Biogas recovery from a temperate climate covered anaerobic pond

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Abstract

New Zealand has over 1000 anaerobic wastewater stabilisation ponds used for the treatment of wastewater from farms and industry. Traditional anaerobic ponds were not designed to optimise anaerobic digestion of wastewater biomass to produce biogas and are therefore uncovered, releasing biogas to the atmosphere, which can cause odour problems and contributes to GHG emissions. The biogas production and treatment performance of an anaerobic piggery waste stabilisation pond retrofitted with a full perimeter cover working under field conditions was monitored over a 14 month period. Biogas composition and water quality were analysed weekly and gas production and wastewater flow were continually monitored. The simple cover design proved successful in capturing biogas, mitigating odour and GHG issues and coping with New Zealand ambient weather conditions. High wastewater solids removal rates (73% and 86% for TS and VS respectively) were achieved in the covered anaerobic pond. An annual average biogas methane production rate of 0.263 $m^3CH_4/kgVS_{added}$ was observed, which is similar to gas production rates of more sophisticated heated and mixed farm waste digesters, although biogas methane production was varied both daily and seasonally. Average CH_4 content of the piggery pond biogas was 66.7%. These results suggest that covered anaerobic ponds treating agricultural wastes in New Zealand have great potential to reduce odour and GHG emissions and recover renewable energy, while producing an easy to handle effluent for land irrigation or further treatment.

Keywords

WSP, biogas, methane production, anaerobic pond, energy recovery.

INTRODUCTION

Anaerobic waste stabilization ponds are widely used for the treatment of agricultural, industrial and municipal wastewaters (McGrath and Mason 2004; Park and Craggs 2007). Anaerobic ponds are simple, usually unheated anaerobic digesters operating in the psychrophillic temperature range (below 35^{o}C); with operating temperatures varying with ambient temperature. Volatile solid (VS) reduction and biogas production rates below 35^{o}C decrease almost linearly with decreasing temperature (Henze 1995), thus psychrophillic ponds require a longer solids retention time than mesophillic digesters to achieve the same volatile solids reduction (Stevens & Schulte, 1977). . Methanogenesis occurs at temperatures as low as 3 - 9^{o}C, but the minimum temperature has been found to decrease as the pond ages (Stevens and Schulte, 1977; Cullimore et al, 1985).

Anaerobic waste stabilization ponds in NZ have been primarily designed for VS and BOD_5 reduction through sedimentation of wastewater solids, rather than for efficient anaerobic digestion and biogas recovery. Therefore anaerobic ponds are uncovered, allowing biogas (comprising primarily CH_4 and CO_2) to escape to the atmosphere, contributing to greenhouse gas (GHG) and odour emissions. Previous monitoring of biogas emissions from anaerobic waste stabilisation ponds using 25 m^2 floating covers (Park and Craggs 2007; Craggs et al. 2008) indicated, that under New Zealand temperate climate conditions anaerobic pig and dairy farm ponds produce similar annual average biogas methane volumes based on the volatile solids (VS) loading to more sophisticated mesophillic digesters, although a pronounced seasonal variation in gas production was observed. Since the New Zealand agricultural sector may soon require mitigation options for its increasing

GHG emissions, there was a need to verify our previous observations at full-scale by developing and demonstrating a practical cover design for biogas capture from ponds in New Zealand. This paper presents monitoring data (organic loading and removal, and biogas production and composition) of an anaerobic piggery pond, which was retrofitted with a full perimeter cover to gain a more accurate understanding of the GHG emission reduction and energy recovery potential of covered anaerobic ponds.

