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Impact of thermobaric pre-treatment on the continuous anaerobic digestion of high-fat cattle slaughterhouse waste

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ABSTRACT

Thermobaric pre-treatment of a combination of dissolved air flotation (DAF) sludge and slaughterhouse wastewater was evaluated for performance over 50 days of continuous anaerobic digestion. Continuous digestion was conducted over three phases represented by varying fat, oils and grease (FOG) concentrations and organic loading. In comparison with earlier biochemical methane potential (BMP) investigations using thermobaric treated substrate by Harris, Schmidt and McCabe (Harris et al., 2017) which yielded an 8.32% increase in specific methane production, pre-treated DAF sludge produced negative impacts on digestion under continuous conditions. Average pH was consistently lower by 0.04, and loss of volatile organics during pre-treatment reduced methane yield by 12.1%. H_2S concentration was 56% higher on average with 795 ppm compared with 510 ppm in the controls owing to enhanced protein degradation. Alkalinity was low due to insufficient replacement from the substrate. Fresh substrate containing double the fat content (236 mg/L) and reduced organic loading rate (OLR) caused both control and treatment reactors to fail, highlighting the need for consistent substrate characteristics. Magnesium hydroxide addition effectively recovered both pH and biogas production within digesters rapidly, addressing the underlying complication of insufficient alkalinity contribution by the substrate.

1. Introduction

Low-rate covered anaerobic lagoons (CALs) offer the Australian red meat processing (RMP) industry an attractive wastewater treatment option with the added benefit of capturing methane-rich biogas that can be combusted to offset onsite fossil fuel consumption [2]. The RMP industry produces high-strength, high fat wastewater which has excellent potential for biogas production. In comparison with carbohydrates and proteins which have theoretical methane potentials of 370 and 480 m^3/kg VS, fat has a potential of 1014 m^3/kg VS [3,4], and thereby has the potential to significantly enhance methane yields from AD systems. However, fats also present operational problems, and can reduce the performance of anaerobic digestion (AD) systems [5]. Fat has potential to cause problems such as blockages, foaming, cover damage, reversible inhibition, sludge flotation, and sludge washout [6,7]. Co-digestion and pre-treatment are two avenues of research which work to overcome these problems and increase methane yields [8]. While co-digestion in RMP facilities in Australia has received little investigation, the country is actively pursuing research in this area [9].

Pre-treatment options for FOG-rich substrates typically fall into the categories of thermal, chemical, thermochemical, mechanical, enzymatic and surfactant methods [10]. Harris, Schmidt & McCabe [1] investigated the effects of thermobaric, chemical and thermochemical pre-treatment on dissolved air flotation (DAF) sludge. Under batch digestion, thermobaric pre-treatment demonstrated improvement in methane yield, increasing specific methane production (SMP; mL_N CH_4/g VS) of DAF sludge by 8.32%, achieving equivalent methane yield 4 days earlier than the controls, and completely eliminated lag phase inhibition.

While BMP tests provide good information regarding the amount of methane that can ultimately be produced from a feedstock, these experiments are not entirely representative of industrial scale AD systems [11]. Lab-scale continuous digestion experiments are the next progression from BMP tests which can elucidate further information regarding the digestion of a substrate, and it's suitability for large-scale AD. Lab-scale continuous digestion experiments allow the operator to optimise organic loading rate (OLR) and hydraulic retention time (HRT), while monitoring for the accumulation of potential inhibitory compounds, or the gradual loss of necessary components (i.e. trace elements, alkalinity, etc.) [3]. One of the assumptions that is made with a BMP test, and challenged with continuous digestion experiments, is the

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Table 1
Initial parameters of sludge, and substrate batches.

	pH	TCOD (mg/L)	VS (%)	FOG (mg/L)	TN (mg/L)	VFA (mg/L)
Inoculum	7.12	ND	2.00 ± 0.01	ND	ND	ND
	n = 1		n = 2			
Phase I: Days 0–33						
Control	7.32	7450 ± 134	1.01 ± 0.04	917	86	151 ± 0
Thermal	7.40	7875 ± 502	1.01 ± 0.07	ND	ND	178 ± 0
	n = 1	n = 2	n = 3	n = 1	n = 1	n = 2
Phase II & III: Days 34–49						
Control	7.42 ± 0.25	7034 ± 2.7	0.85 ± 0.03	1886	102	150 ± 1.15
Thermal	7.50 ± 0.26	6989 ± 2.7	0.86 ± 0.05	ND	ND	180 ± 4.04
	n = 7	n = 9	n = 17	n = 1	n = 1	n = 2

Table 2
Substrate mixtures.

