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Short Communication

Effects of mechanical treatment of digestate after anaerobic digestion on the degree of degradation

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HIGHLIGHTS

- Study of the influence on digestion residues treatment on the degradation degree.
- Clearly comminution of the particle size through mechanical treatment.
- No loses of volatile fatty acids through warming by the treatment.
- The mechanical digestate treatment lead to a triplication of the methane yield.
- The mechanical treatment leads to a faster degradation.

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ABSTRACT

The aim of this study was to increase the biogas production from different substrates by applying a mechanical treatment only to the non-degraded digestate after the fermentation process in order to feed it back into the process. To evaluate this approach, digestates were grounded with a ball mill for four different treatment time periods (0, 2, 5, 10 min) and then the effects on the particle size, volatile organic substances, methane yield and degradation kinetic were measured. A decrease of volatile fatty acids based on this treatment was not detected. The mechanical treatment caused in maximum to a triplication of the methane yield and to a quadruplicating of the daily methane production.

1. Introduction

The anaerobic conversion of organic material into biogas occurs in four microbial process steps (hydrolysis, acidogenesis, acetogenesis and methanogenesis) (Veeken et al., 2000). However, the anaerobic degradation of lignocellulosic rich substrates, which consist mainly of cellulose, hemicellulose and lignin, limits the hydrolysis step and thereby also the overall process efficiency (Bruni et al., 2010a; Jin et al., 2009). Different studies show that the rate of hydrolysis depends on the following factors: of particles' size and particles' surface (Veeken and Hamelers, 1999; Hills and Nakano, 1984). Pretreatment of lignocellulose rich substrates for the enhancement of the methane yield before anaerobic digestion is the subject of much scientific research (Mönch-Tegeder et al., 2014a; Carlsson et al., 2012; Taherzadeh and Karimi, 2008). The main effects of substrate pretreatment are the reduction of particle size, the solubilisation of organic material and the improvement of biodegradability. But intensive pretreatment can also lead to a formation of resistant compounds and losses of organic material (Carlsson et al., 2012). The pretreatment methods can be generally classified as chemical, biological, physical or combinatorial pretreatment (Agbor et al., 2011).

According to Carlsson et al. (2012), chemical pretreatment is the most investigated technique for the lab-scale pretreatment of energy crops and harvesting residues. A batch experiment with barley waste showed an 88% increase of the methane yield by a chemical pretreatment with sodium hydroxide (Neves et al., 2006). However, continuously feeding reactors with alkaline treated materials can lead to a decrease in acetate and glucose degradation rates due to inhibition by the saponification reaction (Mouneimne et al., 2003). High costs for the chemicals and the investments for prerequisite equipment are also an obstacle for the adaption of chemical pretreatment at full-scale biogas plants (Cesaro and Belgiorno, 2014).

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The effect of biological pretreatment on the methane yield is discussed controversially in literature. Applying enzymes to wheat grains before anaerobic digestion led to an enhancement of 7–14% on the methane yield (Sonakya et al., 2001). Also Romano et al. (2009) investigated the biological pretreatment with enzymes before anaerobic digestion of wheat grass. In contrast to the findings of Sonakya et al. (2001), the addition of enzymes to the digester did not have a significant influence on the specific methane yield or on the degradation rate.

Mechanical pretreatment techniques like milling, grinding, crushing or chopping are already available for the full-scale biogas process (Lindmark et al., 2012). The effects on the gas yields through mechanical treatment depend generally on the material properties and the technique used (Lindmark et al., 2012). An increase of the biogas yield of up to 20% by mechanical pretreated sunflower seeds and hay with a cutting mill was described by Palmowski et al., 2001. Another batch investigation with treated ley crop silage by a disperser resulted in an enhancement of the methane yield by 40% after 36 days of digestion (Lindmark et al., 2012). Different full-scale studies on the mechanical pretreatment of manure showed an increase in the specific methane yield of up to approximately 25% (Mönch-Tegeder et al., 2014a; Hartmann et al., 2000). In general, mechanical treatment of organic material leads to a reduction in particle size and produces a larger surface area, which provides a high contact area for the microorganisms and thus resulting in enhanced biogas yields (Lindmark et al., 2012; Sharma et al., 1988).

In comparison to the chemical and thermochemical methods, the main advantage of the mechanical treatment is no toxic and inhibitory byproducts are produced during the disintegration step (Hendriks and Zeeman, 2009). The main disadvantage of the mechanical pretreatment is the additional energy yield may be lower than the supplied energy for the disintegration system (Mönch-Tegeder et al., 2014b; Hendriks and Zeeman, 2009; Kratky and Jirout, 2011). Another detrimental effect is the warming of the substrate during the treatment, which can result in a loss of volatile organic substances and thereby reduce the methane potential (Carlsson et al., 2012).

