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Enhanced anaerobic digestion by ultrasonic pretreatment of organic residues for energy production

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A B S T R A C T

This study is aimed at assessing the improvement of anaerobic digestion yields produced by the ultrasonic pretreatment of solid organic substrates.

The possibility of enhancing methane production from anaerobic digestion of organic residues is particularly interesting. To this end, application of pretreatments represents one of the most suitable options. Among pretreatments, sonolysis arises as a novel technology, whose effectiveness is related to the occurrence of cavitation phenomena. They promote the solubilisation of organic matter, thus increasing the amount of substrate that can be converted into methane.

The application of ultrasound as pretreatment of sewage sludge for biological processing has been extensively studied and full-scale facilities have already been established.

However, ultrasonic pretreatment of solid organic substrates has not yet been actioned as its effectiveness is highly influenced by process conditions.

Experimental results show that ultrasonic energy inputs in the range 31–93 W h/L enhanced biogas production from differently composed substrates up to 71%. The highest increase was found for lignocellulosic-based materials and was related to improvements in solubilisation. Conversely, a lower biogas enhancement, in the range 3–23%, was found for protein-rich substrates. In this case, any relevant variation in soluble COD was observed after ultrasonic pretreatment.

Thus, dependent upon the specific substrate composition, the relationship between solubilisation and anaerobic biodegradability was found to differ significantly and this evidence represents a key point for scaling up of the combined ultrasonic/anaerobic digestion process.

1. Introduction

In Europe, energy consumption increased by 3.3% in 2010, compared to 2009 (EU, 2012). Most of this energy came from crude oil and petroleum products, which accounted for 35% of the total energy consumed in 2010. A slight reduction in the use of these products was observed with reference to the previous year, as a result of European strategies directed towards the promotion of sustainable energy production.

In this context, anaerobic digestion represents an interesting option for the conversion of biomass to energy (Arafat et al., in press; Menikpura et al., 2013). The process consists of the biological degradation of organic matter in the absence of oxygen, to create a methane-rich biogas that can be used to produce energy.

The substrates characterised by high level of biodegradable materials are the most suitable for anaerobic processes (Banks and Zhang, 2010).

Anaerobic digestion is a well-established technology for the recovery of clean energy from solid organic waste (Cesaro et al., 2010) and the current interest is directed towards process optimisation in order to maximise the methane production (Siles et al., 2013).

Several studies (Carlsson et al., 2012) suggest that ultrasound (US) application can positively affect anaerobic digestion through the occurrence of acoustic cavitation phenomena. These phenomena promote the physical disintegration of organic matter or the

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extraction of substances (Neis et al., 2001) along with the enhancement of enzymatic activity (Banduch, 2011; Xie et al., 2009): as a result, an increase in biogas production can be pursued.

The ultrasound-improved anaerobic digestion has been largely applied for sludge treatment (El-Hadj et al., 2007; Naddeo et al., 2009; Tiehm et al., 2001) and full-scale applications have already been tested (Hogan et al., 2004; Neis et al., 2012).

However, the spread of this technology to differently composed organic substrates has been limited, mainly due to the variability of its yield (Pilli et al., 2011). Indeed, several factors influence the extent of the sonolysis effects: the predominance of each one during the sonication as well as their role on the disintegration mechanisms still need to be clarified, especially when ultrasound is applied to solid organic residues.

This work is aimed at evaluating the effectiveness of the ultrasound-improved biodegradability of different organic matrices, in order to assess the influence of substrate composition on the combined process.

To this end, both OFMSW (Organic Fraction of Municipal Solid Waste) digestate and DDGS (Dried Distilled Grains with Solubles) were investigated.

OFMSW digestate originates from the anaerobic treatment of OFMSW and is characterised by a high biogas potential due to the presence of residual and undigested volatile solids (Menardo et al., 2011). The anaerobic processing of OFMSW digestate represents an interesting option (Fantozzi and Buratti, 2011) to take advantage of its residual energetic potential and to reduce the amount to handle after the treatment. However, the organic matter contained in OFMSW digestate is lignocellulosic-based (Hartmann et al., 2000) and hence not readily degradable by bacteria. Therefore, a suitable pretreatment is required to improve its biological degradability.

DDGS is a bio-ethanol fermentation by-product, characterised by a prevailing protein content. Its anaerobic treatment is being regarded as a valuable strategy to produce methane (Taheripour et al., 2010), then used to produce energy. This could reduce energy consumption of bio-ethanol production process, thus making it economically competitive with petroleum fuel production (Gonela and Zhang, 2014). Therefore, in this study, both raw DDGS and its residue from anaerobic digestion were investigated.