Phase	DI water (ml)	Green stream (ml)	DAF sludge (ml)	Total (ml)
I	459	230	11.34	700
II, III	520	173	6.16	700

supply of a substrate of consistent composition, and the impact that this variation has on the digestion process. The chemical and physical composition of wastewater in the RMP industry varies significantly owing to the degree of primary treatment, including the number, size and efficiency of screens, DAF units, contra sheers, screw presses, sterilisation and rendering [12], as well as species slaughtered, seasonal changes, and variation down to the week, day and even between shifts [13].

Although batch investigations provide valuable information, there is often disparity between results obtained from batch and continuous digestion investigations. Schwede, Rehman, Gerber, Theiss and Span [14] thermally treated microalgae and produced a 185% increase in methane yield under batch conditions. However, under continuous digestion, an increase of only 108% was recorded. Similarly, Zhang, Su and Tan [15] measured on average 29% less methane produced from substrate digested in continuous systems when compared with batch systems.

This current study is a progression of work performed by Harris, Schmidt and McCabe [1], and aimed to investigate the impact of thermobaric-pre-treatment on the anaerobic digestion of a combination of DAF sludge and slaughterhouse wastewater during continuous digestion, with respect to methane yield and process stability.

2. Materials and methods

2.1. Inoculum and substrate

The inoculum was anaerobic sludge sourced from a CAL at a local slaughterhouse (Table 1). Sludge was immediately portioned into 6 × 2L continuous stirred-tank reactors (CSTRs), incubated at 37 ± 1 °C for 4 days to allow residual organics to digest.

The substrate was a semi-synthetic combination of distilled water, wastewater collected from the slaughterhouse green stream, and DAF sludge (Table 1), with the intent to limit substrate variability and contribute to a greater C:N ratio. DAF sludge is a concentrated source of FOG residues collected by the DAF process. This material was used for its high FOG content and has a fatty acid composition representative of the fatty material entering the AD system of the red meat processor [1]. Green stream waste is a combination of tripe wash, render, stick water, paunch wash, cattle wash and green wash waste. Green stream waste was diluted to allow for the majority of COD to be contributed by DAF sludge, while attempting to retain some degree of nitrogen to contribute to alkalinity. Both wastewater and DAF sludge were collected as grab samples and immediately returned to the laboratory for storage at 4 °C, and subsequent pre-treatment prior to use. DAF sludge was blended using a 600 W stick blender to improve uniformity prior to portioning into storage containers. Waste components were combined to produce a substrate of 8 g COD/L to allow for an OLR of 1 g COD/L/day while retaining a HRT of 8 days (Table 2).

2.2. Pre-treatment and continuous digestion set-up

Thermobaric pre-treatment of DAF sludge was performed as per Harris, Schmidt & McCabe [1]. Anaerobic reactors were BioProcess Control bioreactor simulator (BRS) reactors (BioProcess Control, Sweden). As described by Strömberg et al. [16], the BRS consists of 5 main parts. Gas from the bioreactors (BR) is measured by a data acquisition instrument (DAI). Information from the DAI is transmitted to the database (DB), and through the website to file storage (FS). The user then accesses this data through the website.

Reactors were operated at a working volume of 1.8 L with a HRT of 8 days. Reactors were fed daily with 225 mL of semi-synthetic substrate, and 225 mL of effluent digestate was recovered for subsequent analysis. Reactors were maintained at 37 ± 1 °C with a thermostatic water bath. Table 3 details the feeding regimes for the reactors. Phase I spanned days 0–32, in which reactors were fed with the first batch of substrate. Phase II spanned days 33–43, in which reactors were fed with a second batch of substrate. Phase III spanned days 44–49, in which reactors were fed with the sec-

Table 3
Operational details of CSTR continued.

Phase	Days	Stirring (hours on/day)[a]	OLR (g COD/L/day)	FOG load (mg/L/day)	$Mg(OH)_2$ (g/ml/day)
I	0–32	20.5	1	115	0
II	33–43	20.5	0.85	236	0.005
III	44–49	23.83	0.85	236	0.005

[a] Stirring interval is 1:5 min on/off.