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# Comparison of start-up strategies and process performance during semi-continuous anaerobic digestion of sugarcane filter cake co-digested with bagasse

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ABSTRACT

The anaerobic digestion of sugarcane filter cake and the option of co-digestion with bagasse were investigated in a semi-continuous feeding regime to assess the main parameters used for large-scale process designing. Moreover, fresh cattle manure was considered as alternative inoculum for the start-up of biogas reactors in cases where digestate from a biogas plant would not be available in remote rural areas. Experiments were carried out in 6 lab-scale semi-continuous stirred-tank reactors at mesophilic conditions (38 ± 1 °C) while the main anaerobic digestion process parameters monitored. Fresh cattle manure demonstrated to be appropriate for the start-up process. However, an acclimation period was required due to the high initial volatile fatty acids concentration (8.5 g $L^{-1}$). Regardless the mono-digestion of filter cake presented 50% higher biogas yield (480 mL $gVS^{-1}$) than co-digestion with bagasse (320 mL $gVS^{-1}$) during steady state conditions. A large-scale co-digestion system would produce 58% more biogas (1008 $m^3$ $h^{-1}$) than mono-digestion of filter cake (634 $m^3$ $h^{-1}$) due to its higher biomass availability for biogas conversion. Considering that the biogas production rate was the technical parameter that displayed the most relevant differences between the analyzed substrate options (0.99–1.45 $m^3$ biogas $m^3$ $d^{-1}$). The decision of which substrate option should be implemented in practice would be mainly driven by the available construction techniques, since economically efficient tanks could compensate the lower biogas production rate of co-digestion option.



## 1. Introduction

The production of sugar and ethanol based on sugarcane as feedstock is responsible for generation of different types of organic waste, which in most cases are still not being properly managed from the energy point of view (De Carvalho Macedo, 2007). In this context, bagasse, a solid waste derived from the extraction of sugarcane juice, is generated in large amounts (260 kg per ton of cane), and usually used as fuel in low-efficiency cogeneration systems or sold by the sugarcane plants to another end-uses (e.g. animal feeding) (Bressan Filho, 2011; Nogueira et al., 2008). On the other hand, filter cake, produced during the clarification (physical–chemical process) of the sugarcane juice, is generated in lower amounts than bagasse (35–40 kg per ton of cane), however it is mostly applied as organic fertilizer on the sugarcane fields without any previous energy recovery (Janke et al., 2015a).

Anaerobic digestion (AD) is a promising strategy to manage such type of waste, since as a result of the biochemical process in which complex organic matter is degraded to $CH_4$ and $CO_2$ by

*Abbreviations:* AD, anaerobic digestion; C:N, carbon to nitrogen; C:P, carbon to phosphorus; C:S, carbon to sulfur; FCM, fresh cattle manure; FM, fresh matter; HRT, hydraulic retention time; MIX, mixture of digestates; NFC, non-fiber carbohydrates; $NH_4$-N, ammonium-nitrogen; OLR, organic loading rate; SBP, specific biogas production; SCSTR, semi-continuous stirred-tank reactor; SUC, specific upgrading cost; TBP, theoretical gas potential; TS, total solids; VFA, volatile fatty acids; VOA, volatile organic acids; VOA/TIC, ratio of volatile organic acids and total inorganic carbonate to calcium carbonate; VS, volatile solids.

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various types of microorganisms biogas could be produced and used as fuel to improve the energy balance of the sugarcane plants (Janke et al., 2015b; Leite et al., 2015a). However, several factors such as temperature, pH, organic loading rate (OLR), hydraulic retention time (HRT), balance of nutrients and presence of inhibitors must be considered for an efficient AD process. Furthermore, the microbial community and the quality of the inoculum used for the start-up of an anaerobic reactor are also considered decisive factors for a successful biogas production (Cho et al., 2013; Moset et al., 2014).

In previous studies (Janke et al., 2014; Leite et al., 2015b) our group has already assessed the possibility of using these type of waste for biogas production in batch tests. However, the feed regime and high proportion of inoculum used during batch tests do not allow an adequately assessment of anaerobic reactors start-up, neither possible process inhibition during digestion of the substrates. Therefore, understanding the reactor's behavior during the start-up phase can be attained only by using a similar feeding regime applied in large-scale applications (semi-continuous system).

For large-scale applications, it is well known that using digestate taken from a stable working digester could be a good strategy to overcome the start-up challenges (Kobayashi et al., 2009). However, in countries where biogas technology is not established in the market yet, plant operators must find alternative sources of inoculum suitable for the start-up period of an anaerobic reactor. In this case, the utilization of animal waste, such as cattle manure, could be a useful strategy, since such material is rich in microorganisms from animal digesting system, as well important macronutrients and trace elements (Seadi et al., 2008).

