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Pilot scale anaerobic co-digestion of municipal wastewater sludge with biodiesel waste glycerin

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HIGHLIGHTS

- Co-digestion was tested in 1200 L control and test anaerobic digesters.
- Six glycerin loading rates were applied to the test digester.
- The digesters' methane production, VS removal and COD removal were compared.
- The maximum upper loading limit that did not cause a process upset was identified.

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ABSTRACT

The effect on process performance of adding increasing proportions of biodiesel waste glycerin (BWG) to municipal wastewater sludge (MWS) was studied using two 1300 L pilot-scale digesters under mesophilic conditions at 20 days SRT. The highest proportion of BWG that did not cause a process upset was determined to be 23% and 35% of the total 1.04 kg VS/(m^3 d) and 2.38 kg COD/(m^3 d) loadings, respectively. At this loading, the biogas and methane production rates in the test digester were 1.65 and 1.83 times greater than of those in the control digester which received only MWS, respectively. The COD and VS removal rates at this loading in the test digester were 1.82 and 1.63-fold those of the control digester, respectively. Process instability was observed when the proportion of BWG in the test digester feed was 31% and 46% of the 1.18 kg VS/(m^3 d) and 2.88 kg COD/(m^3 d) loadings, respectively.

1. Introduction

Anaerobic digestion is a widely used process for the degradation and stabilization of organic waste due to its environmental and economical benefits. Direct anaerobic treatment of many industrial organic wastes is not practical because the wastes do not provide sufficient buffering capacity or nutrients to ensure stable operation, particularly at small scales. Conversely, municipal wastewater sludge is a reliable source of micro-nutrients and many municipal facilities do not employ all of the capacity available in on-site anaerobic sludge digesters (Schwarzenbeck et al., 2008). Therefore, co-digestion of industrial organic waste with municipal wastewater sludge allows beneficial use of materials that cannot be digested alone.

The biodiesel production industry generates a large amount of waste glycerin representing about 10% (wt) of the initial raw material (Chi et al., 2007). Annual waste glycerin generation increased rapidly after 2006 and is expected to reach 8.8 billion kg annually by 2015 (Ayoub and Abdullah, 2012). This has led to a surplus of waste glycerin and a dramatic decline in crude glycerin price (Yazdani and Gonzalez, 2007). The lack of an economical purification process for waste glycerin (Slinn et al., 2008), together with the variability of its quality have made the marketing of waste glycerin uneconomical (Robra et al., 2010). Therefore, beneficial disposal methods for waste glycerin have been investigated (Ayoub and Abdullah, 2012; Gu and Jerome, 2010).

Several studies have evaluated the benefits of co-digesting waste glycerin with organic wastes such as municipal solid waste (Fountoulakis et al., 2010), manure and energy crops (Holm-Nielsen et al., 2008) and pig manure (Amon et al., 2006; Astals et al., 2012). Most studies have been conducted at lab-scale. Yet, pilot-scale studies which more closely resemble full scale operating conditions are required to assess several operational parameters.

The objectives of this study were (1) to investigate the effects of increasing the proportion of biodiesel waste glycerin (BWG) mixed with municipal wastewater sludge (MWS) on pilot-scale anaerobic digester performance with respect to methane production, total

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Nomenclature

MWS	municipal wastewater sludge
BWG	biodiesel waste glycerin
$COD_{removed}$	removed chemical oxygen demand (g/L)
COD_{added}	added chemical oxygen demand (g/L)
GPR	Gas production rate (m^3 biogas/m^3 d)
MPR	Methane production rate (m^3 CH_4/m^3 d)
SCOD	soluble chemical oxygen demand
SMP	specific methane production (m^3 CH_4/kg COD_{added}, m^3 CH_4/kg VS_{added})

COD removal, volatile solids destruction, and process stability; and (2) to identify the upper limit of the BWG proportional loading that does not cause a process upset.

2. Methods

2.1. Substrates

Municipal wastewater sludge (MWS) consisting of a 3:1 (v/v) mixture of primary treatment scum and sludge (PS) and thickened waste activated sludge (TWAS), was obtained from the Gold Bar Wastewater Treatment Plant (WWTP) in Edmonton, Alberta, Canada. Biodiesel waste glycerin from canola oil biodiesel production was collected from a biorefinery in Calgary, Alberta, Canada. Digested sludge from a full scale mesophilic anaerobic digester at the Gold Bar Wastewater Treatment Plant was used as the inoculum (seed) for the start-up of the digesters. The characteristics of MWS and BWG varied somewhat during the study as shown in Table 1. The BWG is an organic readily digestible material which had a high pH and alkalinity compared to the MWS. The SCOD/COD ratio indicates the level of the feed solubilization which directly affects the biogas production (Tang et al., 2010). This ratio was approximately 0.98 in the BWG which was almost 14 times higher than that of the MWS.

