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Anaerobic co-digestion of sewage sludge and sugar beet pulp lixiviation in batch reactors: Effect of temperature

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HIGHLIGHTS

- Methane productivity is higher under a mesophilic than thermophilic regimen.
- Sugar beet pulp lixiviation (SBPL) improves cumulative net methane generation.
- Several sludge/SBPL ratios were tested in biochemical methane potential assays.
- Initial volatile fatty acid (VFA) content of inocula affects BMP test results.
- High VFA content reduces microbial activity.

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ABSTRACT

The feasibility of anaerobic co-digestion of sewage sludge (SS) and sugar beet pulp lixiviation (SBPL) was assessed. Mesophilic and thermophilic batch assays of five different SS/SBPL ratios were used to investigate the effect of temperature, providing basic data on methane yield and reduction in total volatiles. Microbe concentrations (Eubacteria and methanogenic *Archaea*) were linked to traditional parameters, namely biogas production and removal of total volatile solids (TVS). The relationship between Eubacteria and *Archaea* was analysed.

Given equal masses of organic matter, net methane generation was higher in the mesophilic range on the biochemical methane potential (BMP) test. Methane yield, TVS removal data and high levels of volatile fatty acids provided further evidence of the best behaviour of the mesophilic range. At the end of testing the microbial population under of the reactors consisted of Eubacteria and *Archaea*, with Eubacteria predominant in all cases.

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1. Introduction

It is essential to develop sustainable energy supply systems to meet the demand for energy from renewable sources. Reducing greenhouse gas emissions by increasing production of renewable energy production is increasingly important. Biogas production technology is critical to the sustainable use of biomass as a renewable energy source. Biogas can be produced from a wide range of energy crops, animal manures and organic wastes and therefore offers a flexible source of energy which can be adapted to the specific needs of different locations and farming styles. The residues of anaerobic digestion are a valuable fertiliser for agricultural crops.

Anaerobic digestion is a biological process in which a group of micro-organisms biodegrade organic matter (substrate) in the absence of free molecular oxygen (O_2). This complex biological process converts organic matter into a mixture composed mainly of methane (CH_4), carbon dioxide (CO_2) and new bacterial cells (Romano and Zhang, 2008). Complete bioconversion of organic matter into stable end products is accomplished by a series of interdependent metabolic reactions involving several classes of micro-organisms.

The efficiency of anaerobic digestion is highly dependent on the characteristics of the waste, the reactor configuration and other operational parameters. The temperature, organic strength, buffering capacity and solid and nutrient content of the waste are important influences on anaerobic biodegradation. Waste can be treated to improve its digestibility.

Assay of biochemical methane potential (BMP) is a procedure developed to determine how much methane is produced by anaerobic decomposition of a given organic substrate. BMP assay has proved to be a relatively simple, reliable method for determining the extent and rate at which organic matter is converted to methane (Chynoweth et al., 1993).

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Co-digestion can be used to enhance anaerobic degradation of wastes with certain characteristics. Anaerobic co-digestion is the synergistic simultaneous biodegradation of different wastes (Mata-Alvarez et al., 2000). The merits of co-digestion include creation of a suitable nutrient ratio, dilution of potentially toxic compounds (Sosnowski et al., 2003), provision of buffering capacity (Mshandete et al., 2004), equipment sharing, establishment of the required moisture content and easier waste-handling (Mata-Alvarez et al., 2000). Anaerobic co-digestion is also advantageous if the amount of a given waste generated at a particular site is not sufficient to make anaerobic digestion cost effective (Parawira et al., 2004). There have been numerous studies of anaerobic co-digestion of various wastes including food industry wastes (Carucci et al., 2005; Murto et al., 2004), animal manure (Gungor-Demirci and Demirer, 2004), municipal solid waste (Zupancic et al., 2008), waste water sludge (Romano and Zhang, 2008), fish wastes (Mshandete et al., 2004) and algal sludge (Yen and Brune, 2007); most showed a remarkable improvement in both treatment efficiency and biogas production in comparison with single-waste anaerobic digestion.

Both thermophilic and mesophilic co-digestion regimes have been used successfully, making the technique more flexible than conventional anaerobic digestion.

Methane is formed over a wide range of temperatures; however anaerobic digestion processes are highly temperature dependent. Most BMP assays have been performed at mesophilic temperatures. Both pH and temperature have a marked effect on the rate of growth and the composition of the micro-organism population during the digestion process (Callaghan et al., 1999).

