Anaerobic Digestion of Excess Sludge Accumulating Polyhydroxyalkanoate Generated from Energy Saving Activated Sludge Process

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1. Introduction

The activated sludge process, though widely successful biological process for the treatment of wastewater, yet there is scope of improvement by addressing some known issues, one of which is the high aeration energy requirement. In Japan, the energy consumption per unit volume of wastewater is 0.45 $kWhm^{-3}$ and about two-third of which is utilized for oxidizing the organic matter (Goto et al., 2001).

Energy consumption could be improved significantly by replacing existing treatment processes with newly developed technologies like energy saving activated sludge process, Final AeRation of Excess Sludge with Excess Loading (FAREWEL) process was initiated which allows aeration-saving and excess biomass recovery treatment (Oshiki et al., 2009). This treatment system (Figure 1) involves two stages - first, the conventional activated sludge process and second, FAREWEL process where the excess sludge discharged from conventional process is fed fed with influent (final feed) and aerated shortly. The treatment allows microorganisms absorb organic matter in influent as temporal carbon storage materials such as polyhydroxyalkanoate (PHA). As the FAREWEL process is concluded without the consumption of temporal carbon storage materials, oxygen consumption should be less than conventional activated sludge process. Oshiki et al. (2009) estimated the effect of the reduction in aeration volume and the increase in biomass recovery through batch experiments. Their results indicated the reduction in aeration volume by one-tenth and three-tenth increase in biomass recovery. However, the higher accumulation of PHA in FAREWEL process leads to excess sludge with higher PHA accumulation; reduction of which under anaerobic digestion will definitely improve the sludge treatment process. It was thought that anaerobic digestion of excess sludge accumulating PHA to produce excess methane will ultimately facilitate the higher recovery of usable bio-energy. Thus, the main goal of the study was to evaluate the feasibility of FAREWEL process.

Therefore, the objective of the study was to evaluate the degradation of excess sludge accumulating PHA under anaerobic digestion through methane production compared to excess sludge without PHA.

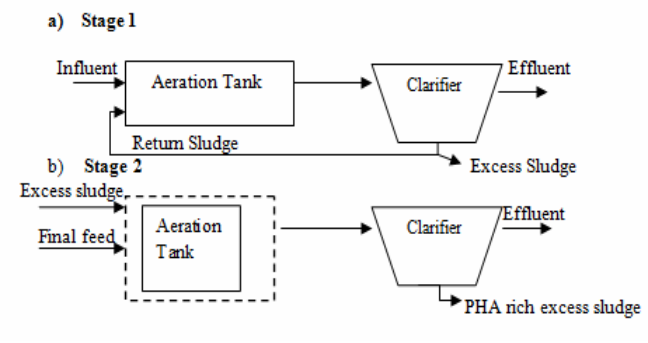

Figure 1: Two stage activated sludge process, *a) stage 1*: conventional activated sludge process; *b) stage 2*: FAREWEL process.

2. Materials and Methods

Anaerobic Digested Sludge (DS)

A laboratory scale anaerobic digester with a liquid volume of 1.5L was operated at 37^{o}C under stirring condition. The loading rate of the digester was 1.0/kgVSS/m^{3}/day and sludge retention time (SRT) was 23 days. Excess sludge from the laboratory scale reactor was used as feed for the digester.

Preparation of Substrates

Excess sludge (2.8 L) was obtained from a laboratory-scale sequential batch activated sludge reactor. Mixed-liquor suspended solids (MLSS) and mixed-liquor volatile suspended solids (MLVSS) and PHA were measured.

Half of the collected sludge (1.4L) was centrifuged, the supernatant was decanted, and the sludge pellet was resuspended in water. The total suspended solids (TSS) and volatile suspended solids (VSS) were measured. The sludge pellet was used as the feed, excess sludge without PHA accumulation (ES).

Another half of the collected sludge was put in a beaker, fed with acetate at a final concentration of 1000mgC/L, and incubated for 5h under aerobic condition by air bubbling. After that, TSS, VSS and PHA were also measured. Then, the sludge was centrifuged, the supernatant was decanted, and the sludge pellet was resuspended in water. The sludge pellet was used as the feed, excess sludge accumulating PHA (ES+PHA).