METHODS

Location and Description of the monitoring site

The anaerobic pond was located at the Waratah Farms Roto-o-rangi piggery near Cambridge (-37.9S, 175.466E) in the Waikato region of New Zealand. The site experiences a moderate maritime climate (annual average air temperature: 13.5^{o}C; annual average rainfall: 1183 mm). The opportunity to cover the existing anaerobic waste stabilisation pond, primarily to mitigate odour concerns, arose as part of an intensive farm redevelopment, during 2007 / 2008. The existing pond was originally constructed in 1973 and clay lined, with dimensions at the water surface of 28 m by 90 m. The pond was 3 m deep with a bund slope of approximately 3:1 (vertical : horizontal), giving a total pond volume of 7,200 m^3. Flush manure from the pig sheds is washed into a collection sump and passed through a solids separator to remove fibrous material before being pumped into the anaerobic pond. Effluent from the anaerobic pond flowed by gravity to a facultative storage pond, before being irrigated to land. Ultimately the pond will receive flush manure, from 1500 grower pigs (average weight 50 kg), however during the redevelopment phase the number of pigs varied between 1200 and 700. Following thorough desludging the existing anaerobic pond was covered with a 0.75 mm Polypropylene (PP) earth sealed perimeter cover. The cover had no in-build flotation, but included an array of weight pipes for rainwater guidance. Rain water was removed from the cover by a float switch operated submersible pump. Biogas draw-off from the cover was accomplished using a 100 mm perforated PVC pipeline around the pond perimeter under the cover, connected to a centrifugal gas blower.

Monitoring

Biogas flow was continually monitored using a domestic gas flow meter (Email Industries (NZ) Ltd) connected to the gas blower. A telemetry data acquisition system was installed to log biogas flow at 15 minute intervals. This consisted of a magnetic event sensor fitted within the gas flow meter that generated a pulse output for every 2 litres of biogas flow. Biogas flow data was logged at 15 minute intervals (Campbell Scientific CR10 data logger, Campbell Scientific Inc, UT, USA) and was downloaded daily through a cell phone modem. All biogas production data was corrected to standard temperature and pressure. Biogas and pond water temperatures were measured at 15 minute intervals using temperature loggers (HOBO Water Temp Pro, Onset Computer Corporation). Biogas temperatures were measured at the biogas draw-off point from the cover. Pond water temperature was measured in the pond effluent taken from 1 m below the pond water surface. Wastewater flow was measured by monitoring the flow of effluent from the covered anaerobic pond in the transfer pipe to the facultative storage pond, using an ultrasonic flow meter (PCS-MWA-M Prosol Process Solutions Ltd. Auckland NZ) strapped to the outside of the pipe. Wastewater flow data was logged at 15 minute intervals by a Campbell data logger and downloaded via a cell phone modem.

Biogas composition (CH_4, CO_2, O_2, NH_3 and H_2S) was determined weekly using a portable gas analyser (GA2000 plus Landfill Gas Analyser, Geotechnical Instruments (UK) Ltd, Leamington Spa, England). The gas analyser was calibrated biannually with certified standard gases. Pond influent and effluent grab samples were taken at weekly intervals. Pond effluent samples were obtained at the transfer pipeline between the anaerobic pond and the facultative holding pond, influent samples were taken downstream from the solids separator. The water quality of the influent and effluent of the anaerobic pond was analysed using standard methods (APHA, 1998) for the following parameters: total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN) and ammoniacal nitrogen (NH_4-N).

RESULTS AND DISUSSION

Cover performance

The perimeter cover was easily installed from 3 sections that were welded together on-site. The cover performed well throughout the monitoring period, with satisfactory guidance of rainwater to the removal pump. The only operational issue was the accumulation of leaves form nearby trees on the cover in autumn which required occasional unclogging of the rainwater draw-off pump. No build up of a crust of organic material underneath the cover was detected over the monitoring period. Billowing of the cover material between the rainwater guidance pipes created gas storage capacity. As demonstrated during a power outage which prevented the gas blower from operating, the cover could store up to 500 m^3 of biogas. This inbuilt gas storage capacity of the anaerobic pond cover is a valuable feature, as it enables, and gives flexibility to, intermittent biogas use.

