Anaerobic digestion of bio-plastic waste: the issue of biodegradation and weight loss

S. De Gisi[1], G. Gadaleta[1], A. Giuliano[1], MK. Kuchta[2], G. Santomasi[1], F. Todaro[1], M. Notarnicola[1]

[1]Department of Civil, Environmental, Land, Building Engineering and Chemistry (DICATECh), Polytechnic University of Bari, Bari, 70125, Italy
[2]Department of Sustainable Resource and Waste Management, Hamburg University of Technology, Hamburg, 21079, Germany.
Keywords: bio-plastics, anaerobic digestion, biodegradation, weight loss, kinetic analysis
Presenting author email: sabino.degisi@poliba.it

The growing awareness of fossil fuels availability and a desire to reduce environmental impact of plastic, has led to a rethinking of plastic production and utilization in our daily lives. In parallel of rational use of plastics programs, several bio-plastics have also been developed to address this problem. Bio-plastics are biodegradable and/or bio-based plastics that can be potentially treated at their end-of-life by biological processes (composting or anaerobic digestion) (Gadaleta et al., 2022). Since bio-plastics composting has been widely documented, including specifications standards and labels for different composting conditions (home and industrial), to date research carried out under anaerobic conditions is still unclear. The suitability of industrial anaerobic digestion as a treatment of bio-plastics is still an open question (Cazaudehore et al., 2022). In addition, there is still confusion and disinformation regarding the degradation of bio-plastics. Biological degradation (biodegradation) of plastics (the conversion of plastic carbon in natural compounds by the action of microorganisms) is usually confused with other physical degradation as fragmentation or weight loss (De Gisi et al., 2022). Thus, the aim of this work is to understand the technical feasibility of bio-plastics anaerobic digestion at industrial scale, to understand the kinetic of anaerobic degradation and to estimate the difference between biological and physical degradation of plastics.

For the scope, five bio-plastics samples has been chosen: 2 cellulose based bio-plastics (CA and CA-LDH), which are commonly known to rapidly degrade in anaerobic environment; polylactic acid (PLA) as a low degradable sample and a blend of poly (butylene succinate) (PBS) and gelatine in different shapes (flakes – PBSg and pieces – PBSp). The latter samples has been consider in order to evaluate in the addition of gelatine could increase the degradation of PBS, which is not anaerobically degradable. A mesophilic (37 °C) and liquid-state (<10% TS) anaerobic digestion in batch has been carried out on the five samples for 32 days, a common hydraulic retention time in industrial anaerobic digester. An Inoculum to Substrate Ratio (ISR) of 2 has been adopted. Methane yield (Nml CH_4/gVS) and biodegradation (%) have been calculated according to a revised version of VDI (Verein Deutscher Ingenieure, 2016) and ISO14853 standard respectively. Finally, kinetic analysis has been carried out by the application of two models: Dual Pool Kinetic Model (DPKM) and Gompertz model.

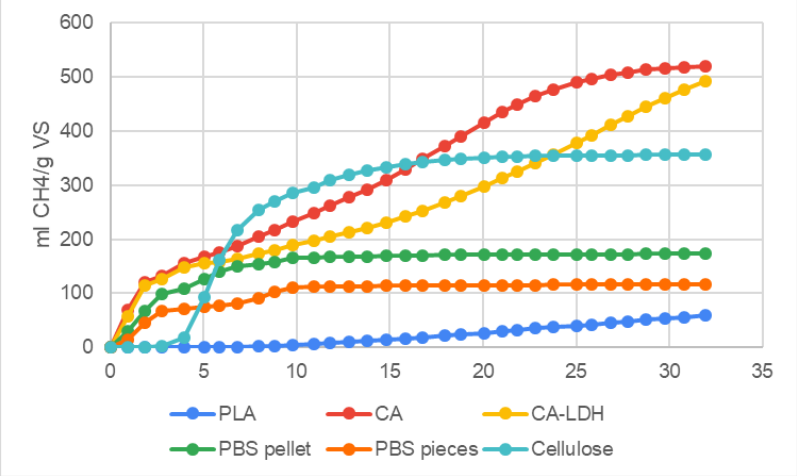

Figure 1. Methane yield (NmlCH_4/gVS) of CA, CA-LDH, PLA, PBSf and PBSp.

