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Semi-continuous co-digestion of solid slaughterhouse waste, manure, and fruit and vegetable waste

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Abstract

The potential of semi-continuous mesophilic anaerobic digestion (AD) for the treatment of solid slaughterhouse waste, fruit-vegetable wastes, and manure in a co-digestion process has been experimentally evaluated. A study was made at laboratory scale using four 2 L reactors working semi-continuously at 35 °C. The effect of the organic loading rate (OLR) was initially examined (using equal proportion of the three components on a volatile solids, VS, basis). Anaerobic co-digestion with OLRs in the range 0.3–1.3 kg VS m^{-3} d^{-1} resulted in methane yields of 0.3 m^3 kg^{-1} VS added, with a methane content in the biogas of 54–56%. However, at a further increased loading, the biogas production decreased and there was a reduction in the methane yield indicating organic overload or insufficient buffering capacity in the digester.

In the second part of the investigation, co-digestion was studied in a mixture experiment using 10 different feed compositions. The digestion of mixed substrates was in all cases better than that of the pure substrates, with the exception of the mixture of equal amounts of (VS/VS) solid cattle–swine slaughterhouse waste (SCSSW) with fruit and vegetable waste (FVW). For all other mixtures, the steady-state biogas production for the mixture was in the range 1.1–1.6 L d^{-1}, with a methane content of 50–57% after 60 days of operation. The methane yields were in the range 0.27–0.35 m^3 kg^{-1} VS added and VS reductions of more than 50% and up to 67% were obtained.

Keywords: Anaerobic; Biogas; Co-digestion; Manure; Slaughterhouse waste; Vegetable waste

1. Introduction

Untreated slaughterhouses waste entering into a municipal sewage purification system may create severe problems, due to the very high biological oxygen demand (BOD) and chemical oxygen demand (COD) [1]. Obviously, this problem is aggravated if the untreated waste directly reaches the recipient, such as for example a river. In the city of La Paz, Bolivia, an estimated volume of 137 m^3 d^{-1} of industrial wastewater (from about 60 cattle and 60 swine slaughtered) is released daily into the Choqueyapu river. This represents a loading of 160 kg BOD and 4.4 tons of solid waste primarily composed of animal ruminal and visceral content [2]. This environmental problem is not unique for the city of La Paz. On the contrary, it is a common problem in many developing countries, which urgently requires a cost-effective solution.

Anaerobic digestion (AD) represents a potential possibility to decrease the environmental burden, and at the same time provide biogas for local energy needs. In addition—in the specific case of treatment of animal waste—the remaining stabilized slurry after digestion may be used as a fertilizer [3]. AD of slaughterhouse waste and animal by-products has recently been considered as an interesting alternative waste management option [4,5]. In Sweden and Denmark, utilization of rumen, stomach and intestinal content, blood waste fraction, and sludge from slaughterhouse wastewater treatment in biogas plants is rather common [4,6–9].

The solid substrates from slaughterhouses mainly consist of untreated blood and the contents of rumen, stomachs and intestines, as well as manure from the delivery hall [4,6]. The digestion of mixed waste consisting of the blood

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and gut fill components in the proportion in which they are produced has shown possible. However, the process is sensitive and prone to failure [5,10]. Most likely, this can be attributed to the accumulation of high levels of free ammonia resulting from the degradation of the nitrogen-rich protein components of blood. Potential inhibition of methanogenic bacteria by ammonia plays a role in almost all media with high nitrogen content wastes, since ammonia is the end product of AD of proteins. The inhibitory concentration of ammonia varies depending on parameters such as origin of inoculum, substrate, pH, and temperature [11–15]. The concentration of uncharged ammonia has been suggested to be the active component causing ammonia inhibition [11,14]. Starting at a value of approximately 700 mg ammonia-N L^{-1}, the maximum specific activity of methanogenic bacteria has been found to decrease with increasing ammonia concentrations [13]. In unadapted methanogenic bacterial sludge, inhibition has been reported at even lower concentration of ammonia (150 mg N L^{-1}) [16]. The possibility of adapting methanogenic bacteria to ammonia has been demonstrated [11–15]. The maximum tolerable ammonia concentration was 6.2 times higher than the initial toxicity threshold level [13].