Wastewater flow and pond loading

Since the anaerobic pond cover prevents evaporation losses and rainwater incursion, and the pond has been sealed for many years, it was assumed that the effluent flow equalled the pond influent flow, which was used to calculate pond loading rates. The low hydraulic head (~0.5 m) between the covered anaerobic pond and the facultative holding pond, and the potential for magnesium-ammonium-phosphate (struvite) build-up meant that the wastewater flow had to be measured with an ultra sonic flow meter (attached to the outside of the pie) rather than an impeller type flow meter (within the pipe). For this reason reliable flow data was only recorded from May 2008 onwards. Pond effluent flows varied strongly; both daily and monthly (Figure 1). Daily variation in pond effluent flow was influenced by daily precipitation, since firstly some stormwater entered the flush manure collection system and diluted the pond influent, and secondly rainwater accumulating on the pond cover, displaced pond water below the cover at times when rainfall exceeded the capacity of the rainwater draw-off pump. Since all rainwater was eventually removed from the pond cover by the pump, spikes in pond water flow caused by heavy rain events were usually followed by days of low pond water flow (Figure 1).

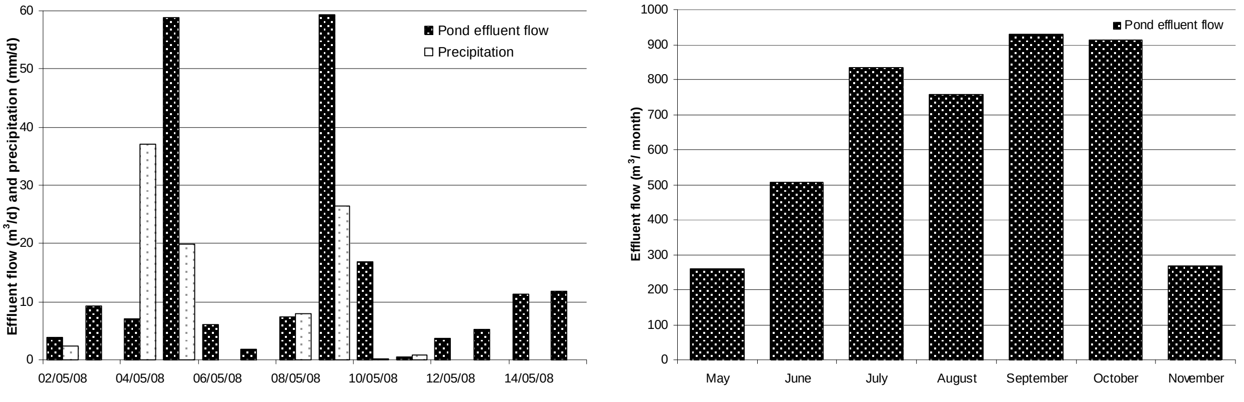

Figure 1. Example of daily variation in pond effluent flow and precipitation (2-15th May 08), and monthly variation in pond effluent flow (May to November 2008).

While the monthly variation in pond water flow may also have been influenced by rainfall, a large proportion of the variation can be attributed to the ongoing redevelopment of the farm, resulting in changes in both, the number of pigs onsite and the area of shed that was flushed. The pond loading rates ($kgVS_{added}$/d & $kgVS_{added}$/pig/day) were calculated by multiplying the total weekly pond water flow with pond influent VS measurements from grab samples taken at weekly intervals (Table 1). The pond loading averages for the period May to November 2008 were calculated as 90 kg VS/day and 0.127 kg VS/pig/day.

Table 1. Weekly pond water flow and influent VS concentrations.

Week	Sampling date (grab sample)	Weekly flow (m^3/week)	VS con. (g/m^3)	VS loading kg/week	VS loading kg/day	Number of pigs	VS loading kg/pig/day
1	8/05/2008	95	6008	568	81	900	0.090
2	16/05/2008	109	6734	732	105	900	0.116
4	28/05/2008	20	1518	30	4	900	0.005
5	5/06/2008	69	8154	561	80	670	0.120
6	12/06/2008	108	8694	942	135	670	0.201
7	19/06/2008	114	6678	764	109	670	0.163
8	26/06/2008	135	6406	863	123	670	0.184
11	18/07/2008	246	2000	493	70	700	0.101
13	31/07/2008	139	2600	362	52	700	0.074
14	7/08/2008	146	3900	570	81	700	0.116
15	14/08/2008	153	2600	397	57	700	0.081
16	21/08/2008	214	3700	790	113	700	0.161
18	4/09/2008	75	6300	475	68	700	0.097
19	11/09/2008	165	1200	198	28	700	0.041
20	18/09/2008	220	4700	1036	148	700	0.211
23	8/10/2008	314	4100	1288	184	700	0.263
24	16/10/2008	192	3700	709	101	700	0.145
27	6/11/2008	132	4600	606	87	700	0.124
	Average	**147**	**4,644**	**632**	**90**	**727**	**0.127**

