2012 International Conference on Clean and Green Energy
IPCBEE vol.27 (2012) © (2012) IACSIT Press, Singapore

Anaerobic Digestion of Meat Wastes

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Abstract. Many meat processing industries use dissolved air flotation (DAF) to treat the wastewater generated onsite before it is discharged or further treated and ending up with large volumes of sludge, usually of 20% TS. The aim of this study was to evaluate the biogas production potential (BPP) from meat processing DAF-sludge for different organic loadings. An associated objective was to compare BPP using acclimatised and non acclimatised seed. Batch reactors operated at mesophilic conditions and loadings of 5, 3.8, 2.5 and 1.2 gCOD/gVS acclimatised seed, and 3.4, 2.6, 1.7 and 0.8 gCOD/gVS non-acclimatised seed were monitored for biogas production on a daily basis. The highest biogas production for non-acclimatised seed was 1930 mL at 3.4 gCOD/gVS, whereas for acclimatised seed 1358 mL was obtained at 3.8 gCOD/gVS. It was observed that using acclimated seed, higher CBP was achieved at a lower loading compared to the non-acclimatised seed.

Keywords: Meat waste; rendering; biogas; ammonia; volatile acid; acclimation

1. Introduction

An increasing interest in sustainable and economic waste management is apparent amongst the meat industries in Australia. With the large volumes of sludge separated from wastewater during its treatment, eg. using dissolved air flotation (DAF), there is a need to treat and manage this sludge effectively. One of the promising options to further treat the DAF sludge is anaerobic digestion (AD) because of its effectiveness in converting organic wastes into useful by-products, eg. methane, hence there is potential for savings in energy and sludge handling costs. There are a number of factors that affect the AD process, including organic loading, temperature, pH and substrate characteristics. One of the main characteristics of the DAF-sludge is the high grease and oil concentration, which makes it a potential candidate for AD.

The high protein and lipid content in meat wastes can cause inhibition to the anaerobic bacteria, which lead to process failure of the anaerobic digester. Protein degradation releases ammonia, which at high concentration inhibits the anaerobic bacteria. It was reported that the increase in ammonia concentrations increases the pH, which if it reaches a high level, can decrease the degrading rate of the methanogenic bacteria. Total ammonia concentration higher than 1500 mg/L was inhibitory at pH levels above 7.4 (Lokshina et al. 2003). The concentrations of volatile acid (VA) are used to indicate the balance between acetogens and methanogens. If the acetogens outgrow the methanogens, the pH will drop, which can inhibit methanogens, and ultimately lead to an upset or 'sour' digester (Gray 2008).

Anaerobic digestion with acclimatised seed has been known to be more susceptible to higher ammonia and VA concentration (Speece 1987, p. 130). Acclimation of methanogenic bacteria to high ammonia level, or raising ammonia tolerance, is a proven useful method for improving the process of anaerobic digestion and production of methane from different kinds of wastes (Abouelenien, Nakashimada & Nishio 2009; Güngör-Demirci & Demirer 2004).

So far, there is limited information on the use of acclimatised seed on the anaerobic treatment of DAF-sludge. Hence, the main objective of this study was to investigate the performance of acclimatised seed on

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the anaerobic treatability and biogas production of DAF-sludge and compare with non-acclimatised seed. It also addresses the effect of volatile acid and ammonia-N inhibition on the biogas production based on a range of organic loadings.

2. Materials and Methods

2.1. Waste and anaerobic seed characteristics

The waste used in this study is DAF-sludge, which was obtained from a meat processing plant that employs a DAF unit to concentrate the wastewater where the DAF-supernatant is discharged to sewer system and the DAF-sludge is sent to landfill. The sample collected from the plant was kept at 4°C prior to use. The anaerobic seed culture used as seed was obtained from the anaerobic sludge digesters of the Eastern Treatment Plant in Melbourne, Australia. It was filtered through a screen of 1.4-mm mesh size and stored at 35°C prior to use. The characteristics of the DAF-sludge, acclimatised and non-acclimatised seed are shown in Table 1. The seed and acclimatised seed had a specific activity of 1.5 and 1.7 gCODt/gVS.day.

Table 1: Characteristics of DAF-sludge and seeds used in this study.

Parameters	Sludge	Seed	Acclimatised seed
pH	9.29	7.07	6.65
TS (mg/l)	53443	21333	11306
TVS (mg/l)	49971	13417	9028
TCOD (mg/l)	105700	20425	15200
SCOD (mg/l)	2351	558	377
T-PO_4^{3-} (mg/l)	1449	827.5	539
T NH_3-N (mg/l)	1912.5	69.5	115
Volatile acid (VA) (mg/l)	4540	36	20
Volatile fatty acid (VFA) (mg/kg)	2700	-	-
Moisture content %	90.3±0.06	-	-

2.2. Experimental methodology

As the DAF-sludge has high total solids (TS) content, water was added to provide a slurry state. The TS, volatile solids (VS) and moisture content were measured. The density of sludge slurry was 0.94±0.075 g/mL.

