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Conditioning the alternating aerobic–anoxic process to enhance the removal of inorganic nitrogen pollution from a municipal wastewater in France

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ABSTRACT

Inorganic nitrogen pollution from surface waters can adversely affect human health and the environment. Coupled nitrification–denitrification can significantly remove the total inorganic nitrogen pollution amount from municipal wastewater; however, researchers only have a limited understanding of the alternating aerobic–anoxic process in a single reactor. This study performed a typical treatment using a completely mixed alternating aerobic–anoxic extended aeration treatment process in a single reactor, biological fluidised bed reactor to remove inorganic nitrogen pollution from a municipal wastewater in France. Comparative analysis of the coupled nitrification–denitrification reactions was carried out to investigate the two different alternating aerobic–anoxic processes of 3-h aerobic digestion and 6-h anoxic time and 3-h aerobic digestion and 3-h anoxic time. The results indicate that the change in anoxic time, specifically, from 6 to 3 h, can increase the alternating aerobic–anoxic process performance by approximately 53.4%. The average effluent inorganic nitrogen concentration decreased from 10.3 to 4.8 mg N/L, achieving the desired inorganic nitrogen concentration of less than 10 mg N/L in the outflow to meet the stringent effluent standards. The study offers a proper treatment that can be used to help reduce inorganic nitrogen pollution from municipal wastewater processed in a single-sludge reactor. The study's results advance the understanding of this simple technique that effectively removes inorganic nitrogen pollution from municipal wastewater.

1. Introduction

Effluent of municipal wastewater treatment plants contains high concentrations of inorganic nitrogen that may lead to the degradation of the receiving water quality. Inorganic nitrogen pollution (INP) of aquatic ecosystems can induce adverse effects on human health and the environment (Camargo and Alonso, 2006). Municipal wastewater has to be treated for removal of inorganic nitrogen such as by an alternating aerobic–anoxic (AAA) process. The use of nitrogen-rich sludge as a fertiliser and soil conditioner in agriculture would be an attractive option (Nair and Ahammed, 2013; Passarini et al., 2014); however; precaution should be taken because of its high salinity (Mañas et al., 2014). The theoretic principles of nitrification–denitrification can possibly provide insight into biochemical properties and reaction mechanisms to understand steady state model for an AAA extended aeration system. Certain bacterial strains are expected to play an important role in the treatment of inorganic nitrogen in municipal wastewater during nitrification and denitrification processes (Wang and Lee, 2001; Fulazzaky et al., 2013a, 2013b). In an aerobic pond, autotrophic nitrifying bacteria convert ammonium ions (NH_4^+) or free ammonia (NH_3) to nitrite ions (NO_2^-) and then to nitrate ions (NO_3^-) while creating organic carbon in the form of biomass and soluble microbial products (Lage et al., 2010; Mohamed et al., 2010; Nyenje

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et al., 2013). The nitrification process consists of two steps performed by distinct groups of bacteria. The first step is carried out by *Nitrosomonas* and *Nitrococcus* bacteria and involves the oxidation of NH_4^+ (or NH_3) to NO_2^- according to the following reaction:

$$NH_4^+ + 1½O_2 \rightarrow NO_2^- + H^+ + H_2O \text{ (or } NH_3 + 1½O_2 \rightarrow NO_2^- + 2H^+ + H_2O) \quad (1)$$

The second step is carried out by *Nitrobacter* bacteria (Cébron et al., 2003) and involves the oxidation of NO_2^- to NO_3^- according to the reaction:

$$NO_2^- + ½\, O_2 \rightarrow NO_3^- \quad (2)$$

Because the molecular formula of biomass: $C_5H_7O_2N$ would be used to represent the composition of heterotrophic biomass (Bae et al., 2002; Chuang and Ouyang, 2000), the overall reaction that describes complete nitrification (Liu and Wang, 2012) is the following:

$$NH_4^+ + 1.83O_2 + 1.98HCO_3^- \rightarrow 0.021C_5H_7O_2N + 0.98NO_3^- + 1.88H_2CO_3 + 1.041H_2O \quad (3)$$

Microbial biomass stoichiometry is an important determinant when microorganisms retain or recycle mineral nutrients (Fulazzaky, 2013; Hall et al., 2011; Rostkowski et al., 2013; Sinsabaugh and Shah, 2012). The stoichiometry of the reaction helps determine the maximum final yield of the desired product (Shah et al., 2012) and must be considered as an important deciding factor in designing wastewater treatment plants.

