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PHOSPHORUS AND POLYHYDROXYALKANOATES VARIATION IN A COMBINED PROCESS WITH ACTIVATED SLUDGE AND BIOFILM

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ABSTRACT

This study investigates variations of phosphorus and polyhydroxyalkanoates (PHAs) in a combined activated sludge - biofilm process, operating under various sludge retention times (5, 10 and 15 days) and different dissolved oxygen conditions (0.1, 0.5, 1.0 and 2.0 mg/l in aerobic stage). Experimental results indicate that phosphorus uptake closely corresponds to utilization of PHAs during anoxic and aerobic stages. Moreover, the sludge in the anoxic stage exhibits a higher PHAs utilization efficiency with respect to phosphorus uptake than sludge in the aerobic stage, when it is under low COD-SS loading conditions. The values of $r_{P/PHAs}$, representing sludge capacity on phosphorus uptake, range from 0.1-1.0 mg P/mg PHAs. In addition, analyzing the distribution of 3-hydroxybutyrate (3HB), 3-hydroxy-2-methylbutyrate (3H2MB), 3-hydroxyvalerate (3HV) and 3-hydroxy-2-methylvalerate (3H2MV) reveals that 3HB and 3HV are the major components of PHAs. The values of 3HB/PHAs and 3HV/PHAs vary with COD-SS loading of the process. When F/M ratio increases, 3HV/PHAs value increases and 3HB/PHAs value decreases simultaneously. This phenomenon implies that more bacteria accumulated 3HV as storage matter under high COD-SS loading conditions. The kind of bacteria population shift would intensify the competition of "G bacteria" with polyphosphate accumulating organisms, possibly causing process deterioration during phosphorus removal.

KEYWORDS

Phosphorus uptake; denitrification; nutrient removal; polyhydroxyalkanoates (PHAs); PHB; PHV.

INTRODUCTION

The anoxic phosphorus release/uptake characteristics have increasingly become a relevant topic for phosphorus removal in an enhanced biological phosphorus removal (EBPR) process (Kerrn-Jespersen and Henze, 1993; Kuba *et al.*, 1994; Barker and Dold, 1996). Although the Activated Sludge Model No.2 (ASM2; proposed by the IAWQ task group, Gujer, *et al.*, 1995) did not introduce the denitrification capacity of polyphosphate accumulating organisms (PAOs), recent studies have recognized the phenomenom of anoxic phosphorus uptake. Kuba *et al.* (1994, 1997) examined both the potential role of denitrifying phosphorus removal bacteria (DPB) in EBPR processes and these bacterias' denitrifying dephosphoration capacity. Additionally, Mino *et al.* (1995) presented a sub-model of ASM2 for denitrification by PAOs. However, the potential of anoxic phosphorus uptake in EBPR processes remains unclear.

In addition, other investigators proposed the concept of competition between G bacteria and PAOs to account for the deterioration of phosphorus removal in EBPR processes (Cech and Hartman, 1993; Satoh *et al.*, 1994). Others have also proposed models to explicate the competitive behaviors (Mino *et al.*, 1994; Liu *et al.*, 1996). In such models, polyhydroxyalkanoates (PHAs) can be accumulated as storage matter on both G bacteria and PAOs under anaerobic condition. Therefore, the connection between phosphorus release/uptake and accumulation/utilization has become an increasingly complex topic in biological phosphorus removal processes.

This study thoroughly investigates phosphorus and PHAs variation in a combined process with activated sludge and biofilm. The potential of anoxic phosphorus removal and the competition phenomena of bacteria in EBPR processes is also discussed in terms of feasible applications.

MATERIALS AND METHODS

Process. As Fig. 1 depicts, the process consists of conventional anaerobic-anoxic-aerobic activated sludge and a RBC only in the aerobic stages. The effective volume of anaerobic, anoxic and aerobic stage is 21.6 l, 43.2 l and 65 l, having a volume ratio of 1:2:3. The diameter, total surface area and submerged ratio of RBC are 32 cm, 1.6 m^2 and 40%, respectively.

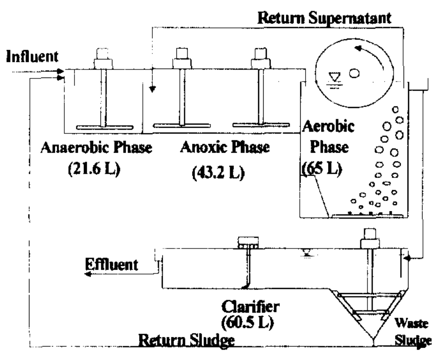

Figure 1. Schematic diagram of the hybrid process.

