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Investigation of microbial community structure in an advanced activated sludge side-stream reactor process with alkaline treatment

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ABSTRACT

An advanced side-stream reactor process with alkaline treatment (SIPER) has been demonstrated excellent sludge reduction potential and nutrient removal in the previous pilot-scale studies. The microbial community characteristic of the process was investigated in this study. The results indicated that the return of alkaline-treated sludge did not influence microbial activity of the activated sludge containing a higher diversity of bacteria in the SIPER process. Sludge in the biological nutrient removal (BNR) system and in the side-stream reactor (SSR) showed significantly different microbial composition, although two systems were connected via sludge recycle. The unique bacterial community was attributed to high pH environment in the SSR. Sequences represented by predominant DGGE bands were affiliated with *Proteobacteria*, *Firmicutes*, *Bacteroidetes*, *Chloroflexi*, and *Chlamydiae*. The predominant bacteria in the system were nitrifying, denitrifying, and hydrolytic acid producing bacteria. The hydrolytic acid producing bacteria played an important role in achieving lysis-cryptic growth of cells while nitrifying and denitrifying bacteria laid the foundation for effective nitrogen removal. Plenty of nitrifying and denitrifying bacteria existed in the SSR, which improved the utility of the supernatant of alkaline-treated sludge as an additional carbon source and enhanced nitrogen removal of the system.

1. Introduction

Activated sludge process has played a primary role in wastewater treatment worldwide. The major limitation with the process is the generation of a huge amount of excess sludge (Kaya et al., 2013). Excess sludge treatment and disposal usually accounts for more than 50–60% of the total operational expenses of wastewater treatment plants (Yang et al., 2011). Thus, treatment and disposal of excess sludge has been considered as one of the most serious problems to wastewater treatment due to the higher energy consumption and higher treatment cost (Huang et al., 2014; Liu et al., 2015). Recently, side-stream reactor (SSR) technologies involving alkaline treatment, ultrasonication, thermal treatment, chemical oxidation, microwave irradiation, and other physico-chemical treatments have been developed to reduce biomass production within activated sludge process based on lysis-cryptic growth mechanism (Wei et al., 2003). Alkaline treatment is widely used in sludge disintegration due to its simple, effective and low energy consumption in the SSR process (Weemaes and Verstraete, 1998; Zhao et al., 2015). Biomass is disintegrated by alkaline treatment, and then cell content released as carbon source is ultimately biodegraded and converted into simple end products and less biomass in activated sludge system. Although sludge minimization can be achieved by alkaline treatment within the activated sludge process, the technology still retains the several defects. For example, most studies on alkaline treatment for sludge reduction are conducted as bench-scale experiments, and the research results often differ among the previous studies, which remaining some uncertainty as to their practical application. Accumulation of inert or inorganic particles occurs in the bioreactor when alkaline-treated sludge was returned into activated sludge system. The microbial community may be negatively affected by the introduction of extra alkaline

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with the return of alkaline-treated sludge, ultimately, resulting in the deterioration of effluent quality.

To overcome these defects, the SIPER process (Fig. 1), an advanced activated sludge side-stream reactor process using alkaline treatment for sludge reduction, was developed by Yan et al. (2013). The pilot-scale system (10 m^3 d^{-1}) was built in a full-scale wastewater treatment plant in Chongqing, China (5×10^4 m^3 d^{-1}). The process showed excellent sludge reduction potential and effluent quality, and lysis-cryptic growth of cells was successfully employed for sludge reduction in this process (Yan et al., 2013). The performance and stability of biological treatment system are thought to be intimately related to the microbial community structure and diversity (Gerardi, 2006); therefore, the microbial community is bound to play a dominant role in sludge reduction and nutrient removal in the SIPER process. But the specific relationship between microbial community and system performance is not clear. Furthermore, microbial community structure and diversity in the reactors have dependence on the environmental conditions (Pholchan et al., 2010; Kim et al., 2015). After the introduction of extra alkaline along with the return alkaline-treated sludge, the environmental conditions of the bioreactor will be altered. Indeed, when the alkaline-treated sludge is recycled to the activated sludge system, which may affect all microbes in the bioreactor. Especially, the microorganisms of SSR will be dramatically different to that of conventional activated sludge process due to extreme high pH environment. Currently, there have been few in-depth investigations on microbial communities and biological performance in the SSR process with alkaline treatment. In this study, the pilot-scale system was employed to systematically investigate the characteristics of the bacterial community structure and the biological activity of the activated sludge in the SIPER process, and evaluate the relationship between this structure and the performance of the process using actual wastewater as an influent, based on the polymerase chain reaction-denaturing gradient gel electrophoresis (PCR-DGGE) approach.

