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Effects of different carbon supplements on phosphorus removal in low C/P ratio industrial wastewater

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ABSTRACT

This study focuses on the effects of different carbon supplements on biological phosphorus removal in the optonics and semiconductor industrial wastewater treatment. Experimental results demonstrate that the addition of a carbon source (glucose, acetate, and digester supernatant) improved phosphorus removal effectively. When the COD/P ratios were controlled in the range of 18–20 (using glucose and supernatant as supplement), the acclimated sludge showed more than 98% removal of phosphorus. In addition, different organic carbons induce dissimilar behavior in anaerobic release and aerobic uptake of phosphorus. The glucose supplement induces significant phosphorus release in anaerobic phase and then an increased phosphorus uptake in aerobic phase. The released phosphorus descended in anaerobic phase when acetate and supernatant were added. There was a good linear relationship of first order reaction between initial COD concentration and specific substrate utilization rate in anaerobic phase.

1. Introduction

Phosphorus removal is essential in advanced wastewater treatment, especially for high-tech industrial wastewater, which contains low organic carbon and high phosphorus concentration. The cleaning processes of the optonics and semiconductor industries are the main source of phosphorus-rich wastewater. In order to conform to the strict effluent standard of the EPA, biological wastewater treatment processes are generally adopted for the high-tech wastewater treatment in Taiwan. However, there is limited knowledge and research about the ability of biological phosphorus removal from such high-tech industrial wastewater.

The enhanced biological phosphorus removal (EBPR) process and phosphorus adsorption are widely accepted and applied for domestic wastewater treatment (Metcalf and Eddy, 2003; Oehmen et al., 2007; Babatunde and Zhao, 2010; Chen et al., 2010; Ge et al., 2010). EBPR can be achieved through an activated sludge process by re-circulating sludge through anaerobic and aerobic conditions (Barnard, 1975). The group of microorganisms that is largely responsible for phosphorus removal, i.e. polyphosphate accumulating organisms (PAOs), can be stimulated in such conditions. The PAOs convert organic carbon into poly-hydroxylalkanoates (PHAs) during the anaerobic phase. The energy for this biotransformation comes from the cleaving of polyphosphate; meanwhile the reducing power is provided by the glycolysis of internally stored glycogen (Mino et al., 1998; Oehmen et al., 2007). The cleaving of polyphosphate leads to an increased phosphorus concentration in the bulk liquid. During the aerobic phase, the PAOs are able to use internally stored PHAs as an energy source for phosphorus uptake, polyphosphate storage, glycogen replenishment, and biomass growth. Then, phosphorus removal from wastewater is achieved through the way of waste polyphosphate-rich biomass.

Numerous operational factors affect the performance of the EBPR process and the competition between PAOs and other bacteria (such as glycogen accumulating organisms, GAOs). Application of different carbon sources and ratios of organic carbon to P in the influent (C/P ratio) have been shown to have significant impacts on the competition between the PAOs and GAOs (Thomas et al., 2003; Ahn and Speece, 2006; Zeng et al., 2006). Numerous studies have found that a high COD/P ratio (e.g. >50 mg COD/mg P) in influent tends to favor the growth of GAOs instead of PAOs (Mino et al., 1998). Thus, a low COD/P ratio (e.g. 10–20 mg COD/mg P) will be more favorable to the growth of PAOs (Mino et al., 1998). On the other hand, a sufficient amount of volatile fatty acids (VFAs) has to be provided in the anaerobic phase in order to induce phosphorus release and achieve good phosphorus removal. Oehmen et al. (2005) reported that phosphorus could be removed effectively at COD/P ratio of 15 when propionate was used as a sole carbon source. Yagci et al. (2003) found good phosphorus removal at

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COD/P ratios between 7 and 10, using acetate as the sole carbon source. Other studies concluded that the mixtures of volatile fatty acids also lead to effective phosphorus removal (Chen et al., 2005; Levantesi et al., 2002). Broughtona et al. (2008) reported that the minimum COD/P ratio for effective treatment of dairy processing wastewater was 13. Therefore, the COD/P ratio must be controlled at an adequate range to achieve good phosphorus removal.

The ratios of carbon to phosphorus (C/P) are usually lower than the theoretical required value in high-tech industrial wastewater. The supplement of carbon source seems to have become necessary to improve the performance of biological phosphorus removal. Therefore, this study aims to investigate the effects of different carbon supplements on biological phosphorus removal. Three kinds of carbon sources namely, glucose, acetate, and digester supernatant were used to compare their behavior on phosphorus removal.