As reported in Figure 1, the samples showed different behaviour. CA and CA-LDH generate a high methane amount. CA expired the main methane yield before the day 32 instead CA-LDH, which showed a lower methane generation speed, reached a similar production at the end of the test. As confirmed by literature studies (Ammala et al., 2011), PLA showed a low methane yield because of the mesophilic environment. Both the blends of PBS and gelatine showed the same trend: after a fast methane production due to the gelatine

degradation, the samples revealed their not-anaerobically degradable nature, resulted in a plateau phase. The shape influenced also the final methane yield, resulting higher in the samples with higher specific surface (PBSf).
The biodegradation and disintegration values showed that CA and CA-LDH samples achieved similar results for both physical and biological degradation because the process was almost complete. When the degradation is not complete (PLA and especially PBS samples) the values can differ significantly, showing a higher physical degradation than a biological one.

Table 1. Biodegradation and weight loss value of CA, CA-LDH, PLA, PBSf and PBSp.

Sample	CA	CA-LDH	PLA	PBSf	PBSp
Biodegradation [%]	99.18	89.70	10.98	30.90	20.23
Weight loss [%]	98.56	90.08	15.87	42.62	27.48

Finally, the application of DPKM and Gompertz models revealed that the degradation kinetics can be represent with high precision for all the samples. Only the Gompertz model for PLA showed a R^2 lower than 0.9.

Table 2. Kinetic parameters of DPKM and Gompertz models for CA, CA-LDH, PLA, PBSf and PBSp.

	Samples				
Model parameters	**CA**	**CA-LDH**	**PLA**	**PBSf**	**PBSp**
DPKM					
G_0 ($NmlCH_4/gVS$)	1817.17	1424.47	24822.06	1424.47	172.30
α	0.95	0.010	0	0.95	0.99
k1 (1/d)	0.010	1.506	0.029	0.010	0.301
k2 (1/d)	0.990	0.95	0	1.506	0.010
R^2	0.994	0.984	0.974	0.984	0.998
Gompertz					
G_0 ($NmlCH_4/gVS$)	569.11	1379.42	59.38	169.38	1113.54
R_{max} ($NmlCH_4/gVS*d$)	24.24	15.17	4.21	34.14	18.99
λ (d)	2.78	0	0	0.2	0
R^2	0.988	0.987	0.858	0.991	0.973

In conclusion, this work has revealed how not all the bioplastics are suitable for anaerobic treatment in industrial retention time, without create a digestate contamination. Furthermore, the physical degradation can not be used to describe biological degradation, which is still confused nowadays. Several models could be applied to describe the kinetic of bio-plastics anaerobic degradation and all of them revealed high precision.

References

Ammala, A., Bateman, S., Dean, K., Petinakis, E., Sangwan, P., Wong, S., Yuan, Q., Yu, L., Patrick, C., Leong, K.H., 2011. An overview of degradable and biodegradable polyolefins. Prog. Polym. Sci. https://doi.org/10.1016/j.progpolymsci.2010.12.002

Cazaudehore, G., Guyoneaud, R., Evon, P., Martin-Closas, L., Pelacho, A.M., Raynaud, C., Monlau, F., 2022. Can anaerobic digestion be a suitable end-of-life scenario for biodegradable plastics? A critical review of the current situation, hurdles, and challenges. Biotechnol. Adv. 56, 107916. https://doi.org/10.1016/j.biotechadv.2022.107916

De Gisi, S., Gadaleta, G., Gorrasi, G., La Mantia, F.P., Notarnicola, M., Sorrentino, A., 2022. The role of (bio)degradability on the management of petrochemical and bio-based plastic waste. J. Environ. Manage. 310, 114769. https://doi.org/10.1016/j.jenvman.2022.114769

Gadaleta, G., De Gisi, S., Picuno, C., Heerenklage, J., Cafiero, L., Oliviero, M., Notarnicola, M., Kuchta, K., Sorrentino, A., 2022. The influence of bio-plastics for food packaging on combined anaerobic digestion and composting treatment of organic municipal waste. Waste Manag. 144, 87–97. https://doi.org/10.1016/J.WASMAN.2022.03.014

Verein Deutscher Ingenieure, 2016. Fermentation of Organic Materials – Characterisation of the Substrate, Sampling, Collection of Material Data, Fermentation Tests, VDI Guideline 4630. Verein Deutscher Ingenieure, Düsseldorf.