Bioresource Technology 245 (2017) 342–350

Contents lists available at ScienceDirect

Bioresource Technology

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

Sugarcane vinasse treatment by two-stage anaerobic membrane bioreactor: Effect of hydraulic retention time on changes in efficiency, biogas production and membrane fouling

Fábio S. Santos[a,*], Bárbara C. Ricci[a], Luzia S. França Neta[b], Míriam C.S. Amaral[a]

[a] Department of Sanitary and Environmental Engineering, Universidade Federal de Minas Gerais, Avenida Antônio Carlos, 6627, Pampulha, CEP 31270-901 Belo Horizonte, Minas Gerais, Brazil

[b] Department of Chemistry, Centro Federal de Educação Tecnológica de Minas Gerais, Av. Amazonas, 5253, Nova Suíça, CEP 30421-169 Belo Horizonte, Minas Gerais, Brazil

A R T I C L E I N F O

Keywords:
Anaerobic membrane bioreactor
Anaerobic digestion
Sugarcane vinasse
Hydraulic retention time
Membrane fouling

A B S T R A C T

This research investigated the effect of hydraulic retention time (HRT) on two-stage anaerobic membrane bioreactor (2-SAnMBR) performance treating sugarcane vinasse. The experimental setup consisted of an upflow acidogenic reactor and a continuous stirred methanogenic reactor, fitted with submersed microfiltration hollow-fiber membranes. The results indicated excellent performance and robustness of 2-SAnMBR. The reduction in HRT of 5.3–3.1 days did not cause loss of its performance. The 2-SAnMBR showed high capacity of removing organic matter (97%), producing biogas (6.3 Nm^3 of CH_4 per m^3 of treated vinasse) and did not completely remove important nutrients to fertigation. Reducing the HRT, the average mass of soluble microbial products (SMP) and extracellular polymeric substances (EPS) per mass of mixed liquor volatile suspended solids (MLVSS) increased. Consequently, the transmembrane pressure (TPM) rate and fouling resistance rise. Despite the fouling effect, physical and chemical cleaning processes were able to recover operational permeability.

1. Introduction

Vinasse is an effluent from the distillation of fermented sugarcane juice or molasses for ethanol production. It is rich in nutrients, mainly nitrogen, phosphorus, potassium and sulfate, combined with high organic matter, in terms of chemical oxygen demand (COD) and biochemical oxygen demand (BOD), low pH and high content of suspended solids (De Bazúa et al., 1991; Wilkie et al., 2000). The vinasse pollution potential is intensified due to the high generation rate. According to van Haandel (2005), 10–15 l of vinasse is generated for each 1 l of produced ethanol.

Facing these characteristics, anaerobic digestion (AD) has been an attractive method for vinasse treatment, aiming pollutants removal and energy recovery from the methane production (Albanez et al., 2016; Fuess et al., 2017). Other advantages of AD process are low energy consumption and rapid re-starting after prolonged shutdown (Shin et al., 2010; Stuckey, 2012). This last advantage is important in vinasse treatment, given the seasonality of ethanol production.

Despite the AD potential for high organic load rate (OLR) effluents treatment, reactor configurations need to be improved in order to allow high rates of pollutant removal combined with large production of by-products, such as methane. Lin et al. (2013) reported that the main operational conditions related to anaerobic reactors applications include hydrodynamic conditions, hydraulic retention time (HRT), sludge retention time (SRT), pH and temperature. Among these parameters, HRT detaches, since it could significantly affect the efficiency of wastewater treatment, as well as the growth and metabolic activity of microorganisms, being the key to further improving the capacity of treatment (Martinez-Sosa et al., 2012; Stuckey, 2012). In addition, there is a great interest in an efficient treatment in the shortest HRT.

