrations of COD, TN and TP were 150 mg/L, 15 mg/L and 0.8 mg/L, respectively. This represented COD, TN and TP removals of 96%, 96% and 99%, respectively. Phase studies show that biological phosphorus uptake occurred in the first aeration period and nitrogen removal took place in the following reaction time by means of partial nitrification and denitrification. The nitrogen balance analysis indicates that denitrification and biomass synthesis contributed to 66% and 34% of TN removed, respectively.

Keywords: Intermittent aeration; Nutrient removal; Partial nitrification; Sequencing batch reactor; Slaughterhouse wastewater

1. Introduction

In Ireland, there are currently 306 licensed slaughterhouses comprising 270 slaughterhouses licensed for the domestic market and 36 approved bovine export slaughterhouses (Howlett et al., 2005). Slaughterhouses produce high-strength wastewater (European Commission, 2005; Irish EPA, 2006). The amount of wastewater generated per cow is approximately 2 m^3 per day and mainly originates in the rendering department and holding yards of slaughterhouses (Johns et al., 1995). In pig slaughterhouses, 1.6–8.3 m^3 of water per tonne of carcase is generated (EC, 2005). Depending on whether preliminary treatment is carried out and its efficiency, the concentrations of contaminants in slaughterhouse wastewater can be variable, with suspended solids (SS), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) concentrations ranging 250–5000 mg/L, 1000–20,000 mg/L, 150–10,000 mg/L and 22–217 mg/L, respectively (Fuchs et al., 2003; Cassidy and Belia, 2005; Del and Diez, 2005; Merzouki et al., 2005; Mittal, 2006). A service fee is normally charged for the treatment of slaughterhouse wastewater in local municipal wastewater treatment plants.

For large-scale slaughterhouses, on-site biological treatment is recommended by the European Commission to remove organic carbon (C) and nutrients before the wastewater is discharged to surface waters or local wastewater treatment plants (EC, 2005). The emission standards in Ireland for slaughterhouse wastewater are: COD $\geqslant$ 75% removal or 125–250 mg/L in the effluent; TN $\geqslant$ 80% removal or 15–40 mg/L in the effluent; and TP $\geqslant$ 80% removal or 2–5 mg/L in the effluent. The European Commission also recommends that sequencing batch reactors (SBRs) be amongst the best available techniques (BATs) for slaughterhouse wastewater treatment, as SBRs are capable of removing organic C, nutrients and SS from

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wastewater, and have low capital and operational costs. Typical COD, TN and TP removals from slaughterhouse wastewater achieved in SBRs are 95%, 60–80% and 40%, respectively (EC, 2005). SBRs are not able to remove nitrogen (N) as efficiently as COD because slaughterhouse wastewater contains very high TN, with a typical biochemical oxygen demand (BOD_5) to TN ratio of 7–9:1.

Typically, biological N removal in SBRs is through pre-denitrification, which occurs during the fill phase (or an anoxic phase between the fill and the aerobic react phase). Anoxic heterotrophic denitrifiers reduce nitrate-N (NO_3-N)/nitrite-N (NO_2-N), which is produced in the preceding operational cycle and remains in the reactor after the draw phase, to nitrogen gas (N_2). Denitrifiers consume the readily biodegradable COD (rbCOD). If simultaneous phosphorus (P) and N removal is expected to be achieved in the reactor, P accumulating organisms (PAOs) will compete with denitrifiers for rbCOD for anaerobic P release. This competition between PAOs and denitrifiers will result in unstable biological P removal if the influent wastewater does not contain sufficient rbCOD. Therefore, chemical precipitation is applied to guarantee a low level of P in the effluent (Filali-Meknassi et al., 2005a).

