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Comparison of non-agitated and agitated batch, thermophilic anaerobic digestion of sugarbeet tailings

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HIGHLIGHTS

- Thermophilic, non-agitated and agitated digestion showed marked differences in performance.
- Methane yield from agitated digester was 74% of that from non-agitated digester.
- Non-agitated digester produced methane at twice the rate of agitated digester.
- Performance of agitated digester inoculum quickly improved when used in non-agitated digester.
- Agitated digester exhibited a high abundance of hydrogen-producing microbial community.

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ABSTRACT

Sugar beet tailings were anaerobically digested at non-agitated and agitated conditions in identical thermophilic batch reactors. The average methane yield in the agitated digester was only 74% of that in the non-agitated digester. Ninety percent of the ultimate methane yield was produced in approximately 5 days in the non-agitated digester whereas it took 12 days in agitated digester. Even upon using an active inoculum from non-agitated digester the methane rate and yield was low in the agitated digester. On the other hand when the poorly performing inoculum from the agitated digester was transferred to the non-agitated digester, its activity was immediately enhanced. The non-agitated digester harbored a diverse microbial community with phylotypes *Methanoculleus* and *Methanosarcina* being dominant methanogens. *Methanosaeta* was the only methanogen detected in the agitated digester. It also contained a hydrogen-producing bacterial phylotype *Petrotoga* in high proportion which was not detected in the other digester.

1. Introduction

Sugar production from sugarbeets generates significant quantities of both solid (tailings, spent beet pulp) and liquid (raffinate, wastewater) organic wastes and by-products. Raw sugar beets are first washed and separated from "tailings" which mainly consist of pieces of beets, weeds, sugar beet tops, debris and soil held by sugar beets when harvested. These sugarbeet tailings were used as the model substrate for experiments reported in this paper. It has been shown that this feedstock was efficiently and rapidly digested in a thermophilic, non-agitated batch system, provided the tailings are adequately bulked during digestion and a method of removing the rapidly solubilizable fraction was implemented (Polematidis, 2007; Liu et al., 2006). To prevent compaction and flotation of the tailings in a non-agitated digester it was necessary to bulk with a bulking agent (Polematidis, 2007). Otherwise compaction of the bed adversely impacted digestion performance as it prevented contact between tailings and microorganisms, and trapped biogas within the bed causing liquid to be expelled followed by bed flotation. In large scale digestion systems it would be expensive and cumbersome to introduce, recover and reuse bulking materials and so may not be a viable option. Another approach would be to mix digester contents so as to keep the tailings dispersed preventing compaction and flotation. Thorough agitation of digester contents also helps particle size reduction and evolution of biogas, distributes microorganisms and nutrients uniformly, and improves mass and heat transfer; therefore is regarded as essential for high rate anaerobic digestion.

Agitation is usually accomplished by mechanical mixers, slurry recirculation or biogas recirculation (Karim et al., 2005). The significance of agitation in anaerobic digestion has been reported in many studies (Hoffmann et al., 2008; McMahon et al., 2001; Stroot et al., 2001; Vavilin and Angelidaki, 2005). Factors effecting agitation

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include agitation strategy (continuous or intermittent), duration and intensity. Observations have been contradictory with regards to the effect of agitation intensity on anaerobic digestion. While some studies showed agitation improved biogas production (Kaparaju et al., 2008; Karim et al., 2005; Vavilin and Angelidaki, 2005), opposite results were reported by others (Chen et al., 1990b; Vedrenne et al., 2008). Agitation at high intensity was shown to result in delayed methane production (Vavilin and Angelidaki, 2005) whereas no significant difference was found in methane production for digesters within a broad range of agitation intensity (Hoffmann et al., 2008). In spite of these disagreements, most studies tended to agree that anaerobic digestion process could be disrupted by excessive agitation while it may benefit from moderate agitation. The negative effect caused by intense agitation was interpreted as being due to high shear forces disrupting microbial floc structures and disturbing syntrophic relationship between bacteria and methanogens (Kaparaju et al., 2008; McMahon et al., 2001; Stroot et al., 2001; Vavilin and Angelidaki, 2005). Investigations into the effect of agitation have been previously conducted on slurry wastes such as animal manure where the degradable components are mostly in soluble form. Studies have not conducted to investigate the effect of agitation on solid wastes like sugarbeet tailings.

The objective of this study was to evaluate and compare anaerobic digestion of sugar beet tailings at non-agitated and agitated conditions. The experiments were carried out in parallel in two identical single-stage batch digesters operated at thermophilic temperature (55 °C). Tailings in the non-agitated digester were added with bulking agents whereas contents of the agitated digester were agitated continuously at low-speed. Digestion performance at both conditions, including methane yield, methane production rate, methane composition and soluble chemical oxygen demand (sCOD) concentration were measured and compared. The microbial community structure in the systems were also studied by comparative analysis of bacterial and archaeal 16S rRNA and the major microbial phylotypes were identified.

