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Improvement of anaerobic digestion of swine slurry by steam explosion and chemical pretreatment application. Assessment based on kinetic analysis

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ABSTRACT

Swine slurry is generated in large quantities and anaerobic digestion may represent an appropriate process to both treat and revalue this waste as an energy source. Pretreatment processes aim to increase the anaerobic biodegradability of a specific waste. In this study, steam explosion and weak thermal-alkali pretreatments are evaluated. The first series of Biochemical potential (BMP) test is set to establish the best substrate/inoculum ratio conditions, and then other tests are carried out to assess the impact of these pretreatments on the methane potential and maximum production rate by using the modified Gompertz equation. The S/I ratio exerts an influence on the BMP results and the optimum ratio was found to be between 0.1–0.25 $gVSs\,gVS_I^{-1}$. Steam explosion leads to an improvement of both the methane potential and the maximum production rate at the highest severity conditions. Weak alkali thermal pretreatment improved the maximum production rate but affected negatively the methane potential of the substrate.

1. Introduction

Pig or Swine slurry (PS, hereafter) corresponds to the liquid fraction that comes from the swine pen which comprises cleaning water, urine and animal feces. Due to the large consumption of pork meat, the generation of the waste poses a significant challenge because of the quantity and the complexity of its composition. A single animal may generate up to 20 l of slurry per day which yields a stunning large amount of waste if, in the case of Chile, we consider that there are around 5.5 million heads of pork.

Anaerobic digestion is a consolidated technology especially in Europe, although increasingly in North and South America as well. Recently the Chilean government released a 20/25 plan, which obligates the electric companies to produce 20% of their electricity from non-conventional renewable energy (ERNC) sources for 2025. For this reason the utilization of waste from the agro-industrial sector for energy conversion, such as biogas, is of increasing importance. Problems related to the emissions from PS could be avoided by using anaerobic digestion process, in addition, energy could be produced. Waste to energy with high efficiency values could be achieved thanks to the use of conventional combined heat-power (CHP) units or more efficient technologies, such as, for instance, the Solid oxide fuel cell (SOFC) energy generators [1]. The anaerobic degradation of swine manure has been largely studied at different scales and currently there are several full scale facilities where the biogas is harnessed to produce electricity [2]. PS has been commonly used in combination with another substrate in a co-digestion process in order to balance the C/N ratio of the substrate [3,4].

PS may contain high fractions of fibers and other compounds, which are slowly degraded by anaerobic microorganisms [5]. Several pretreatment techniques have been implemented in order to improve the methane conversion in anaerobic digestion by making complex substrates more accessible to anaerobic biomass. The type of pretreatment technique to choose will depend on the type of feedstock that will be finally anaerobically digested. An up to date list of suggested pretreatment procedures linked to the type of feedstock is provided in Carrere et al. [6]. However, little

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attention has been paid to the pretreatment of PS prior to anaerobic digestion. Almost all the research has been focused on the soft thermal pretreatment of this waste without steam explosion [7] or with steam explosion [8]. Thermal/steam explosion pretreatment has been implemented in full-scale wastewater treatment plants to solubilize sewage sludge because this technology has demonstrated its economical and energetic benefit [9]. Chemical pretreatments, particularly thermal-alkali, which breaks apart the particulate organic matter, especially proteins ester solvation and saponification, has been applied to the solid fraction of PS and high alkali doses were applied, above 0.1 gNaOH or $Ca(OH)_2$ gTS^{-1} [10,11]. The latter entails the incorporation of a dewatering process as well as the high cost of alkali in full-scale installation and an upstream pH adjustment before anaerobic digestion, in other words, an acid addition.

The Biochemical Methane Potential (BMP) test represents the conventional procedure to evaluate anaerobic biodegradability of any substrate fed into anaerobic digesters. The initial ratio between substrate to inoculum, S/I, exerts a significant influence upon the BMP results [12,13]. The optimum S/I of the anaerobic digestion of PS, to our knowledge, has never been studied, and the influence of this ratio is crucial in order to find the optimum conditions for a BMP test. The aim of the study is to evaluate the impact of two pretreatment technologies, steam explosion and weak thermal/alkali, on both the methane production rate and the methane yield in batch conditions from PS at the optimal initial substrate/inoculum ratio.