2. Methods

2.1. The acclimation of PAOs sludge

An anaerobic–aerobic sequencing batch reactor (SBR) pilot was installed and operated continuously for 180 days for the acclimation of polyphosphate accumulating organisms (PAOs) enriched sludge. The pilot was a rectangular reactor equipped with automatic pH controller and aeration unit. The effective volume of reactor was 15 l. The major constituents of the synthetic wastewater fed to the pilot plant were full-fat dry milk powder, sucrose and other necessary nutrients for biological system. The cycle time of the SBR pilot was 12 h, including 3 h of anaerobic mixing, 7 h of aerobic aeration, and 2 h of idling for discharge and substrate addition. The sludge retention time was controlled at 15 days. The acclimated sludge was taken for following batch experiment when the pilot plant was in a steady state, i.e. days 100–180. Table 1 summarizes the performances of the anaerobic–aerobic SBR pilot in steady state. The concentration of MLSS was about 2710 mg/L in average. The COD and phosphorus were removed effectively in the system. The COD and total phosphors concentration was 600 ± 70 and 10 ± 0.33 mg/L, respectively, in the influent. After 3 h mixing in the anaerobic phase, the concentration of soluble orthophosphate–phosphorus raised to 33.05 ± 5.60 mg/L, which demonstrates a significant polyphosphate release from the sludge. Then, after 7 h aeration in aerobic phase, the phosphorus concentration in the effluent was lower than 0.5 ± 0.37 mg/L and the phosphorus content in the sludge was near 4.2 ± 0.7%. The acclimated sludge was prepared for a series of phosphorus release and uptake experiments under various carbon additions.

2.2. Batch experiments

The wastewater samples for batch experiments were obtained from a high-tech industrial park in Taichung City, Taiwan, which include mainly optoelectronics and semiconductor manufacture industries. The characteristics of high-tech industrial wastewater were low COD and high phosphorus concentration. The cylinder reactors equipped with pH (UB-10, Denver instrument), ORP (Cyberscan), and DO (550A, YSI) meters and mixing stirrer (PC-420D Corning) were applied for evaluating the effects of different carbon supplement on phosphorus removal in high-tech industrial wastewater.

Table 1
Performances of the anaerobic–aerobic SBR pilot plant.

Parameters	Influent	Anaerobic stage	Aerobic eff.
COD (mg/L)	600 ± 70	24 ± 5	11 ± 3.5
TP (mg/L)	10 ± 0.33	–	–
PO_4^{3-}–P	–	33.05 ± 5.60	0.41 ± 0.37
MLSS (mg/L)	–	–	2715 ± 435
Carbohydrate in sludge (%)	–	17.27 ± 2.7	22.15 ± 1.56
Phosphorus in sludge (%)	–	–	4.2 ± 0.7

Table 2
Experiments of carbon addition.

Sludge	Carbon source	Carbon addition concentration (mg COD/L)			
Anaerobic–aerobic SBR	Glucose	300	450	600	900
	Acetate	300	450	600	900
	Digester supernatant	300	450	600	900

Three kinds of carbon supplements, i.e. glucose, acetate, and digester supernatant were used in this study. The glucose and acetate were commercialized products. The digester supernatant was obtained from the domestic wastewater treatment plant of Taichung City, Taiwan, a secondary treatment plant of activated sludge with anaerobic digester. Four levels of carbon additions, i.e. 300, 450, 600, and 900 mg COD/L, were carried out in order to evaluate the effect of carbon supplement on phosphorus removal.

Table 2 shows the experiments involving carbon addition. The acclimated sludge taken from the anaerobic–aerobic SBR was centrifuged in order to obtain the organism solid. Then, the wastewater taken from the industrial park was adjusted with concentrated carbon supplement stock solution to a designed concentration. Therefore, the wastewater samples used for batch tests were industrial wastewater (IWW), IWW added glucose, IWW added acetate and IWW added digester supernatant. The wastewater samples and sludge were poured into reactor simultaneously. After 3 min mixing and nitrogen aeration for maintaining the anaerobic environment, samples were taken hourly for water quality and sludge analysis.

2.3. Sampling and analytical methods

The samples were collected following the time of batch reaction. The collected samples were filtrated immediately with 0.45 μm filter paper (Whatman FG/A, 1820). The filtrates were gathered for soluble COD and orthophosphate analysis. The separated solids were prepared for suspended solid, total phosphorus, and carbohydrate analysis. The COD, orthophosphate–phosphorus, and total phosphorus were analyzed following the Standard Methods (APHA, 1998). The content of carbohydrates in sludge was analyzed according to the phenol–sulfuric acid methods (Herbert et al., 1971). A UV–VIS spectrophotometer (U2001, Hitachi) was used for phosphorus and carbohydrate assay in this study.

3. Results and discussion

3.1. Behaviors of different carbon supplements

The phosphorus release and uptake behavior of the acclimated sludge was affected significantly by the original organic carbon in the high-tech industrial wastewater. Fig. 1 illustrates the variations of COD, phosphorus, and carbohydrate when the acclimated SBR sludge was exposed to the high-tech industrial wastewater without external carbon addition. It shows that neither COD utilization nor phosphorus release occurred during the anaerobic period. The fluctuation of sludge carbohydrate content was also slight when the sludge was shifted from anaerobic to aerobic phase. Obviously, the acclimated sludge did not exhibit enhanced biological phosphorus removal capability in this experiment. The phosphorus removal was only 66.5%. Different carbon sources such as VFAs and non-VFAs (e.g. amino acid and sugar) have been