Nevertheless, in the literature there is no consensus regarding the ideal HRT to be applied in AD reactors, especially due to the different requirements of acidogenic and methanogenic microorganisms involved in AD. According to Demirer and Chen (2005), the microorganisms present in a mixed anaerobic culture diverge, not only in relation to their nutritional and pH requirements, but also regarding their physiology, growth and nutrient uptake kinetics, and in their ability to tolerate environmental stresses. Therefore, favorable conditions to the growth of acid-forming bacteria (short HRT, low pH) may be inhibitory to methane forming bacteria.

In order to provide the best conditions for acidogenic and methanogenic microorganisms growth, two-stage anaerobic reactors have

* Corresponding author.
E-mail address: fabiosoares04@gmail.com (F.S. Santos).

http://dx.doi.org/10.1016/j.biortech.2017.08.126
Received 30 June 2017; Received in revised form 18 August 2017; Accepted 20 August 2017
Available online 24 August 2017
0960-8524/

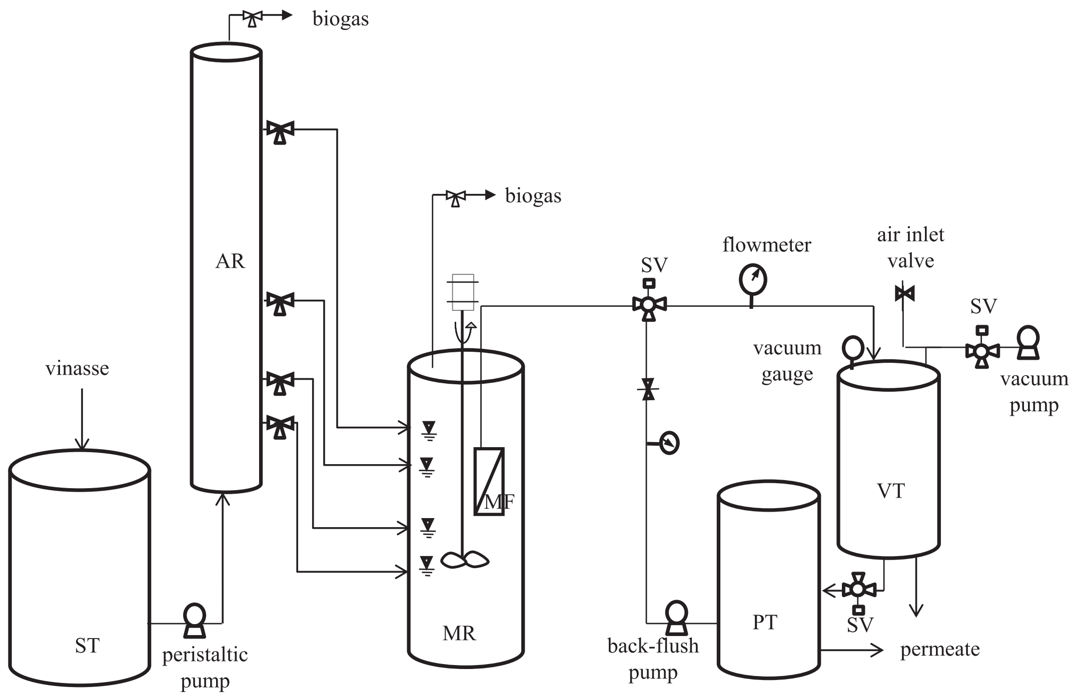

Fig. 1. 2-SAnMBR scheme. ST: storage tank; AR: acidogenic reactor; MR: methanogenic reactor; MF: microfiltration unit; SV: solenoid valve; VT: vacuum tank; PT: permeate tank (Mota et al., 2013).

been studied. These reactors have been shown more effective than conventional AD reactors, especially in the treatment of high OLR and low pH effluents, such as vinasse (Fuess et al., 2017; Meng et al., 2017).

