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High-solids anaerobic mono-digestion of riverbank grass under thermophilic conditions

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ABSTRACT

The purpose of this study was to investigate the potential of high-solids anaerobic mono-digestion of riverbank grass under thermophilic conditions, focusing on the effects of the strength and the amount of inoculum. Ensiled grass was inoculated with three different inocula; inoculum from liquid anaerobic digester (LI), inoculum from dry anaerobic digester (DI), and mixture of LI and DI (MI), at feedstock-to-inoculum ratio (FIR) of 1, 2 and 4. The ensiling process of riverbank grass reduced moisture content ($p > 0.05$), while the hemicellulose content was significantly increased from 30.88% to 35.15% ($p < 0.05$), on dry matter basis. The highest methane production was at an FIR of 2 with MI (167 L/kg VS_{added}), which was significantly higher ($p < 0.05$) than with DI, but not significant compared to LI ($p > 0.05$). At an FIR of 4, digesters inoculated with LI and DI failed to produce methane, whereas 135 L_{CH4}/kg VS_{added} was obtained with MI. The kinetic studies showed that at an FIR of 1 with LI and MI, the inoculum had less of effects on the hydrolysis rate constant (0.269 day^{-1} and 0.245 day^{-1}) and methane production (135 versus 149 L/kg VS_{added}); rather, it affected the lag phase. In a thermophilic HS-AD of riverbank grass, the mixture of inoculum with low and high total solids content (TS) helps increase the TS of inoculum and digestion process. An FIR of 2 was deducted to be the limit for a better startup time and higher volumetric productivity of methane.

Introduction

Cellulosic biomass is an essentially inexhaustible source of raw material; with an annual production of 1.5 trillion tons (Kumar et al., 2008), which can be used for sustainable production of environmentally friendly bioenergy such as biogas. Among feedstock, it is of interest for bioenergy production because it does not compete with human food or animal feed (Yang et al., 2015). Composed mainly of cellulose
Q2 and hemicellulose, and small quantity of lignin (5%–7%) (Frigon and Guiot, 2010), cellulosic biomass is a good feedstock for anaerobic digestion. Based on total solids content (TS), anaerobic digestion (AD) can be categorized as liquid AD (L-AD) when the TS is lower than 15%; otherwise, it is categorized as high-solids AD (HS-AD) (Li et al., 2011a, b). Q3
Both systems have their own advantages and disadvantages; however, the choice of either L-AD or HS-AD is principally based on the characteristics of the feedstock. For example, for substrates that are low in TS, such as animal manure, sewage sludge and food waste, L-AD is preferable, whereas HS-AD is

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more attractive for OFMSW and grass (Li et al., 2011a, b; Kothari et al., 2014) because they tend to scum, float and stratify during L-AD (Chanakya et al., 1999).

Riverbank grass is among the cellulosic biomass that is widely available during summer and fall in Japan. For example, on the bank of the Satsunai River, Obihiro, the yearly production of grass is estimated to be 600 tons. Generally, it is cut, dried, rolled and incinerated, which obviously causes adverse effects on the environment. Therefore, the use of this grass for HS-AD may help recover the energy contained in the grass as a form of methane gas and a valuable compost-like effluent as a biofertilizer. However, it is a challenging process because at a TS of more than 12%, the biogas production of mono-fermentation of ensiled grass, under mesophilic conditions, drops remarkably, as reported by Koch et al. (2009).

Among the disadvantages of HS-AD are its requirements for higher quantities of inoculum and longer hydraulic retention times (Li et al., 2011a, b). The strength and amount of inoculum have been reported to have a remarkable impact on the overall performance of the AD process (Forster-Carneiro et al., 2007; Pozdniakova et al., 2012; Dechrugsa et al., 2013). In the case of mono-digestion of grass, which has a low buffer capacity, high C/N ratio and low macro- and micro-nutrient contents (Wilkie et al., 1986; Demirel and Scherer, 2011), some challenges are addressed, such as the longer acclimation period of the inoculum to the substrate, slower startup, and longer retention time. However, with a good quality and appropriate quantity of inoculum, mono-digestion of grass can be made more efficient and stable (Yang et al., 2015). For HS-AD, the solids content in the inoculum is an important parameter for obtaining high TS content in the digester when it is mixed with the substrate. Up to now, many laboratory works on HS-AD have used centrifuged inoculum from L-AD to inoculate HS-AD of different types of feedstock (Li et al., 2013; Shi et al., 2013; Motte et al., 2013). The main objective of centrifugation is to increase the TS content of the inoculum to obtain a high TS content in the digester (Chen et al., 2014), which may affect the microbial community and the macro- and micro-nutrient contents in the inoculum. Another alternative for increasing the TS of the inoculum is through the mixture of two different inocula, such as low TS inoculum originating from the L-AD process and high TS inoculum originating from the HS-AD process. The effect of this mixture inoculum on methane production for HS-AD is investigated and reported on in this study.