2. Materials and methods

2.1. Wastewater

The wastewater of the pilot-scale study was the effluent of the thin screen of the full-scale wastewater treatment plant, and the concentrations of COD, TN, TP, NH_4^+–N and TSS were 430 ± 93 mg O_2 L^{-1}, 47 ± 8 mg N L^{-1}, 4.4 ± 0.9 mg PO_4^{-3}-P L^{-1} and 44 ± 8 mg NH_4-N L^{-1}, respectively, in the influent.

2.2. Analytical methods

Analyses of TSS, MLSS, MLVSS, COD, TP, TN and NH_4^+–N were performed according to standard methods (APHA et al., 2005). The pH was monitored with a pH meter (HQ40d, Hach Company, Loveland, CO, USA).

2.3. Pilot-scale system operation

The pilot-scale system was consisted of the biological nutrient removal (BNR) system (cyclic activated sludge system [CASS] tank), enhanced sludge hydrolysis and acidification tank (SSR), phosphorus recovery tank and inorganic solids separation module, as shown in Fig. 1, and the operating parameters for each reactor unit were presented in Yan et al. (2013). The settled activated sludge was treated with alkali in the SSR, then alkaline-treated sludge as an additional C-source (pH was 10.12 ± 0.28) was recycled to the BNR system and used to enhance nitrogen and phosphorus removal. Simultaneously, the inorganic solids separation module achieved inorganic particles removal from activated sludge, and underflow sludge containing concentrated inorganic particles was wasted from the system. The phosphorus-rich supernatant from the anaerobic zone was collected in the phosphorus recovery tank, and then was dosed with aluminum polychloride. The supernatant was recycled to the CASS tank for further treatment after complete reaction and settling.

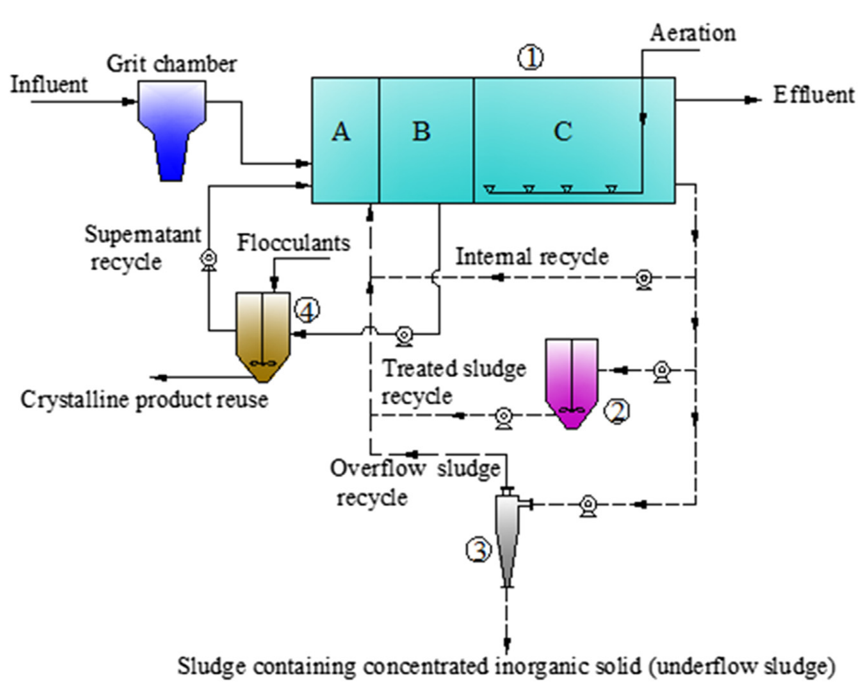

Fig. 1. Schematic diagram of the pilot-scale SIPER process. (1) CASS tank (BNR system); (2) enhanced sludge hydrolysis and acidification tank (SSR); (3) inorganic solids separation module; and (4) phosphorus recovery tank. (A, bio-selector; B, anaerobic zone; and C, aerobic zone).