A two-stage anaerobic digester is based upon the premise that the environmental conditions in most anaerobic wastewater digesters are not optimal for both acidogenic (fermentative) and methanogenic microorganisms. Due to their differing growth characteristics, it is not possible to choose a single set of digester operating conditions that can maximize both acid and methane-forming bacterial growth (Ince, 1998). First of all, the two-phase anaerobic digester system has several advantages over conventional processes, since it permits selection and enrichment for different bacteria in each reactor. Secondly, it increases the stability of the process by controlling the acidification-phase to prevent overloading and build-up of toxic material, which can then affect the methanogenic bacteria. Finally, the first stage may act as a metabolic buffer, preventing pH shocks to the methanogenic bacteria, while, in addition to a low pH, high OLR and short HRT favor the establishment of the acidogenic phase and prevent the establishment of methanogens (Anderson et al., 1994; Solera et al., 2002).

Current anaerobic plants treating complex or high organic load effluents usually apply long HRT in order to allow enough time for the effective degradation of recalcitrant compounds and to prevent the wash out of slow growing microorganisms. Therefore, a challenge in operating AD reactors is maintaining a high-density anaerobic microorganism population, mainly in short HRT conditions (Lin et al., 2013; van Haandel and Lettinga, 1994). In order to solve these problems, membrane separation processes have been conjugated to the AD reactors, which are named Anaerobic Membrane Bioreactors (AnMBR). AnMBR offers advantages in terms of reduced footprint, low maintenance, capacity of handling wide fluctuations in feed quality, complete biomass retention, rapid start-up and a higher loading rate than conventional technologies (Chang and Kim, 2005; Jegatheesan et al., 2016; Lin et al., 2013). Despite this, membrane fouling is a concern in AnMBR, being influenced by HRT. According to Hong et al. (2012), the HRT reduction increases the OLR, which can contribute to shock loading on biomass. It can alter the sludge biomass characteristics, increasing the production of soluble microbial products (SMP) and extracellular polymeric substances (EPS) and, consequently, enhancing the propensity of membrane fouling.

In this context, the aim of this study was to evaluate the influence of HRT on performance of a two-stage anaerobic membrane bioreactor (2-SAnMBR) designed to treat sugarcane vinasse. For this, pollutant removal (organic matter and nutrients), biogas production and membrane fouling at three different HRT (5.3, 4.2 and 3.1 days) were analyzed. HRT optimization in the vinasse anaerobic digestion is very important, mainly considering the large volume of vinasse to be treated. The decrease of the HRT, maintaining the high removal of pollutants, reduces the AnMBR plant size. Consequently, the economic and energy costs for the design and operation of this system will be lower.

2. Materials and methods

2.1. Vinasse samples

Vinasse samples were obtained from the distillery Imãos Malosso located in the state of São Paulo, Brazil, which produces ethanol from fermentation of sugarcane juice. The samples were stored in a refrigerator at 4 °C and protected from light before use to hinder its decomposition. The main physicochemical characteristics of this vinasse are: COD = 16,706 mg L^{-1}, BOD = 5571 mg L^{-1}, total organic carbon (TOC) = 4383 mg L^{-1}, color = 17,325 HU, pH = 3.8, conductivity = 3672 μS cm^{-1}, total solids (TS) = 12,211 mg L^{-1}, total volatile solids (TVS) = 9790 mg L^{-1}, total fixed solids (TFS) = 2420 mg L^{-1}, total nitrogen (TN) = 97 mg L^{-1}, total phosphorus = 98 mg L^{-1}, fluoride = 215 mg L^{-1}, chloride = 541 mg L^{-1}, phosphate = 107 mg L^{-1}, sulfate = 383 mg L^{-1}, sodium = 113 mg L^{-1}, potassium = 3175 mg L^{-1}, magnesium = 391 mg L^{-1} and calcium = 288 mg L^{-1}.

2.2. 2-SAnMBR setup and operating conditions

The 2-SAnMBR used in this study was previously studied by Mota et al. (2013). This reactor (scheme in Fig. 1) and the membrane modules were provided by PAM Membranas Seletivas Ltda. (Rio de Janeiro,