Since the pond loading rates calculated for each week varied widely (Table 1), they were also calculated using an alternative approach based on feed utilisation (Table 2).

Table 2. Calculation of pond loading rate based on feed utilisation.

Pond VS input calculation

Number of pigs	670	
Total feed consumed daily	1492	kg/d
Feed consumption per pig	2.2	kg/d

Composition:			DM (%)[1]	DM intake		VQ (%)[1]	Excreted DM		Separator removal[2]	DM post separator		VS Ratio[3]	VS pond loading	
Barley	550	kg/d	86%	473	kg/d	83%	80	kg/d	50%	40	kg/d	65%	26	kg/d
Maize	550	kg/d	86%	473	kg/d	90%	47	kg/d	20%	38	kg/d	65%	25	kg/d
Meat & bone	184	kg/d	95%	175	kg/d	70%	52	kg/d	25%	39	kg/d	65%	26	kg/d
Soy cake	208	kg/d	89%	185	kg/d	92%	15	kg/d	15%	13	kg/d	65%	8	kg/d
Total	**1492**	**kg/d**		**1306**	**kg/d**		**195**	**kg/d**		**130**	**kg/d**		**84**	**kg/d**
Per pig/day	2.23	kg/d		1.95	kg/d		0.29	kg/d		0.19	kg/d		**0.126**	kg/d

[1] Dry Matter (DM) and digestibility (VQ) data from Kirchgessner 1997
[2] Estimated separator removal rates of various manure components base on industry information
[3] Monitored average TS/VS ratio of post separator wastewater Sep 2007 – Apr 2008

The dry matter excreted by the pigs each day was calculated based on the known amount of feed consumed at the farm (typically 2.2 kg/pig/d), and standard literature figures for dry matter (DM) and digestibility (VQ) of the various feeds used. The solids separator removal rates were assumptions based on industry information, which take into account different concentrations of easy to separate (fibrous and inorganic) compounds in various feeds, while the VS ratio (TS/VS ratio) was an average figure from the weekly monitoring. The calculations (Table 2) indicated pond loading rates of 84 kgVS/d and 0.126 kgVS/pig/day, which were very similar to the values calculated based on pond water flow and influent VS data.

Wastewater treatment performance

The water quality of the pond influent varied widely, in a similar way to the pond flow (Table 3). The covered anaerobic pond provided excellent TS and VS removal (73% and 86% reduction respectively), through sedimentation and anaerobic digestion. These figures are similar to a solids reduction in a temperate climate dairy manure anaerobic lagoon (82.2% and 86.7% for TS and VS respectively) reported by Safley and Westerman (1992). These high removal rates are probably a reflection of the low volumetric loading rate and long retention time the pond was operated with. The NH_4-N concentration of the pond effluent was higher than in the pond influent (Table 3) since ammoniacal nitrogen is released during the anaerobic breakdown of wastewater solids (Henze 1995, Burke 2001). Comparison of pond influent and effluent TKN data shows only a minor reduction of 15% in Total Kjeldahl Nitrogen. Since gaseous (NH_3) ammoniacal nitrogen losses from the pond in the biogas were calculated to be less than 4 kg NH_4-N for the entire monitoring period, this indicated that the majority of the TKN removal was through sludge accumulation within the pond. Some of this accumulated TKN will probably be released over time by bacterial degradation of more recalcitrant organic compounds. Sedimentation and thorough anaerobic digestion in the covered anaerobic pond created a relatively homogenous and inert effluent, which was easy to pump and handle, provided struvite build up was monitored. This effluent could be irrigated to land without the odour and clogging issues commonly encountered with raw effluent.