Wastewater. According to Table 1, the synthetic wastewater was prepared with full-fat dry milk powder and some extra pure grade reagents. The synthetic wastewater simulates the settled wastewater of Min-Sheng Municipal Wastewater Treatment Plant, Taipei. The major components of wastewater are Total COD (TCOD) of 300±10 mg/l, Total BOD (TBOD) of 210±20 mg/l, Total nitrogen (TN) of 40±6 mg/l, ammonium nitrogen (NH_3-N) of 210±2 mg/l, Total phosphorus (TP) of 5±0.5 mg/l and pH of 7.

Methods. The process was operated at various sludge retention times (SRT; 5, 10 and 15 days) and different dissolved oxygen conditions (DO; 0.1, 0.5, 1.0 and 2.0 mg/l in aerobic stage) for assessing phosphorus and PHAs variations. The average HRT was 10 hours and SRT (excluding biofilm sludge) could be controlled by sludge waste from the aerobic tank. The pH was automatically controlled in the range of 7.0-7.2 in aerobic tank, using NaOH-$NaHCO_3$ solution. A more thorough description of analysis methods of PHAs (including 3-hydroxybutyrate, 3-hydroxyvalerate, 3-hydroxy-2-methylbutyrate and 3-hydroxy-2-methylvalerate) and phosphate can be found elsewhere (Chuang *et al.*, 1997).

Table 1. The compositions of synthetic wastewater

Constituents[a]	Dosage (mg)
Full-fat dry milk powder[b]	163.2
Sucrose	16.2
Acetate	37.6
KH_2PO_4	6
$(NH_4)_2SO_4$	78
Urea	30
$FeCl_3$	0.1
NaOH	for neutralizing

(a) The constituents were dissolved in one liter distilled water.

(b) Average components are protein 26.5 %, lactose 36.8 %, fat 28 %, mineral 5.7 % and water 3%.

RESULTS AND DISCUSSION

Experimental results indicate that phosphorus removal closely corresponds to utilization of PHAs during both anoxic and aerobic stages of the process. Moreover, SRT significantly influences the behavior of phosphorus removal and PHAs utilization. As Fig 2 (a) denotes, phosphorus uptake occurs during anoxic and aerobic stages when the process is operated on SRT 10 days conditions. In contrast, anoxic phosphorus uptake ceases under the situation of SRT 5 days; subsequently, phosphorus can not be completely removed in aerobic the stage. Figure 2 (b) illustrates PHAs utilized along with phosphorus uptake. Additionally, phosphorus uptake behaviors resemble each other when dissolved oxygen is controlled among 0.5 to 2.0 mg/l in the aerobic stage. A more thorough description of the experimental results can be found elsewhere (Chuang *et al.*, 1997).

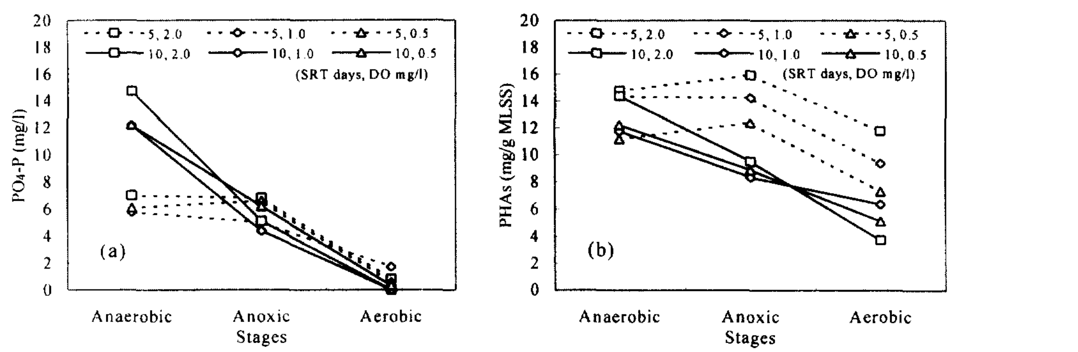

Figure. 2 Phosphorus and PHAs variation in anaerobic, anoxic and aerobic stages of process.

Recent studies focused on anoxic phosphorus release/uptake behaviors have confirm that anoxic phosphorus uptake appears to be a prerequisite for phosphorus removal (Kuba *et al.*, 1994; Barker *et al.*, 1996). Our previous study demonstrated that the available organic substrate determines the kinetic behaviors of phosphorus release/uptake and denitrification (Chuang *et al.*, 1996). In addition, the organic matter sequestered would cause phosphorus release rather than uptake in anoxic conditions. Therefore, when the anaerobic-anoxic-aerobic processes operated under high COS-SS loading conditions, the abundant organic matter was influenced through anaerobic stage to anoxic stage, thereby curtailing anoxic phosphorus uptake; phosphorus removal occurs only at the aerobic stage. Meanwhile, the process capacity for phosphorus removal would decrease.