Many technical feasibilities of removing INP from municipal wastewater have been proposed to show that using the partial nitrification in a continuous plug-flow step feed process can remove approximately 86% of INP with its concentration of 7.23 mg/L in effluent to meet the discharge requirements (Ge et al., 2014), using the membrane bioreactor of conventional denitrification/nitrification scheme operated with a longer duration of anoxic phases can lower excess sludge production (Guglielmi and Andreottola, 2011), using the pilot plant of four-compartment reactor packed with Biolace media operated in the anoxic/aerobic submerged fixed-film and the aerobic modes can increase the denitrification rate linearly with the total oxidised nitrogen loading applied (Hamoda and Bin-Fahad, 2012), and using the anoxic/anaerobic/aerobic processes to remove INP from wastewater can have a much higher efficiency than the anaerobic/anoxic/aerobic processes (Zhang and Gao, 2000). However, it has a limited understanding of nitrifiaction–denitrification rate for the AAA processed in a single reactor, which is expected to have good performance when used for the removal of INP from municipal wastewater.

Denitrification is the biological reduction of NO_3^- to nitrogen gas (N_2) by facultative heterotrophic bacteria (Risgaard-Petersen et al., 2006). During denitrification, some chemoorganotrophs are capable of replacing O_2 with NO_3^- as the terminal electron acceptor under certain conditions. The overall process of reduction of NO_3^- to N_2 is carried out by a variety of bacteria such as *Alcaligenes*, *Achromobacter*, *Micrococcus* and *Pseudomonas* (Caldwell et al., 1979; Mara and Horan, 2003) and proceeds (Lipschultz et al., 1981; Spott et al., 2011; van Rijn et al., 2006) as follows:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \quad (4)$$

Organic pollutants in domestic wastewater originating from food and household-related products can biologically degrade into smaller organic molecules and can then be used by denitrifying bacteria as a carbon and energy source (Castignetti, 1990; Robertson and Kuenen, 1990). However, if insufficient amounts of organic carbon in the wastewater are ingested, methanol (or ethanol) can be used for carbon needs of the bacteria. The use of methanol as a supplementary carbon source to enhance denitrification under anoxic conditions can be described by the following reaction (Ginige et al., 2009; Hamlin et al., 2008; Hasar and Ipek, 2010):

$$NO_3^- + 1.08CH_3OH + H^+ \rightarrow 0.065C_5H_7O_2N + 0.47N_2 + 0.76CO_2 + 2.44H_2O \quad (5)$$

Methanol must be added in sufficient quantity to allow for cell growth. The presence of any dissolved oxygen (DO) will inhibit denitrification (Borden et al., 1995) because the preferential path for electron transfer is to O_2 instead of to NO_3^-. The use of protons during the denitrification process reduces the acidity of the water and thus, pH increases. Because in general, nitrification proceeds slower than denitrification (Kool et al., 2011), it might be expected that organotrophs can reproduce more rapidly than nitrifying bacteria can reproduce (Gerardi, 2002). At low DO concentrations, facultative (aerobic and anaerobic) bacteria are still able to consume organic material during an AAA extended aeration treatment process in a single reactor. Even if both nitrification and denitrification can occur simultaneously in the same reactor (Ju et al., 2007; Tandukar et al., 2006; Zhang and Zhou, 2007), the efficiency of the AAA process (Zeng et al., 2007) with a typical treatment to remove INP from municipal wastewater must be verified. The objectives of this study are to create conditions that favour the use of a single-sludge nitrification–denitrification type process to ensure that facultative aerobes/anaerobes microorganisms can live in the presence or absence of oxygen and to assess the efficiencies of the AAA treatment process for nitrogen removal by comparing two different AAA time periods that drive the coupled nitrification–denitrification in single activated sludge.

2. Materials and methods

This section provides a detailed description of the AAA process and operating procedure, analytical methods, and conditioning the experimental environments.

2.1. Description of the alternating aerobic–anoxic process and operating procedure

This study performed a completely mixed AAA extended aeration treatment process in a single reactor (Fulazzaky et al., 2014), biological fluidised bed treatment system to describe the design

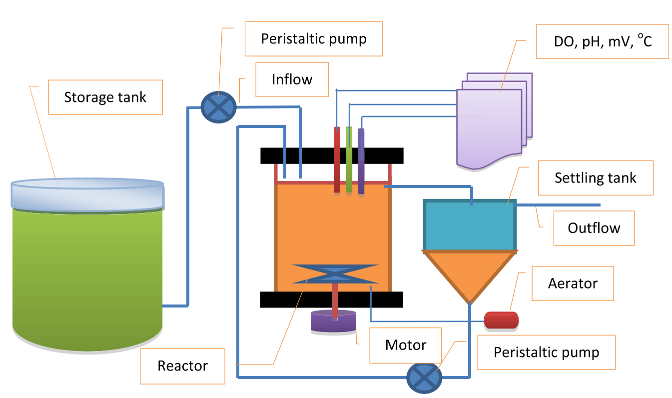

Fig. 1. Schematic of the AAA treatment process.