The acclimation of seed occurred over several months before this study was conducted. The acclimation process involved feeding a reactor which contained fresh seed with wastewater before the DAF on a daily basis. After the seed is stabilised the feeding continued at a sludge retention time of 20 days. The reactor was monitored for pH, TS, VS and COD (total and soluble) on a regular basis. Daily feeding and wasting of the liquid effluent started when the COD was stabilised (Marcos et al. 2010). On the day of this study started, the COD concentration has stabilised at about 10%.

Batch anaerobic reactors (Grace Davison, U.S.) of 250 mL volume each were operated at mesophilic conditions (35°C). The effective volume of the reactors was 150 mL. The AD of the DAF-sludge with non-acclimatised seed was carried out at organic loadings of 3.4, 2.6, 1.7 and 0.8 gCOD/gVS, whereas, with acclimatised seed, organic loadings of 5, 3.8, 2.5 and 1.2 gCOD/gVS were applied. A control and a blank were operated for all organic loadings. All the reactors were sealed with natural rubber sleeve stoppers, and maintained in a shaker (INFORS HT, Switzerland) at 35±1°C and 100 rpm. The reactors were monitored for biogas production on a daily basis, the percentage of CH_4 in the biogas was measured weekly. Full characterisation of the effluent was performed at the end of the experiment.

2.3. Analytical methods

Gas produced in each 250 mL serum bottle was measured daily using a gas displacement device (Demirer & Othman 2008; Ergüder, Güven & Demirer 2000; Woon & Othman 2011). The methane content in the biogas was determined as follow: A known volume of headspace gas (V_1) produced in a serum bottle was syringed out and injected into another serum bottle containing 20 g/L KOH solution. This serum bottle was shaken manually for 3-4 min so that all the CO_2 and H_2S were absorbed in the concentrated KOH solution. The volume of the remaining gas (V_2), which was 99.9% CH_4, in a serum bottle was determined by the means of a syringe. The ratio of V_2/V_1 provided the content of CH_4 in the headspace (Demirer et al. 2000).

TS and VS were measured according to the Standard Methods (American Public Health Association 1998). The measurements of COD, VA, NH_3-N and PO_4^{3-} were made by colorimetric techniques using a HACH spectrophotometer (Model: DR/4000). The samples for COD soluble and VA analyses were centrifuged (4.4 rpm and 20 min) then filtered through 0.45 µm filter paper. The measurement of pH was made using a calibrated pH meter (ThermoOrion, Model 550A).

3. Results and Discussion

3.1. Cumulative biogas production (CBP)

At least two reactors were operated at each conditions. The results shown in Figure 1 are the average values obtained. The highest cumulative biogas production (CBP) was 0.53 m^3 biogas/kg $VS_{added,}$ obtained for DAF-sludge at a loading of 3.4 gCOD/gVS. With the use of acclimatised seed, the highest CBP was 0.55 m^3 biogas/kg VS_{added}, obtained at a loading of 2.5 gCOD/gVS.

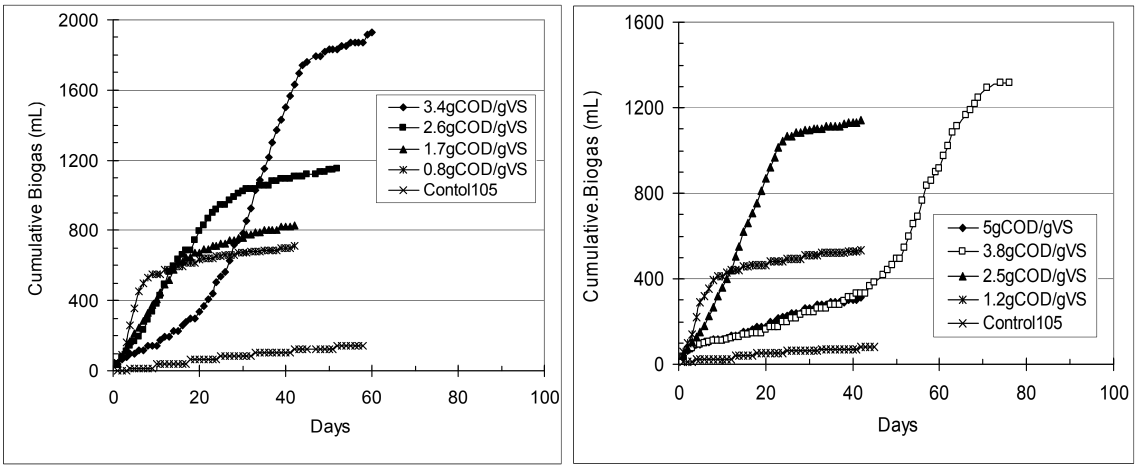

Fig. 1: Cumulative biogas production. A. Sludge without acclimation, B. Sludge with acclimation.

