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Anaerobic digestion of molasses by means of a vibrating and non-vibrating submerged anaerobic membrane bioreactor

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ABSTRACT

Bio-refineries produce large volumes of waste streams with high organic content, which are potentially interesting for further processing. Anaerobic digestion (AD) can be a key technology for treatment of these sidestreams, such as molasses. However, the high concentration of salts in molasses can cause inhibition of methanogenesis. In this research, concentrated and diluted molasses were subjected to biomethanation in two types of submerged anaerobic membrane bioreactors (AnMBRs): one with biogas recirculation and one with a vibrating membrane. Both reactors were compared in terms of methane production and membrane fouling. Biogas recirculation seemed to be a good way to avoid membrane fouling, while the trans membrane pressures in the vibrating MBR increased over time, due to cake layer formation and the absence of a mixing system. Stable methane production, up to 2.05 L L^{-1} d^{-1} and a concomitant COD removal of 94.4%, was obtained only when diluted molasses were used, since concentrated molasses caused a decrease in methane production and an increase in volatile fatty acids (VFA), indicating an inhibiting effect of concentrated molasses on AD. Real-time PCR results revealed a clear dominance of *Methanosaetaceae* over *Methanosarcinaceae* as the main acetoclastic methanogens in both AnMBRs.

1. Introduction

The combination of fossil fuel depletion and detrimental environmental effects caused by their consumption creates an urgent need for alternative resources and processes for both the production of energy and chemicals. Emerging technologies convert bio-based feedstocks through a combination of physical, chemical and biological processes into a range of biofuels and biochemicals. The production of biofuels

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has reached unprecedented levels, with bioethanol being the uncontested number one on a volume basis, predicted to reach 100 billion liters in 2015 [1]. However, it is becoming clear that the success rate of these so-called 'bio-refineries' depends on the full utilization of all resources present in both the original biomass and the waste streams. This concept of the so-called 'zero waste bio-refinery' considers wastewaters, for example, as sidestreams. In the case of bio-ethanol production, up to 20 L of wastewater is generated per liter ethanol produced. This water contains chemical and biological oxygen demand (COD and BOD) in the order of 60–100 g L^{-1} and 35–60 g L^{-1}, respectively [2]. Adequately processing these organics can improve the economics of bio-refineries. Molasses is the most important by-product in cane sugar factories and the production of molasses wastewaters may cause serious environmental problems, due to their high concentration of organic matter, high salt content and low pH [3].

One possibility to fully utilize these organics is the production of biogas by means of AD. Indeed, one could produce 1.1 kWh_{elect} at a value of € 0.1 kWh^{-1} starting from 1 kg COD [4]. In addition to the value of the bio-ethanol itself (currently € 0.6–0.8 L^{-1}), AD could result in an extra € 0.22 L^{-1} bio-ethanol produced.

Several anaerobic bioreactor designs have been used to treat bio-refinery wastewater. Among these, continuously stirred tank reactors (CSTRs), upflow anaerobic sludge blanket (UASB) reactors and the expanded granular sludge blanket configuration (EGSB) are most commonly described [5,6]. In the present study, anaerobic membrane bioreactors (AnMBRs) were constructed for the conversion of synthetic bio-refinery streams into biogas. In general, AnMBRs have distinct advantages over other configurations, such as a small footprint, a high effluent quality, a high volumetric loading rate, and a lower sludge production [7,8]. The separation of the hydraulic (HRT) and sludge retention time (SRT) can be considered the main advantage in treatment of bio-refinery effluents, given the lower stress on the microbial community. Indeed, these streams typically contain high amounts of sulfate, salts and lipids, which negatively affect the biofilm and granule formation in UASBs and ESBGs. In AnMBRs, the membrane filtration component can exist in three configurations: external cross-flow, internal submerged or external submerged [9]. In an internal submerged membrane configuration, membranes are submerged directly into the suspended biomass in the bioreactor and permeate is produced by exerting a vacuum on the membrane. One of the main challenges for industrial scale applications of this configuration is fouling of the membranes. Fouling is typically controlled by recirculation of biogas in order to create shear at the membrane surface [10,11]. Recently, an innovative system using a magnetically induced membrane vibration system was developed as an alternative shear enhancement device for fouling control in aerobic MBRs [12,13]. Aeration was only required to obtain proper mixing of the activated sludge, and the reduced air supply resulted in decreased energy consumption.

The goals of this study were to (i) study the performance of AnMBRs to digest molasses, (ii) evaluate a novel vibration membrane filtration system for AD, (iii) compare the performance between a scouring configuration and the vibrating membrane configuration and (iv) analyze the methanogenic community of both systems. Both concentrated and diluted molasses were used in order to estimate the possibility to treat highly concentrated bio-refinery sidestreams by means of an AnMBR.

2. Materials and methods

2.1. Experimental set-up

Two different set-ups were constructed to compare the performance of AnMBRs with biogas recirculation and AnMBRs with vibration (V-AnMBR) in order to control fouling. A schematic representation of both AnMBRs can be found in Fig. S1. In case of the MBRs with biogas recirculation, two reactors were run in parallel, differing in the applied influent. In the HL-AnMBR concentrated molasses was used in phase 1, after which diluted molasses was used in phase 2. In the NV-AnMBR diluted molasses was used throughout the entire

Table 1 – Characteristics of the influent to the high-load anaerobic membrane bioreactor (HL-AnMBR) during phase 1 and phase 2, the low-load non-vibrating anaerobic membrane bioreactor (NV-AnMBR) and the low-load vibrating anaerobic membrane bioreactor (V-AnMBR) (n.d. not determined).

Parameter	HL-AnMBR phase 1	HL-AnMBR phase 2	NV-AnMBR	V-AnMBR
Substrate	Concentrated molasses	Diluted molasses	Diluted molasses	Diluted molasses
pH	5.50 ± 0.12	5.46 ± 0.11	5.36 ± 0.60	5.41 ± 0.66
Conductivity (mS cm^{-1})	35.2 ± 2.4	5.8 ± 0.6	5.3 ± 2.8	3.9 ± 1.6
Total COD (g L^{-1})	110.9 ± 4.4	14.5 ± 0.6	11.4 ± 7.0	8.3 ± 3.9
Soluble COD (g L^{-1})	94.6 ± 2.4	13.3 ± 0.9	n.d.	n.d.
Total suspended solids (g L^{-1})	n.d.	17.1 ± 1.4	12.6 ± 7.5	8.4 ± 3.5
Volatile suspended solids (g L^{-1})	n.d.	12.0 ± 1.3	8.6 ± 5.4	5.6 ± 2.4
Total ammonia nitrogen, TAN (mg N L^{-1})	399.4 ± 161.3	34.0 ± 30.5	39.8 ± 16.7	32.9 ± 8.9
Kjeldahl nitrogen, TKN (mg N L^{-1})	12,000 ± 1900	1100 ± 200	680.4 ± 433.0	471.2 ± 234.8
Total phosphorous, TP (mg P L^{-1})	n.d.	151.3 ± 17.7	123.7 ± 73.7	84.1 ± 37.9
COD:N ratio	9.0	12.7	16.8	17.6
COD:P ratio	n.d.	95.8	92.2	98.7
TS:VS ratio	n.d.	1.4	1.5	1.5
COD:VS ratio	n.d.	1.2	1.3	1.5