Bioresource Technology 146 (2013) 240–246

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

A full scale anaerobic–anoxic–aerobic process coupled with low-dose ozonation for performance improvement

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HIGHLIGHTS

- Low dose ozone was used and obvious effects were obtained in a full scale A/A/O process.
- Large amount of carbon and little nutrient were solubilized. The ratios of carbon to nitrogen and carbon to phosphorus in ozonated sludge were much higher than influent.
- Performance of A/A/O process was improved by low-dose ozonation.
- Low-dose ozonation didn't destroy sludge cell walls and had no effect on DO concentration of biological reactors.

ARTICLE INFO

Article history:
Received 18 May 2013
Received in revised form 5 July 2013
Accepted 11 July 2013
Available online 19 July 2013

Keywords:
Full scale A/A/O process
Low ozone dose
Sludge ozonation
Performance improvement
Nutrient removal

ABSTRACT

The effectiveness of RAS degradation under low dose ozone and effect of ozonated sludge on a full scale anaerobic–anoxic–aerobic (A/A/O) process were examined. The ratios of chemical oxygen demand (COD) to nitrogen and COD to phosphorus of ozonated sludge were 23 and 91 respectively on average, much higher than in influent. Compared with the performance of A/A/O process alone, COD removal efficiency slightly decreased after insertion of the ozonation system. Ammonia removal became more stable, but total nitrogen and total phosphorus removal efficiency was not improved. Sludge volume index (SVI) of activated sludge reached to an optimal value of 80–120 mL/g quickly due to ozonation combined with A/A/O process which reduced the danger of sludge bulking. Overall, the combination of biological process with ozonation at a low dose rate shows promise. Compared with higher dose ozonation, low-dose ozonation can improve the performance of A/A/O effectively at a smaller cost.

1. Introduction

In recent years, effluent quality requirements have become more stringent in China. Wastewater treatment plants (WWTPs) are facing more and more challenges trying to meet these new requirements. Among these challenges, nutrient removal is one of the most important. The biological nutrient removal (BNR) processes have been extensively studied and full-scale applications have been used around the world. However, the efficiency of BNR on nitrogen (N) and phosphorus (P) removal is not optimal because of the lack of biodegradable organic substrate in domestic wastewater (Park et al., 2011). In order to maintain high nutrient removal and low level of N and P in effluent, an external carbon source such as methanol, ethanol, or acetate must be added (Chuang et al., 2011; Cervantes et al., 2001). However, the addition of external carbon source not only increases the operational cost of wastewater treatment, but also the sludge production of activated sludge process (Park et al., 2011).

The major components of excess sludge include 60% organic compounds, nitrate, phosphorous, metals and bacteria (Khursheed and Kazmi, 2011). Therefore, it is necessary to consider the recovery of organic compounds in excess sludge to improve the performance of BNR. Recovery of internal carbon source can be accomplished by using various chemical (Lin et al., 2012), physical (Muller, 2000) and biological (Guellil et al., 2001) methods to rupture the cells in the sludge resulting in the release of cytoplasm. The pretreated sludge, including large amount of released organics, is then returned into the biological process where further degradation of organic matter and mineralization into CO_2 and H_2O

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0960-8524/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.biortech.2013.07.045

occurs. There are two obvious benefits to this process. First, organic compounds in the biological system are reused and decrease the need for addition of an external carbon source; second, the treated sludge is degraded by microorganisms in biological tanks, leading to a reduction in sludge production on the bases of lysis–cryptic growth in the WWTPs. This waste sludge treatment method will benefit society and environment.

Among the various approaches to sludge disintegration, ozonation is the most widely used because it is effective and has the highest cell destruction capability (Demir and Filibeli, 2012; Dytczak et al., 2007). Ozone is a strong chemical oxidant that can be combined with biological wastewater treatment to remove recalcitrant organics or eliminate sludge bulking (Van Leeuwen et al., 2009; Dziurla et al., 2005; Hollender et al., 2009). In regard to sludge treatment, ozonation is mostly used with the aim of reducing sludge or improving anaerobic sludge digestion (Muller, 2000; Lee et al., 2005; Braguglia et al., 2012). However, research that has focused on the feasibility of ozonation applied to A/A/O process for improvement of overall performance is fairly limited. Some papers have reported that ozone doses of 30–50 mg O_3 g^{-1} total suspended solids (TSS) is technically and economically viable, and the optimal ozone dose is 50 mg O_3 g^{-1} dry solids (Zhang et al., 2009; Boehler and Siegrist, 2007). Cost is proportional to ozone dose. Higher ozone dose is more energy and cost intensive. High cost of ozone is the main factor limiting wide application of ozonation technology in full scale plants (Manterola et al., 2008; Chu et al., 2009).