Table 3. Annual average pond influent and effluent water quality parameters and pond treatment performance.

Parameter	**Pond Influent**			**Pond Effluent**		
	Average	n	s.d.	Average	n	s.d.
Total Solids (TS) concentration (g/m^3)	14,234	33	7,974	3,904	33	538
Volatile Solids (VS) concentration (g/m^3)	7,859	33	5,756	1,110	33	335
Ammoniacal Nitrogen (NH_4-N) concentration (g/m^3)	838	33	396	1,076	33	231
Total Kjeldahl Nitrogen (TKN) concentration (g/m^3)	1,544	37	547	1,311	37	246
Pond treatment performance						
TS reduction (Influent/Effluent)			73%			
VS reduction (Influent/Effluent)			86%			
Ammoniacal Nitrogen reduction (Influent/Effluent)			-28%			
Total Kjeldahl Nitrogen reduction (Influent/Effluent)			15%			

Biogas production and quality

Biogas production from the covered anaerobic pond was monitored from September 2007 to November 2008 and the biogas composition analysed at weekly intervals. The annual average biogas composition was 66.7% methane (CH_4), 30.4 % carbon dioxide (CO_2), 0.2% oxygen (O_2), 2.8% other gases (N_2 etc.), 252 ppm ammonia (NH_3) and 612 ppm hydrogen sulphide (H_2S) (Table 4). These figures are in line with literature values for the quality of biogas from heated and mixed farm waste digesters (Safley and Westerman 1988; Burke 2001), but the CH_4 concentration was lower than 74% reported by Craggs et al. (2008) and 80.4% reported by Safley and Westerman (1992) for small scale floating cover experiments on a piggery and dairy anaerobic pond, respectively. This difference is probably due to less scrubbing of CO_2 from the biogas in the pond water of completely covered anaerobic ponds compared with open pond systems (Green at al. 1995). Monthly biogas methane production (m^3CH_4/month) and monthly biogas methane production per pig (LCH_4/pig/month) for the period September 2007 to November 2008 are shown in Figure 2 along with values of mean pond water and air temperature. Monthly biogas methane production varied greatly, and a general trend between biogas methane production and mean pond water and/or air temperature can be seen. However, the clear seasonal relationship between biogas methane production and pond water temperature identified in experimental cover studies (Safley and Westerman 1989, Craggs et al 2008) could not be confirmed. The lack of a clear connection between biogas methane productivity and temperature remains largely unexplained; however the very low volumetric loading of this pond (~ 0.0125kgVS/m^3/d) and changing manure quantities and qualities resulting from the ongoing reconstruction work may explain some of the variation.