According to earlier studies (Kayhanian and Rich, 1995; Mccarty, 1964), another factor that can influence the performance of the AD process is the nutrient content of the substrates. If a certain substrate has too high C:N ratio and consequently nitrogen deficiency, it may negatively affect the functioning of the microbial community. Thus, a direct effect on their ability to produce enzymes that are needed for the carbon utilization, causing an incomplete conversion of the substrates, resulting in lower $CH_4$ yields. On the other hand, substrates that contain high levels of nitrogen can cause inhibition to the AD process via accumulation of toxic ammonia ($NH_3$) produced from protein degradation or by urea conversion (Lv et al., 2014).

The characteristics of different sugarcane waste assessed by Leite et al. (2015b), showed that bagasse has a C:N variation of 90–101:1 along an operating season, which is higher than the range of values (20–40:1) recommended by others (FNR, 2012). Meanwhile, previous studies (López González et al., 2013) showed that filter cake has a C:N ratio of 26:1, that is around the lowest recommended limit.

Considering that filter cake is a waste stream that currently is not used for any energy purpose, it makes sense to use such type of biomass on the AD process to produce biogas. This would enhance the energy balance of sugarcane plants without losing the essential nutrients for the sugarcane cultivation. Additionally, bagasse that is the major solid waste produced on-site by the sugarcane plants, could be an interesting co-substrate to balance the C:N of filter cake and improve energy production in the biogas system. Thus, the objectives of the present study were to (i) assess cattle manure as alternative inoculum for the start-up phase of semi-continuous anaerobic reactors; (ii) compare the process performance during semi-continuous mono-digestion of filter cake versus the option of co-digestion with bagasse; and (iii) analyze both substrate options (mono-digestion and co-digestion) on the main parameters used for the AD process design integrated to a large-scale sugarcane plant.

## 2. Materials and methods

### 2.1. Substrates and inocula

Samples of sugarcane filter cake and bagasse were collected from a distillery plant in the State of Goiás (Brazil) during the 2012/2013 season, transported to Germany in sealed plastic bags and kept under low temperature (i.e. 4 °C) until its use. A large-scale biogas plant that uses maize silage and fresh cattle manure (FCM) as substrate provided FCM that was used for the start-up of two semi-continuous reactors. A mixture of several digestates (hereafter referred as MIX) from mesophilic lab-scale reactors were used for the start-up of four other semi-continuous reactors. To avoid inlet and outlet pipes from clogging, both inocula were sieved prior to inoculation in the reactors. Tap water was utilized to keep the total solids of the feed below 15% for the wet fermentation process.

### 2.2. Semi-continuous feeding experiments

Six lab-scale semi-continuous stirred-tank reactors (SCSTR) with 5 L total volume and 3 L working volume were carried out in these experiments. The reactors were continuously stirred (100 rpm) using a central stirrer with helix shaped blades located in the lower part of the reactors. The operation temperature was kept under mesophilic conditions (38 ± 1 °C) by recirculating hot water through the double-walled reactors.

Each of the three following experiments performed in our study was carried out in duplicate with the same feeding regime (once per day). Reactors R3.3 and R3.4 were fed with filter cake and MIX for start-up. Reactors R3.5 and R3.6 were fed in a co-digestion system with filter cake (70%) and bagasse (30%) on fresh matter basis, also using MIX for start-up. Reactors R3.7 and R3.8 were fed with the same co-digestion proportion, however using FCM as inoculum. Detailed information about the different feeding rates, OLR and HRT are listed in Table 1.

### 2.3. Analytical methods

For all samples, total solids (TS) and volatile solids (VS) were analyzed according to VDI 4630 (2006). Nutritional values were determined according to Weender followed by Van Soest methods. By the Weender method raw protein, raw fat, non-fiber carbohydrates (NFC) and raw fiber are determined. Van Soest method allows the determination of the remaining carbohydrates and lignin fractions from the neutral detergent fiber (NDF), which represents hemicellulose, cellulose, lignin and ash, acid detergent fiber (ADF) represented by cellulose, lignin and ash, and the lignin content depicted by the acid detergent lignin (ADL). Detailed description of the methods was previously published by Liebetrau et al. (2015). To determinate the major elements contained in each sugarcane waste, dried samples were pre-treated with a mixture of $HNO_3/H_2O_2/HF$ and latter neutralized with $H_3BO_3$, and the resulting clear solution was analyzed by inductively coupled plasma atomic spectrometry (ICP-OES, ThermoFischer iCAP6200) according to standard procedures (DIN, 2011a, 2011b, 2002).

The daily biogas production in each of the semi-continuous reactors was measured by a milligascounter type MGC-10 (Ritter, Bochum, Germany), and corrected to standard temperature and pressure conditions (273.15 K and 101.325 kPa), and the specific biogas production (SBP) was presented in norm milliliters per g of VS (mL $gVS^{-1}$). The composition of the produced biogas ($CH_4$, $CO_2$ and $O_2$) was measured twice a week in the headspace of the reactors by using a GA2000 Landfill Gas Analyzer (Geotechnical Instruments Ltda., UK).