Results presented herein confirm that sludge exhibits different phosphorus uptake behaviors during anoxic and aerobic stages. We recommend using the values of $r_{P/PHAs}$, i.e., phosphorus uptake amount per gram PHAs utilized to account for sludge capacity on phosphorus uptake. Fig. 3 demonstrates that r has dissimilar trends during anoxic and aerobic stages. The $r_{P/PHAs}$ increases with SRT of process in anoxic stage; however, the increment in aerobic stage is only slight. The ratio ranges broadly from 0.1 to 1.0 mg P/mg PHAs in anoxic conditions. This phenomenon reflects that sludge has a high phosphorus uptake potential, i.e., a high efficiency of PHAs utilization, in anoxic stage, when it is at low COD-SS loading conditions. In sum, anoxic phosphorus uptake exhibits a high potential for phosphorus removal in EBPR process.

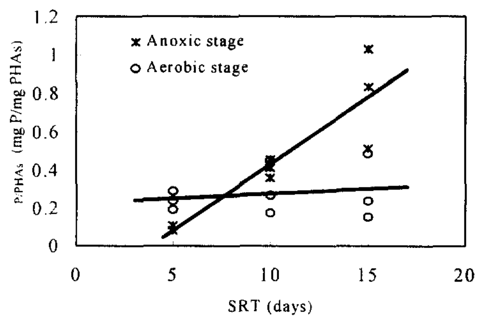

Figure 3. The $r_{P/PHAs}$ variation in anoxic and aerobic stages.

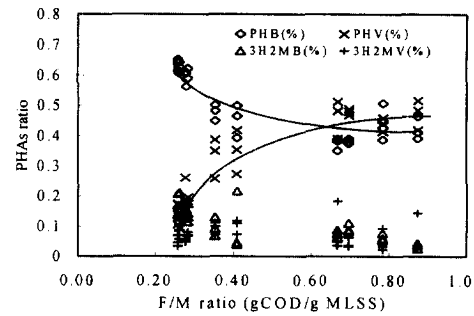

Figure 4. The distribution of PHAs components.

Additionally, the components of PHAs (i.e., 3-hydroxybutyrate, 3-hydroxyvalerate, 3-hydroxy-2-methylbutyrate and 3-hydroxy-2-methylvalerate) are analyzed in sludge in various SRT and DO (in aerobic stage) conditions. Figure 4 reveals that PHB and PHV are the major components of PHAs and the values of 3HB/PHAs and 3HV/PHAs vary with COD-SS loading of the process. When F/M ratio increases, 3HV/PHAs value increases and 3HB/PHAs value decreases simultaneously. This phenomenon implies that more bacteria can accumulate 3HV as storage matter in a high COD-SS loading situation. Thus, the pathway from pyruvate to propionyl-CoA should be involved intensively in the population. Liu *et al.* (1996) investigated glycogen accumulating populations in anaerobic-aerobic activated sludge, suggesting that they could dominate in the deteriorated biological phosphorus removal process. Notably, in their experiments, 3HV was the major component of PHAs. This occurrence appeared also in this study. When the process undergoes high COD-SS loading conditions, 3HV became a major storage matter of PHAs and phosphorus could not be completely removed. Therefore, we can infer that glycogen accumulating population induces the pathway of propionyl-CoA production and accumulated 3HV as a major storage matter. Consequently, they can compete successfully with polyphosphate accumulating population in EBPR process. In sum, this kind of bacteria population shift would intensify the competition of "G bacteria" with polyphosphate accumulating organisms (PAOs), possibly causing process deterioration during phosphorus removal.

CONCLUSIONS

This study investigated variation of phosphorus and PHAs in a combined process with activated sludge and biofilm. Based on experimental results, we can conclude that phosphorus uptake closely corresponds to utilization of PHAs during anoxic and aerobic stages of the process. Anoxic phosphorus uptake exhibits a high potential for phosphorus removal in EBPR process. Sludge under low COD-SS loading conditions displays a high phosphorus uptake potential, i.e., a high efficiency of PHAs utilization, in anoxic stage. Moreover, when more bacteria accumulated 3HV as a storage matter, the "G bacteria" successfully compete with polyphosphate accumulating organisms, possibly causing process deterioration with respect to phosphorus removal.

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