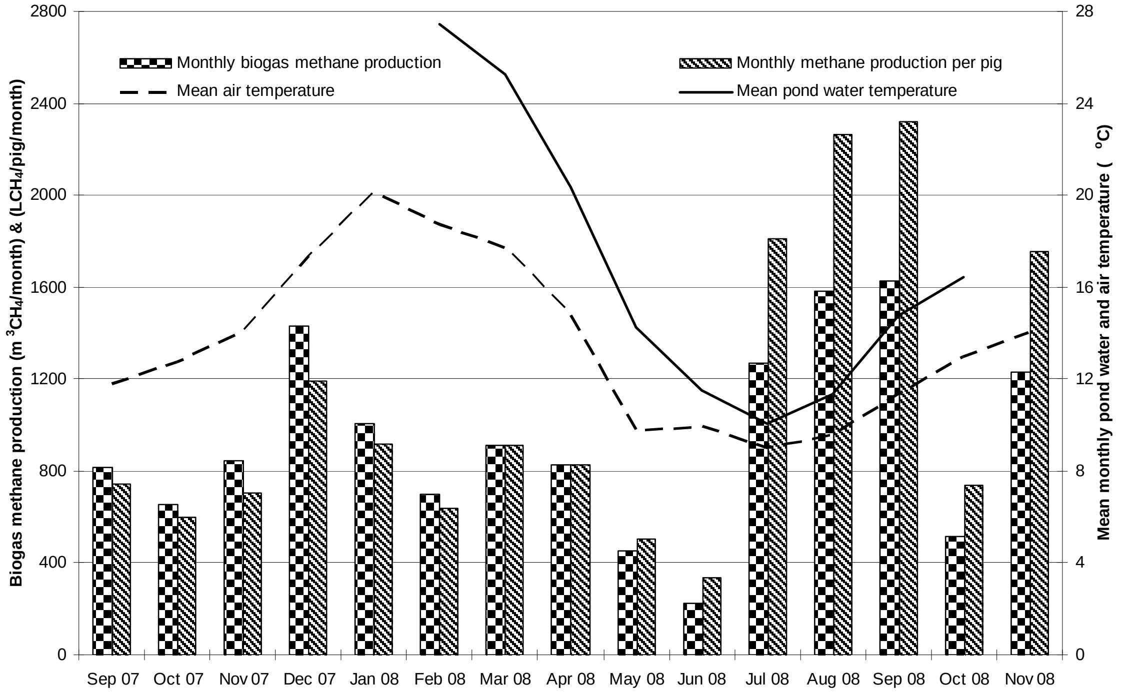

Figure 2. Total monthly biogas methane production (m^3CH_4/month), monthly methane production per pig (LCH_4/pig/month) and mean air and pond water temperatures for the monitoring period.

The average biogas methane production rate for the monitoring period based on VS loading was determined as 0.263 m^3 CH_4/kg VS_{added} (Table 4). This value is in line with methane productivity values of more sophisticated heated and mixed farm waste digesters (Hill 1984; Safley and Westerman 1988, Cobb and Hill 1990; Burke 2001), and indicates that unheated covered anaerobic ponds in temperate climates like New Zealand can fully compensate the disadvantage of lower operating temperatures through extended solids retention times. The value of 0.263 m^3 CH_4/kg VS_{added} is also similar to the figure of 0.279 m^3 CH_4/kg VS_{added} determined in earlier studies on anaerobic piggery ponds (Craggs et al. 2008). A likely explanation for the slightly lower value in the present study is that biogas production does not occur evenly across the pond area (Safley and Westerman 1988), particularly around the pond edges.

Table 4. Average biogas composition and methane production rates from the piggery anaerobic pond for the monitoring period September 2007 to November 2008.

Parameter				
Monitoring period:		Sep 07	-	Nov 08
Number of pigs:		670	-	1200
Biogas Composition:	CH_4 (%)		66.7%	
	CO_2 (%)		30.4%	
	O_2 (%)		0.2%	
	Other gases (%)		2.8%	
	NH_3 (ppm)		252	
	H_2S(ppm)		612	
Biogas production:				
VS production per pig (kgVS/pig/d)			0.127	
Total VS production monitoring period(kg)			53645	
Total biogas methane production (m^3)			14086	
Biogas methane production rate (m^3 CH_4/kg VS_{added})			**0.263**	
Daily average biogas methane production (m^3 CH_4/d)			32	

The capacity of the pond cover to store biogas can compensate for some of the observed variation in biogas production, and also provides flexibility for potential intermittent biogas uses (e.g. peak load generation). Therefore covered anaerobic ponds not only have a great potential for reducing odour and GHG emissions produced by New Zealand’s expanding agricultural sector, but also provide a flexible and versatile source of renewable energy that can help farms and rural communities to achieve a higher level of energy self-sufficiency. As demonstrated, covered anaerobic ponds can retrofit existing pond infrastructure, and purpose built installations are cost competitive with heated and mixed tank digesters. Moves by a number of NZ Regional Councils to mandate deferred irrigation storage for dairy farm effluent in order to mitigate nutrient leaching and run-off concerns, could provide an opportunity for covered anaerobic pond technology, since newly installed uncovered storage ponds will be additional sources of odour and GHG emissions. Further research is required to establish cost effective and reliable biogas utilisation at small scale to realise the distributed energy value of agricultural effluent, for heating, electricity generation and transport applications.

