Effect of Inocula from Full-Scale Anaerobic Plants on Thermophilic Bio-gasification of PLA and PBAT

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INTRODUCTION

Biodegradable plastics (BdPs) have been developed as environmentally friendly alternatives to conventional plastics and are increasingly being applied in everyday products. Among the global BdPs market, the polylactic acid (PLA) market is projected to reach USD 3.3 billion by 2028, and the Polybutylene Adipate Terephthalate (PBAT) market is projected to reach USD 2.8 billion by 2027, suggesting that PLA and PBAT hold a significant share of the BdPs market (MarketsandMarkets, 2023A; MarketsandMarkets, 2023B). As the market for BdPs expands, significant amount of BdPs waste is also being generated. If not properly managed at the end of their life cycle. BdPs can have the same hazardous environmental impacts similar to conventional plastics.

Anaerobic digestion (AD) is provided as an alternative for the biological treatment and energy recovery of BdPs. AD is a biological process involving complex microbial communities that break down organic matter into carbon dioxide and methane. However, BdPs are difficult to biodegrade under mesophilic anaerobic conditions due to their complex structural bonds. In the case of PLA, exhibited a very low biodegradation rate, requiring approximately 500 days for degradation under mesophilic conditions (G. Cazaudehore, *et al*., 2023). In the case of PBAT, previous study reported that PBAT was not degraded under mesophilic conditions (Yan Jin *et al*., 2022).

As an alternative to overcome these limitations, thermophilic AD has been proposed for BdPs treatment. However, studies on the impact of initial microbial communities on digestion efficiency are limited. Existing research has focused on the feasibility of bioplastic digestion, which suggests that in full-scale facilities, results may differ from those observed in lab-scale experiments depending on the initial microbial community, and in severe cases, failure may occur. Therefore, this study aims to evaluate the effect of initial microbial communities on methane production efficiency through PLA and PBAT Bio-gasification, ultimately improving degradation efficiency during the start-up phase of bioplastic AD plants.

MATERIALS AND METHODS

Substrates and Inoculum

PLA Powder (120 mesh) and PBAT Powder (120 mesh) were purchased from Magerial Science (USA). Three inocula were collected from thermophilic AD plants treating food waste in site A, B and C in South Korea, and acclimated under thermophilic (55°C) anaerobic conditions.

Batch test setup

For the three types of inoculum in batch anaerobic digestion (batch-AD) treatments (PLA-A, PLA-B, PLA-C, PBAT-A, PBAT-B, PBAT-C), 3 gVS PLA/L was supplied with 0.5 gVSS/L of inoculum. To observe significant changes in the microbial community, the F/M ratio was set at 6 gVS/gVSS, which is higher than in previous studies. The inoculum control batch (0.5 gVSS per bottle) was used as the negative control.

Batch tests were conducted under thermophilic conditions (58°C) in 120 mL serum bottles with a total mixture volume of 100 mL, including distilled water, inoculum, and BdPs powders (PLA and PBAT). Each batch-AD test was conducted in triplicate. Before sealing the bottles, the pH was measured, and the headspace was purged with nitrogen and carbon dioxide (N2 80% + CO2 20%) to ensure an anaerobic environment.

Sample analysis

Biogas production was measured every 2–7 days using a syringe, and biogas composition was analyzed using gas chromatography (GC-HP 6890 Plus, Agilent). the reported biogas results were corrected by subtracting the negative control values. Physicochemical analyses were conducted in triplicate - at the initial and end points of the experiment. pH, chemical oxygen demand (COD), total solids, and suspended solids were measured according to standard methods.

DNA from batch samples for microbial analysis was collected at the initial and end points of the experiment. To identify the microbial communities, the extracted DNA was analyzed using 16S ribosomal RNA (rRNA)

sequencing with a Nextera® XT index kit v2 (Illumina) and an Illumina® iSeq™ 100 sequencing system (Illumina, San Diego, CA, USA).

RESULTS AND DISCUSSION

After 113 days, the thermophilic AD of PLA-A inoculated with strain A inoculum, the highest biogas production (2.05 L/L, 61.0%), followed by PLA-B (2.03 L/L, 60.3%) and PLA-C (1.91 L/L, 57.0%). In the case of PBAT, PBAT-B inoculated with B inoculum exhibited the highest biogas production (0.90 L/L, 24.0%), followed by PBAT-C (0.87L/L, 23.3) and PBAT-A, (0.85 L/L, 22.6%). Although all batch experiments were conducted under identical conditions except for the inoculum, biogas production varied depending on the inoculum type. Notably, the differences were more pronounced in PLA digestion. This finding suggests that selecting the initial inoculum plays a crucial role in enhancing biogas production.

Additionally, previous research reported that PBAT was not degraded under mesophilic conditions (Yan Jin *et al*., 2022). However, under thermophilic conditions, approximately 23.3% of PBAT was converted to biogas after 113 days. This suggests some thermophilic microbes are involved in thermophilic AD of PBAT in this research. Further discussion on microbial analysis is provided in the main part of this article.

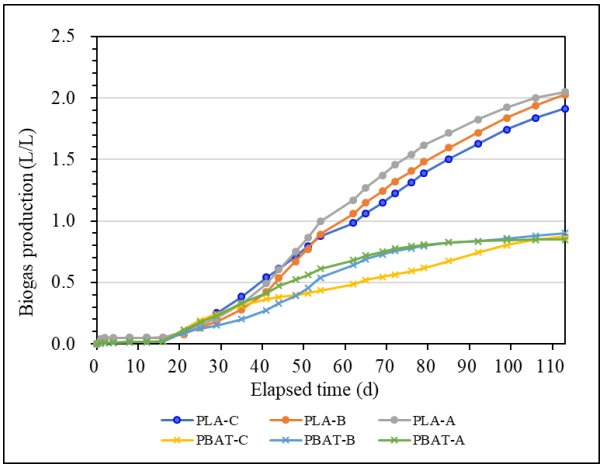

Figure 1. Accumulated biogas production after 113 days for each inoculum and BdPs (PLA and PBAT)

CONCLUSIONS

This study suggests differences in biogas production efficiency during anaerobic thermophilic digestion of PLA and PBAT based on the initial microbial community. This finding provides a practical strategy for selecting inoculum based on the initial microbial community during the start-up phase of anaerobic thermophilic digestion plants for PLA. Additionally, it can be used to enhance the biodegradation rate of BdPs in AD without the need for thermochemical or enzymatic pre-treatment.

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