The majority of methanogens (micro-organisms that produce methane from organic matter) are mesophiles, growing quickly and converting a higher proportion of organic matter in the mesophilic temperature range. Mesophilic systems are more stable than thermophilic systems, which has implications for the design of biogas plants. The stability and growing conditions in a mesophilic digester make the process more balanced, more resistant to chemicals that inhibit digestion (e.g. ammonia) and also more capable of treating a variety of types of biomass and waste.

Only a minority of methanogens are thermophilic, preferring higher temperatures. Reaction rates are higher in a thermophilic system and the microbial population grows faster. This means that thermophilic digesters can be smaller (which means lower manufacturing costs) whilst maintaining very high biogas yields. Thermophilic anaerobic digestion also destroys a higher proportion of the pathogenic bacteria present in organic wastes.

Despite the advantages of the thermophilic process most biogas plants continue to use mesophilic anaerobic digestion systems. This choice can be justified on the grounds that it is more difficult to control and optimise the thermophilic process. Thermophilic methanogens are extremely sensitive to changes in the environment for anaerobic digestion; even a small change in operating parameters can have a negative impact, for example changes of more than 1–2 °C in temperature greater significantly reduce biogas yield. Anaerobic thermophilic conditions are suitable for a smaller range of waste materials than mesophilic conditions, mainly because of the chemical composition of wastes and the greater impact of certain digestion inhibitors on the digestion process.

Anaerobic co-digestion converts the organic fraction of sewage sludge (SS) and sugar beet pulp lixiviation (SBPL) to methane and carbon dioxide. It involves coordinated action of several groups of micro-organisms and is a multi-stage process. The outputs of the intermediate stages are volatile fatty acids (VFAs): acetic acid, propionic acid and butyric acid. The conversion of acetate to methane by methanogenic bacteria is the limiting step in the production of biogas as known methanogens grow slowly meaning that populations remain relatively small (Zinder, 1993). Methanogens are typically divided into two main groups based on their substrate conversion capabilities. Acetoclastic methanogens convert acetate into methane and carbon dioxide; they are the primary methane producers: about 70% of the methane produced in digesters comes from acetate (Zinder, 1993). Methanogenic bacteria which use H_2 also play a critical role in anaerobic digestion since they are responsible for maintaining the partial pressure of H_2 at the very low level (<10 Pa) required by the intermediate group, which is responsible for the conversion of organic acids and alcohols to methane (Pauss et al., 1990).

In this study anaerobic batch reactors were used to determine the anaerobic biodegradation and biogas generation potential (Owen et al., 1979) of SS and SBPL. Both substrates were subjected to anaerobic biodegradation in batch reactors. Sugar beet pulp is a waste product of sugar beet processing plants and is known to be suitable for biological degradation so this study investigated the potential benefits of co-digesting SS and SBPL as well as separate digestion of these wastes. This study was also the first systematic investigation of the effects of variations in temperature on anaerobic digestion of SS and SBPL.

Abbreviations	
BMP	biochemical methane potential
OLR	organic loading rate
COD	soluble chemical oxygen demand
CODt	total chemical oxygen demand
H-Ac	acetic acid
H-Bu	butyric acid
H-Pr	propionic acid
TS	total solids
TVS	total volatile solids
VFA	volatile fatty acid
SS	sewage sludge
SBPL	sugar beet pulp lixiviation
Series 1	assays under thermophilic conditions
Series 2	assays under mesophilic conditions
1-i	inoculum series 1
1-1	100% SBPL series 1
1-2	75% SBPL-25% SS series 1
1-3	50% SBPL-50% SS series 1
1-4	25% SBPL-75% SS series 1
1-5	100% SS series 1
2-i	Inoculum series 2
2-1	100% SBPL series 2
2-2	75% SBPL-25% SS series 2
2-3	50% SBPL-50% SS series2
2-4	25% SBPL-75% SS series 2
2-5	100% SS series 2
Subscripts	
t	total
s	soluble

2. Methods

2.1. Feedstock

The substrates used in the tests were sugar beet pulp, from Azucarera Ebro company in Jerez de la Frontera (Cádiz), and SS from the municipal waste water treatment plant of San Fernando-Cádiz (Spain). Sugar beet pellets were subjected to physical pre-treatment before the co-digestion process to promote hydrolysis and solubilisation of the organic matter and thus improve anaerobic digestion, biogas yield and possibly also the agronomic value of the final residue (Montañés et al., 2013).

2.2. Inoculum

In both series of tests primary sludge from the San Fernando-Cádiz waste water treatment plant was used as the inoculum.

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