The objective of this study is to examine the solubilization of RAS when exposed to low dose ozone and the effectiveness of sludge ozonation for improvement of A/A/O process performance. In this study, after ozonation the treated sludge was pumped directly into the anaerobic tank. Performance of the A/A/O process both alone and with ozonation were compared to determine the feasibility of ozonation combined with the A/A/O process to improve overall performance of A/A/O process.

2. Methods

2.1. Full-scale A/A/O process

The performance of a coupled system was examined in a full scale plant. The integrated system consisted of A/A/O process and a sludge ozonation unit as shown in Fig. 1.

The biological process is comprised of an anaerobic basin, an anoxic basin, an aerobic basin and a secondary sedimentation basin. The system has a total treatment capacity of 500 m^3/day and total hydraulic retention time (HRT) of 16.5 h. More design details for A/A/O process were presented in Table 1.

Dissolved oxygen (DO) concentration in the anaerobic basin, anoxic basin and aerobic basin were maintained at 0.2 mg/L, 0.2 mg/L and 2–3 mg/L respectively. DO was monitored with DO meter twice a day. Mixed liquor suspended solids concentration was maintained at 3500 mg/L, and the temperature was 25–28 °C.

2.2. Characteristics of domestic wastewater

Municipal wastewater was used during the course of this study. Parameters of the wastewater are presented in Table 2. The ratio of carbon to total nitrogen (COD/TN) and carbon to total phosphorous (COD/TP) were 3.5 and 25 on average respectively.

2.3. Ozonation of return activated sludge

The sludge ozonation unit contained ozone generator, ozonation reactor and ozone meter as shown in Fig. 1. Ozone was controlled at a stable concentration of 50 mg/L by limiting the volume of oxygen input to the ozone generator. Ozone gas flow rate was 0.8 m^3/h. Ozone concentration was measured with an ozone concentration meter (LT-200c). Ozonation was carried out in a spiral pipe at ambient temperature. Return activated sludge from secondary sedimentation basin was 5500 mgSS/L and mixed with ozone at a volumetric flow of 80 L/min using a Venturi nozzle. Ozone dose was calculated to be 2 mg O_3/gSS. Ozone was continuously mixed with RAS and contact time in the pipe was 5 min. The ozonated sludge was returned to the anaerobic basin directly to be utilized by sludge microbes. It took more than 3 months to operate A/A/O process from start-up to stable operation, and the performance of the combined system was examined for over 2 months.

2.4. Analytical methods

Samples were collected periodically at the inlet, anaerobic basin, anoxic basin, aerobic basin, outlet of secondary sedimentation basin and before and after ozonation rector (Figs. 1①–⑦). In order to examine the effect of low dose ozone on the returned sludge, the characteristics of sludge before and after ozonation was examined. The composition of the influent and effluent were examined for TN, NH_3-N, TP and COD. The results of these tests were then evaluated to determine the performance of A/A/O process.

Samples collected were centrifuged or filtered using 0.45 μm filter paper. Filtered samples were analyzed for TN, NH_3-N, and TP. Non-filtered but centrifuged at 3200*g* for 3 min samples were used for the measurement of COD. Samples were examined in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, 1995). A microscope with digital camera was used to examine the change of sludge structure.

3. Results

3.1. Sludge ozonation

3.1.1. Sludge solubilization characteristics

In order to evaluate the possible impacts of ozone on excess sludge, samples were collected from the influent and effluent of the ozonation reactor. Changes of COD, TN and TP concentration were expressed as ΔCOD, ΔTN and ΔTP respectively as follows: $\Delta COD = COD_{after\ ozonation} - COD_{before\ ozonation}$ $\Delta TN = TN_{after\ ozonation} - TN_{before\ ozonation}$ $\Delta TP = TP_{after\ ozonation} - TP_{before\ ozonation}$

The concentrations of COD, TN and TP were increased disproportionately during ozonation. At a maximum, ΔCOD was approximately 200 mg/L, while ΔTN and ΔTP always had little net positive gain and occasionally even had net decrease. Carbon was solubilized to a much greater extent than phosphorus and nitrogen. The amount of solubilized COD was 68 and 140 times the TN and TP respectively at maximum and 23 and 91 times the TN and TP respectively on average. The COD/TN and COD/TP ratios were much higher than the influent ratios (3.5 and 25 respectively).

Sludge disintegration by high dose ozone consists of three sequential steps: disintegration of sludge flocs, solubilization of microbe cells and mineralization of released organics (Ahn et al., 2002a). With low dose and short contact time, ozone first destroys the floc, leading to the disruption of the compact aggregates. However, unlike high dose ozonation, low dose ozonation has minimal impact on bacterial cell walls (Yan et al., 2009; Chu et al., 2009; Komanapalli and Lau, 1996). In this study, low ozone dose and short contact time was used. TP increased by only 1 mg/L on average which was much less than reported in a study (18 mgP/L) with high ozone dose (Saktaywin et al., 2005). In addition, the ratio of carbon to nitrogen of ozonated sludge is much higher in this study