Slow biogas production at low loadings was observed for the first 10 days and higher loadings, approximately 20 days. At day 21, sludge samples with normal seed at 2.6 gCOD/gVS showed the best CBP (820 ml), followed by 1.7 (660 ml) and 0.8 gCOD/gVS (680 ml). From day 29-35, reactors at 0.8, 1.7 and 2.6 gCOD/gVS have started to stabilised, which indicated that waste stabilisation for lower loadings can be achieved at about 5 weeks. However at loading of 3.4 gCOD/gVS, biogas production started to accelerate at a daily production rate of 12-23 ml biogas/$gCOD_{waste\ added}$. This showed that the waste has been fully hydrolysed and was being converted into biogas by the methanogens. Overall, loading at 3.4 gCOD/gVS (46000 mg/L COD) showed a similar trend with the work with poultry breeding wastewater at an initial loading of 17633 mg/L COD (Demirer et al. 2000).

When the sludge was mixed with acclimated seed, the CBP of reactors at 2.5 gCOD/gVS showed slightly higher biogas production. Reactors at 1.2 gCOD/gVS showed almost similar production rate with reactors without acclimation at 1.7 gCOD/gVS. Reactors at organic loading of 3.4 gCOD/gVS started producing more biogas from day 27. The production rate on day 27 and 28 were 14 ml biogas/$gCOD_{waste\ added}$ and 19 ml biogas/$gCOD_{waste\ added}$. This may be because the methanogens are acclimatised to the waste in the reactors and the waste was hydrolysed. From day 29-35, reactors containing sludge and acclimated seed at organic loadings of 1.2 and 2.5 gCOD/gVS have also started to stabilise. With reactors at loadings at 3.8 and 5 gCOD/gVS, the biogas production is still slow, and this may be due to process failure due to high volatile acids in the early stages. At 3.8 gCOD/gVS loading, gas production rate was inhibited and for a time was proportional to the toxicant concentration. Even after a prolonged period (50 days) of little gas production, eventual recovery was very rapid and complete (Speece 1996). This is similar to the work done by (Hutnan et al. 1999), which showed that wastewater containing high solids concentrations requires more contact time between bacteria and substrate for complete hydrolysis of particulates.

3.2. Process performance

The other benefits of AD is manifested in the TS, VS and COD removal. A reduction of TS did occur in all of the reactors. TS and VS removal ranged from 20 to 40% and 21 to 46%, respectively. Similar VS removal rate was also reported by Luste & Luostarinen (2010), which indicated that low VS removal was due to the difference on the production sites and relative proportions of fats, proteins and carbohydrates. Results show that a minimum of 90% COD removal was achieved for all the DAF sludge using acclimated seed. This indicates that the organic constituents in the samples were almost completely removed within the 45 days of the experiment at lower loadings.

The ammonia-N content in the reactors was observed at least once a week for 24 days. From the results obtained, it was observed that ammonia-N concentration was below the inhibition range (1500-2000 mg/L). It can also be seen that there was a reduction of ammonia-N content at the end of the experiment, indicating that the methanogenic bacteria were acclimatised to the seed and was tolerable at different loadings of DAF-sludge.

Table 2: Biogas production and process performances in terms of COD, TS and VS removal.

Loading (gCOD/gVS)	**Days**	**Total biogas (ml)**	**Biogas (m3/kgVS $_{added}$)**	**CH4 %**	**COD removal %**	**TS removal %**	**VS removal %**
Acclimatised seed							
5.0	42	312.8	0.10	65±5.8	94.1	19.6	20.7
3.8	83	1358.1	0.52	66±4.4	98.1	41.1	44.1
2.5	42	1143.0	0.55	71±5.4	98.7	41.7	46.0
1.2	42	535.5	0.35	73±5.1	98.6	30.0	34.1
Non acclimatised seed							
3.38	60	1930	0.53	64±7.0	98.2	30	41
2.55	52	1150	0.37	73±7.8	99.3	41	52
1.69	42	831	0.33	72±7.3	98.5	28	37
0.83	42	711	0.36	72±9.2	91.2	22	28

4. Conclusions

DAF-sludge generated at meat processing plants showed promising potential for biogas production. The optimum loadings of DAF-sludge in terms of biogas production were 3.4 gCOD/gVS and 2.5 gCOD/gVS for non-acclimatised and acclimatised seed respectively. Under these loading, the CBP obtained was 0.53 and 0.55 m^3 biogas/kg VS_{added} at 60 and 42 days. It was observed that using acclimatised seed, higher CBP can be achieved. This study also showed that high concentrations of ammonia-N and VA have an inhibiting effect on the AD process, especially at loadings higher than from 3.8 gCOD/gVS. The variation in the amounts of biogas production using acclimatised compare to non-acclimatised seed suggest that feasibility and research studies should identify the type of seed used in their work.

5. Acknowledgements

The authors express sincere appreciation to City West Water for funding this study, and to SWIFT and Eastern Treatment Plant for providing samples to complete this study.

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