Co-digestion of slaughterhouse wastes with different co-substrates has been proposed as a solution to the problems mentioned above. The content of nutrients can thereby be balanced, and the negative effect of toxic compounds on the digestion process may be decreased giving an increased gas yield from the biomass. Murto [7] co-digested slaughterhouse waste, pig manure, vegetable waste, and various kind of industrial waste. A highly buffered system was obtained and the process worked well with gas yields of 0.8–1 $m^3\,kg^{-1}$ VS. Edstrom [6] studied mixtures of animal byproducts, slaughterhouse waste (i.e., rumen, stomach and intestinal content), food waste, and liquid manure at 37 °C, at laboratory and pilot scale. Stable processes at organic loading rates (OLR) exceeding 2.5 kg VS $m^{-3}\,d^{-1}$ and hydraulic retention times (HRT) less than 40 d could be obtained with total ammonia nitrogen concentrations in the range of 4 to 5 g L^{-1}. Gas yields obtained were 0.7–0.86 $m^3\,kg^{-1}$ VS.

A particularly important aspect for the digester performance is the C/N ratio [17] and the buffer capacity [7]. Blood and swine manure, for example, both have high nitrogen content, and should preferably be co-digested with waste that has a low nitrogen content. The nitrogen and phosphorus content in fruit and vegetable wastes (FVW) is often low and for this reason it has been used in co-digestions with wastes with higher N and P content [7,18–21]. Continuous co-digestion of cattle slurry with FVWs and chicken manure was tested by Callaghan et al. [18]. When the proportion of FVW was increased from 20% to 50%, the methane yield also increased from 0.23 to 0.45 $m^3\,kg^{-1}$ VS added at a loading rate between 3 and 5 kg VS $m^{-3}\,d^{-1}$ and a hydraulic residence time of 21 days. However, when the proportion of chicken manure in the feed was increased, a deterioration in the digester performance was seen [18].

The composition of slaughterhouse waste varies considerably. In some regions there are centralized and specialized slaughterhouse facilities, processing only one or two animal species, whereas in other regions small slaughterhouses handle many animal species. The technical feasibility of anaerobic co-treatment thus has to be evaluated carefully with respect to the available substrates [4,8]. The goal of the present study was to investigate a semi-continuous and mesophilic wet digestion system processing a mixture of manure, solid slaughterhouse, and FVWs. The substrates were evaluated separately and in mixtures in proportions of 0–100% (VS/VS) of each substrate. Furthermore, the effect of the OLR on methane yield and solid volatile reduction was investigated.

2. Material and methods

2.1. Raw material

The FVW were obtained from the vegetable market, La Paz, Bolivia. Each item of waste was weighed separately before mixing and the composition is specified in Table 1. The material was initially mixed and minced into smaller pieces with an electric mincer before being further

Table 1
Composition of the fruit and vegetable waste used

Waste fraction	Part used as feedstock	Percentage (w/w)[a]
Achojcha (caigua)	Whole rotten fruit	1.9
Banana	Whole rotten fruit	9.2
Carrot	Leaves, roots	1.7
Cassava	Peels, roots, whole plant	4.7
Cucumber	Whole rotten fruit	6.4
Eggplant	Whole fruit	0.8
Grapefruit	Whole rotten fruit	8.6
Green bean	Whole rotten fruit	0.9
Lemon	Whole rotten fruit	6.2
Lettuce	Leaves	1.3
Lime	Whole fruit	3.1
Locoto (Chile pepper)	Whole rotten fruit	7.5
Onion	Exterior peels, leaves	5.9
Orange	Whole rotten fruit	14.0
Pea	Skins	0.7
Peach	Peels	2.1
Pear mellon	Whole rotten fruit	1.9
Peas	Pods, leaves	0.2
Pineapple	Peels of fresh riped fruit	2.4
Potato	Peels	0.8
Pumpkin	Peels, seeds	1.8
Radish	Leaves, whole plant	2.3
Sugar beet	Leaves, whole plant	0.5
Sweet pepper	Whole rotten fruit	5.2
Tangerine	Whole fruit	2.5
Tomato	Whole rotten fruit	4.8
Turnip	Leaves, whole plant	1.5
Watermelon	Whole rotten fruit	1.3

[a]Wet weight basis.