CONCLUSIONS

A simple, easy to retrofit pond cover has proven successful in capturing biogas from an existing anaerobic pond, to address odour and GHG concerns, and provided options for energy recovery through biogas use. The major findings of this field-scale demonstration were:

- High wastewater solids removal rates (73% and 86% for TS and VS respectively) were achieved with the covered anaerobic pond while a homogenous, low odour, easy to handle effluent was produced.
- Anaerobic digestion of piggery wastewater in the covered anaerobic pond was as efficient as in more sophisticated heated and mixed anaerobic digesters, with an average biogas methane production rate of 0.263 m^3 CH_4/kg VS_{added} for the monitoring period.
- The pond cover provided biogas storage that can compensate for some of the daily variation in biogas production, and provide flexibility for intermittent biogas use.
- The cover was capable of handling the wind and rain conditions typical of New Zealand’s temperate climate.
- Covered anaerobic ponds can retrofit existing pond infrastructure, and are cost competitive in comparison with heated and mixed tank digesters.

- Covered anaerobic ponds have great potential to reduce odour and GHG emissions produced by New Zealand's expanding agricultural sector, while providing opportunities to achieve a higher level of energy self-sufficiency for farms and rural communities.

REFERENCES

APHA, (1998). Standard Methods for the examination of water and wastewater. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

Burke, D.A. (2001). Dairy waste anaerobic digestion handbook: options for recovering beneficial products from dairy manure. Environmental Energy Company, Olympia, WA

Craggs, R., Park, J. and Heubeck S., (2008). Methane emissions from anaerobic ponds on a piggery and a dairy farm in New Zealand. Australian Journal of Experimental Agriculture, 48, 142–146

Cobb, S., and Hill, D. T., (1990). Maximum specific methane productivity of animal wastes and the effect of non-steady-state conditions on anaerobic fermenters, The Sixth International Symposium on Agricultural and Food Processing Wastes, St. Joseph, MI, 115-123.

Cullimore, D.R., Maule, A., Mansuy, N., (1985). Ambient temperature Methanogenesis for Pig Manure Waste Lagoons: Thermal Gradient Incubator Studies. Agricultural Wastes, 6, 175-191.

Green, F.B., Lundquist, T. J. and Oswald, W. J, (1995). Methane fermentation, submerged gas collection, and the fate of carbon in advanced integrated wastewater pond system. Wat, Sci. Tech, 31(12), 55-67.

Henze, M., (1995). Basic Biological Processes. Wastewater Treatment - Biological and Chemical Processes. M. Henze, P. Harremoes, E. Arvin and J. Jansen. Berlin, Springer - Verlag: 55 - 111.

Hill, D.T., (1984). Methane Productivity of the Major Animal Types. ASAE, 27(2), 530-534.

McGrath, R.J. and Mason, I.G., 2004. An Observational Method for the Assessment of Biogas Production from an Anaerobic Waste Stabilization Pond treating Farm Dairy Wastewater. Biosystems Engineering, 87 (4), 471-478.

Park, J. and Craggs R., (2007). Biogas production from anaerobic waste stabilisation ponds treating dairy and piggery wastewater in New Zealand. Water Science & Technology Vol 55 No 11 pp 257–264.

Safley, L.M. and Westerman, P.W., (1988). Biogas Production from Anaerobic Lagoons. Biological Wastes, 23, 181-193.

Safley, L.M. and Westerman, P.W., (1989). Anaerobic Lagoon Biogas Recovery System. Biological Wastes, 27, 43-62.

Safley, L.M. and Westerman, P.W. (1992). Performance of a dairy manure anaerobic lagoon. Bioresource Technology, 42, 43-52.

Stevens, M. A. & Schulte, D. D., (1977). Low temperature anaerobic digestion of swine manure. ASAE-NCR paper 77-1013. Presented at the North Central Region ASAE Meeting. ASAE, St. Joseph, MI, 19.