A conventionally operated SBR can be changed to an intermittently aerated SBR, where one complete operational cycle comprises four phases – fill, react (alternating aeration and mixing), settle and draw. In the react phase, aeration and mixing are alternatively applied. Intermittently aerated reactors have been used to remove N from domestic wastewater (Zhao et al., 1999) and swine wastewater (Mota et al., 2005b). In an intermittently aerated SBR, during the aeration periods, dissolved oxygen (DO) is high and aerobic nitrifiers oxidize ammonium-N (NH_4-N) to oxidized N (NO_2-N and NO_3-N), and during the subsequent mixing periods, DO decreases to such a low level that anoxic denitrifiers reduce oxidized N to N_2 gas. The intermittent aeration strategy can also reduce the demand for rbCOD contained in the influent wastewater in the fill phase by minimizing the occurrence of N removal, so that PAOs will obtain sufficient rbCOD for anaerobic P release; this is beneficial for biological P removal. In addition, in an intermittently aerated reactor, the organic C stored by PAOs can be used by denitrifiers for denitrification during subsequent anaerobic periods (Nazik and Derin, 2005), resulting in less dependence of denitrification on the rbCOD content in the influent wastewater. Therefore, stable and efficient N and P removal can be achieved in intermittently aerated SBRs, which is an advantage over conventional SBRs.

If the DO in the reactor tank is controlled properly by means of intermittent aeration, NH_4-N will be partially oxidized to NO_2-N and then in the mixing period, NO_2-N will be reduced to N_2 gas. This partial nitrification ('nitritation') can reduce the operational cost by reducing oxygen supply and reduce the demands for rbCOD in the denitrification process (Khin and Annachhatre, 2004; Ahn, 2006; Paredes et al., 2007).

In this study, the performance of a laboratory-scale, intermittently aerated SBR for simultaneous N and P removal from slaughterhouse water was investigated.

2. Methods

2.1. Laboratory-scale SBR system

The laboratory-scale SBR system is illustrated in Fig. 1. The reactor tank was made from transparent Plexiglas and had a working volume of 10 L, with an inner diameter of 194 mm and a height of 400 mm. Two MasterFlex® L/S peristaltic pumps were used – one filled the reactor tank with slaughterhouse wastewater from the influent tank during the fill phase and the other decanted the effluent from the reactor tank during the draw/idle phase. A mechanical mixer with a 80 mm-deep by 100 mm-wide rectangular paddle was installed over the reactor. An air pump supplied air through a porous stone diffuser, located at the bottom of the reactor tank. The air flow rate was regulated by an air flowmeter. The operational sequence of the SBR system and the movement of all mechanical devices including the peristaltic pumps, the mixer and the air pump, was controlled by a programmable logic controller (PLC) (S7-222, Siemens, Germany).

DO, pH and oxidation-reduction potential (ORP) in the reactor tank were real-time monitored using electrodes. The DO electrode (EC-DOTPII-S, Eutech, Singapore), pH electrode (Sentix 20, WTW, Germany) and ORP electrode (Sentix ORP, WTW, Germany) were connected to corresponding transmitters (Eutech, Singapore) that transformed the signals from the three electrodes into 4–20 mA analog signals. Then, a data acquisition card (USB-6009, National Instrument, USA) transformed analog signals into digital signals, which were processed by the LabVIEW computer programme (National Instruments, USA).

2.2. Slaughterhouse wastewater

The slaughterhouse wastewater was collected from the conditioning tank in the wastewater treatment plant (WTP) of a local slaughterhouse in western Ireland. The WTP comprises preliminary treatment (screening and dissolved air flotation), a conditioning tank, primary treatment (sedimentation), secondary treatment (conventional activated sludge pre-denitrification process) to reduce COD and N, and tertiary treatment (chemical coagulation) to reduce P. The aeration tanks of this plant are operated at an average organic loading rate (OLR) of 0.5 kg COD/(m^3 d). The sludge retention time (SRT) is 20–30 days and the concentration of mixed liquor suspended solids (MLSS) is 5000–6000 mg/L.

The raw wastewater was collected in 10-L plastic containers and stored in a refrigerator at approximately 4 °C for 10–20 days before use. The wastewater in the influent tank was prepared daily by filtering the raw wastewater through a 0.6 mm mesh screen and a submerged aquarium