WATER RESEARCH 54 (2014) 211–221

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Biomass retention on electrodes rather than electrical current enhances stability in anaerobic digestion

Jo De Vrieze [a,1], Sylvia Gildemyn [a,1], Jan B.A. Arends [a,1], Inka Vanwonterghem [b,c], Kim Verbeken [d], Nico Boon [a], Willy Verstraete [a], Gene W. Tyson [b,c], Tom Hennebel [a,e,2], Korneel Rabaey [a,b,*,2]

[a] Laboratory of Microbial Ecology & Technology (LabMET), Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Gent, Belgium

[b] Advanced Water Management Centre, The University of Queensland, Brisbane, Queensland 4072, Australia

[c] Australian Centre for Ecogenomics, School of Chemistry and Molecular Biosciences, The University of Queensland, Brisbane, Queensland 4072, Australia

[d] Department of Materials Science and Engineering, Ghent University, Technologiepark Zwijnaarde 903, B-9052 Zwijnaarde, Belgium

[e] Department of Civil and Environmental Engineering, University of California at Berkeley, Berkeley, CA 94720, USA

ARTICLE INFO

Article history:
Received 28 October 2013
Received in revised form 16 January 2014
Accepted 23 January 2014
Available online 3 February 2014

Keywords:
Bioelectrochemical system
Methanosaeta
Methanosarcina
Biogas
Methane

ABSTRACT

Anaerobic digestion (AD) is a well-established technology for energy recovery from organic waste streams. Several studies noted that inserting a bioelectrochemical system (BES) inside an anaerobic digester can increase biogas output, however the mechanism behind this was not explored and primary controls were not executed. Here, we evaluated whether a BES could stabilize AD of molasses. Lab-scale digesters were operated in the presence or absence of electrodes, in open (no applied potential) and closed circuit conditions. In the control reactors without electrodes methane production decreased to 50% of the initial rate, while it remained stable in the reactors with electrodes, indicating a stabilizing effect. After 91 days of operation, the now colonized electrodes were introduced in the failing AD reactors to evaluate their remediating capacity. This resulted in an immediate increase in CH_4 production and VFA removal. Although a current was generated in the BES operated in closed circuit, no direct effect of applied potential nor current was observed. A high abundance of *Methanosaeta* was detected on the electrodes, however irrespective of the applied cell potential. This study demonstrated that, in addition to other studies reporting only an increase in methane production, a BES can also remediate AD systems that exhibited process failure. However, the lack of difference between current driven and open circuit systems indicates that the key impact is through biomass retention, rather than electrochemical interaction with the electrodes.

* *Corresponding author*. Laboratory of Microbial Ecology & Technology (LabMET), Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Gent, Belgium. Tel.: +32 (0)9 264 59 76; fax: +32 (0)9 264 62 48.
E-mail address: Korneel.Rabaey@UGent.be (K. Rabaey).
URL: http://www.labmet.Ugent.be

[1] These authors contributed equally to this work.
[2] These authors are both senior author for this work.

0043-1354/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.watres.2014.01.044

1. Introduction

Biorefineries produce sidestreams with high organic content (Verstraete et al., 2005). The success rate of most bio-refineries depends on the full utilization of all resources present in the original biomass, including these sidestreams. In this study, molasses was used to mimic sidestreams originating from bio-refineries. The direct discharge of untreated molasses wastewaters may cause serious environmental issues due to their high concentration of organic matter, high salt content and low pH (Sirianuntapiboon and Prasertsong, 2008). Anaerobic digestion (AD) is an established technology and can be considered the first microbial technology to allow energy recovery from complex organic waste streams. AD therefore has the potential to become a key technology to treat these sidestreams and generate heat and electricity for the refinery (Verstraete et al., 2005). AD can also deal with high loading rates, has limited nutrient demands and low operational control and maintenance costs (Mata-Alvarez et al., 2000; Verstraete et al., 2009). Methanogenic archaea are responsible for the final and most critical step of anaerobic digestion, i.e. the production of methane. One of the main drawbacks of anaerobic digestion is a sometimes-observed process failure due to sensitivity of these methanogens to different environmental factors, such as abrupt pH changes, organic overloading and high salt concentrations, leading to the accumulation of volatile fatty acids (VFA) (Ahring et al., 1995; Chen et al., 2008; De Vrieze et al., 2012; Gujer and Zehnder, 1983).