Batch Experiment

Prior to the batch experiment, the volatile solids (VS) and total solids (TS) concentrations of digested sludge and concentrated excess sludge with and without PHA accumulation were determined. The batch experiment was conducted on three different groups' *viz.* T0 with digested sludge (DS), T1 with the mixture of digested sludge and excess sludge without PHA accumulation (DS+ES) and T2 with digested sludge and excess sludge with PHA accumulation (DS+ES+PHA). All groups were prepared in 10-ml vials with a liquid volume of 7 ml using 23 vials for each group. Each vial of T0, T1 and T2 groups were added with 3.5 mL of digested sludge containing 34 mg VS, and 2.5 mL of concentrated excess sludge without PHA accumulation for T1 and 1.77 mL of concentrated excess sludge with PHA accumulation for T2 containing 34 mgVS. Each vial was added with 1 mL of sodium bicarbonate solution (14 g/L) as a pH buffer. Each vial was supplemented with effluent to make the total volume to 7 mL. All the vials were then made air-tight with butyl rubber and aluminum caps. Nitrogen gas was purged into all the vials using 20 gauge needles for 45minutes. After purging N_2 gas, contents in each of the vials were mixed thoroughly and incubated at 37^{o}C under stirring conditions (200 rpm). Gas and chemical analyses were performed on days 0, 2, 5, 8, 12, 16, 19, 22, 26, 29, and 34. On each day, two vials were used for chemical analysis and gas composition; three vials were used for measuring of gas volume.

Analysis

Gas production was measured using a glass syringe equipped with a 22 gauge needle. Methane was analyzed by a gas chromatograph GC-3200D (GL Science, Japan) equipped with a SUS column (filled with molecular sieve 5A 30/60, 3 mm i.d.x 2 m) at a flow rate of 20 ml min^{-1} using argon as the carrier gas with an injection volume of 0.5 ml and the oven and detector temperatures at 50^{o}C.

pH was measured with a pH-meter (HM 30G, TOA, Japan). Total COD was measured by using HACH company kit following the colorimetric determination. TS and VS were measured following Standard Methods (APHA, 2005).

For the analysis of volatile fatty acids (VFA) and NH_3-N, 2 ml samples from each vial were centrifuged for 2 minutes at 13,000rpm, and filtered through a 0.2 μm membrane filter. The

concentrations of VFA were analyzed by using a liquid chromatography LaChrome Elite system (Hitachi) equipped with a SCR 101H column at 60 ^{o}C with 0.025% sulfuric acid at 1 ml/min as eluent with a UV detector at 210 nm. NH_3-N was measured by using HACH company kit followed by the Salicylate Method. The determination of PHA was performed by gas chromatography after methanolytic decomposition as described by Satoh et al. (1992).

4. Results and Discussion

Cumulative methane production during anaerobic incubation of T1 (DS+ES) and T2 (DS+ES+PHA), total COD concentration, VS concentration, pH, NH_3-N concentration, acetate and PHB concentration are shown in Figures 1(a-d). As shown in Fig. 1a, the methane production (ml/gVS of DS) was recorded higher in T2 (DS+ES+PHA) followed by T1 (DS+ES) and T0 (DS). As shown in Fig. 1b, the total COD_{Cr} declined in all groups but the reduction rate was found slightly greater in T2 than T1 and T0. During the whole experiment, pH and NH_3-N were found in favorable condition (data not shown). As shown in Fig. 1c, higher acetate accumulation was found in T2 than in T1. As can be seen in Fig. 1d, initially, PHB was degraded rapidly in T2 and the degradation was slowed and sturdy after day 2.

The cumulative methane gas production (ml/g VS of DS) at T0 (DS), T1 (DS+ES) and T2 (DS+ES+PHA) during incubation are presented in Figure 1a.The highest yield of methane was recorded in T2 (213 ml/gVS of DS) followed by T1 (170 ml/gVS of DS) and T0 (31 ml/gVS of DS). The methane gas production in T2 was increased by 25% compared to T1. It revealed the ability of excess sludge accumulating PHA to produce excess methane under anaerobic digestion compared to excess sludge only.