The feedstock-to-inoculum ratio (FIR) has been reported to have a remarkable influence on methane production (Dechrugsa et al., 2013; Raposo et al., 2009; Kawai et al., 2014). It is strictly dependent on substrate characteristics and operating temperature (Li et al., 2011a, b; Zhu et al., 2014). The amount of inoculum, on a volatile solids (VS) basis, is very important in assuring a good startup of AD that helps prevent acidic conditions in the digester (Angelidaki et al., 2009). In some cases, inoculum is the only source of nitrogen, heavy metals and the microbial population that guarantees a balanced microbial community in the digester (Zhu et al., 2014; Xu et al., 2013), especially for high C/N ratio substrates. For HS-AD of lignocellulosic biomass, the start-up phase is strictly dependent on the FIR (Motte et al., 2013). In many cases, a high FIR is related to an overloading of the feedstock that leads to the accumulation of volatile fatty acids (VFAs) and to acidic conditions in the digester (Dechrugsa et al., 2013; Shi et al., 2014). In contrast, a low FIR is favorable for a faster startup and increased process performance (Motte et al., 2013; Cui et al., 2011). However, lowering the FIR reduces the reactor's efficiency, which can be defined as the methane production per reactor volume (Li et al., 2013). Therefore, investigating the optimum FIR is of interest for increasing the process performance of HS-AD of riverbank grass.

In HS-AD, digestion temperature is an important factor as it determines the design of digester. For example, Dranco and Kompogas are operated under thermophilic condition, whereas Valorga is operated under mesophilic condition (Karthikeyan and Visvanathan, 2013). It is believed that thermophilic condition is more reliable for HS-AD over mesophilic condition because it enhances the AD process, increases digester's efficiency. Although, higher input energy is required under thermophilic condition, the energy balance can be offset by the higher biogas yield under this condition (Li et al., 2011a, b; Karthikeyan and Visvanathan, 2013). Therefore, the main objective of the study was to investigate the potential of riverbank grass for methane production under thermophilic HS-AD conditions. In particular, the study focused on the effects of the inoculum mixture and its quantity on methane production. Therefore, the specific objectives were (1) to determine the best inoculum for HS-AD of riverbank grass and (2) to determine the appropriate riverbank grass and inoculum ratio for methane production. Since riverbank grass is seasonally available substrate, ensiling is an important conservation process to preserve the energy content of the grass and ensure a constant supply for AD plants (Vervaeren et al., 2010; McEniry et al., 2014). Therefore, the effect of ensiling process on the characteristics of grass was also investigated.

1. Materials and methods

1.1. Feedstock preparation

Grass was collected in October 2013 on the bank of the Satsunai River, Obihiro, Japan (42°55′N, 143°12′E). Fresh grass was chopped into 20-mm lengths and then 500 g of Si-Master-LP (Snow Brand Seed Co. Ltd., Japan), fermentative lactic acid bacteria composed of *Lactococcus lactis* and *Lactobacillus paracasei*, per ton of grass was added to ensure the lactic fermentation of the grass. The grass was fermented under anaerobic conditions for 3 months under room temperature. Since inception of experiment was several months after ensiling process, the ensiled grass was kept in a freezer at −20°C until use in order to prevent any change in terms of characteristics and components. Before use, the silage was thawed at 4°C for 24 hr and was air-dried until the moisture content was lower than 10% in order to reduce the specific energy requirements for milling (Barakat et al., 2013). The dried silage was coarse-milled using a centrifugal mill to pass through a 1-mm sieve, which is the optimum particle size to make AD economically viable (Barakat et al., 2013) and enabled more accessible surface for microbial attack (Li et al., 2011a, b). The dried silage was kept in airtight bags at room temperature prior to use.