Bioelectrochemical systems (BESs) are an alternative technology to anaerobic digestion, capable of directly producing electrical power from liquid organic waste streams. Contrary to AD, very few BES exist beyond the lab-scale, hence their competitiveness with AD remains thus far unproven (Arends and Verstraete, 2012; Pham et al., 2006). On the other hand, BESs are highly versatile in terms of potential application, ranging from energy production from organic substrates to product generation and specific environmental niche creation (Arends and Verstraete, 2012; Logan and Rabaey, 2012; Rabaey and Rozendal, 2010). These last two processes are of main interest to AD due to their possible influence on process stability and microbial activity.

It has been postulated that a BES can be used to alter and/or control the main processes in anaerobic digestion (Arends and Verstraete, 2012; Sasaki et al., 2010b). Several studies already highlighted that combining anaerobic digesters with a BES resulted in a higher level of biogas production (Rabaey et al., 2005; Sasaki et al., 2011a, 2010b; Tartakovsky et al., 2011; Vijayaraghavan and Sagar, 2010; Weld and Singh, 2011). Different AD-BES configurations, such as the utilization of a BES as pre- or post-treatment device outside the AD reactor or the direct application of a BES in the digester, may lead to enhanced methane production. The introduction of a BES in the recirculation loop of a thermophilic UASB resulted in a higher tolerance of the digester to a severe drop in pH due to the addition of an acetate pulse to the system (Weld and Singh, 2011). The direct application of the cathode in an AD reactor resulted in enhanced COD removal and methane production during anaerobic digestion of filter paper and garbage slurry, respectively (Sasaki et al., 2011a, 2010b). The introduction of both the anode and cathode of a BES in the sludge bed of an UASB (Tartakovsky et al., 2011) or in a CSTR (Vijayaraghavan and Sagar, 2010) also resulted in increased methane production. A BES can also be used for post-digestion polishing of highly loaded wastewaters, leading to side products such as H_2 (Rabaey et al., 2005).

The objective of this study was (1) to evaluate whether a BES could stabilize anaerobic digestion (AD-BES) of molasses leading to higher COD removal and methane production, and (2) if a BES could remediate systems that have experienced severe process failure and (3) how this influences the microbial community composition of the entire system. The term "stable" was used as long as total residual VFA remained below 1.0 g COD L^{-1}, whereas the term "failure" referred to a 50% decrease in methane production compared to the initial value. To achieve these goals, different lab-scale anaerobic digesters were operated in the presence or absence of a BES to evaluate the stabilizing potential of a BES in AD. The cell potentials were selected to avoid direct electrochemical production of H_2 at the cathode or O_2 at the anode but to potentially stimulate biologically catalyzed H_2 production, which could lead to an increased methane production. The BESs were also introduced in failing AD reactors in order to evaluate their remediating capacity.

2. Material and methods

2.1. *Experimental set-up and operation*

2.1.1. *Reactor set-up*

Seven lab-scale continuously stirred tank reactor (CSTR) vessels with a liquid volume of 800 mL were each connected to a gas column to collect the produced biogas (Fig. SI1). These reactors are considered reproducible, as indicated in earlier preliminary research (data not shown). Moreover, each reactor was considered a time series in accordance with the research of Wittebolle et al. (2008), Carballa et al. (2011) and Zamalloa et al. (2012). A pair of carbon felt electrodes were introduced in three vessels, each with a surface area of 60 cm^2 (projected area; BET 2 m^2 g^{-1}; Carbon felt, 3.18 mm thickness, Alfa Aesar, Ward Hill, MA, USA), which corresponded to a projected surface area to volume ratio of 0.015 m^2 L^{-1} reactor. The electrodes were fixed in parallel at a distance of 1 cm. The reactors with electrodes contained an Ag/AgCl reference electrode (MF-2052, BASi, West Lafayette, IN, USA) and were connected to a power source (3030D, Protek, USA) via a stainless steel wire and a 1 Ω resistor. The set-up is described in more detail in the SI (S1).

2.1.2. *Reactor operation*

All seven reactors were inoculated with anaerobic sludge from a municipal sludge digester (Ossemeersen WWTP, Ghent, Belgium). The sludge was diluted with tap water to obtain an initial sludge concentration of 10 g L^{-1} volatile suspended solids (VSS). All reactors were operated at 34 °C in fed batch mode and fed 3 times a week (Monday, Wednesday and Friday) for a total period of 154 days. Fresh feed was