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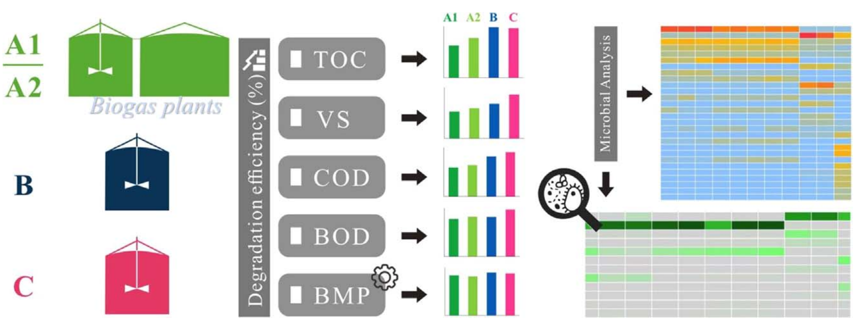
Assessment of the degradation efficiency of full-scale biogas plants: A comparative study of degradation indicators

Chao Li[a,b,c,*], Ivo Achu Nges[a], Wenjing Lu[c], Haoyu Wang[d]

[a] Division of Biotechnology, Center for Chemistry and Chemical Engineering, Lund University, Naturvetarvägen 14, 22241 Lund, Sweden
[b] Nova Skantek Environmental Technology (Beijing) Co., Ltd, Beijing 100027, China
[c] School of Environment, Tsinghua University, Beijing 100084, China
[d] State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, Harbin 150090, China

GRAPHICAL ABSTRACT



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ABSTRACT

Increasing popularity and applications of the anaerobic digestion (AD) process has necessitated the development and identification of tools for obtaining reliable indicators of organic matter degradation rate and hence evaluate the process efficiency especially in full-scale, commercial biogas plants. In this study, four biogas plants (A1, A2, B and C) based on different feedstock, process configuration, scale and operational performance were selected and investigated. Results showed that the biochemical methane potential (BMP) based degradation rate could be use in incisively gauging process efficiency in lieu of the traditional degradation rate indicators. The BMP degradation rates ranged from 70 to 90% wherein plants A2 and C showed the highest throughput. This study, therefore, corroborates the feasibility of using the BMP degradation rate as a practical tool for evaluating process performance in full-scale biogas processes and spots light on the microbial diversity in full-scale biogas processes.

1. Introduction

Biomass energy continues to play an important role in power generation and sustainable development. For instance, animal manure, agricultural and kitchen wastes have become an important resource for biogas (methane) production via anaerobic digestion (AD) in countries such as China and Sweden (Zhou et al., 2017). China's agricultural sector is growing rapidly, resulting in increasing amounts of agricultural wastes such as straw, livestock and poultry manure, and organic wastes from the agro-industry, which can be used to generate biogas. There is a clear trend away from smaller household farming towards larger, intensive farms and consequently the production of

* Corresponding author at: Division of Biotechnology, Center for Chemistry and Chemical Engineering, Lund University, P.O. Box 124, SE-22100 Lund, Sweden.
E-mail addresses: chao_h.li@biotek.lu.se, harvey.lee@hotmail.com (C. Li).

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large amounts of manure; and centralization, which allows for easier collection of this manures (Li et al., 2017).

In order to ensure a competitive return on investment considering the increasing cost of feedstock, it is critically important to ensure a stable, efficient biogas (methane) production so much so that methane potential should approach the ultimate potential of the feedstock i.e. full utilisation of feedstock and a minimum residual methane potential (Ruile et al., 2015). Feedstock/digestate characterization parameters of AD such as the volatile solids (VS) degradation rate which is achieved by measurements of VS concentration in the feed and the digestate are used as routine process parameter (degradation indicator) in most full-scale biogas plants (Weiland, 2010). VS is envisaged as the total concentration of organic matter and not all of this may be bio-available for the AD process (Schievano et al., 2011). Other parameters commonly used to describe the concentration of wastewaters are the chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total organic carbon (TOC). The BOD and COD constitutes the organic compounds in both biodegradable and non-biodegradable forms under aerobic conditions. The BOD is a common measurement of the consumed oxygen by microorganisms to decompose or oxidise organic matter and has its widest application in wastewater treatment (Liu et al., 2004). On the other hand, TOC is the amount carbon bound in an organic compound (Bouallagui et al., 2003). These parameters can represent the (partial) organic content of the feedstock and ratio between inputs and outputs are often used as indicators of process yield (Hartmann & Ahring, 2005) or to track the fate of organic carbon (Gao et al., 2011). However, the above process parameters can only provide limited information about the organic matter degradation or oxidation under one-sample-only circumstance, and it may, therefore, be insufficient to assess the true process efficiency (Schievano et al., 2010). An approach to gain a substantial knowledge about the quality of substrates, as well as its biodegradability is by means of biochemical methane potential (BMP) test of feedstock and that of the digestate (residual methane potential, RMP) (Schievano et al., 2011). The biodegradability embodies the potential to produce methane under anaerobic conditions from organic materials. Besides the quantitative information concerning the methane potential of the substrate, the BMP experimental protocol may also include the degradation kinetics information (VDI 4630, 2016). In an attempt to evaluate process efficiency under practical conditions, it is best to employ an authentic and incisive indicator that would provide fruitful and experimentally determined process information. Numerous bench-scale experimental data have been published on BMP of feedstock for process optimisation in full-scale biogas plants (Asam et al., 2011; Koch et al., 2016; Linke et al., 2013). To our knowledge, only one study has been published wherein a related the BMP-based indicator, the methane volume achieved via BMP assay, was projected as a practical process indicator to assess degradation efficiency in full-scale biogas plants (Schievano et al., 2011). The BMP and residual methane production (RMP) was also hinted in a German standard a viable means to evaluate process performance (VDI 4630, 2016). Considering the practical importance of the BMP as an AD process indicator, it is therefore, worth the continuance especially when presented side-by-side with the other traditional process parameters commonly used in assessing degradation efficiencies or process performance.