To address the negative effects of a pretreatment, the aim of this study was to apply the mechanical treatment only to the non-degraded digestate after the fermentation process in order to feed it back into the process. This should lead to poor losses of volatile organic materials and lower energy consumption due to low organic acid content of the digestate and the small quantity of non-degraded fibers compared to the initial substrates. As this is a quite new topic in literature, the aim of the lab scale experiment was to figure out whether this "intermediary-treatment" has any positive effects on methane yields. To evaluate this approach the digestion residues of a one-phase, full-scale and a two-stage laboratory biogas plant were mechanically treated at four different intensities with a ball mill and the specific methane yield was subsequently measured in a batch test. The ball mill is a robust treatment technology with low energy consumption and a high efficiency for lignocellulosic treatment (Kratky and Jirout, 2011). In addition to the specific methane yields, the study also investigated the warming and the losses of volatile fatty acids in the digestate by the treatment, as well as the effects on the comminuting intensities and on the degradation kinetics.

2. Methods

2.1. Sample material

The investigations of this study are based on separated digestates from the research biogas plant of the University Hohenheim described in detail by Lemmer et al. (2013), and on the digestate of the acidification reactor of a two-stage laboratory biogas plant. The construction, flow and mass schemes of the research biogas plant have been described by several authors (Lemmer et al., 2013; Naegele et al., 2013). The two-stage biogas plant is described by Lindner et al. (2014). The process parameters of the biogas plants are presented in Table 1.

The full scale biogas plant was fed daily with 15.000 kg fresh matter with a mixture of 43.9% liquid manure, 9% solid manure, 19% maize silage, 21.4% grass silage and 6.8% grain. The two-stage biogas plant was fed in two different experiments with a hay/straw (50/50) mixture and maize silage. After the digestion, the liquid and solid residues were separated with a screw separator at the full scale biogas plant and by a spindle press at the two-stage plant. The properties of the digestates are shown in Table 2.

2.2. Mechanical treatment

The digestates were ground with a ball mill PULVERISETTE 6 in combination with a 500 ml grinding bowl made of sintered corundum and eight balls of 30 mm diameter, (Fritsch GmbH, Idar-Oberstein, Germany) with four different treatment time periods: 0, 2, 5, and 10 min. The rotational speed of the grinding bowl was 500 min^{-1}. From each sample, 600 g material was ground in four milling cycles with 150 g each. After milling, the whole sample was mixed and filled in different sample bottles for analyses. The temperatures of the samples were measured before and after milling with the portable thermometer GTH 1160 (Greisinger electronic GmbH, Regenstauf, Germany). Each digestate was milled with two repetitions.

2.3. Wet sieving analyses

To analyze the effects of the comminution intensity on the particle size a wet sieving with the vibrating sieve shaker Analysette 3 SPARTAN (Fritsch GmbH, Idar-Oberstein, Germany) was used. The sieve cascade consisted of eight test sieves according to ISO 3310-1 (diameter 200 mm, height 50 mm) with increasing mesh sizes (0.063 mm, 0.125 mm, 0.25 mm, 0.5 mm, 1 mm, 2 mm, 4 mm and 6.3 mm). At first, 100 g of the sample material was soaked with one liter distilled water for at least one hour. Afterwards, the sample was applied to the topmost sieve and then sieved for ten minutes, with a distilled water flow of approximately 2.9 l min^{-1} and an amplitude of two. Each sieve was then transferred to a paper folded filter MN 615 (Machery-Nagel GmbH & Co. KG, Düren, Germany). The dry tare weight of the filters and the dry weight of the filled filter were determined by drying for 24 h at 80 °C. Each probe was analyzed in triplicates.

2.4. Batch digestion test

The determination of the biogas and methane yields was conducted by using the "Hohenheimer Biogas yield Test" (HBT). This is a highly reproducible batch digestion test according to the VDI

Table 1
Process parameters of the full scale biogas plant and acidification reactor of the two-stage biogas plant.

Process parameters	Full scale	Two-stage
Plant type	Full scale	Lab scale
Digesters volume (m^3)	3 × 923	0.114
Temperature (°C)	40	60
pH-value	8.5	5.75
Retention time (d)	160	24.5
Organic loading rate (kg m^{-3} d^{-1})	5.1	7.5