2. Material & methods

2.1. Inoculum and substrate

Pig slurry samples were taken from the animal protein producer Agrosuper Company located in Corneche Sector, around the city of San Pedro, Chile. The anaerobic inoculum (I), (21.45 ± 0.14 gTS kg^{-1} and 12.42 ± 0.08 gVS kg^{-1}) was obtained from a continuous lab-scale stirred tank reactor maintained in mesophilic conditions and fed with sewage sludge at an OLR of 0.8 KgVS m^{-3} d^{-1}.

2.2. Pretreatments

2.2.1. Steam explosion (SE)

The experiment was carried out in an automatic pilot-scale thermal system located in the Wastewater Treatment Plant (WWTP, Santiago, Chile). This system consisted of a feeding tank, a progressive cavity pump (P_{max} = 12 bar), a steam boiler, a 20 l total volume hydrolysis reactor (working volume = 10 l) connected to a flash tank (V = 10 l) with also outlet pipes for steam and hydrolyzed sludge. The pilot plant is equipped with automatic valves that control the steam entrance from the boiler and the sludge exit from the reactor to the flash. A data acquisition and control system is used to measure pressure and temperature and to automatically control the steam inlet and the hydrolyzed sludge exit to the flash. The pump introduces 10 l of PS into the reactor, and then the steam valve is opened until pressure and temperature reach the set point. At the end of the reaction time, the decompression valve is automatically opened and the hydrolyzed PS flows to the flash tank. The pretreatment conditions applied are shown in Table 1. The equation to calculate the severity factor (R_0) of each evaluated conditions is presented in Eq. (1):

$$LogR_0 = Log\left(t \cdot \exp(\frac{T-100}{14.75})\right) \quad (1)$$

where t represents the time of thermal treatment part (min) and T is the average temperature (°C). It has to be kept in mind that this equation does not take into account the explosion effect but is widely used for data analysis purposes.

2.2.2. Weak thermal-alkali pretreatment (wTA)

Weak-Alkali pretreatment was carried out with two different NaOH solution doses. The pretreatment conditions (time and temperature) were selected according to what has been previously established for this type of pretreatment [14,15]. PS samples were pretreated at different conditions as it is shown in Table 2. Reaction blanks (B) without NaOH solution and blank test without PS addition were prepared. All the tests were carried out in triplicate.

2.3. Biomethane potential test

The biochemical methane potential assay (BMP) was performed according to [16] guidelines. The assay was carried out in a glass bottle with 100 ml working volume. Given the small volume of the BMP test and, consequently, the small amount of substrate and inoculum to be added, both the substrate and inoculum additions were carried out keeping the storage flask stirred continuously in order to assure the homogeneity of the mixture as much as possible. Sodium bicarbonate was added in a 1 g of $NaHCO_3$ per gram of volatile solid of substrate. The initial pH of the assay was adjusted to 7.1 ± 0.1. Blanks were carried out to subtract the biogas produced from the inoculum. All the tests were carried out in triplicate. The temperature of the assay was 37 °C controlled by a thermoregulated chamber. The methane production was measured by liquid displacement using a NaOH solution which absorbs carbon dioxide. The S/I optimum estimation was performed with raw PS. A certain amount of substrate was added in order to have the following S/I ratios: 0.1, 0.25, 0.5, 0.75 and 1 $gVS_S\,VS_I^{-1}$. The inoculum concentration was kept constant at 5 gVS/l. For parameter determination the Modified Gompertz equation (GM) (Eq. (2)), which has been used for methane production [17], was applied

$$B = P \cdot \exp\left(-\exp\left(\frac{Rm \cdot e}{P}(\lambda - t) + 1\right)\right) \quad (2)$$

Table 1
Selected conditions for steam explosion pretreatment.

Notation	Temperature (°C)	Time (min)	Severity Factor
SE1	155	5	2.32
SE2	170	30	3.54
SE3	171	15	3.27
SE4	142	5	1.94
SE5	142	30	2.71
SE6	134	15	2.18
SE7	122	5	1.35

Table 2
Selected conditions for the weak alkali pretreatment.

Condition	NaOH (gNaOH gTS^{-1})	Time (min)	Temperature (°C)
wTA1	0.0045	5	100
wTA2	0.0045	30	100
wTA3	0.0225	5	100
wTA4	0.0225	30	100
wTA5	0.0225	18	35
wTA6	0.0045	18	35
B1-3	–	5	100
B2-4	–	30	100
B5-6	–	18	35