2.2. Semi-continuous pilot digester

Two 1300 L (1200 L active volume) completely mixed digesters housed in a trailer were received from the King County Wastewater Treatment Division in Washington. The trailer pilot plant was transferred to and set up at the Gold Bar WWTP. The continuously stirred tank reactors (CSTR) were operated in the mesophilic temperature range (36 ± 1 °C) with a solids retention time (SRT) of 20 days. Each digester was initially fed 1200 L of seed sludge and then 60 L of digested material was withdrawn and replaced with the same volume of feed each day (7 days/week) to provide a 20 day SRT. The control digester was fed only municipal wastewater sludge (MWS) while the test digester received the same MWS with BWG as a co-substrate. The organic loading rate was determined on the basis of total COD.

Each digester was heated via an external thermal jacket. The digesters' temperatures were monitored by type J thermocouples. A top-mounted three-bladed digester mixer was operated at a nominal shaft speed of 100 rpm in each digester. A data logger collected and logged the digesters' internal temperatures, volumes of biogas produced, and digester active volumes every 5 min.

2.3. Digester feed and organic loading rate protocols

Initially, the digesters received the same amount and type of feed (MWS) in order to establish their baseline performance. This operating mode was continued for 30 days. Subsequently, the COD loading to the test digester was increased with the addition of BWG to the MWS feed to achieve the desired COD loading, while maintaining the 20-day SRT. Except for the highest loading, each COD loading to the test digester (expressed as a percentage of the control digester's COD loading) was maintained for 30 days (Table 2). The test digester loading rate was increased progressively by adding greater volumes of BWG to eventually reach the maximum nominal COD loading of 180% relative to the control digester COD loading.

Each day, a volume of MWS sufficient to meet the line flushing and feeding requirements for both digesters (approximately 70 L for each digester) was obtained from the on-site sludge blend tanks and transferred to a grinder tank where it was thoroughly mixed prior to being transferred to a feed tank (see Fig. 1). Before feeding, 60 L of digested sludge were drained from the control digester to its effluent tank. Samples were collected from the feed and the effluent tanks for subsequent analysis. The control digester feed line was flushed with the MWS and 60 L of MWS were then

Table 1
Characteristics of municipal wastewater sludge (MWS) and biodiesel waste glycerin (BWG).

Feed	Parameters	Nominal COD loading (%)			
		100	130	150	180
MWS	COD (g/L)	34.1 ± 4.5[a]	37.83 ± 2.32	31.06 ± 1.06	31.50 ± 1.35
	SCOD (g/L)	N/A[b]	2.75 ± 0.25	2.29 ± 0.60	1.60 ± 0.07
	TS (g/L)	26.5 ± 1.4	23.90 ± 1.33	23.15 ± 1.92	22.10 ± 1.15
	VS (g/L)	20.5 ± 1.3	18.05 ± 1.12	16.18 ± 1.06	16.33 ± 0.87
	TA[c] (mg/L)	1520 ± 8.5	1487 ± 8.0	1506 ± 9.2	1500 ± 8.7
	pH	6.0 ± 0.2	5.65 ± 0.22	5.77 ± 0.29	5.71 ± 0.18
BWG	COD (g/L)	N/A	1830 ± 21.21	1707 ± 24.75	1707 ± 24.75
	SCOD (g/L)	N/A	1790 ± 6.36	1678 ± 4.95	1678 ± 4.95
	TS (g/L)	N/A	488 ± 3.64	484 ± 1.06	484 ± 1.06
	VS (g/L)	N/A	426 ± 2.56	442 ± 5.65	442 ± 5.65
	TA[c] (mg/L)	N/A	9454 ± 11.5	9448 ± 9.3	9448 ± 9.3
	pH	N/A	8.39 ± 0.02	8.33±.035	8.33 ± 0.35

[a] Standard deviation.
[b] Not applicable.
[c] Total alkalinity (TA) represented as mg/L $CaCO_3$.