2. Methods

2.1. Feedstock

Sugar beet tailings were obtained by American Crystal Sugar Company, Minnesota and stored at 4 °C before the experiment. The tailings were washed several times with tap water to remove residual sugars on the surface. Wash water was discarded.

2.2. Anaerobic digesters

Two identical anaerobic digesters (digester 1 and 2) were constructed by modifying 5 L Pyrex glass bottles. The digester was sealed on top with a glass lid fitted with a rubber ring. The lid was clamped using a stainless steel clamp for gas tightness. The height and inner diameter of the digester were 0.406 m and 0.061 m, respectively. The digester lid was provided with several ports for gas withdrawal and biogas exhaust. A port was provided at the bottom for liquid withdrawal. Biogas production was measured by a positive displacement gas meter, which consists of a clear PVC U-shaped tube filled with anti-freeze solution, a solid state time delay relay (Dayton Off Delay Model 6X153E), a Grainger float switch, a Redington counter and a Fabco Air solenoid valve (Koppar and Pullammanappallil, 2008). The gas meter was calibrated in line to determine the volume of biogas per count.

2.3. Experiment description

The study was carried out in two sets, consisting of six experimental runs each, which were conducted in succession with digester liquor from a previous run being used to initiate the next run, as shown in Fig. 1. In all experiments Digester 1 was non-agitated whereas Digester 2 was agitated. At beginning of a run, 0.3 kg of washed sugar beet tailings on a wet weight basis was added into Digester 1 along with 2 kg bulking materials (lava rocks from a landscaping supplier, 0.025 m average diameter). Three layers of tailings and bulking materials were alternatively placed in Digester 1 in the following manner: tailing-rock-tailing-rock-tailing-rock. The same amount of washed sugar beet tailings (0.3 kg on a wet weight basis) was digested in Digester 2. A 50.8 × 9.5 mm PTFE coated polygon magnetic bar was placed in the digester and its contents were agitated by using a large volume magnetic stirrer (Scienceware Cool Stirrer). The agitation speed was set at 100 rpm. This was the minimum speed required to keep the tailings dispersed and suspended. Both digesters were kept in a 55 °C chamber throughout the experiments. Each run was terminated when the biogas production dropped to as low as 100 mL/day. At the end of each run the digesters were emptied and washed thoroughly. Digester liquor was filtered in a 0.1 cm sieve. Sugar beet tailings residue were discarded, and filtered liquor was saved for next run. The variable in each run was the nature of inoculum that was used to initiate the run.

Three experimental runs were conducted in set 1. In Run 1, each digester was inoculated with 3 L inoculum taken from a thermophilic anaerobic digester that had operating with desugarized molasses as feed for over 2 years. Digester 1 and 2 liquor at the end of Run 1 were mixed and then divided into equal 3 L portions and used as the inoculum for Run 2. For inoculating Run 3, digester liquor at the end of Run 2 was exchanged, that is Digester 1 was inoculated with Digester 2 liquor and Digester 2 was inoculated with Digester 1 liquor. Digester liquors at the end of Run 1 were mixed to keep identical the inoculum fed into the digesters so to confirm the effect of digester agitation on its performance. So both Digesters 1 and 2 in each run would have received identical inoculum. Digester 1 and 2 liquors were exchanged at the end of Run 2 so as to observe the effect of agitated digester inoculum performance under non-agitated conditions and vice versa. Additional three experimental runs were conducted in set 2. Digester 1 liquor that was recovered from Run 3 was diluted by an equal volume of deionized water. The diluted Digester 1 liquor was then divided equally and used to inoculate Digesters 1 and 2 for Run 4. At the end of Run 3 it was observed that Digester 1 performed better than 2, so an active inoculum was used to initiate subsequent runs. Once again the inoculum used to initiate Run 4 in Digesters 1 and 2 was identical. In Run 5 and 6, there was no exchange or mixing of digester liquors. Liquor from digester 1 was used to inoculate digester 1 in the next run. The same procedure was applied to digester 2. Each experimental run operated for 15–20 days.

A large-volume magnetic stirrer was used to provide agitation in Digester 2. In this equipment, the stirrer motor came insulated to prevent the heat from motor from being transmitted to the solution. Dry runs with temperature monitoring before the start of the experiments as well as at the conclusion of experiments described above were conducted to ensure that digesters were maintained within the appropriate temperature range. Three thermometers were used to measure the temperature in the incubator, in Digester 1 and in Digester 2. Temperatures were recorded periodically, sampling time ranging from minutes to hours over a period of a week. It was confirmed that there was no noticeable difference between digester 1 and digester 2 temperature profile. Temperatures in Digester 1 and 2 were maintained between 50 °C and 54 °C.

2.4. Chemical analysis

Total Solids (TS) and Volatile Solids (VS) contents were determined for sugar beet tailings. Tailing samples were dried at