Experimental activity was carried out under the hypothesis that anaerobic digestion yield improvement is directly related to the solubilisation promoted by ultrasound, which determines an increase in the amount of readily digestible materials. Therefore, anaerobic biodegradability tests followed the evaluation of organic matter solubilisation provided by ultrasonic treatments performed under different operating conditions.

2. Materials and methods

2.1. Substrate and inoculum

Experimental work was carried out using the organic fraction of municipal solid waste (OFMSW) digestate, as lignocellulosic material and dried distilled grain with solubles (DDGS), as protein-rich substrate.

The digestate was sampled at the OFMSW anaerobic digestion plant in Luebeck (Germany) and was characterised by a total solid content (TS) of 2.5% (±0.01).

The DDGS was produced by the Südzucker bio-ethanol plant in Zeitz (Saxony-Anhalt, Germany), where it is sold as Protigrain®, a certified animal feed for cattle, pigs and poultry.

The DDGS showed a TS content of 93.00% (±0.02) and a protein content as reported in Fig. 1.

The digested DDGS was collected from a bench scale anaerobic fermenter using Protigrain® solution as feeding material. The

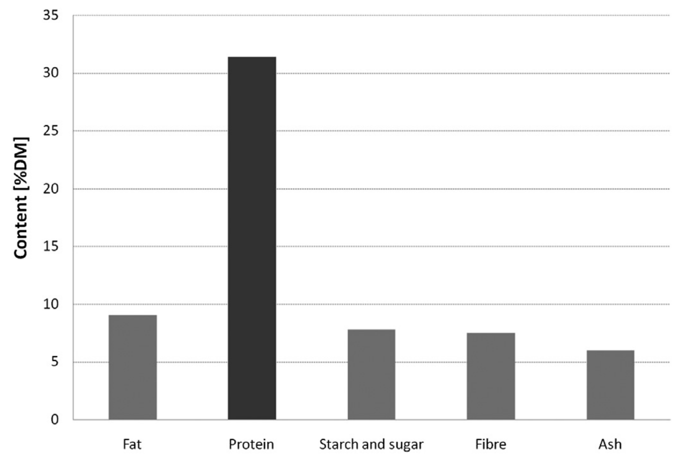

Fig. 1. Protigrain® composition.

related anaerobic process was operated with a loading organic rate of 5 g VS/(L d) and a retention time of 7 d; the resulting digestate was characterised by a dry matter content of 1.69% (±0.01).

The optimal condition for ultrasonic treatment requires a substrate with a TS value ranging between 5 and 10%. Therefore the dry matter content of both OFMSW and DDGS digestates was adjusted by centrifugation at 10,000 rpm for 15 min.

Conversely, raw DDGS was milled and used to prepare a 5% TS solution.

The inoculum for biological tests was thickened digested sludge (Radnige and Clarke, 2007), sampled at the municipal wastewater treatment plant in Hamburg (Germany) and incubated at 35 °C for 5 d ahead of experimental start up. The incubation step was necessary to reduce sludge own gas production. The inoculum was characterised by an average total solid (TS) content of 3.1% (±0.2) and a volatile solid (VS) content of 62.1% TS (±3.2).

2.2. Experimental set up

2.2.1. Ultrasonic unit

Ultrasound technology was applied using the low frequency (20 kHz) sonication unit developed by Ultrawaves GmbH (Hamburg, Germany).

The system consisted of a sonotrode coupled to a generator, characterised by 1 kW nominal power. The power released to the sample was displayed on an energy counter attached to the power source and it was recorded every 15 s, in order to calculate energy input. The instrument amplitude was set to 100%, according to company recommendation and samples were sonicated for 5, 10 and 15 min. The volume of substrate treated in each test was 800 mL. Therefore, average energy inputs of approximately 30, 60 and 90 W h/L were provided.

Each test was performed in a 1000 mL cylindrical beaker with the US sonotrode placed at the centre and immersed up to 2 cm. The substrate was continuously stirred so as to avoid precipitation of solids to the bottom of the reactor.

Table 1
US treatment conditions.

Energy [W h/L]	Specific energy [kJ/kg TS]		
	OFMSW digestate	DDGS	DDGS digestate
31	2102 ± 21	2835 ± 63	2264 ± 4
62	4219 ± 40	5630 ± 122	4581 ± 59
93	6291 ± 95	8493 ± 252	6858 ± 46