The AD process is highly complex and dynamic that makes the assessment of process efficiency a big challenge. This has led to an increased need for process assessment, microbial dynamics and operating knowledge. Methane, renewable energy source, origins from various type of organic matters via a multi-step anaerobic decomposition process involving a well-organized community of various microbial populations (Ghasimi et al., 2015). Besides substrates characteristics and operational conditions, microorganisms and microbial community structure can greatly affect the AD process (Wang et al., 2015). Therefore, in other to understand the degradation process systematically, an investigative look at microbial community structure is vital to provide valuable information for the performance of the AD process. Knowledge about the microbial community structures coupled with proper assessment of process efficiency could be a way forward towards an understanding of the full potential of the biogas plants.

Therefore, in this study, four full-scale biogas plants of different process technologies and fed with different feedstocks were adopted and investigated in terms of process efficiencies and microbial community dynamics. The process efficiencies were assessed and compared, for the first time, both via the traditional indicators which are based on VS, COD, BOD, TOC, as well as the new BMP-based indicator. Microbial community analyses were presented and discussed in relation to the process performances towards a deeper understanding of the full potential of the biogas plants. Since maximizing substrate degradation is necessary for both an economical and environmental stand point, this study may be a way forward assisting feasibility studies, bio-wastes management, evaluating technologies for reduction of greenhouse gas emission.

2. Materials and methods

2.1. Configurations and operating conditions of full-scale biogas plants

Four mesophilic (37 °C) full-scale biogas plants were surveyed over a period of in a bid to gain insights into the average feedstock characteristics and operating conditions (Table 1). In general, the biogas plants were divided into pre-digestion, primary digestion and post digestion steps. The pre-digestion step can be split into three parts: feedstock collection, mixing, and sand removal. The first biogas plant

Table 1
Process parameters of the full-scale biogas plants (A1, A2, B and C) surveyed during the study ($n = 5$).

Parameters/substrates	Units	Plant A1	Plant A2	Plant B	Plant C
Substrate		Chicken manure	Chicken manure	Kitchen waste	OFMSW
Process		CSTR	CSTR	CSTR	CSTR
Pretreatment		Sand removal tank	Sand removal tank	Thermal hydrolysis	Solid-liquid separation
Numbers & type of digesters		8 digestion units 2 production lines, each with 3 primary digesters	12 digestion units 3 productions lines, each with 3 primary digesters	2 digestion unit 2 digesters in parallel	1 digestion unit 1 production line
Total volume	m^3	3300*8	3300*12	3000*2	10,000
Loading rate (w/w)	t/d	557 ± 45	539 ± 63	110 ± 35	600 ± 32
Loading rate (TS)	$kg\ m^{-3}\ d^{-1}$	1.43 ± 0.5	1.23 ± 0.3	1.5 ± 0.44	3.06 ± 0.51
Organic loading rate (VS)	$kg\ m^{-3}\ d^{-1}$	0.97 ± 0.4	0.85 ± 0.3	1.2 ± 0.4	1.13 ± 0.4
SRT (primary)	d	30	45	54	17
SRT (secondary)	d	10	10		
Temperature	°C	37 ± 2	37 ± 2	37 ± 1	34 ± 1
pH		8.3	7.8	7.9	7.6
VFA/TA ratio		0.35 ± 0.05	0.29 ± 0.04	0.1 ± 0.04	0.08 ± 0.03
Total VFA concentration	g/L	4.3 ± 0.8	4.2 ± 0.54	0.83 ± 0.21	0.45 ± 0.11