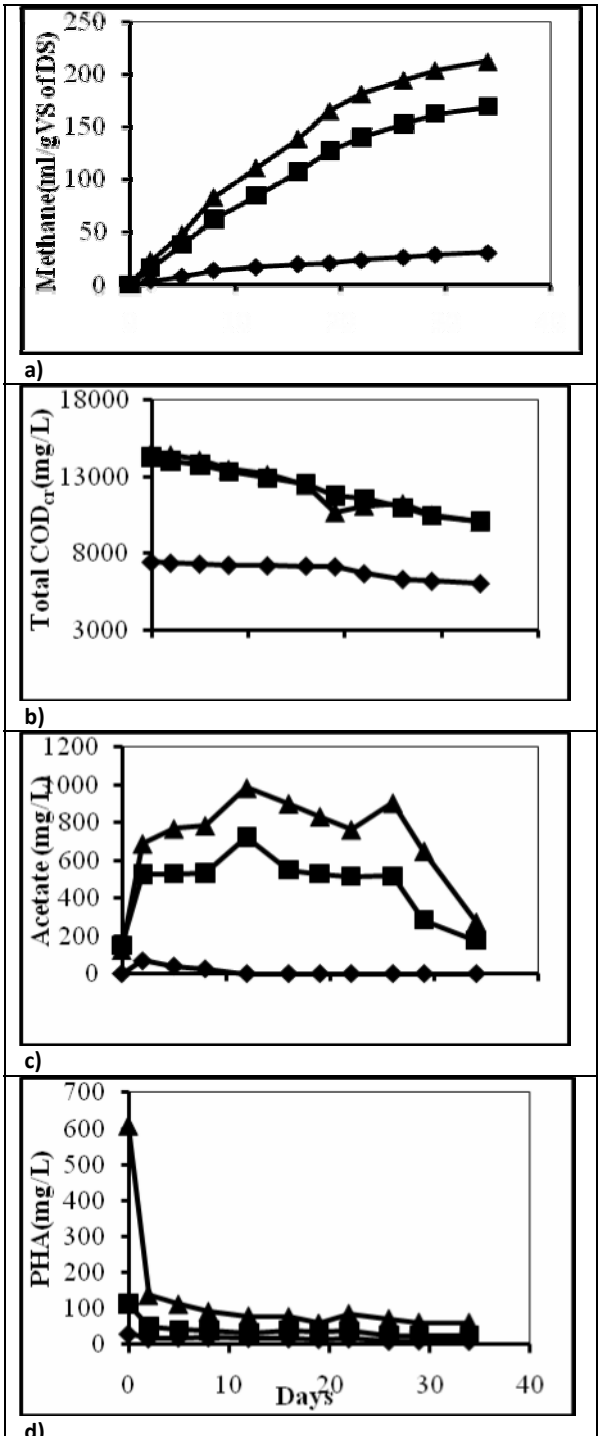

Figure 1: a) cumulative methane production, b) Total COD_{cr}, c) acetate formation, and d) PHA degradation during anaerobic incubation of-♦-T0(DS), -■-T1(DS+ES), and -▲-T2(DS+ES+PHA).

Total COD_{cr} decreased from the day of incubation to last day in both the groups (Figure 1b). Total COD_{cr} in T0, T1 and T2 at the time of incubation were 7440 mg/L, 14300 mg/L, and 14600 mg/L which decreased to 6020 mg/L, 10120 mg/L, and 10060 mg/L respectively. The total COD_{cr} reduced were 19% in T0, 29% in T1 and 31% in T2. When first order kinetics was applied to model the degradation of total COD, the reduction rate parameter were 0.006 in T0, 0.011 in T1 and 0.012 in T2.

During the time of incubation, the acetate concentrations (Figure 1c) were 152 mg/L in T1 and 128 mg/L in T2 and which increased rapidly in both the groups as the experiment progressed but no acetate was found in T0. On day 12, acetate concentration reached to the maximum, 723 mg/L and 987 mg/L for T1 and T2, respectively followed by a decline till the last day of observation when acetate was 177 mg/L in T1 and 275mg/l in T2. It was clear that the acetate formation was higher in T2 than T1.

PHA degradation incubation at different groups was illustrated in Figure 1(d). PHA degraded sharply, almost by 56% in T1 and 77.5% in T2, within two day and then the rate of degradation diminished to a steady state. At the time of incubation, the concentrations of PHA were 114 mg/L in T1 & 609 mg/L in T2 and after two days the concentrations fell down to 50 mg/L in T1 & 137 mg/L in T2. On the final day, the PHA was 25 mg/L in T1 and 61 mg/L in T2. Initial drop of PHA was also observed in T0 and T1.

From the present study, it can be stated that PHA accumulated in excess sludge was initially quickly degraded, and more than 77% of PHA was degraded under anaerobic digestion and produce excess methane Thus, PHA enriched excess sludge generated from energy saving FAREWEL process can be degraded better than that of excess sludge. The results supports the practicability of FAREWEL process where temporal carbon storage materials formed which may be easily degraded and converted to methane gas. But, the degradation of PHA was slowed down after day 2 and after 34 days 10% of PHA was remained that will cause increase of anaerobic digested sludge. As the total COD_{cr} degradation was comparatively better in T2 than T1 so, the increase of anaerobic digested sludge will be small in FAREWEL process.

It was also observed from the anaerobic digestion of PHB-enriched excess sludge that the degradation of PHB was enhanced within the first 2 days whereas acetate formation was increased within first 12 days but methane gas generation was rose after day 18. This behavior is compatible in anaerobic digestion process because microorganisms involves in hydrolysis and fermentation steps grow relatively rapid and forms acetate but the archeal methanogens which convert acetate to methane are more slowly growing and tend to be rate limiting (Rittmann and McCarty, 2001).

Moreover, another experiment was also performed to re-evaluate the methane production and degradation of PHA in PHA enriched excess sludge.

4. Conclusions

From the experiments, it can be concluded that that temporal carbon storage material in excess sludge can produce excess methane compared to excess sludge alone under anaerobic digestion. It is clearly revealed that initially PHB degradation was rapid in PHB-enriched excess sludge and produced excess methane, so it supports the feasibility of FAREWEL process but excess digested sludge needs to be disposed.

6. References

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